Workshop on Climate Change and Disaster Losses

Understanding and Attributing Trends and Projections

25 - 26 May 2006
Hohenkammer
Germany

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Climate Change and Disaster Losses Workshop:
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Report of the Workshop on

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Executive Summary

On the basis of collaboration between Peter Höppe, Munich Re, and Roger Pielke, Jr., University of Colorado, an international workshop on climate change and disaster loss trends was held in May 2006 in Hohenkammer, Germany with sponsorship from Munich Re, the U.S. National Science Foundation, GKSS Research Center, and the Tyndall Centre. In total 32 experts in the fields of climatology and disaster research from various parts of the world (13 countries) participated. "White papers" from 25 participants were submitted in advance and formed the basis of the discussions. This Executive Summary reports 20 statements which each represent a consensus among participants on issues of research and policy as related to the workshop's central organizing questions. A Workshop Summary Report follows which provides greater detail on the statements. The participant white papers, biographies, and workshop agenda are also included.[1]

The focus of the workshop was on two central questions:

- What factors account for increasing costs of weather related disasters in recent decades?
- What are the implications of these understandings, for both research and policy?

To be clear about terminology, we adopted the IPCC definition of climate change. According to the IPCC (2001) *climate change* is

> "Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use."[2]

The IPCC also defines *climate variability* to be

> "Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability)."[3]

We use the phrase *anthropogenic climate change* to refer to human-caused effects on climate.

Consensus (unanimous) statements of the workshop participants:

1. Climate change is real, and has a significant human component related to greenhouse gases.

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[1] The views expressed in this report are those of the participating individuals. Institutional affiliations are only provided for identification purposes.

[2] http://www.grida.no/climate/ipcc_tar/wg1/518.htm

[3] http://www.grida.no/climate/ipcc_tar/wg1/518.htm

2. Direct economic losses of global disasters have increased in recent decades with particularly large increases since the 1980s.
3. The increases in disaster losses primarily result from weather related events, in particular storms and floods.
4. Climate change and variability are factors which influence trends in disasters.
5. Although there are peer reviewed papers indicating trends in storms and floods there is still scientific debate over the attribution to anthropogenic climate change or natural climate variability. There is also concern over geophysical data quality.
6. IPCC (2001) did not achieve detection and attribution of trends in extreme events at the global level.
7. High quality long-term disaster loss records exist, some of which are suitable for research purposes, such as to identify the effects of climate and/or climate change on the loss records.
8. Analyses of long-term records of disaster losses indicate that societal change and economic development are the principal factors responsible for the documented increasing losses to date.
9. The vulnerability of communities to natural disasters is determined by their economic development and other social characteristics.
10. There is evidence that changing patterns of extreme events are drivers for recent increases in global losses.
11. Because of issues related to data quality, the stochastic nature of extreme event impacts, length of time series, and various societal factors present in the disaster loss record, it is still not possible to determine the portion of the increase in damages that might be attributed to climate change due to GHG emissions
12. For future decades the IPCC (2001) expects increases in the occurrence and/or intensity of some extreme events as a result of anthropogenic climate change. Such increases will further increase losses in the absence of disaster reduction measures.
13. In the near future the quantitative link (attribution) of trends in storm and flood losses to climate changes related to GHG emissions is unlikely to be answered unequivocally.

Policy implications identified by the workshop participants

14. Adaptation to extreme weather events should play a central role in reducing societal vulnerabilities to climate and climate change.
15. Mitigation of GHG emissions should also play a central role in response to anthropogenic climate change, though it does not have an effect for several decades on the hazard risk.
16. We recommend further research on different combinations of adaptation and mitigation policies.
17. We recommend the creation of an open-source disaster database according to agreed upon standards.
18. In addition to fundamental research on climate, research priorities should consider needs of decision makers in areas related to both adaptation and mitigation.
19. For improved understanding of loss trends, there is a need to continue to collect and improve long-term and homogenous datasets related to both climate parameters and disaster losses.
20. The community needs to agree upon peer reviewed procedures for normalizing economic loss data.

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WORKSHOP SUMMARY REPORT

Introduction

In summer 2005 Roger Pielke, Jr. of the Center of Science and Technology Policy Research at the University of Colorado and Peter Höppe of the Geo Risks Research Department of Munich Re learned from each other that each planned to organize a workshop on the assessment of factors leading to increasing loss trends due to natural disasters. Both agreed that such a workshop was timely, especially given the apparent lack of consensus on the role of climate change in disaster loss trends. Roger Pielke, Jr. and Peter Höppe decided to have a common workshop in 2006 in Germany to bring together a diverse group of international experts in the fields of climatology and disaster research. The general questions to be answered at this workshop were:

- What factors account for increasing costs of weather related disasters in recent decades?
- What are the implications of these understandings, for both research and policy?

The participants were selected by a workshop organizing team that met in December, 2005. Participants were selected for their high level of competence and to represent a wide range of different attitudes to the subject. All participants came into the workshop agreeing that anthropogenic climate change is a concern.

In total 32 participants from 13 countries attended the two day workshop (list of participants attached). "White papers" from 25 participants were submitted in advance and formed the basis of the discussions. The workshop was organized in 4 sessions:

1. Trends in extreme weather events
2. Trends in Damages
3. Data issues – extreme weather events and damages
4. Syntheses discussion

In the syntheses session the discussion was focused on finding consensus positions among the participants on statements about the attribution of disaster losses and the policy implications. These 20 statements are listed in the preceding executive summary and are described in more detail below. Following the Workshop Summary Report are the white papers which provide the views of individual participants. Participants were provided the opportunity to revise their white papers following the workshop. The report concludes with participant biographies and the Workshop agenda.[3]

The workshop was sponsored by Munich Re, the U.S. National Science Foundation, the Tyndall Center for Climate Change Research, and the GKSS Research Center.

1. Climate change is real, and has a significant human component related to greenhouse gases.

We adopted the IPCC definition of climate change. According to the IPCC (2001) *climate change* is

> "Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use."[4]

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We use the phrase *anthropogenic climate change* to refer to human-caused effects on climate.

2. Direct economic losses of global disasters have increased in recent decades with particularly large increases since the 1980s.

A wide range of datasets and analyses from around the world paint a consistent picture: Direct economic losses (adjusted for inflation, but not otherwise adjusted) have been increasing rapidly in recent decades around the world (Crompton et al. Dlugolecki, Faust et al., Muir-Wood et al., Pielke, and Zapata-Marti white papers). Global data on disasters collected by Munich Re is illustrative of the more general conclusions. Similar data has been collected by Swiss Re and CRED at the Leuven Universty (EM-DAT).

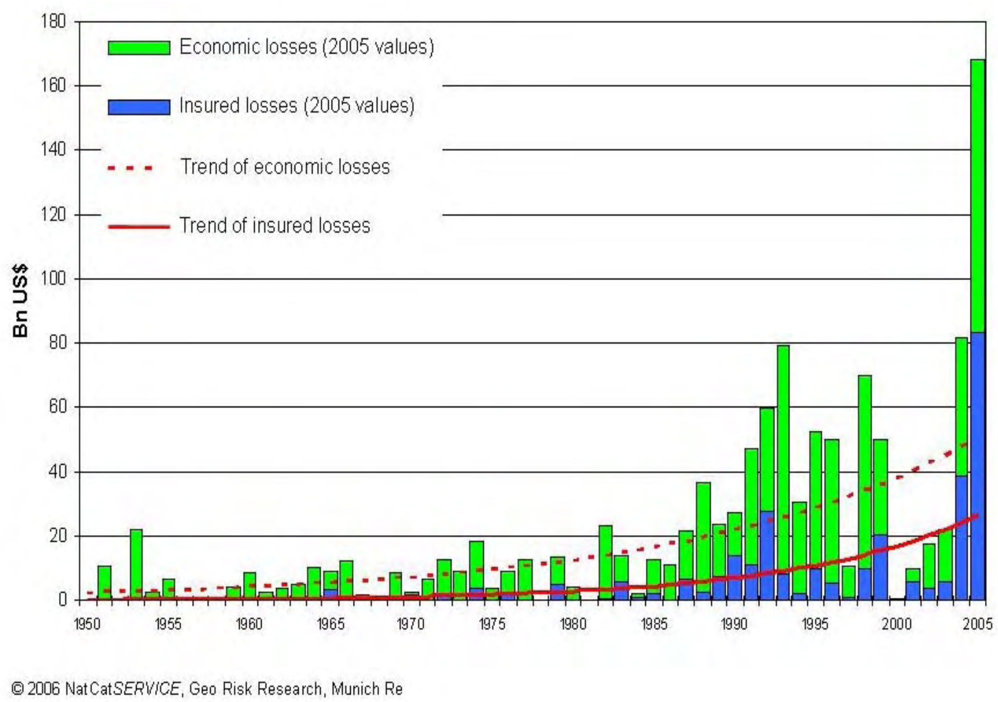

Fig. 1 Global trend in losses due to great weather disasters.

It is important to recognize that disaster losses do not increase in every region at a constant rate (Muir-Wood et al. white paper). Some regions may see decreasing trends (Muir-Wood et al. white paper). Disaster losses typically come in discrete, large values and the trend record is driven by the increase in the costs of the largest disasters, such as hurricanes in the United States (Faust et al. white paper). Since the 1980s there has been a particularly large increase in the frequency and magnitude of disasters.

3. The increases in disaster losses primarily result from weather related events, in particular storms and floods.

According to the data of the Munich Re NatCat*SERVICE*® database of great natural disasters, since 1950 the contribution of weather related events like windstorms and floods amounts to 69% of all economic (38% windstorm, 25% floods, 6% other weather related events) and even 89% (79% windstorm, 5% floods, 5% other weather related events) of insured losses. The trend of the global numbers of great natural catastrophes since 1950 shows a steep increase in weather related disasters from about one event in the 1950s to about 5 in recent decades while geophysically-caused disasters (earthquakes, tsunamis, volcano eruptions) have increased from one to less than 2 in the same time. Weather related disasters therefore are the major contributor to increasing losses due to natural disasters (more details in Faust et al. white paper).

4. **Climate change and variability are factors which influence trends in disasters.**

   Climate change and variability are important factors which shape patterns and magnitudes of disaster losses.

   For example, even after adjusting for changes in inflation, wealth, and population in the 1970s and 1980s the United States experienced approximately $41 billion and $36 billion in hurricane losses, respectively (Data from Pielke white paper). By contrast, the 1990s and 2000s (through 2005) saw $87 billion and $167 billion. The 1970s and 1980s were characterized by below average hurricane activity and storm landfalls, whereas the period since 1995 has seen very active seasons and correspondingly more landfalls, particularly in 2004 and 2005 (Knutson white paper; Faust et al. white paper).

   Similarly, in Australia 13 tropical cyclones made landfall along its east coast from 1966-1975 whereas 7 made landfall from 1996 to 2005 (and 1976-1985 had 7 landfalls and 1986-1995 had 6, Crompton et al. white paper). Loss data adjusted for changes in inflation, wealth, and population show a corresponding decrease in losses between the two periods. Similar results have been found for floods (Pielke white paper) and other weather events in different regions around the world (Muir-Wood et al. white paper). Thus, climate change and variability are factors which influence trends in disasters.

5. **Although there are peer reviewed papers indicating trends in storms and floods there is still scientific debate over the attribution to anthropogenic climate change or natural climate variability. There is also concern over geophysical data quality.**

   According to the methodology of the IPCC, detection and attribution of trends in the frequency and/or intensity of storms and floods to anthropogenic climate change depends on the rejection of the null hypothesis that trends which have been detected as statistically significant are within the range of natural climate variability. When this null hypothesis is rejected, "detection" is achieved and in a second step, the most probable mix of eternal drivers for this change is determined - a step called "attribution". In its 2001 report the IPCC found no overall pattern of increasing extreme events, though it did identify changes in some regions. Attribution of a trend to a specified driver (e. g. anthropogenic climate change) is not easy to achieve. With respect to storms and floods in some cases there are insufficient record lengths, which consequently do not allow the exclusion of long-term internal variability as causes of observed trends or to assess how well real internal climate variability is reflected in climate model simulation runs.

   Other problems arise from inhomogeneous data sets suffering from changes in measurement techniques. For instance hurricane wind speeds were measured by empirical observation of wave characteristics from ships, by using pressure-wind relationships, by measuring velocities of airborne sondes dropped from aircrafts or by Doppler radar techniques. Equally the measurement intervals have changed over time. All these techniques need to be cross-evaluated and adjustments need to be done. Changing river discharges over time might depend on changing flow regimes accounted for by changing land use patterns or changing hydrodynamic characteristics of rivers brought about by hydro-engineering construction work over time.

6. **IPCC (2001) did not achieve detection and attribution of trends in extreme events at the global level.**

   Since IPCC 2001 additional research results have been published on the changing nature of extremes. Regarding 100-year floods on large river basins exceeding 200,000 km^2 Milly et al. (2002) found a statistically significant positive trend consistent with climate model results over the 20th century. A subsequent paper presented evidence that the global pattern of 20th century trends in mean annual streamflow was partially controlled by anthropogenic climate change though trends in single regions might be explained by internal variability (Milly et al. 2005). In addition evidence for increasing occurrences of intense extra-tropical precipitation events has been presented (Groisman et al. 2005).

   Regarding changing hurricane activity levels several studies document over the past decades a trend of more intense storms (in terms of peak intensity and portion of lifetime covered by very high wind speeds). These shifts are associated with positive trends in tropical sea surface temperatures – globally some 0.5 °C since 1970 - as the key parameter (Emanuel 2005a and 2005b; Webster et al. 2005; Hoyos et al. 2006). There are recently published studies attributing trends in sea surface temperatures since 1970 to anthropogenic climate change (e. g. Barnett et al. 2005). SST has been presented as the key parameter for tropical cyclone activity levels with evidence presented for storm intensity shifts driven by climate change due to anthropogenic GHG emissions forcing (Emanuel 2005a and 2005b; Hoyos et al. 2006). Emanuel (2006) stresses that a better parameter to use than SST is the potential intensity. However, the relative importance for TC activity rates of SST or potential intensity versus other factors such as vertical wind shear remains contested among scientists."

The sensitivity of hurricane intensity to sea surface warming implied in the Emanuel (2005a) results exceeds by a factor of 6 the sensitivity inferred from Knutson and Tueleya's (2004) idealized hurricane modeling study, which found a sensitivity of about 4% per degreee Celsius SST increase. In a recent examination of Atlantic potential intensity data since about 1980, the discrepancy with Knutson's modelling work appears to be a factor of 4, and the discrepancy might be partly attributable to a general reduction of surface wind speeds in the basin over time (Emanuel 2006; Knutson white paper). The Emanuel and Webster et al. studies have motivated a scientific debate, which focuses on the question of whether such strong observed tropical cyclone trends arise due to problems with observations—mainly data homogeneity issues (Landsea 2005; Chan 2006; Pielke et al. 2005; Anthes et al. 2006; Pielke et al. 2006). A 2006 statement by the World Meteorological Organization, drafted by scientists holding different views on the subject says:

> Given time the problem of causes and attribution of the events of 2004–2005 will be discussed and argued in the refereed scientific literature. Prior to this happening it is not possible to make any authoritative comment.

The IPCC will report again on this subject in 2007.

7. High quality long-term disaster loss records exist, some of which are suitable for research purposes, such as to identify the effects of climate and/or climate change on the loss records.

The longest and most complete global data sets of disaster losses have been compiled by the leading re-insurance companies Munich Re and Swiss Re. There is another global disaster data base by CRED, focusing on humanitarian aspects of natural disasters. Other (most of them regional) datasets exist in various organizations and government agencies around the world. For instance, flood and hurricane damage data has been kept by the U.S. government since the beginning of the past century. Some regions in Europe have archived records of disasters going back many hundreds of years, and the United Kingdom has been identified as having particularly long records. Such datasets are valuable resources for understanding disaster trends. Only a few however have been rigorously peer-reviewed.

8. Analyses of long-term records of disaster losses indicate that societal change and economic development are the principal factors responsible for the documented increasing losses to date.

Societal change and economic development are the principal factors responsible for the documented increasing losses to date. Such results have been found looking at disasters globally (Burton white paper; Kemfert and Schumacher white paper; Muir-Wood et al. white paper) and in specific regions and for specific phenomena, such as with respect to US tornados (Brooks white paper), Australian weather-related hazards (Crompton et al. white paper), floods in the United Kingdom (Dlugolecki white paper), U.S. hurricane and floods (Pielke white paper), Indian tropical cyclones (Raghavan white paper), Chinese floods and storms (Ye white paper), Latin American floods and storms (Zapata-Marti white paper), and Caribbean hurricanes (Tompkins white paper).

Societal changes include population growth and migration to exposed locations, increasing wealth at risk to loss, policies which lead to increased (and in the case of risk mitigation, decreased) vulnerabilities, development characteristics (Gurjar et al. white paper; Burton white paper; Zapata-Marti white paper). Changes in various societal factors vary according to location. For instance, China has seen its GDP grow as fast as 8.5% per annum (Ye white paper) and regions such as Florida in the United States have seen population growth at a rate far greater than the national average. Europe has seen little population growth overall, but significant increases in wealth. Different patterns of societal change result in correspondingly different effects on trends in disaster losses. There is evidence that in some locations disaster mitigation policies have reduced vulnerabilities (Bouwer white paper), but the effect on losses and loss trends remains to be quantified.

9. **The vulnerability of communities to natural disasters is determined by their economic development and other social characteristics.**

   The impact of extreme weather events therefore varies between the developing and the developed world. While the developed world sees the highest absolute direct economic (and insured) losses from weather extremes, the largest numbers of casualties and affected people occur in poor communities. For instance, the 2005 tsunami disaster that struck in different countries around the Andaman Sea revealed that there are large differences in impacts as well as speeds of recovery afterwards, depending on the economic and social development level of the coastal community (Adger et al. 2005). Disaster losses expressed as a percentage of GDP (e.g. Zapata-Marti white paper), or corrected for purchasing power parity (PPP) may give a better approximation of the economic impacts on developing countries.

   Unsustainable exploitation of natural resources in many regions in the world may exacerbate the impacts of natural disasters, for instance by deforestation that may increase the frequency and intensity of floods (see Gurjar et al. white paper). The quantitative impacts of current and future economic development on vulnerability and loss trends are unknown (see Tompkins white paper). Some developments may reduce risks, as preparedness offsets risk. Others developments may increase risks. The relative role of disaster mitigation activities in addressing disaster losses remains poorly documented and understood. Recent studies comparing relevant cost-benefit analysis conclude, in spite of the methodological challenges, that the benefit to cost ratio of investments in disaster mitigation are about 2-4 (Mechler 2005).

10. **There is evidence that changing patterns of extreme events are drivers for recent increases in global losses.**

    Statistics of loss events related to weather show both globally and for some regions substantial increases over the past decades. The major contributions are from storms and floods. For instance, in the North Atlantic there has been since the mid-1990s a higher basin-wide hurricane activity then on average. Before this period, since the beginning of the 1970s there was a lower-then-on-average activity level. Although there is concern about the quality of intensity data prior to the late 1960s on account of changes in observational techniques there is plenty of evidence that there was another period of high activity prior to 1970. Damage in the U.S. related to hurricanes since 1995 (11 years) already exceeds that which occurred from 1970-1994 (25 years), even after adjusting the data for societal factors.

11. **Because of issues related to data quality, the stochastic nature of extreme event impacts, length of time series, and various societal factors present in the disaster loss record, it is still not possible to determine the portion of the increase in damages that might be attributed to climate change due to GHG emissions.**

    Long time series disaster loss data for some regions is either unavailable or of poor quality for various phenomena, particularly before the 1980s (e.g., for China) and the 1970s (Australia, Canada, Caribbean, Central America, China, Europe, India, Japan, Korea, United States) (Faust et al. white paper). The historical loss record is strongly influenced by a small number of very large events such as hurricane Katrina, which accounts for about 50% of global storm and flood losses in 2005 (Faust et al. white paper; Muir-Wood et al. white paper). Thus there is a strong element of chance in short-term records. Long-term, homogenous loss records of research quality are generally quite rare. Various societal factors such as changes in population and development, risk reduction measures, changing definitions and thresholds of disaster losses, land use and local environmental degradation, and so on, introduce many factors into changing patterns of losses over time.

12. **For future decades the IPCC (2001) expects increases in the occurrence and/or intensity of some extreme events as a result of anthropogenic climate change. Such increases will further increase losses in the absence of disaster reduction measures.**

    It is a logical consequence that, if there will be more extreme events and/or these extreme events will increase in intensity losses will also increase. In general the increase in losses is associated linearly with the number of events (2 events mean 2-times the losses of one event) but nonlinearly with the intensity increase (e.g. for windstorms losses are a function of the exponent of the wind speed, which may range from 3-6). Only preventive measures like stricter building codes or movement of population out of high risk areas could compensate for such increasing trends.

13. In the near future the quantitative link (attribution) of trends in storm and flood losses to climate changes related to GHG emissions is unlikely to be answered unequivocally.

For the near future, issues related to data quality, the stochastic nature of extreme event impacts, length of time series, and various societal factors present in the disaster loss record, are expected to persist, making it unlikely that the quantitative link (attribution) of trends in storm and flood losses to climate changes related to GHG emissions will be answered unequivocally.

As a consequence we urge decision makers not to expect an unequivocal resolution of questions about the linkage of growing disaster losses and climate changes related to GHGs, as this area will remain an important area of study for years to come. Such uncertainty need not preclude proactive decision making. For instance, the insurance industry has already taken decisions to recognize the implications of increasing losses and loss potentials related to changing risk of hurricanes.

Policy Implications

14. Adaptation to extreme weather events should play a central role in reducing societal vulnerabilities to climate and climate change.

There are three main reasons for this conclusion.

1. Adaptation to climate variability and extremes has always been necessary and future adaptation can be most effectively designed if it continues and builds upon past experience. Declining global and U.S. trends over the long term in mortality and morbidity (or injury) rates due to various extreme weather events suggest that adaptation might successfully help contain losses (Goklany white paper).
2. Mitigation of greenhouse gas emissions will take substantial time to become effective and in the meantime adaptation will become increasingly necessary.
3. There is a current adaptation deficit, and practices of maladaptation and unsustainable development are serving to increase vulnerability in many places. In particular, the insufficient pricing of mitigation and adaptation in terms of goods and services preserved in the face of changes and extreme events' impacts leads to inappropriate valuation of risk reducing measures in investment and financial viability calculations both at the public and private sector level, particularly in developing countries.

In all socio-economic sectors impacts of climate variability and extremes occur now and adaptation policies and measures are used to help to reduce exposure and impacts. Climate changes, regardless of cause, may require a broader perspective in adaptive capacity than has been the case in the past. Generally these activities are in the domain of specialized professionals such as agronomists for agriculture, engineers and hydro-meteorologists for water management, irrigation, flood control etc., structural and design engineers for infrastructure , buildings etc., public health officials for infectious and vector borne diseases etc. The work of these professionals is not referred to as adaptation but may be described as plant breeding and selection, flood control or flood damage reduction, and so forth.

Current adaptation as now practiced is not sufficient to prevent the growth of losses from climate change, variability, and extremes. While adaptation cannot be expected to reduce present or future losses to zero it could be more effective.

Decision processes that are dependent upon unequivocal quantitative linkages of disaster losses to climate change might be reconsidered in the context of this expected continuing uncertainty. Decision makers might embrace more fully an alternative approach to decision making, e.g., based on vulnerability reduction or proactive risk management.

15. **Mitigation of GHG emissions should also play a central role in response to anthropogenic climate change, though it does not have an effect for several decades on the hazard risk.**

Anthropogenic climate change results from the emission of greenhouse gases. CO_2 contributes most to the anthropogenic greenhouse effect and primarily is released when burning fossil fuels like coal, oil or natural gas. Other relevant green house gases are Methane, N_2O and CFCs and water vapor. Once released into the atmosphere CO_2 has an average residence time in the atmosphere of up to 200 years. This means that emission reductions of CO_2 cannot reduce its concentration on a short term and therefore cannot result in immediate changes to the climate system. Emission reductions, however, influence the future levels of CO_2 in the atmosphere and by this an even further increase in global temperatures and the potential for more and more intensive extreme events. Emission reductions are necessary to reduce the risk to reach levels of CO_2 concentrations which might lead to abrupt climate changes and/or processes in the atmosphere which could become irreversible (Kemfert and Schumacher white paper).

16. **We recommend further research on different combinations of adaptation and mitigation policies.**

Adaptation and mitigation have been treated largely as separate and unrelated activities. The research and its application are in the hands of different types of professionals with different expertise and technical jargon often working in different domains. From an economic perspective mitigation and adaptation are often regarded as competing alternatives and some theoretical optimal mix of adaptation and mitigation is thus recommended. More recently the idea that there can be useful synergies and complementarities between adaptation and mitigation has been gaining in favor and currency. A chapter in the forthcoming IPCC 4th Assessment will be devoted to the benefits of adaptation and mitigation actions. For instance, this can take the form of seeking adaptation benefits in projects which are primarily motivated by mitigation objectives and vice versa.

17. **We recommend the creation of an open-source disaster database according to agreed upon standards.**

Currently, only a few global databases exist, the most comprehensive being the NatCat*SERVICE*® database of Munich Re, the Sigma reports by Swiss Re and the EM-DAT database of CRED at Leuven University.

The most comprehensive disaster databases are currently not publicly available. An open-source database would enable the scientific community to study worldwide disaster characteristics and trends as well as contribute to assessing and improving its quality.

The databases mentioned above are expected to be reliable for data covering the period since the 1980s only for most areas in the world, however detailed and rigorous peer-reviewing of disaster datasets would provide greater understanding as to their accuracy. This is also the period for which the best quality data is available (see graphs presented in Faust et al. white paper). This period is too short for the purpose of climate-damage investigations. For the time before 1980 many smaller events are often not included, information is mostly available for large disasters, resulting in an incomplete overview of actual impacts from weather events. It has been estimated, however, that including all small events would probably increase the amount of losses recorded from "great natural disasters" in the NatCat*SERVICE*® Database by about 20% only.

There is no single standard for collecting disaster information. Information is collected from various sources, including scientific reports, governmental and non-governmental organizations, weather services, insurance industry and news agencies (Faust et al. white paper). Linked to this, there is no single quality control standard of the disaster reports included in the different databases, though for some of the individual databases a high quality control standard is in place.

18. **In addition to fundamental research on climate, research priorities should consider needs of decision makers in areas related to both adaptation and mitigation.**

Workshop participants agreed that in addition to fundamental research on climate, there exists considerable opportunity to focus research priorities on needs of decision makers taking decisions with short and long term implications related to climate adaptation and mitigation.

19. For improved understanding of loss trends, there is a need to continue to collect and improve long-term and homogenous datasets related to both climate parameters and disaster losses.

The collection of such data would consist of efforts to continue to record current climatological and weather observations and the collection of information on extreme weather events and their impacts, as well as extending current records back into the past.

For the latter, data on climate and extreme weather events dating up to 1000 years before present can be collected from paleo records contained in sediments and various other environmental records. For the more recent past, observational records and anecdotal information on weather and disasters in historical archives that are currently not accessible for research could be made publicly available. For instance, synthesis of document data and instrumental observations can help to extend flood records back to centuries before present (see for example Brázdil white paper). Also robust instrumental proxies for the frequency and/or intensity of weather events need to be compiled, as it has been done for NE Atlantic storminess using local air pressure and local water level readings (von Storch and Weisse white paper). Such proxies can often be compiled for the past two, or so, centuries.

The improvement of such records can aid to assess current investigations of risks and can help put current risks into a wider historical perspective. It will allow better understanding of loss trends by differentiating between long-term changes in the hazards themselves and changes in vulnerability.

20. The community needs to agree upon peer reviewed procedures for normalizing economic loss data.

Methods of normalizing economic loss data provide insight to trends in disaster losses. Various approaches to normalization have appeared in the peer reviewed literature (See, e.g., citations in Muir-Wood et al., Crompton et al., and Pielke white papers). A community consensus on approaches and their application in various contexts would provide a valuable resource to scholars and decision makers. In particular, understanding how to adjust data for significant economic changes over time, the integration of data from different countries and economic systems, and the role of risk reduction policies should be considered in such an effort.

References

Adger, W.N., T.P. Hughes, C. Folke, S.R. Carpenter, and J. Rockström, 2005. Social-Ecological Resilience to Coastal Disasters. Science, Vol. 309. no. 5737, pp. 1036 – 1039.

Anthes, R.A., R.W. Corell, G. Holland, J.W. Hurrell, M.C. MacCracken, K.E. Trenberth, 2006. Hurricanes and Global Warming—Potential Linkages and Consequences. Bulletin of the American Meteorological Society, Vol 87, pp. 623-628.

Barnett, T. P., D.W. Pierce, K.M. AchutaRao, P.J. Gleckler, B.D. Santer, J.M. Gregory, and W.M. Washington, 2005. A Warning from Warmer Oceans. Science, Vol. 309. no. 5732, pp. 284 – 287.

Chan, J. C.L., 2006. Comment on "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment." Science, Vol. 311: pp. 1713.

Emanuel, K., 2005a. Increasing destructiveness of tropical cyclones over the past 30 years. Nature, Vol. 436, pp. 686-688.

Emanuel, K., 2005b. Emanuel replies. Nature, Vol. 438, pp. E13.

Emanuel, K., 2006. Environmental influences on tropical cyclone variability and trends. Proceedings of 27th AMS Conference on Hurricanes and Tropical Meteorology, #4.2, http://ams.confex.com/ams/pdfpapers/107575.pdf.

Groisman, P.Y., R.W. Knight, D.R. Easterling, T.R. Karl, G.C. Hegerl, and V.N. Razuvaev, 2005. Trends in Intense Precipitation in the Climate Record. Journal of Climate, Vol. 18, No. 9, pp. 1326-1350.

Hoyos, C. D., P.A. Agudelo, P.J. Webster, and J.A. Curry, 2006. Deconvolution of the Factors Contributing to the Increase in Global Hurricane Intensity. Science, 16 March.

IPCC - Intergovernmental Panel on Climate Change, 2001.Climate Change 2001: The Scientific Basis. New York: Cambridge University Press.

Knutson, T. R. and R.E. Tuleya, 2004. Impact of CO2 –Induced Warming on Simulated Hurricane Intensity and Precipitation: Sensitivity to the Choice of Climate Model and Convective Parameterization. Journal of Climate, Vol. 17, pp. 3477–3495.

Landsea, C. W., 2005. Hurricanes and global warming. Nature, Vol. 438, pp. E11-E12.

Mechler, R., 2005. Cost-benefit Analysis of Natural Disaster Risk Management in Developing and Emerging Countries. Long Study. Interim report for GTZ.

Milly, P.C.D., R.T. Wetherald, K.A. Dunne, and T.L. Delworth, 2002. Increasing risk of great floods in a changing climate. Nature, Vol. 415, No. 6871, pp. 514-517.

Milly, P.C.D., K.A. Dunne, and A.V. Vecchia, 2005. Global pattern of trends in streamflow and water availability in a changing climate. Nature, Vol. 438, No. 7066, pp. 347-350.

Pielke Jr., R.A. C. Landsea, M. Mayfield, J. Laver, and R. Pasch, 2005. Hurricanes and Global Warming. Bulletin of the American Meteorological Society, Vol. 86, No. 11, pp. 1571-1575.

Pielke, Jr., R.A., C.W. Landsea, M. Mayfield, J. Laver, R. Pasch, 2006. Reply to Hurricanes and Global Warming Potential Linkages and Consequences. Bulletin of the American Meteorological Society, Vol. 87, pp. 628-631.

Webster, P.J., G. J. Holland, J. A. Curry, and H. R. Chang, 2005. Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment. Science, Vol. 309, pp. 1844–1846.

WHITE PAPERS

Increased Scientific Evidence for the Link of Climate Change to Hurricane Intensity

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Germanwatch

Until recently, most scientists would have said that there was no or no clear evidence that global warming has had any effect on the planet's most powerful storms- dubbed hurricanes, typhoons, or cyclones depending on the ocean that spawns them. They would have argued that the changes of the past decade in these metrics are not so large as to clearly indicate that anything is going on other than the multi-decadal variability that has been well documented since at least 1900 (Gray et al. 1997; Landsea et al. 1999; Goldenberg et al. 2001).

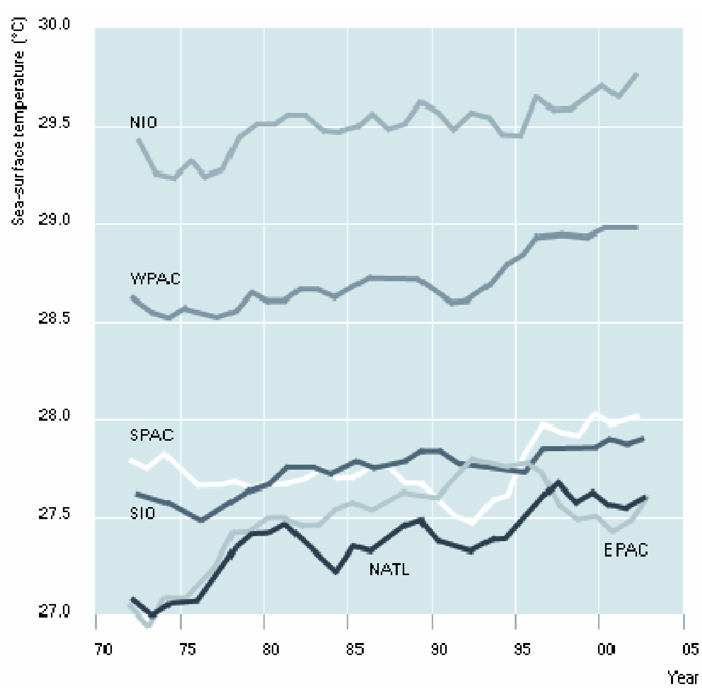
2005 a Turning Point of the Debate?

2005 might prove as a turning point of the debate. Two developments came accomponied. First, the two extreme hurricane years 2004 and 2005 increased attention of scientists: At the latest when Wilma's internal pressure hit 882 millibars, beating a record held by 1988's Gilbert, climatologists took notice. It was the first time a single season had produced four Category 5 hurricanes, the highest stage on the 5-step Saffir-Simpson scale of storm intensity. The 28 tropical storms and hurricanes, that the world faced in 2005, crushed the old mark of 21, set in 1933.

Second, a number of new scientific studies provided much more support to the hypotheses by showing that „now … a connection is emerging between warming oceans and severe tropical cyclones " (Kerr, 2005, 1807). Two papers published in Science and Nature in 2005 started a development described as "Birth for Hurricane Climatology" (Kerr, 2006) by identifying the impact of climate change on hurricane intensity, number and regional distribution. Many other interesting papers added new information. The debate is by far not over yet.

Increase in Sea Surface Temperature

One argument is an observed increase in sea surface temperature. Torre and White (2005) could show an increase in sea surface temperature since 1960. The following graph (Faust, 2006) shows the development of surface temperature in relevant ocean basins:



Development of sea surface temperatures in ocean basins with cyclone activity since 1970.
Source: according to Webster et al. (2005), Science Vol. 309.

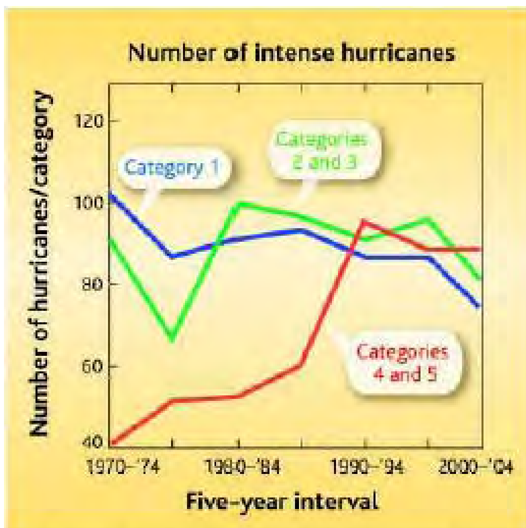
NATL = North Atlantic
NIO = North Indian Ocean
WPAC = West Pacific
SIO = South Indian Ocean
SPAC = South Pacific
EPAC = East Pacific

Barnett et al. (2005) compared sea temperatures with model simulations and found a high probabilitiy, that global warming is strongly influencing the increase in sea surface temperature. If this conclusion is accepted, it would mean, that global warming has already now – in its early status – a significant influence on sea surface temperature.

Increase in Most Intense Hurricanes

The next argument is based on the observation that the most intense hurricanes increased over time. Alone in 2004 and 2005 four of the ten strongest hurricanes ever have been registered (Faust, 2006, 1). Kerry Emanuel (MIT) showed for the first time that major tropical storms, both in the Atlantic and the Pacific region, have already increased since the 1970s in duration and intensity by about 50 percent (Emanuel, 2005). He concluded: "My results suggest that future warming may lead to an upward trend in tropical cyclone destructive potential." In the years before Emanuel had asserted often that no firm link had been established between warming and the intensity and frequency of hurricanes. But then in August 2005, just two weeks before Hurricane Katrina struck the Gulf Coast, Emanuels article in 'Nature' was published, pointing out, that he had discovered statistical evidence that hurricanes were indeed affected by global warming. He linked the increased intensity of storms to the heating of the oceans.

Peter Webster (Georgia Institute of Technology, Atlanta) and his colleagues examined in another study satellite records of storms around the tropics, a history which started 35 years ago. They haven't found a long-term trend in the number of storms per year, only natural ups and downs, even as summer tropical sea surface temperatures rose 0.5°C. In the North Atlantic, where hurricane numbers have surged since 1995, such variability arises from changes in the strength of warm ocean currents (*Science*, 1 July 2005, p. 41). But more relevant is another part of the results: "The researchers did find a sharp increase during the past 35 years in the intensity of storms: The number of category 4 and 5 tropical cyclones, the most intense storms that cause most of the damage on landfall" (Kerr, 2005, 1807.) Globally, category 4 and 5 storms increased regarding to his calculation by 57 percent from the first half of the period to the second.



Bad trend rising. The number of the most intense tropical cyclones is increasing worldwide.

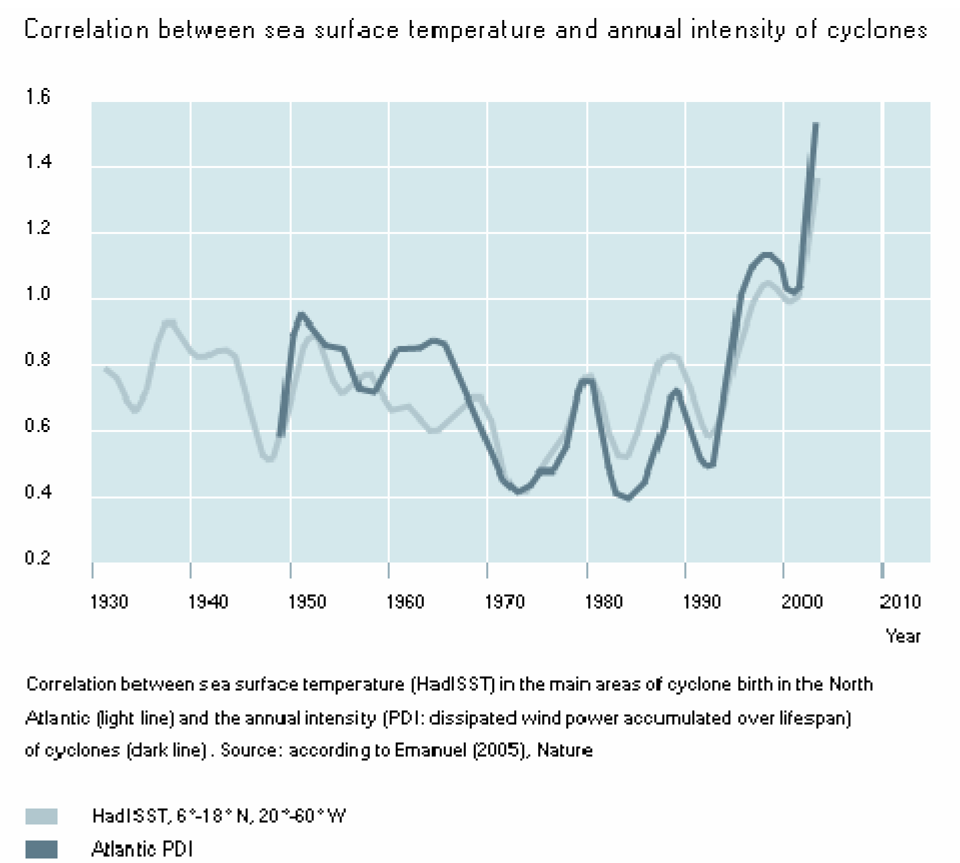
Source: Kerr, 2005, Science, p. 1807

At this point the main criticism of opponents starts. They have suggested that the upward trend of storm intensity might be artificially produced by the insufficient state of tropical cyclone intensity measurements. And two groups – led by John Knauf of CSU and Bruce Harper of Systems Engineering Australia Proprietary Limited in Brisbane – attempted to correct intensity records from parts of the Pacific Ocean for now-obvious errors. Both reanalyses reduced upward trend of storm intensity (See Kerr, 2006). Therefore it seems to make sense to check the reliability of the data base used by Emanuel and Webster. On the other hand, it also has to be noted, that both reanalyses did not eliminate the trend (Kerr, 2006). Webster agrees, that "the data's not very good". But he also adds: "However, to say it's all artificial is an exaggeration. We would have had to have misidentified 160 to 180 category 4's and 5's" (Kerr, 2006).

And a new study by Ryan Sriver and Matthew Huber, which soon will be released in Geophysical Research Letters, supports the results of Emanuel and Webster with a different set of data. It uses a compilation of the world's weather data developed at the European Centre for Medium-Range Weather Forecasting in Reading, UK. They found a 25% increase in storm power between the first half of the 45-year record and the second, consistent with Emanuel's analyses (Kerr, 2006).

Strong Correlation between Sea Surface Temperature and Hurricane Intensity in the North Atlantic

A further aspect of the argument is based on the validity of the datas. In his article, Emanuel displays (Emanuel 2005) that there is a strong correlation between sea surface temperature and hurricane intensity in the relevant part of North Atlantic. In the area just north of the equator in the Atlantic Ocean, where most hurricanes get their start, the power released during their lifetimes is "spectacularly well correlated with sea surface temperature", (Emanuel in Kerr 2006). It is interesting to note that this correlation has been strongest since 1970. This is the periode where the best data exist. Only since the 1970s researchers had satellites that allow them to look directly at hurricanes. However, even for this modern era record, there is some controversy in the wind speed estimates (Landsea, 2005). Based on this strong correlation Emanuel expects that the trend of more intense hurricanes, induced by global warming, will continue in the future, if sea surface temperature is to be further increased.



Correlation between sea surface temperature (HadISST) in the main areas of cyclone birth in the North Atlantic (light line) and the annual intensity (PDI: dissipated wind power accumulated over lifespan) of cyclones (dark line). Source: according to Emanuel (2005), Nature

Faust, 2006 based on Emanuel, 2005

Only Climate Change can Explain this Correllation

Carlos Hoyos and colleagues from *Georgia Institute of Technology* (GIT) in Atlanta et al. (2006) have shown in an additional study based on statistical models and data from six ocean basins in the last 35 years, that all other known factors – as humidity in the lower troposphere, vertical wind shear and the changes in "zonal" winds with longitude - which might potentially be able to explain the increase in intense hurricanes don't show a stable trend over the last 35 years. The new Georgia Tech study has now clarified this issue, showing that while hurricane intensity may be substantially influenced by these other factors for an individual storm or storm season, only an increase in sea surface temperatures can account for the long term increase in hurricane strength. The results show that the trend of increasing numbers of category 4 and 5 hurricanes for the period 1970–2004 is directly linked to the trend in sea-surface temperature; other aspects of the tropical environment, although they influence shorter-term variations in hurricane intensity, do not contribute substantially to the observed global trend.

If this conclusion is accepted as well, it would be clear that global warming has an impact on the intensity of hurricanes.

Wrong Observations or wrong Theory?

The debate doesn't seem to be, whether there exists a link between global warming and hurricane intensity at all, but whether it is really so unexpected strong as the observations from Emanuel, Webster, Sriver and Huver suggest.

Doubtlessly, theory and computer models so far didn't support such a strong connection between global warming and hurricane intensity. The sensitivity of hurricane intensity to sea surface warming implied in the Emanuel (2005) results exceeds by a factor of 6 the sensitivity inferred from Knutson and Tueleya's (2004) idealized hurricane modeling study, which found a sensitivity of about 4% per degree Celsius SST increase. In a recent examiniation of Atlantic potential intensity data since about 1980, the discrepancy with Knutson's modelling work appears to be a factor of 4, and the discrepancy might be partly attributable to a general reduction of surface wind speeds in the basin over time (Emanuel 2006, Knutson 2006). Pielke argues that the global modelling studies suggest the potential for only relatively small changes in tropical cyclone intensities related to global warming. And as Landsea stated, according to theory and computer models the intensification by now should be only a sixth of what Webster and Emanuel have reported. Consequently, the current question is: are the observations, which support an anomalous strengthening trend of hurricane intensity wrong and a fiction, based on a deeply flawed hurricane record? Or are the theory and modelling wrong? As Emanuel puts it: „They tend to count [the anomalous strengthening] against observations. I count it against the theory, although I helped develop the theory." (Kerry, 2006).

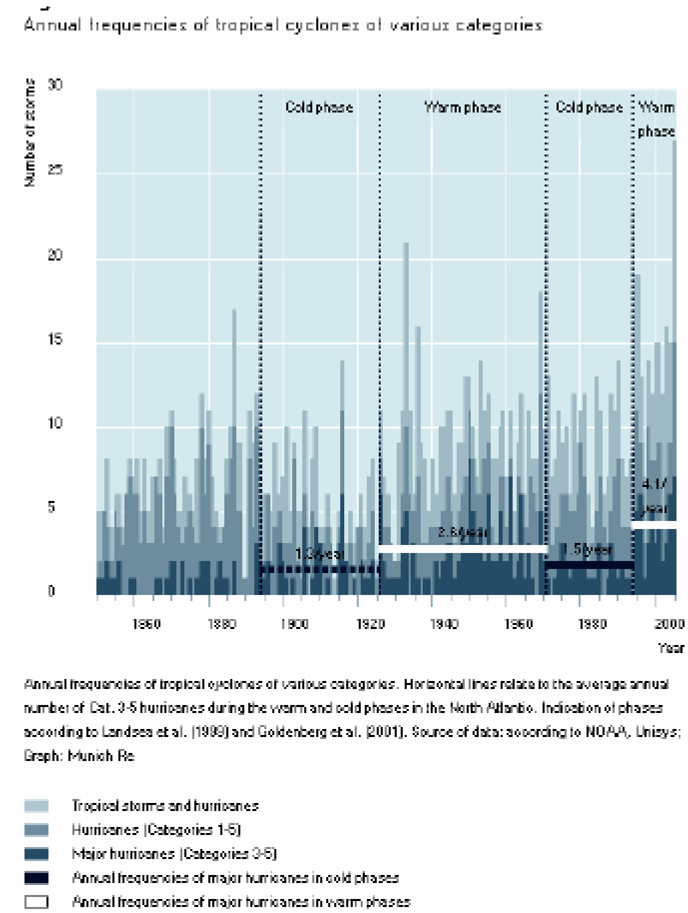
A new simulation from Kazuyoshi Oouchi et al. of the Advanced Earth Science and Technology Organisation in Yokohoma, Japan, runs on Japan's Earth Simulator, the world's most powerful supercomputer devoted to earth sciences. The result supports the idea, that improved modells could reconcile ones with the observations. Global climate models typically calculate climate at points of 200 kilometers or more apart. The resulting pictures of climate are to fuzzy to pick up anything as small as a tropical cyclone. But the Japanese group simulated the present climate and the warming climate near the end of the century at a resolution of just 20 kilometers, thanks to the Earth Simulator's power. That was detailed enough for tropical cyclones to appear in the model, allowing the researchers to roughly gauge their intensities. In fact, in the warmer world, the total number of storms over the globe had actually decreased by 30%. „But the number of the rarer category 3 and 4 storms had increased substantially, not unlike observational results" (Kerr, 2006).

How Big is the Impact of Global Warming in Relation to the Natural Cycle?

Although there is concern about the quality of intensity data prior to the late 1960s on account of changes in observational techniques we take it as given that there was another period of high activity before the period with lower activities started about 1970.

Pielke argues that the relevance of global warming is exceedingly small in the context of, for example, the more than doubling in numbers of major hurricanes between quiet and active decadal periods in the Atlantic (Pielke, 2005, based on Goldenberg et al. 2001). Also the U.S. National Oceanic and Atmospheric Administration (NOAA) stated 2005 in press releases, that „longer-term climate change appears to be a minor factor" in „the most devastating hurricane season the country has experienced in modern times". The surge in Atlantic hurricane activity since 1995 is the latest upswing in a natural cycle, the releases said: As the Atlantic Ocean warms and wind patterns shift, hurricanes increase for a decade or two until a lull sets in again (see Kerry, 2006). Christopher Landsea of the Hurricane Center in Miami, Florida, recently claimed that NOAA public affairs staff members writing the press releases had overstated the case for natural cycle. The warming may well be largely human-induced, cited Kerr Landsea. (Kerr, 2006). As all ocean basins show a warming of sea water surface, it seems very likely that it also plays a significant role in this case.

Faust (2006) used the data provided from NOAA to show a remarkable increase of strong hurricanes over time both in cold and warm phases since 1860. The new warm phase shows more intense hurricanes than former the warm phase. The last cold phase showed more intense hurricanes than the former one:



Annual frequencies of tropical cyclones of various categories. Horizontal lines relate to the average annual number of Cat. 3-5 hurricanes during the warm and cold phases in the North Atlantic. Indication of phases according to Landsea et al. (1999) and Goldenberg et al. (2001). Source of data: according to NOAA, Unisys; Graph: Munich Re

Because of lack on reliable data only four time periods have been compared. Length of time series and data quality don't allow to base a strong argument, about to what extent anthropogenic global warming contributes to the actual increase of intense hurricanes. But at least they demonstrate, that the existing data better support the claim, that climate change is a relevant co-driver of record hurricane intensity than its opposite claim, that the natural cycle is the only driver.

Are Category 4 and 5 Storms also Stronger after Land Fall?

There is still a debate, whether category 4 and 5 storms are not only stronger at sea, but also at the time of landfall (Kerry, Emanuel in Dreifus, 2006). However, Faust has shown, again based on NOAA-data, that between the last (1926 until ca. 1970) and the actual warm period (since ca. 1995) also the number of landfalls has dramatically increased:

category 3-5 hurricanes: +67 %

category 1-5 hurricanes: + 28%

tropical storms and category 1-5 hurricanes: +47.

Faust does consider global warming as the main driver for this difference (Faust, 2006).

Faust, 2006

On the other hand only during 2004 and 2005 did the U.S. landfalling PDI reach or exceed the strong levels that occurred several times in the first half of the 20th century.

Much will depend, whether 2004 and 2005 are interpreted as extreme outliers or as the start of a new trend, which has been masked since 1995 by the fact that U.S. landfalling storms are only a small fraction of all Atlantic hurricanes. Future will show.

he record years 2004 and 2005 could support this assumption of a new trend. But for really seeing a new trend rather than just some extreme years, the timeline from 1995 to 2005 alone is by far too short to show this. If we see from now on an increase of 70 % or (with increasing sea surface temperature) even more 3-5 hurricane landfalls, in all warm phases, then this would be extremely significant. The record numbers of the last years could support such an expectation. Still, there is also the possibility that we have only experienced some extreme landfall years and the rest of the decade will be more like past warm phases. Until 2003 statistics gave little support for other expectations.

Is Climate Change a Significant Factor for Increased Hurricane Impacts on Society?

So far there has been a broad consensus that *for the past* the most significant factor underlying trends and projections associated with hurricane impacts on society is societal vulnerability to those impacts and not the trends or variation in the storms themselves (sea Pielke and Landsea 1998; Pielke 2005). Consensus seems to be that growing population and wealth in exposed coastal locations guarantee increased economic damage in coming years, regardless of the details of future patterns of intensity or frequency (Pielke et al. 2000). "In the past (centennial time scales) variability of natural geophysical hazards (including possible trends) has been orders of magnitude smaller than trend implied by economic or population growth." (Grenier, 2006).

But whether already in the past the impact of climate change – not as the primary but as a secondary factor – on societal impacts can be shown; and whether climate change is becoming an increasingly significant factor for the increase of hurricane impacts on soceity up to now constitutes an open debate. And it has to been noted, that non-detecting does not enable to conclude regarding the existence (Trenberth, 2005).

A further question is, whether the methodology of Pielke really can support his strong hypothesis that „long-term records of economic damages show no upward trend, once the data are normalized to remove the effects of societal changes" (Pielke, 2006; Pielke et al., 2005).

An additional debate of interest could be, whether other methodologies would be more appropriate, to look at the impact of hurricanes on society. One example: As we know, the poor and marginalised population is most affected from weather extremes. Only 11 percent of the people exposed to natural disasters lived in countries classified, according to the UNDP Human Development Index (HDI), as those with a low HDI. But still, these countries account for more than 53 percent of the total recorded deaths (see UNDP 2003). Even more striking is the fact, that over 96 percent of disaster-related deaths in recent years have taken place in developing countries (World Bank 2001). Also the data for weather-related disasters in 2004 show, that countries with a low ranking on the Human Development Index and people living there are more vulnerable:

It is questionable whether Pielke's methodology would adequately reflect significant effects of increased hurricane intensity for the poorest and marginalised part of the population. Such a change might not be relevant in economic terms but most relevant for many people.

Even more relevant might be, whether the conclusion of Pielke (2005) regarding *the future* can be defended. He not only sees no trend identified in various metrics of hurricane damage over the 20th century. While he accepts, that scientists may identify discernible changes in storm behavior, he also argues regarding the future, that it is „exceedingly unlikely that scientists will identify large changes in historical storm behavior that have significant societal implications". (Pielke, 2005).

Rahmstorf et al. (2005) come to a different conclusion: "The current evidence strongly suggests that:

(a) hurricanes tend to become more destructive as ocean temperatures rise, and

(b) an unchecked rise in greenhouse gas concentrations will very likely increase ocean temperatures further, ultimately overwhelming any natural oscillations. Scenarios for future global warming show tropical SST rising by a few degrees, not just tenths of a degree." (Rahmstorf et al. 2005)

SST increases in the Atlantic during 21st century are likely to be much more substantial than seen so far, perhaps by a factor of four (Knutson and Tuleya 2004).

As windstorm damages are exponentially related to wind speed (see for example Dlugolecki et al. 1996, in IPCC WG2 SAR), even small changes could have some effect. The force of increased velocity is proportional to the cube of the velocity. So it is not a linear function. So if we see a significant increase in 4-5 hurricanes and in related landfalls the impact on damage will even be more compelling.

New Regions, New Risks

Another risk for societies, not acknowledged in Pielke's hypotheses regarding the future, is that societies which so far didn't have to expect hurricanes could face this risk in future.

For most tropical meteorologists the most astonishing storm of 2004 took place in March 2004. Hurricane Catarina --

so named because it made landfall in the southern Brazilian state of Santa Catarina -- was the first recorded south Atlantic hurricane in history. Textbook orthodoxy had long excluded the possibility of such an event; sea temperatures, experts claimed until then, were too low and wind shear too powerful to allow tropical depressions to evolve into cyclones south of the Atlantic Equator.

Two other extremely unusual, as far as we know unique, hurricanes emerged in 2005. Hurricane Vince developed in the eastern North Atlantic, a region not previously affected by hurricanes. It passed Madeira as a full-blooded hurricane and even reached the European mainland in southern Spain, but only caused minor damage.

At the end of November 2005, the Canary Islands were hit by Hurricane Delta, the first such storm there since the recording of tropical cyclones in the Atlantic began. This regional extension is one of the strongest arguments, that we might have experienced during the last two years the emergence of a new pattern of hurricane activity.

Sea Level Rise Increases Risk

Global warming also makes hurricanes more destructive by raising the sea level. So even if we wouldn't see any increase in number, intensity and regional distribution of hurricanes, they will become more destructive because of rising sea level, unless substantial damage mitigation steps are undertaken: Assuming current trends of development practice continue, a FEMA study (1991) found that an increase in the expected annual flood damage in the US by the year 2100 for a representative NFIP insured property subject to sea level rise is estimated to increase by 36-58 percent for a 1-foot rise, and by 102-200 percent for a 3-foot rise in sea level. IPCC 2001 expected an increase of 9 to 88 cm during this century. But using the altimetry satellites TOPEX/Poseidon and Jason, a global mean sea-level rise of 2.8 ± 0.4mma was estimated (Cazenave & Nerem, 2004). If this is the actual rate of sea level increase it would be at the upper range of the IPCC 2001 expactations (see Summary for Policy Makers, figure 5; sea also Rahmstorf and Schellnhuber, 2006: 63f) and a 3-foot rise this century seems possible. Also the newest scientific evidence from an unexpected melting dynamic in greenland and west antarctis points in a direction, that even the extreme scenarios of IPCC 2001 (88 cm this century) might now be a very realistic one.   As future sea level rise has a very long equlibration time scale – centuries to millenia – further temperature increase will over time further exacerbate more and more coastal flooding problems from a given hurricane.

Ready to Agree on Rules of the Game to Test the Different Hypotheses?

Pielke et al. have given some criteria, under which circumstances they would be ready to accept that climate change increases significantly the hurricane risk for society. „Looking to the future, until scientists conclude (a) that there will be changes to storms that are significantly larger than observed in the past, (b) that such changes are correlated to measures of societal impact, and (c) that the effects of such changes are significant in the context of inexorable growth in population and property at risk, then it is reasonable to conclude that the significance of any connection of human-caused climate change to hurricane impacts necessarily has been and will continue to be exceedingly small." (Pielke et al., 2005). It would be very interesting if different parties of this debate could agree about similar criteria, which are able to shift evidence to one side or the other.

It is to expect, that for many debates we shouldn't expect quick decisive results. Data still can be used to support different hypotheses. Politics, insurance, investment sector and others nevertheless have to act under uncertainty. It would be very interesting to use Bayesian Logic as a means of quantifying uncertainty. E.g. Carlo Jäger and his team from PIK, Potsdam, work with this method.

Based on probability theory, the Bayesian theorem defines a rule for refining a hypothesis by factoring in additional evidence and background information, and leads to a number representing the degree of probability that the hypothesis is true. Each year we could then see how reality changes the probability of different hypotheses. This would be a suggestion for the next constructive steps in this important debate.

The balance of evidence has been shifted. Strong arguments now point in direction of a hypotheses, which had few supporters only two years ago: that global warming has an increasing effect on the planet's most devastating storms. But there might be much more left to say.

References:

Barnett, T.P. et al. 2005: Penetration of Human-Induced Warming into the World's Oceans, Science 309, S. 284–287.

Cazenave, A., Nerem, R.S., 2004: Present-day sea level change: observations and causes. Reviews of Geophysics 42, 20 (2004).

Dlugolecki, A.F., et al. 1996: Financial Services. In: Climate Change 1995: Impacts, Adaptation, and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change [Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 539–560.

Dreifus Claudia, 2006: A Conversation with Kerry Emanuel: With Findings on Storms, Centris Recasts Warming Debate, in: New York Times, January 10, 2006.

Emanuel, K. (2005): Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436, 686-688.

Emanuel, K. (2006), Environmental influences on tropical cyclone variabiltiy and trends. Proceedings of 27th AMS Conference on Hurricanes and Tropical Meterology, #4.2. Available online at: http://ams.confex.com/ams/pdfpapers/107575.pdf.

Faust, Eberhard, 2006: Changing hurricane risk, Georisks, January 2006, updated to the end of the hurricane season 2005.

FEMA, 1991: Federal Emergency Management Agency, Federal Insurance Administration: Projected Impact of Relative Sea Level Rise on the National Flood Insurance Program; Goldenberg, S.B., et al. (2001), The Recent Increase in Atlantic Hurricane Activity: Causes and Implications, Science 293, S. 474–479.

Gray, W.M., J.D. Sheaffer, and C.W. Landsea, 1997: Climate trends associated with multidecadal variability of Atlantic hurricane activity. "Hurricanes: Climate and Socioeconomic Impacts." H.F. Diaz and R.S. Pulwarty, Eds., Springer--Verlag, New York, 15-53.

Grenier, Hervé, 2006: Climate Change and Disaster Losses: Understanding and Attributing Losses and Projections, in Climate Change and Disaster Losses Workshop, 25-26 May 2006, Hohenkammer, Germany.

Hoyos C.D., P. A. Agudelo, P. J. Webster, J. A. Curry, 2006: Deconvolution of the Factors Contributing to the Increase in Global Hurricane Intensity, Science 7April 2006: Vol. 312. no. 5770, pp. 94 – 97; DOI: 10.1126/science.1123560; Originally published in Science Express on 16 March 2006.

Kerr, R.A., 2005: Is Katrina a Harbinger of Still More Powerful Hurricanes?, Science Vol. 309, p. 1807.

Kerr, R.A., 2006: A Tempestous Birth for Hurricane Climatology, Science, Vol. 312, 5.5. 2006, p.676-678.

Knutson, T. K. , 2006 : Perspectives on Focused Workshop Questions Regarding Past Economic Impacts of Storms or Floods, in : Climate Change and Disaster Losses Workshop, 25-26 May 2006, Hohenkammer, Germany.

Knutson, T.K., and R.E. Tuleya, 2004 : Impact of CO2-induced warming on simulated hurricane intensity and precipitation : Sensitivity to the choice of climate model and convective parameterization. J. Climae, 17 (18), 3477-3495.

Landsea, C. W. et al., 1999:, Atlantic Bassin Hurricanes: Indices of Climatic Changes, in: Karl, T. R. et al. (1999), Weather and Climate Extremes, Dordrecht, S. 89-130.

Landsea, C.W., 2005: Hurricanes and global warming. Nature, 438, E12-E13.

Pielke, Roger (Jr), 2005: Attribution of Disaster Losses, Corrected Version, Science 27 January 2006, Vol. 311. no. 5760, p. 470.

Pielke, Jr., R. A., 2005: Are there trends in hurricane destruction? Nature, Vol. 438, December, pp. E11. Brief comment on K. Emanuel's.

R. Pielke Jr. et al., Bull, 2005:. Am. Meteorol. Soc. 86, 1481 (2005). Hurricanes and Global Warming, Revised 18 August 2005; Accepted 27 August 2005.

Pielke, Jr., R. A., C. Landsea, M. Mayfield, J. Laver and R. Pasch, December 2005: Hurricanes and global warming, Bulletin of the American Meteorological Society.

Pielke, Jr., R. A., and Landsea, C.W., 1998: Normalized U.S. hurricane damage, 1925-1995. Weather and Forecasting, 13:621-631.

Rahmstorf et. Al, 2005: Stefan Rahmstorf, Michael Mann, Rasmus Benestad, Gavin Schmidt, and William Connolley, Hurricanes and Global Warming - Is There a Connection? 2. September, 2005; www.realclimate.org; Schellnhuber HJ (ed), 2006: Avoiding dangerous climate change Cambridge University Press, Cambridge.

Rahmstorf S. and Schellnhuber H.J. 2006: Der Klimwandel, Munich.

Tourre, Y.M., White, W.B. ,2005:, Global Climate Signals and Equatorial SST Variability in the Indian, Pacific and Atlantic Oceans during the 20th Century, submitted to Geophys. Res. Lett.

Trenberth, K. (2005), Uncertainty in Hurricanes and Global Warming, Science 308, p. 1753–1754.

UNDP, 2005 : Reducing Disaster Risk – A Challenge for Development, New York.

Webster, P.J. et al. 2005: Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment, Science 309, S. 1844–1846.

World Bank, 2001: World Development Report 2002. Washington, D.C.

The benefits of disaster risk reduction and their effects on loss trends

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Abstract

Trends in economic losses from weather related disasters have often been attributed to changes in exposure as well as to changes in weather extremes. Exposure is generally expressed as the number of people, or the economic value of capital, that are put at a certain risk. The reduction of disaster risk may affect exposure, but is often ignored. In this short paper I argue that effective disaster risk reduction may change exposure over time. Studies that do not consider disaster risk reduction may overestimate the effects of socio-economic factors that drive loss trends, such as population growth and the accumulation of capital. These studies may also underestimate the impacts of historic and future changes in climate and extreme weather events.

1. Introduction

Worldwide direct economic losses from natural disasters have been increasing considerably over the last (e.g. Munich Re, 2005). Time-series analysis of loss records has shown that this increase for some weather related hazards in the US can largely be explained by changes in socio-economic factors, most importantly population growth and the accumulation of capital in areas that are at risk from natural hazards (e.g. Pielke and Landsea, 1998; Changnon, 2003). These factors together have resulted in an increasing exposure. Some other scholars however have argued that climate change and consequent shifts in extreme weather events may have an important contribution to the increase in losses from weather related disasters (e.g. Mills, 2005).

Another important factor that may also affect losses is often ignored in the analyses of loss trends. That factor consists of efforts aimed at reducing risks from natural hazards. Increased efforts to reduce risks over time may decrease losses that result from extreme events. These efforts may consist of land-use planning, constructing dikes, improving and enforcing building codes, as well as the implementation of forecasting and early warning systems.

The Intergovernmental Panel on Climate Change (IPCC) stated in 2001 in its Summary for Policymakers of Working Group II: "The costs of weather events have risen rapidly despite significant and increasing efforts at fortifying infrastructure and enhancing disaster preparedness" (McCarthy *et al.,* 2001). It appears therefore that the many efforts around the world to reduce risk have not been able to curb the impacts from increasing exposure. At the same time, many efforts have been put in place over time, and may in recent times have mitigated the increasing losses to some extent.

The goal of this paper is first to argue how risk reduction may influence the impacts from weather related disasters, and to present some examples. Secondly, it aims to argue why it is important to consider these effects.

2. Definition and benefits of disaster risk reduction

Disaster risk reduction can be defined as "The conceptual framework of elements considered with the possibilities to minimize vulnerabilities and disaster risks throughout a society, to avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of hazards, within the broad context of sustainable development" (http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm).

Disaster risk reduction may address the extreme event itself, as well as the vulnerability to losses associated with that event. For example, one may try to reduce the peak height of a flood in a river basin, by implementing flood mitigation measures, such as the building of weirs, or by promoting afforestation of uplands. As a result, the probability of the extreme event (high water levels/flooding) may decrease. But additionally, one can make sure that the consequent losses are reduced while the extreme event still has the same probability of occurrence, for instance by improving the construction of houses. This makes disaster risk reduction simply one of the many factors that affect risk (Table 1).

Natural factors	Socio-economic factors
- Frequency of extreme event - Intensity of extreme event - Duration of weather events	- Increasing population - Habitation of particularly vulnerable areas (coastal zones, flood plain areas) - Increasing wealth (more expensive construction of buildings, larger amount of increasingly expensive goods, larger stocks, larger number of increasingly expensive vehicles) - Increasing urbanisation - Change in management of rivers and coastal zones - Land use change (environmental deterioration, changed agricultural techniques, vegetation cover) - Changing or negligence of building codes and construction methods - Improving forecast, warning, and evacuation schemes - Increasing awareness of population

Table 1. Factors that may influence natural disaster risk (from Bouwer and Vellinga, 2002).

It is important to note that risk reduction may affect the impacts of different natural disasters in different ways. For instance, in a particular region one may be successful in reducing the risks of storm damage by enforcing building codes, but one may be less successful in reducing the risks of damage resulting from heavy rainfall due to the low-lying nature of the area.

Also, disaster risk reduction may act as a two-edged sword: while it will largely reduce risks, it may also create a false sense of security that can result in reluctance to further reduce losses and may even lead to increasing development, thereby again increasing the risk of high losses.

3. Some examples of successful risk reduction

3.1 Loss of life from natural disasters

One clear example of the success of mitigating disaster risk is the reduction of the number of worldwide fatalities due to natural disasters (Figure 1). This reduction is likely to be due to a combination of increasing understanding of processes behind natural disasters, the ability to create structural as well as non-structural mitigation measures, such as the implementation of early warning systems and education of populations at risk.

The more extensive analysis in the white paper by Indur Goklany shows that this decline is largely due to a reduction in mortality resulting from

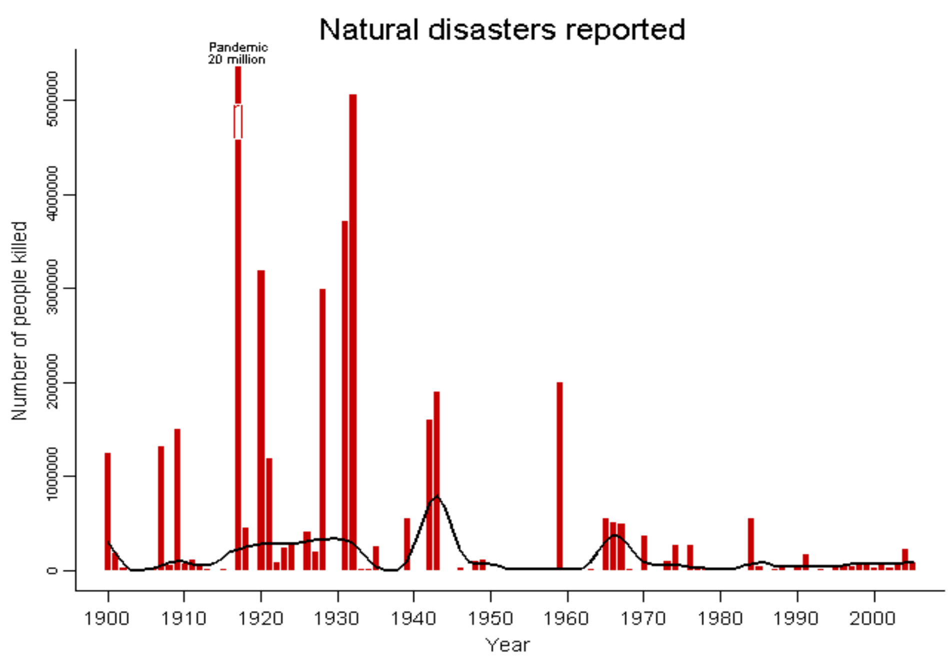

Figure 1. Number of fatalities from natural disasters, including diseases (source: CRED, EM-DAT database, http://www.em-dat.net).

droughts and floods. The analysis by Jonkman (2005) using the same EM-DAT database from CRED shows that there may be a slight upward trend in the number of people killed per event over the period 1975-2002, but he concludes that it is difficult to determine trends with certainty. At the same time, it is important to note that the estimated number of people that are affected by natural disasters appears to have increased over recent years (IFRC, 2002).

3.2 Windstorm losses

Building codes and consequent building construction are important factors in determining the vulnerability of assets at risk from storms. Over time, codes and construction may change. The effects of construction codes on building vulnerability are also explicitly used in vulnerability models, in order to decide on the costs and benefits of retrofitting (e.g. Englehardt and Peng, 1996; Stewart, 2003).

An analysis of the improvement of building codes in Florida (USA) has shown that these codes were rightfully developed, as they help to reduce direct economic losses, as well as reduce the risk of casualties (Englehardt and Peng, 1996). However, how the actual vulnerability of the building stock has changed needs to be assessed separately.

It has been shown that during hurricane Andrew buildings constructed decades ago performed better than buildings constructed more recent, mainly due to the style of houses (Pielke and Pielke, 1997). On the other hand, a survey in Florida, USA, found that buildings that were constructed according to the new 2002 state-wide building code performed much better in the 2004 hurricane season than older buildings (American Re, 2005: p. 26). Similarly, in Australia, improved building codes are estimated to have reduced vulnerability up to 65% (Ryan Crompton, personal communication).

3.3 Flood losses

The reduction of the amount of losses from extreme events is an important prerequisite for implementing risk reduction measures. For instance, cost-benefit analyses are being performed for justifying investments in flood control and determining the optimal design of the measures (Brouwer and Kind, 2005; Pearce and Smale, 2005). Within such evaluation of costs and benefits of risk reduction measures, the avoided damages are an important benefit, next to other indirect and often non-priced benefits, such as public safety.

An analysis of flood losses in the 2002 flood in Germany showed that local household protection measures may influence losses to a considerable extent (Kreibich *et al.,* 2005).

In The Netherlands, improving protection against storm surges and river floods was motivated by the benefit of protecting the assets present in the areas that lie below sea-level or close to the rivers. Over centuries, the flooding frequency has varied considerably, depending on climatic factors, but according to Tol and Langen (2000) above all depending on factors such as technological developments, institutional change, and risk perception (Figure 2).

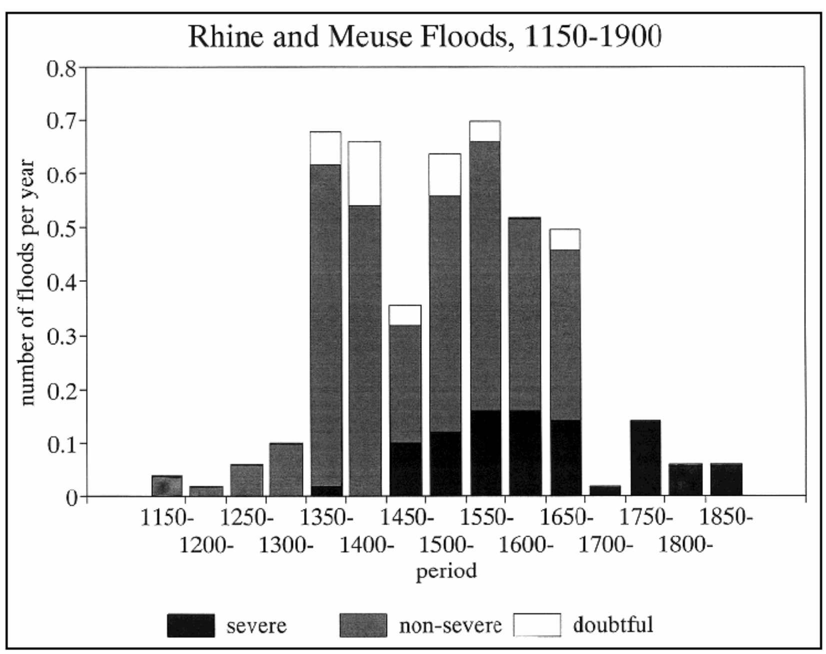

Figure 2. Flooding frequency in The Netherlands (from: Tol and Langen, 2000).

Awareness can be an important factor, as people may be able to better anticipate to floods, and prevent damage from occurring if they prepare for a disaster. This can for instance be illustrated by the two Rhine floods in Germany that occurred in December 1993 and January 1995. As these two floods quickly followed one another, the population living along the river was prepared for the next flood. People cleared their belongings to above the 1993 flood level, and consequently the damage of the second flood was reduced. The costs reflected this, as the flood in 1995 in Cologne caused about half the damage of the flood in 1993 (1202 and 617 million DM total economic losses, respectively), despite the same water level (Bavaria Re, 1994; Bavaria Re, 1995).

4. The importance of analysis of risk reduction benefits

Analyses of benefits of risk reduction are not commonplace, and are probably unknown for most locations around the world. Many efforts have been made to reduce risks from natural hazards (ISDR, 2004), although the exact number of the total amounts of investments, let alone their direct benefits, is lacking. A good understanding of the effects and effectiveness of risk reduction is missing as well.

Tools to determine the benefits of natural disaster risk reduction are available, but may need to be further improved and applied more widely. For example, some of the tools used by development agencies could be used to assess risks and benefits of risk reduction (Benson and Twigg, 2004). A proper analysis of the global effects of risk reduction would need to discriminate between different world regions, as risk reduction may have been implemented differently and at different times in the various regions.

It appears that a good understanding of the effects of risk reduction is not present at this time. There is a need to further analyse the benefits of risk reduction, for a number of reasons. First of all, the analyses of the success of risk reduction may help to gain further support for the reduction of the impacts from natural disasters. Secondly, it may show that part of the effects of increasing exposure due to population growth and increases in wealth and the amount of capital may have been curbed, for some hazards, in some areas.

Such analyses may have implications for disaster risk reduction policy and efforts in development cooperation, as it shows to what extent the efforts are successful. It may further show that there are opportunities for integrating climate change adaptation into efforts aimed at reducing risks from weather related disasters (e.g. Bouwer and Vellinga, 2005; Sperling and Szekely, 2005; Thomalla *et al.,* 2006). Along similar lines, the financing of climate change adaptation could also largely tap into funds aimed at disaster risk reduction, as current funds under the UNFCCC are limited (Bouwer and Aerts, 2006).

These analyses may also have implications for our understanding and analyses of historic disaster losses. Loss records that are only adjusted for population growth and increases in wealth and the amount of capital may show a decrease in losses over time that is the result of risk reduction efforts. Adjusting for risk reduction effects may still show a climate signal in the record, that is, the effects of interannual climate variability, but it could reverse the long-term trend of losses and thereby show the impact of other environmental factors, such as climate change.

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References

American Re 2005: Topics: Annual Review of North American Natural Catastrophes 2004. American Reinsurance Company, Princeton, NJ, USA.

Bavaria Re 1994: The "Christmas Floods" in Germany 1993/94. Bavaria Reinsurance Company, Munich, Germany, 23 pp.

Bavaria Re 1995: …13 Months Later – The January 1995 Floods. Bavaria Reinsurance Company, Munich, Germany, 8 pp.

Benson, C. and J. Twigg 2004: Measuring Mitigation: Methodologies for Assessing Natural Hazard Risks and the Net Benefits of Mitigation: A Scoping Study. ProVention Consortium, Geneva.

Bouwer, L.M. and P. Vellinga 2002: Changing climate and increasing costs: implications for liability and insurance. In: Beniston, M. (ed.) *Climatic Change: Implications for the Hydrological Cycle and for Water Management*. Dordrecht and Boston, Kluwer Academic Publishers, 429-444.

Bouwer, L.M. and P. Vellinga 2005: Some rationales for risk sharing and financing adaptation. *Water Science and Technology*, 51(5), 89-95.

Bouwer, L.M. and J.C.J.H. Aerts 2006: Financing climate change adaptation. *Disasters*, 30(1), 49-63.

Brouwer, R. and J.M. Kind 2005: Cost-benefit analysis and flood control policy in The Netherlands. In: Brouwer, R. and Pearce, D.W. (eds.) *Cost-Benefit Analysis and Water Resources Management*. Edward Elgar Publishing, Cheltenham, UK, 93-123.

Changnon, S.A. 2003: Shifting economic impacts from weather extremes in the United States: a result of societal changes, not global warming. *Natural Hazards*, 29, 273-290.

Englehardt, J.D. and C. Peng 1996: A Bayesian benefit-risk model applied to the South Florida building code. *Risk Analysis*, 16(1), 81-91.

IFRC 2002: World Disasters Report 2002: Focus on Reducing Risk. International Federation of Red Cross and Red Crescent Societies, Geneva.

ISDR 2004: Living with risk: a global review of disaster reduction initiatives. International Strategy for Disaster Reduction, Geneva.

Jonkman, S.N. 2005: Global perspectives on loss of human life caused by floods. *Natural Hazards*, 34(2), 151-175.

Kreibich, H., A.H. Thieken, M. Müller and B. Merz 2005: Flood loss reduction of private households due to building precautionary measures: lessons learned from the Elbe flood in August 2002. *Natural Hazards and Earth System Sciences*, 5(1), 117-126.

McCarthy. J. J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White 2001: *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group 2 to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.

Mills, E. 2005: Insurance in a climate of change. *Science*, 309, 1040-1044.

Munich Re 2005: Topics Geo, Annual Review: Natural Catastrophes 2004. Munich Reinsurance Company, Munich.

Pearce, D.W. and R. Smale 2005: Appraising flood control investments in the UK. In: Brouwer, R. and Pearce, D.W. (eds.) *Cost-Benefit Analysis and Water Resources Management*. Edward Elgar Publishing, Cheltenham, UK, 71-92.

Pielke, Jr., R.A. and R.A. Pielke, Sr. 1997: Hurricanes: Their Nature and Impacts on Society. Wiley, New York, NY.

Pielke, Jr., R.A. and C.W. Landsea 1998: Normalized hurricane damages in the United States 1925-95. *Weather and Forecasting*, 13(3), 621-631.

Sperling, F. and F. Szekely 2005: Disaster Risk Management in a Changing Climate. Discussion paper. World Bank, Washington, D.C.

Stewart, M.G. 2003: Cyclone damage and temporal changes to building vulnerability and economic risks for residential construction. *Journal of Wind Engineering and Industrial Aerodynamics*, 91(5), 671-691.

Tol, R.S.J. and A. Langen 2000: A concise history of Dutch river floods. Climatic Change, 46, 357-369.

Thomalla, F., T. Downing, E. Spanger-Siegfried, G. Ham and J. Rockström 2006: Reducing hazard vulnerability: towards a common approach between disaster risk reduction and climate adaptation. *Disasters*, 30(1), 39-48.

Climate Change and Losses through Natural Disaster: Some Remarks from Experience in the Czech Republic

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Of all natural disasters, floods and windstorms are the most devastating in the Czech Republic. They often involve loss of human life and extensive material damage. The most spectacular cases to date have been the July 1997 flood in the eastern part of the Czech Republic (52 dead, material damage 63 billion Czech crowns) and the August 2002 flood in the western areas (19 dead, material damage 73 billion Czech crowns). Events of lesser extent occurred in July 1998 (flash flood in eastern Bohemia with 6 dead and damage estimated at 2 billion Czech crowns) and March/April 2006 (9 dead, damage 5.6 billion Czech crowns).

Recent developments in climate change, floods and windstorms in the Czech Republic

The process of global warming is reflected in the Czech Republic by statistically significant increases in air temperature with reference to the average series for 1848–2000, with the following linear trends: winter 0.93, spring 0.88, summer 0.36, autumn 0.52 and year 0.69ºC/100 years. These trends are even more marked in the case of some individual stations. On the other hand, series of seasonal and annual precipitation totals show no significant linear trends, with the exception of an increase in winter.

Some important conclusions may be derived from analysis of floods in the instrumental and pre-instrumental periods in the Czech Republic (Brázdil et al., 2005a). In the period covered by systematic hydrological observations (i.e. since around the mid-19th century), the total numbers of the floods, as well as their extremities expressed through the N-year return period of maximum peak discharges, have been falling (Fig. 1). This decline may be ascribed primarily to a reduction of the frequency of floods of the winter synoptic type, those related to snow melting and ice damming accompanied by rain. This, in turn, is a consequence of global warming in which, following on from a later onset of winters and lower accumulation of water in snow cover, the number of floods has decreased, mainly in the months of February to April. Information held in documentary evidence makes it possible to extend the flooding information base back for several centuries. A synthesis of floods based on instrumental data and documentary sources indicates long-term trends, with a maximum of floods in the 19th century and the second part of the 16th century. From this analysis it becomes evident that, although several destructive floods occurred in the 20th century, it could well be classed as a very favourable hundred years (with the exception of the flood of July 1997).

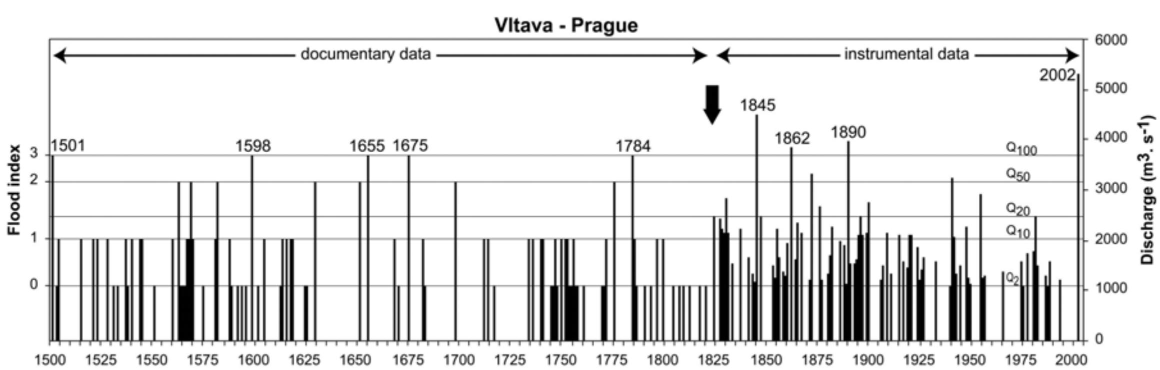

Fig. 1. Chronology of floods on the River Vltava at Prague in 1500–2002 – a synthesis of documentary data and instrumental records. Left axis: flood indices with reference to documentary data interpreted on an intensity scale of 0–3. Right axis: measured maximum peak discharges during floods with N-year water levels; for example, Q20 corresponds to a maximum peak discharge with a return interval of 20 years (Brázdil et al., 2005b)

The state of knowledge about changes in windstorm conditions (Brázdil et al., 2004) is blurred by far more complication than that involved in floods. Wind speed measurement data are significantly biased by changes in instruments over time, rendering the matter of obtaining homogeneous series complex, at best. The apparent frequency of strong winds reflects, at least to some extent, an increase in the number of documentary sources from the past. Despite this, it remains possible to speak of a higher frequency of strong winds at the cusp of the 16th and 17th centuries and largely in the years 1800–1830 and 1900–1940. On the other hand, the series of strong winds created does not allow presentation of any serious conclusions about long-term trends; the documentary records are simply incomplete (Fig. 2).

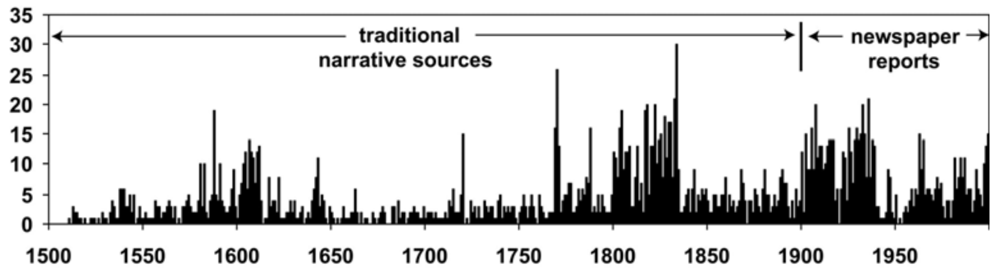

Fig. 2. Annual frequencies of strong winds derived from documentary evidence in the Czech Republic in the period 1500–1999 (Brázdil et al., 2004)

Factors accounting for increased costs associated with disasters in recent decades

No series of calculations of the costs of disasters exists for the Czech Republic. No institution systematically collects this type of data, while problems remain inherent to any comparison of recent costs of disastrous natural events with historical ones. Regardless of this, meteorological and socio-economic factors contribute to loss of human life and material damage in the course of disasters. With respect to climate change, it is expected that changes in the mean values will accompany changes in the simple occurrence of extreme weather patterns, followed by changes in the frequency and severity of extremes. The impacts proper can be then modulated by various socio-economic circumstances:

- **failure of historical memory**
  It appears that people quickly forget that floodplains are not suitable places for building and other localised human activities. Lack of foresight in the utilisation of such areas increases material damage during floods. Historical buildings, such as churches, have not usually been flooded in the course of recent events because more care went into selecting safe areas for them.
- **changes in the landscape**
  Considerable changes in land-use have taken place that largely reduced the water-retention capacity of the landscape. This is related to a significant increase in the area of arable land, expanding through deforestation and the drying-out of water-meadows and wetlands. Forestry management has concentrated on the production of monocultural fast-growing trees, growths that not only influence the water-bearing capacity of the land, but are not resistant to weather extremes such as wind, snow, ice deposits, drought and pollution. The canalisation of rivers is also an important factor. Original riverbeds have often been significantly shortened, straightened and reshaped by various water structures. In many cases, this has resulted in acceleration of runoff and the parallel occurrence of flood waves on different rivers.
- **the more complicated structure of human society**
  An increasing number of inhabitants and the extension of human activities have increased pressure on the landscape and extended its use. In comparison with the past, significant changes in life-styles, as well as the use of more developed equipment in households, increase the potential for loss in recent events.
- **mistakes in planning and zoning**
  An important means of diminishing losses is sensible territorial planning and zoning. Although information on potentially inundated areas by floods of various return periods is freely available, building permission has

nevertheless often been given in potentially dangerous areas.

- **poor social education about disasters**
  Disastrous natural events have a long return period. The severity of floods is expressed in terms of the N-year return period of culmination discharges in which the corresponding value is achieved, or higher on average, than once per N-years. This is, however, confusing for lay people who often believe that, for example, "a hundred-year water will not occur twice in my lifetime". On the other hand, people believe in the potential for technological protection; the system of water reservoirs on the Vltava below Prague (known as the Vltava Cascade) was built in the 1950s and a relatively quiet period followed. Many believed, until the catastrophic events of 2002, that Prague had been exempted from floods by the intervention of civil engineering.

Recent insights into natural disasters: implications for research and policy

Research related to natural disasters should address the following questions:

- Is the occurrence and severity of natural disasters part of a random process, or is it already a reflection of recent global warming (e.g. as reflected in the increased frequency of flood disasters in the Czech Republic, or Central Europe since the 1990s, or in the course of the past 10 years in the Czech Republic)?
- Can local or regional data on disasters indicate anything about larger trends and relationships?
- What conditions are necessary and sufficient to identify signals of climate change in disasters on local or regional scales?
- Are instrumental records long enough for useful insight into disastrous events with long return periods? For example, on the Vltava in Prague, a flood with a return period of $N \geq 100$ years recurred after 112 years (September 1890 and August 2002), but before 1890 similar floods occurred in February 1784, February 1799, March 1845 and February 1862
- How useful is information about extremes derived from documentary (the past millennium) and palaeclimatological sources (before that) in the study of the severity, seasonality and impacts of past disasters – mainly in terms of the magnitude of events not experienced in recent time.

The recent behaviour of the insurance industry raises problems, in that it is now impossible to insure a house and/or property if they are located in a potential floodplain. In concrete terms, this entails a shift or responsibility for assistance in such events to the government (politicians) or to other parts of the decision-making sphere (managers).

It becomes clear that only one alternative exists for the future – to cope with natural disasters. Society, managers and politicians must have only one aim in preparation for extreme situations: to save human lives and diminish potential material damage. This needs organisation of all the activities that might make any contribution whatsoever in such critical situations.

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References

Brázdil, R., Dobrovolný, P., Elleder, L., Kakos, V., Kotyza, O., Květoň, V., Macková, J., Müller, M., Štekl, J., Tolasz, R., Valášek, H. (2005a): Historical and Recent Floods in the Czech Republic. Masaryk University and Czech Hydrometeorological Institute, Brno, Prague, 370 pp.

Brázdil, R., Dobrovolný, P., Štekl, J., Kotyza, O., Valášek, H., Jež, J. (2004): History of Weather and Climate in the Czech Lands VI: Strong Winds. Masaryk University, Brno, 378 pp.

Brázdil, R., Pfister, C., Wanner, H., von Storch, H., Luterbacher, J. (2005b): Historical climatology in Europe – the state of the art. Climatic Change, 70, 3, 363–430.

Tornado and Severe Thunderstorm Damage

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ISSUES IN REPORT DATABASES

The historical records of the occurrence of and losses from severe thunderstorms and tornadoes present significant challenges in attempting to establish trends, if they exist. Very few countries collect data on events as an activity of the national meteorological service. Within those that do, spatial and temporal differences in reporting procedures or effort mean that consistency is rarely achieved (e.g., Doswell et al. 2005). It is likely that the highest-quality dataset of significant length is the tornado dataset of the United States, which began in the early 1950s. Even these data have serious problems with consistency (Brooks 2004; Verbout et al. 2006) (e.g., Fig. 1). Even though the vast majority of the increase has been in the weakest tornadoes (Brooks and Doswell 2001b), serious inhomogeneities exist even when consideration is restricted to the strongest tornadoes, which have typically been viewed as being better reported (Fig. 2). Recent and planned policy changes within the US National Weather Service may add even more problems to the interpretation of the record.

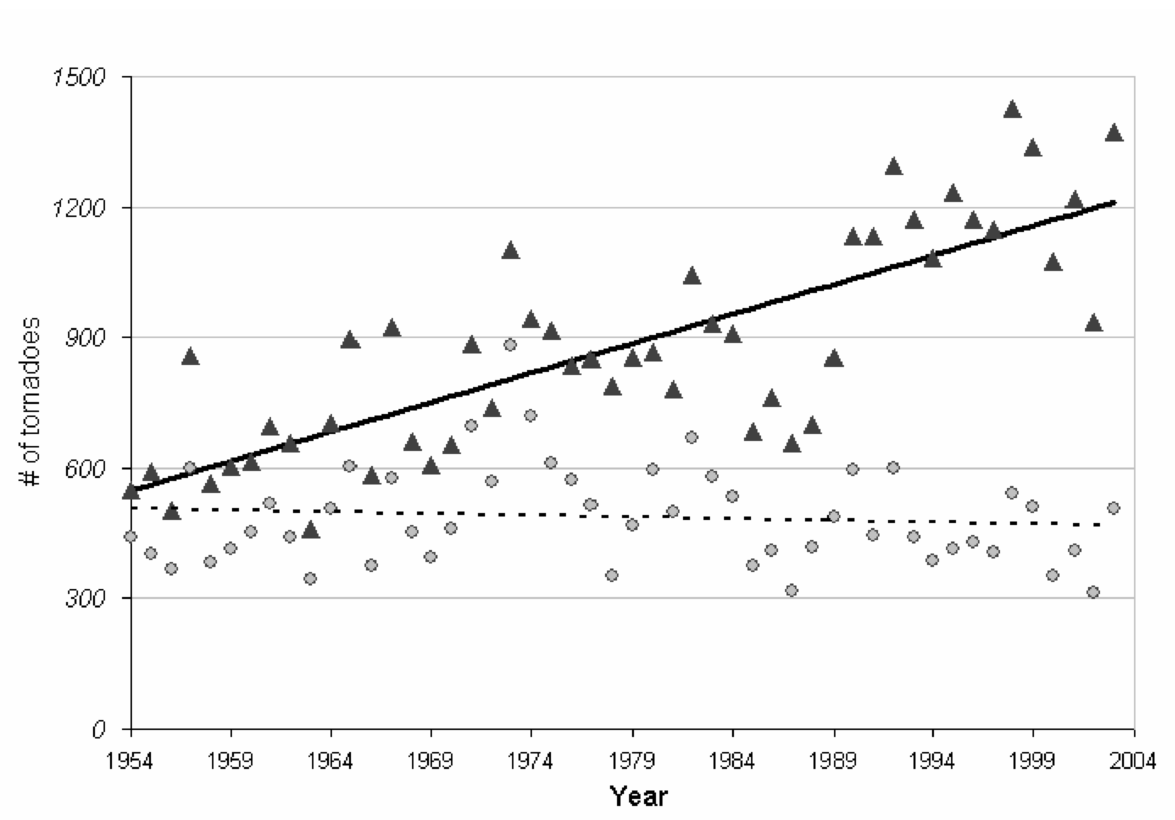

Fig. 1: 1954-2003 annual tornado reports in US. Total (black triangles), and tornadoes rated F1 or higher (gray circles). Linear regression fits to time series in solid and broken lines, respectively. (From Verbout et al. 2006).

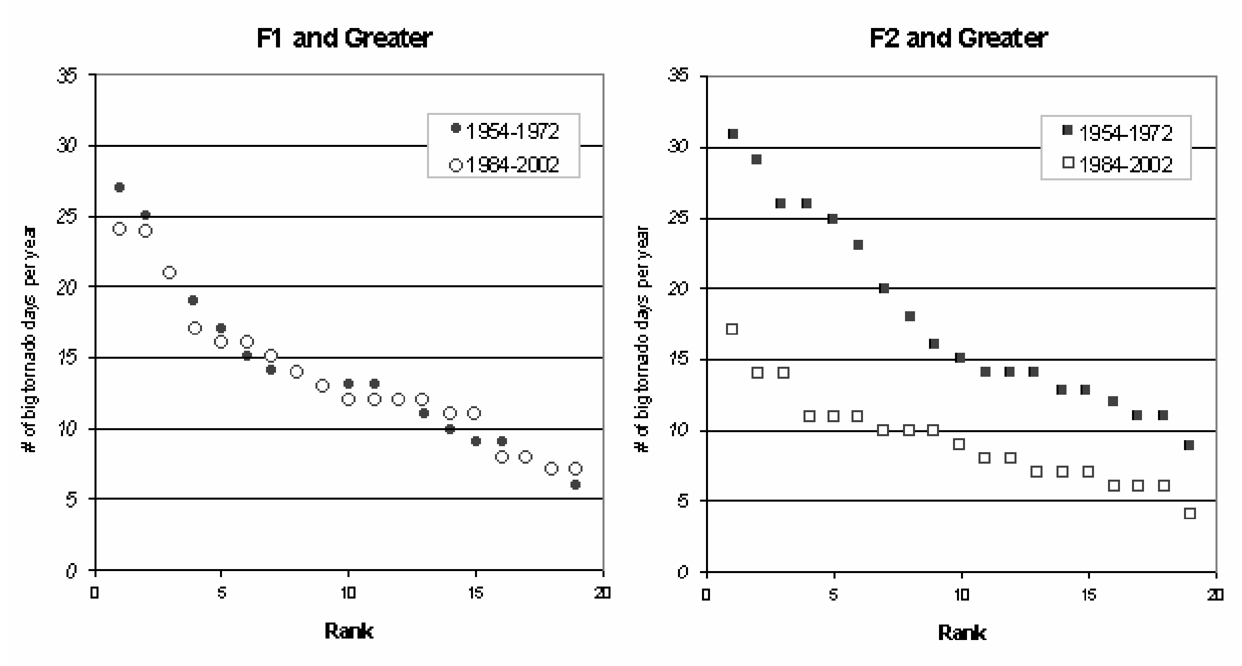

Fig. 2: The ranked distribution of number of days per year exceeding threshold for "big tornado days," as defined by Verbout et al. (2006). F1 and greater series (left) and the F2 and greater series (right). The early portion of the dataset (1954-1972) is denoted by black points; the later portion of the dataset (1984-2002) is represented by open points. The leftmost point in each series is the greatest value and decreases to the right. (From Verbout et al. 2006).

The number of tornadoes reported per year has increased by about 13 per year, or roughly 1% of the current number of reports. Fundamentally, it is effectively impossible to determine whether any changes have occurred in the actual meteorological events from the official observed records in the US. Relatively large physical changes (say, 20% in the period of record) *could* have happened, but would be difficult to detect in the background of reporting issues. There is a profound break in the reported number of strong tornadoes (at least F2 on the Fujita scale, going from F0 to F5) in the mid-1970s, as shown in Fig. 2. Brooks (2004) also showed that the reported path length and width information has undergone large changes, seemingly independent of official policy alterations. It is possible to smooth the report data to produce a distribution of tornado occurrence that may be a reasonable estimate of "truth" (Brooks et al. 2003a), but that smoothing is likely to make the estimate sufficiently resistant so that real changes would be masked. In related work, Dotzek et al. (2003, 2005) and Feuerstein et al. (2005) have shown that the distribution of tornadoes by intensity is similar over much of the world by fitting statistical distributions to reports. Although different environmental regimes can be distinguished (e.g., the US vs. the United Kingdom), the quality of the fit at the most intense end of the spectrum, which represents the rarest events, means that detecting changes in the distribution by intensity of the strongest tornadoes will be difficult at best, unless those distributions are very different.

ENVIRONMENTAL CHANGES

An alternative approach to the question of changes in meteorological events is to look for possible changes in environmental parameters favorable for severe thunderstorms. Brooks et al. (2003b) followed techniques from forecasting research and developed relationships between large-scale environmental conditions and severe thunderstorms and tornadoes, using global reanalysis data. Recently, the work has been expanded to look at a longer period of record around the globe. Interannual variability on a global scale in the frequency of favorable severe thunderstorm environments has been large, with no discernable trend. Regionally, there have been changes, although the question of the quality of the reanalysis representation requires caution to be applied to the interpretation. The eastern US showed a decrease from the late 1950s to the early 1970s, followed by a slow increase through the 1990s

(Fig. 3a). For the same size region including the high-frequency severe thunderstorm areas of southern Brazil and northern Argentina, there has been a decrease though the period of record (Fig. 3b).

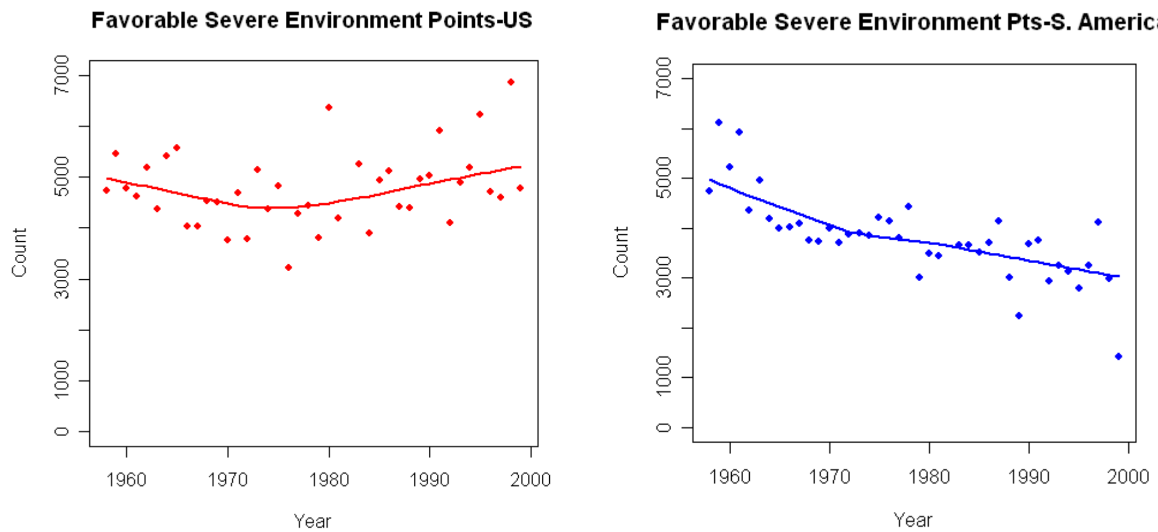

Fig. 3: Counts of 6-hourly periods at individual gridpoints with favorable environments for severe thunderstorms in the US, east of the Rockies (left) and South America (right).

The inflection point in 1973 in the US record is consistent with an inflection point in the number of reports of 3-inch (7.5 cm) diameter and larger hail per year. The reanalysis suggests an increase of 0.8% per year in the number of favorable environments in the region, whereas the reports have increased by 6%. If we take the reanalysis as an estimate of the real changes, a step to be taken with a grain of salt, it implies that the environmental changes have accounted for about 13% of the total changes in reports. It is interesting to note, perhaps, that the reanalysis trend in the US qualitatively resembles the US surface temperature record. Observations of events in South America are insufficient to corroborate the trend seen in the reanalysis.

DAMAGE AMOUNTS

The question of changes in the property damage caused by severe thunderstorms is a separate issue. The difficulties encountered in the report databases seem minor compared to those in the damage databases. Again, the systematic collection of data is a serious issue. Looking at historical descriptions of damage in national meteorological services, it is not always apparent whether damages that are reported are insured losses or total losses. Also, for some storms, no monetary estimate may be given. In other cases, the estimates that get recorded may be preliminary. For example, in some sources, the 1975 Omaha, Nebraska tornado is listed as the biggest-damage tornado, in inflation-adjusted dollars, in US history, based on a statement made the next day by the mayor of the city that there might be $750 billion in damage, an estimate that turned out to be high by a factor of three. Nevertheless, the original estimate made it into some "official" records and still appears in some lists of the damage.

Another issue is that severe thunderstorm damage tends to be relatively isolated (in space), but occurs relatively frequently. Where and when storms occur can dramatically affect the amount of damage, even for the exact same meteorological event. An urban area may suffer little property damage from a widespread fall of 1 cm diameter hail, while a vineyard or grain crop at certain times of the year might be devastated. Hail of 5 cm diameter might cause vast amounts of damage in an urban environment, especially to vehicles, while, if it occurs before crops have emerged from the ground in spring, it might have little impact in a rural location.

Brooks and Doswell (2001a) looked at the record of property losses from the most damaging tornadoes in the US from

1890-1999 and adjusted the losses for inflation and national wealth. [1] They found that, by including the wealth adjustment, there was no tendency for changes in the most damaging tornadoes in recent years, with a return period of about 10 years for a billion dollar tornado. As possible support for the notion of using wealth adjustment, Beatty (2002) took the most damaging tornado from the Brooks and Doswell study, the Saint Louis tornado from 1896 and put its damage path on the current area to estimate property damage. His estimate was about 10% smaller than the approximately $3 billion estimate from Brooks and Doswell based on national wealth adjustment.

As part of preparing for this workshop, I've built a simple model of the damage process. The model consists of two parts-tornado description and damage associated with the tornado. For the first part, I start with the mean number and standard deviation of annual reported tornadoes based on the linear regression from Verbout et al. (2006), roughly 1200 and 150, respectively. For each simulated year, a count of tornadoes is drawn from the distribution. Each tornado is then assigned a Fujita scale rating, drawing randomly from the empirical distribution of tornadoes by intensity for 1995-2004. A damage amount is assigned to each tornado. The damage amount for each F-scale is assumed to be exponential and has an absolute lower bound. The maximum damage is capped at $6 billion, in order to avoid rare, but extremely large values that might bias the results. As a first guess, the lower bound of F5's damage was $100 million, with a 10% probability of exceeding $1 billion. The lower bound for each successively smaller F-scale was an order of magnitude smaller. The 10% probability was taken as an order of magnitude above the lower bound. (I've done some exploration with the various shapes of the distributions and bounds, but the results of the study are qualitatively similar.)

The distribution of annual damage from this model is log-normal, roughly similar to the observed annual reported damage. The mean of the distribution is roughly $400 million per year and the return period for a single billion-dollar tornado is approximately a decade, in keeping with the observed record. The annual damage is, in effect, controlled by the damage associated with a small number of tornadoes, almost exclusively from the F3 and stronger tornadoes.

I explored the effects of changing the annual number of tornadoes and the distribution of intensity, looking for statistically significant differences in the distribution of annual damage. Increasing the mean number of tornadoes by less than 30% (more than two standard deviations) failed to produce statistically significant differences from the control simulation. Similarly, increasing the number of the most damaging tornadoes (F4 and F5) by 50% was necessary to get significant differences or to make the return period for billion-dollar tornadoes much shorter than a decade. These results aren't surprising, given that the damage is concentrated in a small number of rare events. Thus, large changes are needed to give a high probability of generating damaging tornadoes. As a result, it seems unlikely that damage amounts will provide a clear indication of changes, even with reasonably large physical changes.

CONCLUDING THOUGHTS

Problems in the reporting databases mean that it is extremely unlikely that climate change will be detectable in severe thunderstorm and tornado reports, even if there is a physical effect. Estimation of changes in the frequency of favorable environments may be more useful. There is no evidence to date to suggest that changes in damage are related to anything other than changes in wealth in the US. Given inflation on the order of 3% per year and a real GDP growth rate of 3.5%, reflecting the trends of the last half century, we would expect unadjusted damages to double every 10-11 years. From the adjusted damage work of Brooks and Doswell (2001a), there has been one year (1953) with 5 of the 30 most damaging tornadoes in US history. Thus, even a year with multiple events would not be evidence of changes.

It is of fundamental importance for future work to develop systems that collect data on the events and their effects in a systematic, consistent way. In the absence of databases of at least reasonable quality, it is extremely difficult to say much of substance.

[1] As of the middle of April 2006, no tornadoes have occurred that would have been included in the top 30 in terms of adjusted-damage in the US.

REFERENCES

Beatty, K. A., 2002: What would be the monetary loss if the 1896 St. Louis/East St. Louis tornado happened today? *Preprints*, 21st Conference on Severe Local Storms. Amer. Meteorol. Soc., San Antonio, Texas, 247-250.

Brooks, H. E., and C. A. Doswell III, 2001a: Normalized damage from major tornadoes in the United States: 1890 1999. *Wea. Forecasting*, 16,168-176.

Brooks, H. E., and C. A. Doswell III, 2001b: Some aspects of the international climatology of tornadoes by damage classification. *Atmos. Res.*, **56**, 191-201.

Brooks, H. E., and C. A. Doswell III, 2002: Deaths in the 3 May 1999 Oklahoma City tornado from a historical perspective. *Wea. Forecasting*, **17**, 354-361.

Brooks, H. E., C. A. Doswell III, and M. P. Kay, 2003a: Climatological estimates of local daily tornado probability. *Wea. Forecasting*, **18**, 626-640.

Brooks, H. E., J. W. Lee, and J. P. Craven, 2003b: The spatial distribution of severe thunderstorm and tornado environments from global reanalysis data. *Atmos. Res.*, **67-68**, 73-94.

Brooks, H. E., 2004: On the relationship of tornado path length and width to intensity. *Wea. Forecasting*, **19**, 310-319.

Doswell, C. A. III, H. E. Brooks, and M. P. Kay, 2005: Climatological estimates of daily local nontornadic severe thunderstorm probability for the United States. *Wea. Forecasting*, **20**, 577-595.

Dotzek, N., J. Grieser, and H. E. Brooks, 2003: Statistical modeling of tornado intensity distributions. *Atmos. Res.*, **67-68**, 163-187.

Dotzek, N., M. V. Kurgansky, J. Grieser, B. Feuerstein, and P. Névir, 2005: Observational evidence for exponential tornado intensity distributions over specific kinetic energy. *Geophys. Res. Lett.*, **32**, L24813, doi:10.1029/2005GL024583.

Feuerstein, B., N. Dotzek, and J. Grieser, 2005: Assessing a tornado climatology from global tornado intensity distributions. *J. Climate*, **18**, 585-596.

Verbout, S. M., H. E. Brooks, L. M. Leslie, and D. M. Schultz, 2006: Evolution of the US tornado database: 1954-2003. *Wea. Forecasting*, **21**, 86-93.

The Proximate, Underlying and Ultimate Causes Accounting for the Increasing Costs of Weather Related Disasters: A Diagnosis and Prescription

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1. Climate Change Among a Wide Array of Factors.

"What factors account for increasing costs of weather related disasters in recent decades?" "What are the implications of these understandings for both research and policy?"

A small part of the answer to the first question is that anthropogenic climate change is adding further and increased destabilization to the climate system, and resulting in some places in more extreme and perhaps more frequent events. This in turn contributes to increasing costs of weather related disasters. It is not possible to specify with any precision or confidence what this causal fraction is but it is probably quite small at the moment. Given projected increases in greenhouse gas concentrations over the next few decades the amount of costs attributable to climate change may confidently be expected to increase. One policy implication of this is that efforts to reduce emissions of greenhouse gasses and to adapt to inevitable climate change should be strengthened and accelerated.

There are many other reasons for adopting stronger and more effective policies of mitigation and adaptation in relation to climate change. Prominent among them are the catastrophic and irreversible (on a human time scale) longer term consequences such as considerable rise in sea level and displacement of millions of people and the loss of species and ecosystems. In the case of weather related disasters the policies that are needed should be directed not only to climate change (as a relatively minor but growing contributor) but also to the other causes of weather related disaster.

The argument of this paper is that these causes can be divided into three types or levels. These can be termed the immediate or proximate causes; the underlying causes; and the ultimate causes. Climate change belongs for the present in the first two categories, which means that these form part of the context for climate change policies. At some point in the future changing climate may come to overwhelm the other causes and so quality as an ultimate cause. We appear, fortunately, to be some distance from that point.

2. Immediate or Proximate Causes.

The immediate or proximate causes of the increase in disaster losses have been well rehearsed. They include generic factors such as the growth in human populations, and increases in wealth and real property. These factors lie beyond the reach or domain of the disaster management community. The size and growth rate of human populations are the business of demographers and experts in human health and fertility, and the governments and agencies that they advise; increases in wealth and real property are similarly the domain of economists and the financial and investment worlds, and development specialists. It has not been considered the business of the disaster management community to advocate the reduction of human population growth or the reduction of economic growth and increases in wealth and real property. Perhaps this should be questioned. The disaster management community might make common cause with those who want to curb the growth in human populations, (and rejoice when growth is low or negative as in some countries?) and those who question the headlong rush to growth at any price and make common cause with the supporters of sustainable development or those who eschew high mass consumption and opt for lives of voluntary simplicity.

In addition to these broad generic causes of population growth and increases in wealth there are other proximate causes of the growing disaster losses that are more nuanced and which very considerably in character from place to place. These are clearly within the domain of the disaster management community. These include the disproportionate occupation of hazardous zones and the continuing invasion of such lands by human settlements despite their known risks. The proximate causes also include the poor quality of construction, or when a minimal standard of construction is mandated by governmental authorities, the systematic avoidance or evasion of such regulations, usually for short term benefit. In recent decades there has been a considerable expansion of knowledge about natural disasters including those that are weather related. Why despite this increased understanding have costs continued to rise if climate change is ruled out for the time being as a major contributor? The simple answer is that there are some underlying causes which inhibit or prevent to adoption of good and effective policies and measures. Beyond these underlying causes are some even less tractable ultimate causes which pose greater challenges to policy. Disaster management therefore involves understanding and actions on many levels ranging from the immediate or proximate causes, to the underlying and ultimate causes.

3. Underlying Causes.

What explains the apparently ineffective efforts of the disaster management community to curb the growth in losses despite several decades of expanding concern and allocation of resources? Why did the International Decade for Natural Disaster Reduction (1990 – 1999) have so little effect, and why has the successor institution, the International Strategy for Disaster Reduction, similarly enjoyed slow progress at best, despite the compelling evidence of more calamities, and more conferences, and the much promoted Hyogo Declaration?

In a recent paper (White, Kates, and Burton 2001) four hypotheses have been identified as possible underlying explanations. The four hypotheses have to do with the existence of knowledge; the use of knowledge; the ineffective use of knowledge; and the time-lag problem.

- To what extent is knowledge lacking and disaster management flawed or rendered ineffective by simply not knowing?

  Recent decades have seen a dramatic increase in understanding and predictability of atmospheric weather-related hazards. Satellite tracking of storms has enabled timely forecasts and warnings to be issued, and this has undoubtedly contributed to a significant reduction in fatalities world wide. Nevertheless an unacceptably high loss of life still continues and property losses continue to rise at an apparently exponential rate. To some extent this may be explained by lack of knowledge. Hazard zones have not everywhere been well mapped or identified, and the probabilities of extreme events are not well estimated, and perhaps not estimated at all. There is a case to be made for more research on the "natural" causes of disasters, and for the identification of high risk places. While lack of knowledge might be offered as a partial explanation for growing losses in developing countries such an excuse is much less valid in developed countries, but losses continue to grow in developed countries as well. The recent losses in the United states from Hurricane Katrina (2005) and other extreme events cannot be explained by a lack of knowledge.

- To what extent is knowledge available and not used?

  Clearly the knowledge that exists could be more effectively used. In developed countries and in the more highly developed regions of developing countries there is more reason to attribute rising losses to the failure to act appropriately, than to the lack of knowledge. Yet there is evidence that in both developed and developing countries disasters continue to take people by surprise and that insufficient preparations have been made to deal with emergencies, even though this has been a major thrust of international activities. In developing countries this likely reflects the lack of resources, and the lack of adaptive capacity. There has been a rhetorical shift to arguing for more than emergency disaster relief and rehabilitation towards the long-term strengthening of the capacity to design and execute mitigation and vulnerability reduction efforts. As the climate changes and as the need for adaptation becomes more evident and recognized, there is clear opportunity for synergies between climate change adaptation and disaster prevention and mitigation. In developed countries the failure to use available knowledge can rarely be attributed to the absence of financial resources or adaptive capacity. Other explanations are needed.

- To what extent knowledge is used ineffectively?

  Whereas in developing countries available knowledge may not be used due to lack of resources and capacity, in developed countries there are often major programmes designed to use knowledge that do not work effectively. At times this almost can be described as a pretence at using knowledge. Even where the knowledge is considerable, and the resources and capacity are available the administrative functions fall short of what might be expected. Land use planning and building regulations frequently exist "on the books" but have often been applied with a lack of conviction or are subject to frequent variances obtained by legal or political means. Building codes have similarly not been properly enforced. Insurance, even when coupled to land use regulation, as in the case of the US National Flood Insurance Programme, may have increased and in any case not reduced losses for similar reasons. Variations in the application of regulations can grow under conditions where there are conflicting interests and lack of political will. This may account for much of the failure to apply knowledge effectively.

- To what extent may the growth in costs be a time-lag problem?

  A further possible explanation is that knowledge is increasing and becoming more widely available and is being used with growing effectiveness, and that with trial and error and a slow learning process the underlying situation is improving and it is only a matter of time before the positive results become manifest. While it would be reassuring to attribute rising disaster losses to a time-lag effect in the effective use and application of knowledge there is little room for complacency on this score. While the record of attempts to manage disasters is at best a slow success story proceeding in very small increments, there is little reason to expect fundamental change in the near term. Beyond these underlying causes there are more profound and intractable factors at work.

4. Ultimate Causes.

The foregoing hypotheses concerning the proximate and underlying causes of the growing costs of weather related disasters are based on an assumption that a combination of scientific understanding, and the application of a rational approach can and will prevail, or on the hope that this will eventually prove to be the case. The International Decade for Disaster Reduction in the 1990s was based on this sort of belief, and the work of the Kobe Disaster Conference (January 2005) and the Hyogo Declaration which it produced, seem to have been similarly inspired. It is appropriate therefore to take a step back and ask if there are other factors that lie behind the persistent and evidently growing failure to control the growth in disaster losses. This question has been asked before and the answer seems to fall into three parts – the nature of the problem; the deficiencies of human society or human nature; and the lack of measures to offset the situation.

Disaster events by definition occur infrequently in any one place. Human society has proved to be remarkably effective in adapting to variations in the natural environment. It is one of the distinguishing traits of our species. Humans have effectively spread and occupied virtually all the environments on the planet from sub-artic to semi-desert, to mountains and coasts. That successful livelihoods have been achieved in all these environments is testimony to adaptability and adaptive capacity. Throughout history there have been sudden losses and setbacks and perhaps even collapse due to environmental extremes to which people were not adapted. The fact that this obtains today is therefore not new. It is the scale and speed of human development and the globalization of communications which makes the failure to adapt to extremes so costly and more visible. Elsewhere this has been described as the "adaptation deficit". But the phenomenon itself is not new. It stems from the nature of rare events in concert with the nature of human society. There probably has always been some level of adaptation deficit – greater exposure to extreme events and greater vulnerability due to the failure to adopt the right kind and enough mitigation measures. Due to the proximate and underlying causes identified above the adaptation deficit is now growing at an apparently exponential rate (Burton 2004).

People have, and always have had, as noted by economists among others, a short term time preference. Not with standing our knowledge of the future and our capacity to anticipate, we tend to have a strong preference for the immediate and the short term. Indeed our time preference is probably getting shorter over time. Discount rates as applied in most economic analysis reflect such preferences and their use in planning and decision making encourage societies and governments to take little account of the future beyond three or four decades. By such calculations the present value of an asset or a risk avoided that can only be obtained over a fifty year or longer period is practically zero. This is of course reflected in the behaviour of our political institutions.

While the cannons of economic benefit-cost analysis help to explain some short sighted decision making they are a reflection of other characteristics of the human species. Elsewhere some of these have been listed as the tendency to cater to vested interests as expressed for example in the power structure; as the propensity to resort to wishful thinking of the "it won't happen to me"

genre; as a failure of imagination or on the use of scientific uncertainty as an excuse for inaction or the avoidance of unpopular actions. (Burton and May 2004). Some of these psychological and perception dimension have been recognized for decades at least (Burton and Kates 1964).

What is to be done? We can throw up our hands and say – that is the nature of the human condition and it cannot be changed. Or we can turn our attention to finding the antidote, at least as far as disasters are concerned.

5. Policy and Research Implications.

The policy and research implications of the foregoing diagnosis can be summed up in terms of the old fable – we must be both hedgehog and fox. The hedgehog you will recall knows one thing, one big thing, and the fox knows many things.

i) The first the big thing. Some sort of cultural transformation is needed that permits us to incorporate the rare and the long term into the everyday. Ken Hewitt (Hewitt 1997) was among the first in the disaster field to argue that disasters are not just rare events but that they are built into our everyday decisions. Dennis Miletti (Miletti 1999) has echoed this in his call for a "redesigned national culture" and a "cultural shift". In recent years many other voices have repeated this message, but it is one thing to identify a need and a direction and quite another to know how to get there. The recognized need and the direction involve moving to sustainable development; to the an order of magnitude increase in respect for and harmony with the environment; to the achievement of much greater social equity on a global scale; and to the creation of a world managed by the rule of law and to an expansion and strengthening of international law. The case for such changes would be more easily understood if people could come to adopt a longer term view and the willingness to reduce the demand for instant gratification.

   Such hopes and expectations it will be argued are well beyond the scope or capacity or even the interest of the disaster management community, although they are increasingly heard among disaster specialists and perhaps even more assertively in the climate community. On the other hand if any such transformation is to be achieved it will require the combined efforts of many communities of interest. The disaster community is one such community and we can most help by making common cause with like-minded groups. One of the foremost to be considered is surely the climate change community. While probably only a very small part of the increase in disaster losses over the past few decades can be attributed to climate change, there is now evidence that climate change is affecting the intensity and frequency of some weather extremes and this trend is projected to continue and accelerate. If the costs of weather related disasters are not to rise further and faster with climate change then a fundamental shift in values, attitudes and behaviour is essential.

Beyond working with the climate change and adaptation community to achieve such ends the disaster mitigation community can design its own work to achieve such results through incremental means. This requires not one big thing but many smaller and clever things.

ii) Smaller and Smarter.

Clearly there is much to be done in further advancing knowledge and scientific understanding of the causes of the increased costs of disasters in recent decades, and more needs to be done to ensure that the knowledge is disseminated and available and that the capacity to use it is strengthened. More and better is also needed to ensure that knowledge is used effectively and in a timely way, and that the political will to act accordingly is generated and supported.

The creation of the political will is perhaps the most crucial element and since there are many obstacles this cannot be achieved without the growth of public awareness. Many of the efforts of the recent past have been directly or indirectly aimed at creating public awareness including the UN Decade on Disaster Reduction, the work of the International Strategy for Disaster Reduction (ISDR), and the Kobe Conference and the Hyogo Declaration. Similarly the work of the Red Cross/Red Crescent in promoting grass roots attention to natural hazards and community based risk and vulnerability assessment contributes from a bottom-up perspective.

Beyond these efforts some new and additional ideas might be advocated and adopted. These involve institutional change. If a culture shift is to be brought about the aspirations of scientists; those at risk, and those with social concern should be supported by institutional change.

It has been suggested that an Intergovernmental Panel on Natural Disasters (IPND) (Burton 2001) would be a helpful way of periodically updating scientific knowledge and bringing it to the attention of the public and decision makers. This is modeled on the Intergovernmental Panel on Climate Change which has been so effective in assessing and articulating the science of climate change. It could also work together with the Planning Group on Natural and Human-Induced Environmental Hazards and Disasters now being established by the International Council of Scientific Unions. An Intergovernmental Panel could also be augmented by a more popular institution such as an annual or periodic international forum on disasters similar to those that now exist for water resources (World Water Forum) and forests. These fora have been effective in calling attention to their respective issues and to the need for policy shifts that are in line with what is required to curb the growth in disaster losses.

Other institutional innovations could include the specific incorporation of natural weather-related disasters into the post-2012 regime of the UN Framework Convention on Climate Change, including a new legal instrument for adaptation. The use of insurance as a social policy instrument has received little serious consideration, and the work of the Munich Climate Insurance Initiative (MCII) could be further developed and widely promoted.

6. Conclusion and Summary.

There are many factors, proximate, underlying, and ultimate, that can account for the increased costs of disasters in recent decades. The implications for research and policy that stem from the diagnosis made in this white paper are that the efforts directed at the proximate and underlying causes should be redoubled without delay, and that the more basic or fundamental causes must also be addressed through the generation of public awareness and the strengthening of political will. Recognizing that this is a slow process some immediate attention could be focused on institutional changes at the international level.

References

Burton, Ian. 2001 "The intergovernmental panel on natural disasters (IPND)". Environmental Hazards. Vol 3. No. 3. 2001. pp. 139-141.

Burton, Ian. 2004. "Climate Change and the Adaptation Deficit", Occasional Paper No. 1. Adaptation and Impacts Research Division. Meteorological Service of Canada. Downsview, Ontario, Canada. November 2004

Burton, Ian. and Robert W. Kates. 1964. "The Perception of Natural Hazards in Resource Management". Natural Resources Journal. Vol 3. January 412-441. Reprinted in Howard Kunreuther and Adam Rose, 2004. The Economics of Natural Hazards. Volume 1. pp. 53 – 82. Edward Elgar. Northampton, Massachusetts.

Burton, Ian. and Elizabeth May. 2004. "The Adaptation Deficit in Water Resource Management". IDS Bulletin. Vol 35. No. 3 July.

Hewitt, Kenneth, 1997. Regions of Risk; A Geographical Introduction to Disasters. Addison Wesley Longman. Harlow, Essex. 1997.

Mileti, Dennis S. 1999. Disasters by Design. Joseph Henry Press, Washington D.C. 1999.

White, G. F., Kates, R. W., and Burton, I. (2001) "Knowing better and losing even more: the use of knowledge in hazards management." Environmental Hazards. Vol 3. 2001 pp. 81-92

Natural Disaster Losses and Climate Change: An Australian Perspective

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Summary

Ninety-five percent of building losses in Australia over the last century are due to natural hazards of a meteorological nature – tropical cyclones, floods, thunderstorms (especially hailstorms) and bushfires. This study reviews a recent analysis of insured property losses due to natural hazards over the last four decades that found no obvious remaining trend after these losses had been indexed correctly for changes in population, wealth and inflation. In other words, no signal remains that could be ascribed to other factors including anthropogenic climate change. Such trends are also noticeably absent from changes in a frequency-severity potential destructiveness index developed for land-crossing tropical cyclones on the east coast of Australia. This is also the case for the probability of national losses from bushfire, which has remained remarkably stable over the last century. We can say little about flood, which although important, is not uniformly insured in Australia. We conclude that to date, societal changes – wealth and population - are the principal reasons for increasing inflation-adjusted costs of natural disasters in this country.

We can cite few examples of legislative changes that might encourage communities to adapt more aggressively to anticipated changes in global climate. We suspect that this is in part due to the very large uncertainty associated with climate change predictions at a local level. Nonetheless, improved building codes introduced after the destruction of Darwin in 1974 by Tropical Cyclone Tracy show what can be done where there is a demonstrated need. We also argue that in addition to more scientific studies on improving climate predictions under different emission scenarios, more quantitative effort be invested in detailing the vulnerability of communities to climate change. The recent study by Chen and McAneney (2006) looking at fine resolution estimates of the global coastal population as a function of distance from the shoreline and elevation above sea level is one example of this type of work.

Background

Meteorological hazards dominate losses in Australia's short-recorded history of natural disasters. In terms of the total number of buildings destroyed (insured and uninsured) between 1900 and 2003, tropical cyclones have been most destructive, accounting for almost one third of losses with floods and bushfires each contributing about another 20%, as do thunderstorms if hail, gust and tornado are combined. Earthquake only accounts for 7%, a proportion that is heavily dependent upon a single event - the 1989 Newcastle earthquake[1] (Figure 1). This breakdown of cumulative losses by hazard suggests that Australia should be more sensitive than many other jurisdictions to changes in global climate, but by itself tells us nothing about how things are changing over time. The bulk of this paper will address this question.

We begin with an examination of a recent indexation of the Australian Insurance Disaster Response Organisation's (IDRO) database of insured losses since 1967. Our interest is to see whether any observable signal remains after we have adjusted original losses for changes in inflation, population and wealth, in much the same way as has already been done for the US hurricane record (Pielke and Landsea 1998). The effort has been to estimate event losses in today's dollars; in short, what this event would cost the insurance industry if it were to reoccur today. Any residual trend might

[1] For long return period events such as damaging earthquakes, the historical record in Australia is an inadequate sample on which to judge the future.

then be ascribed to other factors including anthropogenic climate change.

In attempting to probe more deeply, we then look at two particular hazards: tropical cyclones and bushfires. We will have less to say about flood, which despite being important in an Australian context (Blong, 2004) has not been universally insured.

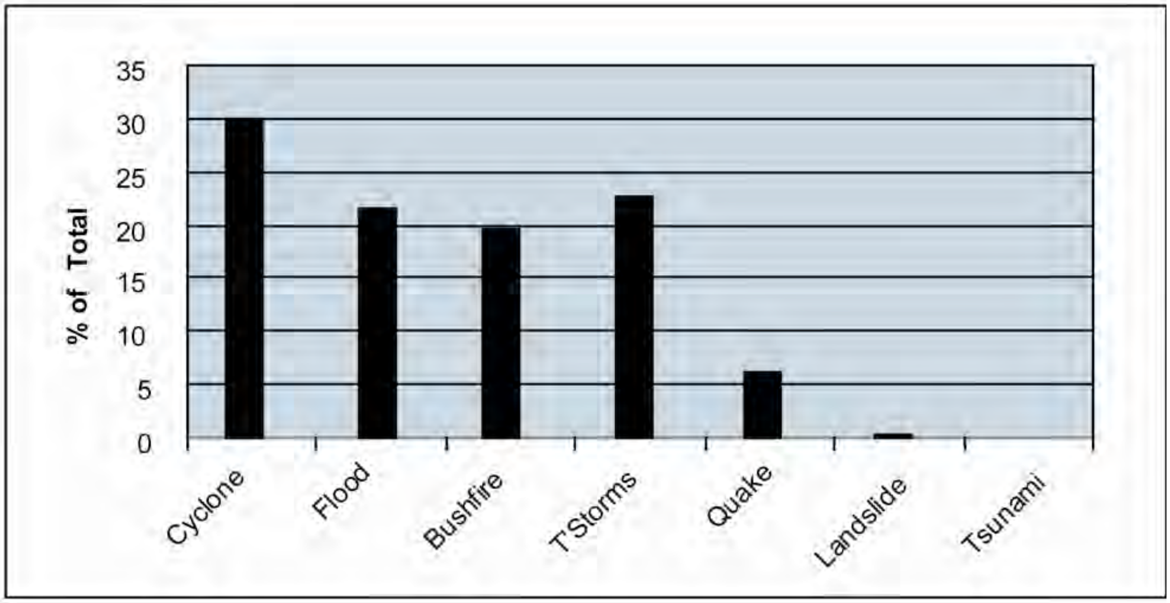

Figure 1: Percentage of the accumulated building damage between 1900 and 2003 attributed to different perils. T'storms refers to the combined losses from thunderstorms – hail, gust and tornadoes. Damaged buildings (including commercial premises) have been normalized to *residential house equivalents* destroyed using relative floor areas and building costs, where one *house equivalent* could equal two homes each 50% destroyed or 10 homes each of which experienced damage amounting to 10% of their replacement value. During bushfires, as compared with some other perils such as hailstorms, say, homes are more often than not completely destroyed (Source: *PerilAUS* database, Risk Frontiers.)

Insured losses – what would they cost today?

Crompton (2005) has previously explored a number of different indexation methodologies and applied them to the IDRO Natural Disaster Event List. The Disaster List is a record of natural hazard events in Australia that have caused significant insured losses. The list begins in 1967 and contains details of each event including date; areas affected; total insured (industry) cost in "original" dollars; and total industry loss in "equivalent current" dollars. Although the threshold loss for inclusion in the database has been varied over time, most refer to events with insured losses in excess of $A10 million.

Each of the indexation methodologies developed by Crompton (2005) incorporated a range of surrogate factors to account for changes in population, inflation, and wealth across regions. The preferred approach (Appendix A) possesses important attributes of simplicity; easy accessibility of the underpinning information; and, by adjusting only for changes in building value, is *independent* of land value. This methodology and that of Pielke and Landsea (1998) produce very comparable adjustments. Since damage to dwellings often makes up a major component of most catastrophe losses, our approach assures reasonable alignment to total insured losses.

Figures 2a and b below present the results of this analysis[2] with the five non-weather-related events in the Disaster List – four earthquakes and one tsunami – excluded. Annual losses have been calculated for years ending 30 June to take account of the southern hemisphere seasonality of the main meteorological hazards. Indexed tropical cyclone losses in

[2] The 1974 Brisbane flooding due to Tropical Cyclone Wanda has been classified as a flood rather than a cyclone.

Figure 2b have been reduced by 50% in a notional effort to account for improved building standards in tropical cyclone-prone areas introduced after Tropical Cyclone Althea devastated Townsville in 1971 and Tropical Cyclone Tracy destroyed Darwin in 1974. In fact, the actual reduction will be unique for each tropical cyclone path. Using Tropical Cyclone Tracy as an example, our research suggests that the current loss for the event would reduce by approximately 65% if Tracy were to reoccur today and all buildings affected were constructed as per the new building code (i.e. post-1980 construction).

When correctly indexed, the time series of insured losses exhibit no obvious trend (increase or decrease) over the last four decades. Figure 2b reveals that the increasing trend in unadjusted losses (Figure 2a) is largely attributable to changes in the number and value of dwellings.

Figures 3a and b show the breakdown by frequency and contribution to insured losses by hazard type. Hailstorms have the highest average loss per year followed by tropical cyclones and flood. The breakdown in insured losses by peril over this shorter time period is somewhat different to that of the total number of buildings lost over the last century as displayed in Figure 1.

Frequency & severity of tropical cyclones that made landfall on the Australian east coast

We now consider the time series of tropical cyclones that have crossed the east coast of mainland Australia during the last 45 years. Only events having a central pressure less than or equal to 995hPa were included. The analysis begins from the 1961 season and ends at the current 2005 season.

Cyclone activity in the South-Western Pacific region is strongly related to the El Niño - Southern Oscillation (ENSO). Cooler ocean temperatures exist in the Western Pacific and Coral Sea during El Niño episodes and ocean temperatures near the Queensland coast are typically above average during La Niña phases. Consequently, cyclone activity tends to shift further away from the east coast of Queensland and further north resulting in fewer than normal landfalling tropical cyclones during the El Niño phase than during the La Niña phase.

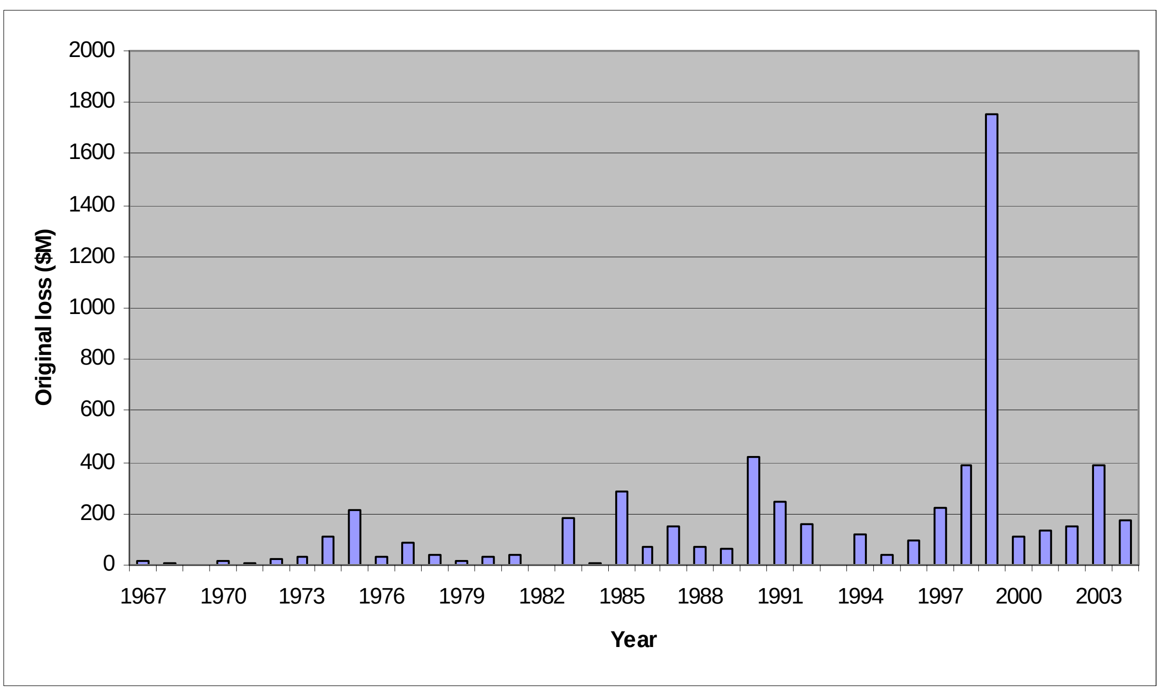

Figure 2a: Original annual aggregate insured losses ($M) for weather-related events in the IDRO database for 12-month periods ending 30 June.

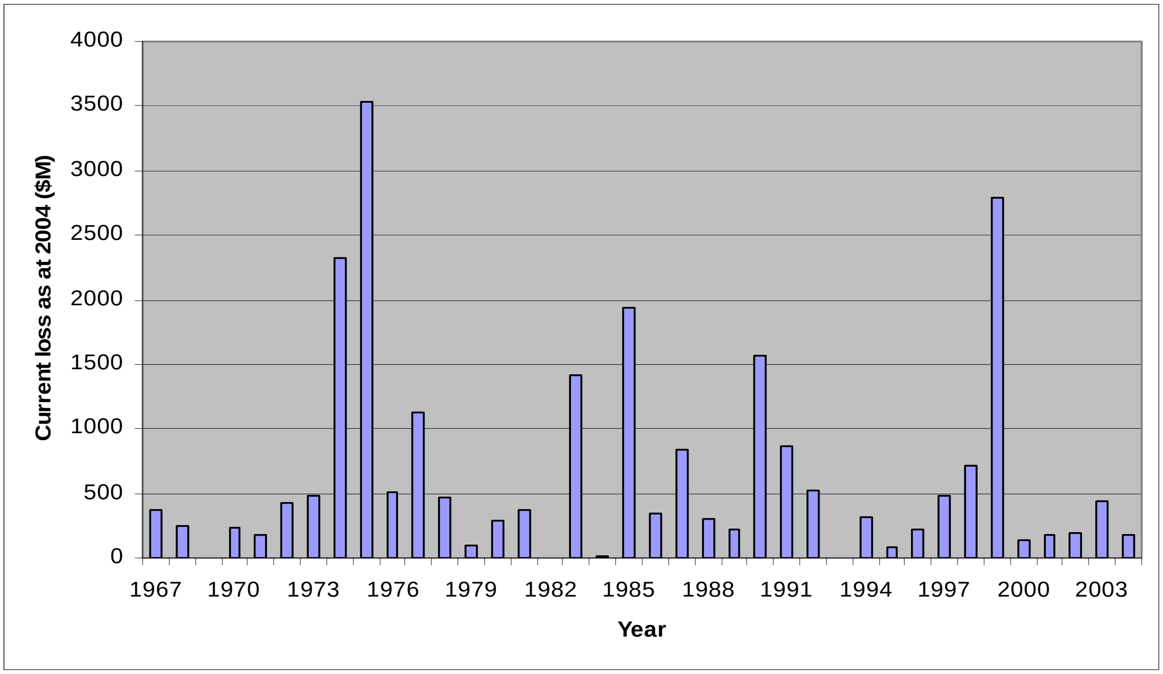

Figure 2b: As for (a) above but losses have been indexed to 2004 dollars. Tropical cyclone losses have been reduced by 50% in a notional attempt to account for post–1980 improvements in building codes in tropical cyclone-prone areas.

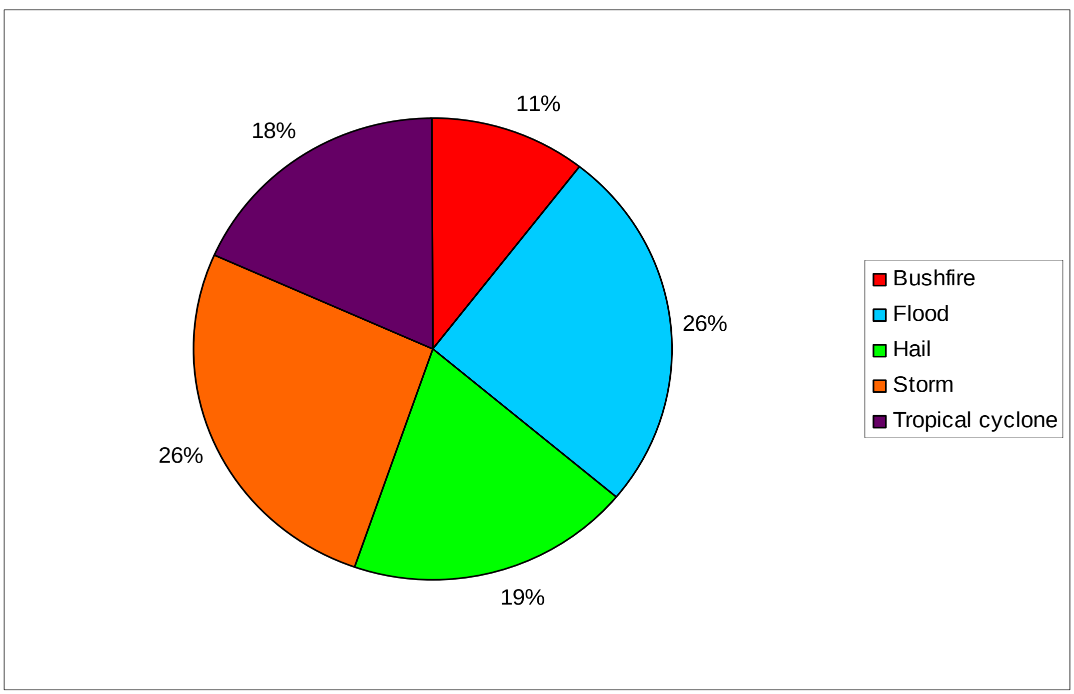

Figure 3a: Percentage of the number of weather-related events classified by hazard type in the IDRO database. Here event losses from hailstorms have been separated from other forms of severe weather – tornados and high winds.

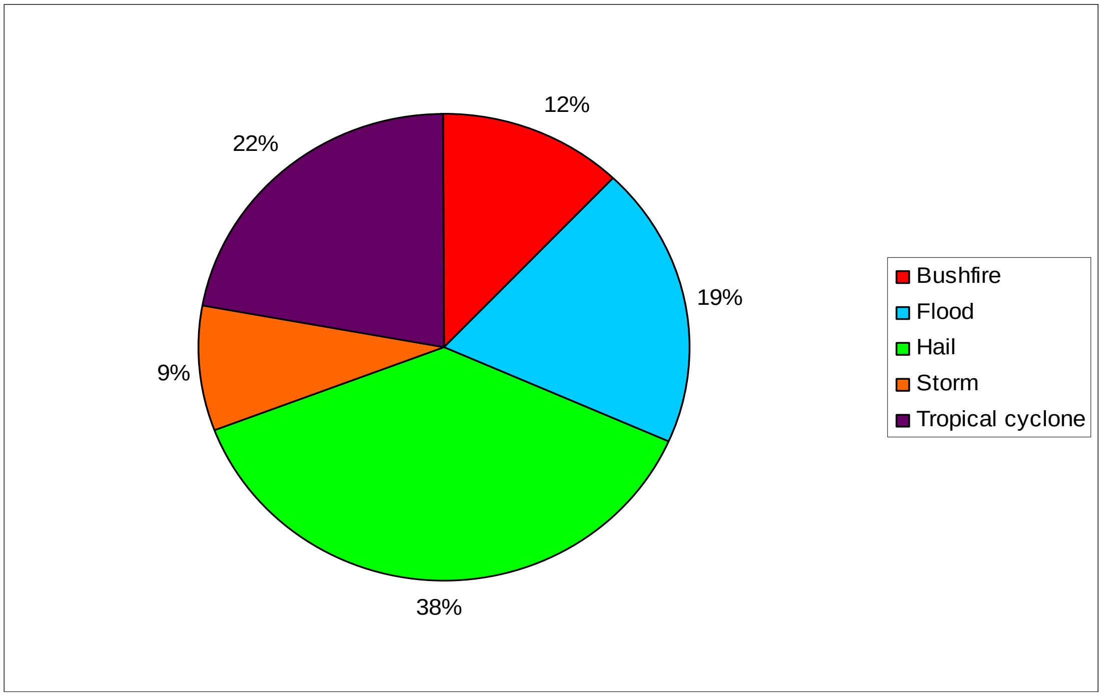

Figure 3b: Percentage of the total current loss as at 2004 ($M) of weather-related events classified by hazard type. Tropical cyclone losses have been reduced by 50% in a notional attempt to account for post–1980 improvements in building codes in tropical cyclone-prone areas.

Figure 4 shows successive five-season period frequencies of tropical cyclones that have crossed the east coast. Within each of the five-season periods there are different numbers of El Niño, La Niña, and neutral events. With the exception of 1971-75, there have been between two and four tropical cyclones for each period. It comes as no surprise that La Niña episodes dominated during this period.

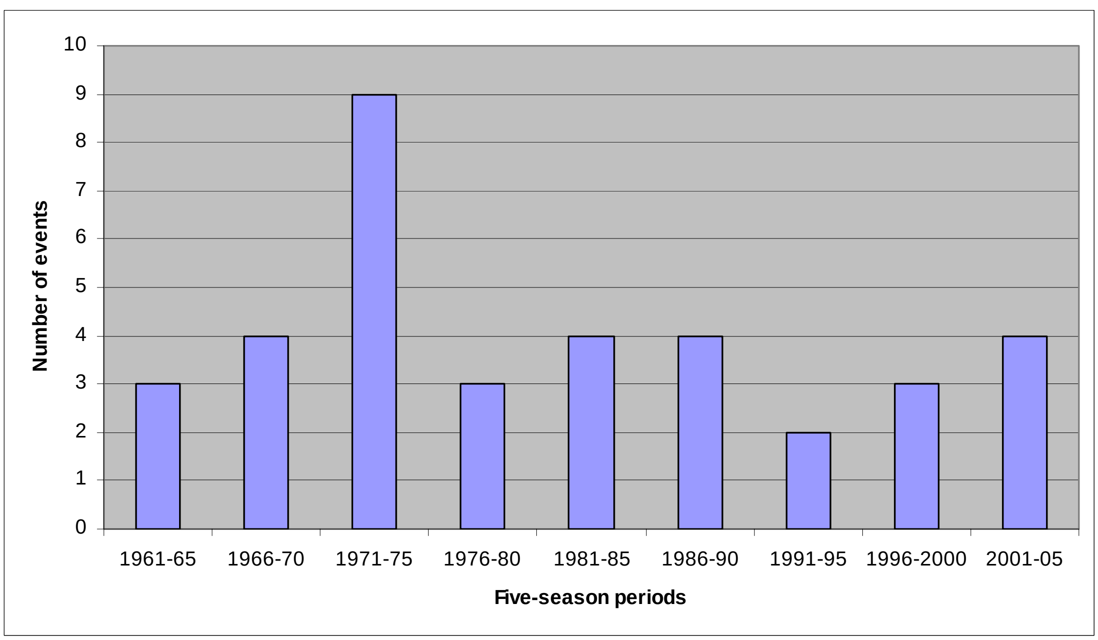

Figure 4: Number of tropical cyclones to cross the east coast during five-year periods.

Figure 4 only tells part of the story. Of more interest is the combination of frequency and intensity. According to Gray (2003), when normalised for coastal population, inflation, and wealth per capita, tropical cyclone-spawned damage in the US rises by a factor of four for each successive increase in Saffir-Simpson intensity category. Thus a landfalling

Category-3 hurricane typically causes about four times the normalised damage of a Category-2 hurricane and so forth. Assuming that this same ratio between cyclone categories holds true for Australian conditions, Figure 5 takes this weighting into account. In calculating these figures, Category-5 and -4 events have each been assigned an equal weighting of 1/4; Category-3 a weighting of 1/16; Category-2 a value of 1/64 and Category-1 events 1/256. These are then summed for each 5-year period to obtain a relative potential destructiveness index.

By concentrating on the damage potential of the hazard alone, Figure 5 assumes a uniform portfolio of assets at risk. It also allows for Australia's low population density and the large physical distances between population centres on the exposed east coast. Actual damage arising from individual tropical cyclones will vary widely as a result of differences in population, terrain, topography, proportions of construction conforming to improved (wind loading) building codes, wealth per capita, direction and forward speed, storm surge, and rainfall.

Again we see no obvious change (increase or decrease) in the potential destructiveness over the time periods represented in Figure 5. Figures 4 and 5 focus on the east coast because this is where most of the insured exposure is located; however, very similar results hold for the western and north coasts of Australia or for the entire coastline. Nonetheless we do acknowledge that the small number of cyclones per five–year time interval makes it difficult to draw very robust conclusions.

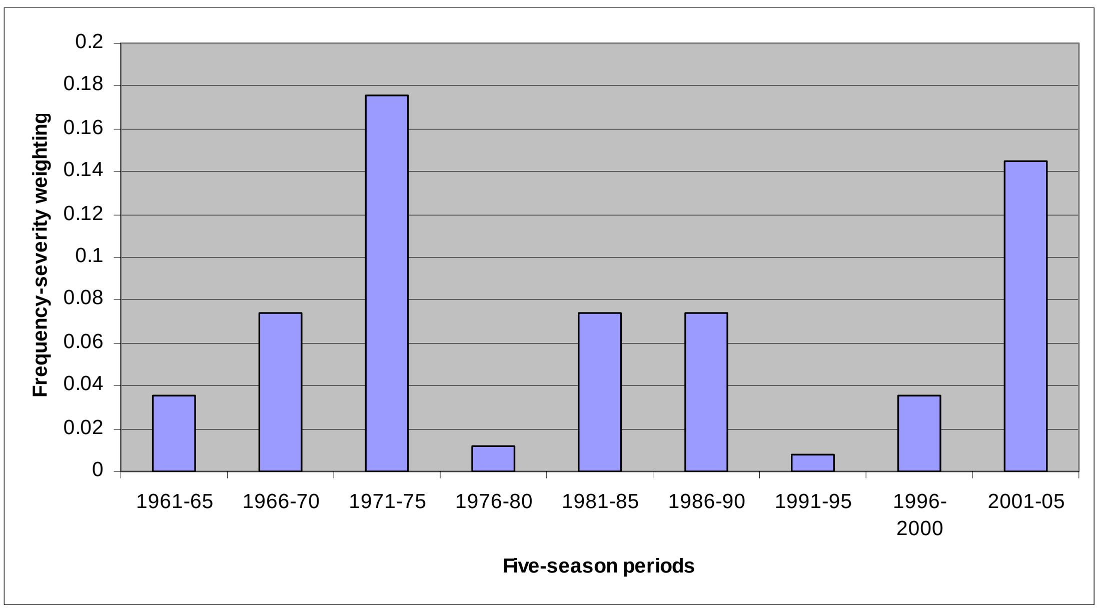

Figure 5: Combined frequency-severity of tropical cyclones that have crossed the east coast of Australia during five-year periods.

Annual probability of bushfire losses

Many papers on bushfire risk in Australia have concluded that the bushfire hazard will increase under high carbon dioxide emission scenarios (e.g. Pitman et al., 2006 and papers cited therein). With this in mind, it is interesting to look at the statistics of event losses over the last century. Table 1, drawn from Risk Frontiers *PerilAUS* database of building losses, lists two relevant statistics and illustrates how these change when calculated between a given start year and 2003. The first row indicates that at least some home destruction can be expected in approximately 60% of years, a statistic that has remained remarkably constant despite large increases in population, improvements in fire fighting technology and better understanding of bushfire physics. The corollary is that in 40% of years, bushfires cause no home losses. On reflection, this stability is perhaps not too surprising given that the propensity for fires to escalate once started is largely a function of the surface water budget, ambient temperatures, windspeed, and fuel load. Of these variables, only the latter is subject to human intervention through controlled burnoff practices. Moreover, once a fire exceeds a certain scale, there is very little that can be done to stop it until it runs out of fuel.

The second row of Table 1 lists the average annual frequency of having more than 25 homes destroyed within a single week, in other words, the annual probability of having a significant event loss as opposed to a large annual loss. This statistic has similarly remained remarkably constant at around 40%. At current average asset values (AU$375,000 for average home and contents), an event loss of 25 homes would come close to AU$10 million, the lower limit for consideration in the IDRO database. The 7-day time window has some relevance for reinsurance contracts but is introduced here merely to confirm that the stability of the annual probability of any loss mentioned already also holds true for larger events.

Although we concede that bushfire losses are the result of a complicated mix of social and climatic phenomena, the inference is again clear. We have little signal that can be unequivocally assigned to a human-induced changing climate. To argue that global increases in temperature and an increasingly lengthy urban-forest interface (Chen and McAneney 2005) have been exactly compensated by improved fire management techniques would stretch credulity.

Table 1: Statistics of bushfire loss probabilities (Source: *PerilAUS*, Risk Frontiers) calculated between the start year and 2003. The top row lists the frequency of any (non-zero) loss, while the second includes only those that resulted in more than 25 homes destroyed within a single week. Data in the first column (1900) has been adjusted to account for missing data (McAneney 2005).

Start Year	1900	1926	1939	1967	1983	1990
Annual probability of a loss	57%	54%	49%	59%	62%	64%
Annual Probability of a major event	40%	43%	41%	38%	38%	36%

Implications for research and policy

The evidence reviewed above suggests that, in Australia, population, inflation and wealth are the predominant reasons for increased insurance losses to this point. The role of monotonic changes in the magnitude of natural disaster losses attributable to anthropogenic climate change or otherwise, appears minor and is not detectable at this time.

Given the above conclusion, it seems reasonable that research on climate change science should go hand in hand in a holistic manner with disaster management and mitigation research. As in other parts of the world, there is not a strong formal connection between researchers in the two communities in Australia. An important area of common interest between the disciplines should be quantifying and reducing vulnerability to coastal inundation, storms, bushfires and floods.

An encouraging example of what is possible is work undertaken at Risk Frontiers on identifying Australian addresses vulnerable to a wide range of ocean-related natural catastrophes such as storm surge, tsunami and significant sea-level rise under global warming (Chen and McAneney, 2006). Using the most recent, fine resolution global databases, this work quantifies the number of addresses in Australia located within 3 kilometres of the coast and having an elevation less than 6 metres above mean sea level. This paper also provides a way of providing plausible lower bound global estimates on the numbers of people at risk in coastal areas.

When it comes to developing and implementing climate change adaptation policy to, for example, reduce vulnerability in a particular locality or constituency, there is a disconnect. On the one hand, confidence in global climate models is highest for global average temperature and perhaps rainfall and sea-level rise. Policy implications have naturally centred on reducing global emissions at a global level, e.g. Kyoto protocol. Meanwhile, disaster management and mitigation requires projections at a local level and for small-scale event-based phenomena such as floods, hailstorms and tropical cyclones. Global climate models cannot currently provide these projections with any skill.

There are very few examples of policies or legislation in Australia developed to help communities adapt to possible future climate change. An often-cited reason is the lack of reliable information at the local scale noted above. Given the truth of the oft quoted "all politics is local" attributed to Tip O'Neil, the Speaker of the House of Representatives in the US, it is difficult to see significant changes occurring in the near future in this country.

One positive Australian adaptation example to which we can point is the improved wind loading code introduced in the 1980's as part of a *National Building Code of Australia*. These codes have been mentioned already and were introduced and enforced for all new housing construction following the destruction of Darwin by Tropical Cyclone Tracy in 1974. As a result, dramatic reductions in tropical cyclone-induced losses were observed following Tropical Cyclones Winifred (1986) and Aivu (1989) (Walker, 1999) and more recently, Larry (2006) (Guy Carpenter, 2006). While these improvements were introduced in response to existing natural variability in the occurrence of natural hazards, they provide a perfect example of steps that should be taken to start to adapt to any future impacts of climate change.

It is not unknown for insurance companies to adjust their risk profile in response to perceived changes in climate variability or extreme events. After Samoa suffered three major tropical cyclones within four years in the late 1980s and 1990s, the country's only insurer refused to renew insurance policies for tropical cyclone damage and clients could only get new policies at a higher premium and with a structural engineer's certificate. Similarly Fiji was hit by a succession of tropical cyclones in the mid 1980s. Half the insurance companies operating in the country withdrew and those that remained raised premiums and insisted on engineering reports for commercial buildings (Leigh *et al.* 1998). More recently Allstate in the US has been reported as stopping offering polices in coastal parts of New York City and Nassau, Suffolk and Westchester counties where the risk of hurricanes is perceived to be too high (as reported in the New York Times, 11 March 2006).

The 12-month cycle of insurance and reinsurance means that such reactive responses by the industry can take effect very quickly. They can also have important social and economic consequences. On a positive note, the withholding of insurance or inclusion of conditions relating to building construction can prompt policy and legislative changes that reduce overall vulnerability to current natural hazards regimes and to the anticipated impacts of climate change. In other words, they promote adaptation.

Clearly, scientific research that will improve the reliability of global climate projections under different emission scenarios and improve confidence in their representation of smaller scale phenomena and extreme events is important. Similarly important are strategies that address the root cause of the changing risk and increasing uncertainty: greenhouse gas emissions. However, in the context of this paper, policies and research directed at helping societies adapt to the effects of current and future climate change and variability through quantifying and reducing physical and social vulnerability to extreme events is the critical issue. Researchers and practitioners in fields such as disaster risk reduction, disaster studies, natural hazards research and insurance and reinsurance already have the relevant tools, knowledge and experience to make an important contribution; indeed they deal with extreme events, variability and uncertainty on a regular basis. Improved understanding and ability to cope with current climate variability and weather extremes is a fundamental step towards adapting to potential future climate variability and weather extremes.

References

Blong, R. 2004. Residential building damage and natural perils: Australian examples and issues. *Building Research & Information* 32 (5), 379-390.

Chen, K. and K.J. McAneney. 2006. High-resolution estimates of Australian coastal population: with validations of global data on population, shoreline and elevation. *Geophysical Research Letters*, (in review).

Chen, K. and K.J. McAneney. 2005. The bushfire threat in urban areas**.** *Australasian Science*, *26(1*): 14-16.

Crompton, R.P. 2005. *Indexing the Insurance Council of Australia Natural Disaster Event List.* Report prepared for the Insurance Council of Australia, Risk Frontiers.

Gray, W.M. 2003: Twentieth century challenges and milestones, In *Hurricane! Coping with Disaster* edited by Robert Simpson, American Geophysical Union, Washington DC 2003.

Guy Carpenter. 2006. *Tropical Cyclone Larry Review*. Guy Carpenter, Inc.

Leigh, R.J., Taplin, R. and G.R. Walker. 1998, Adaptation of the insurance industry to climate change, and consequent implications, *Australian Journal of Environmental Management*, 5(2), pp.81-96.

McAneney, K.J. 2005. Australian bushfire: Quantifying and pricing the risk to residential properties**,** pp. 13-22. In R. J Morrison, S. Quin and E.A. Bryant [eds.] *Proceedings of the Symposium on Planning for Natural Hazards – How Can We Mitigate the Impacts?* 2-5 February 2005, University of Wollongong.

Pielke Jr, R.A. and C.W. Landsea, 1998: Normalized hurricane damages in the United States: 1925-95. *Weather & Forecasting,* 621-631.

Pitman, A. J., Narisma, G.T. and K.J. McAneney. 2006. The impact of climate change on Australian bushfire risk. *Climatic Change* (in review).

Walker, G.R. 1999. Designing future disasters: An Australian perspective. Pp. 17-24. In Proceedings of Aon Group Australia Conference: *The Changing Risk Landscape: Implications for Insurance Risk Management,* Southwood Press, Sydney, Australia.

Appendix A

Indexation Methodology

$$CL_{04} = L_a \times N_{a,b} \times D_{a,s}$$

CL_{04} - event loss converted to 2004 value (current loss);

a - year the event occurred;

L_a - event loss in year 'a' (original loss);

b - Urban Centre / Locality (UC/L) impacted by the event. The UC/L Structure groups Census Collection Districts (CCDs) together to form defined areas according to population size criteria (http://www.abs.gov.au);

$N_{a,b}$ - dwelling number factor, determined by the ratio of the number of dwellings as at 2004 in the UC/L originally impacted by the event to the number in year 'a'. This information is derived from the 1966 and 2001 Census of Population and Housing;

s - State/Territory that contains the UC/L impacted by the event;

$D_{a,s}$ - dwelling value factor, determined by the ratio of the State/Territory average *nominal* value of new dwellings in 2004 to that of year 'a'. The dwelling value factor is calculated for the State/Territory that contains the UC/L impacted by the event. State/Territory average *nominal* values of new dwelling units are calculated by dividing the value of building work completed within a year by the number of completions within the same year. The relevant values are taken from the ABS *Building Activity* reports (http://www.abs.gov.au).

Note that the increase in average dwelling value is in part due to increasing average dwelling size and marked improvements in the quality of the housing stock (http://www.abs.gov.au).

While it has been shown the most important factors have been quantified and combined in the above indexation methodology, it is important to recognise factors not accounted for in the adjustment process. These include but aren't necessarily limited to the following:

- changes in insurance penetration;
- changes in the quality of insurance issued over time i.e. companies ceasing to offer policies in high risk areas;
- changes in the impact of post-event inflation (demand surge);
- possibility of no change in population or exposure for particular events even though it is automatically assumed in the adjustment - imagine a hailstorm whose footprint extended across an already densely populated area where there have been no material changes in population or dwelling numbers since the time of the event;
- the impact of loss mitigation measures, e.g. improved bushfire prevention and fighting measures or new levees constructed near or around rivers in the case of flood;
- possibility that some recent events in the Disaster List not registering a loss had the same event occurred years ago, i.e. demographic changes mean that it's now possible for an event to register a loss in an area where there may not have been any people living in the past. This is particularly a problem for hazards such as hailstorms where there is no record of the event unless it impacted a populated area;
- frequency and magnitude of some of the hazards in the Disaster List are affected by meteorological and atmospheric cycles.

Note that not all of these adjustments increase the original loss.

When applied to the Disaster List, the preferred approach and that of Pielke and Landsea (1998) produce comparable current loss values. This is no coincidence, as dwelling assets comprise the main driver of the Australian wealth factor (63% for the 12-month period ending in June 2004) while the preferred methodology uses dwelling number and dwelling value factors directly. A disadvantage of the Australian wealth factor is that the dwelling assets also include land value. Moreover, an indexation methodology based on dwellings rather than population has advantages in that the housing stock increased at almost double the rate of population during the period 1911 to 1996. The outcome has been a marked decline in the average number of occupants of each dwelling in Australia from around 4.5 in 1911 to around 2.5 by 1996 (http://www.abs.gov.au).

THOUGHTS ABOUT THE IMPACT OF CLIMATE CHANGE ON INSURANCE CLAIMS

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Summary

This paper focuses on the type of extreme event that is important to property insurers, and considers evidence on how those risks have been changing, and how they might move in future with climate change. In particular, evidence is drawn from UK, which has wide insurance coverage for weather perils and also much familiarity with international catastrophe insurance. The facts that UK weather is changing at an unprecedented rate, and that abnormal weather causes insurance claims, mean that climate change is already affecting the risks, though socioeconomic factors have also caused change. Further, the risk of extremes is changing very rapidly. However, because the costs of extreme events are heavily skewed towards the very rare ones and the pace of economic development has been so fast, it is difficult to discern a trend in the relatively short data series of economic costs. These hidden trends mean that we must expect frequent surprises. Hurricane Katrina showed how sensitive the global economic system is to climatic disruption, and this vulnerability will grow with the increasing reliance on regions that are prone to sealevel rise, tropical storms, and water shortages or floods. Private insurers may be able to limit the financial risk, as they did with Katrina, but then the cost spills over into wider society.

In this context, the question must be asked, whether it is right or prudent to take as the null hypothesis that damage is NOT increasing due to climate change rather than a Bayesian approach that damage should be increasing already.

1. Introduction

Potentially, the insurance industry is exposed to climate change in a number of ways, although the effects may vary greatly between jurisdictions, due to industry structure and practice, as well as climatic and geographical differences. The insurance industry is already encountering aggravated claims for insured property damage in extreme events, particularly flood, storm, and drought. As yet, the main causes of the rising trend in property claims in recent decades are socio-economic rather than climatic, but the contribution of climatic change will likely rise quickly, due to the strongly non-linear relationship between climatic variables and damage, and the fact that a small shift in mean conditions can create a large change in extremes. The pace of change regarding weather extremes is <u>fast</u>. The underlying rate of change can be 12% per year for very rare events, and in the range 2 to 4 % for extreme, but "insurable" events. This means that underwriting strategies are inadequate to the real risks. Already target regions are evident, on coasts and particularly on deltas. Likewise some sectors could be strongly affected, with greatly increased risks. For some hazards, like freeze and drought in UK, the risk may diminish, but this will be more than offset by increases in flood and storm risk.

A key source of evidence is UK, because of its wide insurance cover and good statistical database, as well as its familiarity with overseas markets, through its subsidiaries and also reinsurance of external markets. Next we look at global trends using data from Munich Re. Then we shall consider the literature as revealed by IPCC. Finally we look at European storm, from two studies not in the current IPCC draft.

2. UK Evidence[1]

2.1 The climate data

The UK has the longest series of scientific weather records in the world (1659 for monthly temperature, and 1766 for

[1] This section draws heavily on the technical annexes to Dlugolecki (2004) available at http://www.abi.org.uk.

precipitation - see Hadley Centre website. This gives us the ability to calculate long-term weather patterns with confidence. For insurers, it is the extremes that matter, since those are what cause property damage.

Any month in which the monthly temperature or rainfall fell in the top or bottom ten percent of the historical range will have experienced some rather extreme days, so this decile threshold can be used to identify the extreme-weather months (hot, cold, wet, and dry). Since we are using the decile level to pick the months, there ought to be twelve such months in every decade (10 % of 120 months).

The table shows the pattern of extreme months in recent decades in the UK (bold font indicates high and low values, as values outside the range 7 to 17 are statistically significant at the 5% confidence level).

Table 2.1 Recent UK weather: extreme months since 1960 (see Also Figure 2.1 below)

Number per decade (12 expected)	1960's	1970's	1980's	1990's	2000's (pro-rated to March 2004)
Hot	10	17	**18**	**34**	**33**
Cold	**5**	7	8	**3**	**0**
Wet	14	11	**19**	15	**26**
Dry	10	15	10	15	**2**

Note to Table 2.1. The figures for the 2000's decade are estimated by scaling up the observed occurrence of extreme months to March 2004, by the factor 120/51 to allow for the remaining months of the decade.

- For hot months, the 1960's were just below average, with only 10 hot months. Since then the frequency has risen dramatically, and it has been running at nearly 3 times the expected rate since 1989 in fact. This is the highest level since records began.
- Cold months however have been running well below the expected level since 1960, and have now disappeared. Again, this is unprecedented.
- Wet months have become steadily more frequent, now running at double the customary rate. This is particularly a winter phenomenon.
- Dry months seem to have receded for the moment. However, it is worth noting that what matters here from an insurance point of view is a succession of below-average months, rather than simply isolated very dry months. A prolonged dry period leads to shrinkage of clay soil, with consequent damage to the foundations of buildings and claims for subsidence.

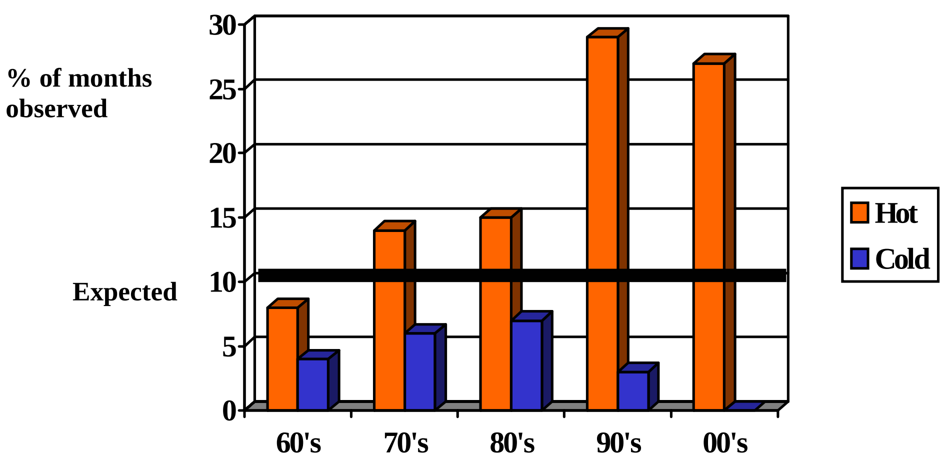


Figure 2.1 Recent patterns of hot and cold months in UK (Central England Temperature observation series)

2.1.1 Statistical significance of the recent observations

To test whether the data is generally consistent with the long-term average of 12 extremes per decade, we can use the standard χ^2 test, with 4 degrees of freedom. The test results are:

Hot $\chi^2 = 61.3$ Cold $\chi^2 = 15.6$ Wet $\chi^2 = 12.1$ Cold $\chi^2 = 5.5$

Since the significance levels at 98%= 11.7, and at 99% = 13.3, the test results confirm that, apart from cold months, the observed weather since 1960 has been abnormal.

Applying the standard normal distribution approximation test to the deviations from expected:

z= (observed-expected)/ ✓ (expected x probability of not occurring) for temperature after 1990 gives:

Hot z=7.75 Cold z=3.47

These values would be seen by chance 1 in a million and 1 in 4000 times respectively, confirming how very abnormal this weather is by historical standards.

2.1.2 Implications

This change to warmer winters is associated with more storms (the number of winter storms crossing the UK has doubled over the last 50 years), more rain, fewer frosts, and faster thaws. Warmer, drier summers mean more clay-soil subsidence. Significant weather events affecting the UK during this period include:

- The extended drought and heatwave of 1975/6
- The "hurricane" of October 1987
- The severe windstorms of January and February 1990
- Numerous severe local floods eg at Perth in January 1993 (see Annex 2 for more detail)
- The Shetland storm of 1993, probably the deepest ever depression in NW Europe, which wrecked the tanker Braer
- The drought and heatwave of 1995
- The Easter floods of 1998
- A close call - three storms devastated mainland Europe (December 1999)
- The Autumn floods of 2000
- The drought and heatwave of 2003
- Looming drought in 2006

2.1.3 Prolonged drought

Whereas individual dry months do not have a significant implication for insurers, longer periods do. In fact the seasonality of precipitation has shifted in the last 40 years, with more frequent dry months in Q3, and more frequent wet months in Q1 and Q4 (see Table 2.2). In those quarters, the months at the opposite end of the distribution have lessened. Q2 has seen a change to more variable precipitation, with an excess of wet and dry months.

Table 2.2 Seasonality of precipitation since 1965: occurrence of decile months
(12 expected for each quarter in 40 years)

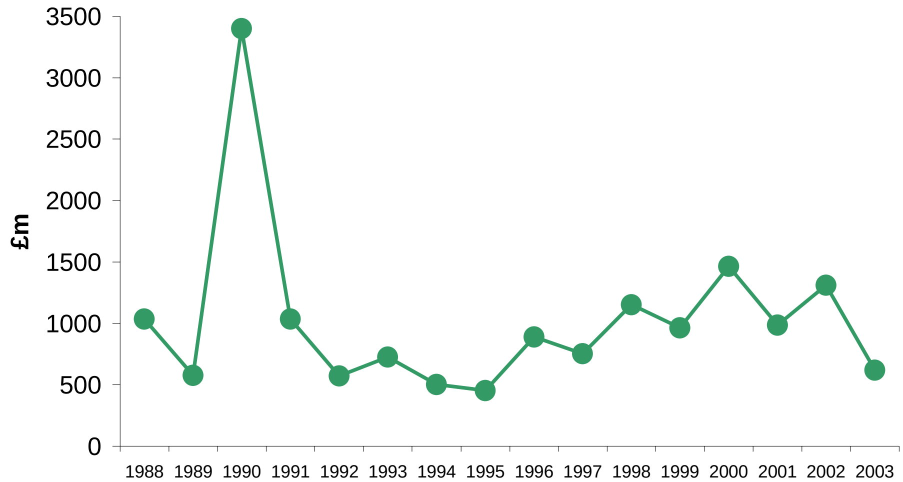
	Q1	Q2	Q3	Q4
Wet	20	18	8	19
Dry	7	14	17	4

A relevant statistic for building damage is given by the following *drought index*: precipitation accumulated for 18 months to September. Using the historical data for precipitation (available from 1766), we can investigate whether there has been a shift in the behaviour of the drought index. For the period 1766-1965, the upper decile threshold is 1551mm, and the lower decile is 1151 mm. In the last 40 years (1966-2005), there have been five occurrences at the high end.

Although this is not statistically significant, one of the periods (2001) was a new record and was associated with high numbers of flood claims in 2000. At the other extreme, there have been six occurrences, of which two have been new lows (1976 and 1996), while three occurred in succession (1989, 1990, 1991). The sixth one occurred in 1997, adding to the effect of the 1996 low value. All of these lows have seen large numbers of subsidence claims (see Figure 2.3). The behaviour of the drought index is suggestive of a change to more erratic conditions, which is perhaps not surprising given the change in seasonality of the rainfall.

2.2 UK Insurance Data

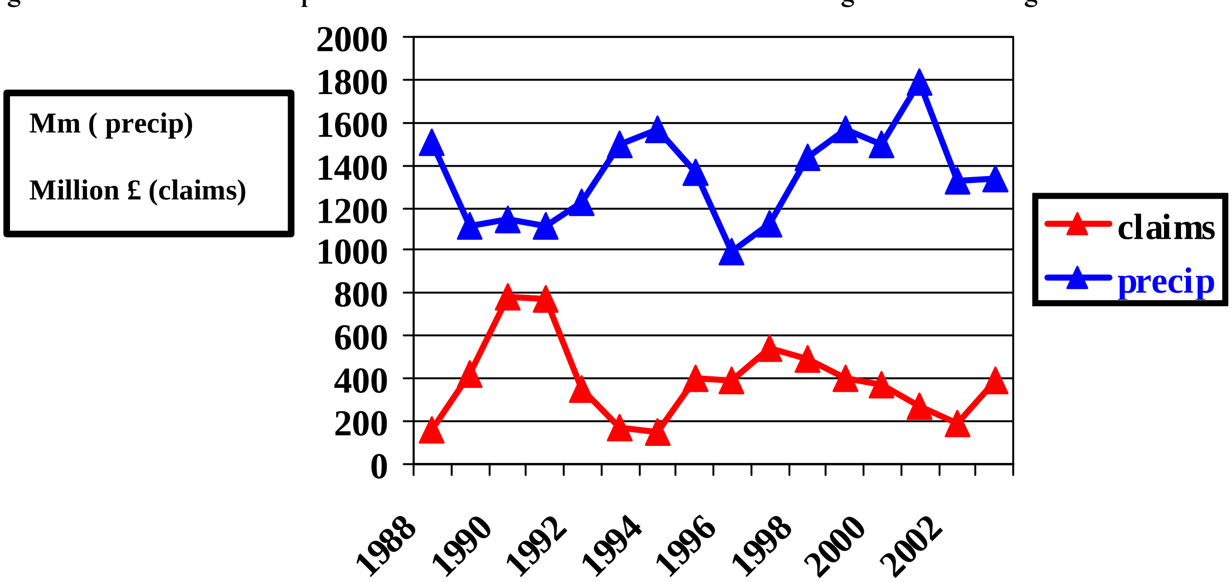
Figure 2.2 ABI member companies' weather claims, 1988-2003 (excluding subsidence)



While it is true that insurance claims respond to abnormal weather conditions, it has to be borne in mind that the impacts develop unevenly when looked at on an annual basis, because of catastrophes. Figure 2.2 shows this for "weather" claims recorded by members of the Association of British insurers (ABI), excluding subsidence claims. The cost is measured in constant values, which demonstrates the scale of the 1990 peak. The massive spike in 1990 was due to a four-week period of storms commencing on Burns' Day. The fact that individual years have been lower since then does not mean the risk is diminishing, because of the random occurrence pattern. There was another great storm in 1987, a near-miss in 1993 and three near-misses in 1999!

Subsidence claims respond strongly to drought (see Figure 2.3). There are of course other factors, such as the state of the housing market, and the relationship given here is only approximate because most claims arise in the clay belt of mid and SE England, whereas the data shown here relates to all UK for claims, and all England and Wales for precipitation. If anything, the data suggests a downward trend in subsidence claims. This is not surprising, given the trend to wetter winters seen in Table 2.2, which militates against prolonged droughts.

Figure 2.3 ABI member companies' subsidence claims 1988-2003 versus drought index for England and Wales.



2.3 Weather Risk Trends

The UK insurance industry has been willing to underwrite the broadest range of weather perils. However, the prospective increase in UK weather damage may make such risks unacceptable for insurers. Two approaches indicate that the risk is already rising quickly, so that this could soon become a significant issue for the industry and its customers. The first method is based on projections by the Foresight Programme[2] in their recent work on flooding while the second looks at the issue with an illustrative example for a reinsurer. It is important to remember that without reinsurance many risks would not be insured at all. For example, when reinsurers withdrew from the UK market for terrorism risk in 1993, the government had to create Pool Re as a backstop for primary insurers, who were about to withdraw in the absence of reinsurance.

2.3.1 The Foresight Programme's view of flooding in the 2080's

Table 2.2 shows the basic estimates of UK flood risk now and in the 2080's, as provided by the Foresight Programme. The costs in the 2080's are based on four scenarios of how society might develop, using a classic two-dimensional approach (scale and sustainability). It should be emphasised that these scenarios are non-interventionist ie they assume that no action is taken on account of climate change in flood defence or planning policy. Thus they give a true view of how the underlying risk will behave. Of course society will be able to take precautionary measures (at a cost) to control the future damage, but the inherent risk will still exist.

	Current	World markets	National Enterprise	Local Stewardship	Global Sustainability
Annual expected damage (£billion, constant value)	1.3	28.4	20.7	2.2	6.7

Table 2.3 Annual Expected Flood Damage in UK, present day and 2080's

The increase in flood damage for "local stewardship" is 69% over the 80-year period, but this scenario seems almost utopian in that it requires a reversal of current trends in consumption and globalisation, and the estimated damage lies well away from the other three projections. It has been ignored for the purposes of these calculations. The increase in flood damage between now and the "global sustainability" scenario is an increase of 415%. If the underlying process is uniformly continuous this implies an annual change of 2.1%, compounded for 80 years. The increase in damage between now and the "world markets" scenario is an increase of over twenty times the amount. To generate this would require an annual increase of just over 3.9%. The calculation for the "national enterprise" scenario is an annual increase of just over 3.5%.

Thus on the basis of the Foresight Programme view of future flood risk, the risk of flood damage is already increasing by between 2.1% and 3.9% per annum, or in round terms a range of <u>two to four percent per year</u>. As Annex 3 indicates, not all of this is due to climate change, but a very substantial part is. An alternative view is that the risk should be normalized according to the future exposure, since that gives a relative measure of riskiness after taking account of economic growth and other socio-economic factors. If that is done , then the two "growth" scenarios present a risk which is between two and four times higher than currently, while the two "sustainable" scenarios present a picture where the risk declines, because in those society pays more attention to risk. In the growth scenarios, the flood risk escalates at around one to two percent per annum, reflecting climate change and less risk aversion. It is well understood in the insurance industry, that when extreme events occur, in fact the costs increase far beyond the normal scale, due to the compounding effect on the capacity of the repair and recovery resources and processes. This was seen after Hurricane Katrina, and after recent European storms. For that reason, this author believes that it is appropriate to retain the risk escalation factor <u>at two to four percent per year</u>.

[2] *Future Flooding*, Foresight Programme, Office of Science and Technology, April 2004

2.3.2 Illustrative Reinsurance Example

Reinsurers tend to work on very focussed risk portfolios, because they are dealing with those risks which are unacceptable to primary insurers. The example below illustrates how this could escalate in future and become unacceptable. Suppose that in 2000 the reinsurer assessed there were three possible event outcomes, normality, an extreme event (defined as a 1-in-100 year probability), and a catastrophe (defined as having a 1000 year return period). Swiss Re's estimates for inland flood and windstorm in the UK in 2004 are shown in Table 2.4 below.

Event type	Normal	Extreme	Catastrophe
Return period (years)	Annual	100 yrs	1000 yrs
UK river flood	-	£1.7 bn	£3.9 bn
UK Storm	-	£10 bn	£24 bn

Table 2.4 Estimated event costs

If the reinsurer ignores the possibility of other events (ie slightly smaller than the 100 year flood, or between the 100- and 1000-year flood, or greater than the 1000 year event) then it would assess the annual expected claim cost, or risk premium due to inland flood as £20.9 million (1% of £1,700 million, and 0.1% of £3,900 million). Of course a reinsurer would not be presented with the risk for the entire UK, but would receive presentations from individual insurers for their share of the UK market. Thus for an insurer with a 5% market share the exposure for river flood is £85 million in the 100 year event, and £195 million in the 1000 year event.

However, the balance of these events will be disturbed by climate change. Judging what the change will be is problematic, because the current generation of climate models is not well-suited to dealing with extreme weather events like storms, which are, in climate-science terms, rather small-scale even though their impacts are large. However, for heatwaves and intense rainfall floods, there is a growing body of evidence that indicates that the frequency of today's extremes will be much higher in future, perhaps 4 times greater[3]. Furthermore, this escalation factor rises rapidly as one raises the definition of "extreme" due to the shape of the tail in statistical distributions (see section 2.3.3).

This might lead the reinsurer to assess that the typical distribution of events in 2050 will shift to 4% and 1%. (ie four times more frequent extremes, and ten times more frequent catastrophes, on today's definitions). This is the scale of change which UKCIP is suggesting for future flood risk[4]. On that basis the annual risk level rises to £107 million (4% of £1,700 million, and 1% of £3,900 million), an increase of 412% over a 45 year period, or roughly 3% per year, which is in the middle of the 2-4 % range based on the Foresight projections.

2.3.3 Potential Range of Increase in Risk Premium

The approaches above support a range of 2 % to 4% as an annual increase in risk premium, based on consideration of the potential weather hazard, and potential changes in exposure. However, experience has shown that riskiness increases for other reasons also, such as vulnerability of materials and behaviour. There are no reliable measurements of this factor, but it is significant that the cost of natural disasters had been rising rapidly for several decades (see Section 4) before the influence of climate change began to appear. Clearly therefore this factor is significantly greater than zero. We can conclude that a conservative estimate of the underlying increase in risk premium is **two to four percent per annum**.

An attitude which comes up repeatedly among underwriters is that recent extreme events are simply a feature of normal climatic variability. This is reinforced by the view that since property insurance policies are annually renewable, it would be easy to extricate oneself from a deteriorating risk situation before permanent damage was done to the balance sheet. But, we are in a dynamic situation, which produces very rapid change in the likelihood of extreme events.

[3] *Regional climate-model predictions of extreme rainfall for a changing climate*, Huntingford C et al, Quarterly Journal of Royal Meteorological Society, vol 129 pp1607-1621, 2003

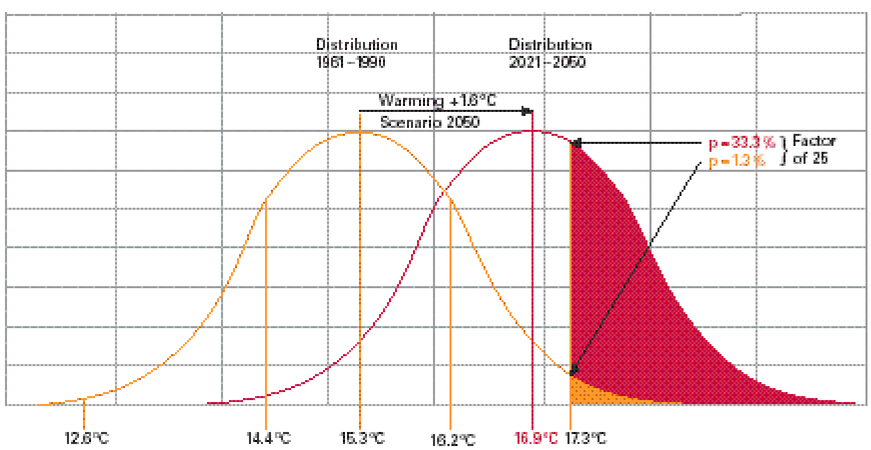
[4] *Climate Change Scenarios for the United Kingdom: the UKCIP02 Scientific Report*, Hulme M et al, Tyndall Centre for Climate Change Research, April 2002

The diagram below shows the expected change in temperature distribution for UK summers due to climate change. A hot summer, like that of 1995, with a temperature of 17.3 °C was likely to occur about once in 75 years or 1.3% of the time on the climatic pattern of the period 1961-90, where the average was 15.3 °C. For the period 2021-2050, centred on 2036, the average temperature will be 16.9 °C. On that basis the chance of exceeding a temperature like 1995 will be 33.3% ie one year in three! This implies a change in return period of 25 times, and the rate of change will be faster still for less frequent events. Clearly this process is already under way, and it is reasonable to suppose that the rate of change is constant. It might be objected that temperature is not a critical variable for insurers- in fact recent evidence on hurricanes (see CERES report, 2005) shows that rapid increases of intensity have been occurring there, and are correlated with rising sea temperatures.

Taking the midpoint of the two periods as representative, gives a time span of 60 years between the two patterns. To produce a 25-fold change within 60 years implies an annual rate of change of about 4.5% per year. Such a rapid change, if ignored, soon accumulates into a significant error. In five years, it means that return period calculations for the event would be 25% too low. The only reason it is not noticed soon is that the probability of the event is still quite low for the initial part of the transition time. Similar calculations based on the estimated rate of change of the risk of extreme heatwaves in Europe following the 2003 event, produce an annual rate of change for very extreme events of 12%.

What it means is that one can expect "surprises" to start occurring: there are many potential low probability events, so that some of them do start to occur "too often". (Of course the reverse happens at the other end of the distribution, where events do not happen as often as they should- a phenomenon that is harder to notice obviously. Usually, we can assume that damage only happens at one side of the distribution.)

Figure 2.4 Change in distribution of UK summer temperatures: disjoint effect on extremes
(source Climate Change Impacts Review Group, 1991)



However, the position is really even more extreme, because we are dealing with a multi-dimensional, nonlinear system. The shifts can compound across more than one factor to produce very unexpected costs - for example inland and marine flooding at the same time eg Hurricane Katrina. Other factors which could raise costs are pressure to make ex gratia payments, repair price inflation due to scarcity of supplies, close repetition (eg Lothar and Martin 1999, or the 1990 European storms, or the 2004 hurricane and typhoon season), and denial of access or failure of utilities, as in New Orleans 2005. If events become more frequent, that will also increase the chance of coinciding with an uncorrelated event eg an earthquake, or an economic catastrophe, as happened in UK on October 17th 1987, when the 87J storm coincided with a global stockmarket crash.

The consequences for insurance companies could be serious:

- Risk assessment will be wrong, and prices consequently will also be wrong. If historical data is used to set prices, the error might be in the region of 25% for "average" weather risks, much more for catastrophic risks.
- Exposure accumulations will be too large.

- Reinsurance plans may be inaccurate, and reinsurers themselves may be taking on too much risk.
- Estimates of risk-based capital will be incorrect- eg the risk of .0007% failure for an AA rating will be too generous

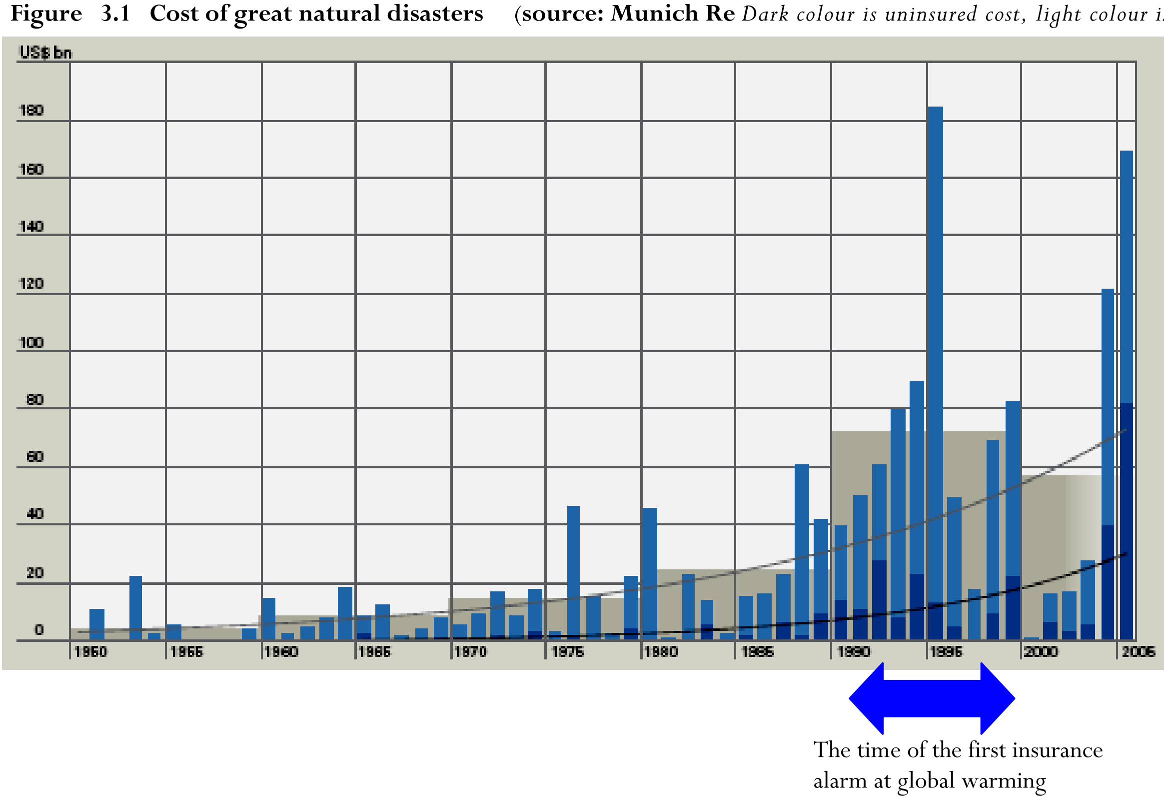
3. 2005 in Perspective

The 2005 hurricane season can be seen as an indicator of climate change, in the same way that the European heatwave of 2003 is now recognised to have been. Before Katrina, the statistical evidence was accumulating rapidly that global warming causes more intense hurricanes, and the records broken in 2005 confirm this:most storms (27) , most hurricanes (13), most strong US-landfalling hurricanes (4), costliest in total ($200billion+), single most expensive (Katrina), and strongest ever (Wilma). The season also had three of the six strongest hurricanes recorded (Wilma, Rita, Katrina) and continued a very active phase (most storms, hurricanes, and strong hurricanes ever in a two-year or three-year period). The hurricane season of 2005 may cost insurers $60 billion, more than double any previous year. The true cost is much greater – possibly $250 billion direct economic loss including uninsured losses and property blight, and even greater globally when higher oil prices and lost economic production is included- not to mention the over 1,300 dead and thousands of people traumatised. Post- Katrina issues include coverage disputes with Mississippi State, the cost and quality of the new levees, land zoning, business interruption, and long-term relief payments.

In terms of relevance to insurers, climate change will make tropical storms more intense (ie stronger winds, heavier rain, and higher sea-surges). In USA this will possibly be reinforced by natural cyclicity over the next two decades. This author is sceptical of this argument on cycles for two reasons. Firstly, the data required to estimate a cycle length is roughly ten times the cycle, and we don't have such a long timeseries for hurricanes. Secondly, there is a tendency to view climate change simplistically as a monotonic increase in temperatures. In fact we know that in the third quarter of 20th century, a cooling effect occurred due to the large amount of eg sulphur dioxide being emitted, which suppressed the longterm warming. This cooling therefore put a brake on various extreme events eg hurricanes, winter storms for some decades.

It could be argued that we have been here before. The insurance market reacted strongly to a series of great storms between 1987 and 1992, which were then followed by a lull. However, the magnitude and number of events this time is on a new level- see Figures 3.1 and 3.2.

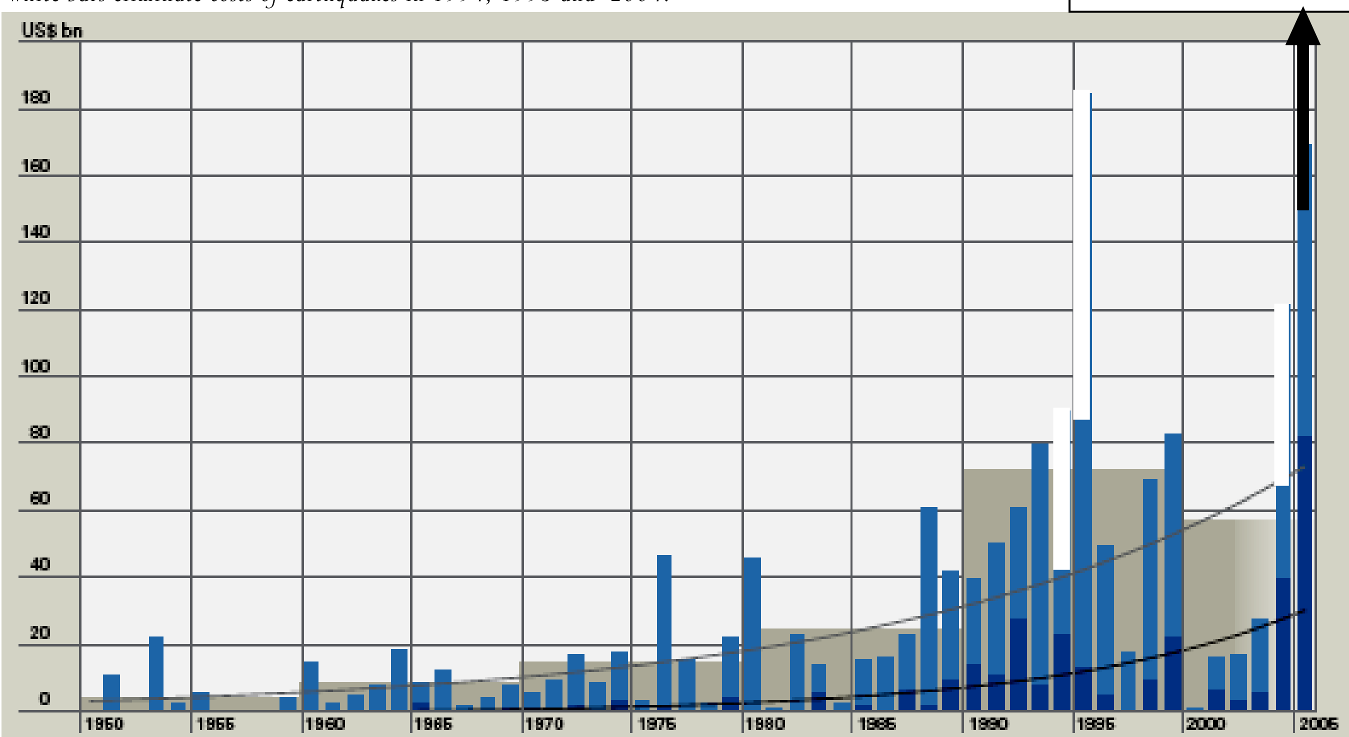
Figure 3.1 Cost of great natural disasters (**source: Munich Re** *Dark colour is uninsured cost, light colour is insured*).



In fact, we shall focus on the economic losses, rather than insurance claims, because the latter are a rather variable proportion of the total, depending on the state of the insurance market and its interaction with other stakeholders. It can be argued that even without climate change or variability the total damage varies depending on such factors as risk awareness, preventive measures, and an efficiently prepared crisis management (Munich Re, 2006)

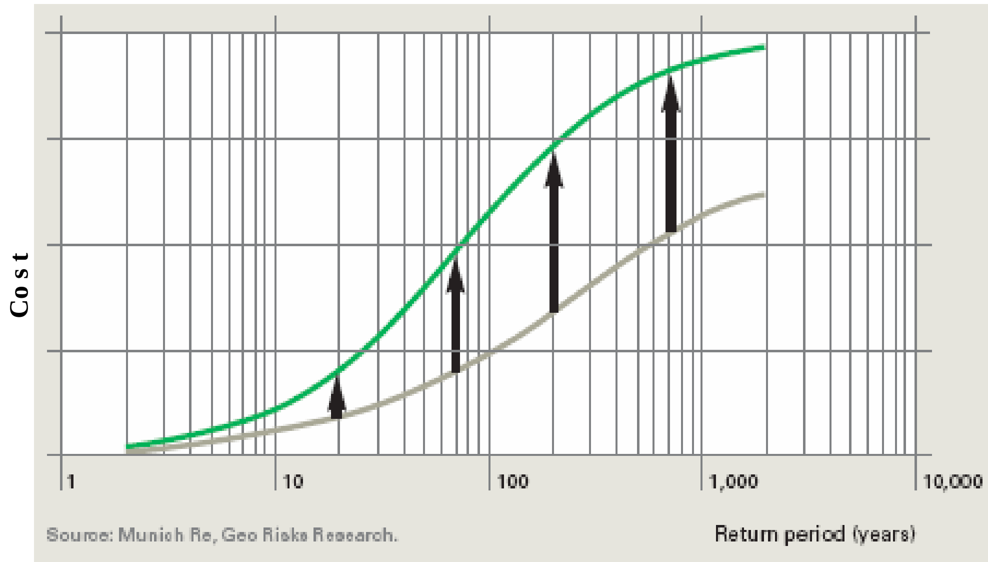
Also, Figure 3.1 presents a misleading impression, because it includes earthquakes and tsunamis as well as climatic disasters. Further, this author believes that the costs attributed to 2005 are too low, because Katrina and Rita caused massive disruption on global energy markets with harmful effects to many nations around the world. Figure 3.2 attempts to rectify these points by removing the largest earthquakes (1994, 1995, and 2004) and adding a speculative amount for global disruption to energy markets (see below). It is worth noting, that the effect of the hurricanes lingers on locally. New Orleans may never recover, (as happened to Galveston in 1900), and the defences will be weaker in 2006 than in 2005.

Figure 3.2 Adjusted cost of great natural disasters
Source Munich Re *Dark colour is uninsured cost, light colour is insured. Supernormal cost of Katrina and Rita is shown by black arrow*
white bars eliminate costs of earthquakes in 1994, 1995 and 2004.



While Munich Re has a more conservative view regarding the economic costs, it does believe there is a watershed regarding insurable costs, following the 2004 and 2005 hurricane seasons. Figure 3.3 indicates that Munich Re now believes that the damage curves have shifted by almost a factor of two, for a number of reasons. Similar views are shared by many expert commentators (eg Tillinghast, RMS)

Figure 3.3 Shift in return period after 2005 season (Munich Re)



- Munich Re states that historical data understates the potential present-day risk by up to 60%
- The upper curve shows the adjustment of the loss distribution including the following factors:
  - Higher hurricane frequency
  - Higher intensities
  - Re-evaluation of the storm surge and flood risk (not including NFIP)
  - Loss-aggravating factors in connection with mega-catastrophes

- **The Munich Re curve gets relatively closer in % as the return period rises**
- **However, non-insured costs kick in then eg global shortages, labour unavailability, competitors - SUPERSATURATION**

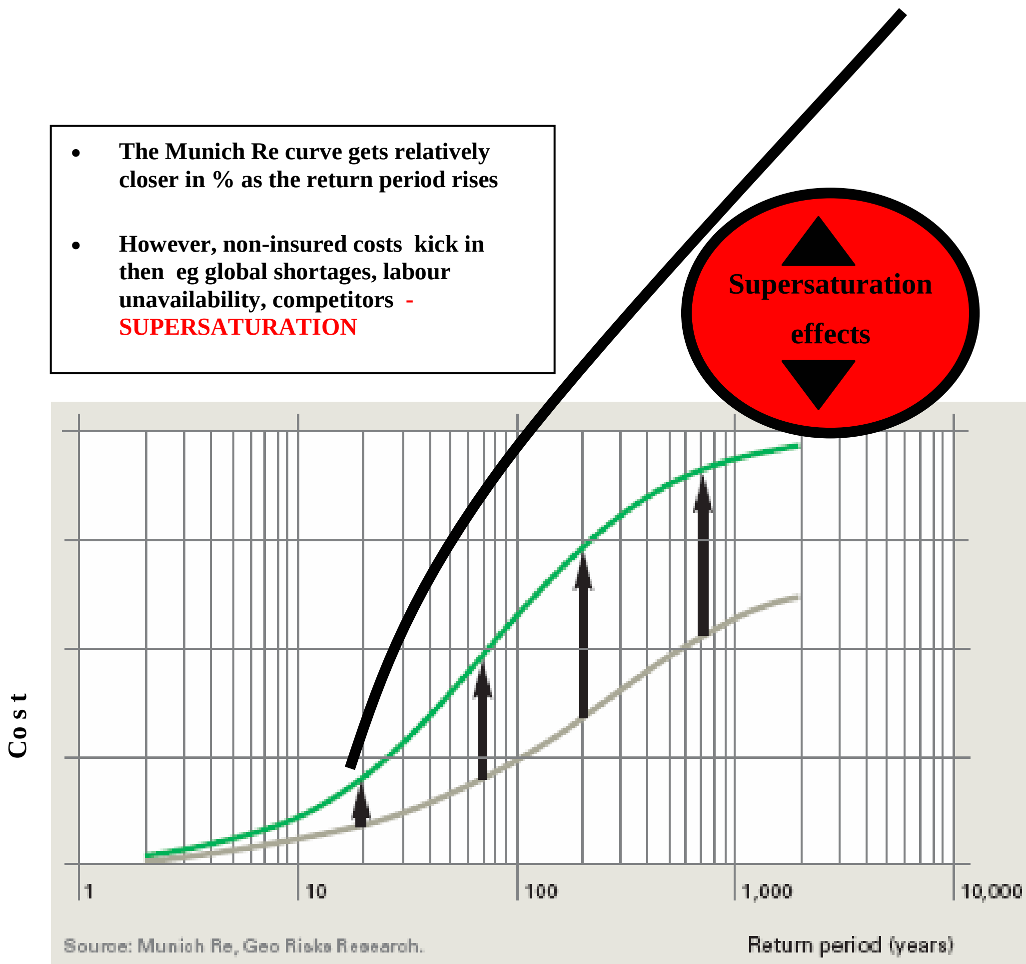


Figure 3.4 Supersaturation and damage curves

This author believes that once damage reaches a certain level , the effects escalate dramatically, due to firstly their longevity- the recovery is more extended, with consequent vulnerability and greater on-costs, while the geographic extent is much greater through effects like migration and global market disruption. We saw this happen in 2005. Some economists have dismissed the likely costs of climate impacts as acceptable, around 0.2 % or less of GDP by mid-century. In fact Katrina may have cost 2% of US GDP in 2005 already. For New Orleans it was a turning point; tens of thousands may never return, and new defences may cost $32 billion + for which there is no budget.

In Super Catastrophes like Katrina, losses become nonlinear, i.e., the scale of the event itself causes losses to increase further, through a variety of processes (see eg RMS, 2005). Indeed costs might have been even greater if Katrina had not weakened before landfall, or Rita and Wilma had not veered away. After Hugo in 1989, roughly a dozen insurers were financially overwhelmed. Generally, these were smaller regional insurers that had not purchased sufficient reinsurance. After Andrew, nine insurers failed. Even some very large carriers were stressed to the limit. There have been no reports of private insurance company failures after Katrina (Tower Perrins, 2005), but ironically two airlines filed for bankruptcy due to high fuel prices (RMS, 2005), and the government-funded National Flood Insurance Program is insolvent.

It was an accident waiting to happen. A classic deltaic city in the literature, slowly subsiding and threatened by sealevel rise and storm surge, it grew during the hurricane pause (1965-95). **Did climate change play a part in the cost of Katrina? The answer must be yes, but we cannot quantify the share precisely**. Sealevel rise contributed to the storm surge obviously. In addition, the sea was unusually warm, which is a classic symptom of climate change. Finally, there is strong statistical evidence (Emanuel, Webster, Munich Re) that once a storm starts it is now likely to become stronger. Some commentators put a range of 10 to 60% on the contribution of climate change.

4. Munich Re Climate-Related Losses

Munich Re has been compiling statistics of natural disasters for many years because they illustrate the need for risk management. Their definition of what are "major natural catastrophes“ follows the criteria laid down by the United Nations - the affected region's ability to help itself is distinctly overtaxed, in that interregional or international assistance is necessary, thousands are killed, hundreds of thousands are made homeless, and there are substantial economic losses and/or considerable insured losses. In this section we exclude those disasters like earthquakes and volcanoes which are not weather-related.

Table 4.1 Great weather-related disasters 1950-2003: Munich Re, monetary data in constant 2003 values.

	1950's	1960's	1970's	1980's	1990's	1994-03
Number	13	16	29	44	74	47
Economic loss ($ bn)	41.8	54.8	82.8	130.5	439.1	288.8
Insured loss ($ bn)	-	6.1	12.1	23.9	101.2	58.8

Table 4.1 shows great weather-related disasters for the period 1950-2003. Clearly there has been a global increase in numbers and costs of weather disasters, paralleling the UK picture. Of course, there are many reasons for this trend, including increased volumes of assets located in more hazardous areas. It will be noted that the 1990's were the most costly decade, and that the moving 10-year figure figures have fallen since then. This partly reflects the fact that the early 90's witnessed major incidents in the USA (1992 Hurricane Andrew, 1993 Mississippi flood) where the concentration of assets is much greater than elsewhere. A more reliable indicator is the number of incidents which shows a strong upward trend.

Table 4.2 Great flood disasters 1950-2003: Munich Re, monetary data in constant 2003 values.

	1950's	1960's	1970's	1980's	1990's	1994-03
Number	6	6	8	18	26	16
Economic loss ($ bn)	31	22	20	28	234	163
Insured loss ($bn)	-	0.24	0.41	1.52	8.39	8.02

The number of flood events has stabilised at a level well above the mid-twentieth century level, but the costs have risen enormously, both in pure economic terms and in insured value, reflecting the incidence of flooding in wealthier countries like UK and Germany.

On the New Orleans flood of 2006, Munich Re notes that the levees were built in the 1960s and were designed to withstand Saffir-Simpson Category 3 hurricanes. They were also supposed to stand up to storm surges with wind speeds of up to 209 km/h. Why then did this catastrophe occur when Katrina only hit New Orleans with wind speeds of a Category 1 and 2 hurricane? Most of the levees are made of swamp peat with a high concentration of organic substances. They stand on a relatively thin layer of clay which lies on a natural layer of peat. In the centre of the levee is an impervious concrete wall which extends into the peat layer. Initial studies suggested that the impervious wall was not deep enough. Water probably flowed under the wall and saturated the subsoil, thus reducing its stability (Munich Re 2006)

New Orleans is by no means an isolated case. Munich Re has identified a number of other flood scenarios in the USA:

Storm surge in Texas (Galveston/Houston), Storm surge in Florida (Miami), Storm surge in the northeast (New York),

Mississippi-Missouri flood (St. Louis), Levee breach in the Central Valley, California (Sacramento), Flash floods in the west (Las Vegas, Denver).

Table 4.3 Great windstorm disasters 1950-2003: Munich Re, monetary data in constant 2003 values.

	1950's	1960's	1970's	1980's	1990's	1994-03
Number	7	10	19	21	42	26
Economic loss ($bn)	11.1	32.9	51.7	54.1	189.9	97.4
Insured loss ($ bn)	0	5.9	11.7	21.0	82.9	43.3

The number of windstorm events has trended strongly upward, with a peak in the early 90's. The costs have not risen quite as fast as for flood, but are still double the levels encountered in the 1980's for insured and total damage.

4.1 Parallels with UK

The increase in global economic losses from weather recorded by Munich Re is broadly consistent with the ABI data for UK only. (It is better to take the economic cost, rather than insured cost, for the global losses, because practice varies so widely in the use of insurance as a compensation vehicle). Between the 1980's and the ten-year period 1994-2003, the cost in constant currency rose from $130 billion to $289 billion, an annual rate of increase of 6% over fourteen years. During the same period in UK the annual increase was about 6.5% in the constant-value cost of climate-related claims.

It is interesting too that the global figures have recently exhibited a strong uplift in flood damage, as has happened in the UK. This indicates that the UK experience is part of a general pattern.

5. Loss trends and projections

Pielke and others argue that the upward trend in losses shown by Munich Re is just due to socioeconomic factors, not increases in climatic extremes. Recently RMS has been examining global loss trends. Preliminary results seem to show that climatic factors are important. The 1990's were much worse than previous decades, and this pattern has resumed again after a short lull in the early 2000's. This is not conclusive, since there are various factors that cloud the issue, such as the effectiveness of disaster preparations and the wealth of the affected regions (USA has a disproportionate effect on the total losses due to its wealth), but it does mean that one of the standard objections to using loss statistics as an indicator of climate change is weakening.

One example of a positive finding is that after correcting for wealth, population and location, **at the national level, a 1% increase in precipitation results in about a 2.8% increase in US catastrophic losses**.

Studies of the potential net losses to USA from climate change have produced estimated in the region of 0.1 to 0.2 % of GDP. **This seems much too low now- the 2005 hurricane season may cost two percent of US GDP, with international repercussions beyond that eg high winter fuel costs in UK**. Recent works by Mills in USA have not provided robust figures for future loss potential, but merely indicated that on the basis of current trends, the losses demand a coherent response from government and the private sector.

Results for 3 out of 4 climate scenarios for the UK imply an annual increase of 2 to 4% in the cost of flood damage, which will have a large impact on the medium and long-term planning of infrastructure (see above, section 2.3.1). A preliminary study by this author for Association of British Insurers (ABI) indicated that future climate-related insurance claims in UK might be two to three times higher than current levels by 2050 assuming no change in government policy on climate adaptation. (ABI, 2004). One of the main uncertainties in this calculation is the future frequency and severity of extreme climate events because climate models do not yet provide a consistent estimation of future storm tracks and intensity. This is a key weakness: in the UK, the cost of a 1000-year extreme climate event is roughly two-and-a-half times larger than the cost of a 100-year event. In Germany, insurance claims increase as the cube of maximum wind speed, or even a power relation of the fourth or fifth degree according to Munich Re, because of collateral damage from debris. A recent study of German storm losses estimated a 60% increase in insured losses in Germany by 2080 without adaptation.

ABI estimated the increased insurance cost of hurricanes (US), typhoons (Japan) and European winter storms due to climate change as around two-thirds by the 2080's, keeping other factors constant, to a new annual average of $27 billion. The extreme seasons would be worse, around 75% higher than currently due to the nonlinear damage curve as windspeeds increase. These calculations may now be regarded as on the low side, especially for USA, as they came before some of the more recent papers on observed increases in hurricane intensity. ABI also made a cursory estimate of future European flood costs, but it should be disregarded as it simply assumed they would parallel the UK trend (ABI, 2005).

ABI 2005 went on: under high emissions scenarios (where carbon dioxide levels double) insurers' capital requirements could increase by over 90% for US hurricanes, and by around 80% for Japanese typhoons. In total, an additional $76 bn could be needed to cover the gap between extreme and average losses resulting from tropical cyclones in the US and Japan. Higher capital costs combined with greater annual losses from windstorms alone could result in premium increases of around 60% in these markets. These loss estimates do not include likely increases in society's exposure to extreme storms, due to growing, wealthier populations, and increasing assets at risk. For example, if Hurricane Andrew had hit Florida in 2002 rather than 1992, the losses would have been double, due to increased coastal development and rising asset values.

Strong and properly enforced building codes have been shown to prevent and reduce losses from windstorms. If all properties in south Florida were built to meet the strongest local building code requirements, damages from a repeat of Hurricane Andrew would fall by nearly 45%. If design codes for buildings in the South East of the UK were upgraded by at least 10%, increases in climate-induced damage costs from windstorms could be reduced substantially.

In the UK, taking account of climate change in flood management policies, including controlling development in floodplains and increasing investment in flood defences, could limit the rising costs of flood damage to a possible four-fold increase (to $9.7 bn or £5.3 bn) rather than 10 – 20 fold by the 2080s.

6. Science of climate change[5]

There is high vulnerability in certain key areas with insurable infrastructure- particularly deltas, but most coastlines are sensitive to damaging events. Global figures are not relevant to local underwriting: the sea is not flat (!), and the rate of SLR (sea-level rise) is accelerated by subsidence in deltas, while storm surges are more damaging in the absence of sea-ice in northen latitudes, or due to the trend to more intense hurricanes (see later). The rates of change in risk are significant: for example in Los Angles area, the return period for severe flooding is decreasing at **between 2.5 and 4 % per year**.

At first sight trends on river flooding are contradictory, with the risk increasing in some regions, but decreasing in others. However, this reflects clear underlying trends in precipitation and warming. High-latitude regions are getting wetter, while low-latitude continents are experiencing droughts in the interior. At the same time, warmer weather is advancing the thaw dates for arctic regions. Thus most of USA, Russia and northern Europe are experiencing greater floods. This was reported by Milly in a study of mega-rivers which noted that the probability of such floods occurring at random was well below 5% ie there is a new factor- climate change. It has been argued that land-use and other human factors are intensifying the problem, but there is no doubt that the underlying risk has changed already. In some areas of Europe, the risk of severe flood is changing at over 3% per year (a current 100 year return period will be just 10 years for the Mosel by 2070 for example). Naturally, the higher the greenhouse gases, the stronger the risk will be. The effect will be seasonal- with much wetter winters in Northern Europe (20% more rain on average), and drier summers (as much as one-third less rain). Monsoons in Asia are also expected to be much wetter. (In fact the 2005 monsoon saw a record 994 mm of rain fall in 24 hours at Bombay).

Drought will be a major issue for the Mediterranean/ Maghrib regions. (Portugal currently has a rainfall deficit of 77% below normal, which would occur just once in 400 years randomly). The risk of severe heatwaves in Europe is rising rapidly- possibly at 12% per year, so that the 2003 drought will be the normal pattern of summer in 60 years.

Large-scale circulation changes like ENSO (El Nino Southern Oscillation) and NAO (North Atlantic Oscillation) are important for extreme events. Currently climate models (GCM's) cannot say what the future pattern of ENSO will be (one side benefit of more ENSO's would be a likely reduction in hurricane frequency, but there is no reason to plan for this). On the other hand, modellers do expect NAO to remain positive until mid-century, which means higher sea-levels for northwest Europe, stronger onshore winds, and more rain.

Regarding European storms, the most important feature is the steady intensification of the wind pattern "CP11" (previously called Wz), which means stronger, possibly clustered storms for northwest Europe, and heavy rain for southwest Europe. There is still disagreement among modellers, but a weak consensus for somewhat stronger European storms by late 21st century (an 8% increase in windspeed)- see section 7.

One of the most striking recent results is that intense tropical hurricanes have almost doubled in frequency in recent decades, at the same time that SST (sea surface temperature) has risen by about 0.5C. This is an unexpectedly strong relationship, indicating that the potential damage is rising at around 2% per year, according to Emanuel's Power Dispersion Index (PDI). Some have argued that the trend is exaggerated because older records are incomplete, or that there are natural cycles of regional activity. These points can be dismissed- the records have been well-validated, and the trends are global, not localised. Future results confirm this trend to more intense events. Some researchers believe that return periods could reduce by two-thirds or more in 50 years or so, due to warmer oceans. Even sceptics believe that we are in for a period of up to 30 years of more active hurricanes, so there is a consensus for the planning horizon! Most of the work has focussed on Atlantic hurricanes, but similar views have been expressed for typhoons also.

[5] with acknowledgements to IPCC WG II, in draft, for providing a convenient literature search.

While attention is drawn to the catastrophic events, attritional losses can also be expected to rise. A wide range of indicators of temperature and precipitation (known as Frich indices) are expected to become more extreme. Particular issues are heatwaves in northwest and northeast America, and regions adjoining the Mediterranean.

7. European Storm

Two studies are considered here, historical storms, and future climatology.

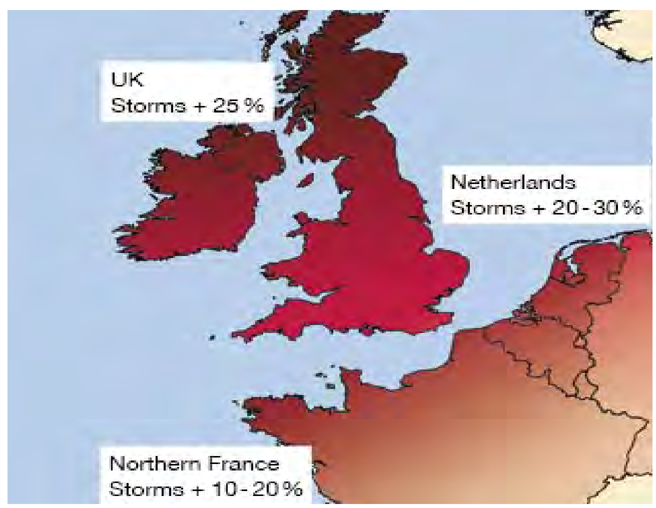
The author reported a striking correlation between winter temperature and the occurrence and strength of great European storms, using the CET as a proxy for temperature, and Lamb's record of great storms (Dlugolecki et al. 1994). This has been dismissed by some meteorologists as unscientific, since it relies on a subjective catalogue, rather than instrumental observations of storm strength. However, it is currently the only long time series, and the findings seem quite robust. Indded . Lamb himself did not notice this correlation, but did note that 1990 (which fell after his record formally ended) produced great storms, and that was a very warm winter indeed. Since then there was the great 1993 storm, probably the deepest European depression since records began, that destroyed the tanker Braer off Shetland, and the storms of 1999 and 2005. Therefore, it seems that this may be worthy of further investigation as a pointer to the future. (On the other hand, it has been argued that winter months are warm in terms of CET when the atmospheric flow is westerly, which is conducive to storms, rather than that warm temperatures cause storms ie the relationship may be correlation rather than causation).

Type of winter month	Storm frequency	Storm intensity
Warm	15%	2,568
Medium	7%	2,544
Cool	6%	1,075

Table 7.1 Great storms and winter temperatures
Temperatures from CET series, storms data from Lamb

WWF has recently carried out a scientific assessment of future storminess, with the results indicated in Figure 7.1. The map indicates that strong increases in storm frequency are expected by 2090 in NW Europe. Additionally, maximum windspeed could increase in the range 8 to 16%. The joint effect would be an increase of about 75% in storm costs, other things being equal, in a range 50% to 100% increase. If we then allow a margin for "saturation" effects eg lack of recovery capacity, the costs there could be well over 100% increase- making no allowance for economic growth in the meantime.

Figure 7.1 Late 21st century storm activity in Europe
Source "Stormy Europe" WWF 2006



8. Other Issues

Other property/casualty classes may be affected by shifts in extremes also e.g. business interruption, automobile, travel, but this author does not believe that the industry faces the prospect of a wave of climate-change –related liability claims.

Automobile In the USA, 16% of automobile accidents are attributed to adverse weather conditions as are one-third of the accidents in Canada. Vehicles also sustain insurance losses during natural disasters, amounting to $3.4 billion between 1996 and 2000 and averaging 10% of all disaster-related property losses. In some events, such as hailstorm, damage to automobiles can exceed 50% of total catastrophe losses (Mills, Roth and Lecomte, 2005). In Hurricane Katrina, one estimate reckoned that about half a million vehicles had been damaged, mainly by flood-water, with about half of them insured. The insured costs alone fell in the band $1.2 to 2.3 billion, or between three and four percent of the total insured losses (Towers Perrin, 2005). While this is normally a major loss, it was so dwarfed by the concurrent buildings damage that another estimate ignored automobile entirely (RMS, 2005).

In less severe climates, such as UK, automobile claims are correlated with meteorological conditions, with dry /warm weather seeing less accidents reported, and cold/wet being the opposite. The exception to this is that in very severe winters motorcycle claims diminish owing to their drivers' greater awareness of the dangerous conditions. However, the type of accidents also change, with many more minor "shunts" in icy conditions, so historically the UK is not exposed to major catastrophes in this class.

Agriculture another obvious impact area is agriculture, particularly crops, but the private market avoids this area, so it is hard to comment on trends.

Health/life The effects could extend into life and health and pensions also, albeit probably less strongly, for the private insurance industry isinceprivately insured people are wealthier than average and generally have better health and access to medical care. The latest estimate of excess deaths in the European heatwave of 2003 is around 50,000, but with minimal effect on insurance emarkets. Similarly, the 1300 deaths in Katrina had little effect on US insurers. In the USA there has been a major programme of research into climate change and human health. Five areas were examined: heat stress, extreme events, air pollution, water-borne/food-borne disease, and vector-borne/rodent-borne disease. Among the findings were that heavy precipitation is strongly linked to outbreaks of water-borne disease: 58% of outbreaks were preceded by a rainfall event in the top decile, and 68% of outbreaks by events in the top two deciles. Water contamination was also linked to extreme precipitation, but with a greater lag effect.

Insurance products have very low penetration in less developed countries, where the impacts of climate change are expected to be most acute, due to the greater vulnerability of those regions to extreme events. Consider Asia. Glaciers in the Himalaya are receding faster than in any other part of the world and many disappear by the year 2035, with catastrophic results for rivers in India, China, etc. Six mega cities in Asian deltaic regions will have population exceeding 10 millions by 2010. These deltas are shrinking due to sediment starvation eg the Changjiang sediment discharge will fall by 50% after construction of the Three-Gorges Dam. For a 1 m rise in sea level, half a million square hectares of Red river delta and up to 2 million square hectares of Mekong river delta is projected to be flooded. The deltas are also usually economically more developed. The GDP of the three metropolitans located in the Zhujiang delta, Changjiang delta and Huanghe delta will represent 80% of China's total GDP in 2050. The current rate of sea level rise in coastal areas of Asia is reported to be between 1 to 3 mm per year – marginally greater than the global average, and is accelerating gradually. Clearly, refugees from such regions would disrupt neighbouring regions also, besides placing a burden on global society.

8. Insurers will also be touched by climate change by government mitigation policy which will alter the economics of energy consumption, with effects on technologies offered for insurance, and on investment returns in a wide range of industries (beside being underwriters, insurers are also major investors, but that is beyond the remit of this paper.

9. The Right Null Hypothesis?

In the context of already evident rapid change in the climate, and the established high sensitivity of society to extreme weather, the question must be asked, whether it is right or prudent to take as the null hypothesis that damage is NOT increasing due to climate change rather than a Bayesian approach that damage should be increasing already. In the former case, it may be some time before "significant" deviations from past behaviour can be discerned, which could lead to delay in taking precautionary action. In the latter case, recent observations are surely "consistent with" a new trend toward higher weather-related damage caused by climate change.

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References

ABI (Association of British Insurers) Investing in social responsibility Association of British Insurers, London, September 2001 (author R Cowe).

ABI (Association of British Insurers) Risk returns and responsibility Association of British Insurers, London, February 2004 (author R Cowe).

ABI (Association of British Insurers) A changing climate for insurance, Association of British Insurers, London, June 2004 (author A Dlugolecki).

ABI (Association of British Insurers) Financial risks of climate change ABI, London 2005.

Christofides S, Pricing of catatrophe linked securities ASTIN 35th Annual Colloquium Bergen, 2004.

Dahlstrom K et al, Innovation, insurability and sustainable development; sharing risk management between insurers and the state Geneva Papers on Risk and Insurance 28 (3), July 2003.

Dlugolecki A et al, The impact of changing weather patterns on property insurance, Chartered Insurance Institute, London 1994.

Dlugolecki A et al, Climate change and insurance, Chartered Insurance Institute, London 2001.

Dlugolecki A and Keykhah M Climate change and the insurance sector: its role in adaptation and mitigation Greener Management International 39 (Autumn 2002).

Dlugolecki A and T Loster, "Climate Change and the Financial Services Sector" in Geneva Papers on Risk and Insurance 28.3 July 2003.

Dlugolecki A. (2004) A Changing Climate for Insurance Association of British Insurers, London, June 2004 24pp.

Dlugolecki A and Lafeld S, Climate change – agenda for action: the financial sector's perspective , Allianz Group and WWF, Munich 2005.

Dlugolecki, A. et al Financial services in T. Watson, M. Zinyowera, R. Moss and D. Dokken (eds) Climate Change 1995:Impacts, Adaptation, and Mitigation of Climate Change: Scientific-Technical Analysis, Cambridge University Press, for Intergovernmental Panel on Climate Change, Working Group II, Cambridge , UK 2001.

Emanuel K Increasing Destructiveness of Tropical Cyclones over the Past 30 Years, Nature 436 August 4 2005.

Epstein P and E Mills (ed) (2005) Climate Change Futures: Ecological, Health and Economic Dimensions The Center for Health and Global Environment, Harvard Medical School, Boston , November 2005, 142pp.

Few, R., M. Ahern, F. Matthies, S. Kovats (2004) Floods, health and climate change: a strategic review Working Paper No. 63, Tyndall Centre For Climate Change Research, November 2004 138pp.

Foresight, Future Flooding, Foresight Programme, Office of Science and Technology, HMSO, 2004.

Hadley Centre, Climate change observations and predictions: research on climate change science from the Hadley Centre, December 2003.

Hanson C, Palutikof J and Dlugolecki A, Bridging the gap between science and the stakeholder: the case of climate change research Climate Research forthcoming.

Lamb H Great Storms of Northwest Europe 1991.

Hartington T et al Catastrophe Modelling Working Party Report presented at Institute of Actuaries GIRO Conference 1997.

Hewitt R The economy of climate: consequences for underwriting in Topics 2003/2, Munich Re 2003.

Hickling M and Grace E How climate change is impacting financial services presented at the Institute of Actuaries of Australia 2004 Financial Services Forum July 2004.

King D, Climate change science: adapt, mitigate or ignore? Science 303 January 9, 2004.

Kovats S et al (2004) Heatwave of August 2003 in Europe: provisional estimates of the impact on mortality Kovats S et al, Eurosurveillance Weekly, 11 March 2004.

Kovats S, and A Haines (2005). Global climate change and health: recent findings and future steps. Canadian Medical Association Journal, 172 (4):501-502.

Mills, E et al US Insurance Industry Perspectives on Global Climate Lawrence Berkeley National Laboratory MS 90-4000, US Department of Energy, University of California, 2001).

Mills,E., Roth R. and Lecomte E.(2005) Availability and Affordability of Insurance Under Climate Change:A Growing Challenge for the U.S. Investor Network on Climate Risk, CERES Inc, Boston, December 2005, 50pp.

Munich Re 2006(1) Hurricanes – More intense, more frequent, more expensive: insurance in a time of changing risks Munich Re, Munich, 2006 44pp.

Munich Re 2006 (2) Annual review: natural catastrophes 2005 Munich Re, Munich, 2006 56 pp.

National Health Assessment Group (2001) Climate Change and Human Health , (NHAG), Johns Hopkins University, May 2001.

Orr J, Piniecka B and Choi S The overhaul of Lloyd's realistic disaster scenarios-2003 update Institute of Actuaries GIRO Conference 2003.

RMS (Risk Management Solutions) (2005) Hurricane Katrina: Profile of a Super Cat : Lessons and Implications for Catastrophe Risk Management Risk Management Solutions Inc., Newark, California October 2005.

Ross N et al European weather derivatives Second Report of Weather Derivatives Working Party, presented at Institute of Actuaries GIRO Conference 2002.

Swiss Re (2006) Annual review: Natural catastrophes 2005 Sigma2006/2 Swiss Re, Zurich 2006 40pp.

Towers Perrin (2005) Hurricane Katrina: Analysis of the Impact on the Insurance Industry Towers Perrin, Oct. 2005, 35pp.

Trenberth, K. (2005) Uncertainty in Hurricanes and Global Warming Science 308 17 June 2005 1753-54.

UNEPFI (United Nations Environment Programme Finance Initiative) (2002), Climate Change and the Financial Services Industry: Module 1 Threats and Opportunities. Module 2 A Blueprint for Action Climate Change Working Group, UNEP Finance Initiative, Geneva , Switzerland.

US Environment Protection Agency (2001) Climate Change and Human Health: the potential consequences of climate variability and change. US Environment Protection Agency, May 2001.

Vellinga P and Mills E, et al (2001) Insurance and other financial services ed. A Dlugolecki in J. McCarthy, O. Canziani, N. Leary, D. Dokken, K. White (eds) Climate Change 2001 : Impacts , Adaptation,and Vulnerability (Cambridge , UK:Cambridge University Press for Intergovernmental Panel on Climate Change Working Group II).

Webster P et al Changes in Tropical Cyclone Number, Duration and Intensity in a Warming Environment, Science 309, 16 September 2005.

World Health Organisation (2003) Climate change and human health: risks and responsibilities. World Health Organisation, 2003.

WWF (2006) Stormy Europe- the Power Sctor and Extreme Weather, WWF International, Berlin, 2006. See also Methodology and References Annex.

Annex 1 - ABI Climate-Related Claims

Year	Original values (£ million)			Constant values (2003 £ million)		
	Subsidence	Weather	Climate	Subsidence	Weather	Climate
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1988	91	605*	696*	157	1037*	1194*
1989	255	351	606	418	577	995
1990	506	2194	2700	784	3401	4185
1991	540	723	1263	772	1038	1810
1992	259	427	686	347	573	920
1993	134	566	700	172	727	899
1994	125	404	529	156	504	660
1995	326	373	699	398	455	853
1996	333	752	1085	393	891	1284
1997	472	656	1128	542	753	1295
1998	437	1030	1467	489	1153	1642
1999	364	885	1249	397	964	1361
2000	350	1377	1727	375	1467	1842
2001	265	945	1210	276	987	1263
2002	183	1285	1468	187	1312	1499
2003	390	621	1011	390	621	1011
1992-1997	1649	3178	4827	2008	3903	5911
1998-2003	1989	6143	8132	2114	6504	8618
Six-year increase	21%	93%	68%	5%	67%	46%

Table A.1 ABI climate-related claims costs

Notes to table A.1

*The 1988 figures have been calculated by estimating the cost of commercial weather claims, missing in the original data, from the ratio of such claims to domestic claims in other years.

1) motor and other non-property classes other than business interruption are excluded from these figures.

2) The constant value figures adjust for the effect of inflation, by scaling the figures using the government RPIX index of prices.

Table A.1 shows the total amount reported annually by ABI member companies in respect of weather-related (burst pipe, storm, flood) and subsidence claims for commercial and household property accounts, including the related business interruption figures for commercial business.

As can be seen, over the period 1998-2003, the claims for weather alone came to nearly £6.2 billion, which was an increase of 93% over the comparable six year period 1992-97, virtually double in original values. This is indicative of the underlying increase in “attritional” weather events, whereas most attention is caught by the spectacular events ie great storms or floods.

Preliminary Assessment of Future Costs

This section presents the current scale of insurance industry costs from climate-related incidents, based on ABI data, together with projections of the top-range potential costs under the UKCIP climate change scenarios. Table A.2 gives the historical data, in 2003 values, relating to claims paid by ABI member companies. They relate to the period from 1998 only, since figures split by cause are not available before then. In making the adjustments in the table as described in the footnotes, the author used quarterly data also (available back to 1991), and applied judgement based on extensive experience with insurance industry claims statistics.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Commercial of which flood	Business Interrup. of which flood	Domestic Pipes of which flood	Domestic Storm of which flood	Domestic Flood	Revised storm	Revised Flood
1998	286 188	32 21	239 0	457 317	139	249	665
1999	269 171	26 15	278 0	333 193	58	249	437*
2000	467 369	85 74	238 0	420 280	258	249	981
2001	178 80	14 3	354 102	278 138	163	249	486*
2002	270 172	27 16	420 168	479 339	117	249	812
2003	98 0	11 0	310 58	140 0	61	249	119*
Average						250	350

Table A.2 Base calculations of present-day weather claim costs (£million at 2003 values)

Column (1) Left-hand figures from ABI. Right-hand figure derived by assuming steady figure of around 2003 level is due to storm, nil for burst pipe claims, and that the residue is from flood.

Column (2) Same procedure as for column (1).

Column (3) Left-hand figure from ABI. Right-hand figure derived by assuming the true cause of these claims is mainly burst pipes (non-weather or frost) rather than flood and that this applied to all claims in 1998,1999, and 2000. This is based on the author's experience, and the remarkable stability of the quarterly loss figures for those years, all lying in the range £48m to £62m, apart from Q3 1999 at £79m, The average amount in these years came to £252 million, and this is subtracted from the left-hand figures for 2001-03 to derive hidden flood claims in those years.

Column (4) Left-hand figure from ABI. Right-hand figure by assuming 2003 figure was entirely storm, in the absence of any major events, applying the same correction to previous years.

Column (5) From ABI, with no adjustment.

Column (6) This is the sum of the residual amounts from columns (1), (2), and (4) after removing the amounts assumed to be flood. Effectively, it assumes that the 2003 figures in those columns were entirely due to storm, since 2003 was a very dry year, and that those figures were typical of earlier years, in the absence of any major reported incidents.

Column (7) Column (5) plus flood allocations in Columns (1)-(4). Since the years 1998, 2000, and 2002 were affected by major flood incidents, the cost of a "typical" year is taken buy averaging the values for 1999, 2001 and 2003, marked *.

Subsidence

Current levels

Subsidence claims have been fairly static in recent years, with a running 5-year total of around £1.6bn, or about £300m per year. The peak years were 1990 and 1991, with over £750m each in 2003 values (see Figure 3.2), but since then the worst year has been 1997 at £542m, suggesting that the current peak may lie around £600m.

Future levels

An unpublished study by a leading scientific agency for ABI derived a relationship between meteorological conditions and claims costs historically, based on insurance company data. The study then considered the implications of future climate scenarios up to the 2080s. The findings suggested a doubling of cost, i.e. £3.2bn over five years, or £600m per year. The peak might be £1.2bn in a year (double the average cost). This is less than twice the cost of the peak years 1990 and 1991. Although the general tendency is for climate change to exacerbate the peak costs, this is unlikely for subsidence, because wetter winters will prevent lengthy droughts like that in 1990/91. This is true even for the south-east with its drought-sensitive clay soils, where the above-average trend towards drier summers, could be largely offset by a contrary trend towards wetter winters.

Storm

Current levels

From above the background level is around £250m per year currently, since there were no major storms in the period 1998-2003. The cost of a major storm is around £1,500m on the basis of the 1987 storm and industry data on the individual 1990 events. Allowing for a return period of ten years, this would generate a further allowance of £150m per year for major storms, giving £400m annually for storm risk currently (background and major elements combined).

An extreme year in the UK might be seen as around £2,500m currently, taking 1990 as a base. The total weather cost in 1990 was 3,400M, while the average annual cost during the period 1988-2003 ran at 990m. Subtracting the "average" gives 3,400-990 = 2,410, or £2,500m rounded up. Note that this is considerably less than the 100-year storm estimate of £10bn in Table 5.1 from Swiss Re for UK. This is due primarily to the fact that we are looking at a shorter return period, of roughly ten years.

Future levels

Going by the UKCIP outlook, we should allow +50% for frequency in the more populated regions of UK. At the same time, it seems that there could be a 6% increase in wind strength. Figure A.1 shows a clear non-linear relationship between windspeed and damage, with a gearing of approximately 1:5 i.e. a 6% increase in windspeed would produce a 30% rise in damage. The compound effect on claims costs of the increases in frequency and windspeed are 1.5x1.3=1.95 i.e. about double. Therefore the future annual smoothed cost could be 2x£400m=£800m pa.

The peak loss in future might be equivalent to three major storms in one year. There were four major storms inside four weeks in northwest Europe in 1990, and three within three weeks in 1999. Since we are anticipating a general increase in winter depressions frequency of 50%, a figure of three in a severe year may even be on the low side. The cost of a major storm could rise by perhaps 30% due to faster windspeeds (as explained above). Additionally, future storms will be wetter, (on the basis that by 2050 winters will be about 15% wetter, with more intensive events), and so cause more damage, particularly in a multiple-event scenario, where damage cannot be repaired before the next storm arrives. Based on the author's unpublished analyses of company claims data, an allowance of 30% for these elements is required. This gives a peak year cost of £7.6bn=£1.5bnx3x1.3x1.3, or £7.5bn rounded.

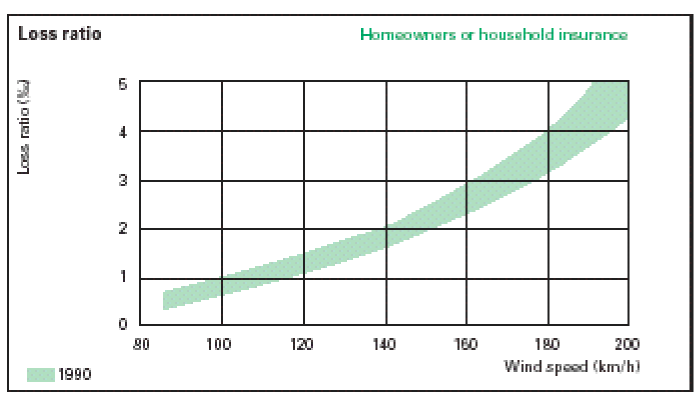


Figure A.1 Great Britain Household Insurance: damage versus windspeed, 1990 storms [Source Munich Re: Winter storms in Europe (II), 2002]

Inland Flood

Current levels

The background level for flood claims including commercial lies at around £350m per year. High years cost about £800m (i.e. an additional cost of £450m), so allowing for one every five years gives an additional £90m pa. This amounts to about £350m+£90m=£440m pa, or £400m rounded.

A recent ABI study of flood potential provided an estimate of about £1,500m as the likely worst case exposure. This compares closely with the estimate of £1,700m given by Swiss Re for a 100-year flood event.

Future levels

The Foresight study provides a very wide range, depending on the climate change scenario and response strategies. If responses are implemented, the range is much narrower, with a topside of double today's costs. Therefore, even with a substantial amount of action on flood risk management, the background level of flooding would rise from £400m to £800m.

Peak cost could be three times the current level. This reflects the trend towards heavier and more intense rainfall patterns (conservatively a doubling effect- Huntingford, 2003 estimates that return periods for extreme monthly rainfall could reduce by a factor of between four and seven times by late 21st century), and also the nonlinear nature of the damage response curve, whereby higher flood levels and longer flood durations produce disproportionate increases in damage (roughly a 50% effect). This gives an extreme-year cost of 3x£1.5bn = £4.5bn in a year.

Coastal flood

Current levels

Coastal flood is negligible in terms of insurance claims currently, largely thanks to the high quality of defences. The last significant incursion was in February 1990 at Towyn in North Wales, and cost under £100M.Therefore the background level has been set at nil. Since the Thames Barrier defence complex currently provides a very high level of security for London, the extreme cost would occur elsewhere e.g. East Anglia, and informal industry estimates indicate a potential value for such an event of around £5bn.

Future levels

For background levels, it is assumed that the Foresight recommendations are adopted, so that the risk of coastal flooding continues to be well-managed, with an absence of any significant incursions, and an annual cost of nil.

For the peak cost, it is assumed that the Thames Barrier defence complex fails, and that the event is compounded by other factors, for example up-river flooding due to heavy winter rains, and generally stormy conditions affecting the efficiency of the recovery process. Based on information from the Environment Agency, the London Climate Change Partnership puts £80bn assets at risk, and £30bn estimated economic loss from a major flood. Perhaps two-thirds of this would be insured because much of the infrastructure damage and business interruption costs would not be covered due to public policy and customer choice, giving a current exposure of £20bn insured damage. Allowing for the greater depth of water in future, and the compounding effect, an increased of two to four times can be envisaged, resulting in a cost of, conservatively, £40bn.

All the above estimates ignore the effects of socio-economic changes, such as the location and value of assets, and any substantial changes in Government policy.

Annex 2 Floods in Perth, Scotland

The UK has been hit almost annually since the early 1990's by severe local floods. The first significant one of these occurred in 1993 in Central Scotland, at the town of Perth, where the author lived and worked for the international insurer, General Accident, which had its world headquarters there. In January 1993, 45 cm equivalent rain fell in 18 days, but the effect was made worse by the accumulation of snow which then rapidly thawed (see Table below). 42 square kilometres were flooded and the total cost to insurers was £125 million, a very substantial figure considering that the town had only 40,000 inhabitants.

January 1993	Weather	Temperature (^oC)	Comments
11th	Gales, snow	1	Blizzard, roads cut
12t h	Gales, snow	2	Food runs out
13th	Snow showers	2	Rescue convoys
14th	Heavy rain	5	Local floods
15th	Thaw, rain	5	Head waters flood
16th	Heavy rain	7	Rivers rise
17th	Showers	4	Record flow on

Table A.3 Chronology of the Perth 1993 flood

The situation was extraordinary, because initially the problem was a surfeit of snow which resulted in Perth being cut off by road, rail and air. The Army was called out to attempt to break through with emergency supplies, either by special vehicles, or by helicopter if the weather cleared. Just as this started, a fast thaw arrived, with continuous rain. Soon the River Tay began to rise, reaching record flows on 17th January, and bursting through the flood defences in several places. Hundreds were evacuated, and some remained in temporary accommodation for nine months. Many of the losses were borne by insurers, though often under-insurance complicated matters.

The area was known as a flood hazard (as far back as 1210, when King William the Lion had to escape by boat from Perth Castle, which was built of wood and was destroyed utterly, and never rebuilt). The local flood defences were constructed in 1974 to a standard that could cope with any "normal" flood of the previous 200 years ie up to about 6.2 metres. (There had been one in 1814 which was 7 metres, but that was due to ice-blockages). The town deliberately permitted a major housing development in this floodplain, believing that the wall made it safe. In fact the 1993 flood reached 6.5 metres, and the wall broke, resulting in 1500 houses being flooded. This flood came on top of previous storms, so there were many other claims from houses which were not flooded, due to power cuts causing food spoilage, and also for damage to property stored at low-lying golf-courses.

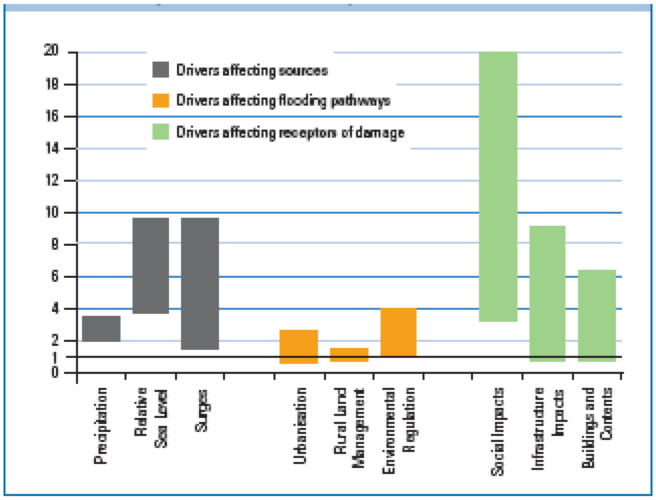
Following the incident, insurers continued to provide flood cover to former clients, but naturally they adjusted their premium levels and deductibles. A key factor in this was the intentions of the public authorities. Perth was fortunate, in that it was the first major flood in Scotland for many years, and attracted great sympathy and political support for new defences. As a result, magnificent new flood defences including holding tanks, were commissioned and completed in 2001. However, that did not solve all the problems.

In 2002, wet weather in the spring filled the holding tanks. Unfortunately, a severe thunderstorm latched on to the town in July, and the ensuing cloudburst could not be contained. Localised flooding ensued, exacerbated by the flood walls. For the first time in its 100-year history, the two-day Perth Agricultural Show had to be cancelled and the central park was closed to visitors for the entire summer due to health fears from sewage. The Show had a lucky escape in 2004, when just after it ended torrential rain fell for three days from a decaying hurricane, causing the cancellation of the Perth Highland Games for the second time in three years.

The floods of 1993 and 2002 are both events that are typical of climate change: a prolonged wet winter period with rapid thawing, and a violent summer thunderstorm. The 2004 flood was maybe bad luck- we do not know yet.

Foresight evaluated the influence of 19 drivers on future flood risk for each of the four future scenarios (see Figure A2).

Figure A2 How key drivers might affect UK flood risk by the 2080's.
(Source Foresight Programme, bars represent range of possibilities dependent on scenarios)



- Climate change – has a high impact in every scenario. Risks at the coast will be particularly affected: relative sea-level rise could increase the risk of coastal flooding by 4 to 10 times. Precipitation will increase risks across the country by 2 to 4 times, although specific locations could experience changes well outside of this range.
- Urbanisation – particularly in flood-prone areas, could increase rainwater runoff, increasing flooding risk by up to times. At the same time, new developments and weak planning controls on the types, densities and numbers of new buildings could also increase risk.
- Environmental regulations – could be risk-neutral or could affect flood pathways by constraining maintenance and flood-risk management along rivers, estuaries and coasts, thereby raising risk. This argues for an integrated approach to decisions on flood management and environmental regulation in order to achieve multiple benefits for people and nature.
- Rural land management – a recent major study showed that there is substantial evidence that current land-management practices have led to increased surface runoff at the local scale. However, there is a general absence or uncertainty of evidence of the impacts at the catchment scale, or how small-scale impacts combine at larger scales.
- Increasing national wealth – will increase the value of the buildings and assets at risk and is therefore a strong driver of economic impacts. However, increases in flood damage as a proportion of national wealth will be much smaller and may even reduce in certain scenarios (see next Figure).
- Social impacts – these are difficult to quantify, but the analysis showed a large increase in social risks in all scenarios, by 3 to 20 times. Unless these risks are managed, significant sections of the population could be blighted. Many of the drivers that could have the most impact are also the most uncertain. Some of this uncertainty relates to scientific understanding – for example, uncertainties in how to model the climate. However, other sources of uncertainty are inescapable – such as the extent to which the international community will succeed in reducing greenhouse-gas emissions. It is therefore important to develop policies that can cope with a wide range of possible futures, and which can respond flexibly to an evolving world.

Figure A3 UK annual flood costs as a percentage of UK GDP in 2080's
(Source –Foresight Programme)

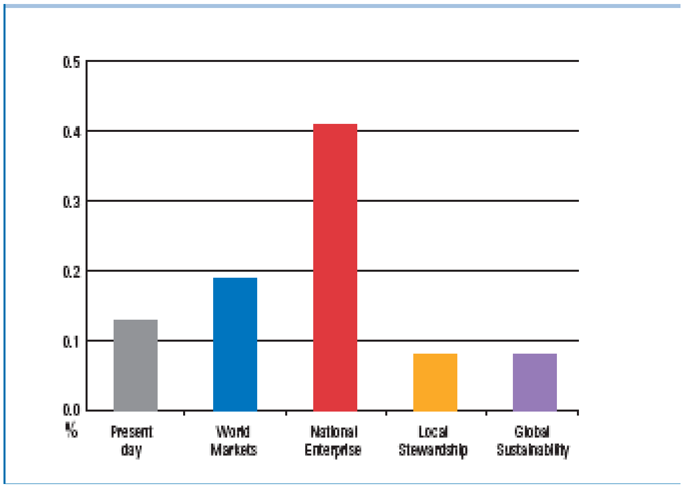


Figure A3 shows that whereas the future costs in monetary terms are many times greater than current levels, to a large extent this is explicable by socio-economic factors, because when the costs are normalised against future GDP, the impact varies from about two to four times current level under the World Market and National Enterprise scenarios, to a decrease under the more sustainable scenarios. However, the analysis did not incorporate the findings of recent events like the New Orleans flooding of 2005, when the severity of the event caused the costs to soar well above accustomed levels, and to extend far more widely than before. It may be expected that particularly for the two "growth" scenarios, Figure A3 underestimates the costs by a substantial factor.

Climate Change and Storms: The Role of Deep Ocean Warming

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Summary

Storms are increasing in severity and in associated economic damages, at a time when climate is changing. The logarithmic rise in economic losses from the 1980s to the 1990s, and again a half log in 2004/2005 cannot be explained alone by social factors, including population shifts, rising real estate prices and greater insurance penetration. Moreover, the increases in multiple types of extreme weather events, major outliers, correlated events related to climatic factors, and the diminished return times and recovery periods between events all indicate that climate change is playing a mounting role in driving up insured and uninsured losses from catastrophic weather. The underlying scientific finding that helps to explain the unexpected pace and magnitude of climate change and its impacts is that the oceans have warmed 22 times more than has the atmosphere over the past half century.

Methodology for Assessing Global Change

Studying whole systems requires integrative approaches. While these forms of analyses are not applied in this work, they are presented as concepts that may prove useful for future collaborative assessments of climate-related events. As climate changes, the distribution of events and extremes may continue to change over time; with the spread of tails in both directions (i.e. anomalies greater than one or two standard deviations from the mean. Assessment of changes occurring in multiple arenas – events, impacts and costs -- requires following emerging patterns and trends, and agreement between data and models ("fingerprint studies"), which are related by way of plausible mechanisms. Bayesian thinking (using prior probabilities derived by composite assessments and meta-analyses) can also improve the generation of plausible scenarios and improve predictive capability.

In addition, multilevel analysis/modeling is a new tool derived from the field of epidemiology (see Galea and Ahern 2006). This methodology can aid in assessing trends that span multiple fields with multiple types of events, and those occurring in multiple arenas and along multiple dimensions.

Multilevel analysis and modeling is a methodology that extends regression analysis for individual data sets, and can be used to analyze processes and events operating on multiple levels and in multiple settings. In studying climate-related events, multilevel modeling enables one to consider the full import and combined impacts of observations; in particular, those indicating increased frequency of anomalies of multiple types, involving multiple data sets; e.g. hurricanes, winter windstorms, heat waves, droughts and floods.

Multilevel analysis also affords a framework in which to develop new indices, such as 1. sequences of extremes, 2. the short lapse times, 3. the concurrence of severe events occurring across the globe, and 4. the wide swings from one extreme to another (e.g. heavy downpours) – in which the first event (e.g. intense drought and soil drying) can create more vulnerable conditions to the full impacts (flooding) of the second event.

Assessing Systemic Stability: As anomalies and major outlier events may also be seen as "strange attractors," in system theory parlance, an assessment of events occurring in multiple realms also offers a way of examining systemic stability. The new indices to assess the full sweep of impacts can also be helpful in assessing systemic and sensitivity to an abrupt change or thresholds or "tipping points" (NAS 2002; Epstein and McCarthy 2004; Walker 2006). Such indices can include rates of change, volatility, anomalies and outliers, and, in addition to these first derivatives, second derivatives, such as changes in rates of change, and changes in the rates of anomalies and major outliers.

Storm Destructiveness and Deep Ocean Warming

Storm intensity has increased significantly since the 1980s and economic damages from storms have also escalated. Increases in coastal populations, rising real estate values and greater insurance penetration have all played significant roles; *along with* more and more intense storms and anomalies of multiple types. Recent research finds a strong association between the increasing severity of storms and warming of the oceans (Emanuel 2005; Webster et al. 2005; Hoyos et al. 2006). Emanuel points to the increase in SSTs *and* in the deep ocean to explain the increase in storm destructiveness (a function of peak winds and storm duration); Webster et al. found that category 4 and 5 storms had nearly doubled since 1950 as ocean temperatures warmed; while Hoyos et al. (2006) reached the conclusion that increased ocean temperatures far outweighed all other factors in explaining the observed increased intensity of storms.

Reinforcing these findings, Sriver and Huber (2006) found that tropical SSTs are regulating the integrated intensity of tropical cyclones, and the findings of these studies were again reinforced by Robert Scott, a University of Texas oceanographer, and Steven Lambert of Canada's Meteorological Service, addressing the 40th annual Canadian Meteorological and Oceanographic Society (CMOS) congress in Toronto in June 2006. Scott demonstrated that the area that spawns hurricanes has grown dramatically in recent years; since 1970 the eastern side of the Atlantic, near the coast of Africa, has become warmer, topping the 26.5ºC temperature threshold for hurricanes to form, and hurricanes have been getting started an average of 500 Km further east since 1970, thus spending more time over warmer water.

In addition, novel events are occurring in places that have not, in the historical records since the 1870s, previously experienced hurricanes (and consequently have no insurance to buffer the risks). A hurricane appeared in the Southern Hemisphere in 2004, forming off the NE of Brazil, and, in 2005, hurricanes hit Spain and Morocco. In addition, Atlantic winter windstorms are penetrating deep into Europe. In 1999 Lothar (26 Dec) and Martin (28 Dec) windstorms did extensive damage to France's forests and reached Zurich (RMS 2002), while in January, 2005 windstorm Erwin felled a year's worth of harvests in southern Sweden. The European summer heat wave of 2003 was six standard deviations from the norm; and Stott et al. (2004) concluded that global warming has increased the probability of such an event two to three fold. That event killed 21-35,000 people, spread wildfires, damaged crops, killed livestock, shut down hydroelectric power, led to nuclear plant shutdowns (due to warming water) and melted 10% of the Alpine glacial mass (that had been losing about 0.7%/yr previously (Epstein and Mills 2005).

Climate change has profound implications for all industries, including public utilities, timber, automotive, electrical appliances, energy sector infrastructure; and for finance (insurers, banks, pension and mutual fund managers, raters and brokers). The financial sector, given its broad portfolio and sensitivity to risk, is especially aware of emerging trends (CROBriefing 2006).

Leading reinsurers have asserted that a third year of losses on the level of those in 2004 and 2005 could bankrupt many insurance companies. And all four hurricane prediction centers – NOAA's National Hurricane Center (NHC); the Tropical Storm Risk (TSR, Benfield, London); Accurate Environmental Forecasting (AEF); and Colorado State University (Wm. Gray) -- are predicting a severe fall storm season.

Weather is a function of natural variability and climate change; as well as deep ocean warming-driven changes in natural cycles, such as the El Niño/Southern Oscillation (ENSO), the monsoons, the North Atlantic Oscillation, etc. Long-term natural cycles appear to be aligned. There is 1. the 20-30 year Pacific Decadal Oscillation, which may have shifted to a cool phase around 1998; 2. possibly a warm Atlantic Multidecadal Oscillation that began about 1995 [Note: the existence of this oscillation vs. long term warming and salinization (Curry et al. 2003) of the tropical Atlantic is questionable (Emanuel and Mann 2006)]; and 3. the current ENSO-neutral conditions (June 2006); mean relatively reduced strength of westerlies and increased the force of easterlies. All these factors – some of which may have been influenced by climate change and deep ocean warming -- are lined up to compound the influence of the baseline shift created by the deep ocean warming and warming (and increasing salinity -- due to greater evaporation) of the tropical Atlantic and Caribbean sea surfaces; all leading to projections of a high number of intense storms in the fall of 2006.

The studies of Emanuel (2005) and Webster et al. (2005) demonstrate that hurricanes have increased in intensity and destructiveness in the past three decades. And absent from these analyses are measurements of hurricane breadth and moisture content; and lapse times, sequences and recovery periods. Thus, they may be underestimates of the true destructiveness of storms and the vulnerability inflicted by sequential storms. The assessments of the increasing Accumulated Cyclone Energy (ACE) Index used by the three Cat Modeling Groups -- Risk Management Services (RMS), AIR World Corporation (AIR) and EQECAT – are consistent with these studies.

The underlying reason for the miscalculations of the past two seasons can most probably be traced to the warming of the deep ocean. This warming was first reported by Parrilla and colleagues (1994) and Bindoff and McDougall 1994). But these initial transect measurements were confirmed by Sydney Levitus and colleagues of NOAA in 2000 and reinforced by Tim Barnett and colleagues of Scripps in 2005. Levitus et al. (2000; 2005) found that all the world's oceans were heating down to great depths and they concluded in 2005 that the deep ocean is holding 22 times the heat that has built up in the atmosphere. Barnett et al. (2005) – previously quite skeptical about global warming (as was Kerry Emanuel before his latest work) -- found that the pattern of the deep ocean warming is unmistakably attributable to the buildup of greenhouse gases.

That the oceans are the repository for the past century's global warming helps explain the acceleration of the world hydrological cycle. With deep ocean warming comes greater evaporation and atmospheric water vapor levels (Trenberth and Karl 2003). In the US, precipitation levels increased 7% from 1902-2002; while precipitation events greater than 50 mm (or above the 95th percentile) have increased 14%, and events over 10 cm (or above the 99th percentile) have increased 20% (Groisman et al. 2004). And deep ocean warming, together with the disproportionate atmospheric warming in the Arctic (ACIA 2004), help explain the unexpected acceleration of Greenland ice melt; with some outlet glaciers moving at 14 Km a year that were moving at half that speed in 2001 (Rignot and Kanagaratnam 2006).

It is the deep ocean warming that helps explain the sequences of extremes we are experiencing, such as the Katrina, Rita and Wilma, and the 28 named storms, including 15 hurricanes in 2004 and 2005 (see Kerr 2005a; see Figure 2). Warm water at depths replaces that which evaporates to fuel the first storms to fuel the subsequent ones. Modelers (Tom Knutson, Munich Re workshop) found that storm intensity is 5 to 7 times what they projected it to be in 2006. The magnitude of changes we are observing were previously projected to occur around 2080.

The North Atlantic

In terms of the North Atlantic, itself, the changes are altering the circulation, the gradients, thus windspeeds, and the locations of hurricanes. Greenland Ice melt and rain falling at high latitudes are leaving warmer, *saltier* tropical seas; and creating *freshwater* films in the region around Iceland (Curry and Mauritzen 2005). Cold, salty water is heavy and dense and sinks; the downward flow creating a pulley system that draws up the Gulf Stream – and drive the worlds ocean "conveyor belt" (thermohaline circulation) that stabilizes the global climate over millennia.

With freshwater, the sinking has slowed. By the most recent calculation, the overflow has slowed some 30% in the past several decades (Bryden et al. 2005). This again was a projection for the magnitude of change we might expect occur in 2080.

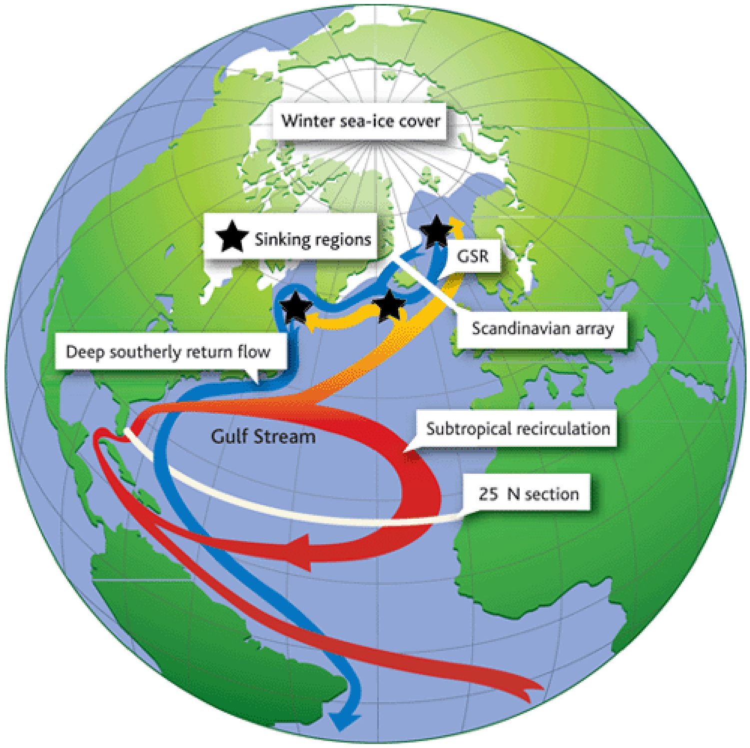


Figure 1. Based on Bryden et al. 2005, the overturning of the thermohaline circulation may have declined some 30% since the late 1950s. In tandem, the Atlantic surface circulation – in red – appears to be speeding up; changes that may be contributing to the increase in hurricanes hitting the US, European heat waves (due to decreased evaporation from the northern North Atlantic), strong European windstorms, and hurricanes hitting the west coast of Africa. (Kerr 2005b)

As you can see from the above diagram, this slowed sinking up north has also sped up the surface circulation – the large gyre of red one sees in the middle of the Atlantic. This may help explain the rapid trajectory of hurricanes hitting the US; the windstorms penetrating deeper than ever into Europe; and the hurricanes forming in Eastern Atlantic down to the Canary Islands and Morocco; and that in the Southern Ocean hitting Brazil in 2004.

Sea Level Rise Projections

As surface melt water flows through crevasses, it is lubricating the base of the Greenland glaciers (Bindschadler 2005). Greenland glaciers are moving in jolts or glacial earthquakes at rates twice what they were just five years ago; and perhaps six times more than they were in 1993 (Ekstrom et al. 2006). In Antarctica, as floating ice shelves attached to the West Antarctic Ice sheet (WAIS) disintegrate, they eliminate back pressure on land-based ice sheets in the WAIS – and they too are accelerating their movement toward the sea.

The acceleration of ice melt puts in doubt all linear projections for sea level rise over this coming century, as depicted in the IPCC 2001 report (Houghton et al. 2001). While no–one is projecting complete collapse of the Greenland ice sheet (which would raise sea levels 20 meters) or collapse of the WAIS (another 20 meters) any time soon, we can project that pieces of each could be discharged; changing sea levels by multiple centimeters over short periods of time; and increasing, in a non-linear fashion, the storm surges associated with storms.

Implications for the Insurance Sector

For the insurance sector the hardest message to digest is that imagining the unmanageable is no longer unimaginable. Escalating costs from recurrent years of storms and extremes – with rapidly diminishing return times between events – could render all nations vulnerable to climate change (Mills 2005). There is every indication that climate processes are less coherent and that the system itself is becoming increasingly unstable, with events less predictable, and more destructive. To improve projections we must integrate historical, statistical models with dynamic models to assess current and near-future conditions.

The financial sector may be viewed as the central nervous system of the global economy and it experiencing the pain. Loses from catastrophes (primarily weather-related) rose from $4 billion a year up through the 1980s to $40 billion/year in the 1990s; then to $125 billion in 2004 and $225 billion in 2005. In addition to these step-wise changes in overall losses, the *insured* losses rose from 10% to 30%; thus from $400 million/yr in the 1980s to $83 billion in 2005 – a rise of 200% -- as more extremes since 2000 are hitting Europe, the US and Japan. (See Figures 3 and 4.) The vast majority of the $83 billion insured losses in 2005 are attributable to the changes in the North Atlantic; and these changes are directly attributable to climate change.

In addition, there are long-term biological damages of the events of 2005 that may lead to "long tails" in insured losses. These include mold and an oil spill the size of the Exxon Valdez of 1989 (11 million gallons) in and around New Orleans. The profound warming of the Caribbean in 2005 also led to extensive coral bleaching, compounded by a coral disease (white plague), with implications for fisheries, livelihoods, shore lines buffering, hotels, travel and tourism. Such impacts have not yet entered into the loss calculations for 2005; and they increase the vulnerabilities to future severe weather (McCarthy et al. 2001). Moreover, a new body of work is developing to analyze the potential for non-linear changes in *impacts*; as examples, forest pest infestations and massive diebacks and fires; collapse of coral reefs; loss of wetlands from accelerated sea level rise (Burkett et al. 2005; Epstein and Mills 2005).

Optimizing Adaptation and Mitigation

Regarding adaptation and mitigation, distributed forms of clean energy generation can increase adaptation as well as drive markets for technologies to mitigate reduce greenhouse gas emissions and ultimately mitigate climate change.

Specifically, distributed generation (DG) with clean and renewable energy systems can increase adaptive capacity and resilience by:

- Feeding into the grid, where available
- Increasing energy security in the face of storms, heatwaves, blackouts
- In developing nations, provide energy sources for:
    - Small enterprises
    - Light for schooling and studying
    - Cooking (thus reducing wood extraction and deforestation)
    - Purifying and pumping water for agriculture (nutrition) and public health (washing, drinking, cooking, bathing).

These measures can also:

- Provide market pull for clean technologies
- Help begin businesses that will forward climate mitigation and stabilization, primary prevention and risk reduction.

Thus, DG clean energy systems can improve energy security, public health and nutrition, and help drive economic growth and poverty alleviation – all of which will decrease vulnerability to climate change. These systems can optimize climate adaptation and mitigation.

Conclusion

Looking across the spectrum of multiple levels and multiple events it is possible to conclude that the recent period is extremely anomalous. Given the plausible explanation -- the deep ocean integrator and repository for the warming of the last century – we may look back at 2004/2005 as having entered a new climate regime. A full assessment suggests that the pace and magnitude of climate change quickened and that the system has become non-linear, with exponential and even step-wise changes occurring in the destructiveness of extreme weather events (Hansen 2005; Hansen et al. 2005).

We have exited the "Holocene" or recent climate and have entered a new era: the "Anthropocene." The most hopeful scenario is that systems do seek new equilibriums. If the conveyor belt does shut down in the coming decades, the full potential impacts of such a shutdown -- a return to an ice age – may be moderated by the degree of global warming and the lack of large ice sheets at present. (We have been going between large and medium size caps for 650,000 years and probably two million, according to ice core records.) If the climate does re-stabilize into a state that affords a modicum of predictability, this may give us a "cooling off " period in which to radically change our energy diet. (This is my own speculative scenario; though shared quietly by several prominent scientists, who are cautious about issuing a hopeful, new equilibrium scenario.)

Risk management and risk transfer must be complemented with primary prevention and risk reduction.

The good news is the enormous opportunities for investments in hybrid and smart technologies, solar, wind, tidal, geothermal, combined cycle energy systems, urban reformation and ecological restoration. These are the businesses of tomorrow and the financial sector, having first sensed the pain, has a special role to play in working with scientists, civil society and UN organizations to develop the national and international policies to enable the transition. Strong policy signals will be needed to facilitate these solutions – new rules, bold incentives and removal of "perverse" subsidies for oil and coal.

Examining the full life cycle of solutions – for public health, safety, environmental and economic costs can help guide investment in and insure "no-regrets" measures, including energy efficiency, smart technologies, geothermal, solar, reforestation, and differentiate those from the ones that need further study (fossil-fuel-based and nuclear). (See figure 5 based on "wedge concept of Pacala and Socolow 2004.)

The climate and energy crises – energy security, conflicts over oil, peaking of supplies and climate instability -- are converging to create a confluent agenda to alter the international financial architecture and enable private industry to flourish with new incentives as well as new constraints. And the clean energy transition becomes the first and necessary step toward greater governance and rearrangement of financial incentives to drive sustainable development, *writ large*, including forestry, farming and fisheries?

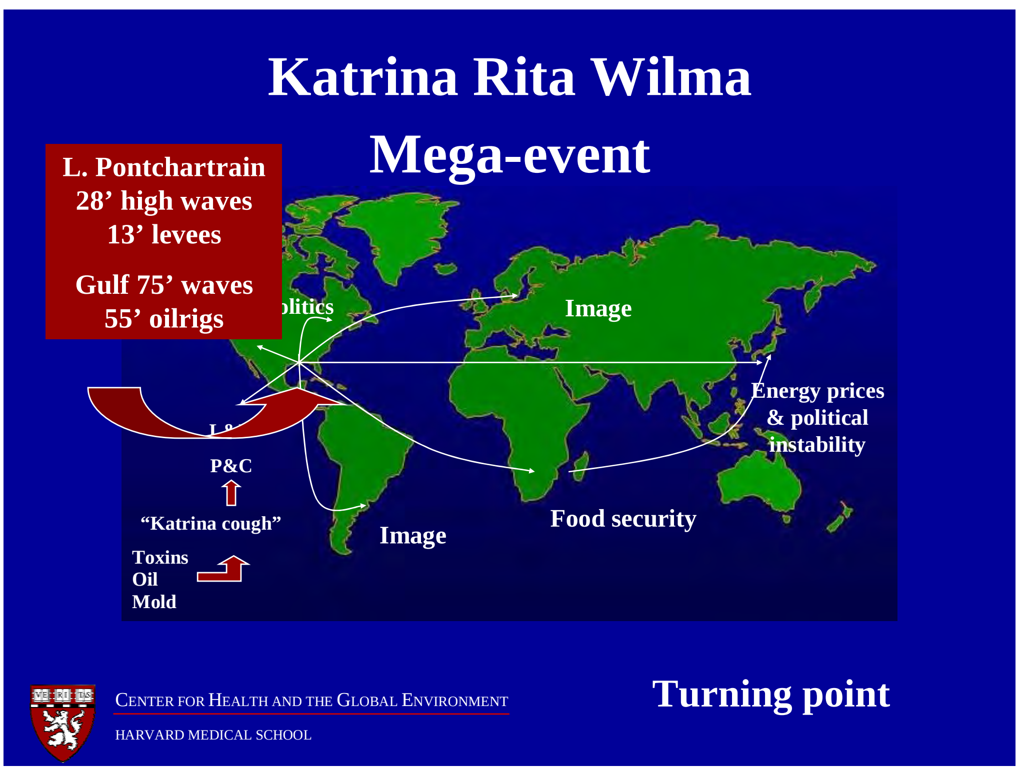


Figure 2. The cascading consequences of Katrina

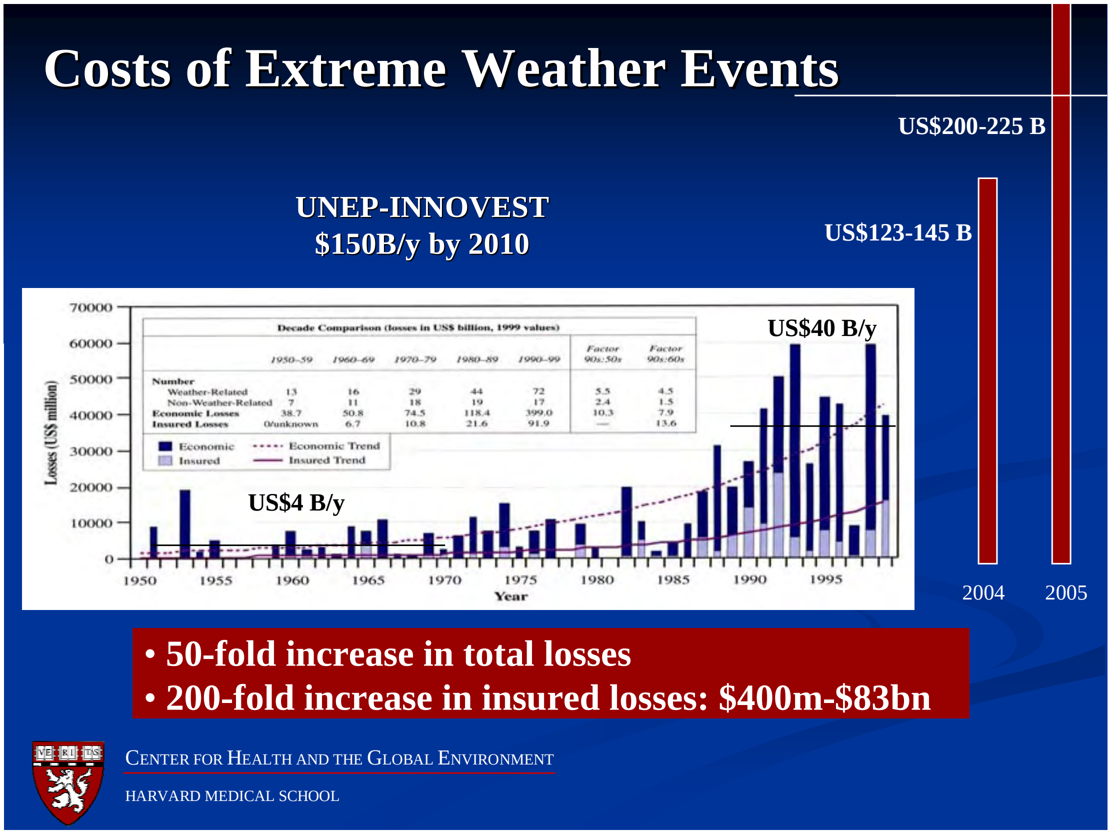


Figure 3. Calculating the costs of natural catastrophes

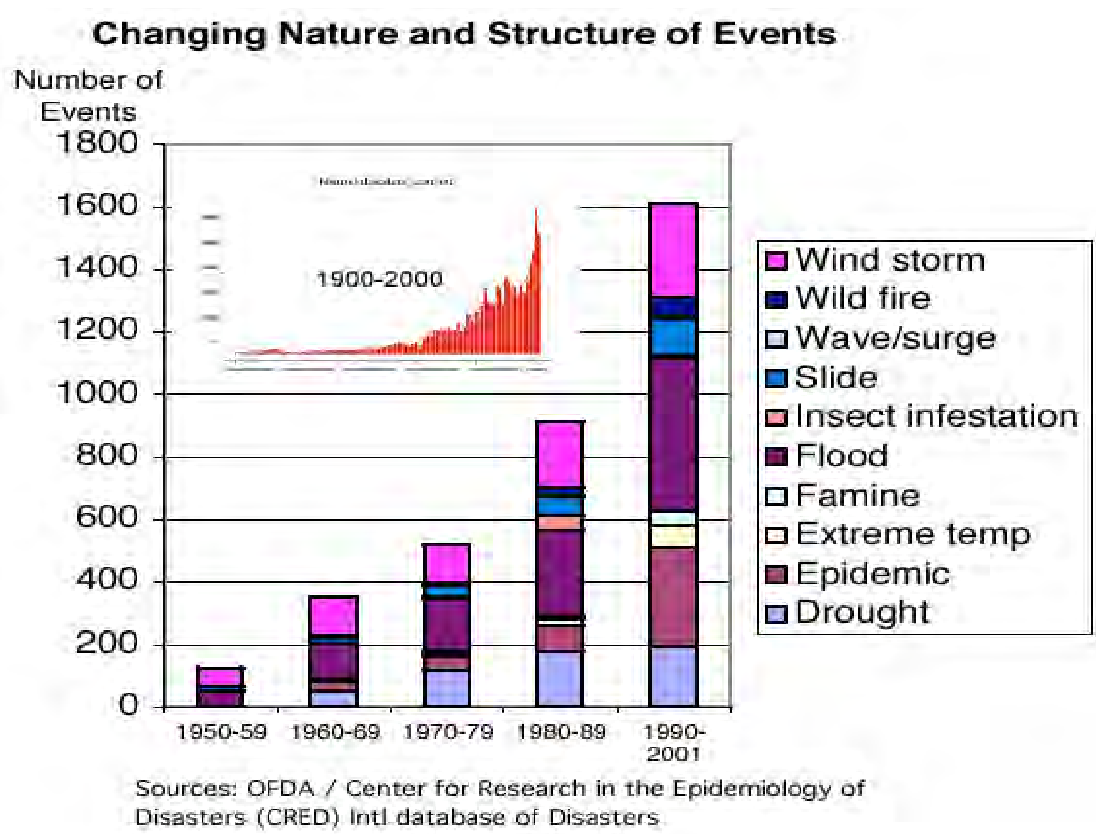
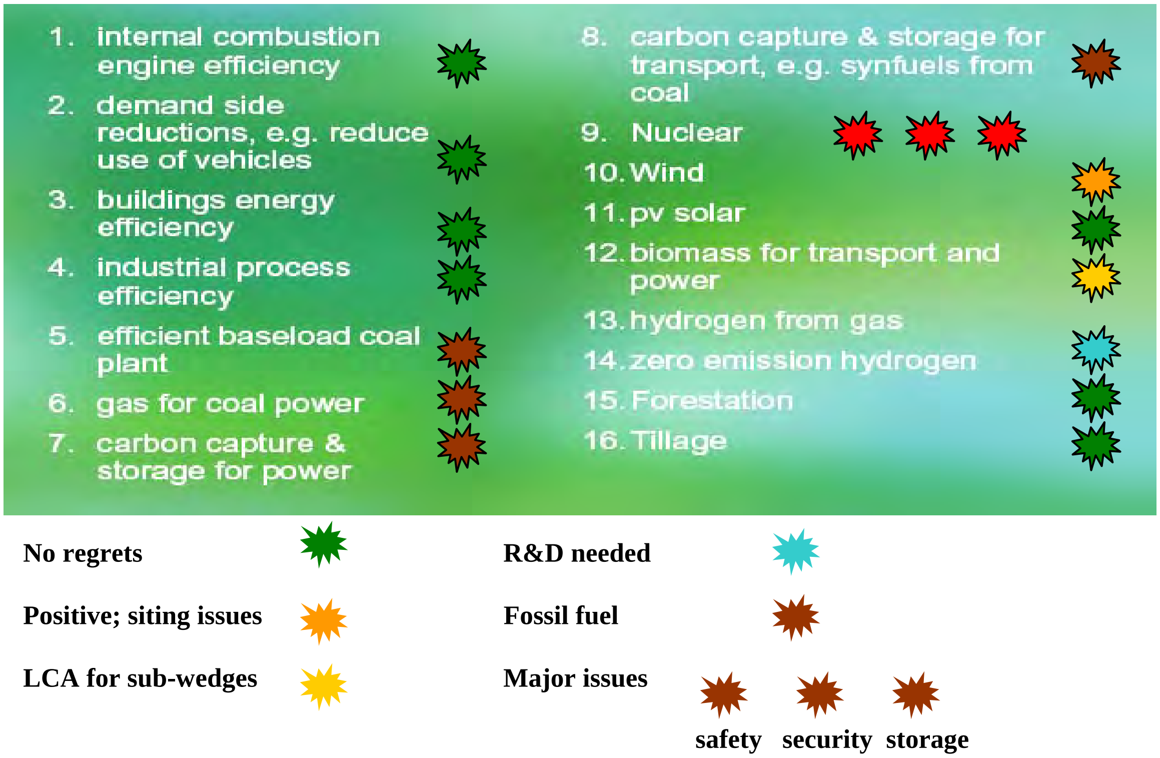


Figure 4. Trends in extreme weather events

Figure 5. Rating the wedges: First pass.
Given the potential of plug-in hybrids for transport, and combined power and heat for buildings, cleaning the grid becomes the central problem. Combining clean wedges of distributed generation measures that feed into national grids is one approach. "Smart technologies" can play a pivotal role in development of a more efficient and resilient grid, by focusing energy delivery to regions at times of maximum usage, for example.



References

ACIA: Impacts of a Warming Arctic - Arctic Climate Impact Assessment. Cambridge University Press (2005).

Barnett, T. P., Pierce, D. W., AchutaRao, K. M., Gleckler, P. J., Santer, B. D., Gregory, J. M. & Washington, W. M. Penetration of human-induced warming into the world's oceans. Science 309, 284-287 (2005).

Bindschadler, R. Hitting the ice sheets where it hurts. Science 311, 1720-1721 (2006).

Bindoff, N.L., McDougall, T.J. Diagnosing climate change and ocean ventilation using hydrographic data. J. Phys. Oceanogr. 24:1137-1152 (1994).

Bryden, H.L., Longworth, H.R., Cunningham, S.A. Slowing of the Atlantic meridional overturning circulation at 25° N. Nature 438, 655-657 (2005).

Burkett VR, Wilcox DA, Stottlemyer R, et al. Nonlinear dynamics in ecosystem response to climatic change: Case studies and policy implications. Ecological Complexity 2,357-394 (2005).

(CROBriefing 2006) Chief Risk Officers Briefing: Emerging Risk Initiative- Position Paper. Authors: Markus Aichinger, Allianz; Eberhard Faust, Munich Re; Jean-Noël Guye, AXA; Pamela Heck, Swiss Re; Annabelle Hett, Swiss Re; Peter Höppe, Munich Re; Ivo Menzinger, Swiss Re; Ernst Rauch, Munich Re; Samuel Scherling, Swiss Re; Martin Weymann, Swiss Re (2006).

Curry, R., Dickson, R., Yashayaev, I. A change in the freshwater balance of the Atlantic Ocean over the past four decades. Nature 426, 826-829 (2003).

Curry, R. Mauritzen, C. Dilution of the northern North Atlantic Ocean in recent decades. Science 308, 1772-1774 (2005).

Ekstrom, G., Nettles, M., Tsai, V.C. Seasonality and increasing frequency of Greenland glacial earthquakes. Science 311:1756-1758 (2006).

Emanuel, K. The dependence of hurricane intensity on climate. Nature 326, 483-485 (1987).

Emanuel, K. Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436, 686-688 (2005).

Epstein, P. R., McCarthy, J. J. Assessing climate stability. Bulletin of the American Meteorological Society 85, 1863-1870 (2004).

Epstein, PR, Mills, E. (eds.). Climate Change Futures: health, ecological and economic Dimensions, Center for Health and the Global Environment, Harvard medical School, Boston, MA (2005).

Galea, S., Ahern, J. Considerations about specificity of associations, causal pathways, and heterogeneity in multilevel thinking. American Journal of Epidemiology 163, 1079-1082 (2006).

Groisman, P.Y., Knight, R.W., Karl, T.E., et al. Contemporary changes of the hydrological cycle over the contiguous United States: Trends derived from in situ observations. Journal of Hydrometeorology 5, 64-85 (2004).

Hansen, J. E. A slippery slope: How much global warming constitutes dangerous anthropogenic interference? Climatic Change 68, 269-279 (2005).

Hansen, J., Nazarenko, L., Ruedy, R., Sato, Mki., Willis, J., Del Genio, A., Koch, D., Lacis, A., Lo, K., Menon, S., Novakov, T., Perlwitz, J., Russell, G., Schmidt, G.A., Tausnev, N. Earth's energy imbalance: Confirmation and implications. Science 308, 1431-1435 (2005).

Houghton, J. T., Ding. Y. & Griggs, D.J. et al. (eds.) Climate change 2001: The Scientific Basis. Contribution of

Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. (Cambridge University Press, Cambridge, UK, New York, USA, 2001).

Hoyos, C.D., Agudelo, P.A., Webster, P.J., Curry, J.A. Deconvolution of the factors contributing to the increase in global hurricane intensity. Science 312, 94-97 (2006).

Kerr, R.A. Is Katrina a harbinger of still more powerful hurricanes? Science 309: 1807 (2005a).

Kerr, R.A., The Atlantic Conveyor may have slowed, but don't panic yet. Science 310, 1403-1405 (2005b).

Levitus, S., Antonov, J.I., Boyer, T.P., & Stephens, C. Warming of the world ocean. Science 287: 2225-2229 (2000).

Levitus, S., Antonov, J.I., Boyer, T. Warming of the world ocean, 1955–2003, Geophys. Res. Lett., 32, L02604 (2005).

Mann ME, Emanuel KA. Atlantic hurricane trends linked to climate change. EOS, Transactions, American Geophysical Union. 87:233,238,241 (2006).

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., White, K. S. (eds.) Climate change 2001: Impacts, adaptation, & vulnerability contribution of working group ii to the third assessment report of the intergovernmental panel on climate change. Cambridge University Press (2001).

Mills, E. Insurers in a climate of change. Science 308, 1040-1044 (2005).

National Academy of Sciences. Abrupt Climate Change: Inevitable Surprises Committee on Abrupt Climate Change. National Research Council (2002). Available at: http://www.nap.edu/catalog/10136.html.

Pacala, S., Socolow, R. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. Science 305:968–972 (2004).

Parrilla, G., Lavin, A., Bryden, H., Garcia, M., Mill, R. Rising temperatures in the subtropical North Atlantic Ocean over the past 35 years. Nature 369, 48-51 (1994).

Rignot, E., Kanagaratnam, P. Changes in the Velocity Structure of the Greenland Ice Sheet. Science 311, 986-990 (2006).

Risk Management Solutions. European Windstorm. London, England (2002).

Sriver R, Huber M. Low frequency variability in globally integrated tropical cyclone power dissipation Geophys. Res. Lett. 33, L11705 (2006).

Stott, P.A., Stone, D.A., Allen, M.R. Human contribution to the European heatwave of 2003. Nature 432, 610-614 (2004).

Trenberth, K., Karl, T.R. Modern global climate change. Science 302, 1719-1723 (2003).

Trenberth, K. Uncertainty in hurricanes and global warming. Science 308, 1753-1754 (2005).

Walker, G. The tipping point of the iceberg. Nature 441, 802-805 (2006).

Webster, P. J., Holland, G. J., Curry, J. A., and H.-R. Chang, Changes in tropical cyclone number, duration, and intensity in a warming environment. Science 2005 309: 1844-1846.

TRENDS IN NATURAL CATASTROPHES – POTENTIAL ROLE OF CLIMATE CHANGE

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Introduction

For more than 30 years now, Munich Re scientists have been analysing natural hazards throughout the world. The Geo Risks Research department today has a staff of 27, of whom 20 have a natural science degree.

Over the past few years, there have been growing indications that the frequency and intensity of natural catastrophes are being influenced more and more by the unfolding process of climate change. Recent years have been marked by a particular accumulation of weather-related extreme events:

- In the summer of 2002, the hundred-year flood in the Elbe and Danube region (Germany and eastern Europe), caused by a large-scale circulation pattern, which was also behind the extreme summertime precipitation events of 1997 (Odra), 2001 (Vistula), and 2005 (Alpine region)
- In 2003, the 450-year hot summer with excess mortality due to heat affecting more than 35,000 in Europe
- In 2004, a new record of losses caused by hurricanes in one season
- In 2004, the record typhoon season in Japan (ten landfalls)
- In March 2004, the first appearance of a tropical cyclone in the South Atlantic leading to losses in South America (Brazil)
- On 26 July 2005, India's highest precipitation in 24 hours: 944 mm in Mumbai
- In 2005, the largest number of tropical cyclones (27 and 15 hurricanes) in one season in the North Atlantic since recordings began in 1851
- Three of the ten strongest Atlantic hurricanes ever recorded occurred in 2005: the strongest hurricane of all times (Wilma – core pressure: 882 hPa), the fourth-strongest hurricane (Rita), and the sixth-strongest (Katrina) since recordings began
- In 2005, Hurricane Katrina, the costliest single event of all time in absolute terms with over US$ 125bn in overall losses and approx. US$ 60bn in insured losses
- In October 2005, the most northerly and easterly hurricane (Vince), which formed off Madeira
- In November 2005, the first tropical storm to reach the Canary Islands (Delta)
- The 2005 hurricane season in the North Atlantic was marked by an early high activity record and an exceptionally long duration. By the end of July, seven tropical cyclones had already developed, thus topping the previous record of five cyclones by that time. Further on, we saw four cyclones during November and December, the last one being active until 6 January 2006. The extraordinary length of the 2005 hurricane season accords with the long-term observation of an increasing trend in terms of the length of the hurricane season in the North Atlantic (linear trend of 4.8 days/decade since 1915 – Webster and Curry, 2006b).

Munich Re's NatCatSERVICE® database

Munich Re's GEO experts have been researching loss events due to natural hazards around the globe for over 30 years. These losses are documented in the NatCat*SERVICE*® database, which has a record of all natural catastrophes since 1970 (19,000 events). Major historical events (3,000 events since the eruption of Mt. Vesuvius in 79 AD) and all great natural catastrophes back to 1950 have also been included retrospectively.

The reports of events are based on a large number of very different sources and are only entered in the database after thorough review and verification. The possibilities for researching information on natural phenomena throughout the world have improved constantly (Table 1 and Fig. 1). Good descriptions and analyses of major loss events in the past can still be found today, for instance in historical reports. The earliest natural catastrophe recorded in the NatCat*SERVICE*® database is the eruption of Vesuvius in Italy in 79 AD, which was described in precise detail by Pliny the Younger.

Scientific reports

- Annali di geofisica
- BSSA (Seism. Soc. of America)
- Climatic Perspectives
- Disasters in China
- Earthquake and Volcanoes
- Earthquake Spectra
- EERI (EQ Engineering Res. Inst.)
- Hong Kong Observatory
- International Seismological Centre
- Journal of Meteorology
- National Hurricane Center
- Natural Hazard Observer
- Natural Hazards
- NOAA
- PIK (Potsdam Inst. of Climate Impact Research)
- University of Hawaii
- Swiss Earthquake Service
- Transactions Am. Geophys. Union
- USGS (United States Geological Survey)
- World Meteorological Organisation
- Various newsletters and periodicals (e.g. THW German federal disaser relief agency)

NGOs and GOs

- ECLAC
- International Federation of Red Cross and Red Crescent Societies
- OCHA/DHA
- United Nations
- USAID/OFDA
- Others

Weather services

- Fiji Meteorological Service
- German Weather Service
- Monthly Weather Report
- United States Weather Service
- Weekly Climate Bulletin

Insurance industry and news agencies

- 10+ insurance-related (WIR, PCS)
- 5+ news agencies
- Worldwide network of contacts in science, economy etc.
- Proceedings
- Munich Re Branches, 50+ countries
- Claims/Loss reports from clients
- Reports from insurance companies
- Insurance associations worldwide

Tab. 1 Main sources of Munich Re's NatCat*SERVICE*® database

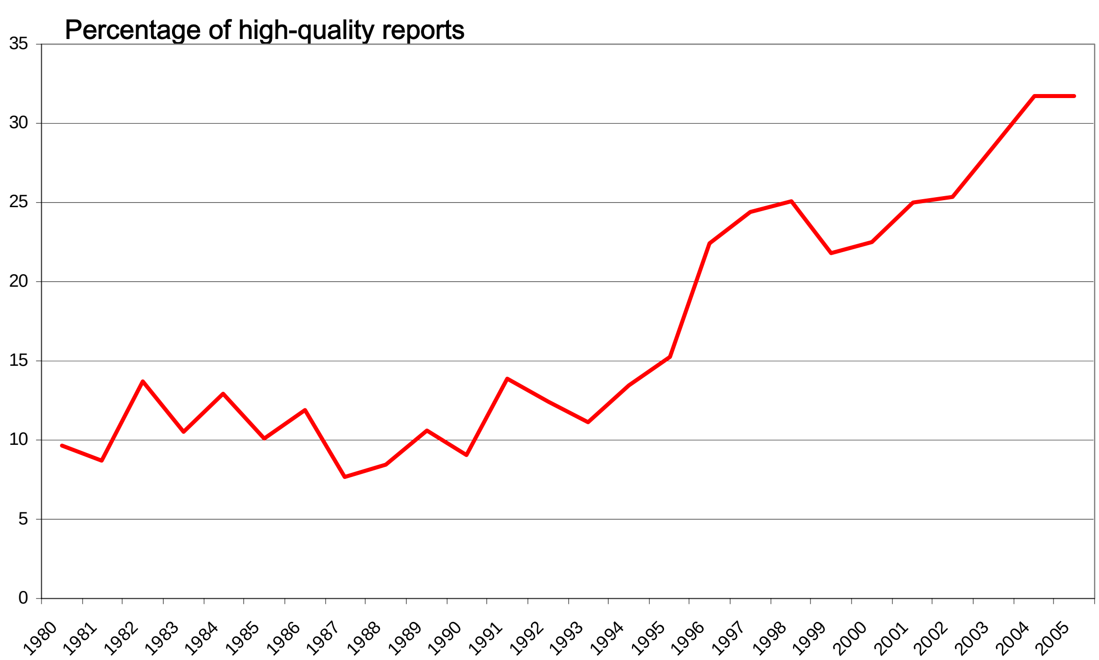


Fig. 1 Percentage of high-quality reporting in relation to all available records over time

The quality of data on natural catastrophe losses is mainly dependent on the level of reporting on natural catastrophes.

Public perception of catastrophes is strongly influenced by reports in the media. As reports on climate change have become more frequent, for example, people have become more aware of weather-related natural catastrophes, and reporting has increased. Reporting is also influenced by distorted information provided by authorities or by the unavailability of information because of intransparent information policies in some countries. In China, for example, the increase in the number of natural catastrophes coincides not only with the growth in population and values but also with the political opening-up of the country since 1980.

However, this does not affect the input of data into Munich Re's NatCat*SERVICE*®, since most of the information used comes from claims reports from insurance companies and insurance associations and is not influenced by reports in the media. Claims reports from insurance companies and insurance associations are based on the losses they have paid out.

Distorted information or intransparent information policies have no effect on NatCat*SERVICE*®'s long-term statistics, as they only relate to so-called great natural catastrophes, on which reporting has always been consistent (e.g. number of great natural catastrophes in China in the 1950s: 4; 1960s: 0; 1970s: 2; 1980s: 4; 1990s: 7; since 2000: none). A graph (Fig. 2b) produced from a current analysis of data records in NatCat*SERVICE*® shows that the loss data on China since the 1980s is of sufficient quality for all natural catastrophes. High-quality data is only available for major natural catastrophes since the 1950s (Munich Re starts with the year 1950 in its classification of catastrophes as major natural catastrophes).

Every data record in our database is given a quality level between 1 and 6 (1 being the highest quality, 6 the lowest) according to the sources used and how good the loss description fits with the loss figures. As a basis for deciding on the quality level, we introduced a decision tree (Fig. 2a and Table 2) to ensure a uniform procedure. First-class sources are information provided by insurance companies and insurance associations, scientific bodies, international organisations (e.g. UN, IFRC, WHO), and some first-class news agencies (e.g. Reuters, dpa). Second-class sources are reliable newspapers and information by brokers. Third-class sources are historical sources and some online information providers.

Our evaluation shows that the records on the largest and most devastating natural catastrophes going back to the 1950s are quality level 1 or 2. The records on smaller events since the 1980s are of sufficient quality for most countries. For some countries like the United States there is a sufficient quality level for a longer time period (Fig. 2c).

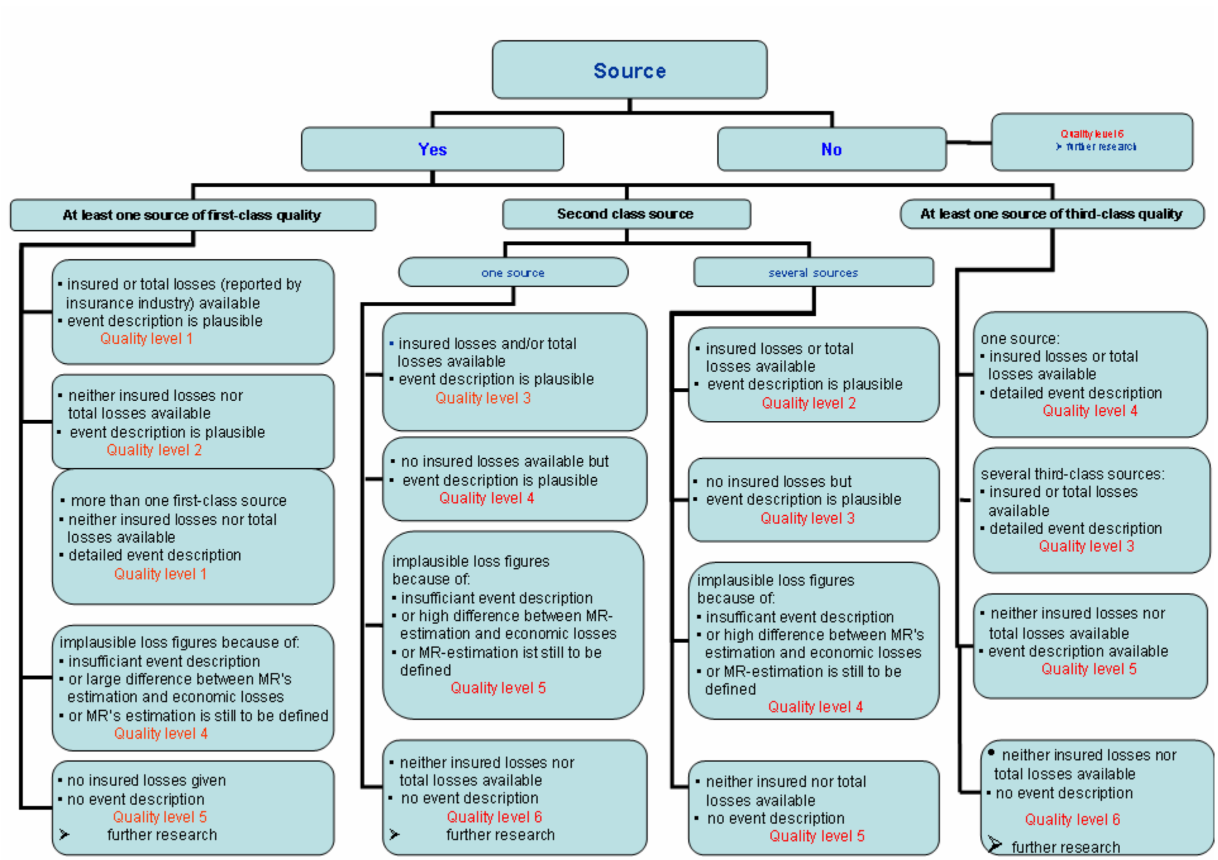


Fig. 2 Decision tree for the classification of data quality

Quality level 1	Loss assessment with very good reporting
Quality level 2	Loss assessment with good reporting
Quality level 3	Loss assessment with satisfactory medium reporting
Quality level 4	Loss assessment with sufficient, brief reporting (loss amount without clear plausibility)
Quality level 5	Loss assessment with faulty, poor reporting (loss amount without plausibility) ➢Dataset (loss assessment) cannot be used for analysis
Quality level 6	Loss assessment with inadequate or missing reporting ➢ Dataset (loss assessment) cannot be used for analysis

Tab. 2 Data quality levels

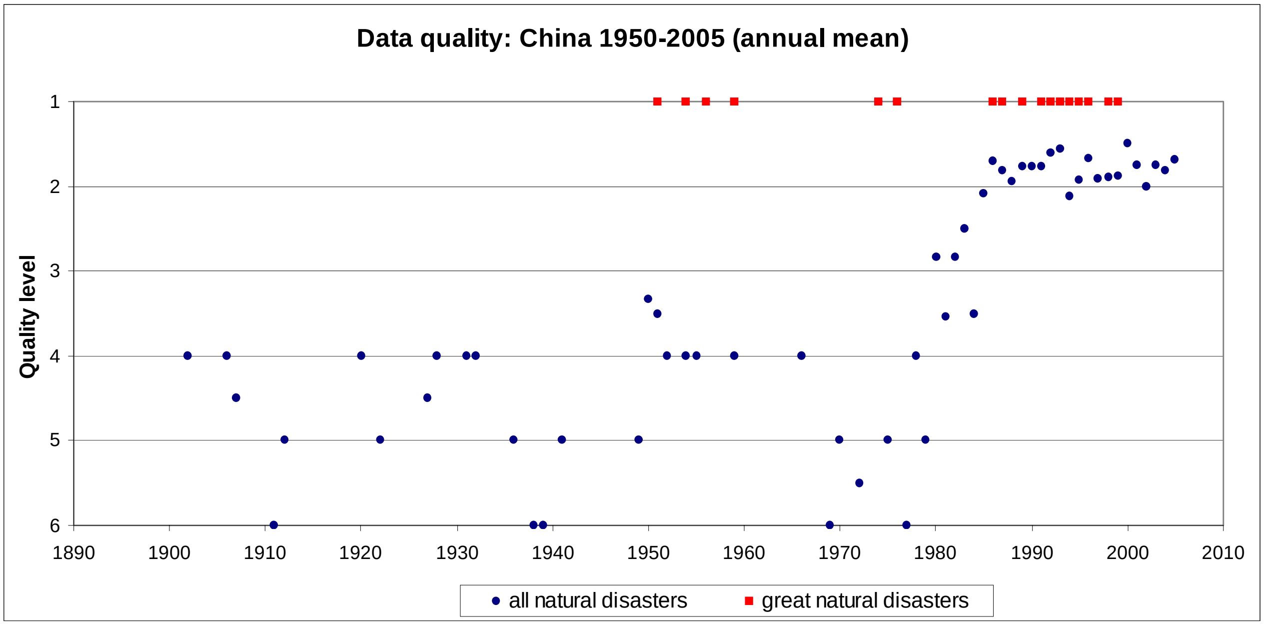


Fig. 2b Quality of data records on natural catastrophes occurring in the P.R. China

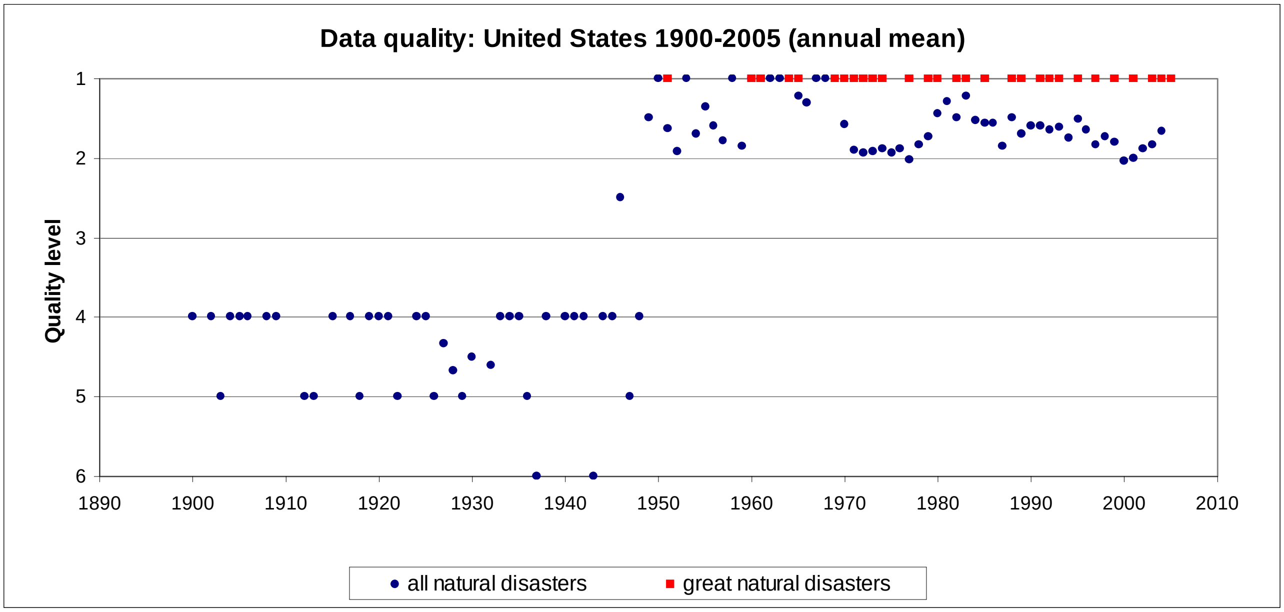


Fig. 2c Quality of data records on natural catastrophes occurring in the United States

In order to be able to perform trend analyses and avoid any distortions of information, all events are assigned to one of seven categories according to their financial and/or humanitarian effects – from pure natural events with a very modest or virtually no economic effect to major natural catastrophes. Our analyses and statistics do not take into account pure natural events (Table 3).

0	Natural event	No property damage (e.g. forest fire with no damage to buildings)
1	Small-scale loss event	1-9 fatalities and/or hardly any damage
2	Moderare loss event	10-19 deaths and/or damage to buildings and other property
3	Severe catastrophe	**2000-2005 1990s 1980s** 20+ fatalities and/or overall losses US$ > 50m >40m >25m
4	Major catastrophe	100+ fatalities and/or overall losses US$ > 200m >160m >85m
5	Devastating catastrophe	500+ fatalities and/or overall losses US$ > 500m >400m >275m
6	Great natural catastrophe *„GREAT disaster“*	Thousands of fatalities, economy severely affected, extreme insured losses (UN definition)

Tab. 3 Classification of catastrophe size into seven catastrophe categories

Trend analyses of the data show very clearly that natural catastrophes have dramatically increased in number throughout the world and are causing more and more damage. The trend curve of great natural catastrophes (category 6 – thousands of fatalities, billion-dollar losses) worldwide per year reveals an increase from about two at the beginning of the 1950s to a current figure of about seven (Fig. 3).

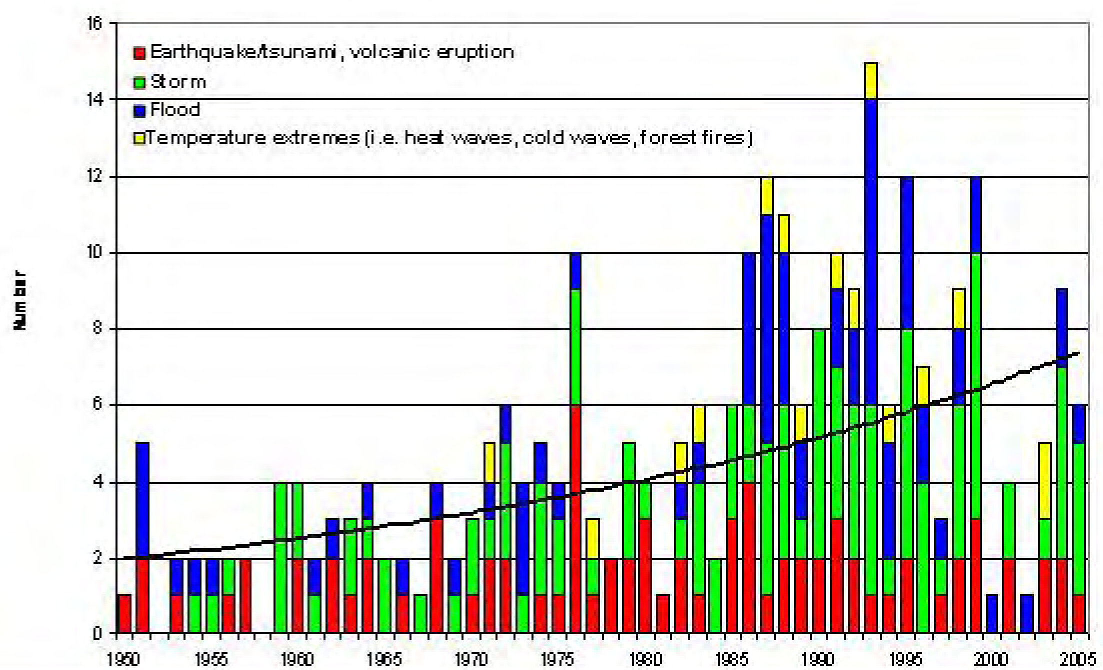


Fig. 3 Great natural catastrophes 1950 – 2005, number of events

In material terms, overall and insured losses from these great natural catastrophes rose even more steeply – to US$ 173bn in overall losses and US$ 83bn in insured losses in the record year of 2005 (Fig. 4). The original overall losses in the year 1995 (Kobe earthquake) were lower compared to 2005 – when adjusted for inflation, however, they exceed the 2005 level by a small amount.

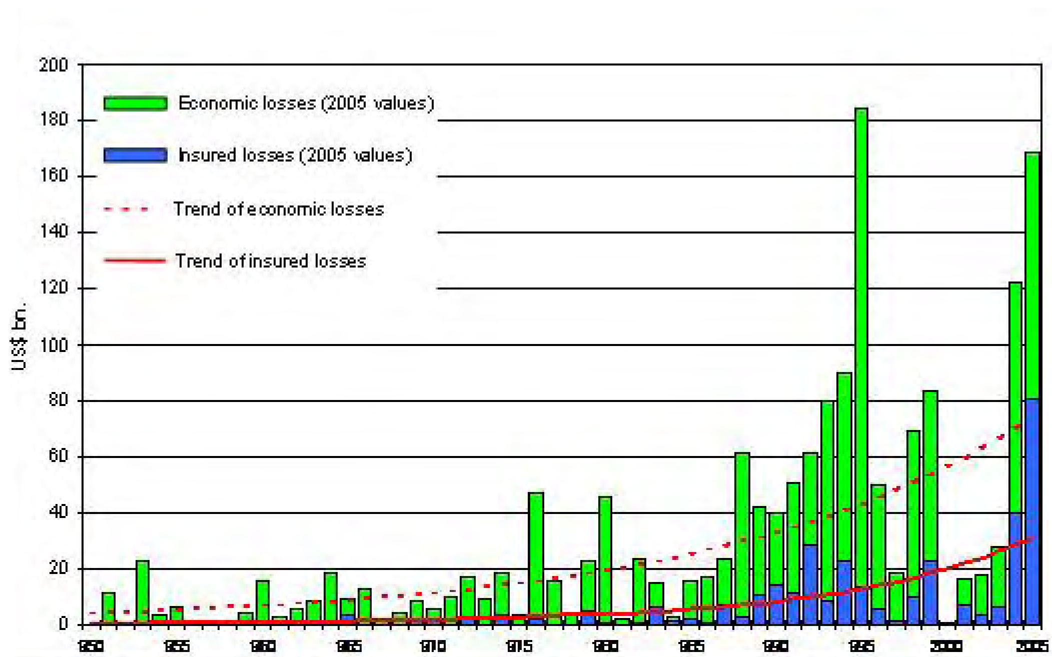


Fig. 4 Great natural catastrophes 1950 – 2005, overall and insured losses

This trend is apparent not only in the events classified as "major natural catastrophes", but also when we analyse all loss events worldwide in catastrophe categories 1 to 6 (Figs. 5 and 6). Similar to the preceding years, major natural catastrophes contribute 78 % to the overall and 88 % to the insured losses.

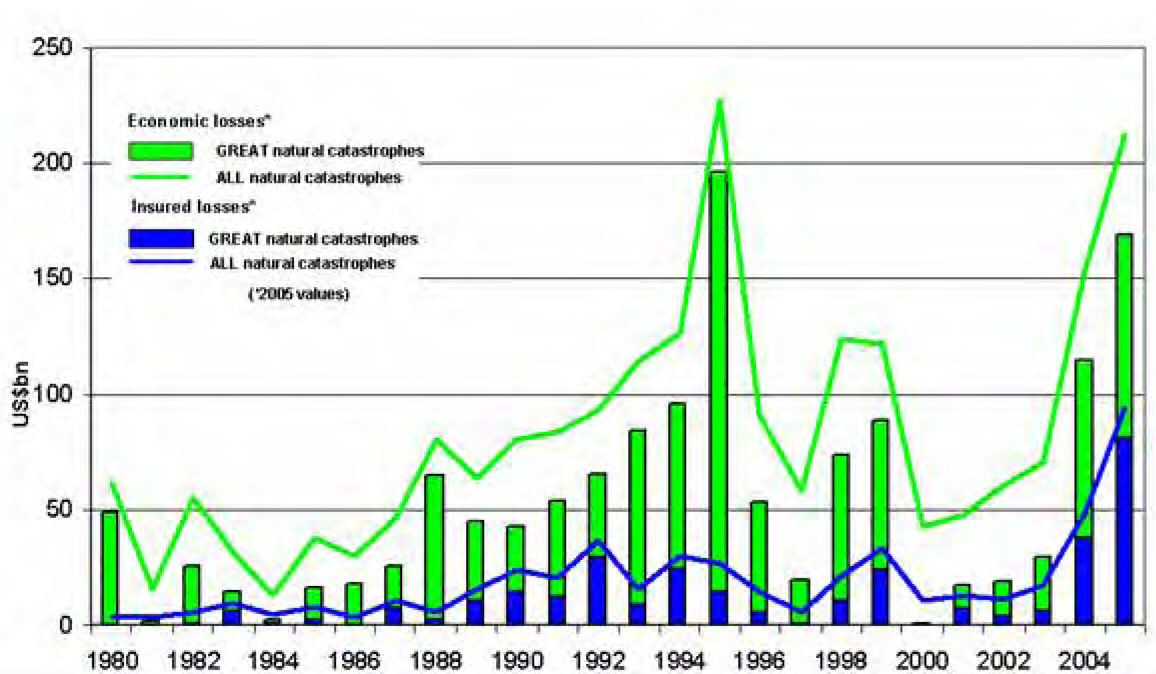


Fig. 5 Natural catastrophes 1980–2005, comparison between great natural catastrophes and all natural disasters worldwide 1980–2005

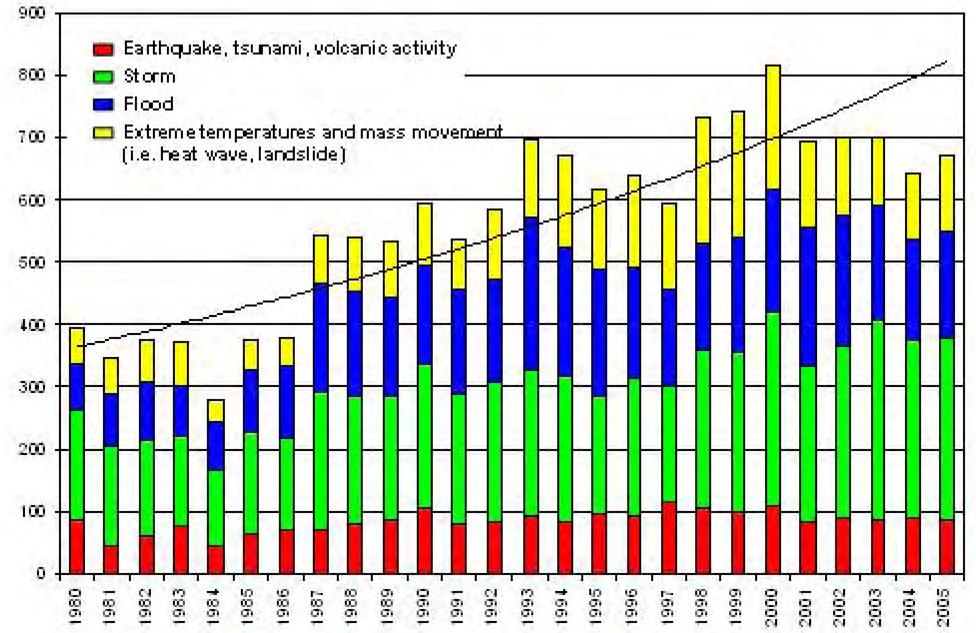


Fig. 6 All natural catastrophes worldwide 1980 – 2005, number of events

The comparison of temporal trends in the numbers of all and major natural catastrophes reveals a much steeper increase in the costly major ones.

The strong rise in losses over time is influenced by population growth, development and industrialisation of highly-exposed regions, elevated vulnerability of modern technologies, and increased insurance cover. As the upward trend in the number of natural catastrophes is mainly due to weather-related events like windstorms and floods and is not apparent in the same way as in the case of events with geophysical causes like earthquakes, tsunamis, and volcanic eruptions, there is some justification for assuming that it is not the result of a reporting bias but of changes in the atmosphere and particularly climate change.

Climate change and changing frequencies and intensities of natural catastrophes

The past few years have provided mounting support for the hypothesis that a changing climate contributes to the positive trend in natural catastrophes over time.

- Analyses of air bubbles trapped in Antarctic ice cores suggest that throughout the past 750,000 years the concentration of carbon dioxide – the most important of the greenhouse gases – has never before been anywhere near the level it has reached today (EPICA community, 2004).
- The last five years (including 2005) rank second to sixth in the table of the warmest years worldwide since 1861. The warmest year to date globally was 1998, in the northern hemisphere 2005 (World Meteorological Organization, 2005).

The third status report of the Intergovernmental Panel on Climate Change (IPCC, 2001) regards the link between global warming and the greater frequency and intensity of extreme weather events as highly significant. The expected increase in global average temperatures by the end of the century – of between 1.4 and 5.8°C, depending on the emission and climate models used – increases the probability of record temperatures enormously. Global warming raises the air's capacity to absorb water vapour and thus the precipitation potentials. Together with stronger convection processes, this leads to more frequent and more extreme intense precipitation events, which are today responsible for the majority of flood losses. The milder winters that are now typical in central Europe also reduce the snow areas over which stable cold high-pressure systems used to act as a barrier to the low-pressure systems coming in from the

Atlantic. Therefore, the barrier is often weak or driven eastwards so that devastating series of winter storms like those in 1990 and 1999 can no longer be considered exceptions. The wind readings at representative German weather stations reveal a clear increase in the number of storm days in the past three decades (at Düsseldorf Airport, for example, this figure has risen from about 20 to 35 a year; Otte, 2000). Although not scientifically confirmed, a trend towards more frequent and more extreme low-pressure systems, i.e. an increase in windstorm activity as such, has been observed in the North Atlantic over the past few decades.

It has been indicated in an increasing number of scientific publications in recent years that there is a connection between climate change and the frequency and intensity of natural catastrophes.

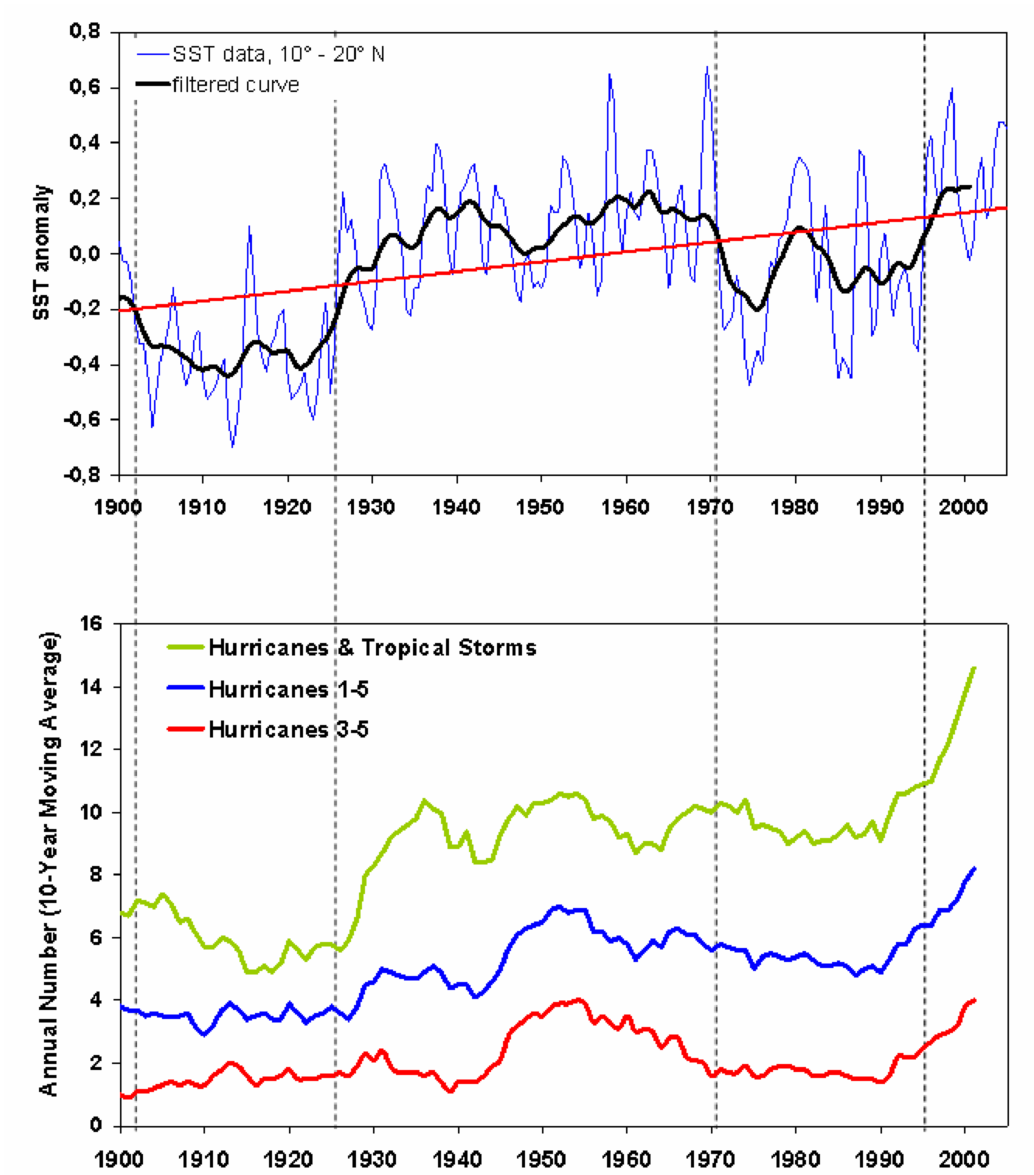
- According to British scientists, it is highly probable (>90%) that the influence of human activity has at least doubled the risk of a heat wave like the one that hit Europe in 2003 (Stott et al., 2004).
- Simulation models of future hurricane activity which factor in climate change show that by 2050 the maximum wind speed of hurricanes will have increased by 0.5 on the Saffir-Simpson Scale and that the associated precipitation volume will have increased by 18% (Knutson and Tuleya, 2004).
- The signal of anthropogenic warming has clearly been detected in a global warming of the world's oceans. The temperature of the uppermost layers of the world's oceans has increased substantially over the past four decades (Barnett et al., 2005).
- There are strong indications, for instance, that one of the consequences of the increasing sea surface temperature of the tropical Indian Ocean is the ever-increasing drying up of southern Africa due to a zonal circulation (similar to the Walker Circulation). This trend was observed over the second half of the 20th century and has recently been shown to be closely connected with the warmer trend in the Indian Ocean, which is most probably caused by global warming (Hoerling et al., 2006). Increasing drought and famine risks will be among the consequences for the countries affected in southern Africa.

At this point we will go into some detail regarding the tropical cyclone issue in the North Atlantic.

As shown in a study by Barnett et al. 2005, the temperature of the uppermost layers of the world's oceans has increased substantially over the past four decades. Especially the sea surface temperature of the tropical ocean regions – one of the major factors for development and intensity of tropical cyclones – has risen globally by about 0.5°C since 1970 (Agudelo and Curry, 2004). One might question the relative importance of SSTs and the warmth of the uppermost water layers – as the primary source of energy and moisture – in comparison with other decisive preconditions for TC development such as, for instance, low vertical wind shear in the troposphere or the change in zonal winds with longitude. A new paper studying the period 1970 to 2004 gives strong indications that the clear increasing global trend in Category 4 and 5 hurricanes is directly linked to the long-term trend in tropical SSTs, while the other aspects of the tropical environment, though responsible for short-term variations in hurricane intensity, do not contribute significantly to the global trend of increasing hurricane intensity over time (Hoyos et al., 2006; see also Webster et al., 2006a). Although there is no distinctive trend in the global number of cyclones occurring every year, the percentage of Category 4 and 5 hurricanes has been increasing since 1970 and indeed has more then doubled since then. There has been a steep increase in absolute terms too, from about eight per year at the beginning of the 1970s to eighteen per year in the period 2000 to 2004 (Webster et al., 2005). These findings are corroborated by the tight correlation found by Emanuel between the intensity of TCs in the North Atlantic and West Pacific – as measured by the annual aggregate of wind power release – and SSTs (Emanuel, 2005a; Emanuel, 2005b; cf. Kerr, 2006).

Especially for the North Atlantic, scientific findings over the past few years indicate two factors affecting sea surface temperature and hence hurricane activity variations over time: firstly, there is a multidecadal SST oscillation (Atlantic

Multidecadal Oscillation – AMO) caused by a natural sea current fluctuation and secondly a superimposed long-term warming process most probably caused by climate change – the resulting clear linear warming trend since 1870 amounts to 0.036°C/decade for the tropical North Atlantic (Fig. 7).



Figures 7A and 7B Upper panel (7A): Sea surface temperatures 1900 to 2004 in the tropical North Atlantic 10°–20° N (excluding the area west of 80° W). Anomalies relative to 1961 to 1990. Data taken from Trenberth, 2005. Red line: linear trend; heavy black line: filtered curve.

Lower panel (7B): Ten-year running mean curves for annual numbers of major hurricanes (red), all hurricanes (blue), and all named tropical cyclones (green) in the North Atlantic basin. Data from NOAA and UNISYS.

Independent of human-induced changes, natural cycles make the SST of ocean basins oscillate. In the North Atlantic this phenomenon is described by the "Atlantic Multidecadal Oscillation (AMO)" which in the 20th century showed a periodicity of about 65 years (Knight et al., 2005). The associated cold and warm phases are characterised by a margin of deviation of around 0.5°C in SST, which is about the same range as the presumed climate-change effect. The natural climatic fluctuation is most probably driven by the ocean's large-scale currents (Thermohaline Circulation THC – Knight et al., 2005; Vellinga and Wu, 2004). The current warm AMO phase started in 1995 and is expected to last for another ten to twenty years.

Warm phases produce a distinct increase in hurricane frequency and also more intense storms, whereas cold phases have the opposite effect. In the current warm phase, 4.1 major hurricanes (Saffir-Simpson Categories 3–5) have already occurred per year on average whilst in the previous cold phase this figure was only 1.5 (which means an increase of approx. 170%). Of course, a definite value for the average annual level of activity for the whole warm phase can only be given when this phase has ended and the 11 years of data since 1995 are not that much in comparison with the 45 years of data for the 1926–1970 warm phase. However, these 11 years are all we have at present and there is no reason to believe that they are far from being representative for the whole phase.

A comparison of corresponding AMO phases since 1900 indicates that the natural fluctuation is superimposed by a long-term warming process. This is to be expected from the above-mentioned global SST warming over time. Hence the level of tropical cyclone activity increases from one warm phase to another (Figure 7B). The increase in the number of major hurricanes per year from 2.6 to 4.1 on average from the previous warm phase to the current one means an increase of approx. 60%.

The changes observed for the North Atlantic basin are also reflected in US landfalls (Figure 8). In the case of major hurricanes, the annual average number of landfalls in the US has increased by about 230% from 0.3 to 1.0 compared with the last cold phase (approx. 1971 – 1994) and by about 70% from 0.6 to 1.0 compared with the last warm phase (approx. 1926 – 1970).

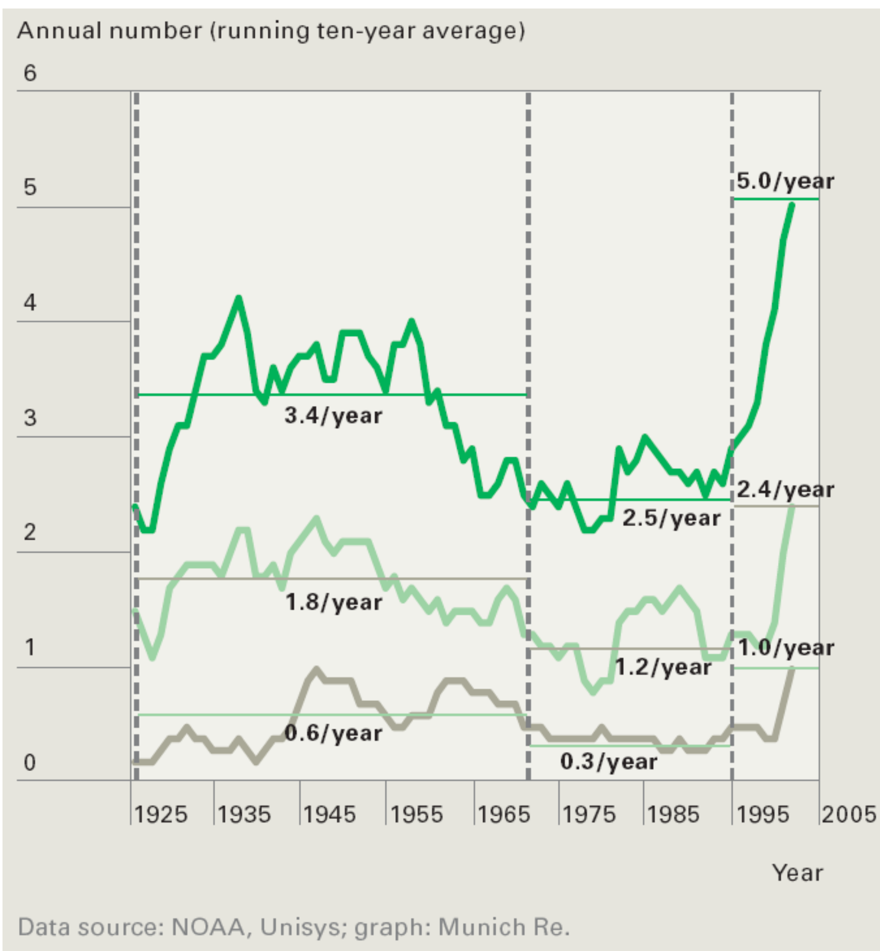


Fig. 8 Annual number of tropical cyclone US landfalls (ten-year running mean) and annual means over climatic phases for major hurricanes (grey curve), all hurricanes (light green curve) and all named tropical cyclones (green curve). Data source: NOAA/Unisys.

The cold/warm phase swing is also reflected in the data relating to losses. As a basis, we took the hurricane loss dataset adjusted to socio-economic conditions as of 2005 by Roger Pielke Jr. We based our analysis on this dataset because it is widely used in scientific contexts (Figure 9), although Pielke's data deviate from the data in Munich Re's MRNatCat*SERVICE*® in some cases.

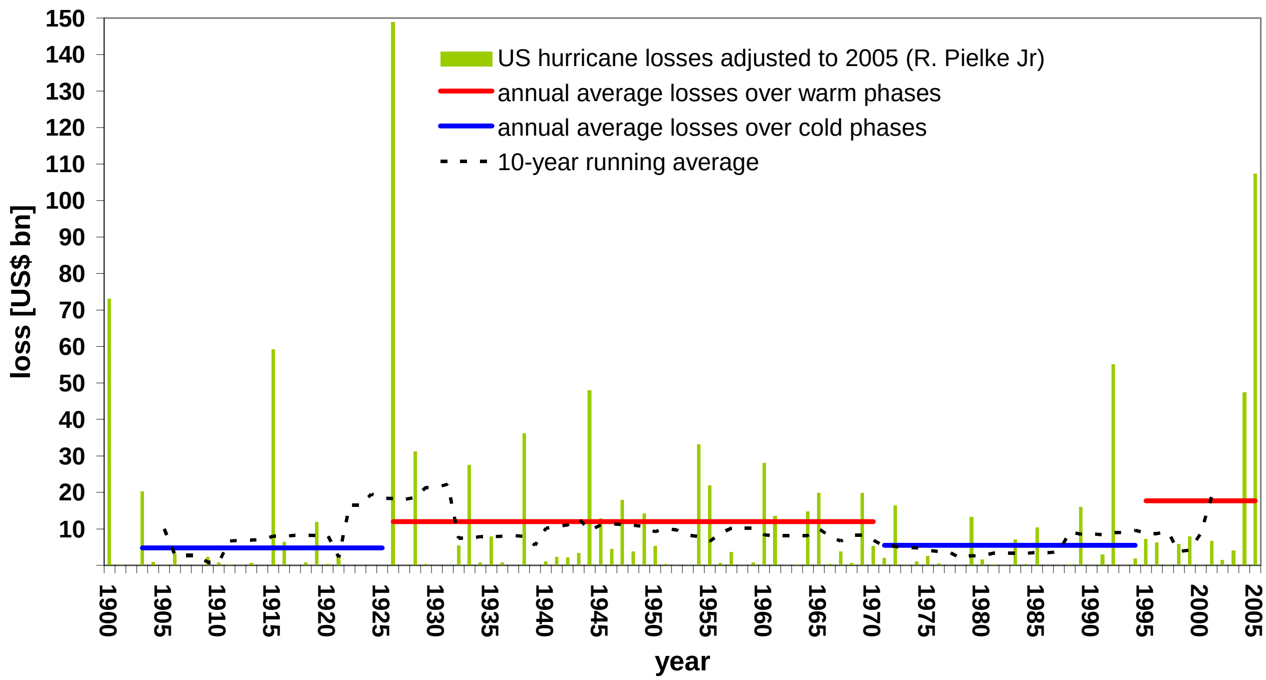


Fig. 9 Historical US hurricane losses adjusted to 2005 socioeconomic conditions (population, wealth, inflation) (green bars) from Pielke, R.A., Jr. (2006). Black dashed line: 10year running average; blue and red lines: annual average losses over cold and warm phases (for definition see the text).

For instance, according to Munich Re's database, economic losses from Katrina 2005 amounted to approx. US$ 120bn whereas Pielke's list gives US$ 80bn for the same event. The swing between cold and warm phases in the Main Development Region of the tropical North Atlantic is clearly indicated in Figure 7A, where we observe sharp changes in the degree of sea surface temperature swings for 1902–1903, and again for 1925–1926, 1970–1971 and finally for

warm phase (n = 56 years)		
mean US$ 13.1 bn	median US$ 3.9 bn	std dev US$ 25.7 bn

cold phase (n = 47 years)		
mean US$ 5.1 bn	median US$ 0.5 bn	std dev US$ 12.2 bn

U-test acc. to WILCOXON/MANN/WHITNEY:
both loss-frequency distributions and respective median values are different in a statistically significant way ($\alpha = 1\%$).
($\zeta = 2{,}93 > z_{\alpha=1\%} = 2{,}33$)

Tab. 4 Properties of loss-frequency distributions of annual losses from warm and cold phase years

	cold phase years	**warm phase years**
> US$ 1 bn	19 (of 47) 40%	36 (of 56) 64%
> US$ 5 bn	10 (of 47) 21%	26 (of 56) 46%
> US$ 10 bn	8 (of 47) 17%	17 (of 56) 30%

Tab. 5 Percentages of years exceeding specified annual loss thresholds in warm and cold phases of the 20th century.

1994–1995. These changes define the respective multidecadal cold and warm phases in the 20th century (cold: 1903–1925; 1971–1994; warm: 1926–1970; 1995–present day). We compared the frequency distributions of annual losses in the warm phase years and the cold phase years in the 20th century (Table 4). Median and mean values are much higher in the warm phase distribution and the application of the WILCOXON-MANN-WHITNEY test showed that both distributions and the respective median values are different in a statistically significant way (α = 1 %). If we look at the exceedance of specified loss thresholds – US$ 1bn, 5bn and 10bn – we find that the percentage of years exceeding these thresholds is much higher in warm phases than in cold phases (Table 5).

If we compare the loss frequency distributions of the two cold phases in the 20th century, we find a higher median value (and mean) in the second cold phase. The difference between the distributions is statistically significant (α = 10%) and can be explained by sea surface temperatures being higher in the second cold phase than in the foregoing one (Table 6). As far as the two consecutive warm phases of the 20th century are concerned, there is only a statistically weak significant difference between the distributions (α = 20%), but median and mean values are nevertheless substantially higher in the second warm phase than in the previous one (Table 7). If we compare consecutive cold (warm) phases in

cold phase 1 1903-1925 (n = 23 years)		
mean US$ 4.8 bn	median US$ 0.3 bn	std dev US$ 12.8 bn

cold phase 2 1971 - 1994 (n = 24 years)		
mean US$ 5.5 bn	median US$ 0.7 bn	std dev US$ 11.8 bn

U-test acc. to
WILCOXON/MANN/WHITNEY:
both loss-frequency distributions and respective median values are different in a statistically significant way (α =10%).
($\zeta = 1{,}511 > z_{\alpha=10\%} = 1{,}282$)

Tab. 6 Properties of loss-frequency distributions of annual losses from consecutive cold phases.

warm phase 1 1926-1970 (n = 45 years)		
mean US$ 12.0 bn	median US$ 3.6 bn	std dev US$ 24.1 bn

warm phase 2 1995 - 2005 (n = 11 years)		
mean US$ 17.7 bn	median US$ 6.3 bn	std dev US$ 32.6 bn

U-test acc. to
WILCOXON/MANN/WHITNEY:
both loss-frequency distributions and respective median values are different in a statistically weak significant way (α =20%).
($\zeta = 0{,}918 > z_{\alpha=20\%} = 0{,}842$)

Tab. 7 Properties of loss-frequency distributions of annual losses from consecutive warm phases.

terms of loss exceedance thresholds, we find a higher percentage of years exceeding the US$ 1bn, 5bn and 10bn thresholds in the second cold phase than in the previous one (Table 8). Equally, as far as consecutive warm phases are concerned, we find higher percentages of annual losses exceeding the US$ 1bn and 5bn thresholds in the second phase than in the previous one (Table 9). As to the US$10bn threshold, there is no increase, which is due to only two years (2004 and 2005) covering all the large losses of the current warm phase. Taken together, these findings are a strong indication that climate variations exert a great influence on the distribution of annual losses: warm phase and cold phase years have significantly different loss frequency distributions, with higher mean, median and percentage of years exceeding specified loss levels in the warm phases. Equally, there are strong indications of changing distribution properties between consecutive cold phases (warm phases) in the 20th century, resulting in higher loss frequencies in the second phase characterized by higher sea surface temperatures.

	cold phase 1	cold phase 2
> US$ 1 bn	7 (of 23) 30%	12 (of 24) 50%
> US$ 5 bn	4 (of 23) 17%	6 (of 24) 25%
> US$ 10 bn	3 (of 23) 13%	5 (of 24) 21%

Tab. 8 Percentages of years exceeding specified annual loss thresholds in consecutive cold phases of the 20th century.

	warm phase 1	warm phase 2
> US$ 1 bn	27 (of 45) 60%	9 (of 11) 82%
> US$ 5 bn	19 (of 45) 42%	7 (of 11) 64%
> US$ 10 bn	15 (of 45) 33%	2 (of 11) 18%

Tab. 9 Percentages of years exceeding specified annual loss thresholds in consecutive warm phases of the 20th century.

The insurance industry is affected by climate change in a number of ways:

- The greater number and severity of extreme events are increasing the frequency and dimensions of the losses incurred.
- The volatility of losses is growing.
- New types of exposure are developing (e.g. hurricanes in the South and Northeast Atlantic).
- Unprecedented extreme values are being registered (in 2005, the strongest hurricane ever recorded).
- Premium adjustments often lag behind claims developments.

In spite of the unfavourable loss trends, the insurance industry still offers a wide range of covers for natural hazard losses. At the same time, it is endeavouring to encourage loss prevention on the part of its clients. Furthermore, it is making great efforts to control its own loss potentials through the application of modern geo-scientific methods. A quantitative forecast of future climate change's impact on the frequency and intensity of extreme weather events is still a problem.

The insurance industry has great potential for promoting climate protection and thus exerting a positive influence on future losses – by considering climate protection aspects in its products, investments, sponsoring activities, and its communications.

Munich Re will continue to play a leading role in these areas.

Conclusions

The data in Munich Re's NatCat*SERVICE*® clearly show significant trends with ever-increasing numbers of extreme weather events and losses caused by such events during the last decades. There is convincing evidence that climate change is occurring already, affecting not only air temperatures but also sea surface temperatures. A growing number of serious scientific studies provide evidence of causal links between climate change and an intensification of natural catastrophe hazards, such as tropical storms, floods, droughts or heat waves. Especially, we found strong indications that climate variations exert a great influence on the distribution of annual hurricane losses. Taken together, these facts form the basis of our conviction that the increasing losses caused by natural catastrophes are partly a consequence of global warming.

Literature

Agudelo, P. A., Curry, J. A. (2004),
Analysis of spatial distribution in tropospheric temperatures, Geophysical Research Letters 31.

Barnett, T. P. et al. (2005),
A Warning from Warmer Oceans, Science 309, S. 284–287.

Emanuel, K. (2005a),
Increasing destructiveness of tropical cyclones over the past 30 years, Nature 436, S. 686-688.

Emanuel, K. (2005b),
Emanuel replies, Nature 438.

EPICA community (2004),
Eight glacial cycles from an Antarctic ice core, Nature 429, S. 623 – 628.

Hoerling, M. et al. (2006),
Detection and Attribution of 20th Century Northern and Southern African Rainfall Change, Journal of Climate, in Press.

Hoyos, C. D. et al. (2006),
Deconvolution of the Factors Contributing to the Increase in Global Hurricane Intensity, Sciencexpress, 16 March 2006.

IPCC - Intergovernmental Panel on Climate Change (2001),
Climate Change 2001: The Scientific Basis, Cambridge 2001

Kerr, R. A. (2006),
A Tempestuous Birth for Hurricane Climatology, Science 312, S. 676-678.

Knight, J.R. et al. (2005),
A signature of persistent natural thermohaline circulation cycles in observed climate, Geophysical Research Letters 32.

Knutson, T. R., Tuleya, R. E. (2004),
Impact of CO2 –Induced Warming on Simulated Hurricane Intensity and Precipitation: Sensitivity to the Choice of Climate Model and Convective Parameterization, Journal of Climate 17, S. 3477–3495.

Otte, U. (2000),
Häufigkeit von Sturmböen in den letzten Jahren, Deutscher Wetterdienst (ed.), Klimastatusbericht 1999, Offenbach.

Pielke, R.A., Jr. (2006),
White Paper Prepared for Workshop on Climate Change and Disaster Losses: Understanding and Attribution Trends and Projections, Workshop Booklet 2006.

Stott, P. A., Stone, D. A., Allen, M. R. (2004),
Human contribution to the European heat wave of 2003, Nature 432, S. 610-614.

Trenberth, K. (2005),
Uncertainty in hurricanes and global warming, Science 308, S.1753-1754.

Vellinga, M., Wu, P. (2004),
Low-Latitude Freshwater Influence on Centennial Variability of the Atlantic Thermohaline Circulation, J. Clim. 17, S. 4498-4511.

Webster, P. J. et al. (2005),
Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment, Science 309, S. 1844–1846.

Webster, P. J. et al. (2006a),
Response to Comment on "Climate in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment ", Science 311, S. 1731.

Webster, P. J., Curry, J. (2006b),
Is global warming contributing to an increase in tropical cyclone activity? (Presentation prepared for the Workshop "Climate Change and Disaster losses", 25-26 May 2006, Hohenkammer, Germany).

Death and Death Rates Due to Extreme Weather Events: Global and U.S. Trends, 1900-2004

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Abstract

Despite the recent spate of deadly extreme weather events such as the 2003 European heat wave and the hurricanes of 2004 and 2005, aggregate mortality and mortality rates due to extreme weather events are generally lower today than they used to be. Globally, mortality and mortality rates have declined by 95 percent or more since the 1920s. The largest improvements came from declines in mortality due to droughts and floods, which apparently were responsible for 95 percent of all deaths caused by extreme events during the 20th century. For windstorms, which contributed most of the remaining 5 percent of fatalities, mortality rates are also lower today but there are no clear trends for mortality. Cumulatively, the declines more than compensated for increases due to the 2003 heat wave. With regard to the U.S., current mortality and mortality rates due to extreme temperatures, tornados, lightning, floods and hurricanes are also below their peak levels of a few decades ago. The declines for the last four categories range from 55 to 95 percent. If extreme weather has indeed become more extreme for whatever reason, global and U.S. declines in mortality and mortality rates are perhaps due to increases in societies' collective adaptive capacities owing to a variety of interrelated factors — greater wealth, increases in technological options, and greater access to and availability of human and social capital — although luck may have played a role. Because of these developments, nowadays extreme weather events contribute less than 0.06 percent to the global and U.S. mortality burdens in an average year, and, by and large, seem to be declining. Equally important, mortality due to extreme weather events has declined despite an increase in all-cause mortality suggesting that humanity is adapting better to extreme events than to other causes of mortality. In summary, there is no signal in the mortality data to indicate increases in the overall frequencies or severities of extreme weather events, despite large increases in the population at risk.

Introduction

Even prior to Hurricanes Katrina and Rita striking the U.S. coast, there was speculation in medical and scientific journals, the popular press and elsewhere that climate change would exacerbate extreme weather events through, among other things, intensification of the hydrological cycle, hurricanes and other storms, and, thereby, raise deaths and death rates globally as well as in the United States (see, e.g., IPCC 2001: Table SPM-1; Patz 2004; MacMichael and Woodruff 2004; Schiermeier 2003, 2005; Trenberth and Taylor, no date).[2] Since then, this speculation — fueled by recent, somewhat controversial studies suggesting that hurricane intensities might be stronger because of climate change (e.g., Webster et al. 2005; Emmanuel 2005a, 2005b; Pielke, Jr., 2005; Landsea 2005) as well as the occurrence of recent weather related disasters ranging from the Central European floods of 2002, the 2003 European heat wave, and the back-to-back disastrous Atlantic hurricane seasons of 2004 and 2005 — has only intensified as epitomized by the recent *Time* magazine cover story warning all to worry more about global warming (Kluger 2006; see also, for example, Anderson and Bausch 2006).

This note examines whether losses due to weather-related extreme events (as measured by aggregate deaths and death rates) have increased globally and for the United States in recent decades, as they should have if — all else being equal — climate change has indeed increased the frequencies or severities of such events, as some have claimed might occur

[1] Views expressed in this article are the author's, and not of any unit of the U.S. government.

[2] This paper uses "extreme weather events" synonymously with "extreme events."

(see, e.g., IPCC 2001; Patz 2004; MacMichael and Woodruff 2004). It will also try to put these deaths and death rates into perspective by comparing them with the overall mortality burden, and briefly discuss what trends in these measures imply about human adaptive capacity.

Trends in deaths and death rates while of intrinsic interest for public policy purposes, may also have a bearing on trends in economic losses. Goklany (2000) speculates that while a wealthier society may take extra effort to limit loss of life, it may be less concerned about property losses, and that a wealthier society is also likely to have more property at risk. This suggestion finds some support in findings that the ratio of death-to-property-loss for tornadoes in the U.S. has declined in recent decades (Doswell et al. 1999, Brooks and Doswell 2001).

Trends in Mortality and Mortality Rates

GLOBAL TRENDS, 1900-2004

In general, climate change could change the frequencies, intensities and/or durations of extreme weather events such as floods, droughts, windstorms and extreme temperatures — increasing them at some locations and for some periods while decreasing them at other locations and other periods. Some of the effects of these changes will tend to offset each other and/or be redistributed over space and time. For instance, an increase in deaths due to heat waves at one location might be compensated for by a decline in deaths due to fewer or less intense cold waves at the same or another location. Alternatively, climate change might redistribute the temporal and spatial pattern of rainfall, droughts and other such events. Accordingly, to estimate the net impact, if any, of climate change on mortality, it is probably best to examine cumulative deaths at the global level aggregated over all types of extreme events. Because of the episodic nature of extreme events, such an examination should ideally be based on several decades, if not centuries, worth of data. Any such examination should, of course, be cognizant that adaptive capacity and exposure of human populations to risk also change over time.

In particular, one should examine mortality rates so as to filter out the effect of population growth on the population at risk. However, it may be argued that the use of mortality rate may be inadequate to eliminate the effect of increases in populations at risk since, as the population becomes larger, people will migrate to riskier and more vulnerable locations as the less vulnerable locations are occupied. In addition, inappropriate state policies and the availability of insurance, which allows individuals to bear less than their full burden of risk, may place even wealthier populations at greater physical risk (in addition to increasing financial risk; Goklany 2000).

Figure 1, based on data from EM-DAT, the International Disaster Database maintained by the Office of Foreign Disaster Aid and Center for Research on the Epidemiology of Disasters at the Université Catholique de Louvain, Brussels, Belgium, displays data on aggregate global mortality and mortality rates between 1900 and 2004 for the following weather-related extreme events: droughts, extreme temperatures (both extreme heat and extreme cold), floods, slides, waves and surges, wild fires and windstorms of different types (e.g., hurricanes, cyclones, tornados, typhoons, etc.).[3,4] It indicates that both death and death rates have declined at least since the 1920s. Specifically,

[3] Figure 1 is constructed using data the following sources: (1) For deaths, EM-DAT (2005). (2) For population from 1900-1925, McEvedy & Jones (1978). (3) For population from 1950-2004, World Resources Institute (2005). (4) For population from 1926-1949, estimates were based on interpolation for each year using the 1925 estimate from McEvedy and Jones and the 1950 WRI estimate, assuming exponential population growth. For 2004, I excluded the deaths due to the Boxing Day Tsunami disaster (which, according to EM-DAT killed 226,435 people). Death estimates, in particular, are approximate and, possibly, more prone to error as we go further into the past. As is evident from the following footnote, EM-DAT is not quite complete. While events in the earlier years might have been missed, EM-DAT should have captured the major natural disasters, particularly in recent years. This suggests that mortality and mortality rates might have been higher in the early decades of the 20th century than is indicated in Figure 1, and subsequent figures and tables.

[4] EM-DAT contains data on the occurrence and effects of over 12,800 mass disasters in the world from 1900 to present. The data are compiled from various sources, including UN agencies, non-governmental organizations, insurance companies, research institutes and press agencies. For a disaster to be entered into the database one or more of the following criteria must be met: (a) at least 10 people must have been reported killed, (b) at least 100 people must have been reported as affected, (c) a state of emergency must have been declared, or (d) there should have been a call for international assistance.

comparing the 1920s to the 2000-2004 period, the annual number of deaths declined from 485,200 to 19,400, a 96 percent decline, while the death rate per million dropped from 241.8 to 3.1, a decline of 98.7 percent.

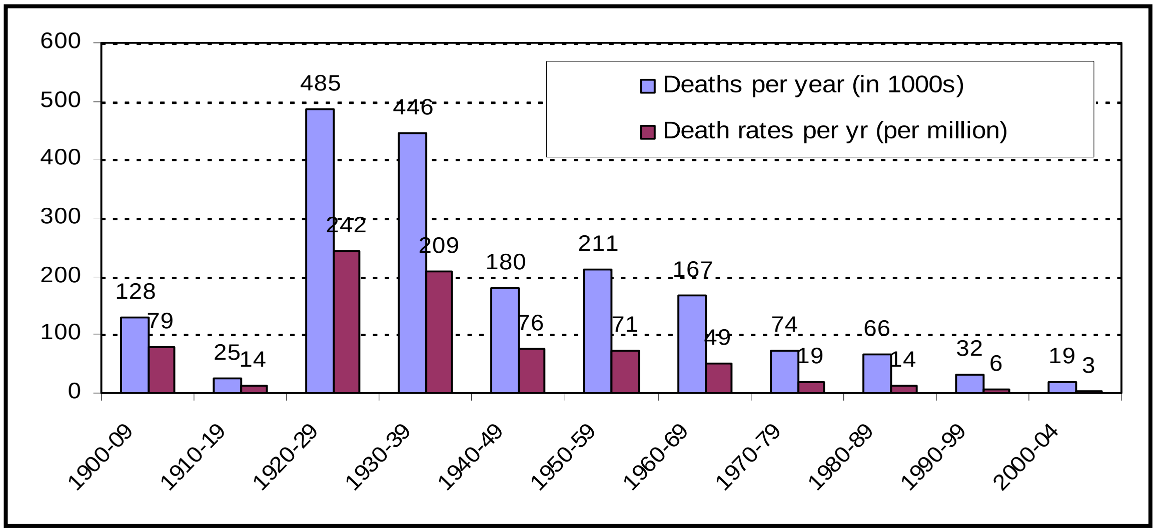

Figure 1: Global Death and Death Rates Due to Extreme Events, 1900-2004. Note that data for the last period are averaged over five years worth of data. Sources; EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

Table 1 provides a breakdown of the average annual global deaths and death rates for the various categories of extreme events for 1900–1989 and 1990–2004. The columns are arranged in order of declining mortality ascribed to the various events (highest to lowest) for the former period. This shows that:

- During much of the 20th century, the deadliest extreme events were droughts, followed by floods and windstorms. Over the 105 year record, droughts and floods were responsible for 55 and 38 percent of all fatalities worldwide due to all extreme weather events, while windstorms contributed an additional 7 percent. Thus, these three categories together accounted for over 99 percent of the fatalities due to extreme events.
- Aggregate annual mortality for the seven categories of extreme events declined by 86 percent between the 1900-1989 and 1990-2004 periods, while the annual mortality rate dropped by 94 percent.
- Mortality declines between the two periods were mainly due to declines in annual fatalities owing to droughts and floods (see also Figures 2 and 3). The remarkable 99.9 percent drop in annual drought fatalities indicates that, for whatever reason, available food supplies per capita have increased in marginal areas, possibly due to greater food production at the global level and an enhanced ability to move food from food surpluses areas to deficit areas through institutions such as international trade and governmental and nongovernmental aid agencies and philanthropies (e.g., through the World Food Program or the International Red Cross) facilitated by better transportation and communication networks, and irrigation facilities (Goklany 1998). The 89.5 percent decline in flood fatalities between the two periods possibly reflects better control, prevention and management of floods through construction of dams and other infrastructure, supplemented by better emergency response measures facilitated by improvements in transportation systems, flood forecasting, and management of water facilities, among other things.
- While average annual fatalities due to windstorms increased from around 11,000 to 15,000 per year between the two periods, the annual mortality rates declined by about a third (see also Figure 4).
- Annual mortality rates dropped for virtually every category except extreme temperatures. However, the spike in deaths and death rates owing to extreme temperatures during the 2000-2004 period, which occurred because of the 2003 European heat wave, were more than compensated for by declines in flood and drought fatalities.[5]

[5] EM-DAT (2005) ascribes over 45,700 deaths to the 2003 European heat wave.

	Deaths per year		Death Rates per yr (per million people)	
	1900-1989	***1990-2004***	***1900-1989***	***1990-2004***
Droughts	111,185	126	49.77	0.02
Floods	75,216	7,872	31.96	1.34
Windstorms	10,858	14,780	3.96	2.68
Slides	457	839	0.15	0.14
Waves/Surges	126	181	0.06	0.03
Extreme Tem-peratures	99	4,253	0.03	0.69
Wild Fires	21	49	0.01	0.01
TOTAL	197,963	28,099	85.94	4.92

Table 1. Global deaths and death rates for various types of events, 1900-1989 and 1990-2004. Sources: EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

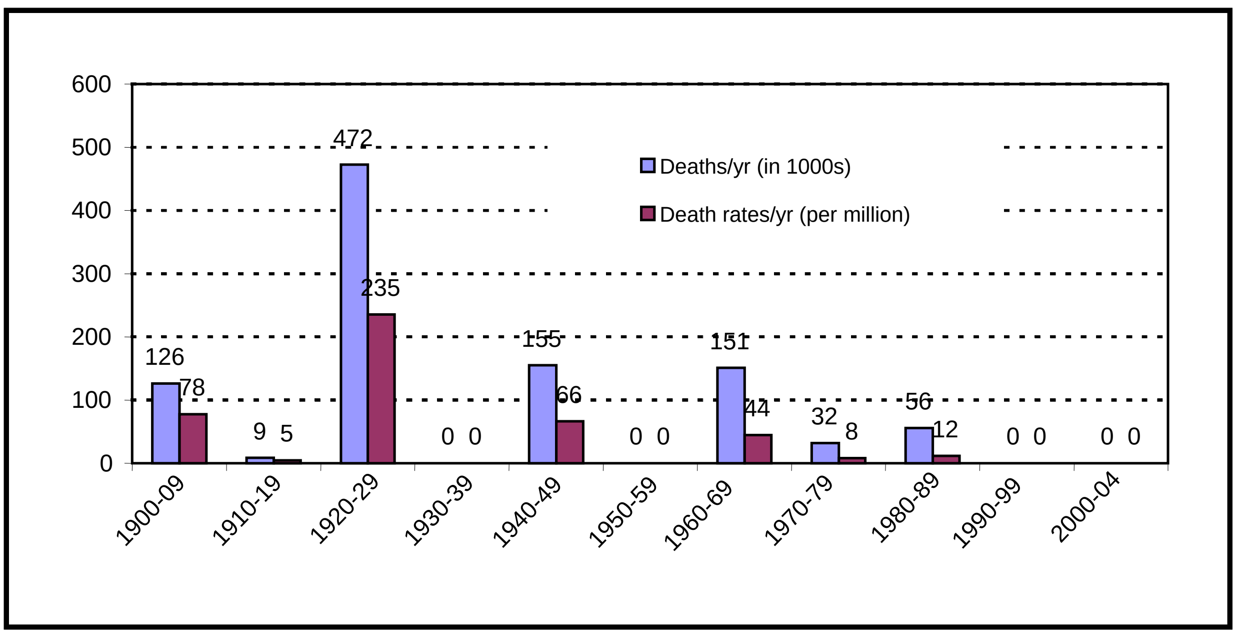

Figure 2: Droughts - Global Deaths & Death Rates, 1900-2004. Sources: EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

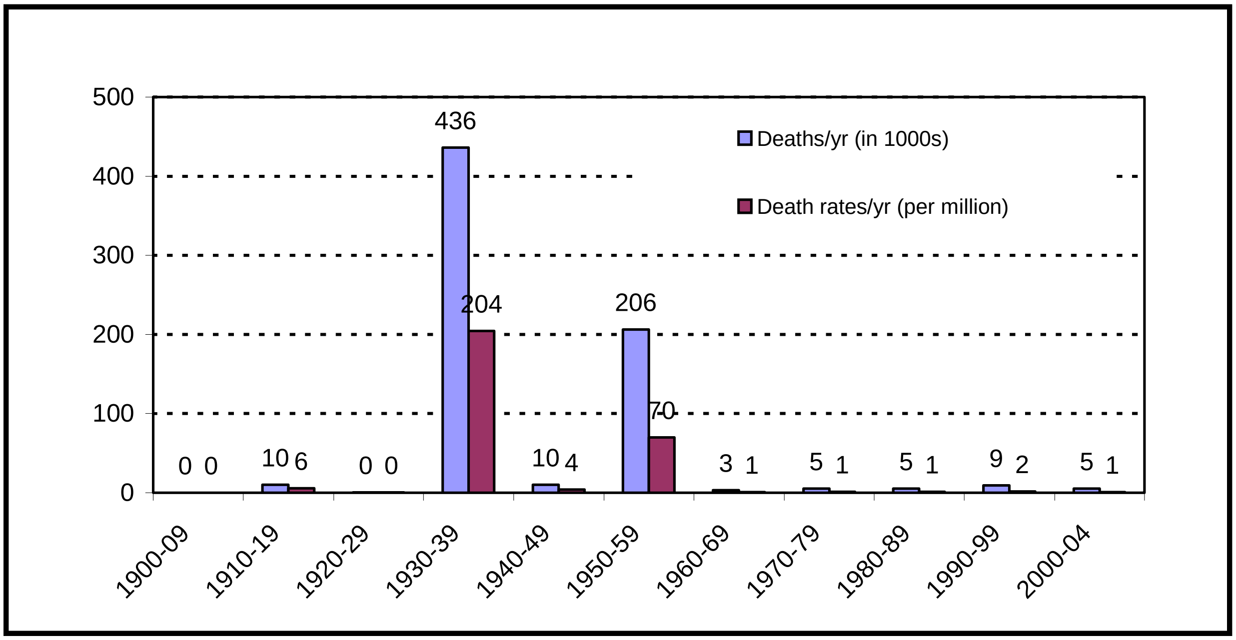

Figure 3: Floods: Global Deaths and Death rates, 1900-2004. Sources: EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

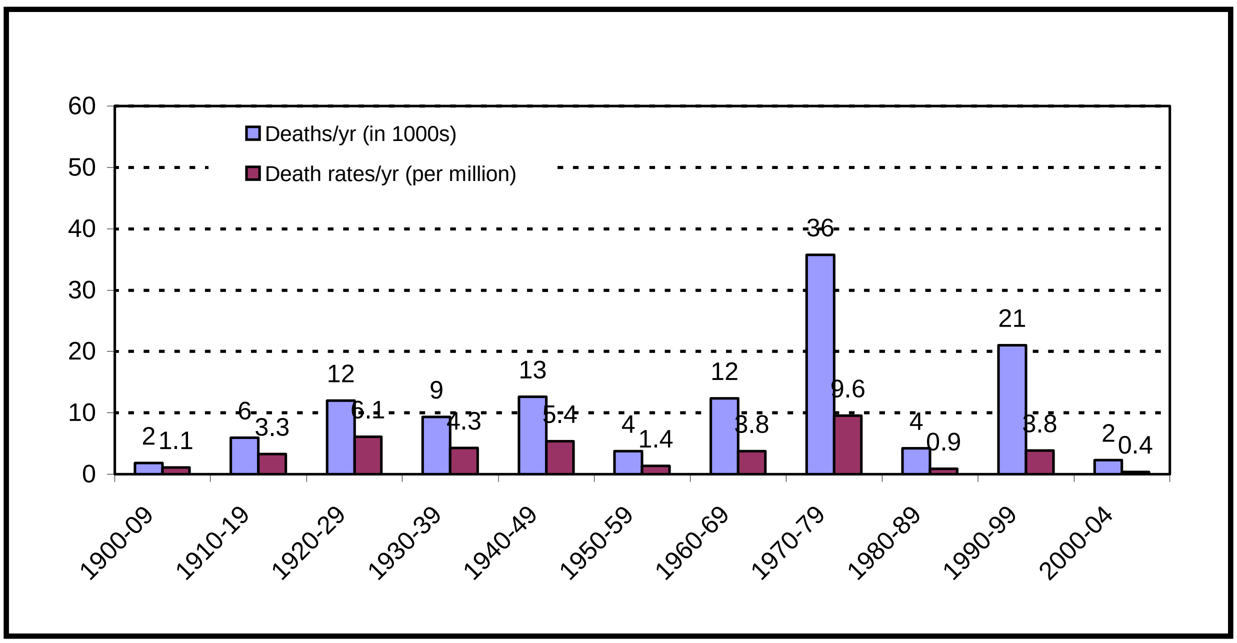

Figure 4: Windstorms: Global Deaths and Death Rates, 1900-2004. Sources: EM-DAT (2005); McEvedy and Jones (1978); WRI (2005).

Cause of Death	No. of Deaths	Percent of Total Deaths
I. Communicable Diseases	**18,324,000**	**32.13%**
Tuberculosis	*1,566,000*	*2.75%*
HIV/AIDS	*2,777,000*	*4.87%*
Diarrhoeal diseases	*1,798,000*	*3.15%*
Malaria	*1,272,000*	*2.23%*
Other tropical diseases	*129,000*	*0.23%*
Other infectious & parasitic diseases	*3,362000*	*5.90%*
Subtotal -- Infectious and parasitic diseases	*10,904,000*	*19.12%*
Respiratory infections	*3,963,000*	*6.95%*
Nutritional deficiencies	*485,000*	*0.85%*
Maternal and perinatal conditions	*2,972,000*	*5.21%*
II. Noncommunicable Conditions	**33,537,000**	**58.81%**
Malignant neoplasms	*7,121,000*	*12.49%*
Cardiovascular diseases	*16,733,000*	*29.34%*
Respiratory diseases	*3,702,000*	*6.49%*
Other noncommunicable conditions	*5,981,000*	*10.49%*
III. Injuries	**5,168,000**	**9.06%**
Road traffic accidents	*1,192,000*	*2.09%*
Violence	*559,000*	*0.98%*
War	*172,000*	*0.30%*
Extreme weather events	**19,400**	**0.03%**
All other injuries	*3,225,600*	*5.66%*

Table 2: Global deaths per year due to various causes, early 2000s. NOTE: All data are for 2002, except for deaths due to extreme weather events, which are based on the annual average from 2000-2004. Sources: WHO (2004), EM-DAT (2005).

THE GLOBAL MORTALITY BURDEN FROM EXTREME EVENTS

To place the current death toll due to all extreme weather events in a wider context, consider that the average annual death toll for 2000-2004 due to all weather-related extreme events according to EM-DAT (2005) was 19,400. By contrast, the World Health Organization (2004) estimates that in 2002 a total of 57.0 million people died worldwide from all causes, including 5.2 million from other kinds of accidents. Out of these, road traffic was responsible for 1.2 million deaths, violence (other than war) for 0.6 million, and war for 0.2 million (see Table 2). Thus, while extreme weather-related events, because of their episodic nature, garnish plenty of attention worldwide, their contribution to the global mortality burden is, at 0.03 percent of global deaths, relatively minor. Their contribution to the global burden of disease should be similarly small.

Notably, the contribution of extreme events to the mortality burden for accidental causes of death is also small (at 0.4 percent). Also, over the last fifty years at least, the general decline in annual mortality due to extreme weather events (see Figure 1) has occurred despite an increase in all-cause mortality (WRI 2005).

A recent review paper in *Nature* (Patz et al. 2005) estimates that climate change may have been responsible for over 150,000 deaths worldwide in 2000. This estimate is largely based on an analysis put out under the auspices of the World Health Organization (McMichael et al. 2004). The latter study arrived at its estimate by ascribing to climate change (a) 77,000 out of about 250,000 deaths due to protein malnutrition, 47,000 out of about 2 million deaths due to diarrheal disease, and (c) and 27,000 out of over 1 million deaths due to malaria (see WHO 2002). It also ascribed 2,000 deaths to floods in 2000, based on the EM-DAT data base. Although this study's estimates for non-flood-related deaths are problematic,[6] if one accepts them as valid, that means that climate change currently accounts for less than 0.3 percent of all global deaths. Accordingly, based on current contributions to the global mortality burden, other public health issues outrank climate change.

U.S. TRENDS IN MORTALITY AND MORTALITY RATES, 1900-2004

Among the problems in developing a long time series for U.S. deaths due to all (or most) extreme weather phenomena is that the length of the U.S. (data) record varies according to the type of event. The *Annual Summaries* (e.g., NOAA 2004, 2005) published by National Oceanic and Atmospheric Administration (NOAA) provides time series data on fatalities due to hurricanes, floods, tornadoes and lightning, respectively, from 1900, 1903, 1916 and 1959 onward. Each year's summary also gives that year's death toll due to a variety of other weather related phenomena such as extreme cold, extreme heat, drought, mudslides, winter storms, avalanches, etc., but it does not provide any time series data for these other categories of natural disasters. Another problem is that the data for several phenomena from these summaries are at variance with other data sources. Specifically, there are discrepancies between mortality data from these Annual Summaries and (a) the Hydrologic Information Center's (HIC 2005) estimates for floods, (b) the National Hurricane Center's data for hurricanes (Blake et al. 2005), and (c) CDC's WONDER database for extreme cold and extreme heat. Based on previous conversations with personnel from the various agencies (Goklany 2000), it

[6] The authors themselves note that among the challenges in developing estimates of the health impacts of climate change is that "climate change occurs against a background of substantial natural climate variability, and its health effects are confounded by simultaneous changes in many other influences on population health….Empirical observation of the health consequences of long-term climate change, followed by formulation, testing and then modification of hypotheses would therefore require long timeseries (probably several decades) of careful monitoring. While this process may accord with the canons of empirical science, it would not provide the timely information needed to inform current policy decisions on GHG emission abatement, so as to offset possible health consequences in the future. Nor would it allow early implementation of policies for adaptation to climate changes." Hence the estimates were based on modeling studies, with quantification based on anecdotal information. The temperature-disease relationship used to develop the estimate for diarrhea, for example, was based on 6 years worth of data from Lima, Peru, and 20 years of data from Fiji. In addition, the amount of climate change estimated for 2000 was based on the results of a general circulation model at resolution of 3.75o longitude and 2.5o latitude. The results of such models, which are inexact at best at the global level, tend to greater uncertainty as the resolution gets finer.

was decided to use HIC data for floods (as adjusted per Goklany 2000), and Blake et al. (2005) for hurricanes through 2004. The Center for Disease Control's WONDER database was used for extreme heat and cold, because it is based on actual death certificate records, which, in turn, are based on medical opinion as opposed to the National Weather Service's expert opinion. To date (April 2005), these data are readily available only from 1979 to 2002.[7]

Figure 5 shows the trend in cumulative deaths and death rates for a subset of extreme weather events, specifically, hurricanes, floods, tornados, lightning, and extreme heat and cold from 1979-2002.[8] It shows that despite any warming that may have occurred, both deaths and death rates have not increased over this period. If anything, they might have declined over this period, during which all-cause mortality increased by 28 percent (USCB 2004).

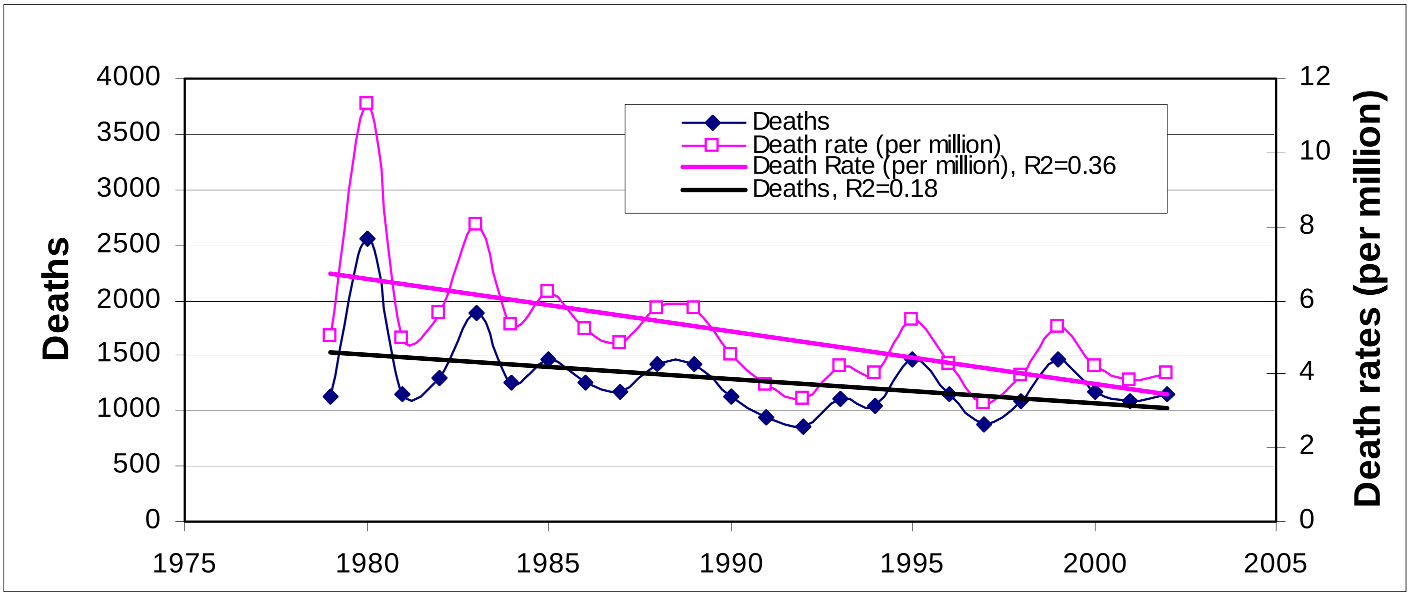

Figure 5: Cumulative U.S. Deaths and Death Rates, 1979-2002, for Hurricanes, Floods, Lightning, Tornados, Extreme Heat and Extreme Cold. Sources: for hurricanes, Blake et al. (2005); for lightning and tornados, NWS (2004, 2005) and Hinson (2005); for floods, HIC (2005); for extreme heat and cold, CDC (2005).

The linear trend lines plotted in Figure 5 (and any subsequent figures) were automatically generated by EXCEL, which uses ordinary least squares analysis. Notably, the bulk of the weather-related deaths (53 percent) during this period were caused by extreme cold. In importance, these were followed by extreme heat, floods, lightning, tornados, and hurricanes, which contributed 28, 8, 5, 4 and 2 percent, respectively. See Table 3.

[7] To further complicate matters, the NOAA website provides a "65-Year List of Severe Weather Fatalities" (from 1940-2005. Unfortunately, the data in this list for lightning is inconsistent with the data from its *Annual Summaries*. Enquiries to NOAA, so far, have not resolved these discrepancies satisfactorily.

[8] In the WONDER database, mortality data for 1979-1998 are coded using the International Classification of Disease, version 9 (i.e., ICD-9) for 1979-1998, and ICD-10 for 1999 onward. To identify deaths due to extreme heat, I used codes E900.0 and E900.9 for ICD-9 (per Goklany and Straja 2000), and X30 for ICD-10. The corresponding codes used for extreme cold were E901.0 and E901.9, and X31, respectively.

	Cumulative deaths	Deaths per year	Percent of annual all-cause deaths
Extreme cold (XC)	16,313	680	0.031%
Extreme heat (XH)	8,589	358	0.016%
Flood (F)	2,395	100	0.005%
Lightning (L)	1,512	63	0.003%
Tornado (T)	1,321	55	0.003%
Hurricane (Hu)	460	19	0.001%
Sum	30,590	1,275	0.058%
Total deaths, all causes, 1979-2002 average		2,189,000	100.000%

Table 3. US deaths due to weather-related events, 1979-2002. Sources: for extreme events, see text; for total all-cause mortality, USCB (2004).

Figures 6 (and 7) show the 10-year moving averages for deaths (and death rates) due to hurricanes from 1900-2005, floods from 1903-2004, tornados from 1916-2004, and lightning from 1959-2004, as well as for cumulative deaths (and death rates) from these four individual categories of events (from 1959 to 2004). Death rates in Figure 7 are calculated using national population estimates from the US Census Bureau (USCB).[9]

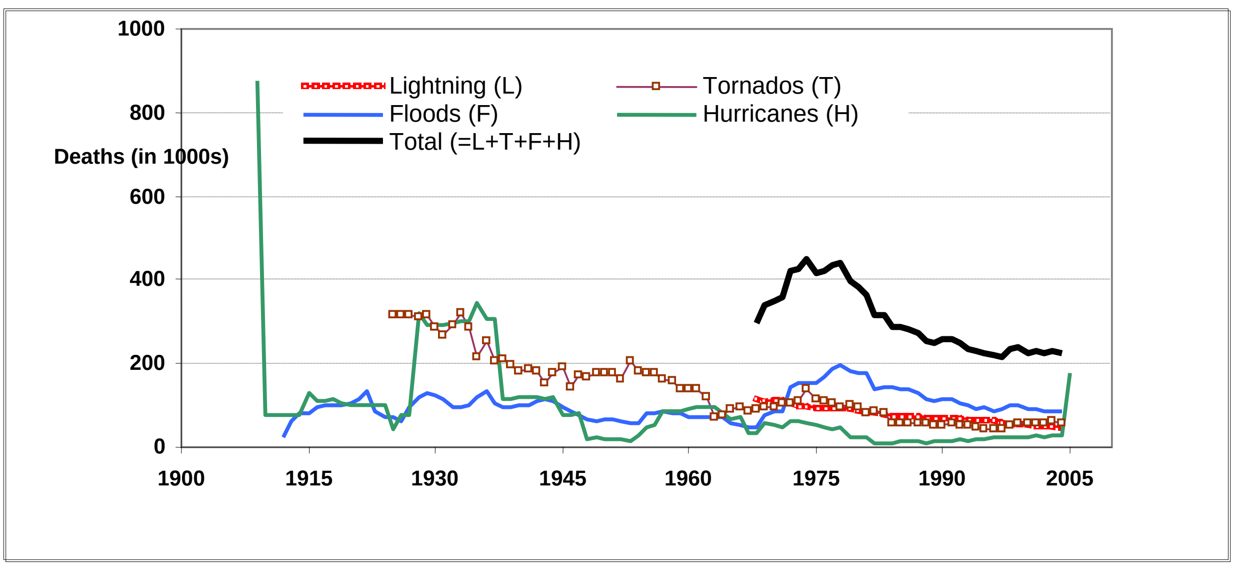

Figure 6: U.S. Deaths due to Hurricanes (1900-2005), Floods (1903-2004), Tornados (1916-2004), Lightning, (1959-2004) and Total (1959-2004); 10-year moving averages. Sources: for hurricanes, Blake et al. (2005), and NHC (2006); for lightning and tornados, NWS (2004, 2005) and Hinson (2005); for floods, HIC (2005) and Goklany (2000).

[9] For hurricanes it might have been more appropriate to use annual estimates of the coastal population to estimate death rates, but that would have complicated calculations of cumulative death rates.

Figure 6 shows that for the most recent 10-year period for which data are available or estimated (i.e., from 1996-2005 for hurricanes and 1995-2004 for the other types of events), deaths declined below their earlier peaks in the 10-year moving averages by 56 percent for floods, 58 percent for lightning, 82 percent for tornados and, despite Hurricane Katrina, 80 percent for hurricanes. Such declines are consistent with results of earlier analyses (Goklany 2000). Similarly, Figure 7 indicates that the corresponding declines for death rates (comparing their peaks with the most recent 10-year period) were 76 percent for floods, 72 percent for lightning, 95 percent for hurricanes and 93 percent for tornados.

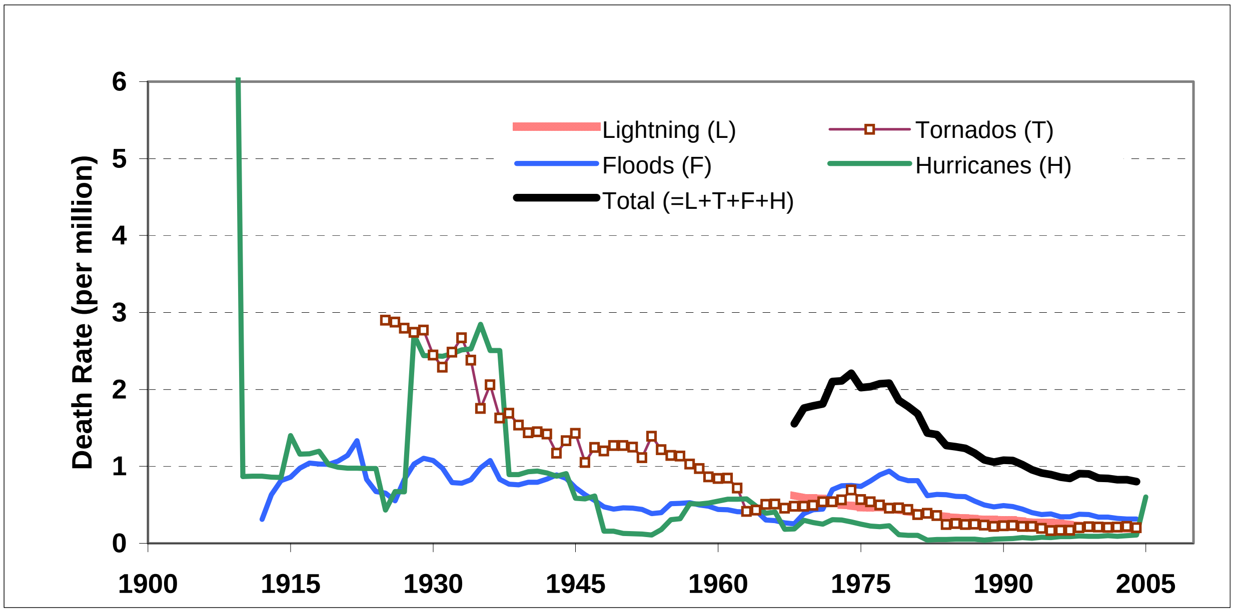

Figure 7: U.S. Deaths Rates due to Hurricanes (1900-2005), Floods (1903-2004), Tornados (1916-2004), Lightning, (1959-2004) and Total (1959-2004); 10-year moving averages. Sources: for hurricanes, Blake et al. (2005) and NHC (2006); for lightning and tornados, NWS (2004, 2005) and Hinson (2005); for floods, HIC (2005) and Goklany (2000); for population, USCB (2006).

Both figures show:

- A large spike for hurricanes at the very beginning of the record due to the Galveston Hurricane of 1900, and a smaller spike due to Hurricane Katrina at the very end punctuated by a relatively high plateau in the late 1920s which extended into the late 1930s, and troughs extending from the late 1940s to the early 1950s and, again, in the 1980s and 1990s.[10] This is also illustrated in Figure 8.[11]
- Mortality and mortality rates dropped more or less steadily for lightning and tornados over the period for which records are available. These results are consistent with earlier analyses for both sets of events by Goklany (2000), and Doswell et al (1999) for tornados.
- Mortality from floods exhibit no particular trend from 1903 to 2004, although mortality rates might have declined somewhat (see also Figure 9).[12] Mortality due to floods in 2005 is expected to be higher than in previous years because of floods related to hurricanes that year.

[10] These figures assume 1,500 deaths in 2005. As of 10 April 2006, according to the National Hurricane Center (2005) there were 1,409 confirmed deaths due to hurricanes during 2005. However, I rounded this number up because the Katrina count is not yet complete. The figures also assume a death toll of 8,000 for the 1900 Galveston Hurricane (Blake et al. 2005).

[11] Note that in Figure 8 the data for the last period is based on a six year average, while that for other periods are based on ten year averages.

[12] In Figure 9 the data for the last period is based on a five year average, while that for other periods are based on six year averages.

- Cumulative annual mortality and mortality rates for the above four categories of extreme weather events have declined since the mid-1970s. Figure 10 indicates that both deaths and death rates for these four categories declined 24 and 52 percent, respectively, from 1959-64 to 2001-04.[13]

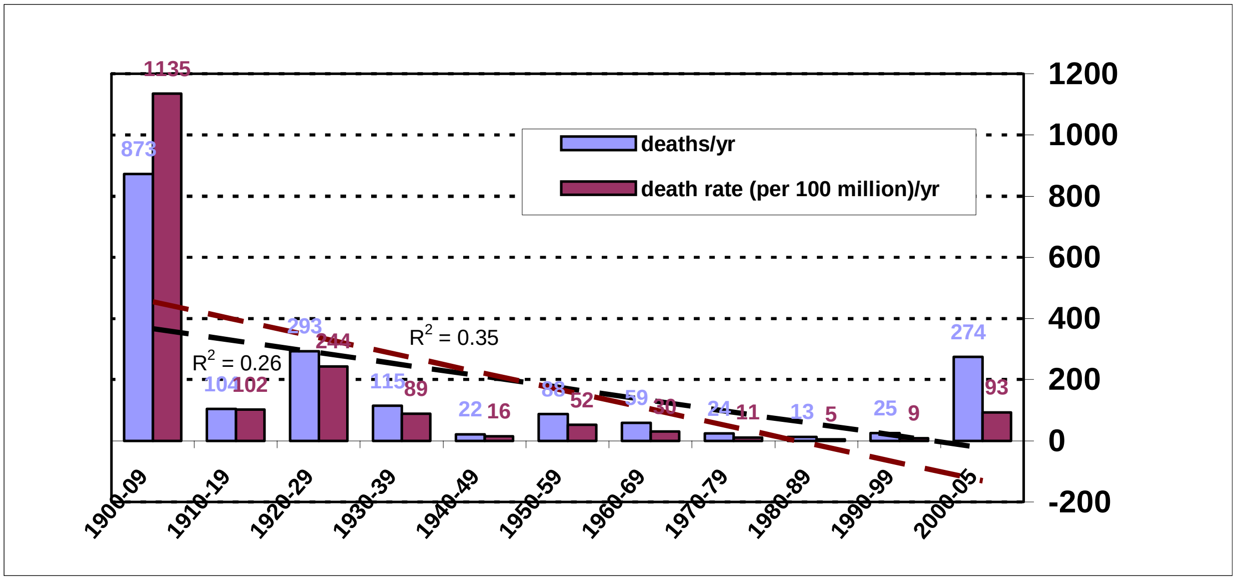

Figure 8: Annual U.S. Deaths and Death Rates due to Hurricanes, 1900-2005. Sources: Blake et al. (2005); NHC (2006); USCB (2006).

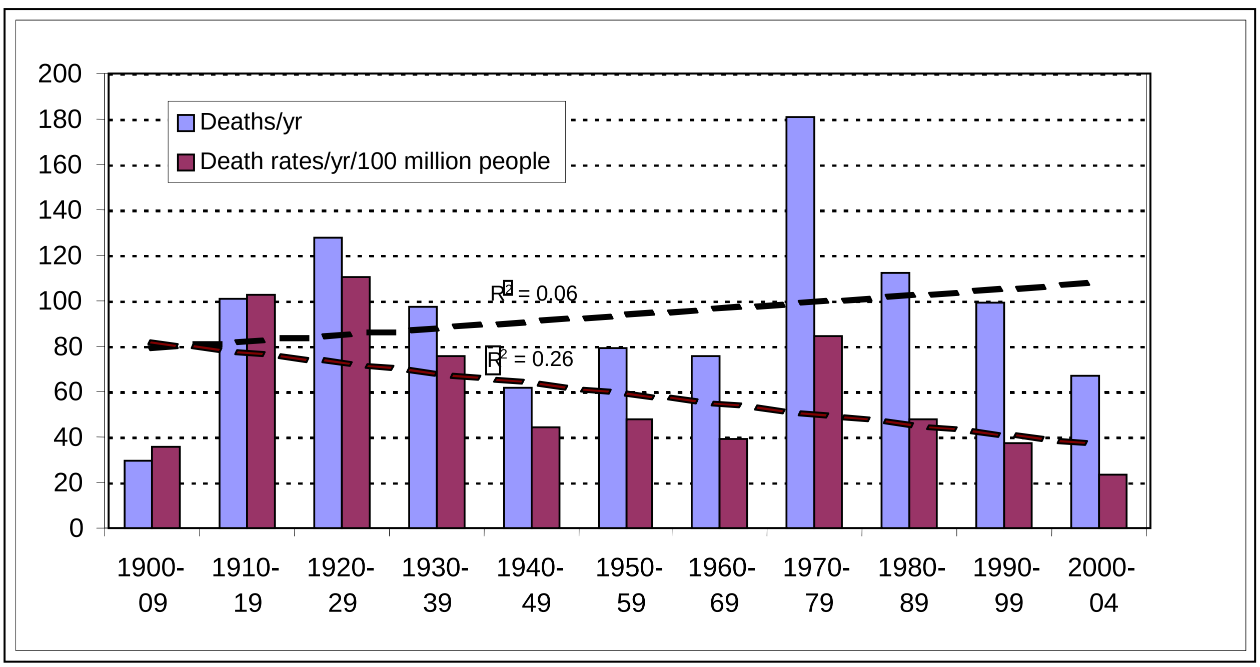

Figure 9: Annual U.S. Deaths and Death Rates due to Floods, 1903-2004. The data for 1900-1909 are based on the seven-year average from 1903 through 1909 because the HIC's series starts in 1903. Sources: HIC (2005); USCB (2006).

[13] Note that the last period spans four years, while the other periods span six years. Also, the decline between 1971-76 to 2001-04 ranges from 56 percent for mortality and 68 percent for the mortality rate.

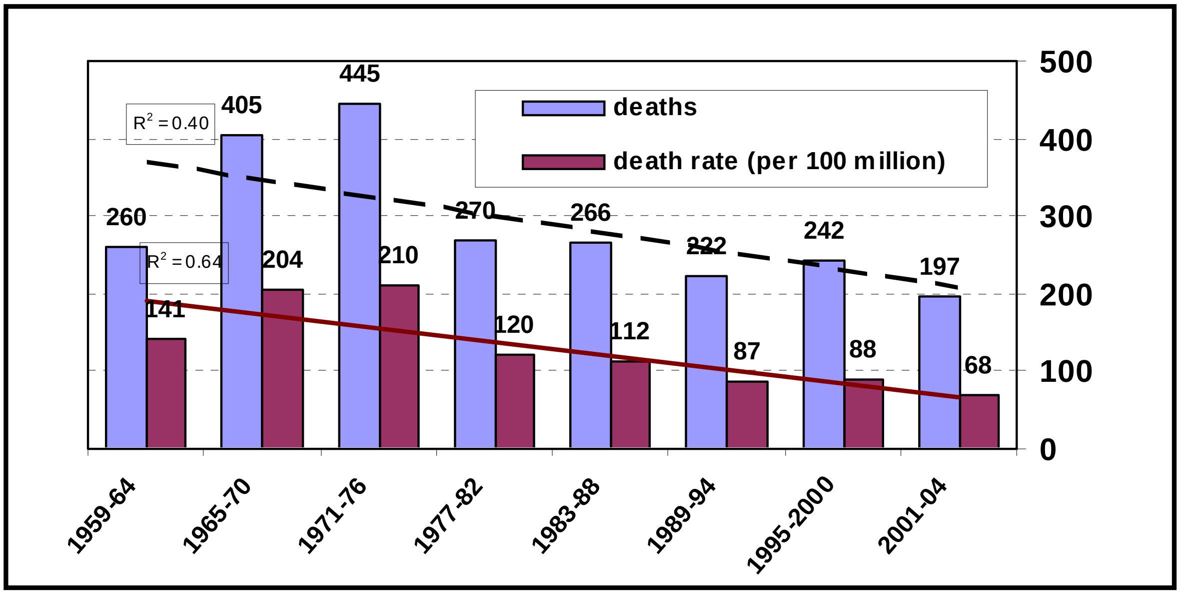

Figure 10: Cumulative Annual U.S. Deaths and Death Rates from Hurricanes, Floods, Lightning, and Tornados, 1959-2004. Sources: For hurricanes, Blake et al. (2005); for lightning and tornados, NWS (2004, 2005); for floods, HIC (2005); for population USCB (2006).

The previous figures (6 through 10) show that currently deaths and death rates are, in general, lower than they used to be in the past. Predictably, death rates have declined more rapidly than deaths per year, confirming results from previous studies (Goklany 2000).

Discussion and Conclusions

The information presented above indicates that globally as well as for the United States, the aggregate contribution of extreme weather events to the mortality burden is currently relatively minor, ranging from 0.03 to 0.06 percent.

Moreover, if the frequency, intensity and duration of extreme weather events has increased in recent decades — all empirical issues best left to climatologists — there is no signal of that in the data on either mortality rates or, more importantly, mortality despite an increase in populations at risk.

At the global level, the data, while incomplete, indicate:

- Aggregate annual mortality and mortality rates owing to extreme weather events have declined between 95 and 99 percent, respectively, since the 1920s regardless of whether the frequencies, intensities and/or durations of extreme weather events have increased (or not) due to human-induced or natural climate change.
- Much of the above improvement is due to a substantial decline in mortality due to droughts and floods, which apparently caused 95 percent of the fatalities due to extreme events between 1900 and 2004.
- Death rates for the different categories of extreme events were generally lower in the 1990s and early-2000s than in previous decades, with the notable exception of extreme temperatures, which were higher because of the 2003 European heat wave.
- Regarding windstorms, both mortality and mortality rates peaked in the 1970s. The average annual mortality due to windstorms over the past 15 years exceeded the average over the rest of the 20th century but the mortality rate was a third lower.

With respect to the United States:

- In an average year, more lives are lost to extreme temperatures — both extreme heat and extreme cold — than to more heavily publicized events such as tornados, hurricanes and floods. According to data from the Centers for

Disease Control, extreme cold, on average, claims more lives than tornados, floods, lightning, hurricanes and extreme heat, combined.

- In general, mortality and mortality rates from the various categories of extreme events examined here (tornados, hurricanes, floods, lightning and extreme temperatures) are lower today that they have been in the past. Based on 10-year moving averages, for the most recent 10-year period for which data are available (or for which data can be approximated), mortality declined by 55-80 percent for floods, lightning, tornados and hurricanes while mortality rates declined by 70-95 percent. However, there are no consistent trends for mortality due to floods, and both mortality and mortality rates for hurricanes spiked in 2005. However, these spikes are lower than levels that had been reached in previous periods.

Thus, mortality rates and, more significantly, mortality for the most deadly and destructive forms of extreme weather events have apparently declined substantially over the past several decades. This suggests that if climate change has exacerbated extreme events then either mankind has been extremely lucky in terms of where and when these events have struck or — a more likely explanation — society's ability to cope with extreme events has not only improved, it has for the most part put its increased adaptive capacity to good effect.

Several interrelated factors have contributed to this increase in adaptive capacity. First, today's societies have available to them a wider range of technological options to finesse the consequences of extreme events before they strike and to cope with their aftermath after they have struck. Such options range from early warning systems, building codes, and better meteorological forecasts to better construction, communications and transportation systems which increased the ability to transport men and materiel (including food, medical and other essential supplies) in and out of disaster zones. Second, many of these options were learnt through experience and were enabled through the ability of wealthier societies to research and develop new technologies and practices. Greater wealth also allowed them to obtain and implement more effective technologies. Once developed, it is possible for poorer societies to learn from and adapt technologies developed in wealthier, more technologically sophisticated nations. Third, societies have greater access to human and social capital to protect themselves from, and cope with, adversity in general and extreme weather events in particular (IPCC 1991; Goklany 1995, 2000, 2006; Goklany and Straja 2000).

However, as indicated by the European experience with the 2003 heat wave and the U.S. experience with Hurricane Katrina, the importance of human and social capital cannot be overemphasized. They are just as important as wealth and increased access to technology. Moreover, greater adaptive capacity is necessary but not sufficient to effectively cope with extreme events. Such capacity must be deployed more rapidly and used more fully.

Nevertheless, the decline in deaths and death rates from extreme events indicates that if the frequencies, intensities and durations of extreme events have increased then adaptive capacity has evolved even faster, and thus far wealth, technology, and human and social capital have, despite notable exceptions, have for the most part apparently trumped natural climatic variability and human-induced climatic change.

Finally, it has been suggested that declining trends for deaths (and death rates) due to extreme events might be accompanied by — or might contribute to — increasing trends in economic losses based on the general notion that individuals might accept greater financial risks provided personal safety is more assured (Goklany 2000). In addition, a wealthier society is likely to have more property at risk which, moreover, would be exacerbated by the fact that improvements in housing stock, infrastructure and support systems undertaken to cope with extreme events further adds to the property at risk.

For the U.S., results of this paper combined with previous studies of economic losses due to various categories of extreme events suggests (but does not prove) that declining mortality is indeed accompanied by higher economic losses if losses are measured in terms of real (constant) dollars for floods, hurricanes, and tornados; but this does not seem to be the case if losses are measured in terms of a fraction of wealth (measured as fixed tangible reproducible assets, which excludes land values) (Pielke and Landsea 1998, Doswell et al. 1999, Goklany 2000, Pielke, Jr, and Downton 2000, Downton et al. 2005).

Globally, the analysis in this paper and the estimates of economic losses in constant dollars provided by the IPCC's Third Assessment report suggest that declining mortality is also accompanied by increasing property losses (see also, Faust et al. 2006). However, it is impossible to say at this time whether the upward trend for economic losses would hold were global economic losses to be measured in terms of global wealth because appropriate data are lacking.

References

Anderson, J.; Bausch, C. 2006. Climate change and natural disasters: Scientific evidence of a possible relation between recent natural disasters and climate change. Policy Brief for the EP Environment Committee, IP/A/ENVI/FWC/2005-35. Available at: http://www.europarl.eu.int/comparl/envi/pdf/externalexpertise/ieep_6leg/naturaldisasters.pdf. Accessed on 27 April 2006.

Brooks, H.E.; Doswell III. C.A. 2001: Normalized Damage from Major Tornadoes in the United States: 1890–1999. *Weather and Forecasting*, 16, 168–176.

Blake, E.S.; Jarrell, J.D.; Mayfield, M.; Rappaport, E.N.; Landsea, C.W. 2005. *The Deadliest, Costliest, and Most Intense United States Hurricanes from 1851 to 2004 (and other Frequently Requested Hurricane Facts)*.

Doswell III, C.A.; Moller, A.R.; Brooks, H.E. 1999. Storm Spotting and Public Awareness since the First Tornado Forecasts of 1948. *Weather and Forecasting,* 14, 544–557.

Downton , M.W.; Miller, J.Z.B.; Pielke Jr., R.A. 2005. Reanalysis of U.S. National Weather Service Flood Loss Database. *Natural Hazards Review,* February 2005: 13-22.

Emanuel, K.. 2005a. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, 436, 686-688, posted on-line August 4, 2005, doi:10.1038:nature3906.

Emanuel, K. 2005b. Meteorology: Emanuel replies. *Nature,* 438, E13.

EM-DAT: The OFDA/CRED International Disaster Database, available at www.em-dat.net, Université Catholique de Louvain, Brussels, Belgium. Data downloaded on 6 September 2005.

Faust, E.; Höppe, P.; Wirtz, A.: Schmidt, S. 2006. Trends in natural catastrophes – potential role of climate change, *Climate Change and Disaster Losses Workshop: Understanding and Attributing Trends and Projections*, Hohenkammer, Bavaria, Germany, May 25–26, 2006.

Goklany, I.M. 1995. "Strategies to enhance adaptability: technological change, economic growth and free trade." *Climatic Change,* 30, 427-449.

Goklany, I.M. 1998. "Saving habitat and conserving biodiversity on a crowded planet." *BioScience*, 48, 941-953.

Goklany, I.M. 2000. "Potential consequences of increasing atmospheric CO_2 concentration compared to other environmental problems." *Technology,* 7S, 189-213.

Goklany, I.M. 2006. "Integrated strategies to reduce vulnerability and advance adaptation, mitigation, and sustainable development." Forthcoming in *Mitigation and Adaptation Strategies for Global Change* .

Goklany, I.M.; Straja, S.R. 2000. U.S. death rates due to extreme heat and cold ascribed to weather, 1979-1997. *Technology*, 7S, 165-173.

Hinson, S. 2005. National Climatic Data Center. Personal communication (August 22).

Hydrologic Information Center. 2005. Flood Fatalities. Available at http://www.nws.noaa.gov/oh/hic/flood_stats/recent_individual_deaths.shtml. Accessed 22 August 2005.

Intergovernmental Panel on Climate Change. 1991. *Climate Change: The IPCC Response Strategies*. Wash., DC, Island Press.

Intergovernmental Panel on Climate Change. 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge, Cambridge University Press, p. 7.

Kluger, J. 2005. Climate change: The culprit? *Time*, October 3, 2005.

Kluger, J. 2006. Earth is at the tipping point. *Time*, March 27, 2006.

Landsea, C.W. 2005. Hurricanes and global warming. *Nature*, 438, E12-E13.

MacMichael, A, Woodruff, R. 2004. Climate change and risk to health *BMJ* , 329, 1416-1417 (18 December), doi:10.1136/bmj.329.7480.1416.

McEvedy, C.; Jones, R. 1978. *Atlas of World Population History*, New York, Penguin.

McMichael, A., et al. 2004: Global climate change. In: *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors*. World Health Organization, Geneva, pp. 1543-1649.

National Hurricane Center, 2005. *2005 Atlantic Hurricane Season*. Available at http://www.nhc.noaa.gov/2005atlan.shtml. Accessed 10 April 2006.

National Weather Service. 2004. *2003 Annual Summaries*. Available at http://www.nws.noaa.gov/om/severe_weather/sum03.pdf.

National Weather Service. 2005. *Summary of U.S. Natural Hazard Statistics*. Available at http://www.nws.noaa.gov/om/severe_weather/sum04.pdf.

Patz J. 2004. Climate change: Health impacts may be abrupt as well as long-term. *BMJ* , 328, 1269-70.

Pielke, Jr., R.A. 2005. Are there trends in hurricane destruction? *Nature*, 438, E11.

Pielke, Jr., R.A.; Downton, M.W. 2000. Precipitation and Damaging Floods: Trends in the United States, 1932–97. *Journal of Climate*, 13, 325-337.

Pielke, Jr., R.A.; Landsea, C.W. 1998. Normalized Hurricane Damages in the United States: 1925–95. *Weather and Forecasting*,13, 621–631.

Schiermeier, Q. 2003. Climate change: The long road from Kyoto. *Nature*, 426, 756.

Schiermeier, Q. 2005. Trouble brews over contested trend in hurricanes. *Nature*, 435, 1008-1009.

Trenberth, K.; Taylor, G. Undated. "Does Climate Change Cause More Extreme Weather? YES. Economic Effects of Weather Disasters Warrant Action on Warming; NO. Blaming Disasters on Global Warming Doesn't Help." *Washington Post Issues Forum: Global Climate Change*,. Available at http://www.washingtonpost.com/wp-adv/specialsales/nei/global/article9.htm. Accessed 4 February 2003.

U.S. Census Bureau. 2004. *Statistical Abstract of the United States, 2004-2005*. Available at http://www.census.gov/statab/www/.

U.S. Census Bureau. 2006. *Statistical Abstract of the United States, 2006*. Available at http://www.census.gov/statab/www/.

Webster P., et al. 2005. Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science*, 309, 1844-1846.

World Health Organization. 2002. *World Health Report 2002 — Reducing Risks, Promoting Healthy Life*. WHO, Geneva, Annex Table 2, p. 186.

World Health Organization. 2004. *World Health Report 2004 — Changing History*. WHO, Geneva, Annex Table 2, p. 120.

World Resources Institute. 2005. *Earth Trends*. Available at http://www.wri.org.

CLIMATE CHANGE AND DISASTER LOSSES: UNDERSTANDING AND ATTRIBUTING LOSSES AND PROJECTIONS

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Question 1: What factors account for the dramatically increasing costs of weather-related disasters (specifically, floods and storms) in recent decades?[2]

Losses (adjusted for inflation) caused by natural catastrophes, as defined by the US property insurance industry, have risen by a factor close to 100 between the 1950s and the past decade (Changnon et al. 2000). For a storm to create significant economic losses, two conditions have to be met: storm occurrence at a sufficiently high intensity, and exposition of vulnerable assets to this hazard. Losses increases have to be driven by one of these two factors, or recent appearance of new loss drivers.

Could part of these losses increases be driven by greenhouse induced global warming? Over the tropical North-Atlantic, the tropical cyclone record extends back to 1900. The North-Atlantic is the basin where data is the most complete, but it is only since 1970 that the data set is considered appropriate for detection of trends. Prior to that date, storms may have been missed. Post-1970 hurricane wind speed records indicate a clear increase in hurricane activity over the past decades (Emanuel 2005, Webster et al. 2005) which is well correlated with North-Atlantic Sea Surface Temperatures (SST) trend. At least part of this trend is attributed to anthropogenic activities (Pierce et al, 2006). However, even for this modern era record, there is some controversy in hurricane wind speed estimates (Landsea, 2005). Added to the short duration of the record, this makes Landsea (2005) question whether the observed recent increase in hurricane activity is forced by anthropogenic activities. Longer records over the US continent show that in the past, hurricane activity did fluctuate at multi-decadal time scales (Landsea 2005), and that these fluctuations correlate well with the principal modes of low-frequency variability in the Tropics (Bell and Chelliah 2006). This low-frequency tropical cyclone variability is evidenced through coherent behaviour of the entire circulation in the Tropics (Bell and Chelliah, 2006) and affects mostly the annual rate of occurrence of major events (Goldenberg et al. 2001). From the current literature, it is therefore not quite clear whether the recent increase in hurricane dissipation power (Emanuel 2005) is a manifestation of global warming (through SST increase) or whether it reflects natural climate variability, or a combination of both.

Modelling studies regarding the intensification of hurricanes as a result of warmer SSTs can help resolve this issue. Oouchi et al (2005) report results obtained with a very high horizontal resolution climate model (20 km grid resolution) that show an increase in maximum wind speed as a result of anthropogenic activities, but a significant decrease in cyclone frequency (except over the North-Atlantic). These results obtained with a model that explicitly resolves tropical cyclone circulations, are in line (in terms of intensity) with those reported by Knutson and Tuleya (2004) and with theoretical considerations (Emanuel 1987). However, it is worth noting that up to now, no trends in maximum hurricane wind speed have been detected from the data (Webster et al. 2005). One reason for this may be that hurricane maximum intensity has a short tail distribution and therefore an upper bound, obtained from theoretical considerations (Bister and Emanuel 1998, Emanuel 1999) or from modelling the data with extreme value distributions.

[1] The views expressed are those of the author and do not necessarily reflect the views of the AXA group

[2] Answer is provided in the context of the tropical cyclone discussion

Because storms only occasionally reach this theoretical upper limit, and because this particular moment in the storm life cycle may not be properly reported in 6-hourly records, it may be a while before trends in hurricane maximum intensity are actually detected from observational data.

Hurricane losses records properly normalized reflect the multi-decadal variability of hurricane activity over the North-Atlantic and the US coast, but do not reflect any long-term trend (Pielke and Landsea, 1998, Pielke 2005). For eleven years, the activity has been intense if not extreme across the North-Atlantic and losses are very significant over the past two years, but *normalized per-storm loss* does not show evidence of a trend over the 20th century (Pielke 2005). Over a sufficient amount of time, trends in hazard should manifest in trends in per-storm loss (after proper normalization, a manifestation of increasing severity), and/or trends in annualized cumulative losses (after normalization, a manifestation of increasing annual rate of occurrence). As none can be detected today, it seems premature to attribute recent hurricane losses to trends in hazards resulting from global warming, although following Trenberth (2005) we note that non-detecting does not enable to conclude regarding the existence.

Corrected for inflation, the cause of increasing disaster losses over the past century is for a very large fraction a result of increasing asset exposure to natural hazards (Changnon et al. 2000, Pielke 2005). In the past (centennial time scales) variability of natural geophysical hazards (including possible trends) has been orders of magnitude smaller than trend implied by economic or population growth: Hurricane Andrew loss estimate doubled in just 10 years because of migration and rise in assets values.

Recently, new loss drivers have contributed to record loss amounts. We specifically refer to demand surge, generally understood as the temporary increase in repair prices (building materials and labour costs) resulting from the surge of demand for rebuilding homes and services, following major events. Industry surveys, professional sources and CAT models vendor's communications indicate that in 2004 and 2005, demand surge was a very significant, non-linear component of the overall reported loss. Demand surge is a complex phenomenon, difficult to quantify and model, as it depends on micro- and macro-economical aspects, but also behavioural, environmental and political drivers. It is probably becoming an increasingly important component of the overall loss as the economy tends to operate in a particularly tense demand and supply environment. Another potential current and future loss driver is inflation of legal costs.

Question 2: What are the implications of these understandings, for both research and policy?

We provide an answer to this question in the context of assessing the economical cost of natural disasters for the society. Consequently, the metric needed for this assessment shall reflect the cost, for the society, of a given disaster economic loss. As the society – irrespective of the hazard occurring or even existing – evolves, the evolution of the cost for the society of a given natural hazard shall not reflect the overall society gradual move (economical growth, demography) but shall solely reflect the changes, in either the natural hazard itself or the society specific exposure and vulnerability to the natural hazard. A proper yearly metric reaching this goal can be defined as the yearly loss normalized by annually defined *cumulative nationwide asset*. This strongly relates to the GNP (Gross National Product). As stated above, this metric, the loss per asset value, or loss per GNP provides a time-varying view of the cost incurred by the society, undistorted by its overall evolution which occurs irrespective of the hazard, but which exemplifies specific factors affecting the loss itself. These specific factors are either geophysical, either societal:

- trends in natural hazard
- specific migration towards hazard-prone regions (meaning differential in coastal population growth versus overall nationwide population growth)
- modifications in exposure or vulnerability of assets exposed to the hazard (where, how, how vulnerable are assets).
- Sensitivity of the society to disaster losses (demand surge effects, claims litigation cost surge, …) different growth rate of the hazard-prone region compared to national growth rate

It is likely that only the first four factors are significant players in long-term variations of loss per asset value. It is interesting to note that if for example we were to address the question of future disaster losses incurred, not by the society, but for example by the US insurance industry, the metric used would be different. It should only reflect changes in natural hazards, and changes in exposure and vulnerability of the insured assets (points 1 and 3 above).

This metric is also appropriate to consider when discussing virtues of climate mitigation policy versus society adaptation for natural disaster assessment. This debate can be phrased as, for the Society (in the future), which policy should be promoted now in order to reduce the cost for the Society of future natural hazards. Clearly, what matters is the cost incurred by the Society and therefore loss per GNP is a proper measure of cost. The debate should therefore focus on comparing the benefit of society adaptation in reducing this loss per GNP, versus the benefit of reducing greenhouse gases emission in preventing any rise in this loss per asset value (taking as a possible scenario that loss per asset value could raise either by increasing storm frequency or severity). It is clear that taking society adaptation measures to protect against natural catastrophes should be promoted as it provides valuable benefits to the society and the people, irrespective of increasing hazard. The same argument holds however for climate mitigation: it provides benefits by reducing impacts of climate change on the environment and the society, irrespective of whether climate change is responsible for more severe extreme events. Benefits of one policy versus the other is not straightforward to assess because of the complexity of societal behaviour affecting losses. In the future, loss per asset value could be reduced if enforcement of stronger construction codes results in reduced vulnerability, reliable warnings were issued in advance to the exposed population and protection measures of homes were taken, construction was promoted further inland in less vulnerable areas than right on the coast, flood defences be erected, better awareness of people through education and media communication that ends up in a reduction of the migration flow towards exposed areas, etc …

How to measure the sensitivity of the loss per asset value to specific measures? Risk models, because they incorporate all aspects of the risk (hazard, exposure, vulnerability, cost surge and loss estimate) are very good candidates to address these issues. Sensitivity experiments can be specifically designed to quantify for example, the reduction in cost the society can expect from certain adaptation measures (as well as from mitigation measures, see for example the ABI 2005 report). The insurance industry, the scientific and the private sector modelling community, policymakers and local communities would benefit mutually from using these risk models to assess the sensitivity of the loss to varying assumptions.

References

Association of British Insurers, 2005 : Financial Risks of Climate Change, *Climate Risk Management and Metroeconomica*.

Bell, G. D. and M. Chelliah, 2006 : Leading tropical modes associated with interannual and multidecadal fluctuations in North Atlantic hurricane activity, *J. Climate*, **19**, 590-612.

Changnon, S.A., R. A. Pielke Jr., D. Changnon, R. T. Sylves, R. Pulwarty, 2000 : Human factors explain the increased losses from weather and climate extremes, *Bull. Am. Meteor. Soc.*, **81**, 437-442.

Bister, M. and K. Emanuel, 1998: Dissipative heating and hurricane intensity, *Meteor. Atmos. Phys.*, **65**, 233-240.

Emanuel, K, 1987: The development of hurricane intensity on climate, *Nature*, **326**, 483-485.

Emanuel, K., 1999: Thermodynamic control of hurricane intensity, *Nature*, **401**, 665-669.

Emanuel, K., 2005: Increasing destructiveness of tropical cyclones over the past 30 years, *Nature,* **436**, 686-688.

Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Nunez and W. M. Gray, 2001: The recent increase in Atlantic hurricane activity : causes and implications, *Science,* **293,** 474-479.

Knutson, T. R. and R. E. Tuleya, 2004 : Impact of CO2-induced warming on simulated hurricane intensity and precipitation : Sensitivity to the choice of climate model and convective parameterization, *J. Climate*, **17**, 3477-3495.

Oouchi, K., J. Yoshimura, H. Yoshimura, R. Mizuta, S. Kusunoki and A. Noda, 2005: Tropical cyclone climatology in global-warming climate as simulated in a 20 km-mesh global atmospheric model : frequency and wind intensity analyses, *J. Meteor. Soc. Jap.*, accepted.

Pielke R. A. Jr., and C. Landsea, 1998 : Normalized hurricane damages in the US : 1925-1995, *Wea. Forec.* , **13**, 621-631.

Pielke, R. A. Jr., 2005: Are there trends in hurricane destruction? *Nature,* **438**, 686-688.

Pierce, D. W., T. P. Barnett, K. M. AchutaRao, and P. J. Gleckler, 2006 : Anthropogenic warming of the oceans : Observations and model results, *J. Climate*, 19, 1873-1900.

Trenberth, K., 2005: Uncertainty in hurricanes and global warming, *Science*, **308**, 1753-1745.

Webster, P.J., G.J. Holland, J.A. Curry and H.-R. Chang, 2005: Changes in tropical cyclone number, duration and intensity in a warming environment, *Science*, **309**, 1844-1846

Overexploitation of ecosystem resources vs. the costs of storms and flooding risk management

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Introduction

Historically, human settlements followed land terraces and banks close to watercourses, but avoided main riverbeds because of flood risks. Especially during recent decades, enlarging human settlements like cities broke this habit and extended themselves within riverbeds, with the help of grand works of river regularization. In the same period, intense local and regional deforestation changed the flow regimes of large river basins, in the sense that rivers increased basic and flood volumes of waters. By the time human settlements and agglomerations already went a long way in incorporating riverbeds, changes in hydrological regimes determined that river systems found their old natural course and flooded the primary river beds (Plate, 2002).

A highly typical way of overexploitation of natural resources that leads to high water-related risks is deforestation. Forests regulate directly the surface water circuits through their physiological and ecologic functions. In addition, forests have indirect influences on natural water circulation as their biomass traps moisture and atmospheric carbon dioxide – the gas most responsible for the "greenhouse effect", thus acting as sinks. On the other hand, new findings (e.g. Keppler et al., 2006) state that methane (an important greenhouse gas) is readily formed in situ in terrestrial plants under "oxic conditions" by a hitherto unrecognized process, thus acting as a source. Nevertheless, the extensive loss of Earth's forests may contribute to increasing global warming (e.g. Arrow et al., 2000; Andreassian, 2004; The Economist, 2005), and eventually contributing to changes in weather and climate.

Dealing with climate-driven and weather-related risks requires fair understanding of three fundamental aspects. First, climatic changes (in temperatures and precipitations) are not equally distributed across the Earth. Second, socio-economic and techno-infrastructural capacity to deal with environmental hazards is also not equally distributed among regions and countries. Third, detailed mechanisms of interactions and influences of human and natural factors are rarely clear, and need highly complex analysis, because of a) co-variation of anthropogenic and natural gradients in the landscape, b) scale dependence of mechanisms, c) nonlinear behaviour of natural systems, and d) complex history of natural influences and land-uses (e.g. Doorkamp, 1998; Simonovic, 2000; Allan, 2004). Given these limitations, we make an attempt in this background paper to address the following two questions in context of the overexploitation of ecosystem resources versus the costs of storms and flooding risk management:

Question 1: What factors account for the dramatically increasing costs of weather-related disasters (specifically, floods and storms) in recent decades?

Question 2: What are the implications of these understandings, for both research and policy?

A brief analysis of factors (e.g. overexploitation of ecosystem resources) accounting for increasing costs of climatic/weather-related disasters, their implications, and insights followed by a summary is presented hereinafter.

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Contributing Factors

The weather-related disaster losses have increased dramatically in recent decades, as shown in a figure (http://www.grida.no/climate/ipcc_tar/wg2/fig8-1.htm) published in 2001 by the IPCC (Pielke, Jr., 2005). Moreover, the magnitude, frequency and impacts of storms and floods appear to have increased in the last decade apparently as a consequence of global climatic changes – but also because of higher human pressures over environment viz. deforestation, urbanization and river regularization (e.g. Kundzewicz and Kaczmarek, 2000; Muzik, 2002; WWDR1, 2003). In 2002, for example, approximately 47 percent of the Brazilian Amazon was under some type of human pressure including deforested areas, urban zones, agrarian reform settlements, areas allocated for mining and mining exploration as well as areas under pressure as indicated by incidence of fire in Fig. 1 (Barreto et al., 2006).

The mechanism through which forests control the surface water circuits is complex and not completely understood, but the basic processes are mainly related to mechanical reception of precipitations, respiration and biomass production, variation of soil hydrological and hydro-chemical properties (e.g. Naef et al., 2002). The runoff of meteoric water on surface slopes is dependent of the hydraulic properties of soils, notably soil infiltration capacity, the later being influenced by changes and memory effects associated with land-uses (Naef et al., 2002; Zimmermann et al., 2006). Agricultural expansion against forest cover can lead to constant degradation of land, albeit without significant increase in agricultural yields, especially in steep slope areas, for example like in Central Himalaya, India, during the 1967-1997 period (Wakeel et al., 2005).

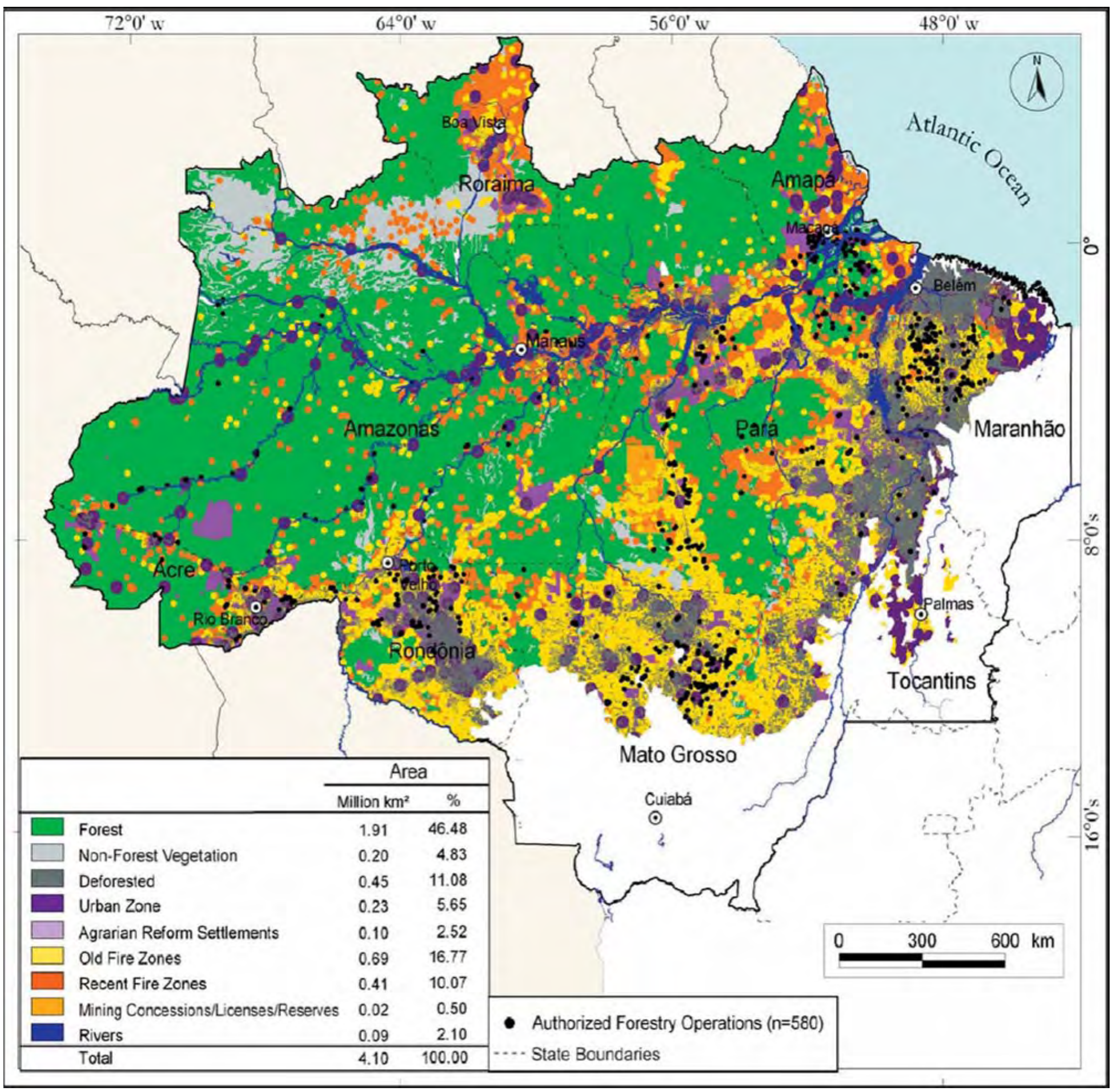

Fig.1: Human Pressure in the Brazilian Amazon - All Indicators (Source: Barreto et al., 2006).

It has been observed that the timber harvest and forest cover reduction usually results in increases of the stream flow. Just to give a short example, studies from southern Appalachian catchments showed that commercial clear-cutting resulted in 28% increase of the stream flow; water discharges diminished in the subsequent years as the wood vegetation started to recover (Swank et al., 2001). The extent of forest reduction needed to result in observable changes in water yield varies with geographical and biological properties of the river catchments (e.g. Stednick, 1996; Sun et al., 2005). Forest composition in a river collection basin directly influences how much effects forest have on low flows and peak flows in rivers (Robinson et al., 2003). Moreover, rapid urbanization of forested watersheds may cause higher peak flows and lower low flows, especially in areas with frequent heavy rains and steep slopes, one such representative example being Taiwan (e.g. Cheng et al., 2002).

Extreme storms and floods in the last decades happened mostly in Asia, but also in America and Europe. At present, about 40% of human population live in areas vulnerable to floods and rising sea levels, among nations most at risk being Bangladesh, China, India, Netherlands, Pakistan, Philippines, USA, and small island developing countries (Doornkamp, 1998; WWDR2, 2006). Tropical countries with monsoon climates (e.g. Bangladesh and India) are more prone to floods. Nevertheless, floods in the relatively small Red river in Canada and the USA in April-May 1997 have shown that developed temperate zone countries are not immune from them (Singh, 1997). In wealthy countries, however, while the number of fatalities from storms and floods go down, the material loses and economic risks keep rising, due to a increasing economic vulnerability in the general context of present policies (e.g., Kundzewicz and Kaczmarek, 2000; Hall et al., 2005). For example, costly ice storms in the US have been increasing strongly in recent years – as shown in Fig.2 (Changnon, 2003).

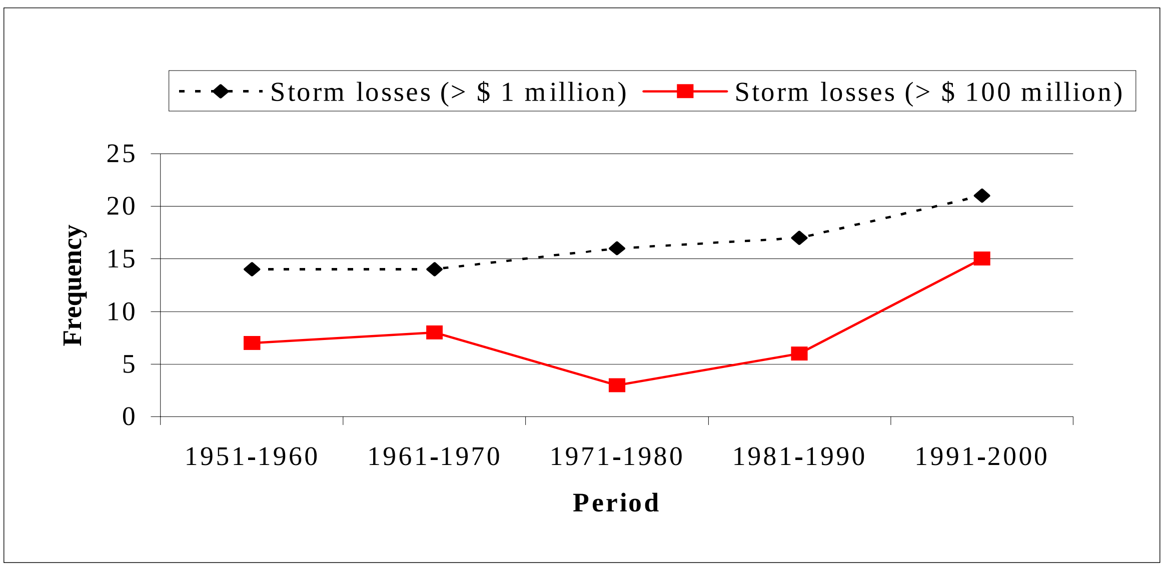

Fig. 2: The frequency of damaging ice storms during 1951-2000 in the US (as defined at two levels of losses – 1998 US $) (Data source: Changnon, S.A., 2003)

There are evidences that engineering measures such as storage, marginal embankments, improvement of waterways, etc. can and do reduce flood intensity and flood damage (Ojha and Singh, 2004). In contrast, Kundzewicz and Kaczmarek (2000) argue that higher cost of flood events is not only a policy issue, but a result of present practices e.g. over-reliance on engineering solutions such as dikes. The fact is that failure of physical solutions like dykes is usually, and inadvertently, considered as highly improbable. As a result, no significant preparation is carried out for such a possibility. One such example is the flooding of the New Orleans city in 2005, following dike failures during the level 5 hurricane Katrina. But this is not an isolated case. As a rule in the coastal areas, engineering works removed the danger from most (and low intensity) floods, so that what remain are only two situations: no flood or catastrophic floods (Doornkamp, 1998). Also, it is not uncommon that floods repeatedly visit the same country/area in short intervals, like it occurred in the Rhine River area in Germany during 1993 and 1995 and in South Korea in 1995 and 1996. In both cases, the later floods were less costly than the earlier ones, showing that some lessons were learned and appropriate actions were taken in time (Kundzevicz and Kaczmarek, 2000).

Case Study

Recently, Romania was the European country most hit by water related events, i.e. heavy storms and floods. In 2005, the yearly amount of rainfall in Romania was with 34% higher than the normal average (866.5 mm, instead of 647.0 mm), and with monthly distribution more uneven than usually, with several local highest recordings ever for rainfalls and river flows. The mean annual temperature was with 0.1°C lower than the reference period 1961-1990, with monthly average also with significant variations from the normal. Storms with heavy precipitations were concentrated in certain months, including winter snow covers. In almost every month it occurred that the flood defence levels were exceeded on rivers across the country, and a series of large floods affected the whole country mainly between April and September. The 2005 floods affected all 41 counties, and resulted in 76 human casualties and ca 2.0 billions US dollars (ca 1.7 billions Euros) (REIFMP2005, 2005). The extensive damages, notably on agriculture and infrastructures is thought to have strongly impacted on the national GDP annual growth, which dropped to ca. 4.3 in 2005, from 8.3 in 2004.

The recognized cause for such events and damages are: melting of snow (locally over 1 m thick) and heavy rainfalls (locally over 200 litres/m^2) or the two combined; deforestation; dikes failures due to higher, repeated and longer periods of high flow (up to 20 days); insufficient maintenance of flow-control system of reservoirs and channels; unauthorized and/or inappropriate constructions in high risk areas; under-equipped and inefficient institutions responsible for prevention and mitigation of disaster effects.

Putting aside the unusually extreme climate events and the unavoidable limits of any physical river regularization and the financial means, the big floods during 2003-2005 in Romania were most disastrous in areas that have undergone extensive deforestations following legal changes from state to private ownerships (law 400/2002), particularly on the slopes of the Carpathians Mountains. After flooding, new rules have being adopted in 2005, stipulating that, irrespective of ownership type, reforestation is compulsory within two years after deforestation. In case of reforestation failure with private owner, reforestation will automatically be realized by the National Forest Administration – RNP, at the cost of the owner. As reforestation is not very cheap, owners are expected to tend to avoid clear-cutting in the first place.

In addition, a detailed national map of flood risk is currently being worked by Romanian and German specialists, and due to be finished by 2008. Such measures are part of the National Strategy for Climatic Changes (SNSC) in Romania, developed by the National Commission on Climate Changes, within the authority of the Romanian Ministry for Environment and Waters, and in collaboration with other ministries, in order to comply with the United Nation Convention on Climatic Changes (law 24/1994) and the Kyoto Protocol (law 3/2001), and with the environment requirements of the European Union (SNSC, 2005), as well as the National Strategy for the Flood Risk Management (SNMRI, 2005), which also includes special first version of manuals like the Prefect's Manual for the Management of Flood Emergencies (MprefMSUCI, 2005) and the Mayor's Manual for the Management of Flood Emergencies (MprimMSUCI, 2005). Moreover, as a consequence of the floods in the spring of 2006 in all countries along Danube River, talks have began for building a joint international systems of early flood warning and associated management in the Danube's catchment. All such initiatives and management practices currently have a purely national character.

So far it seems that, with the support of the European Union to which it is planned to adhere most probably in 2007, Romania did learn the right lessons. However, now experts look at how efficiently applied these plans are: a matter of governance effectiveness. This was a point on which experts insisted during the negotiation of the treaty of EU – Romania association, namely Chapter 22 – Environment. New large floods are expected during 2006 and the next years, but casualties and material losses are due to decrease. A cost analysis of this evolution will be highly instructive for future measures of reduction in the costs caused by storms and floods.

Implications

In the past, once countries attained a certain level of economic development, they could deal better with issues of environmental protection and management. However, in the present era, developing countries appear to be stuck in a vicious cycle of poverty and deficient nature management. For example, economic development in lower income economies is accompanied by extensive overuse and/or natural resource conversion (Barbier, 2005).

In the context of a country's national strategy for sustainable development, holistic actions are a prerequisite to address climate and water-related crises in a cost-effective manner (Duda and El-Ashry, 2000). However, adoption and implementation of such action plans are a most difficult problem in developing countries in Asia, South America, Africa and Central-Eastern Europe, due to lack of financial and institutional resources (Loucks, 2000) and also due to the conflict in interests of different stakeholders. For example, a highly ambitious and massive water project that would integrate most of India's major waterways primarily aimed to mitigate problems of floods and droughts in different regions of the country has become a topic of intense debate in the scientific and policy-making communities (Gurjar, 2003).

The costs of facing natural hazards like storms and floods reflect the fact that prevention of and recovery from such extreme events is positively correlated with how sustainable society use natural resources. The rising costs of facing and recovering from storms and floods indicate *unsustainable* patterns of development, meaning human-caused climate and sea level changes, urban land claiming into flood plains and other wetlands, poor land use management like undiscerning deforestation, and short-sighted governance based on destroying the self-regenerating capacity of the natural life-support systems.

According to recommendations adopted by International Union for the Conservation of Nature (IUCN) in 2004, the *Precautionary Principle* should prevail in environmental decision-making and management. This appeal was followed by a resolution titled *Protecting the Earth's waters for public and ecological benefit*, and stating that the ecosystem approach to water resources management need to be central in any water governance policy (IUCN Congress Bulletin, 2004). The sustainable management of water resources involve anticipation and acceptance of change (as opposed to inflexibility in the face of new information and new objectives), clear goals, and adaptability in finding multi-objective tradeoffs in a multi-participatory decision making process involving all stakeholders (e.g., Peterson et al., 1994; Loucks, 2000; Simonovic, 2000; Plate, 2002).

In short, both investors and local authorities and populations must become fully aware that forests help catch and retain meteoric water where it falls (source control), with many advantages, most notably conservation of water resources (including recharges of groundwaters), and buffering natural systems and ecosystem resources from possible climate change impacts on local investments and economic and social activities. For example, even in currently highly centralized countries like China local people were recently involved in extensive works of reforestations aiming at mitigating destructive effect of floods (Wan, 2003). This might be due to the fact that in this country that pioneered grand work of engineering to regularize the streams of rivers, water containment by dikes proved to be inappropriate for the present days, and reduction of water runoffs are to be preferred (Plate, 2002).

Consequently, if they want to have a long-term perspective, investors should assist responsible institutions in updating knowledge and mechanisms of integrated local environmental management in areas with high risk of storms and flooding. Particularly developing countries should demand investors proceed to long term planning, and they should develop incentives for investors to make such long-term investments. One such solution is forest plantations for commercial logging, as alternatives to natural forest cutting; but also, such plantations should be knowledge-based, e.g. located in areas with best-suited topography and hydrology.

Insights

As nature recognizes no political border and the World is now acknowledging the benefits and the challenges brought by globalization, the considerate part of the human society is in process of merging economic, social and ecological perspectives into one paradigm: *sustainable development* (WCED, 1987; Giddings et al., 2002). This concept and theory developed around the idea of mitigating long-term risks in human activities, i.e. present developments should not compromise future developments.

In a narrow sense, flood risk management is the process of managing an existing flood risk situation, by being prepared for the storm and/or flood, and to mitigate the disaster. This includes performing (and continuously updating) risk and vulnerability analysis (which includes maps produced with the help of Geographical Information Systems – GIS) as a basis for long-term management decisions. In a wider sense, it includes planning of a disaster protection system (Todini, 1999; Plate, 2002).

An important aspect of flood risk management is that the flood-insurance when subsidized by governments may encourage settlements of hazardous areas, and increase material losses due to flooding. Without such incentives, settlers may consider leaving – permanent evacuation from high-risk areas should actually be encouraged, as it is safer and cheaper. Absolute safety against water-related risks is impossible. However, a disaster-conscious society should combine prevention of, preparedness to, and mitigation of disaster effects (e.g. Kundzevicz and Kaczmarek, 2000; Plate, 2002; Priest et al., 2005.). However, sharing risk management between insurers and the state might be an option for sustainable development in high-risk areas (e.g. Dahlstrom et al., 2003). In addition, investors might find incentives and mechanisms to contribute flood recoveries, especially in poor countries, which do not afford paying for protection prior to disasters (Kunreuther and Linnerooth-Bayer, 2003).

The above viewpoints indicate that risk management plans at national levels are essential but not sufficient – involvement of local people is needed. Particularly in countries with a history of centralized administration (e.g. in the former Soviet Union and its satellite countries), people tend to look for help from government rather than to help themselves (e.g. Nunes Correia et al., 1998; McDaniels, 1999; Vari, A., 2002). It is to be expected that integration of these countries into the European Union, will help improve local attitudes in governance, via the implementation of the "subsidiarity principle" of the EU, which states that what the lesser entity can do adequately should not be done by the greater entity unless it can do it better. In short, this means that any measure that can be taken locally should be taken locally (Duda and El-Ashry, 2000). The contrary would only impede upon operability, efficiency and costs of the storm and flood risk management.

Valuable toolkits, such as revealed-preference (RP) techniques, stated-preference (SP) techniques, and conjoint analysis (CJ), required for estimating individual and group preferences and options in valuations of complex (multi-attribute) natural resources (including in watersheds), and between alternatives of environmental management, are being already developed by economists. But they need further refinement, especially towards applicability to real-world management (e.g. Farber and Griner, 2000). Several researchers (e.g. Duda and El-Ashry, 2000; Allan, 2004; Reynolds and Hessburg, 2005) have a viewpoint that although it is hard to ascribe precise limits to most certain landscapes, management decisions (evaluation, restoration, and so on) should follow an integrated landscape perspective at the most natural landscape unit which is the river collection basin. As an illustration, instead of extending into riverbeds, the development of human settlements should be planned by giving priority consideration to river's natural course of flow. And further, regularization work all along river streams should be more relaxed, i.e. allowing more space for rivers; river flows should be regularized at the collection basin level by measures of adapted land uses (scenarios) and ecosystem management (Niehoff et al., 2002). As a result of such policy measures, with the floods along Danube River in Romania, in the spring of 2006, many previous agricultural fields have undergone controlled flooding, and some of them are planed to be left and restored as flood wet lands.

Forestry practices influence water yield and quality. Locally, forest management must integrate several basic water goals, at the level of each river catchment basin: quantitative and qualitative stream flow regularization in the target river basin, including limiting peak flows (Twery and Hornbeck, 2001). In this respect, management should be based on paired-catchment studies: similar river basins, one untreated (acting as reference) and one treated (deforestation of reforestation) (e.g. Watson et al., 2001). Lack of uncoordinated exploitation of forest and water resources can only result in reciprocally excluding measures and investments in forestry and hydrology, hence higher costs for the local community, including the costs of living with natural risks. This requires that the cost-benefits analyses of natural resources management must include details on the best type of forest (and other vegetation) cover (Sahin and Hall, 1996) for given local needs. For example, if the flood risk is high, the goal of diminishing the costs of environmental changes associated with floods should be aimed at by favouring forest types that insure low water yields and low peak flows. Agricultural and urbanization plans must take into account the effect of changing land uses implied by urban expansions within peri-urban ecosystems, in the context of current climate changes (e.g. Hartig et al., 1996; Nunes Correia et al. 1999; Niehoff et al., 2002; Naef et al., 2002; Pivot et al., 2002). Scientific research should support such planning, by investigating the climatic and ecological mechanisms that influence the water circuits and the weather-related risks. For example, the few studies on the effect of reforestation (most studies deal with deforestation) upon stream flows lead sometime to contradictory results (Andreassian, 2004). More knowledge is needed upon how ecosystems can regulate water circuits at river basin landscape. Long-term studies (with permanent stations) on both deforestation and reforestation are largely missing and should be promoted and supported.

During the 2003-2005, while the wood demand was basically stabilized, the demand for environmental services of forests, related to the protective roles of forests has soared (Leslie 2005; FAO, 2006). Thus, the relationships between the economic concept of value and the bio-physical dimensions of forests (especially uplands) need be further tackled by extensive research (e.g. Kramer et al., 1997). Similarly, flood (alluvial) plains have various functions which are not taken into consideration when river regularizations are planned, but which need economic valuation (e.g. Gren et al., 1995). In addition, combined natural risk effects must be studied and managed. For example, the Shanghai area is strongly exposed to and affected by typhoons. Beside wind-caused damages, storm-induced floods sometimes combine with high spring tides to produce highly destructive floods (Zhong and Chen, 1999). Similar effects are also well accounted in Europe, in the North Sea area; the situation can be further complicated, for example by coastal subsidence following gas extractions (e.g. Doornkamp, 1998).

In island and coastal countries, such as in the Pacific area that is particularly hit by cyclones, or in countries hit by monsoon and El Niño storms and floods, it is important not only to try to mitigate but also adapt to climate changes. Starting with the Pacific Islands Climate Change Assistance Programme and the Pacific Islands Framework for Action on Climate Change, Climate Variability and Sea Level Rise (2000), the region has seen a renewed interest in climate change adaptation over the past few years (Bettencourt et al., 2006). The broad solution at hand appears to be the promotion of research and global policy for carbon trapping (mainly by forests) to diminish the concentration of carbon dioxide in the atmosphere. But adaptations to climate change and risk management of natural hazards have emerged as core development issues particularly for Pacific Island countries. In this area the protective role of coastal forests (mangrove) is required to be further studied and employed in measures of risk attenuation and in general sustainable costal development. Among the most important properties of mangrove forests are: reduction of severity of storms and coastal flooding, high regeneration capacity and productivity, key roles in the stability and productivity of coastal marine ecosystems – including for the regeneration of the fish populations (e.g., Arrow et al. 2000; Benfield et al., 2005). The 2004 Indian Ocean tsunami showed the importance of maintaining natural wave breakers, by managing coral reefs, mangroves, and sand banks (Bettencourt et al., 2006).

In addition to the necessity of appropriate economic incentives and mitigation/adaptation related efforts, the general fundamental insight pertaining to risk costs and risk management is that nothing can be done on long term (i.e. in a sustainable fashion) without the involvement of the local people in a fair and inclusive manner. The concept of sustainable management of natural resources is (unfortunately) only recent, and it challenges most old cultural habits. It is, therefore, clear that no sustainable management can be carried out successfully without first achieving basic ecological education through all age groups, education levels, and professions. Otherwise, management efforts not including the local people (including owners, beneficiaries, etc) in a proper manner would simply be ineffective.

In this respect, particular international actions worth mentioning, like the conference "Education and public awareness for sustainable development", held in November 1995, in Pruhonice, Czeck Repunblic, and the European "Convention on Access to Information, Public Participation in Decision-Making, and Access to Justice in Environmental Matters", from 25 June, 1998, Aarhus, Denmark (http://europa.eu.int/comm/environment/aarhus/). Also, in order to raise efforts in the field of environmental education and public awareness pertaining to environmental issues, the United Nations declared the period 2005-2014 the Decade of Education for Sustainable Development. Further information about educational and public awareness actions taken by United Nations, including those towards disaster reduction, are available at http://portal.unesco.org/education/en/ev.php-URL_ID=27234&URL_DO=DO_TOPIC&URL_SECTION=201.html.

To put it differently, old habits die hard. As a consequence, costs of water-related risks will probably go lower only on medium and long-term, and only on the condition that environmental education (including education for sustainable development) will be properly resourced and planned. Thus, economic agents have an interest in financing such education, desirably in a coordinated fashion with state authorities, because ecological education is the first step for any national environmental policy. Further, eco-efficiency of economic activities (e.g. Pickett et al., 2001; Huppes and Ishikawa, 2005 Wall-Markowski et al., 2005) should be a central issue in ecological education at levels of specialists in industrial planning and production.

Summary

Increasing environmental stresses associated with global climate change and less employment opportunities in rural areas force people to migrate towards burgeoning cities (Gurjar and Lelieveld, 2005) leading to significant changes in the regional landscape and anthropogenic emissions. A recent research report states that land-use conversion in the Brazilian Amazon is triggering forest loss and degradation and rapidly changing the regional landscape. According to the Food and Agriculture Organization (FAO) of the United Nations, Brazil accounted for approximately 42 percent of global net forest loss from 2000 to 2005; most of this deforestation occurred in the Brazilian Amazon (Barreto et al., 2006). The global water cycle is influenced by both global climate changes and Earth's ecosystems, and both undergo transformations caused by anthropogenic activities, e.g. release of greenhouse gases into the atmosphere and landscape modifications. As reported by the Intergovernmental Panel on Climate Change (IPCC), the average Global temperature increased by 0.6 ± 0.2 °C during the 20th century, and it has been estimated to rise further with 1.4 – 5.8 °C until 2100. This may lead to changes in frequency, intensity, and duration of extreme events, e.g. more hot days, heat waves and heavy precipitation events. It is argued that many of these projected changes would cause increased risks of floods and droughts in many regions, and predominantly adverse impacts on ecological systems and socio-economic sectors (IPCC, 2001).

Ecosystems and the functions they render to individuals and society (such as – providing food, fiber, medicines and energy; processing carbon and other nutrients; and purifying and regulating water resources) are sensitive to variation and change in climate (Brenkert and Malone, 2005). As natural systems are subject to considerable stochastic variations, sensitivity analysis is needed to investigate the uncertainty associated key parameters (e.g. storms intensity, rainfall amounts) and thus estimate floods risks and necessary management strategies and actions (Kramer et al., 1997; Doornkamp, 1998; Arrow et al., 2000). Insights from such analyses might help policy makers and managers identify appropriate trade-offs between the costs and the benefits of protecting forests in sensitive river catchments. From an economic and financial perspective, the idea is that ecosystems (notably forests) must actually be counted as water infrastructure, and valued using cost-benefits balance (Emerton and Bos, 2004). Also, because the price of timber usually does not include the removal of other forest benefits, the price of timber is naturally underestimated, particularly with clear-cutting. Correct estimation should not only include the costs of wood extraction and transport, but also the costs of removing the other functions of the forest (especially the protective effects), for example the costs of reconstruction after floods that are expected thereafter. In economic terms, this would mean bringing the so-called "shadow prices" (which account for all values that a product has to society) into the light (Freeman, 1993; Gardiner et al., 1995; Farber and Griner, 2000).

Economic welfare of human societies across the Earth depends on capital flows, but investments are very sensitive to perceived as well as actual risks. Therefore, natural events like climate-born phenomena qualify as most serious, long-term menaces to local, national and global economies. In this context, all socio-economic actors are deemed to corroborate efforts for achieving coherent action and effective risk management. The real-life success of any risk management program is key-conditioned by finding case-by-case answers to a pervasive problem – *the conflict of usages of natural resources*. Such unsolved conflicts can only result in the destruction of natural resources, due to overexploitation, and subsequent price escalations. For example, according to FAO of the United Nations, Indonesia is losing each year almost two millions hectares of forest (i.e. about the size of Wales), while South America loosed between 2000-2005 ca 4.3 hectares per year.

Since the world's rainforests, a global asset, are owned by the mainly poor and developing countries, cutting them down for profit or livelihood is a tempting source of income for their owners. On the other hand, the forests are sinks for atmospheric CO2 and hence help in mitigating the problem of man-made global warming and climate change. They are also rich storehouses of biodiversity – another global resource. In such situations, in order to stop illegal exploitations of forests in developing countries, economic incentives and use of advanced science and technology for controlled and sustainable logging are a promising solution – provided a good governance equipped with efficient socio-political institutions and effective policy instruments are there in place to ensure constructive co-operation between local community, government, industry and environmentalists. Fortunately, today science and technology is developed enough to help conserve the forests. For example, there could be a possibility that genetically engineered trees are used to make plantations faster growing and more viable, and consequently lessen the pressure to hack down wilderness forest (The Economist, Mar 23rd, 2006). Hence, with an aim to make markets work for the welfare of forest based communities, imparting education and giving control to the local people (including property rights) could probably result in the cost-effective and sustainable ways to avoiding overexploitation of ecosystem resources and reducing costs involved in storms and flooding risk management.

References

Allan, J.D., 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. Annual Review of Ecology and Systematics 35: 257-284.

Andreassian, V., 2004. Waters and forests: from historical controversy to scientific debate. Journal of Hydrology 291: 1-27.

Arrow, K., Daily, G., Dasgupta, P., Levin, S., Maler, K.-G., Maskin, E., Starrett, D., Sterner, T., Tietenberg, T., 2000. Managing ecosystem resources. Environmental Science and Technology 34: 1401-1046.

Barbier, E.B., 2005. Natural Resources and Economic Development. Cambridge University Press. 410 pp.

Barreto, P., C. Souza Jr., R. Noguerón, A. Anderson and R. Salomao (in collaboration with J. Wiles), 2006. Research Report: Human Pressure on the Brazilian Amazon Forests. World Resources Institute, Washington, DC. ISBN: 1-56973-605-7. URL: http://pubs.wri.org/pubs_description.cfm?PubID=3869

Benfield, S.L., Guzman, H.M., Mair, J.M., 2005. Temporal mangrove dynamics in relation to coastal development in Pacific Panama. Journal of Environmental Management 76: 263-276.

Bettencourt, S., Croad, R., Freeman, P., Hay, J., Jones, R., King, P., Lal, P., Mearns, A., Miller, G., Pswarayi-Riddihough, I., Simpson, A., Teuatabo, N., Trotz, U., Van Aalst, M., 2006. Not if but when – Adapting to natural hazards in the Pacific Islands Region: A policy note. East Asia and Pacific Region, Pacific Islands Country Management Unit; The World Bank, Washington D.C.

Brenkert, A.L. and E.L. Malone, 2005. Modeling vulnerability and resilience to climate change: a case study of India and Indian states. Climatic Change 72: 57–102

Changnon, S.A., 2003. Shifting economic impacts from weather extremes in the United States: a result of societal changes, not global warming. Natural Hazards 29: 273–290.

Dahlstrom, K., Skea, J., Stahel, W.R., 2003. Innovation, insurability and sustainable development: sharing risk management between insurers and the state. The Geneva Papers 28(3): 394-412.

Doornkamp, J.C., 1998. Coastal flooding, global warming and environmental management. Journal of Environmental Management 52: 327-333.

Duda, A.M., El-Ashry, M.T., 2000. Addressing the global water and environmental crisis through integrated approaches to the management of land, water and ecological resources. Water International 25(1), 115-126.

Ehrlich, PR, and AH Ehrlich. 1981. Extinction: The Causes and Consequences of the Disappearance of Species. Random House, New York.

Emerton, L., Bos, E., 2004. Value. Counting ecosystems as an economic part of water infrastructure. IUCN, Gland, Switzerland and Cambridge, UK. 88 pp.

FAO, 2006. Global Forest Resources Assessment 2005. Progress towards sustainable forest management. FAO Forestry Paper 147, Rome.

Freeman, A.M., 1993. The measurement of environmental and resource values: theory and methods; Resources for the future: Washington DC.

Gardiner, J., 1995. Developing flood defence as a sustainable hazard alleviation measure. In Gardiner, J., et al. (Eds), Defence from floods and floodplain management. Kluwer, Dordrecht, The Netherlands, 13-40. Cited by Kundzewicz, Z.W., Kaczmarek, Z., 2000. Coping with hydrological extremes. Water International 25: 66-75.

Giddings, B., Hopwood, B., O'Brian, G., 2002. Environment, economy and society: fitting them together into sustainable development. Sustainable Development 10: 187-196.

Gren, I.-M., Groth, K.-H., Sylven, M., 1995. Economic values of Danube floodplains. Journal of Environmental Management 45: 333-345.

Gurjar, B.R., 2003. Interlinking of rivers: A climatic viewpoint. Current Science 84 (11), 1381 -1382.

Gurjar, B.R. and J. Lelieveld. Megacities and global change. New Directions / Atmospheric Environment 39 (2005) 391–393.

Hall, J., Sayers, P., Dawson, R., 2005. National-scale assessment of current and future flood risk in England and Wales. Natural Hazards 36(1-2): 147-164.

Hartig, K.E., Grozev, O., Rosenzweig, C., 1996. Climate change, agriculture and wetlands in Eastern Europe: vulnerability, adaptation and policy. Climatic Change 36 (1-2): 107-121.

Huppes, G., Ishikawa, M., 2005. A framework for quantified eco-efficiency analysis. Journal of Industrial Ecology 9(4), 25-41.

IUCN Congress Bulletin, 2004. A daily report of the 3rd IUCN World Conservation Congress, volume 39 (15), 28 November, published by the International Institute for Sustainable Development.

IPCC, 2001. Climate Change 2001: Synthesis Report. Summary for Policymakers. An Assessment of the Intergovernmental Panel on Climate Change (IPCC).

Keppler, Frank, John T. G. Hamilton, Marc Brass and Thomas Röckmann, 2006. Methane emissions from terrestrial plants under aerobic conditions. Nature 439, 187-191 (12 January 2006). Doi:10.1038/nature04420.

Kramer, R.A., Richter, D.D., Pattanayak, S., Sharma, N.P., 1997. Ecological and economic analysis of watershed protection in Eastern Madagascar. Journal of Environmental Protection 49: 277-295.

Kundzewicz, Z.W., Kaczmarek, Z., 2000. Coping with hydrological extremes. Water International 25: 66-75. International Water Resources Association – IWRA.

Kunreuther, H.C., Linnerooth-Bayer, J., 2003. The financial management of catastrophic flood risks in emerging-economy countries. Risk Analysis 23(3): 627-639.

Leslie, A, 2005. What will we want from the forests? International Tropical Timber Organization (ITTO), Tropical Forest Update 15(1): 14-16.

Loucks, D.P., 2000. Sustainable water resources management. Water International 25: 3-10. International Water Resources Association – IWRA.

McDaniels, T.L., Gregory, R.S., Fields, D., 1999. Democratizing risk management: successful public involvement in local water management decisions. Risk Analysis 19(3): 497-510.

MprefMSUCI, 2005. Manualul prefectului pentru managementul situatiilor de urgenta in caz de inundatii. The Romanian Ministry for Environment and Waters, http://www.mmediu.ro/home/home/Ape/Manual%20Prefect.pdf.

MprimPMSUCI, 2005. Manualul pprimarului pentru managementul situatiilor de urgenta in caz de inundatii. The Romanian Ministry for Environment and Waters, http://www.mmediu.ro/home/home/Ape/Manual%20Primar.pdf.

Muzik, I., 2002. A first-order analysis of the climate change effect on flood frequencies in a subalpine watershed by means of a hydrological rainfall-runoff model. Journal of Hydrology 267: 65-73.

Naef, F., Scherrer, S., Weiler, M., 2002. A process based assessment of the potential to reduce flood runoff by land use change. Journal of Hydrology 267: 74-79.

Niehoff, D., Fritsch, U., Brostert, A., 2002. Land-use impacts on storm-runoff generation: scenarios of land-use change and simulation of hydrological response in a meso-scale catchment in SW-Germany. Journal of Hydrology 267: 80-93.

Nunes Correia, F., Da Graça Saraiva, M., Da Silva F.N., Ramos, I., 1999. Floodplain management in urban developing areas. Part I. Urban growth scenarios and land use controls. Water Resources Management 13(1): 1-21.

Nunes Correia, F., Fordham, M., Da Graça Saraiva, M., Bernardo, F., 1998. Flood hazard assessment and management: interface with the public. Water Resources Management 12(3): 209-227.

Ojha, C.S.P. and V.P. Singh, 2004. Introduction. In: V.P. Singh, N. Sharma and C.S.P. Ojha (eds.). The Brahmaputra Basin Water Resources. Kluwer Academic Publishers, The Netherlands. ISBN: 1-4020-1737-5.

Peterson, D.L., Silsbee, D.G., Schmoldt, D.L., 1994. A case study of resources management planning with multiple objectives and projects. Environ. Management 18(5): 729-742.

Pickett, S.T.A., Cadenasso, M.L., Grove, J.M., Nilon, C.H., Pouyat, R.V., Zipperer, W.C., Canstanza, R., 2001. Urban ecological systems: liking terrestrial, ecological, physical, and socioeconomic components of metropolitan areas. Annual Review of Ecology and Systematics 32, 127-157.

Plate, E.J., 2002. Flood risk and flood management. Journal of Hydrology 267: 2-11.

Pielke, Jr., R.A., 2005. Making Sense of Trends in Disaster Losses, Bridges-OST's Publication on Science & Technology Policy, Vol. 7.

Pivot, J.-M., Josien, E., Martin, P., 2002. Farms adaptation to changes in flood risk: a management approach. Journal of Hydrology 267: 12-25.

Priest, S.J., Clark., M.J., Treby, E.J., 2005. Flood insurance: the challenge of the uninsured. Area 37: 295-302.

REIFMP2005, 2005. Raport privind efectele inundatiilor si fenomenelor meteorologice periculoase produse in anul 2005.

Reynolds, K.M., Hessburg, P.F., 2005. Decision support for integrated landscape evaluation and restoration planning. Forest Ecology and Management 207: 263-278.

Robinson, M., Cognard-Plancq, A.-L., Cosandey, C., David, J., Durand, P., Führer, H.-W. et al., 2003. Studies of the impact of forests on peak flows and base flows: a European perspective. Forest Ecology and Management 186 (1–3), 85–97

Sahin, V., Hall, M.J., 1996. The effects of afforestation and deforestation on water yields. Journal of Hydrology 178: 293-309.

Singh, B., 1997. Water resource development in India – a perspective. In: Singhal, D.C., N.K. Goyal, D.K. Srivastava, R. Singh, H. Joshi and B.S. Mathur (eds.). Proc. Int. Symp. On "Emerging trends in hydrology", Sept. 25-27, 1997, University of Roorkee, India, pp. 1-17.

Simonovic, S.P., Tools for water management. One view of the future. Water International 25: 76-88.

SNSC, 2005. Strategia Nationala Privind Schimbarile Climatice pentru Romania. 2nd version, 17 February 2005. Ministerul Mediului si Gospodaririi Apelor, Romania.

SNMRI, 2005. Hotararea Guvernului nr 1.854/22 decembrie 2005 pentru aprobarea Strategiei nationale de management al riscului la inundatii. Bucuresti, 22 decmbrie 2005.

Sun, G., McNulty, S.G., Lu, J., Amatya, D.M., Liang, Y., Kolka, R.K., 2005. Regional annual water yield from forest lands and its response to potential deforestation across the southeastern United States. Journal of Hydrology 308: 258-268.

Swank, W.T., Vose, J.M., Elliott, K.J., 2001. Long-term hydrological and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. Forest Ecology and Management 143: 163-178.

The Economist, 2005. Backgrounders – Forests, May 11th 2005.

Todini, E., 1999. An operational decision support system for flood risk mapping, forecasting and management. Urban Water 1(2): 131-143.

Twery, M.J., Hornbeck, J.W., 2001. Incorporating water goals into forest management decisions at a local level. Forest Ecology and Management 143: 87-93.

Vari, A., 2002. Public involvement in flood risk management in Hungary. Journal of Risk Research 5(3): 211-224.

Wakeel, A., Rao, K.S., Maikhuri, R.K., Saxena, K.G., 2005. Forest management and land use/cover changes in a typical micro watershed in the mid elevation zone of Central Himalaya. Forest Ecology and Management 213: 229-242.

Wall-Markowski, C.A., Kicherer, A., Wittlinger, R., 2005. Eco-efficiency: inside BASF and beyond. Management of Environmental Quality: An International Journal 16(2), 153-159.

Wan, Hongtao, 2003. Policies and Measures on Flood Mitigation in China since 1998. The International Conference on Total Disaster Risk Management, 2-4 December 2003, pp. 31-38.

WCED (World Comission on Environment and Development), 1987. Our Common future. ("The Brundtland Report") Report of the World Commission on Environment and Development, to the General Assembly of the United Nations (04.08.1987).

Whatson, F., Vertessy, R., McMahon, T., Rhodes, B., Watson, I., 2001. Improved methods to assess water yield changes from paired-catchment studies: application to the Maroondah catchments. Forest Ecology and Management 143: 189-204.

WWDR1, 2003. The 1st United Nations World Water Development Report "Water for People, Water for Life, March 22, 2003, The 3rd World Water Forum, Kyoto, Japan.

WWDR2, 2006. The 2nd United Nations World Water Development Report "Water, a shared responsibility", March 22, 2006, The 4th World Water Forum, Mexico City, Mexico.

Zhong, Y., Chen, X., 1999. Typhoon hazards in the Shanghai area. Disasters 23: 66-88.

Zimmermann, B., Elsenbeer, H., De Moraes, J.M., 2006. The influence of land-use changes on soil hydraulic properties: Implications for runoff regeneration. Forest Ecology and Management 222: 29-38.

FINNISH METEOROLOGICAL INSTITUTE

FINNISH LOCAL VIEW ON THE FACTORS ACCOUNTING FOR THE COSTS OF WEATHER-RELATED DISASTERS (SPECIFICALLY, FLOODS AND STORMS) IN RECENT DECADES AND IMPLICATIONS OF UNDERSTANDING THESE FOR BOTH RESEARCH AND POLICY

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1. Introduction

As the factors accounting for the costs of weather-related disasters (specifically, floods and storms) in recent decades and the implications of understanding these for both research and policy are considered in the Finnish context. The climatology of the pertinent weather phenomena are discussed also with some outlook to the scenarios. Here some possible future shifts in both flood and storm types causing damages and losses are pointed out. In addition some policy issues are discussed as this seems to be another pertinent point.

2. Factors in weather-related disasters

2.1 Floods

Since 1960 (Puupponen, 2006) in terms of house damage costs the three most severe flood episodes in Finland have occurred as follows.

Spring 1966 – Southern Finland: This spring flood has been since 1969 the highest flood in the rivers of Southern Finland. The water equivalent of the snow at the beginning of April was still widely 200 – 250 mm which was roughly double compared with the normal value and in fact a record value. The melting of the snow was postponed to a late time point around 1 May. Consequently the recurrence value of the observed flood flows exceeded in several drainage basins 100 years in terms of a Gumbel distribution estimate. No exact damage data are available, but in relation to later damage inventories the probable cost level has been of the order of 10 million euros.

Summer 2004 – Southern and Central Finland: The heavy rains end of July 2004 around the line Helsinki – Jyvaskyla – Kajaani were exceptional both in their extent and heaviness. The five-day precipitation at the end of July exceeded 100 mm over a very wide area. As the July precipitation in these areas was of the order of 200 mm, the soil was saturated already prior to the heavy rain episode. Consequently flood damages on houses took place especially in Riihimaki, some 60 km north of Helsinki, and in Voyri and Oravainen close to the central west coast. The damage costs were some 8 million euros excluded any harvest losses or damages to enterprises and public communities.

Spring 2005 – Lapland: At the beginning of May there was a lot of snow in Lapland and its water equivalent increased still slightly during early May. The water equivalent exceeded at places 180 mm in Northwestern Lapland and the head areas of the Kemijoki river and the Ivalonjoki river drainage basins around 10th May. This value was approximately double compared with the normal value. The snow melted very fast after the middle of May, at its fastest by some 20 mm per day. This caused a record flood in the Ounasjoki river and the Ivalonjoki river with highest water levels in 50 years and with an approximate recurrence time of 50 years. The extreme flood caused mainly house damages maily in Ivalo and Kittila (cf. Fig. 1). The damage costs were some 5 million euros excluding any harvest losses or damages to enterprises and public communities.

Extreme spring floods occur when large snow amounts melt under rainy conditions which prevent the more typical conditions of fair weather and consequent large evaporation of snow. In this sense an extreme spring flood can be seen as a combined, accumulative phenomenon which can be foreseen by appropriate early warning systems. Also in case of extreme summer floods their formation is to some extent accumulative in terms of prior saturated soil wetness. Although also extreme summer floods can cover wide areas, in Finland these episodes have been mostly fairly restricted and caused mainly by local heavy showers.

Regarding the potential of extreme spring floods it should be pointed out that the snow water equivalent studies of Hyvarinen (2003) revealed that in the Kemijoki river drainage basin the snow water equivalent on 1 April 1947 – 2001 had an increasing trend (cf. fig. 2). As Hyvarinen (2003) points out the short time series might have exaggerated the slope of this increasing trend. In addition the melting of the snow takes often place under clear sunny weather and a consequent relatively large evaporation. Hence even an increasing snow water equivalent in Lapland does not necessarily imply risk for increasing spring floods there. In more southern parts of Finland the results of Hyvarinen (2003) indicated no or a decreasing trend in snow water equivalent.

Even if two of the floods of large costs in terms of damages have occurred quite recently it should be emphasized that the type of these floods was quite different and that these do not necessarily reflect any climate changes in Finland in terms of an increasing number of extreme floods. Rather they are outcomes of the large natural variability of the Finnish climate and quite possible extreme values even under the latest WMO standard normal period 1961-1990. All in all it should be remembered that even in the future both some spring and some summer floods can be extreme and cause losses in Finland.

Figure 1: Spring 2005 extreme flood in Kittila, Lapland

Beside the floods in inland drainage basins it is possible to have floods due to high water levels on the coasts of the Baltic Sea basin. On the Finnish coast the most severe situation of this type was experienced in the context of storm Gudrun 8-9 Jan, 2005 (cf. fig. 3), when the sea level in the central and eastern parts of the Gulf of Finland reached new record values. In Helsinki the situation was quite critical as the pumping stations could barely survive from the extra load. Fig. 4 shows estimated recurrence values of high sea level at Loviisa (some 100 km east of Helsinki) adjusted by parameterization for the expected climate in 2030 (Johansson et al., 2004).

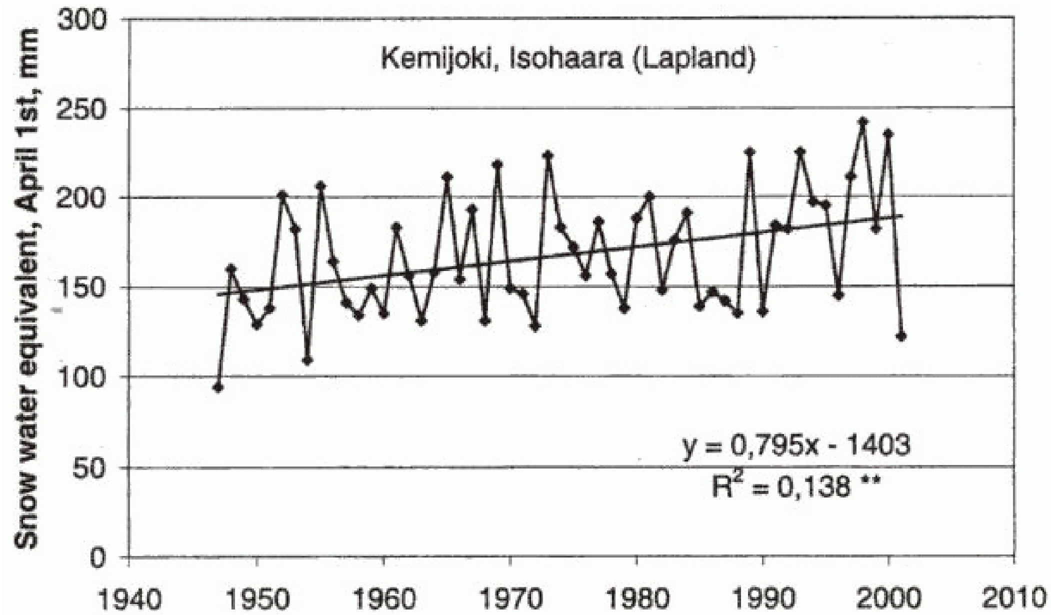

Figure 2: Water equivalent of snow in Kemijoki river drainage basin in Lapland on 1 April 1947 – 2001 (Hyvarinen, 2003)

The exceptionally high sea level can be understood as a coincident combination of several factors. First, we have the natural oscillation or seiche of the water mass in the Baltic Sea basin. Just at the occurrence of the storm Gudrun the phase of the seiche was such that the sea level in the area of the Gulf of Finland was high. Second, the prevailing surface wind direction during Gudrun was such that the strong wind piled water to the Gulf of Finland and kept it there causing record high sea level values in the whole area with the highest values in the easternmost parts of the gulf. This kind of a combination is rare but possible as observed during the passage of the storm Gudrun. The consequent high sea level rise can be foreseen with an appropriate early warning model.

In Helsinki the peak value of the sea level was 1.51 m above the normal sea level and the situation was quite critical with the pumping stations managing just barely the incident.

2.2 Storms

Regarding storms there is a semantic difference between the English word storm and its equivalent in Finnish as the Finnish equivalent is restricted exclusively to wind storms. In addition already the strong gale with a wind speed of at least 21 m/s is classified as wind storm in the Finnish coastal areas. In inland locations the wind is considered dangerously strong as the wind speed is 14 m/s or higher. Both of the adapted definitions are supported by both acceptable climatological risk levels and observed damages and losses in practice.

In addition to the wind storms and severe storms some other phenomena, like freezing rain/slipperiness and heavy snow loads/clinging snow are considered from the point of view of damages.

The annual number of wind storm days for the Finnish maritime areas is given in fig. 5. The corresponding numbers of dangerously strong wind days for the Finnish inland areas are presented in fig. 6. Both of these figures show that there is at least no indication of an increasing trend after 1990.

Gudrun 8 – 9 January 2005

Figure 3: The track and affected regions of the storm Gudrun 8 – 9 January 2005

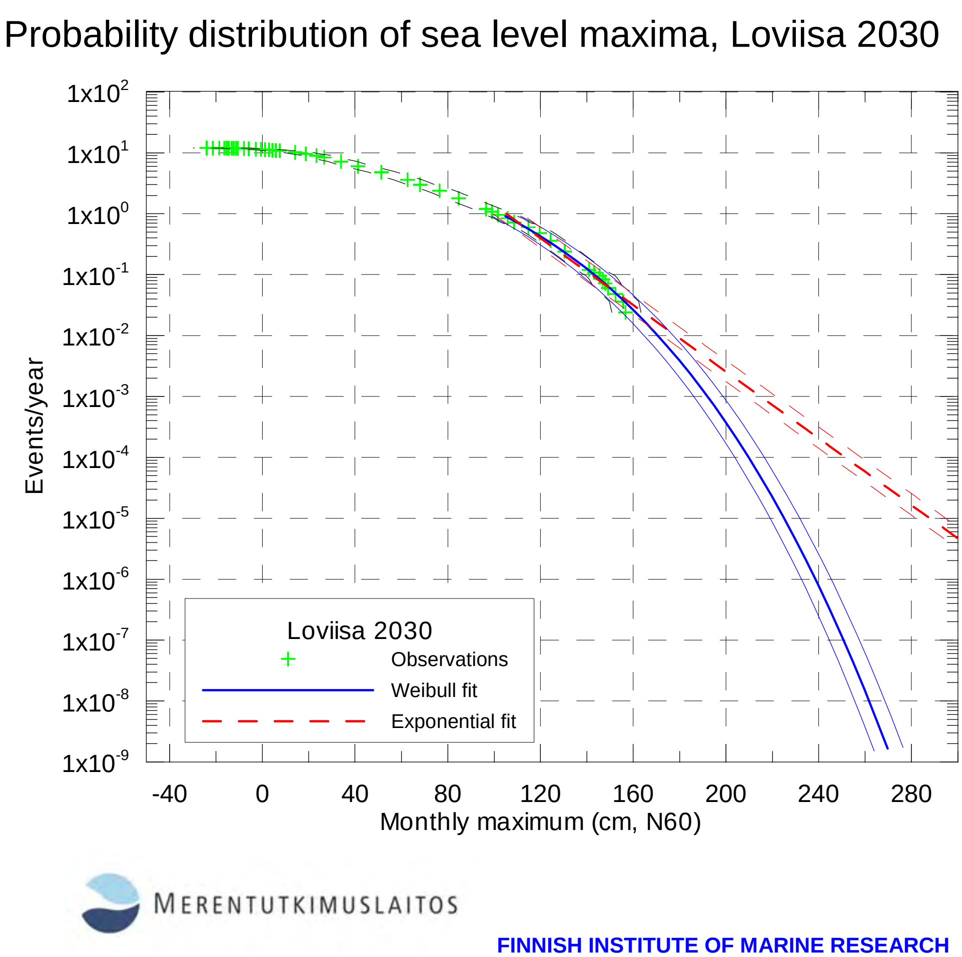

Figure 4: Extreme value distribution fits to observed maximum sea level values at Loviisa with adjustments to the expected climate in 2030 (Johansson et al., 2004). (The figure by courtesy of the Finnish Institute of Marine Research)

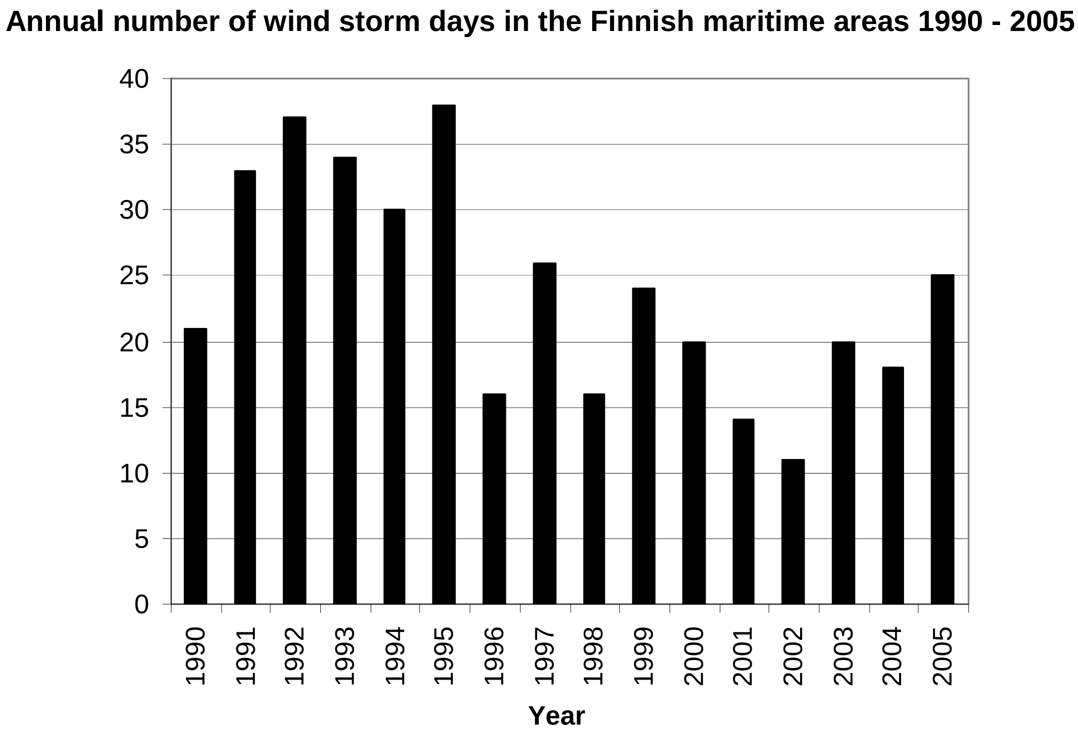

Figure 5: The annual number of wind storm days in the Finnish maritime areas 1990 – 2005

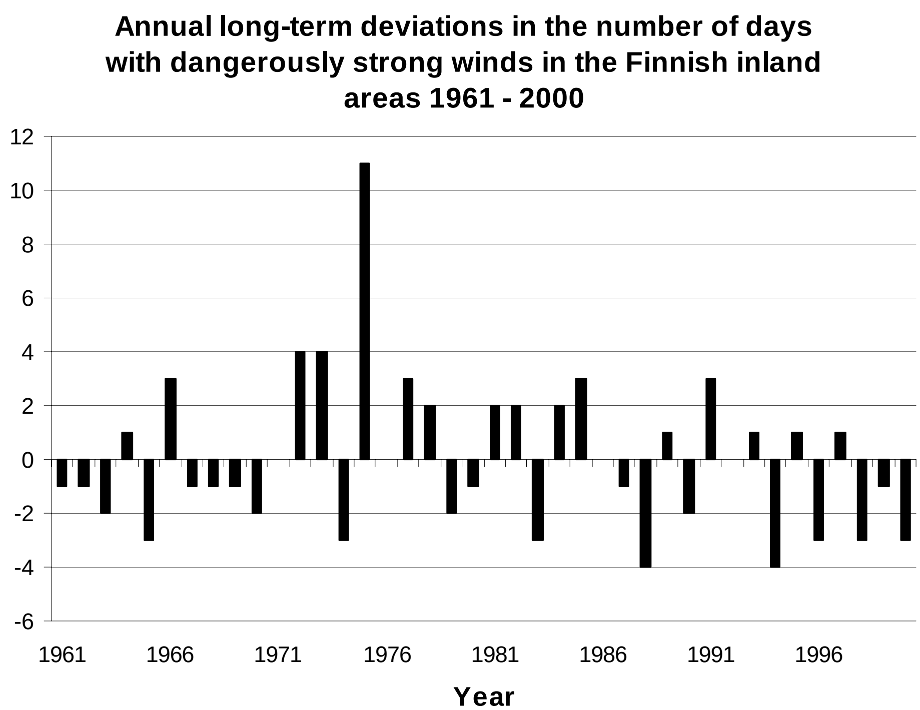

Figure 6: The annual deviations from 1961 – 1990 normal values of the number of days with dangerously strong winds in the Finnish inland areas in 1961 – 2000.

Another study (Myllys, 2006) indicates that the number of deep low pressure systems crossing Finland has remained relatively constant, whereas the number of disturbances moving from southwest to Finland in the context and along the eastern rim of a so-called central low located typically west of Scandinavia is increasing. All this is in line with figs. 5 and 6 as the Finnish wind storms and dangerously strong wind situations are associated with the deep lows which have a different and more northerly path than those causing the largest damages in Southern Sweden and the Baltic countries. Although the storm Gudrun was a close call for some coastal areas of Southern Finland, all the major damages caused by it took place south of Finland.

The annual deviations from 1961 – 1990 normal values of the number of days with dangerously strong winds in the Finnish inland areas in 1961 – 2000.

With the recently installed modern Doppler weather radar network in Finland and encouraged reporting by public on local storms, like trombs and downbursts, the former synoptic manual observations are not comparable in their sparse regional resolution. Despite of the increased public awareness and publicity of these phenomena it is too early to give any estimates of the recent trends in the occurrence of severe local storms in various parts of Finland. With the increasing number of free-time houses in many parts of the country it is possible that there is the statistical chance of getting increases in damages of this kind (cf. fig. 7) (Teittinen, 2006). However, one should be cautious to conclude that this would mean an increase in the number of severe storm events in Finland.

One recently well documented severe storm (storm Unto) event took place in Finland on 5 July 2002 (cf. fig. 8) (Teittinen, 2006). The wind damage area of this storm was 450 km in its length and some 100 km in its breath. In the damage areas the gust speeds exceeded at many places 33 m/s. In some areas of Eastern Finland the gust speeds exceeded 50 m/s so that storm Unto reached at some sites the F2 class. Widely extended thunderstorm related wind damages alike have been documented formerly mainly in North America and only once in Europe. It should be emphasized, however, that there is no reason to believe that severe storms like storm Unto would not have occurred

Figure 7: Damage caused by the F2 class (wind speed 50 – 69 m/s) tromb in Kontiolahti (north of Joensuu), Eastern Finland on 20 August 2004.

earlier in Finland. In fact there is one description in Finnish of an intense tromb family, which swept through Southern and Central Finland on 4 August 1932 and reached at some sites the F4 class (Angervo and Leiviska, 1944).

General probabilistic forecasts of the occurrence of thunderstorms are given 24 hours in advance, but more detailed warnings pose a challenge to the nowcasting and at most some hours ahead.

Freezing rain events, per se, are known to cause problems on power lines and in power supply although such events are rather rare in Finland. The trend in the number of freezing rain events is slightly or modestly increasing both in Helsinki (0.7 events/decade) and Rovaniemi (at the polar circle; 2.4 events/decade). It must be remembered though that Rovaniemi observation station upon a nearby hill is known to encounter freezing rain events more than its surroundings. On the other hand the slight increase in the freezing rain events is in concert with the warming winters and reflects well in general the effect of the mild winters since the 1990's in Finland.

The formation of slipperiness on roads and pavements is a phenomenon connected not only with freezing rain but in fact in many cases with sublimation taking place right at the road or pavement surface. Therefore the prevention of the road and pavement slipperiness is still a challenge both for the weather service and the service providers, as the slipperiness causes annually severe problems both for traffic and pedestrians. Measured in the number of slipperiness prevention tasks per winter season the largest values are encountered in Southwestern Finland with large values in

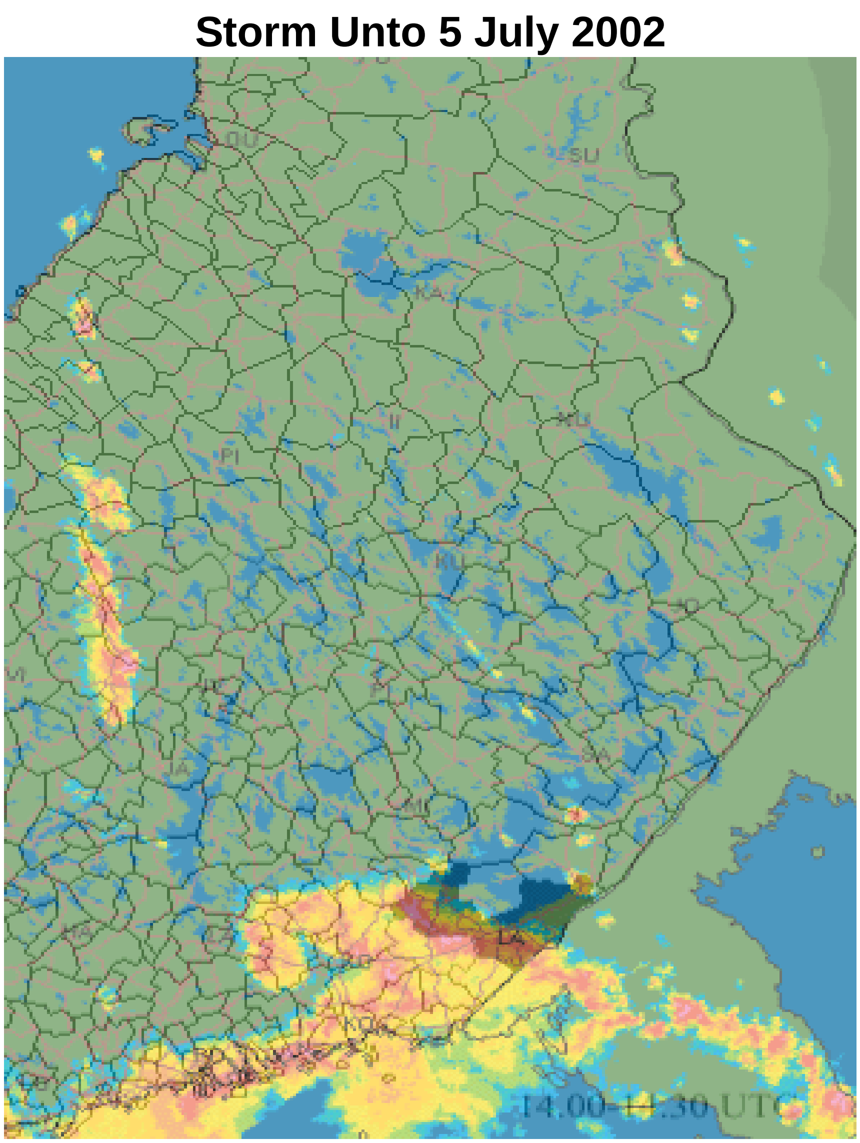

Figure 8: Composited radar observation of storm Unto on 5 July 2002 14:00 – 14:30 UTC

southern, central and western parts of the country. With the relatively short records on traffic accidents and injuries of pedestrians it is still a challenge to relate the slipperiness to its consequences in terms of costs.

According to fig. 2 the snow water equivalent had an increasing trend in Lapland. Even if it per se does not necessarily mean increasing risks for extreme spring floods another risk is more obvious and that is the increasing snow load on the roofs of buildings. Lately incidents of broken roofs have been experienced even in more southern parts of Finland under circumstances where the design loads based on climatological snow water equivalent recurrence values have not been exceeded. Hence the climatic change is not to be blamed on all these damages. In addition the Finnish Environment Institute gives timely regional warnings and recommendations to shovel the snow down from the roofs. This can be considered as an appropriate early warning service.

Clinging snow is another mechanism by which snow can cause excessive loads. In practice this needs specific rain, thawing and snowfall conditions around zero degrees centigrade. As a consequence of such incident trees can get heavy snow load on them which forces them to bend. This can cause local power lines to be broken especially, if a wind storm gets the chance to blow on the preloaded trees. Fig. 9 gives recent 10-year mean numbers on heavy snow load (in excess of 20 kg/m^2) events in various parts of Finland. The map indicates the regional distribution of this risk. Recently two rather consecutive wind storms (storm Pyry, 1 Nov 2001 and storm Janika 15-16 Nov 2001) after a heavy clinging snow incident on 31 Oct 2001 caused large losses of cut trees and broken power lines in Southern and Central Finland.

2.3 Climate scenarios

Climate scenarios for the 21st century in Finland have been published elsewhere by Jylha et al. (2004) in the context of the FINADAPT project and will not be discussed here.

Regarding the floods the shortening snow season is anticipated to decrease the peak values of spring flood flows by 2021 – 2050 (Tammelin et al., 2002).

3. Implications

3.1 Floods

As pointed out by Hyvarinen (2003) the improvement of drainage basin flood forecasts depends primarily on improvements in estimating areal precipitation. This in turn poses challenges to the development of various remote sensing techniques, primarily on weather radar networks, and dense enough rain gauge networks as references. In Finland this challenge is focused both on reliable estimates of snowfall precipitation and on area precipitation estimates in the context of showers. All these improvements would give us a better basis to dimension properly the needed infrastructure, like dams

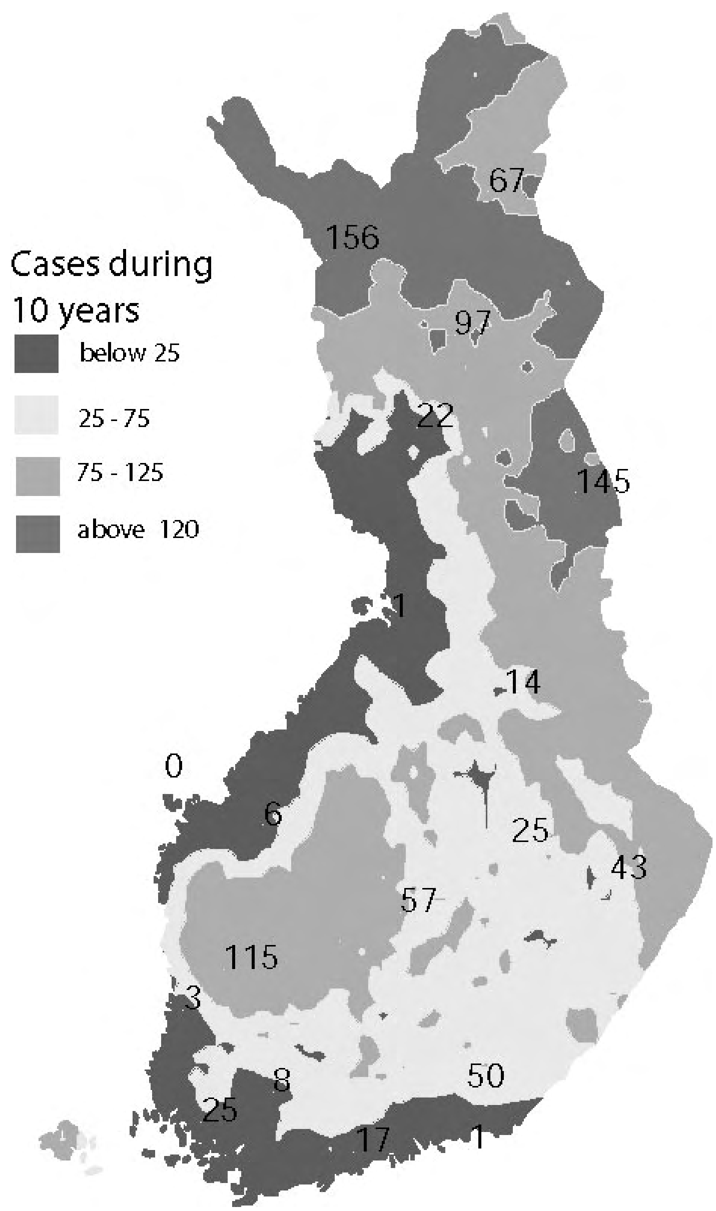

Figure 9: Number of cases in which the snow load on the average during ten years exceeds 20 kg/m2

and reservoirs, of various drainage basins in order to avoid excessive floods.

Another important topic is the estimation of recurrence values in the context of short intense showers. With the traditional 24 hour or at its best 12 hour rain gauge measurements it is almost impossible to get any meaningful estimates for the intensities of short showers, although this is important also for the dimensioning of local sewerages and the estimation of local extreme flood risks. Many of the current dimensioning estimates of shower intensities are quite uncertain and need to be improved. This problem is complicated further by the need to consider the simultaneous soil wetness.

In order to hedge against the extreme summer floods caused by intense local showers and thunderstorms under saturated soil wetness we need to improve our knowledge of the mesoscale climatology where we have a joint interest with the development of the nowcasting.

Parallel to the efforts mentioned above we should also develop appropriate early warning models cooperatively with the various users and stakeholders. From the meteorological point of view the use of ensemble forecasts would be a natural choice to bring in the probabilistic view needed.

3.2 Storms

When we widen our view to the hedging against wind storms and the prevention of slipperiness and excessive snow loads as well, we face the fact that with the advanced technology and the post-modern trend to maximize the profit of various services we have exposed us to increased insecurity. This should be kept in mind as we consider the possible trends in weather-related risks and damages. Are we ignoring the impacts of the current natural variability of our climate, when we are trying to blame the damages on the more popular concept of climate change? So far this seems to be the case to a considerable extent in Finland as there seems not to be almost any convincing increasing trends in the weather related phenomena of concern.

The storm category as understood here in the Finnish context consists mainly of short-term phenomena, but also of some accumulative or combined phenomena of longer time span. Most of them relate to typical time scales of the weather service and some even to nowcasting, although the related macro- and mesoscale climatology must not be ignored. Here one important research area is the development of limited area forecasting models and their verification. The use of ensemble forecasts would give a good starting point to develop appropriate early warning models.

3.3 Policies

As far as policies are concerned the view in this paper has been to emphasize the role of the early warning services of the meteorologists, hydrologists and oceanographers where appropriate. In addition it has been pointed out that in Finland its climate of the extremes has so far been relatively stable and indicated predominantly no increasing trends.

On the other hand the Finnish society and business environment have undergone recently quite remarkable changes which should be taken into account in the efforts to build the future on a reasonable balance between the security and the uncertainties and risks to be managed as well as possible with the available resources, the insurance sector included. The example on broken roofs due to more or less regular late winter snow load indicates rather problems in the assembly phases of the roof construction and the liability chain within the construction industry.

4. Summary

Both the weather-related disaster types and the presented implications reflect the related issues of the Finnish climate with respect to insurance. As pointed out, so far it is quite hard to assign any of the weather-related disasters to the recently monitored climate warming of some 1 °C increase in the monthly mean temperature of December – March. In case of increased costs of weather-related disasters in Finland the currently adapted policies should be considered as one important factor as steps to improve the management of risks for the Finnish climate are taken.

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References:

Angervo, J. M. and I. Leiviska, 1944: Maapallon ilmastot (Climates of the World). Werner Soderstrom, Porvoo – Helsinki, Finland.

Hyvarinen, Veli, 2003: Trends and Characteristics of Hydrological Time Series in Finland. Nordic Hydrology, 34 (1/2), pp. 71-90.

Johansson, Milla M., Kimmo K. Kahma, Hanna Boman and Jouko Launiainen, 2004: Scenarios for sea level on the Finnish coast. Boreal Environment Research, 9, pp. 153 -166.

Jylha, K., H. Tuomenvirta and K. Ruosteenoja, 2004: Climate change projections for Finland during the 21st century. Boreal Environment Research, 9, pp. 127 – 152.

Myllys, Hilppa, 2006: Personal communication. Finnish Meteorological Institute.

Puupponen, Markku, 2006: Personal communication. Finnish Environment Institute.

Tammelin, Bengt, John Forsius, Kirsti Jylha, Pekka Jarvinen, Jarkko Koskela, Heikki Tuomenvirta, Merja A. Turunen, Bertel Vehvilainen and Ari Venalainen, 2002: Ilmastonmuutoksen vaikutuksia energiatuotantoon ja lammitysenergian tarpeeseen (In Finnish with English summary) (Effect of climate change on energy production and heating power demand). Reports 2002:2, Finnish Meteorological Institute, Helsinki, Finland.

Teittinen, Jenni, 2006: Personal communication. Finnish Meteorological Institute.

A brief review on reasons and implications of the increasing disaster losses

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1. Introduction

Ever since the beginning of human history, natural disasters have been closely associated with human beings. According to the statistics, economic losses caused by meteorological disasters in China account for over 70% of the total losses by all natural disasters. Each year the stricken crop areas damaged by various meteorological disasters reach 50 million hectares, and the stricken population amount to over 400 million, the total economic loss equals 3%-5% of GDP in China. Moreover, the losses of meteorological disasters increase rapidly, according to the German insurance company Munich Re, the costs of major disasters raised more than tenfold in the second half of the twentieth century, from an average of about $4 billion per year in the 1950s to more than $40 billion in the 1990s, in inflation-adjusted dollars.

2. Reasons for the increasing disaster losses

Many factors account for the dramatically increasing costs of weather-related disasters in recent decades. Time-series analysis of loss records has shown that the increase of some weather related hazards in the US can largely be explained by changes in socio-economic factors, most importantly population growth and the accumulation of capital in areas that are at risk from natural hazards. Some other scholars however have argued that climate change and consequent shifts in extreme weather events may have an important contribution to the increase in losses from weather related disasters.

2.1 Population growth

Population growth may result in the increase of disaster losses. Natural phenomena are likely to affect more people because earth's population has increased. According to the United Nations Population Fund, this stands at about 6.5 billion people and is projected to reach 9.1 billion people in 2050. Compared with densely populated area, disaster with the same magnitude hit sparsely populated areas will therefore cause less damage. High population density means more deaths in a disaster, at the same time, growing population pressures have led many people to settle on vulnerable flood plains and hillsides. Satellite photographs taken of the China's Yangtze River over the past decade show increasing numbers of people moving into the most flood-prone areas, so in a flood in 1998 resulted in 3700 deaths, dislocated 223 million people, inundated 25 million hectares of cropland, and cost $30 billion. In China, The flood prone area accounting for 8% of national territory is inhabited by nearly 50% of the total population, where the gross industrial and agricultural product is estimated to be 2/3 of the national total. This is a very important problem.

2.2 Ecological degradation

Ecological degradation exacerbates flooding and landslides. Human activities, like deforestation, excessive land reclamation, large scale road construction, mining in mountainous and hilly areas and wetlands destruction, will inevitably degrade the soil and water, which will further result in floods or landslides. The soil erosion rate along the Yangtze River has doubled since the 1950s. Devastating landslides and floods have been exacerbated in recent years by deforestation and dikes that have hemmed in the Yangtze River and eliminated wetlands. Excessive logging of hillsides is partly to blame for the worst floods on the Yangtze River in China in 1998, and in that flood, over 550 people died as a result of mud slides.

The destruction of forests also results in natural water storage loss and silting of rivers and lakes and has raised the level of the rivers more and more. The Yangtze River flow rates in the summer of 1998 were below the historic highs but water levels are setting records because of the silting of river beds. Dongting Lake, a major regulator of the Yangtze floods, shrunk from 6,000 km^2 in 1700 to 4,350 km^2 in 1949 and by another third to just 2,820 km^2 by 1980. When tropical storms hit the Caribbean in September 2004, there was nothing to stop storm waters gathering and wreaking devastation in Haiti because of deforestation.

2.3 Urbanization and industrialization

Disasters are also a consequence of development and industrialization. In Europe, experts believe that countries such as France and Germany are more adversely affected by floods today because major rivers, such as the Rhine, have been straightened to ease commercial traffic. Urbanization increases runoff two to six times over what would occur on natural terrain. The rapid urbanization will result in bigger and more frequent floods on the one hand and more economic losses on the other. More importantly the damage of the system/network of communication, water supply, electricity supply, oil and gas supply, information net work in one place will affect the system in other places of the same city or other cities, which may paralyze the whole system of a region. The Chinese rush toward industrialization and economic modernization has indirectly contributed to the severity of the flooding. The government of Hunan Province in China in May 1992 tore down one kilometre of dikes in the name of opening up new agricultural land. The result was that 80,000 hectares of farmland and 700,000 people lost their protection from flooding.

2.4 Irrational land use and plan

Land reclamation for agriculture in flood-prone areas and accompanying human settlements increase flood vulnerability and losses by floods. Man-made irrational production activities, such as the filling in of lakes and rivers, have reduced their ability to regulate the floodwaters. The most densely populated 10% of Chinese territory which produces 70% of its agricultural and industrial product lies below the flood level of China's rivers, so China has been frequently hit by big floods and suffered from flood disasters. Owing to the reclamation of the flood plain and detention lakes, the detention area for the lower Yangtze has been reduced to about a half of that in 1954. The Jingjiang detention area and other man-made detention areas not been employed for flood storage as in 1954's flood event.

2.5 Poor and bad dwelling conditions

Poor and bad dwelling conditions also lead to the increase of disaster losses. There's a huge relationship between the damage and poverty, and disasters disproportionately harm poor people in poor countries. In several countries, poor people are looking for spaces that are not already used to build their houses or their communities, and those spaces are usually at higher risk for natural disaster. Those countries typically have densely populated regions, shoddily constructed buildings, sparse infrastructure, and grossly inadequate public health capabilities. Moreover, there are increasing numbers of people living in areas such as coastlines, and they have the potential for more devastating disasters. Thus, while the world's poorest 35 countries make up only about 10 percent of the world's population, they suffered more than half of the disaster-related deaths between 1992 and 2001.

2.6 Inadequate prevention capacity and preparation

One reason for the Yangtze River flood of 1998 is that the dikes and reservoirs are only built to counter floods that might come once every 10 to 20 years. That is a far lower standard than in the US or Japan. More silt and less water storage capacity in the Yangtze River basin will mean that even with less water, floods will become more serious than ever before. Hurricane Katrina in the United States is also a good example, The storm struck a city whose levees had not been maintained or strengthened for years, and government agencies' response to the emergency was at first inadequate. Early warning systems and education are essential to prevent and militate against the effects of natural disasters. In its World disasters report 2005, the International Federation of Red Cross and Red Crescent Societies notes that a simple phone call saved thousands of lives when the giant tsunami waves hit India in 2004.

2.7 Climate change

Climate change-whether helped by human behavior or not-is playing a role. Hurricane experts say the world is in the midst of a routine, cyclical climate change that causes the Caribbean to heat up, increasing the frequency of powerful storms. But whether climate change is becoming an increasingly significant factor for the increase of hurricane impacts on society up to now constitutes an open debate. The seasonal floods afflicting China every summer are caused by the Asian monsoon winds, which sweep rain clouds from the oceans toward China in the spring and summer, in 1998, however, the rains began earlier and were heavier than usual, and the Chinese dikes were not prepared nor properly fortified to withstand the tremendous downpour.

3. Implications for research and policy

There are significance for research, policy and action if we understand these factors that lead to the increasing losses of disasters. Disasters stem from a complex mix of factors, including climate change, socioeconomic factors, and inadequate disaster preparedness and education on the part of governments as well as the general population. The escalating costs of disasters could be attributed in part to climate change, but in most case, the effect of human activities was greater than that of global warming. So some disasters experts reject the term “natural disasters”, arguing that there is almost always a man-made element. In the Yangtze River flood in 1998, government officials initially denied that were anything but natural, but at last recognized the human factor in worsening "natural" disasters.

Both natural climate change and human factors should be considered in disaster research and decision-making. But if we only consider disaster losses, much more attention should be given to human activities and corresponding ever-growing societal vulnerabilities to disaster. Compared with the long-term climate change control, we could improve disaster vulnerability more directly and the function is immediate, though this is complicated and difficult because of the limited land resources and increasing population pressure. There is a need to reach a common understanding and agreement from all concerned of this solution.

Natural disasters would not have such a devastating effect on people’s lives if they were not exposed to such risks in the first place. Adaptation to extreme weather events should play a central role in reducing societal vulnerabilities to climate and climate change. Today many countries are working to improve their disaster preparedness. Some experts also believe the most practical approach to preparedness of disaster may be to focus on reducing the risks rather than factors behind the risks, so preparation should focus on making people less vulnerable to disasters.

Most tools needed to reduce disaster vulnerability already exist, such as risk assessment techniques, better building codes and code enforcement, land-use standards, and emergency-preparedness plans. PAHO has expanded its programmes to focus not only on preparedness but also on mitigation. This involves reducing secondary deaths and destruction that can occur in the aftermath of a disaster, and implementing building codes that require hospitals, schools, military bases other vital structures to be built to withstand such disasters. Many effective actions are possible to reduce disaster losses even in the face of poverty and dense population. Mitigation of GHG emissions should also play a central role in response to anthropogenic climate change, though it does not have an effect for several decades on the hazard risk.

Application of the insurance and fund is no doubt a feasible way to reduce disaster effectively, It has been demonstrated by the past several years of practices that the insurance can play a very important role in reconstruction of afflicted regions and in rearrangement of victims and that the use of a large amount of insurance money accelerated greatly the economic rebuilding in disaster areas. Microfinancing is another avenue, giving poor people the means to improve their economic situation so that a disaster does not hit them as hard as it would otherwise, and also by lending them money to use in recovering from it.

References

Birgit Hauke. 1999. Yangtze Floods in China: Their Reasons and Environmental Impact. Casualty & environment Forum, 1999(2).

Changnon S A. 2003. Shifting economic impacts from weather extremes in the United States: a result of societal changes, not global warming. Natural Hazards, 29(2), pp. 273-290.

Laurens M. Bouwer. 2006. The Benefits of Disaster Risk Reduction and Their Effects on Loss Trends. Climate Change and Disaster Losses Workshop, May 25-26, Germany, pp. 18.

Mills E. 2005. Insurance in a climate of change. Science, 309, pp. 1040-1044.

Munich Re. 2006. Annual review: natural catastrophes 2005. Munich Re, Munich, pp.1-56.

Pielke R A, Landsea C W. 1998: Normalized U.S. hurricane damage, 1925-1995. Weather and Forecasting, 13, pp. 621-631.

Pielke R A. 2005. Attribution of Disaster Losses, Science, 310, pp. 1615. Response to "Attribution of Disaster Losses" by Evan Mills on pp. 1616.

Pielke R A. Disasters, Death, and Destruction: Accounting for Recent Calamities. Ocean Studies Board's Seventh Annual Roger Revelle Commemorative Lecture, March 15, 2006, Washington, DC

Pielke Roger Jr. 2006. 2005: Attribution of Disaster Losses. Science, 311, pp. 470

WHO > WHO sites > Bulletin of the World Health Organization > Past issues > Volume 84: 2006 > Volume 84, Number 1, January 2006, pp. 1-80

Cost of Inaction and Costs of Action in Climate Protection

Assessment of Costs of Inaction or Delayed Action of Climate Protection and Climate Change

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Summary

The ultimate objective of the climate convention and of related instruments like the Kyoto protocol is to reduce greenhouse gas emissions to a level that avoids dangerous climate change. In order to considerably reduce risks of climate change, the European Union already decided a climate protection target: to prevent global surface temperature to increase more than 2°C (Celsius) compared to pre industrial levels. The number and intensity of extreme weather events, such as flooding caused by heavy precipitation, heat waves and big storms has considerably increased in the past. With a temperature increase of over 2°C the probability of even more frequent heavy climate events could rise substantially. Big re-insurance companies, such as the MunichRe, figured out that extreme weather events have risen by a factor 3.1 since 1960. This has led to drastic growth in both economic and insured losses. For example, the flooding in Europe in the year 2003 caused losses of 9.3 billion Euros only in Germany.

This study aims at calculating the costs of inaction, i.e. when no climate policy takes place, contrasted with the costs of action, i.e. the costs of climate policy. We intend to shed some light on what might happen if concrete climate policy started today or started at a later point of time. In particular, we are interested in the costs of inaction, and thus the potential economic damages from climate change. For this, we apply a world economic model that includes damage functions and economic interrelations from climate impacts. We assess the potential impacts of climate change and provide some sensitivity analyses with respect to the assumptions on the reaction of the climate system.

The main difficulties with such quantitative impact studies lie in the monetary valuation of damages from climate change and in regional as well as in temporal differences of action and impact. Mitigation costs and ancillary benefits as well as adaptation costs and benefits typically accrue in the same region. However, this is not true for mitigation benefits: local or regional emissions reduction efforts result in globally and temporally dispersed benefits. Benefits of avoided climate change impacts amass much later than the costs of mitigation (OECD 2004). Impact assessment studies most often only evaluate responses to changes in mean climate and not those associated with abrupt changes or extreme events. Furthermore, monetising damages of goods like biodiversity or health is very problematic as the uncertainties are very large and inherent value judgements cannot objectively be made.

This paper assesses and compares the costs and benefits of climate protection, i.e. the „costs of inaction“, which include climate damages, adaptation costs on the one hand with the “costs of action”, i.e. mitigation costs on the other hand. We apply a scenario approach with which we compare different emissions stabilisation scenarios to a reference case. The assessment of the “costs of inaction” is based on a globally very aggregated and simplified damage approach, which crucially depends on the parameter values taken into account.

The scenarios aim at avoiding a global surface temperature increase of more than 2°Celsius (C) compared to pre-industrial levels. Especially we assess a reference scenario where no climate protection or emission mitigation actions take place and two mitigation scenarios: scenario one "early Action" (ScenA) intends not to overshoot the 2°C limit, scenario two "delayed Action" (ScenB) starts with drastic emission reduction effects at a later time period (2030).

It turns out that only with early emission reduction warming beyond the limit of 2°C can be avoided. Even drastic emissions reduction efforts starting at a later point of time (2030) will not be sufficient to stay within the 2°C limit. Damages from climate change are lower if the limit is met. The costs of action are substantial. However, the avoided damage costs are even higher than the costs of action. This is particularly the case when emission reduction efforts are postponed to later time periods. Both policy scenarios provide benefits in terms of avoided damages. ScenA leads to higher positive effects than ScenB in terms of gross world product (GWP) because the avoided damages are higher and overcompensate the mitigation costs.

Introduction

The number and intensity of extreme weather events, such as flooding caused by heavy precipitation, heat waves and big storms has considerably increased in the past. With a temperature increase of over 2°C the probability of even more frequent heavy climate events could rise substantially. Big re-insurance companies, such as the MunichRe, figured out that extreme weather events have risen by a factor 3.1 since 1960. This has led to drastic growth in both economic and insured losses. For example, the flooding in Europe in the year 2003 caused losses of 9.3 billion Euros only in Germany.

The ultimate objective of the climate convention (Art. 2) and related instruments like the Kyoto protocol is to reduce greenhouse gas emissions to a level that avoid dangerous climate change. In order to reduce risks of climate change considerably, the European Union already decided a climate protection target: to avoid global surface temperature increase of more than 2°C compared to pre-industrial levels. The temperature target has been repeatedly reiterated by the Environmental Council since 1996, and, in March 2005, also by the Heads of Government of the EU. However, even an increase of the global temperature by 2 C compared to the pre- industrial level leads to substantial climate impacts, such as on ecosystems and water scarcity. In order to stay within the temperature limit of 2°C with high likelihood, a stabilisation of greenhouse gas concentrations of 400 ppm would be necessary (Hare and Meinshausen 2004). Greenhouse gas emissions need to be reduced drastically, globally by at least 50% up to 2050.

After the Russian ratification of the Kyoto protocol, the Kyoto protocol entered into force on 16 February 2005. This also means that in 2005 international negotiations for further emissions reduction targets need to begin. The German government is aiming for an EU greenhouse gas emission reduction target of 30% by 2020 compared to 1990 emissions level and similarly ambitious targets for other industrialised countries. Germany would then be prepared to accept an emissions reductions target of 40% by 2020.

The European spring council (March 2005) reaffirmed that the overall global annual mean surface temperature should not exceed 2°C above pre-industrial levels. Furthermore, the Council notes that there is increasing scientific evidence that the benefits of limiting overall global annual mean surface temperature increase to 2°C above pre industrial level outweigh the costs of abatement policies. The Council encourages considering mid- to long-term strategies and targets (2020: 15-30 %) and therefore asked the Commission to continue to work on a cost benefit analysis of emissions reductions strategies. The costs of climate protection need to be compared with avoided damages, avoided adaptation costs and ancillary benefits (as for example avoided air pollution). There are only a few quantitative assessment studies that evaluate the cost of inaction, i.e. the costs of climate change (e.g. Tol et al. 2004, Nordhaus and Boyer 2000, Fankhauser 1994, Hope 2004. For an overview see for example Pittini and Rahman 2004 and Schellnhuber et al. 2004). The main difficulties with such quantitative impact studies lie both in regional as well as timely differences. Mitigation costs, adaptation costs and benefits and ancillary benefits typically accrue in the same region. However, this is not true for mitigation benefits: local or regional emissions reduction efforts result in globally and timely dispersed benefits. Benefits of avoided climate change impacts amass much later than the costs of mitigation (OECD 2004). Impact assessment studies most often only evaluate responses to changes in mean climate and not those associated with abrupt changes or extreme events. Furthermore, quantitative impacts are difficult to assess, as both the evaluation of non-market impacts as well as the aggregation of regional impacts is very problematic. In particular, monetising damages of goods like biodiversity or health is very problematic as the uncertainties (as for example the chosen discount rate) and impreciseness are extraordinary large. Because of these difficulties cost benefit analyses alone are not an appropriate tool for the assessment and determination of strategies and targets for climate protection.

This paper assesses and compares the costs and benefits of climate protection, by quantifying so called „costs of inaction", i.e. climate damages and adaptation costs, on the one hand and the "costs of action", i.e. mitigation costs on the other hand. We compare the benefits of mitigation (that means the avoided damages of climate change, avoided adaptation costs and ancillary benefits), with the costs of action, i.e. the costs of meeting concrete emissions reductions targets to stay within the limit of 2°C global warming above pre-industrial levels. In particular, we assess a reference scenario where no climate protection or emissions mitigation activities take place and compare it with two mitigation scenarios: scenario A ("early action") intends to avoid average global warming of more than 2°C, scenario B starts with are economically feasible at a later time period (2030) ("delayed action").

Overview of Impact – Integrated Assessment- Studies

The majority of studies in climate policy have focussed on the costs of climate policy, i.e. the costs of action. To date, detailed information is available on the regional and global costs of various climate policies. Policy makers want to compare these costs to the benefits that arise due to the climate policies they initiate. Not many studies so far, however, have tackled the challenge of evaluating the costs of inaction or the benefits of climate policies. Many problems occur that make a simple cost benefit analysis challenging. Those problems relate to the dispersion of costs and benefits over time and space, to uncertainties and the synthesis of quantitative and qualitative information. This section thus gives a detailed overview of current research activities in this area. Among the initiatives, the most comprehensive one is the recently published OECD book on 'the benefits of climate change policies' (2004).[1]

The OECD book presents a selection of review papers each focussing on different aspects of the benefits of mitigation policy. The study points out that problems with coherent benefits research arise for two reasons, partly due to lack of research and partly due to lack of synthesis of research into some coherent measure or set of measures for policymakers and the public to understand and weigh the benefits. The goal, thus, is to provide a survey of available information and to set out a framework and priorities for future research work. The overall aim of the OECD initiative is to improve the information on the benefits of climate policies for policymakers. Several interesting studies exist that focus on the quantitative assessment of the costs and benefits of mitigating climate change with the help of integrated assessment models (e.g. Tol et al. 2004, Nordhaus and Boyer 2000, Fankhauser 1994, Hope 2004, etc.). The models differ in their regional, sectoral and time coverage and need to be seen in light of the model structure, assumptions and uncertainties as pointed out below. For a survey and discussion of studies using an integrated assessment approach see also Pittini and Rahman (2004) and Schellnhuber et al. (2004).

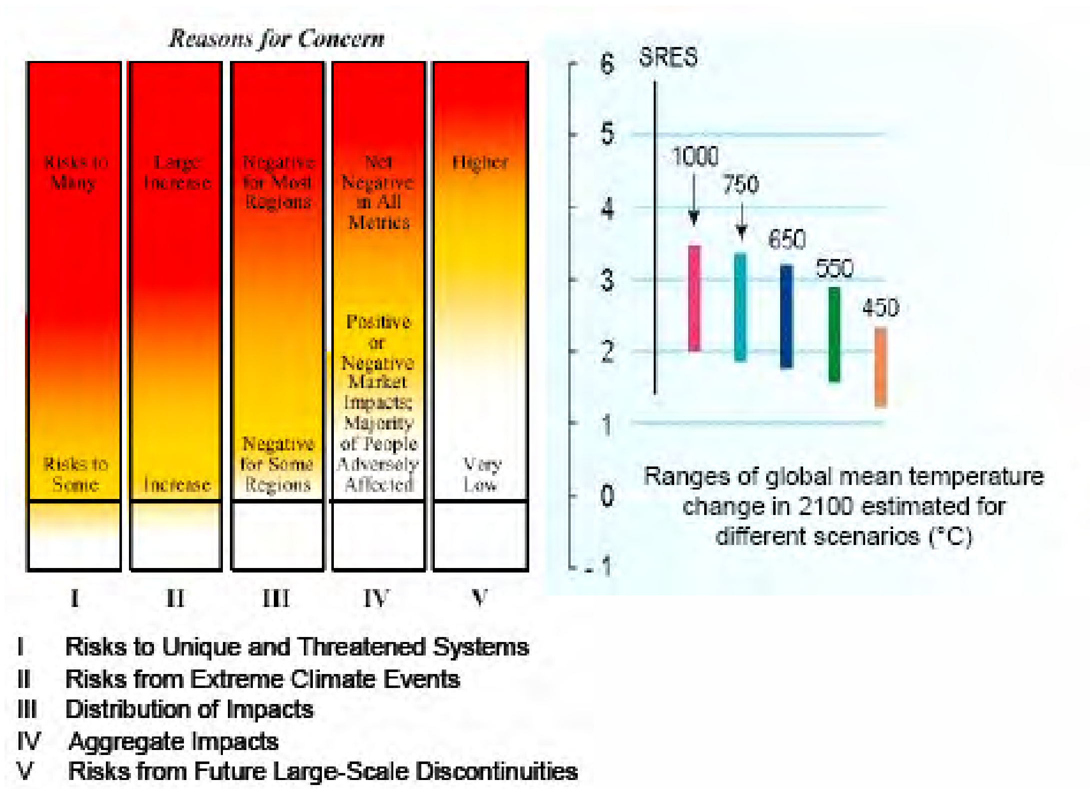
Climate change: Why bother?

The Intergovernmental Panel on Climate Change (IPCC) in its Third Assessment Report sets out five reasons for concern relating to I) the risks to unique and threatened systems, II) the risks from extreme climate events, III) the distribution of impacts, IV) to aggregate impacts and V) to risks from future large-scale discontinuities, and assessed the

[1] That is the benefits of avoiding climatic change and reducing the likelihood of any resulting net adverse impact.

links between those concerns (or impacts) and global mean temperature change in 2100 (see Figure 1). These can then be linked again to different emissions pathways or concentration levels as for example provided by the IPCC's Special Report on Emissions Scenarios (SRES). (IPCC 2000) and stabilisation scenarios based on these SRES scenarios. It shows that even a CO2-concentration of 450ppm which is well known to be associated with high costs is likely to lead to an increase in global mean temperature above 2°C compared to 1990 (0.6°C have to be added to get the warming above pre-industrial levels) (see also Hare and Meinshausen, 2004) and to substantial impacts related to the reasons of concern I and II and also some for III and IV. The IPCC assessment clearly reveals the high and multidimensional uncertainties that exist regarding any impact analysis.

Impacts of climate change occur not only due to a change in mean climate (warmer mean temperature, melting of glaciers and pole caps), but also in due to changes in climate variability and frequency and severity of extreme events (such as the magnitude and quantity of droughts, storms and floods) and due to irreversible abrupt non-linear changes. It would mean that the system - due to external forces - is pushed from one equilibrium to the other, thus crossing a threshold that can lead to unpredictable and/or irreversible changes. Examples for such events are a change in the thermohaline circulation in the North Atlantic Ocean or the die-back of the Amazon forest, leading to a release of the stored carbon thus enhancing global warming.



Source: IPCC (2001), Synthesis Report.

Figure 1. Relating global mean temperature change to reasons for concern

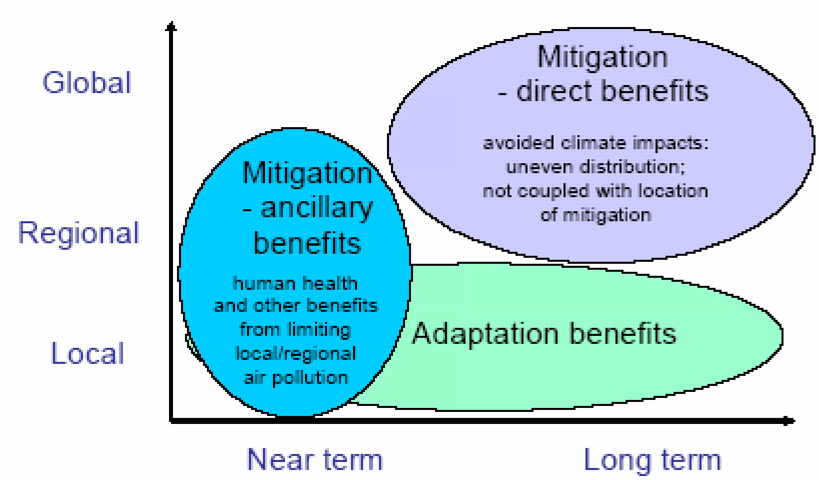
Impact studies so far most often focus on changes in mean climate only. However, a number of studies, among others by Schneider and Lane (2004), Narain and Fisher (2000), Baranzini et al. (2003), suggest that accounting for variability in climate and abrupt non-linear change is likely to shift the 'optimal' level of abatement. Moreover, Schneider and Lane (2004) argue that a reduction of the likelihood of high consequence events could be among the main benefits of early and stringent GHG mitigation.

Benefits – What? Where? When?

For the assessment of global mitigation policy benefits it is important to note the various dimensions of benefits. Firstly, a common understanding is needed what kind of benefits may occur. There are direct benefits of mitigation in the form of avoided damages in, for, example agricultural production, coastal and water resources, terrestrial ecosystems productivity, biodiversity etc. In addition, there are adaptation benefits, in form of avoided adaptation costs, and indirect or ancillary benefits. Ancillary benefits of GHG mitigation exist in the form of a reduction of harmful air pollutants such as sulphur dioxide (SO2), nitrogen dioxide (NOx), volatile organic compounds (VOC) and primary particulate matter (PM10). (Schellnhuber et al. 2004) Carbon sequestration technologies often also remove other pollutants from the waste gas stream. A policy that reduces the use of fossil fuels has beneficial effects in terms of mitigating both climate change and regional scale/large scale air pollution. In addition, considerable costs of fossil fuel transports including damage costs from accidents such as oil spills would be mitigated., Climate policy may also lead to a diversification of energy sources, which would decrease the economic and societal sensitivity to disruption of supply.

The other dimensions of benefits relate to the distribution over space and time. Mitigation efforts undertaken now or at any point in time will lead to benefits that partly arise at a much later point of time. This requires a normative judgement of the value of future generations when comparing the costs and benefits in present time values. For economic analyses an appropriate discount rate needs to be chosen. Apart from the distribution of costs and benefits over time, the long-term horizon of climate change presents another major research challenge. Greenhouse gases, in particular carbon, stay in the atmosphere for very long time periods, thus contributing to climate change on a long-term scale. Thus emissions mitigated today produce benefits that reach far into and beyond the 21st century. Any such long-term analysis suffers from very high uncertainties.

Similarly to the time dimension or intergenerational aspects, intragenerational or regional equity of the distribution of costs and benefits plays a major role. Mitigation costs and ancillary benefits typically occur in the same location (or region) where mitigation efforts are taken. Similarly, adaptation costs and benefits accrue in the very same location. However, mitigation costs and direct benefits from mitigation are not immediately linked. Mitigation efforts may take place anywhere in the world and reduce global GHG concentrations. The benefits from the reduction in terms of avoided climate change impacts, however, may show at a very different location from where mitigation originated. The challenge for policy makers thus is to weigh the benefits of climate policy on a global scale rather than a regional one. In this context, equity issues become of importance as the vast majority of GHG emissions stem from industrialized countries while the impacts of climate change are expected to hit less developed countries the hardest. Figure 2 provides an overview of how those different dimensions of mitigation and adaptation policy benefits are linked.



Source: Morlot and Agrawala (2004)

Figure 2. Mitigation and adaptation policy benefits over space and time

Another distributional aspect relates to the sectoral allocation of climate change mitigation benefits. As the IPCC's five reasons of concern show some sectors or systems will be affected harder at lower temperature increases than others.

Hitz and Smith (2004) survey the existing literature on global impact from climate change by sector. The sectors cover agricultural production, coastal resources, water resources, human health, energy, terrestrial ecosystems productivity, forestry, biodiversity, and marine ecosystems productivity. The survey reveals that some sectors, such as coastal resources, health, marine ecosystems, and biodiversity exhibit increasing adverse impacts. Increasing adverse impacts means there are still adverse impacts with very small increases in global mean temperature. These adverse impacts increase with higher global mean temperatures. The authors (Hitz and Smith 2004) were unable, however, to determine whether the adverse impacts increase linearly or exponentially with global mean temperature. Other sectors, such as agriculture, terrestrial ecosystems productivity and forestry exhibit parabolic relationships between temperature increase and impact. This means that a small increase in temperature may exhibit positive impacts while the impact turns adverse for larger increases in temperature. At which temperature increase the inflection point occurs differs by sector as well as by region and is difficult to determine due to uncertainties concerning adaptation (agriculture) and the lack of studies especially for the lower range of temperature change to compare with (forestry). For the other sectors, the authors could not establish a consistent pattern between temperature and impact from the existing data. An overview of their findings together with their assessment of a level of confidence for the deciphered relationships is given in Table 1.

Sector	Increasing adverse impacts[a]	Parabolic	Unknown	Confidence
Agriculture		X[b]		Medium/Low
Coastal	X			High
Water			X	
Health	X[c]			Medium/Low
Terrestrial ecosystem productivity		X		Medium
Forestry		X[d]		Low
Marine ecosystems	X[e]			Low
Biodiversity	X			Medium/High
Energy			X	
Aggregate			X	

Notes:

a. Increasing adverse impacts means there are adverse impacts with small increases in GMT, and the adverse impacts increase with higher GMTs. We are unable to determine whether the adverse impacts increase linearly or exponentially with GMT.

b. We believe this is parabolic, but predicting at what temperature the inflection point occurs is difficult due to uncertainty concerning adaptation and the development of new cultivars.

c. There is some uncertainty associated with this characterisation, as the results for the studies we examine are inconsistent. On balance, we believe the literature shows increasing damages for this sector.

d. We believe this is parabolic, but with only one study it is difficult to ascertain temperature relationship, so there is uncertainty about this relationship.

e. This relationship is uncertain because there is only one study on this topic.

Source: Hitz and Smith (2004)

Table 1. Summary of sectoral damage relationships with increasing temperature

Though positive impacts appear at lower levels of temperature change in some sectors and regions, research suggests negative impacts as global mean temperatures increase beyond certain levels. Across all sectors one consistent pattern among all studies is an increasingly adverse impact beyond an approximate increase in global mean temperature of 3 to

4°C. At lower levels of temperature increase, however, a number of studies show negative impacts for some sectors. These conclusions need to be seen in light of the existing uncertainties, including a lack of impact studies for the lower temperature range and problems of estimating existing impact studies, which prevent them from identifying a precise critical temperature beyond which damages are adverse and increasing. Hitz and Smith (2004) do not attempt to aggregate impacts across sectors. This is because the results vary widely within studies, from scenario to scenario and between studies. The studies do not analyse the same scenarios or use the same baselines and are most often based on different units. Also, there are important linkages between sectors (such as agriculture and water resources), which cannot be accounted for in individual sector studies. Many studies do not take into consideration extreme events or the possibility of abrupt non-linear disruption. Also, the assumptions on the speed and nature of economic and technological development differ by study and influence how vulnerable systems will react to climate change. In addition to these concerns, all of the above mentioned aspects and uncertainties apply (regional and timely impacts, long term aspects, kind of benefits etc.).

<u>From sectoral to global, from physical to economical: Aggregation and monetization of impacts</u>

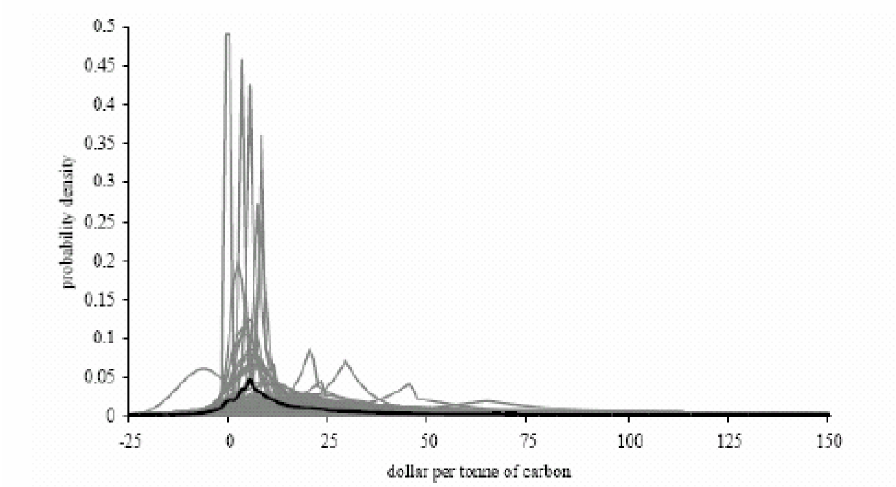
As climate change is a global problem and the costs of climate policies (costs of action) can relatively easy and meaningfully be expressed in economic units (e.g. price per ton of carbon), policymakers seek to compare these costs with the associated global benefits of climate policies (costs of inaction). However, while it is difficult to aggregate impacts across sectors, giving impacts an economic value is seen to be even more challenging. In addition to all the uncertainties mentioned, an economic valuation of climate change impacts inevitably implies value judgements with respect to which non-market impacts[2] to include and how to value them, with respect to predicting how relative and absolute impacts will develop into the future and with respect to aggregating the costs of climate change across regions and countries (equity weighting) and aggregating across generations (discount rate).

Pittini and Rahman (2004) provide an overview of findings with respect to marginal costs of climate change impacts (i.e. the social cost of carbon). The estimates mainly result from analyses with integrated assessment models (IAM). IAMs combine scientific and economic aspects of climate change into a single dynamic modelling framework. They produce estimates for the social costs of carbon either as shadow prices of carbon in comparing marginal abatement costs to marginal damage costs or as average incremental costs of a small perturbation in emissions from a business as usual baseline. Pittini and Rahman point out that results from IAMs are driven by inherent value judgements, which renders it difficult to compare carbon price estimates. In addition, the IAMs surveyed differ in their regional aggregation, in their complexity of climate and/or economic components, in their level of including non-market impacts, and in the assumptions on their business as usual baseline. Tol (2004) stresses that IAMs - in order to assess absolute damage costs - need to establish the future size of the population and the economic, natural, social and human capital stocks at risk. With a timeframe as long as global warming damages, no prediction of future developments can be done with any confidence. Scenarios are thus used to describe possible futures. They do not claim to describe the most likely future. Because of the use of these scenarios, global warming damage assessments have a contingent nature: they are contingent upon the assumptions embedded in socioeconomic scenarios, whether explicit or not In addition, Pittini and Rahman point out that there are severe limitations in the coverage of some key climate change issues, such as the impacts of low-probability high-risk impacts, extreme weather event, social contingent impacts and impacts in the areas of biodiversity, ecosystems. Thus, the social costs of carbon presented in the following need to be seen in light of the shortcomings. They will not represent any true value of the marginal damage costs until these issues are better understood and supplementary probabilistic sensitivity analyses are undertaken and incorporated into the estimates to account for uncertainties.

[2] Non-market impacts are impacts for which a market price does not exist, such as biodiversity, ecosystems, health, tourism, recreation.

Findings from several review studies provide a range of a possible carbon damage costs. In particular, Pittini and Rahman (2004) refer to estimates from the following studies:

- Pearce et al. (1996) review existing studies for the IPCC 2nd assessment report and report a range of **5-125 US$/tC** (tons of carbon) in 1990 prices (or 6-160 US$/tC in 2000 prices) relating to carbon emissions from 1991-2000. For the period 2001-2010, the estimates range from **7-154 US$/tC** 1990 prices (and 9-197 US$/tC in 2000 prices). Social cost estimate increase over time, as marginal damage costs tend to increase with higher greenhouse gas concentrations.
- 8 major studies are reviewed by Clarkson and Deyes (2002) and reveal an estimated range of **50-200 US$/tC** for the global damage costs of carbon emissions. In real terms these number should be increased by approximately 1.5 US$/tC per year because the costs of climate change are likely to increase over time.
- 24 estimates from 12 studies are reviewed in Pearce (2003) and lead to a range of **6-39 $/tC** for the social price of carbon.
- Tol (2003b) conducts a meta-analysis of 88 estimates from 22 published studies for the marginal social costs of carbon dioxide. He finds a very wide and right skewed distribution of costs (see Figure 3), with a mean at **104 US$/tC**. Weighing these estimates, Tol concludes that the marginal costs may not exceed **50 US$/tC** and are likely to be even lower than that. The weights are based on Tol's normative value judgement. They are applied to reflect different quality levels of the estimates and to account for the fact that there are groups of results in the database that originate from the same modelling exercise and thus incorporate an inherent bias. Thus, the results need to be seen in light of the method and normative assumptions chosen by Tol.



Source: Tol (2003b).

Note:

Tol (2003b) collects 88 estimates of marginal social cost of carbon dioxide figures, from 22 studies. As Tol notes, one would expect the reported estimates to vary considerably, with high to low end marginal social cost estimates ranging from USD 1666/tC through to USD 7/tC. The probability density function in grey highlights the full range of the 88 estimates. The combined probability density function appears in black.

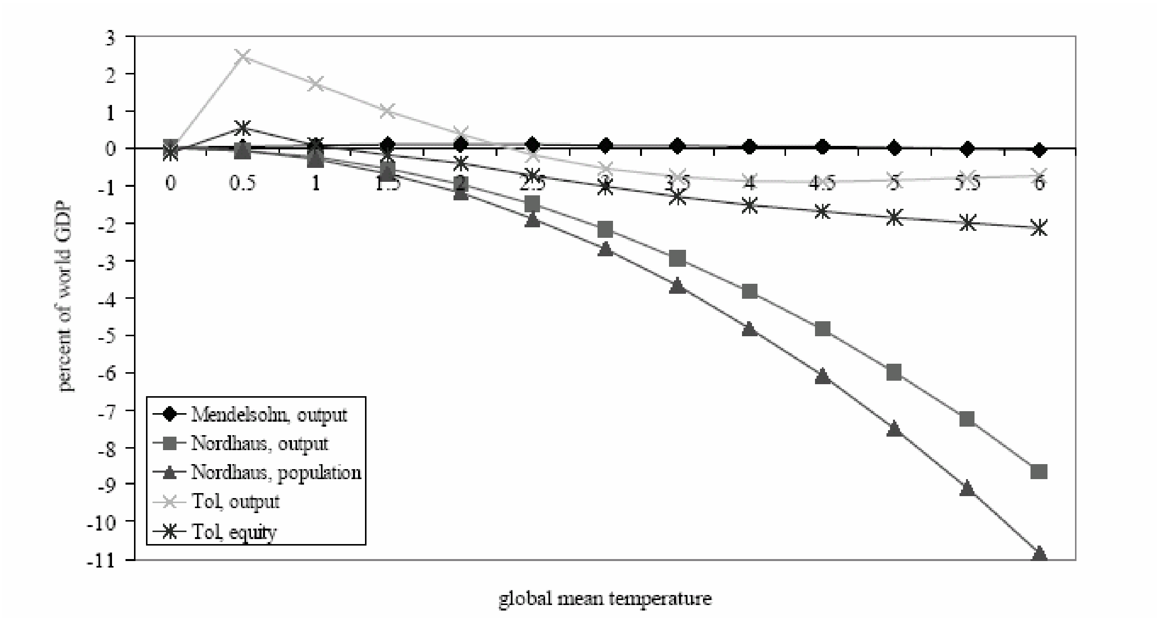
Figure 3. Meta-analysis of 88 estimates of the marginal social costs of carbon

The range of impacts of changes in global mean temperature (up to 6°C) on global GDP is illustrated in Figure 4.[3] Four scenarios from three studies with different approaches to aggregating costs show a broad range of possible damage costs.

[3] The global GDP loss for a specific time period or point in time can be deduced for each GHG concentration scenario in multiplying the social costs of carbon (in $/tC) with the amount of global emissions (C) and comparing the resulting global total costs with global GDP to yield the percentage global loss.

It needs to be pointed out that any such quantitative assessment and its interpretation needs to seen in light of the underlying problems and caveats as discussed above (such as differing model structures, approaches, and assumptions taken as well as differing time horizon, regions, sectors, and kind of damages covered). They do, however, serve as an illustration of the range of results from such efforts. Depending on the weighting factor used for aggregating costs across sectors and regions, some studies imply initial aggregate benefits from small changes in mean temperature while others show substantial damages even at low level of temperature changes.

However, all four scenarios consistently show increasing damages (in terms of GDP losses) for higher magnitudes of climate change.



Source: Tol et al. 2004.

Note:
Mendelsohn et al. (1997) aggregate impacts across different regions weighted by regional output. Nordhaus and Boyer (2000) aggregate either weighted by regional output or weighted by regional population. Tol (2002) aggregates either by regional output or by equity, that is, by the ratio of world per capita income to regional per capita income.

Figure 4. Impact of climate change as a function of the change in global mean temperature

<u>Conclusions: What to draw from the existing and where to go from here?</u>

Despite these challenges, the OECD study (2004) points out some general patterns that can be detected in the literature

1. Some sectors, such as agriculture, may experience net positive impacts globally of a small amount of climate change
2. Some sectors show adverse impacts even for low levels of global warming (such as biodiversity, health, marine ecosystems)
3. No research indicates any positive impact from climate change as temperatures increase beyond certain levels.
4. Marginal adverse impacts emerges across all sectors for a temperature increase beyond 3-4°C in global mean temperature
5. Number of studies indicates that the economically 'optimal' level of mitigation is increased when accounting for the risks of irreversible, abrupt climate change. Thus, calling for more investment in abatement in the near-term.

A broad conclusion is that sound summary estimates of benefits in a single (monetary) measure to compare with aggregate costs may not be adequate on their own to inform policy decisions. Cost benefit methods alone may be inadequate and should be complemented with risk-based methods (such as probabilistic approaches). The OECD study calls for a presentation of benefits in two different forms: monetised estimates and physical impact estimates. They point out that a coherent set of indicators and research strategy is needed. Such a strategy would involve the following steps: Firstly, global physical variables for impacts should be researched and identified. Thereafter, regional physical variables should be tackled. These should be followed by an economic valuation leading to a set of regional monetary variables. Finally, an attempt of monetised aggregate benefits assessment can be undertaken. A modest and preliminary research goal thereby should be to have consistent and comparable regional information so that impacts associated with levels of global mitigation can be assessed.

Climate Change- Extreme Weather Events

The number and intensity of extreme weather events, such as flooding caused by heavy precipitation, heat waves and big storms has increased considerably. Table 2 illustrates extreme climate events, the probability of occurrence and potential impacts. Not only the number of extreme climate events is expected to increase but also the intensity,

Extreme Climate Event	Probability	Impacts
Higher max. Temperature. More Hot Days and Heat Waves over nearly all land areas	Very likely	Increased Incidence of Deaths and serious diseases in older age groups and urban poor. Increase of Heat Stress in livestock and wildlife Shift of Tourist Areas Încrease of risks of damages to a number of crops Reduction of Energie Supply Reliability Increase of Energy Demand for Cooling
Higher minimum Temperatures, fewer cold days, frost days and cold waves over nearly all land areas	Very Likely	Decreased cold- related human Morbidity and Mortality Decreased Risks of Damages to a number of Crops, and increased Risks to Others Extrended Range and Activity of some pest and Disease Vectors Reduced Heating Energy Demand
More Intense Precipitation Events	Very Likely	Increased Flood, Landslide, Avalanche and Mudslide Damage Increased Soil Erosion Increased Flood Runoff could Increase Recharge of some Floodplain Aquifiers Increased Pressure on Government and Private Flood Insurance Systems
Increased Summer Drying over most Mid-Latitude Contiental Interiors and associated Risks of Drought	Likely	Decreased Crop Yields Increased Damage to Building Foundations caused by groud Shrinkage Decreased Water Resource Quantity and Quality Increased Risk of Forest Fire
Increase in Tropical Cyclone Peak Wind Intensities, mean and peak precipitation intensities	Likely	Increased Risk to Human Life, Risk of Infection Disease Epidemics and many other Risks. Anstieg der Risiken für Krankheiten und Epidemien Increased Coastal Erosions and Damage to Coastal Buildings and Infrastructure. Increased Damage to Coastal Ecosystems such as Coral Reefs and Mongroves.
Intensified Droughts and Floods associated with El Nino events in many different Regions	Likely	Decreased Agricultural and Rangeland Productivity in Grought- and Flood Prone Regions. Decreased Hydro- Power Potentials in Drought prone Regions
Increased Asian Monsoon Precipitation Variability	Likely	Increase in Flood and Drought Magnitude and Damages in Temperature and Tropical Asia
Increased Intensity of mid- latitude storms	Low	Increased Risk to Human Life and Health Increased Property and Infrastructure Losses Increased Damage to Coastal Ecosystems

Source: IPCC (2001).

Table 2 Projected Changes during the 21st century in extreme climate phenomena and their likelihood

especially of extreme precipitation events. Some regions (particularly poor regions) will and already have been more strongly affected than other regions. It is expected that in the region of North America more storms, hurricanes and tornados with extreme wind intensities will occur. In Asia floods are more likely to happen. In Europe, however, not only extreme heat waves or floods are more likely but also storms, such as tornados (MunichRe 2002).

Table 3 shows the number of extreme weather events and their economic and insured losses from 1950 until today. As the figure shows, the number of extreme weather events went up drastically. From the 1960s to the 1980s the number of such events went up by a factor of 2.8. Moreover, within the last ten years the number of extreme events was as much as 3.1 times higher than in the 1960s. This led to drastic increases for both economic and insured losses (Table 3 and Figure 5).

Great Weather Disasters 1950 - 2004

Decade comparision

Decade	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	last 10 1995-2004	Factor 80s : 60s	Factor last 10: 1960s
Number	13	16	29	44	74	49	2,8	3,1
Economic losses	43,9	57,6	86,9	136,9	460,8	331,1	2,4	5,8
Insured losses	unknown	6,4	12,7	25,1	106,2	87,6	3,9	13,6

Losses in US$ bn (2004 values) MRNatCat*SERVICE*®

Source:2004 Geo Risks Research Dept., Munich Re

Table 3 Great weather disasters 1950- 2004

Extreme heat phenomena and precipitation events also happened in Europe (including Germany): in the summer of 2002 Middle and Eastern Europe were infested by a flood catastrophe, caused by heavy rainfalls. This extreme weather event affected the Eastern and Southern part of Germany, the South West of the Czech Republic and Austria and Hungary caused by the strong flooding of the main rivers, Danube, Elbe, Moldau, Inn and Salzach. The flood hit Germany, Austria and the Czech Republic the hardest. Economic damages amounted to up to 9.2 billion Euros in Germany only.[4]

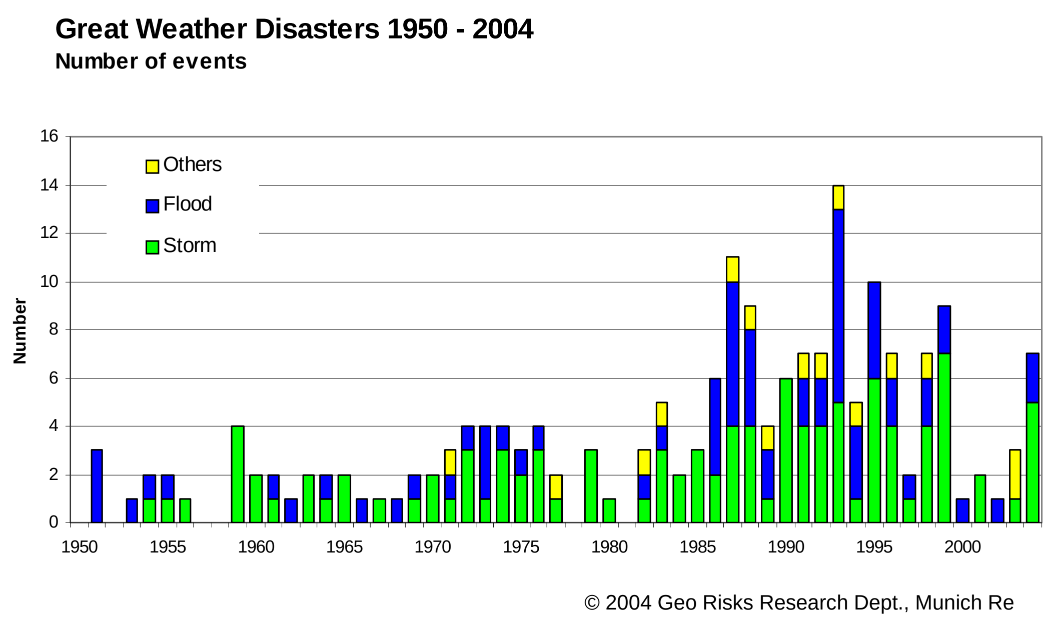


Figure 5: Great weather disasters 1950-2004

[4] One of the largest re-insurance companies, the Munich Re assessed the damages associated with the flood, see Münchner Rück: Jahresrückblick Naturkatastrophen 2002, München 2002

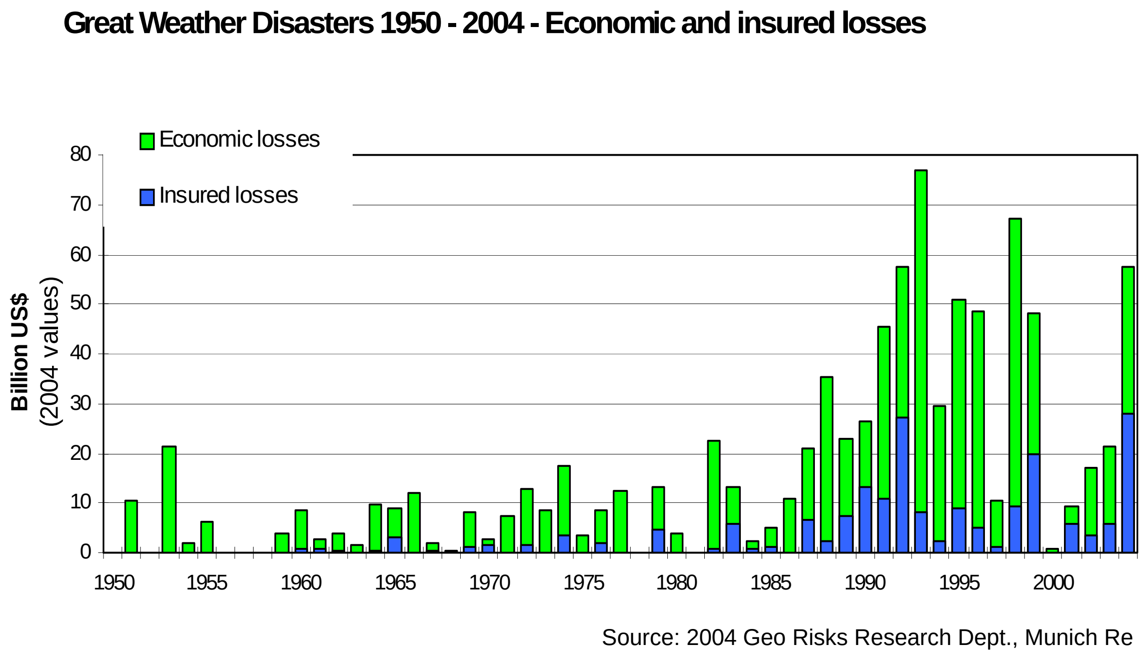


Figure 6: Economic and insured losses of great weather disasters 1950-2004

In the summer of 2003, only one year after the big flood, Europe suffered from an extreme heat wave. The economic damages included increased diseases (such as cardiovascular problems or, for example, malaria that can occur also in the European country area) and an increased number of heat related deaths. Especially in France, the mortality rate of elderly people increased considerably in this period. Furthermore, damages of crop gains, disruption of energy supply and an increase of forest fires, especially in Southern Europe, took place.[5] In total, economic damages related to the European heat wave can be assessed at 10 to 17 billion Euros.[6]

Costs of Action versus Cost of Inaction of Climate Protection- A Quantitative Assessment

We assess the costs of action, i.e. the costs of emissions reduction, and the costs of inaction, i.e. the impacts of human induced climate change, with the help of a quantitative modelling tool (WIAGEM - World Integrated Assessment General Equilibrium Model). We compare three scenarios: The reference scenario, which does not include any climate protection measures. Scenario A (ScenA, "early action") limits the increase in global surface temperature to 2°C, while Scenario B (ScenB, "delayed action") defers the introduction of emissions reductions to a later point of time (2030). Here, we assume that concrete emissions mitigation policies that intend to reach specific emissions reduction targets start after 2030. No climate policy takes place before 2030.

Our analysis is performed using the multi-regional WIAGEM model. WIAGEM is an integrated economy-energy-climate model that incorporates economic, energy and climatic modules in an integrated assessment approach (Kemfert 2002a and 2002b). To evaluate market and non–market costs and benefits of climate change, WIAGEM combines an economic model - with special focus on the international energy market - with a climate model that accounts for temperature changes and sea level variations. The design of the model focuses on multilateral trade flows. The representation of economic activities is based on an intertemporal general equilibrium approach and contains the international markets for oil, coal and gas. The climatic model is based on general interrelations between energy and

[5] High water temperatures of rivers due to high outside temperatures cause risks of inadequate cooling of nuclear reactors. In 2003, this initiated a shut down of nuclear power plants in Germany and France.

[6] Tony Blair assessed the economic damages at about 13.5 billion US$ and 26.000 fatalities, see speech of the British Prime Minister on the occasion of the 10th anniversary of the "Price of Wales Business & the Environment Programme", London 14. September 2004.

non-energy related emissions, temperature changes and sea level variations, all inducing substantial market and non-market damage cost economic impacts. WIAGEM accounts for all six greenhouse gases (GHG) that potentially influence global temperature, sea level variation and the assessed probable impacts in terms of costs and benefits of climate change. Additionally, the model includes net changes in GHG emissions from sources and removals by sinks resulting from land use change and forestry activities.

Market and non-market damages are evaluated according to the damage costs approaches of Tol (2002, 2003 and 2004) who calculates different damages of regional climate change. To assess impacts by climate change, we follow Tol's approach (2003) to cover impacts on forestry, agriculture, water resources and ecosystem changes as an approximation of a linear relationship between temperature changes, per capita income or GDP and adaptation costs due to climate change. This means, increased emissions lead to an increase of the global surface temperature which causes global economic impacts. Regional economic imapcts depend on the countries economic performance and population development, i.e. per capita income. Tol (2003) estimates climate change impacts covering a variety of climate change impacts. Along with sectoral impacts on agriculture, forestry, water resources and energy consumption, he covers impacts on ecosystems and mortality due to vector borne diseases and cardiovascular and respiratory disorders. In addition to the damage cost assessments of Tol, we implement adaptation costs and additional costs to the economy lowering other investments (crowding out effect).

We include the same regional damage functions in our model. However, the damage functions are disaggregated according to the specific sort of damage (impacts on forestry, water, mortality). We assume that there is a functional relationship between overall temperature change and regional economic income (see Annex). The model results differ substantially from the findings of Tol (2004). This is because of two main reasons. First; we apply a fundamentally different global economic approach than Tol (2002) applies in his cost assessment study. We use a global general equilibrium approach that covers interregional and intersectoral trade effects, he uses a much simpler approach that neglects the interregional trade effects. The model applies a recursive dynamic approach so that we cover feedback effects from damages or other shocks. This means, in each time period (the model covers 5 year time intervals), impacts occur due to temperature change and regional per capita productivity change . This affects the dynamic impacts in the model: if impacts of climate change occur countries face higher expenditures. These expenditures cannot be spent as initially planned (thus crowding out investment). The main difference in the modelling framework here in comparison to Tol is that we apply a recursive dynamic approach where countries face impacts of climate change. Second, we include a detailed climate model that assesses the temperature changes from emission profiles (Kemfert 2002). Both reasons cause the fact that the dynamic feedback effects from the climate and the economic system yield much higher damage costs as earlier studies. In addition to the pure economic income effects we cover economc shocks due to adaptation. Countries spend a certain amount on adaptation when climate change occurs.[7] These expenditures are crowding out investments that cannot be spent as previously intended in a growth model. Adaptation (or protection costs) in WIAGEM mean costs that occur to adapt to damages. They do not prevent future damages. Future damage costs are only reduced in the following way: with less climate change by, for example reduced emissions, countries spend less protection costs. Ancillary benefits are related to the level of emissions. A reduction in emissions implies higher ancillary benefits. We find that these effects cause reactions on economic development.

Figure 7 graphically illustrates the modelling structure and the interaction of economic activities, energy consumption, climate and ecological impacts in WIAGEM. Uncertainty about the correct determination of the model, data and key parameters distorts the understanding of the social, economic and ecologic impacts of climate change. Uncertainties could justify postponing significant mitigation efforts. However, uncertainty also includes the risk of significant climate

[7] If climate change is reduced (by for example reduced emissions), countries spend less percentage of investments for adaptation.

changes that induce considerable impacts. The uncertainty about data quality is reduced because the model is based on a detailed economic database representing a well-known and scientifically accepted economic database. Model and parameter uncertainties are covered by choosing an innovative modelling approach and by including parameter sensitivity analysis.

WIAGEM is a multi-sector, multi-region dynamic intertemporal integrated assessment model. The model covers a time horizon of 100 years and solves in five-year time increments.[8] The basic idea behind this modelling approach is the evaluation of market and non-market impacts induced by climate change. The economy is represented by 25 world regions, which are further aggregated into 11 trading regions for this study (see Table 4).

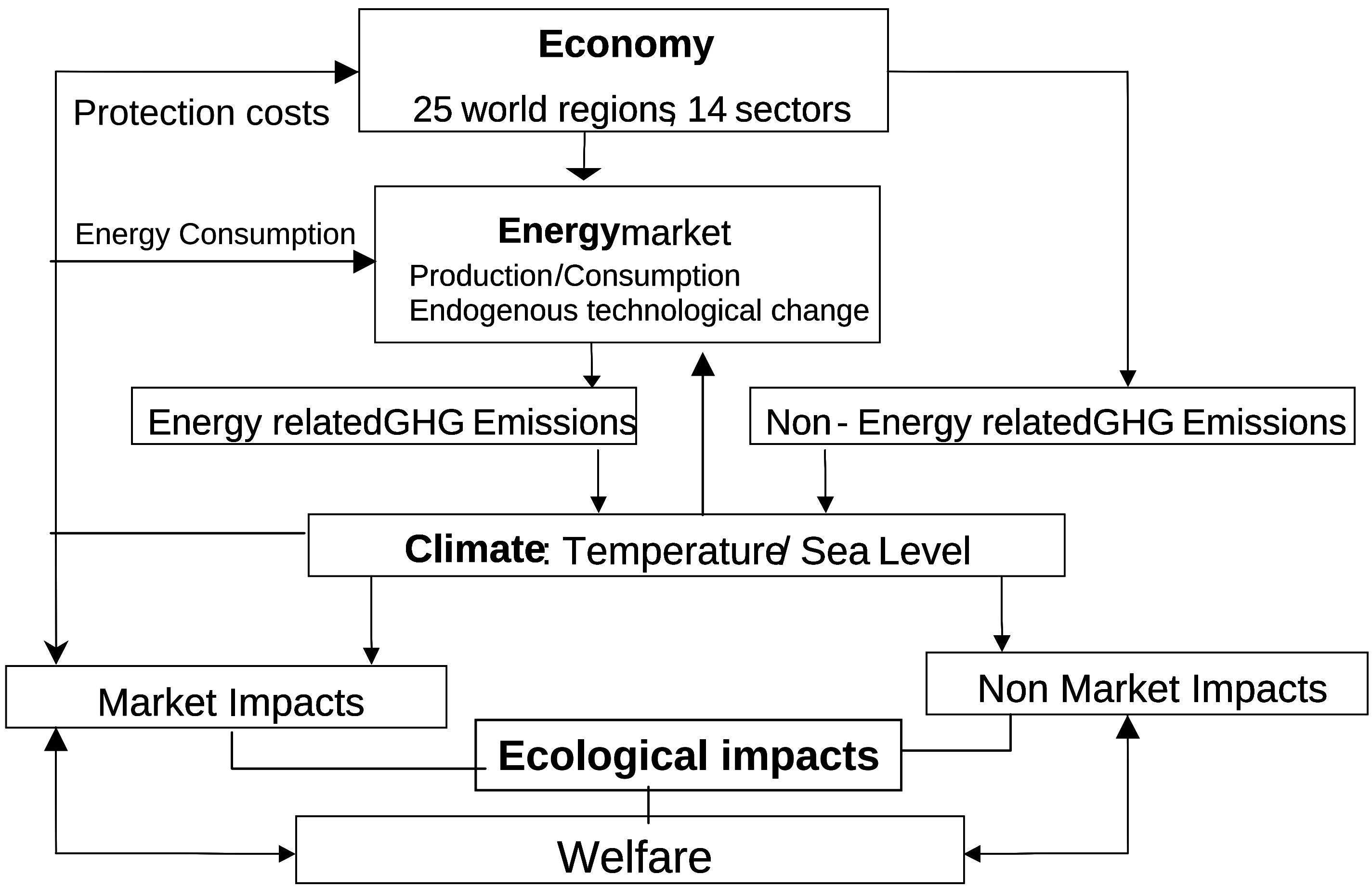


Figure 7 Modelling structure in WIAGEM

The economy of each region is disaggregated into 14 sectors, including five energy sectors: coal, natural gas, crude oil, petroleum and coal products, and electricity. Goods are produced for the domestic and export markets. The output of the non-energy sectors is aggregated into a non-energy macro good. WIAGEM covers a production function that allows for (imperfect) substitution between the input goods, labour, energy (i.e. coal, oil and gas) and capital (so called constant elasticity of substitution CES production function). The substitution elasticities are crucial parameters of the model: if we allow for a very good substitution option between the individual energy inputs, mitigation costs may be reduced as countries simply substitute coal with gas. Vice versa, if we allow for low substitution options, countries face higher mitigation costs, as it is more difficult to substitute for example coal with gas.

[8] See Kemfert (2002b) for a detailed model description.

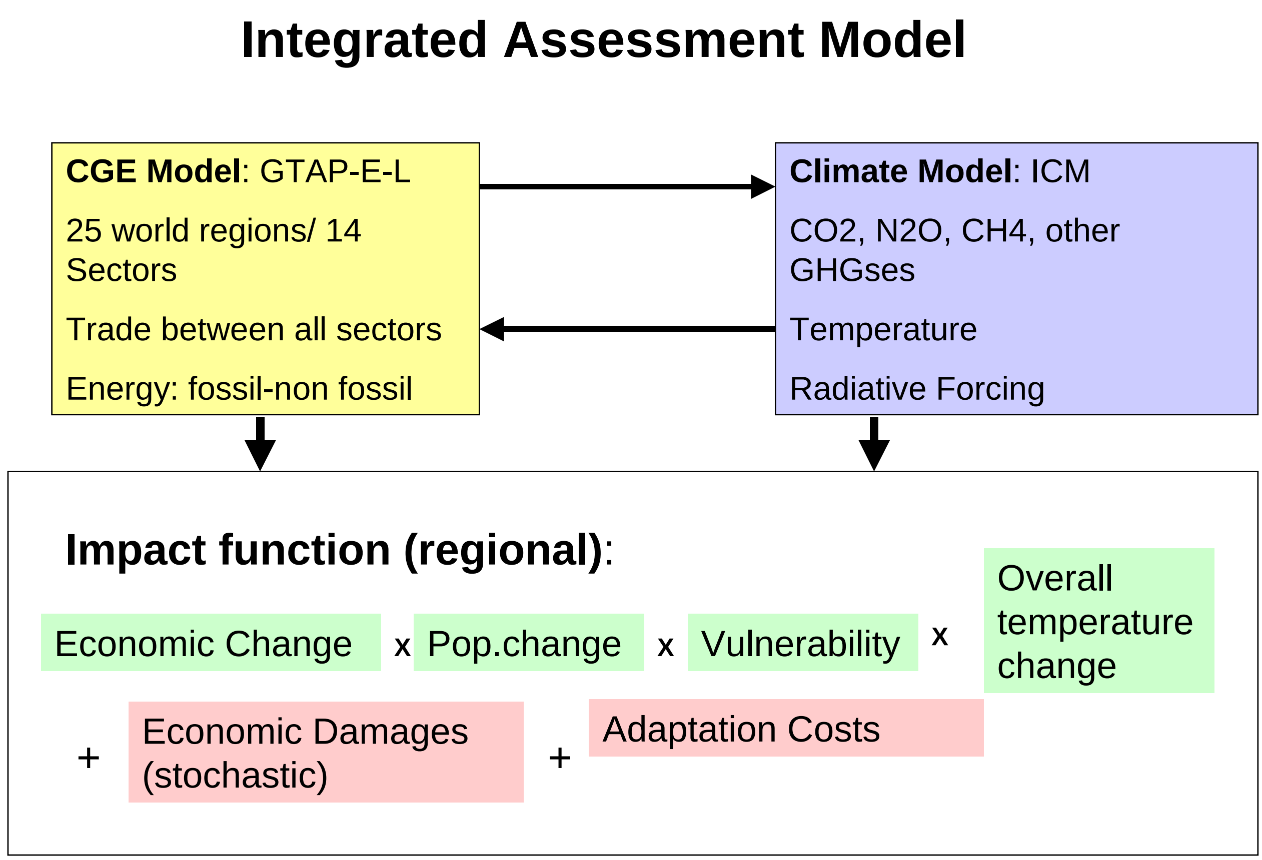


Figure 8: Integrated Assessment Model- Impact Assessment

The same functional form (CES) is assumed for the household's utilities: they can choose between current consumption or savings, under the constraint of individual incomes. Also here the substitution elasticity is a crucial parameter, as with high savings and low current consumption economic growth can be lower. The basic assumptions for the elasticity values are shown in Table 5.

	Regions
ASIA	India and other Asia (Republic of Korea, Indonesia, Malaysia, Philippines, Singapore, Thailand, China, Hong Kong, Taiwan)
CHN	China
CNA	Canada, New Zealand and Australia
EU15	European Union
JPN	Japan
LSA	Latin America (Mexico, Argentina, Brazil, Chile, Rest of Latin America)
MIDE	Middle East and North Africa
REC	Russia, Eastern and Central European Countries
ROW	Other Countries
SSA	Sub Saharan Africa
USA	United States of America

Table 4 Definitions of countries and regions in WIAGEM

WIAGEM covers the option to increase low carbon technologies which lowers mitigation costs. Countries invest in R&D expenditures that brings low carbon technologies with reduced costs. Even those countries can benefit by technological changes that do not increase their expenditures in R&D by so called spillover effects: if, for example, Europe invents a new low carbon technology, it will be exported also to other countries (e.g. China).

Type of elasticity	Value
Armington elasticity of substitution	1
Armington elasticity of transformation	2
Elasticity of fossil fuel supply	1 (coal), 4 (gas, oil)
World interest rate	2
Elasticity of substitution between non-energy and energy composite in production and final demand	0.25-0.5 (Annex B), 0.20-0.4 (non-Annex B)
Interfuel elasticity of substitution	0.5 (final demand) 2 (industry)

Table 5 Key parameter of model WIAGEM

In addition to the non-energy macro good, oil, coal and natural gas are traded internationally. The global oil market is characterized by imperfect competition to reflect the ability of the OPEC regions to use their market power to influence market prices. Coal is traded in a competitive global market, while natural gas is traded in competitive regional markets with prices determined by global or regional supply and demand.

Energy-related greenhouse gas emissions occur as a result of energy consumption and production activities. WIAGEM includes all six greenhouse gases covered under the Kyoto Protocol: carbon dioxide (CO2), methane (CH4), nitrous dioxide (N2O), and the fluorinated gases HFC, PFC and SF6. Thereof the first three are considered to have the greatest impact on climate change over the 100-year period covered by the model. Key assumptions about the gases are shown in Table 6. WIAGEM also covers non-energy related emissions, we assume a constant growth rate over time, see Table 6.

Trace Gas	CO2	CH4	$N_2$0
Atmospheric Concentration Pre- Industrial (ppmv) 1992 (ppmv)	 278 353	 0.789 1.72	 0.275 0.310
Energy related Emissions 1992 (billion tons) Growth rate, post 1992	 6.0	 0.08	 0.0001
Non-energy related Emissions 1992 (billion tons) Growth rate, post 1992	 0.2 0	 0.454 0.8	 0.0139 0.2

Table 6: Summary key assumptions greenhouse gases [9]

Impacts of climate change cover market and non-market damages; the former comprise all sectoral damages, production impacts, loss of welfare etc., while the latter contain ecological effects such as biodiversity losses, migration, and natural disasters. To assess impacts by climate change, we follow Tol's approach (2002) to cover impacts on forestry, agriculture, water resources and ecosystem changes as an approximation of a linear relationship between global temperature changes, per capita income or GDP and adaptation costs due to climate change. We estimate climate change vulnerability covering a comprehensive evaluation of diverse climate change impacts. Along with sectoral impacts on *agriculture, forestry, water resources and energy consumption*, he covers impacts on ecosystems and mortality due to vector borne diseases and cardiovascular and respiratory disorders (see Appendix I for more details). We assume that there is a functional relationship between global

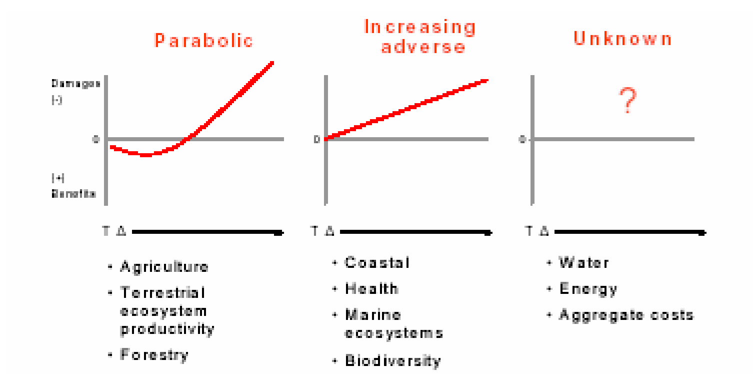
[9] Source: IPCC (1990) and IPCC (1992)

temperature change, regional population change and economic income change that affects the impacts on ecosystems, forestry, health and water. We furthermore assume that energy consumption, here space heating and cooling, depends on the economic income, energy productivity and overall temperature change (see Annex for detailed mathematical description and parameters): That means, with increasing global temperature impacts of climate change increase, depending on the regional economic performance of a country (per capita income) and the population development. We assume a linear relationship between temperature change and climate change impact on forestry and water. Energy consumption for heating and cooling depends on the temperature development, population and income change, and technological progress within the energy sector. The loss of ecosystems depends on the per-capita income change and population change. We furthermore assume a non-linear relationship between health[10] (mortality) and regional temperature change and income. The main shortcoming of this approach (from Tol covered in this study) is the assumption of a global surface temperature that leads to regional impacts, and not a regional temperature development. Only for the impact assessment of health and mortality we account for regional temperature weights.

We apply the same functional relationships as Tol (2004) who assesses economic impacts of climate change on ecosystems, forestry, water and health. He applies damage functions that relate on the global temperature change (not regional temperature change) and the per capita economic performance of a region. However, as we apply a fundamentally different economic model, our model results show that damage assessments are much higher than earlier studies. Most of the previous Integrated Assessment studies (Nordhaus 1991, Cline 1992) assume one damage function for the global assessment of damages. Tol (2002) firstly assessed regional damages in relation with global surface temperature and regional per capita performance. We apply the same functional relationship for the sectors ecosystem, forestry, water and mortality (parameters see Appendix). However, we cover detailed and disaggregated dynamic economic and climate feedback effects. Two main reasons lead to different damage effects than previous studies: First, we cover a detailed CGE model that incorporates interregional and intersectoral trade effects and dynamic investment decisions. Second, most integrated assessment models so far include one aggregate damage function for the world and do not disaggregate regional impacts. In this model approach, we assume that regional impacts of climate change are caused by the overall (global) temperature changes, income changes of a country and regional population. We then sum up all impacts. However, regional differences in climate change are not accounted for.

Model Results

This chapter presents our model results on the costs and benefits of climate policy. The first section highlights previous estimates from comparable studies. Our results are then presented in light of those estimates.



Source: Morlot and Agrawala (2004), Chapter 1 OECD study

Figure 9 Damage functions

<u>Results from Comparable Studies</u>

Quantitative modelling studies crucially depend on the assumptions about economic development, the incorporation of dynamic interrelations, the aggregation level, time and the climate threshold. Furthermore, the assumptions about damages of climate change significantly affect the quantitative impact assessment.

Within the terrestrial ecosystem productivity area, a parabolic damage function is seen to be most realistic, as especially in the short term time horizon benefits from climate change might be most likely (Morlot and Agrawala, 2004). Most studies assume a linear relationship between temperature change in time and impacts on health, biodiversities, marine ecosystems and

[10] Although there exist more recent studies that estimate an economic growth reduction of malaria disease alone by 1 % per year, we still stick to the chosen relationship with less drastic impact assumptions, see Malaney et al (2004)

coasts. Still highly uncertain are impacts on water and energy. As some model studies only incorporate few aspects, a comparison of impact assessment studies becomes very challenging.

The range of uncertainties related to impact assessment studies is very high. Market and non-market impacts estimates vary widely between individual studies (OECD 2004).

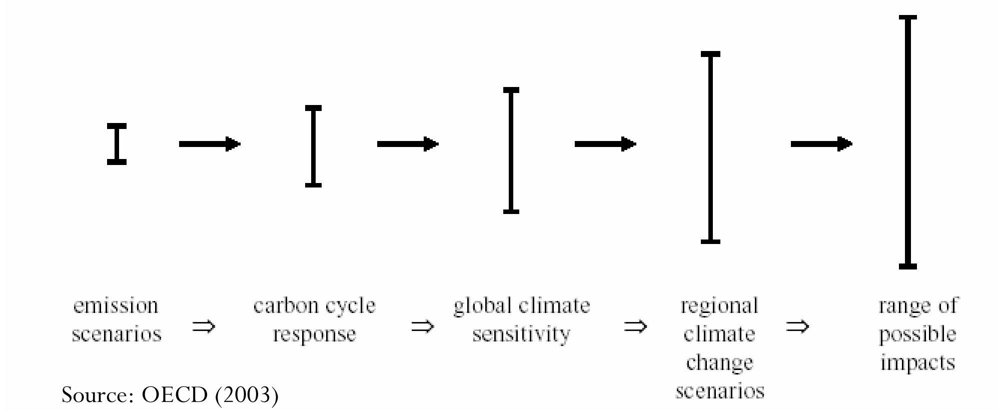
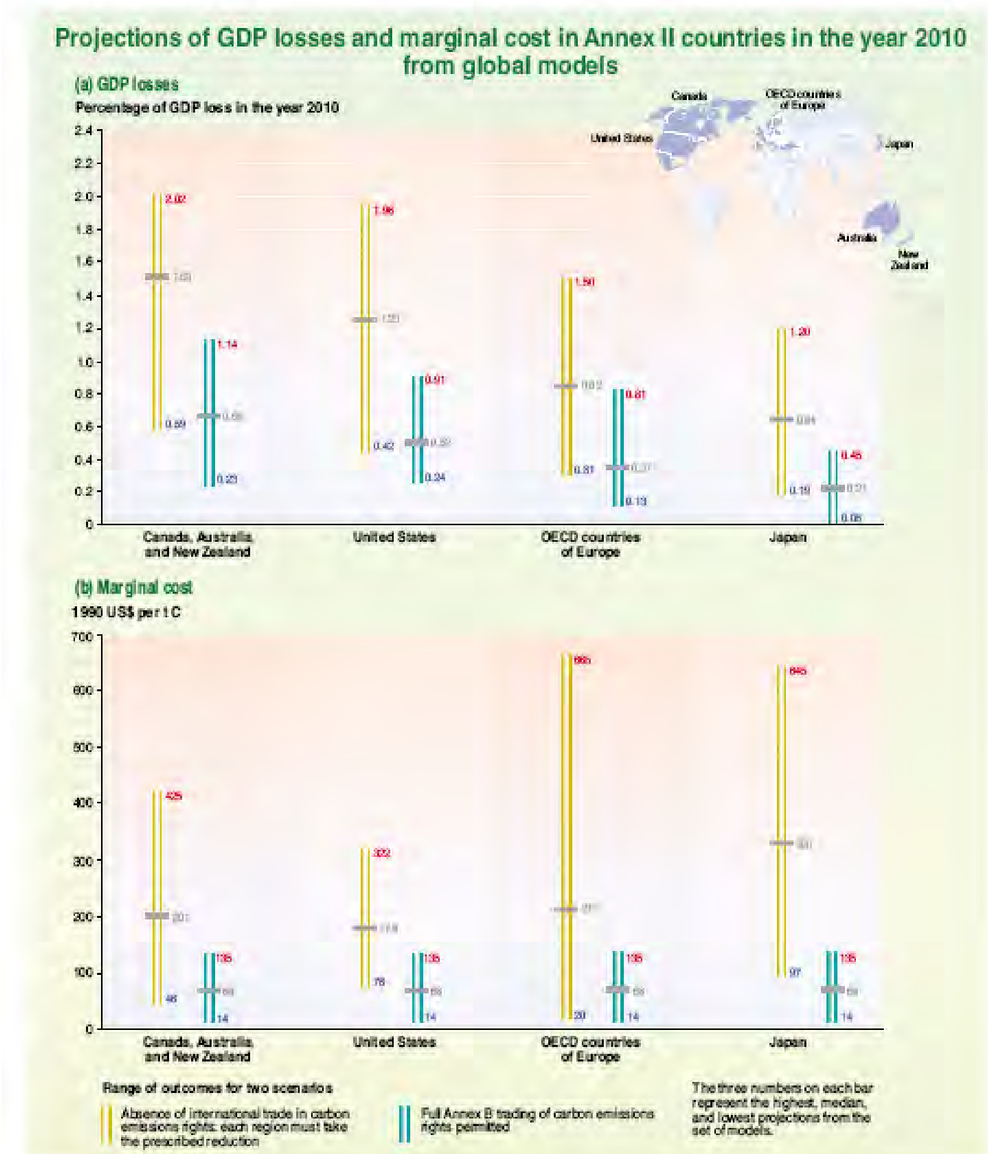


Figure 10. Range of major uncertainties in impact assessments

In this study, we incorporate both market and non-market impacts. Market impacts are reflected in a very detailed way as we apply a disaggregated CGE model that cover the main economic regions of the world that are linked via bilateral trade flows.



Source: IPCC (2001) and Weyant (1999)

Figure 11. Global Mitigation Costs as GDP losses and marginal costs of different global models

Non-market impacts are included by a very aggregated functional relationship, that certainly crucially depends on the key assumptions and parameters. Also, impacts from damages are covered based on sectoral and regional damage functions that depend on global temperature and regional economic income and population changes. As regional climate change is not taken into account, and damage functions are very aggregated and stylised, this is still a very rough global estimate of impacts.

Global mitigation costs assessments differ widely, as model constructions, assumptions and parameterization diverge substantially. IPCC (2001) summarised abatement costs as percentage of GDP of different regions. An emissions trading system reduces costs considerably.

Model Calculations

This section presents our model calculations. We compare the benefits and costs of climate protection, that is, on the one hand the avoided climate damages and adaptation costs as well as the ancillary benefits, on the other hand i.e. the costs of emissions mitigation related to avoiding global mean warming by more than 2°C. Especially, we assess a reference scenario where no climate protection or emission mitigation actions take place and two mitigation scenarios: Scenario one "early Action" (ScenA) aim at avoiding a global surface temperature increase of more than 2°C compared to pre-industrial levels, while scenario two "delayed action" (ScenB) starts with drastic emission reduction policies at a later time period (2030) resulting in much higher levels of emissions and temperature increase throughout the entire time horizon of 100 years. Furthermore, we assume in ScenA and ScenB a climate sensitivity of 2.8°C (see Appendix I). In an additional sensitivity analysis, we compare the results with those for a high climate sensitivity (HCS-4.2°C) and a low climate sensitivity (LCS-1.5°C).

Scenario Description	**Emission Mitigation Start**	**Climate sensitivity**
Scenario A (ScenA)	Now	middle (2.8°C)
Scenario B (ScenB)	2030	middle (2.8°C)
Scenario B with faster technological change (Scen-B-ITC)	2030	middle (2.8°C)
Scenario A- high climate sensitivity (ScenA-HCS)	Now	high (4.2°C)
Scenario A- low climate sensitivity (ScenA-LCS)	2030	low (1.5°C)
Scenario B- high climate sensitivity (ScenB-HCS)	2030	high (4.2°C)
Scenario B- low climate sensitivity (ScenB-LCS)	2030	low (1.5°C)

Table 7. Scenario description

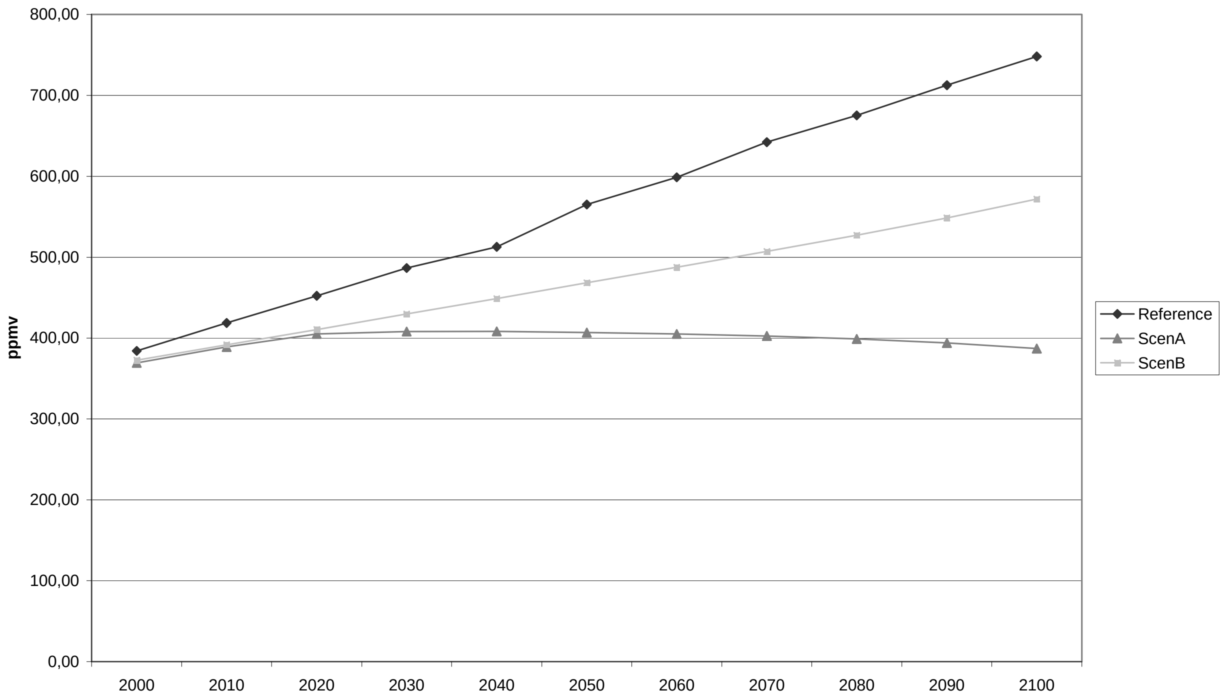


Figure 12. Greenhouse gas concentrations of different scenarios (in ppm CO2)

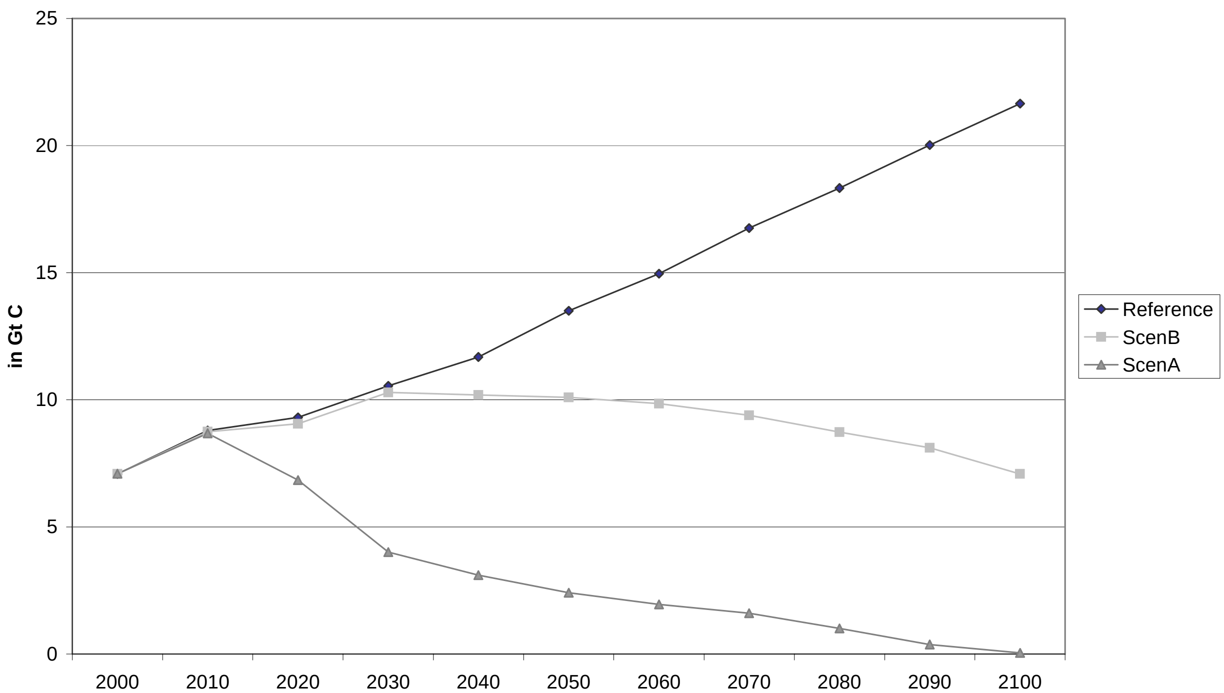


Figure 13: Carbon dioxide emissions development in Gt

In ScenA, we assume that a temperature limit of 2°C is met (assuming a climate sensitivity of 2.8°C). This implies that emissions need to be reduced considerably in comparison to the reference scenario. In the reference scenario, emissions reach a concentration of about 750 ppm (CO2 equiv.), which is transformed into a temperature increase of 4.3 °C in 2100 (Figure 11 and Figure 13). In order to avoid a temperature increase of more than 2°C, emission concentration need to be reduced by about 45 percent to a level of slightly over 400 ppm in 2100 (CO2). Assuming lower climate sensitivity, a higher emissions concentration (slightly less than 600 ppm) is possible in accordance with the 2°C target). Reversely, with higher climate sensitivity more severe emissions cuts are necessary to reach the 2°C target. The CO2 concentration would need to come down to less than 400 ppm compared to 750 ppm in the baseline.

It turns out that in ScenB avoiding global warming of more than 2°C cannot be fulfilled at all as climate protection in form of concrete emission reduction starts too late (2030). In order to avoid a temperature increase of more than 2°C, we have to incorporate induced technological developments. This means that we implement a scenario where we explicitly allow technological innovations, i.e. energy efficient and cheap technologies. In the other scenarios, we also include technological innovations (exogenous and endogenous) but not in that large extend. But even with the inclusion of induced technological development, warming exceeds the temperature limit of 2°C if climate policy starts in 2030. Even with the assumption of low climate sensitivity in ScenB, the temperature target of 2°C cannot be met.

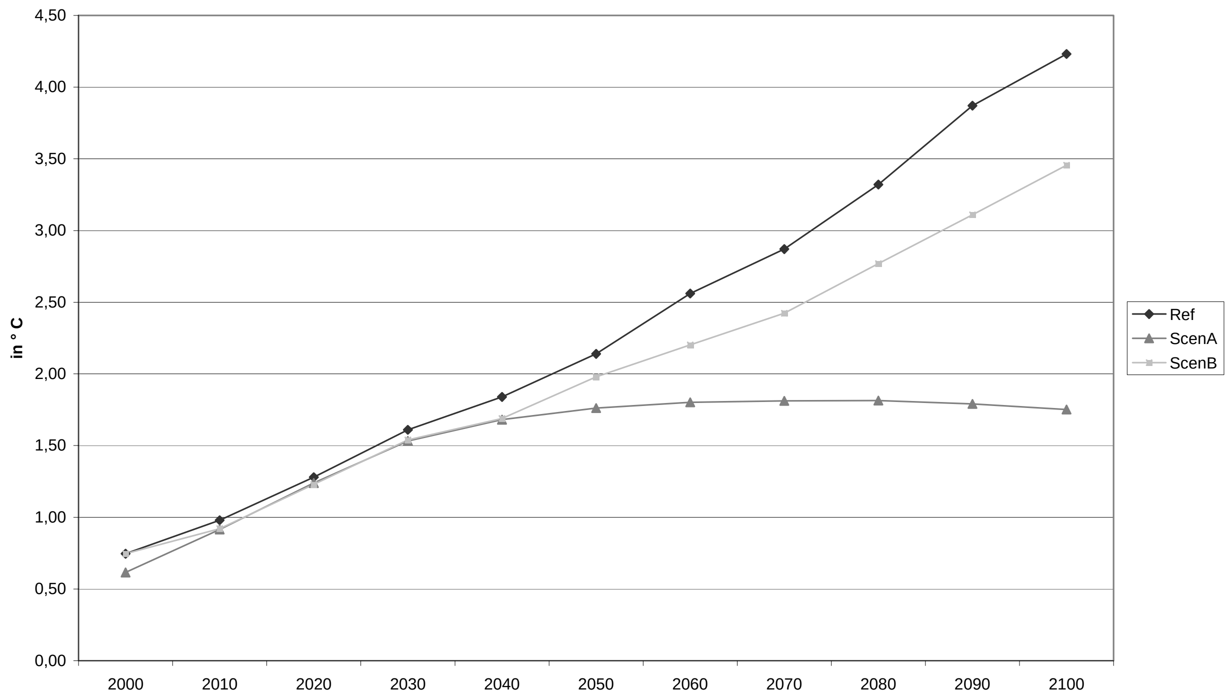


Figure 14 Temperature development of different scenarios (in °C)[11]

We report the total costs as the sum of mitigation costs (as a result of a climate policy) and the damage costs (Figure 14). The damage costs, or costs of inaction, refer to the damages that occur as a result of the temperature increase (Figure 13) and the corresponding emissions concentration (that is, including ancillary costs e.g. due to air-pollution). It shall be noted that even the target of limiting the temperature increase to 2°C above pre-industrial levels (ScenA) will still result in damage costs i.e. in costs related to damages that occur at a temperature increase of 2°C. In the reference scenario where no mitigation action is taken costs solely relate to damage costs.

Total costs, i.e. the sum of mitigation costs and damages costs[12], are substantially lower in ScenA than in ScenB. Because climate policies start early, mitigation costs are initially higher in ScenA than in ScenB. Interestingly, however, despite a much later start of climate mitigation policies in ScenB, the costs of action are almost identical in terms of

[11] In scenario A, the temperature target is 2°C in 2100, some decline below 2°C is because of terminal conditions of the model in 2100.

[12] Mitigation costs assess all economic costs to reach the emissions targets, i.e. production declines or substitution costs towards another technology. We compute these costs as shadow costs of emissions reduction measured in percentage of GDP. Damage costs cover all impacts due to climate change.

percentage GDP losses in the two time periods 2050 and 2100. This is because, in ScenB, more drastic measures need to take place after 2030, which overcompensate reduced mitigation costs in the time before 2030. As in ScenB emission mitigation starts late and the temperature target of 2°C cannot be reached by 2100, damages are much higher than in ScenA, especially in later time periods (2100). This results in higher total costs for ScenB.

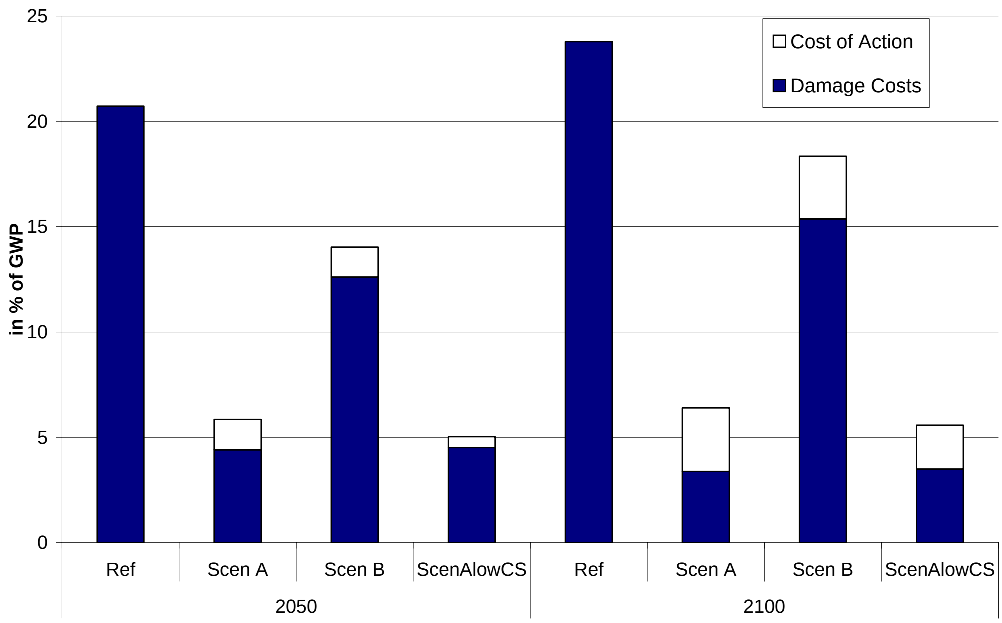


Figure 15. Total costs as sum of costs of action (mitigation costs) and damage costs in 2050 and in 2100

Figure 15 shows the damages avoided in ScenA and ScenB compared to the reference scenario. Both ScenA and ScenB result in lower emissions concentration and temperature increase than the reference scenario. Thus, both policy scenarios provide benefits in terms of avoided damages. As the temperature target of 2°C is met in ScenA and the corresponding emissions concentration is substantially lower, the avoided damages are much higher in ScenA than in ScenB.

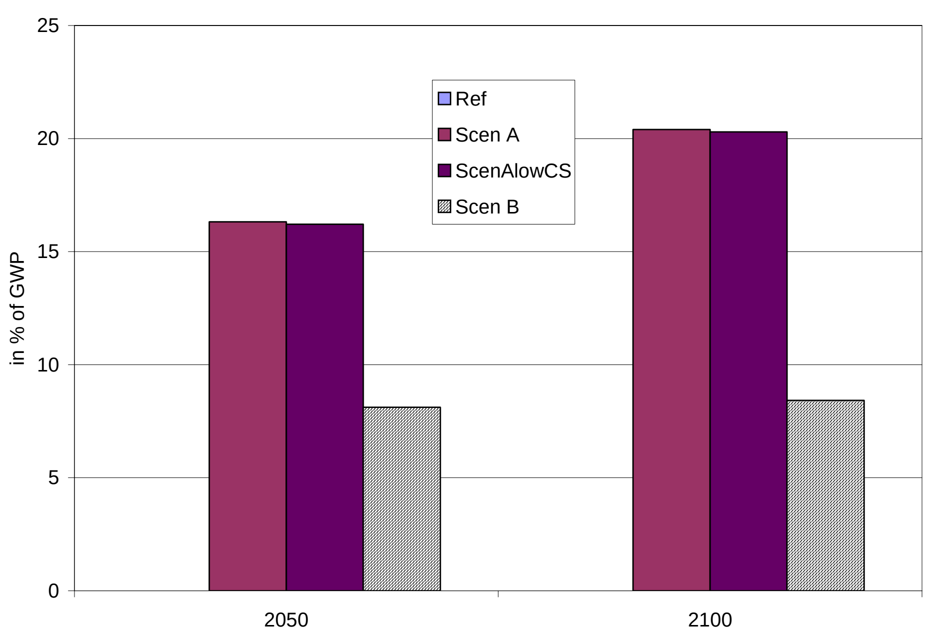


Figure 16. Avoided damages compared to the reference scenario

The net effects compared to the reference scenario, i.e. the difference of avoided damages (compared to the reference case) and mitigation costs are shown in terms of percentage changes of gross world product (GWP) in Figure 16. We see the net gain the policy scenarios induce compared to the reference scenario. ScenA leads to higher positive effects in terms of gross world product (GWP) than Scen B, compared to the reference scenario because the avoided damages are higher and mitigation costs are almost identical.

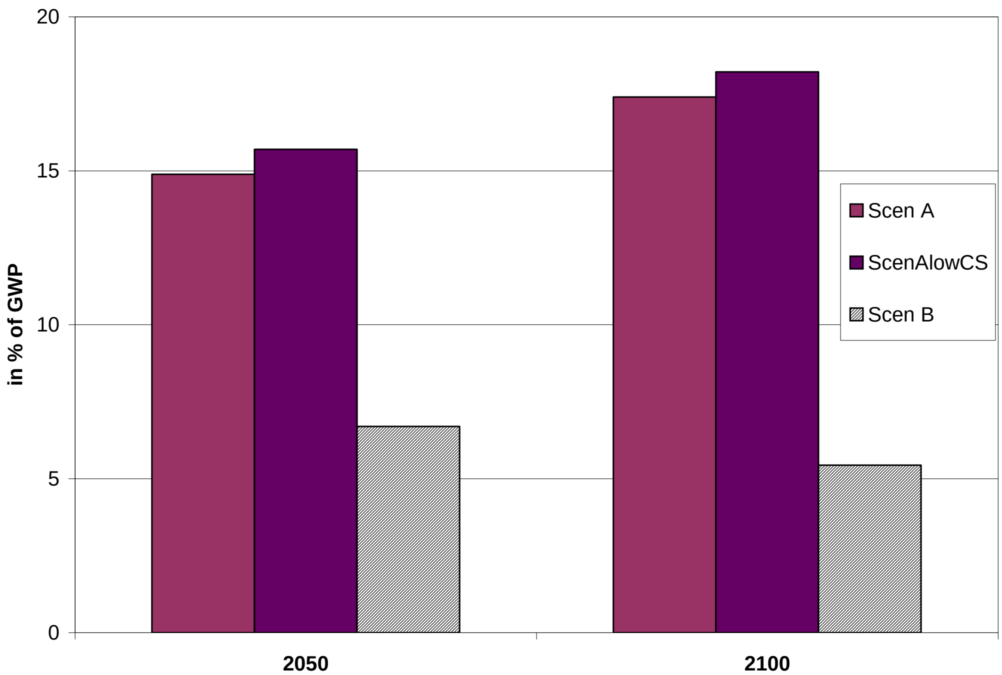


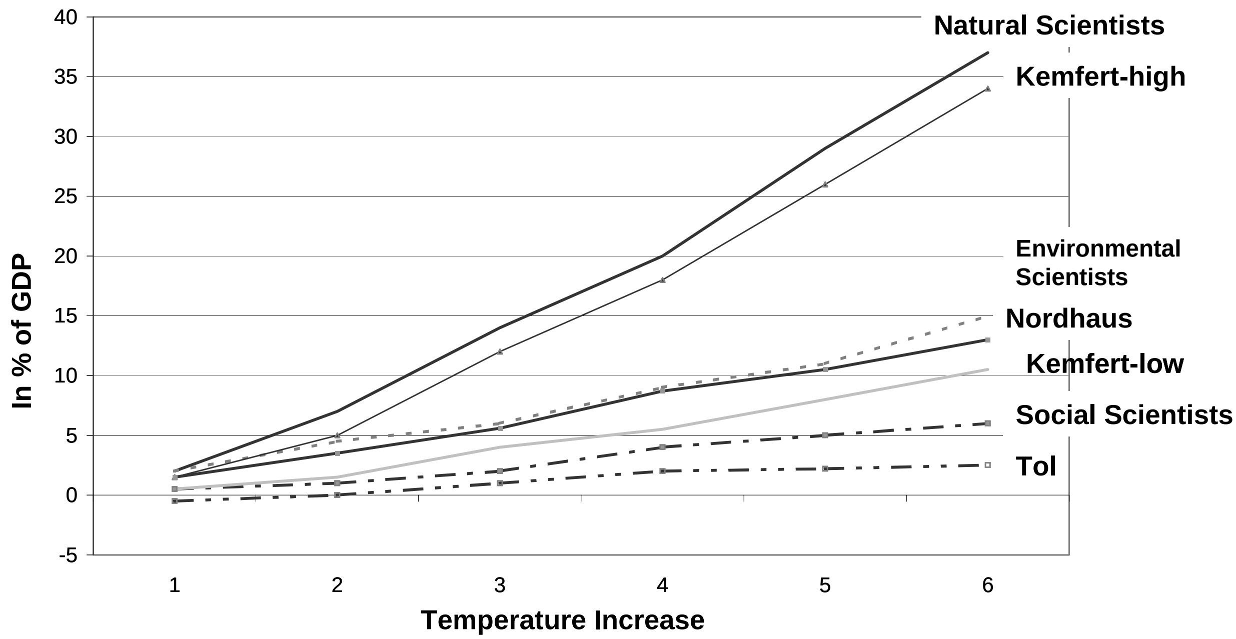
Figure 17. Net effects compared to reference case as difference of avoided damages and mitigation costs

If we assume a lower climate sensitivity (ScenA lowCS), a higher greenhouse gas concentration, and thus higher emissions, would be possible in order to meet the 2°C temperature target. This would lead to lower mitigation costs and, thus, lower total costs. At the same time, avoided damages would be slightly lower than in ScenA as the same temperature target is reached at a higher corresponding level of greenhouse gas emissions and thus damages are higher with the lower climate sensitivity.[13] The net effect, i.e. the difference between avoided damages and mitigation costs, would be higher than for higher climate sensitivity, as the reduction in mitigation costs overcompensates the slight reduction of benefits (i.e. avoided damages).

Global damages in the reference case reach 20 to 23 percentage of global GWP in 2050 and 2100, respectively. In the spectrum of previous results (Figure 17) these results lie within the area of environmental and natural scientists. In comparison to previous studies (i.e. IPCC 2001 and Weyant 1999), we estimate higher damages than other economic studies. In this study we cover a full economic CGE model linked with a climate model that is able to assess dynamic impacts (economic growth, trade) but also monetise damages of climate change. The costs of action (mitigation costs) estimations lie well within the range of earlier studies (Weyant 1999).

Our damage assessment differs substantially from previous findings (Nordhaus (1991), Cline (1992) or Tol (2002, 2004). This is because of two main reasons. First; we apply a fundamentally different global economic approach than

[13] Higher damages occur because ancillary benefits are lower. Ancillary benefits are related to the emissions level and not to the change in temperature. Thus, with a lower climate sensitivity and correspondingly higher emissions ancillary benefits decrease even though temperature related damages remain the same.



Source: OECD (2003) with own additions

Figure 18 Damage assessments of different science perspectives [14]

Tol (2002) applies in his cost assessment study. We use a global general equilibrium approach that covers interregional and intersectoral trade effects, he uses much simpler approach that neglects the interregional trade effects. The model applies a recursive dynamic approach so that we cover feedback effects from damages or other shocks. Second, we include a much more detailed climate model that assesses the temperature changes from emissions development (Kemfert 2002). We find that the dynamic feedback effects from the climate and the economic system cause much higher damage costs as earlier studies. In addition to the pure economic income effects we cover economc shocks due to adaptation. Countries spend a certain amount on adaptation when climate change occurs.[15] These expenditures are crowding out investments that cannot be spent as previously intended in a growth model. We find that these effects have an additional major impacts on economic development.

In contrast to Nordhaus and Cline we apply regionally different damages function that are based, however, on the global temperature change. Damages occur basically because of three main issues: First, the global temperature change which is caused by energy related and non-energy related emissions, second, the regional population change and third the economic performance, the economic income change of a region. So, not only regions with a high economic performance but also with high population growth are affected by climate change if the global temperature changes. In comparison to other studies, higher economic damages have three reasons: the dynamic modelling approach with interregional and intersectoral feedback effects, the detailed climate system that is affected by the emissions coming from the economic performances and sectoral disaggregation of damage functions instead of adding one damage function into the model. The total effects differ from many economic studies but not from earlier studies of natural scientists. Figure 18 illustrates the individual damages in percentage of GDP: ecological impacts have the highest impact

[14] RICE-99 is an Integrated Assessment model that combines a simplified economy-growth model with a climate model and assumes a global damage function for the world developed by William Nordhaus. The model has been modified over time, RICE-99 refers to the version of 1999 (Nordhaus und Boyer 2000)

[15] If climate change is reduced (by for example reduced emissions), countries spend less percentage of investments for adaptation.

as well as health and mortality. In this study, this is especially the case because of the relationship between income changes and population (health) and temperature and population (mortality). With increasing temperature energy demand for cooling increases.

Tol (2002) finds total world damages within the range of 6-9 % of world GDP (sum of all regions). These damages differ widely between regions. The regional disparities of damages occur because of population development and economic performances. Our model approach takes the same assumptions about the relationship between global surface temperature, population development and economic performances. However, as we cover dynamic feedback effects the total impacts are higher, here in the range up to 20 % of global GDP. For example, high-developed nations such as Europe, USA and Japan heavily depend on international trade.[16] If these nations have to divert expenditures to climate impacts and adaptation, these investments are not available to be spent in other sectors. As the model covers the dynamic growth effects and trade effects, economic losses are higher. Especially fast growing nations such as China have to accept welfare losses if climate change occurs.

Conclusion

Increased greenhouse gas emission cause climate change. The share of human induced climate change increase in the future. Past economic damages can hardly be purely attributed to increased greenhouse gas emissions. Primary factors for increased economic damages are increased population, wealth and migration to vulnerable regions. However, especially the extreme climate events of the past years give an indication of first impacts through man made climate change. As increase of future greenhouse gas emissions significantly increase the number and intensity of extreme climate events. If no emissions reduction take please, economic damages increase by factor 10. Because of that, we need concrete climate policy strategies to reduce greenhouse gas emissions and an increase of expenditures in research and development for alternative energies.

We conclude with the following two statements:

1. Only with early emission reduction warming beyond the limit of 2°C can be avoided. Even drastic emissions reduction efforts starting at a later point of time (2030) will not be sufficient to stay within the 2°C limit.
2. Damages from climate change are lower if the 2°C temperature limit is met. The costs of action are substantial. However, the avoided damage costs are even higher than the costs of action.

Acknowledgement

We thank the German Ministry of Environment for financial support of this study.

[16] Trade in goods account for more than 35 % of GDP (PPP)

References

Clarkson, R. and K. Deyes (2002). Estimating the social cost of carbon emission. Government Economic Service Working Paper 140. London.

Cline, W.R (1992): The Economics of Global Warming, Washington D.C.

Baranzini, A., M. Chesney, and J. Morisset (2003). The impact of possible climate catastrophes on global warming policy. *Energy Policy* **31:** 691-701.

Bruckner, T.,G.Hooss, H.-M.Fuessel, and K.Hasselmann (2003). "Climate system modelling in the framework of the tolerable windows approach: The ICLIPS climate model." *Climatic Change* **56**: 119-137.

Fankhauser, S. 1994. "The social costs of greenhouse gas emissions: An expected value approach." In *Energy Journal* 15(2):157-184.

Harvey, L.D.D., J. Gregory, M. Hoffert, A. Jain, M. Lal, R. Leemans, S.C.B. Raper, T.M.L. Wigley, and J.R. de Wolde (1997). An Introduction to Simple Climate Models Used in the IPCC Second Assessment Report. IPCC Techinical Paper II. Geneva, Switzerland.

Hare, Bill and Malte Meinshausen: How much warming are we committed to and how much can be avioded?, PIK report No 93, October 2004

Hasselmann, K. M.Latif, G.Hooss, C.Azar, C.C.Jaeger, O.M.Johannesson, M.Welp, C.Kemfert and A.Wokaun, in prep.: The challenge of long term climate change. Discussion paper of the *European Climate Forum.*

Hasselmann, K., S.Hasselmann, R.Giering, V.Ocaña and H.v.Storch (1996): "Sensitivity study of optimal CO_2 emission paths using a simplified structural integrated assessment model (SIAM). " *Climatic Change* **37**: 345 - 386.

Hitz, S. and J. Smith (2004). Estimating global impacts from climate change. in *The Benefits of Climate Change Policies*. OECD. Paris.

Hope, C. (2004). The marginal impact of CO_2 from PAGE2002: An integrated assessment model incorporating the IPCC's five reasons for concern. Mimeo University of Cambridge, UK.

Hooss, G., R. Voss, K. Hasselmann, E. Maier-Reimer and F. Joos (2001)."A nonlinear impulse response model of the coupled carbon cycle-climate system (NICCS)." *Climate Dynamics* **18**:189-202.

Hooss, G. (2001). Aggregate models of climate change: development and applications. Max Planck Institute for Meteorology, Examensarbeit 83, *Dissertation* am Fachbereich Geowissenschaften der Universität Hamburg.

IPCC (Intergovernmental Panel on Climate Change) (1990). First Assessment Report. *Cambridge University Press*. Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change) (1992). Climate Change 1992 - The Supplementary Report to The IPCC Scientific Assessment *Cambridge University Press*. Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change) (1996). Climate Change 1995: The Science of Climate Change. *Cambridge University Press*. Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change) (2000). Special Report on Emissions Scenarios. Special Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press*. Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change) (2001), Climate Change 2001: The Scientific basis. *Cambridge University Press*. Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change) (2001). Climate Change 2001: Synthesis Report: Contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press*. Cambridge, UK.

Joos, F., M. Bruno, R. Fink, U. Siegenthaler, Th. F. Stocker, C. LeQuere and J.L. Sarmiento (1996). "An efficient and accurate representation of complex oceanic and biospheric models of anthropogenic carbon uptake. "*Tellus* **48 B**: 397- 417.

Joos, F., C. Prentice, S. Sitch, R. Meyer, G. Hooss, G.-K. Plattner and K. Hasselmann (2001). "Global Warming feedbacks on terrestrial carbon uptake under the IPCC emission scenarios." *Global Biogeochemical Cycles* **15**(4): 891-907.

Kemfert, C. (2002a). "Global Economic Implications of alternative Climate Policy Strategies", *Environmental Science and Policy* **5** (5): 367-384.

Kemfert, C. (2002b). "An Integrated Assessment Model of Economy-Energy-Climate – The model WIAGEM-", *Integrated Assessment* **3** (4): 281-299.

Maier-Reimer, E. and K.Hasselmann (1987). "Transport & storage of CO_2 in the ocean - an inorganic ocean-circulation carbon cycle model." *Climate Dynamics* **2**: 63 - 90.

Maier-Reimer, E. (1993). "The biological pump in the greenhouse. Global & Planetary." *Climatic Change* **8**: 13 - 15.

Malaney, P., Spielman, A. and Sachs, J. (2004): The Malaria Gap, Americal Journal of Tropical Medicine, 71, pp. 141-146

Meyer, R., F.Joos, G.Esser, M.Heimann, G.Hooss, G.Kohlmaier, W.Sauf, R.Voss and U.Wittenberg (1999). "The substitution of high-resolution terrestrial biosphere models and carbon sequestration in response to changing CO2 and climate." *Global Biogeochemical cycles* **13**(3): 785-802.

Mendelsohn, R. and M. Schlesinger (1997). Climate Response Functions. University of Illinois: Urbana-Champaign.

Morlot, J. C. and S. Agrawala (2004). Overview. in *The Benefits of Climate Change Policies*. OECD. Paris.

Münchner Rück (2002): Jahresrückblick Naturkatastrophen 2002, München.

Narain, Urvashi and Anthony Fisher (2000). Irreversibility, Uncertainty and Catastrophic Global Warming, Gianinni Foundation Working Paper 843, Berkeley: University of California, Department of AGriculture and Resources Economics, Berkeley.

Nordhaus, W. and J. Boyer (2000). Roll the Dice Again: Economic Modeling of Climate Change. Cambridge, MA: MIT Press.

Nordhaus (1991) and D William: To Slow of not to Slow: The Economics of the Greenhouse Effect. In: The Economic Journal, vol 1001, 1991, S. 920-937

Nordhaus, W., Boyer, J.: Warming the World: Economic Models of Global Warming, MIT Press, Washington

OECD (2003): Estimating the Benefits of Climate Change Policy, ENV/EPOC/GSP. OECD. Paris .

OECD (2004). The Benefits of Climate Change Policies. OECD. Paris.

Osborn, T.J. and T.M.L. Wigley, (1994): A simple Model for Estimating Methane Concentrations and Lifetime Variations. *Climate Dynamics* **9**: 181-193.

Pearce, D. W. (2003a). "The Social Cost of Carbon and its Policy Implications." Oxford Review of Economic Policy **19**(3): 362-384.

Pearce, D. W., W. R. Cline, A. Achanta, S. Frankhauser, S., R. Pachauri, R., R. Tol and P. Vellinga (1996). The Social Costs of climate change: Greenhouse damage and the Benefits of control. in *Intergovernmental Panel on Climate Change 1995, Climate Change 1995: Economis and Social Dimensions of Climate Change,* Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change, *Cambridge University Press*. Cambridge, UK.

Pearce, D. W. (2003), The Social Costs Of Carbon And Its Policy Implications". *Oxford Review of Economic Policiy* **19** (3). London.

Pittini, M. and M. Rahman (2004). The social cost of carbon: Key issues arising from a UK review. in *The Benefits of Climate Change Policies*. OECD. Paris.

Schneider, S.H., J. Lane (2004). Abrupt non-linear climate change and climate policy. In *The Benefits of Climate Change Policies*. OECD. Paris.

Schnellnhuber, J., R. Warren, A. Haxeltine and L. Naylor (2004). Integrated Assessment of Benefits of Climate Policy. in *The Benefits of Climate Change Policies*. OECD. Paris.

Tol, R.S.J. (2001). "New Estimates of the Damage Costs of Climate Change, Part I: Benchmark Estimates." *Environmental and Resource Economics*.

Tol, R. S. J. (2002). Estimates of the Damage Costs of Climate Change, Part II: Dynamic estimates. *Environmental and Resource Economics* **21**: 135-160.

Tol, R. S. J. (2003a). The Marginal Costs of Carbon Dioxide Emissions: an Assessment of the Uncertainties, Working Paper FNU-19, Hamburg University. Hamburg.

Tol, R. S. J. (2003b). The Marginal Costs of Carbon Dioxide Emissions. Paper presented at the Defra International Seminar on the Social Cost of Carbon. London.

Tol, R., T. Downing, O. Kuik and J. Smith (2004). "Distributional aspects of climate change impacts." *Global Environmental Change: Special Edition on the Benefits of Climate Policy* Part A, **14(3)**: 259-272.

Wigley, T.M.L. (1988). "Future CFC concentrations under the Montreal Protocol and their Greenhouse-effect Implications." *Nature* **335**: 333-335.

Wigley, .M.L. and S.C.B. Raper (1992). "Implications for Climate and Sea Level Rise of Revised IPCC Emissions Scenarios." *Nature* **357**: 293-357.

Wigley, T.M.L. (1994). MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change): User's Guide and Scientific Reference Manual. National Centre for Atmospheric Research, Boulder, CO.

Wigley, T.M.L., S.C.B. Raper, and M. Salmon (1996). Source Code of the MAGICC Model (as used in MiniCam, Version 2.0), Climate Research unit, University of East Anglia, Norwich, U.K.

Weyant, John P. and Hill, Jennifer N. (1999). "The Costs of the Kyoto Protocol: A multi-model Evulution - Introduction and Overview." *The Energy Journal - A Special Issue: The Costs of the Kyoto Protocol: A Multi-Model Evaluation*: vii-xliv.

Appendix I: Detailed Description of WIAGEM

By coupling the economic and climate impact part of WIAGEM with the detailed climate module ICM, we consider the relationship between man-made emissions and atmospheric concentrations and their resulting impact on temperature and sea level. We cover classes of atmospheric greenhouse gas stocks with different atmospheric lifetimes (modelled by the impulse response function) and reduced forms of the carbon cycle model developed by Maier-Reimer and Hasselmann (1987) and applied by Hooss (2001). Energy and non-energy related emissions of CO_2, CH_4 and N_2O as well as those of halocarbons and SF_6 alter the concentrations of these substances which in turn influence radioactive forcing.

As a result, the multi-gas climate model ICM was obtained that takes into account all important greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, tropospheric and stratospheric ozone, and stratospheric water vapour) and aerosols by modelling their dynamic atmospheric behaviour as well as the radiative forcing originating from changes in the concen-tration of the respective substances.

ICM is driven by time-dependent paths of the anthropogenic emissions of CO_2, CH_4, N_2O, halocarbons, SF_6 and SO_2. In WIAGEM total anthropogenic emissions are determined by:

$$TOTEM_{r,t} = E_{r,t} + NonE_{r,t} - S_{r,t}$$

with TOTEM indicating the total anthropogenic emissions per region and time period, $E_{r,t}$ as regional emissions per time period. Non-energy related emissions are countered for each greenhouse gas, regional and time period. Sinks ($S_{r,t}$) reduce total emissions. [17]

The atmospheric concentration of greenhouse gases may be altered due to direct emissions, exchange with reservoirs (e.g., ocean, biosphere, pedosphere) and chemical reactions (destruction or formation). The biogeochemical submodules of ICM take into account these different processes in a greenhouse gas-specific manner. In general, the modules are reduced-form mod-els of complex two- or three- dimensional greenhouse gas cycles or atmospheric chemistry models and are calibrated with respect to historical concentration records.

The carbon cycle module (see Appendix I) developed at the Max-Planck Institute for Meteorology in Hamburg consists of (a) a differential impulse-response representation of the 3 dimensional Hamburg Model of the Ocean Carbon Cycle (HAMOCC), extended into the non-linear high-CO_2 domain by explicit treatment of the chemistry governing the CO_2 uptake through the ocean surface, and (b) a simple non-linear impulse response model of the terrestrial biosphere's CO_2 fertiliza-tion. Applying an inverse calibration technique, the quantitatively unknown CO_2-fertilization factor has been adjusted in order to give a balanced 1980s mean budget as advised by the IPCC inter- model comparison exercise.

Various components of the MAGICC model (Wigley, 1988; Wigley and Raper, 1992; Wigley, 1994; Osborn and Wigley, 1994; Wigley et al., 1996, Harvey et al., 1997) were adopted in order to simulate the atmospheric chemistry of major non-CO_2 greenhouse gases.

Changes in the concentration of non-CO_2 greenhouse gases (CH_4, N_2O, halocarbons, and SF_6) are calculated by a simple one-box model approach according to

$$\frac{dC(t)}{dt} = \frac{1}{b}\sum_r TOTEM_r - \frac{1}{\tau}(C - C_{pre-industrial})$$

[17] This means also that the emissions reductions targets are reduced.

where b is a concentration-to-mass conversion factor and τ is the lifetime of the greenhouse gas. For N_2O, halocarbons and SF_6, the lifetime is assumed to be constant (IPCC, 1996; Harvey et al., 1997). CH_4 is removed from the atmosphere by soil uptake and chemical reactions with OH. The lifetime of CH_4 takes into account both processes and as the OH concentration itself is influenced by CH_4, the lifetime attributed to chemical processes is modelled to be dependent on the CH_4 concentration according to Osborn and Wigley, 1994).

The atmospheric concentration of different greenhouse gases has the following impact on radiative forcing (IPCC, 1990):

$$\Delta F_{CO2} = 6.3 \ln\left(\frac{CO2}{CO2_0}\right)$$

$$\Delta F_{CH4} = 0.036\,(CH4^{0.5} - CH4_0^{0.5}) - f(CH4, N2O) + f(CH4_0, N2O_0)$$

$$\Delta F_{N2O} = 0.14(N2O^{0.5} - N2O_0^{0.5}) - f(CH4_0, N2O) + f(CH4_0, N2O_0)$$

with ΔF measured in Wm^{-2}, concentrations for CH_4 and N_2O given in ppbv and the subscript 0 used to indicate pre-industrial concentrations. . The CH_4-N_2O interaction term (expressed in Wm^{-2}) is determined by:

$$f(CH4, N2O) = 0.47 \ln\left[1 + 2.01 \cdot 10^{-5} \cdot (CH4 \cdot N2O)^{0.75} + 5.31 \cdot 10^{-15} \cdot CH4 \cdot (CH4 \cdot N2O)^{1.52}\right]$$

where CH_4 and N_2O have to be replaced by actual CH_4 and N_2O concentrations or alternatively by their respective pre-industrial levels as expressed in equations 3 and 4.

Total radiative forcing F can be approximated (IPCC, 2001, p. 355) by adding each greenhouse gas radiative forcing effect. In addition to the components just described, the radiative forcing description in ICM takes into account the contributions from SF_6, tropospheric ozone and stratospheric water vapour (both dependent on CH_4 concentrations), aerosols, and halocarbons including indirect effects according to stratospheric ozone depletion.

The time evolution of the global annual mean surface air temperature is calculated according to the impulse response function approach used in NICCS. A detailed description of this component can be found in Hooss (2001), Hooss et al. (2001), Bruckner et al. (2003), Joos et al. (2001), and Meyer et al. (1999). In order to include the radiative forcing of non CO_2-greenhouse gases, the carbon dioxide concentration used in NICCS is to be replaced by the equivalent carbon dioxide concentration (measured in ppm) defined by IPCC (1996a, p.320):

$$C_{Equiv} = 278\,ppm \cdot Exp\left(\frac{\Delta F}{6.3\frac{W}{m^2}}\right)$$

Aggregated impacts of climate change are evaluated by:

We follow the approach of Tol (2001) for economic impact assessment of ecosystem changes:

$$E_{t,r} = a\frac{y_{t,r}}{y_{1990,r}} P_{t,r} \frac{y_{t,r}/y_b}{1 + y_{t,r}/y_b} \qquad (3.9)$$

with E as the value of the loss of ecosystems and y the per capita income and P as population size. α and y_b are parameter (α =0.5, y_b=\$20.000).

Impact assessment of vector borne diseases are determined by:

$$m_{r,t} = \alpha_r T_t^{\beta} \left(\frac{y_c - y_{t,r}}{y_c - y_{base,r}}\right)^{\gamma} \quad (3.10)$$
$$\perp y_{t,r} \geq y_c$$

with m representing mortality, and α, γ and y_c denoting parameter (α= 1 (0.5-1.5), γ= 1 (0.5-1.5), y_c= $3100 (2100-4100).

Furthermore, mortality due to changes in global warming are measured:

$$\Delta M = \alpha + \beta T_B \quad (3.11)$$

Where ΔM denotes the change in mortality due to a one degree increase in global warming, T_b as current temperature and α and β are parameter.

Furthermore, we take into account Tol's approach to determine demand for space heating (SH) and space cooling energy (SC):

$$SH_{t,r} = a_r T_t^{\beta} \left(\frac{y_{t,r}}{y_{t,1990}}\right)^{\varepsilon} \left(\frac{P_{t,r}}{P_{t,1990}}\right) \prod_{s=1990}^{t} EP_{s,r} \quad (3.12)$$

$$SC_{t,r} = a_r T_t^{\beta} \left(\frac{y_{t,r}}{y_{t,1990}}\right)^{\varepsilon} \left(\frac{P_{t,r}}{P_{t,1990}}\right) \prod_{s=1990}^{t} EP_{s,r} \quad (3.13)$$

Total damages are assessed by the following relation:

$$\Delta DAM_t^r = \alpha_t^r \cdot (\Delta PT_t^{\beta} \cdot \frac{y_t^r}{y_0^r}) + PC_t^r \quad (3.14)$$

ICM estimates the climatic changes due to greenhouse gas emissions and the impact modules estimates the corresponding impacts. Market and non-market damages associated with these impacts, are assessed by coupling the climate module of ICM with WIAGEM. We express impacts as changes to regional and global welfare and GDP.

Mathematically the carbon cycle model containing all differential equations can be described as follows:

$$c_1 = D(c1) \cdot \left\{ e - \frac{n_2}{h_s} c_s(c_1) + \frac{n_2}{h_2} c_2 - (b_3 + b_4) B(c_1) + \frac{1}{\tau_{B3}} c_{B3} + \frac{1}{\tau_{B4}} c_{B4} \right\}$$

$$c_2 = \frac{\eta_2}{h_s} c_s(c_1) - \frac{\eta_2 + \eta_3}{h_2} c_2 + \frac{\eta_3}{h_3} c_3$$

$$c_3 = \frac{\eta_3}{h_2} c_2 - \frac{\eta_3 + \eta_4}{h_3} c_3 + \frac{\eta_4}{h_4} c_4$$

$$c_4 = \frac{\eta_4}{h_3} c_3 - \frac{\eta_4}{h_4} c_4$$

$$c_{Bc} = A(c1) \cdot c1$$

$$c_{B3} = b3 \cdot B(c1) - \frac{c_{B3}}{\tau_{B3}}$$

$$c_{B4} = b4 \cdot B(c1) - \frac{c_{B4}}{\tau_{B4}}$$

with:

t	Simulation time
x	Spatial coordinates
s	Season index
e	Anthropogenic CO_2 emissions
C_{CO2}	Atmospheric CO_2 concentration (by volume)
$C_{CO2,\ equiv}$	Atmospheric equivalent CO_2 concentration
$C_{CO2,\ pre}$	Pre-industrial CO_2 concentration
c_a	Anthropogenic carbon in the atmosphere (in GtC)
c_s	Anthropogenic carbon in the oceanic mixed layer
c_j	Anthropogenic carbon in the *jth* oceanic layer
c_l	Anthropogenic carbon in the composite layer
q_j	Carbon flux from layer $j - 1$ into layer j
c_B	Anthropogenic carbon allocated by the land vegetation
c_{Bi}	Anthropogenic carbon in land biosphere reservoir *I*
c_{Bc}	Short-term anthropogenic carbon in land biosphere
$B(_{C1})$	Nonlinear auxiliary function (= additional NPP)
$A(_{C1})$, $D(_{C1})$	Nonlinear auxiliary functions
T	Near-surface temperature change (relative to pre-industrial level)
CC	Cloud-cover change (relative to pre-industrial level)
P	Precipitation change (relative to pre-industrial level)
H	Humidity change (relative to pre-industrial level)
SLR	Sea-level rise (relative to pre-industrial level)
PC	Principal component
EOF	Empirical orthogonal function

PERSPECTIVES ON FOCUSED WORKSHOP QUESTIONS REGARDING PAST ECONOMIC IMPACTS OF STORMS OR FLOODS

Tom Knutson

Geophysical Fluid Dynamics Laboratory
National Oceanic and Atmospheric Administration

1. According to research currently available, what factors account for the increased costs of disasters in recent decades?

a. Hurricanes

For the case of U.S. landfalling hurricanes, Pielke and Landsea (1998) make a strong case that societal factors such as increasing population in coastal areas affected by hurricanes, increases in value of structures in those areas, and inflation are the key drivers of increased economic damages from hurricanes in recent decades. In contrast, changes in U.S. landfalling hurricane climate appear to play a more minor role. A recent key analysis on the latter influence is Landsea's (2005) U.S. Power Dissipation Index (PDI) for landfalling tropical cyclones (TCs) since 1900, updated through 2005 (Fig. 1). This TC climate metric shows no strong evidence for an upward trend during the 20th century, although 2004 and 2005 appear as strong outliers at the end of the series. Landsea (2005) comments that 1886, although not shown on the figure, is estimated to be comparable to 2004 and 2005, again emphasizing the limited evidence for a long-term trend in this metric at this time.

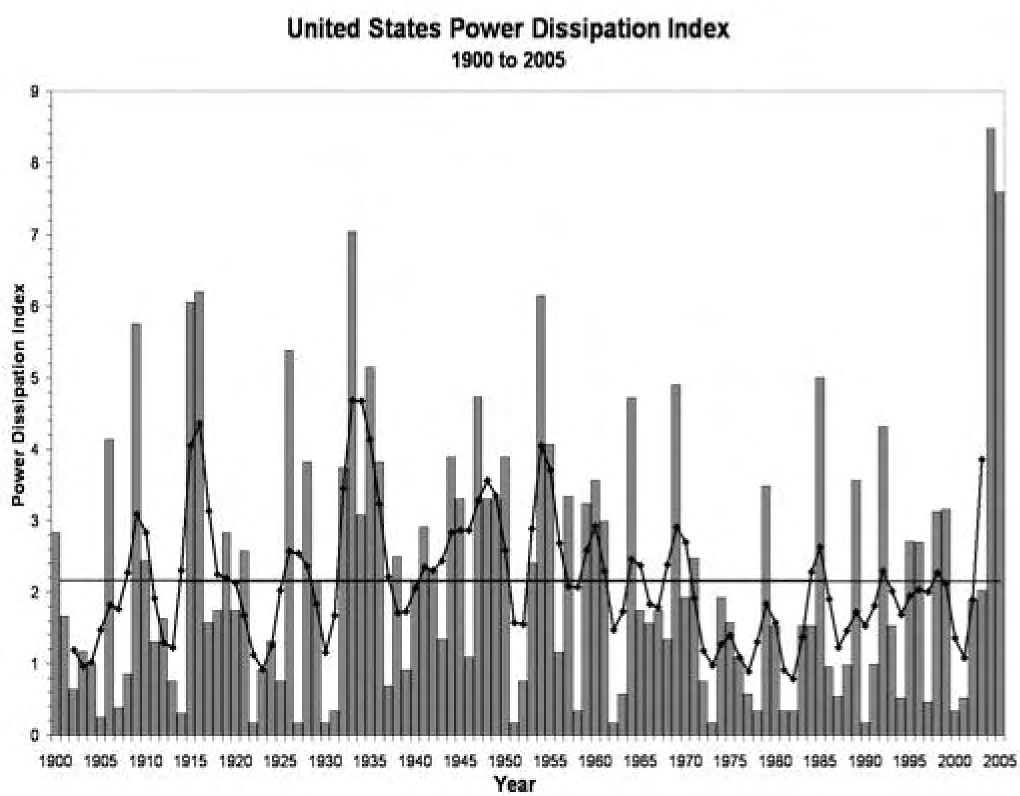


Fig. 1. Power Dissipation Index (PDI) for continental United States, 1900-2005 in units of m^3s^{-3}, multiplied by 10^{-5}. Based on all tropical storms, subtropical storms, and hurricanes at time of impact. Black curve smoothed with two passes of 1-2-1 filter. From Landsea (2005).

The absence of a strong trend is noteworthy given indications of a century-scale SST warming trend in the tropical Atlantic Main Development Region (e.g., Fig. 2, see also Knutson et al., 2006), and of possible SST-correlated upward trends in Atlantic *basin-wide* TC counts and storm maximum PDI (Figs. 3 and 4, Emanuel 2006). Interestingly, the U.S. landfalling PDI also does not clearly show the pronounced multi-decadal modulation seen in the basin-wide Atlantic PDI (Fig. 5) and major hurricane counts (not shown) since the late 1940s. Although the current "active era" of Atlantic hurricane activity apparently began in 1995, only during 2004 and 2005 did the U.S. landfalling PDI reach or exceed the strong levels that occurred several times in the first half of the 20th century (Fig. 1).

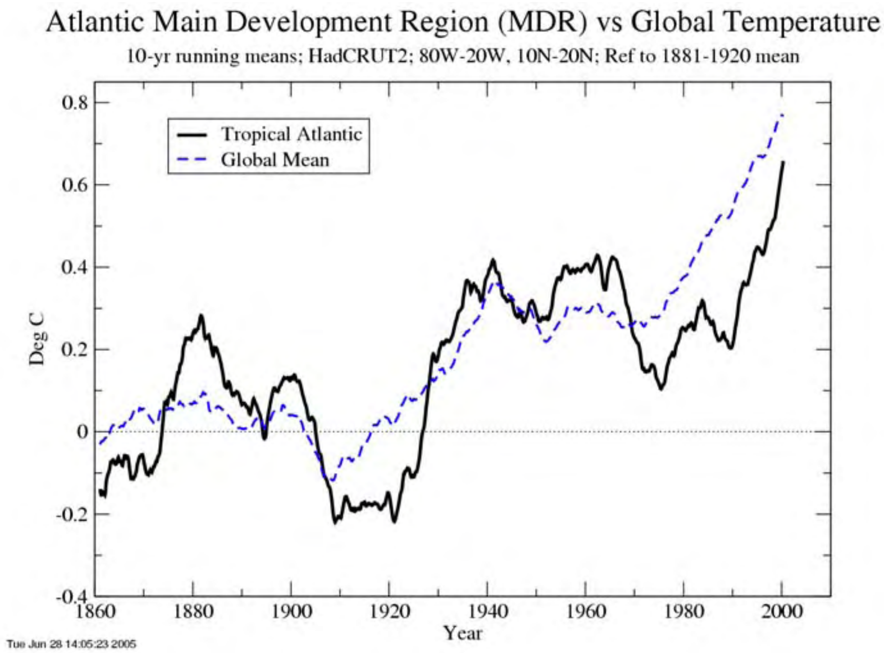


Fig. 2. Atlantic Main Development Region (MDR) surface temperature vs global mean surface temperature. MDR region defined as 80W-20W, 10N-20N. 10-yr running annual means, referenced to 1881-1920 are plotted.

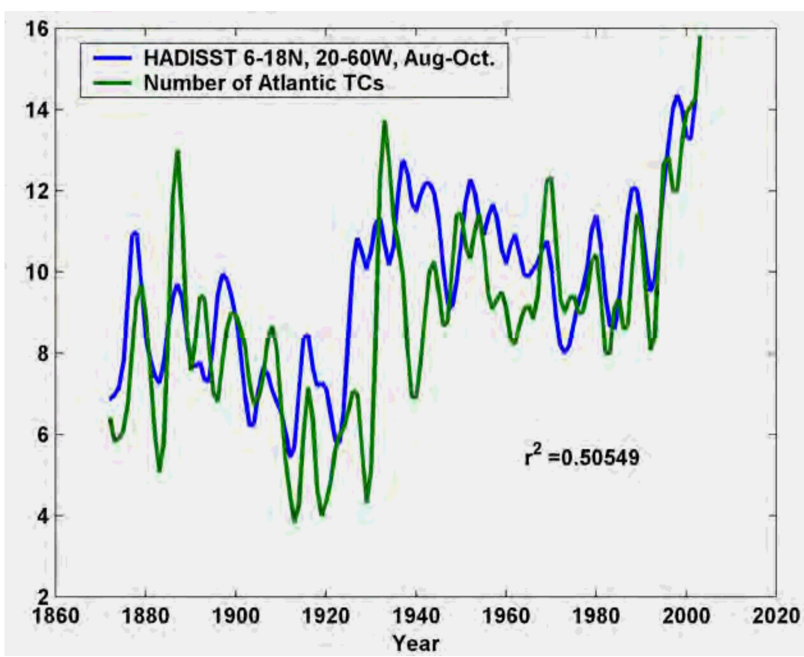


Fig. 3. Annual number of Atlantic tropical cyclones (smoothed) versus sea surface temperature (Aug. – Oct.) in the tropical Atlantic (6-18N, 20-60W). Source: Emanuel 2006.

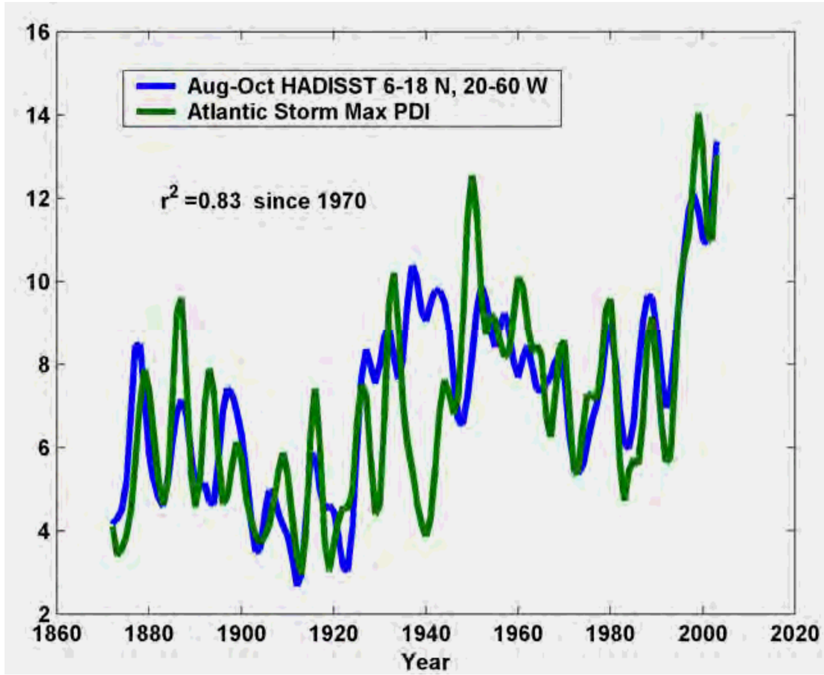


Fig. 4. Storm maximum power dissipation index (one value per storm) for the Atlantic basin versus sea surface temperature (Aug. – Oct.) in the tropical Atlantic (6-18N, 20-60W). Values scaled by arbitrary constants to show correlation of curves. Source: Emanuel 2006).

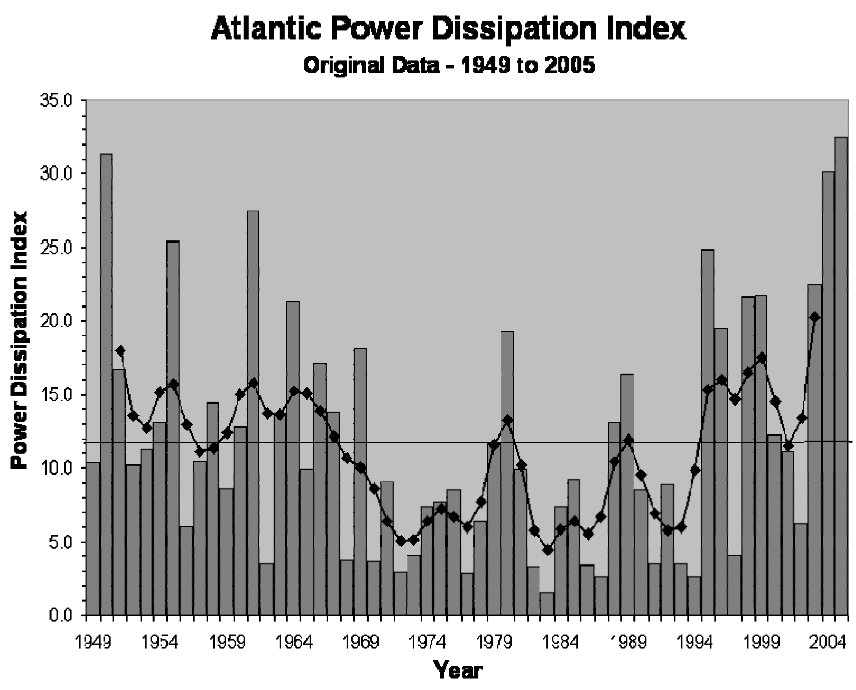


Fig. 5. Atlantic Power Dissipation Index (PDI) from Landsea (2005) using no correction of early period wind intensities, in contrast to Emanuel (2005). Values multiplied by 10^{-6}, in units of m^3sec^{-3}.

Thus, while there is debate about whether there is a century-scale trend in various Atlantic basin-wide TC measures (e.g., Emanuel 2006; Landsea, personal communication 2006), there does not appear to be any real debate about the lack of trend to date in U.S. landfalling PDI statistics. A key question to resolve is why this is the case. Emanuel (2005b) raises a fair point that U.S. landfalling storms are only a small fraction of all Atlantic hurricanes so that a basin wide index is based on about 100 times more data than the U.S. landfalling PDI. This means that the failure to see a trend in the U.S. landfalling PDI may be a signal to noise issue, with a possible underlying trend masked by the high noise levels and limited sample size for U.S. PDI. On the other hand, the sensitivity of hurricane intensity to sea surface warming implied in the Emanuel (2005a) results exceeds by a factor of 6 the sensitivity inferred from the Knutson and Tuleya's (2004) idealized hurricane modeling study, which found a sensitivity of about 4% per degree Celsius SST increase. In a recent examination of Atlantic potential intensity data since about 1980, the discrepancy with our modeling work appears to be about a factor of 4, and that discrepancy might be partly attributable to a general reduction of surface wind speeds in the basin over time (Emanuel 2006).

In summary, in attributing the sharp rise in U.S. hurricane damages to various factors, the U.S. landfalling PDI results to date do not support a clear role for century-scale climate change in the observed damage trend.

b. Floods

Concerning possible trends in damaging floods, Milly et al. (2002) tentatively detected an upward trend (Fig. 6) in the global frequency of "great floods" (100-year floods on river basins larger than 200,000 km^2). In their climate-model-based estimates of sensitivity of great-flood rates to an idealized quadrupling of atmospheric CO2, the most sensitive regions were in the high latitudes and the tropics (Fig. 7). Milly et al. (2005) presented evidence that the global pattern of 20th-century trends in mean annual streamflow was partially controlled by forced climate change, although trends in any single region generally could be explained by internal variability. The latter study lends some credibility to climate models' retrospective and prospective estimates of flood risk.

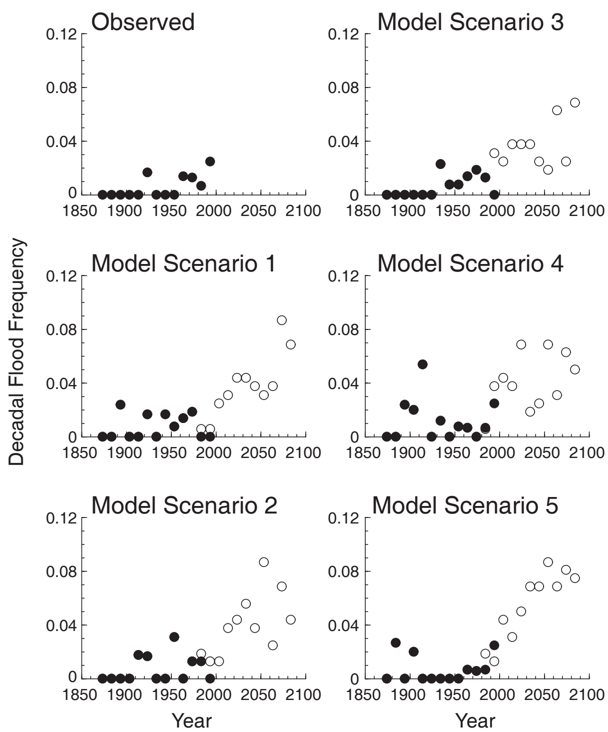


Fig. 6. Decadal extratropical flood frequencies for observations (upper left) and a series of climate model experiments with the GFDL R30 coupled climate model forced by historical estimates of greenhouse gases and direct effect of sulfate aerosols, with +1%/yr CO2 forcing for post-2000. The flood frequency is defined as the number of events exceeding the 100-yr discharge divided by the number of station years of observations. In modeled output, filled circles are obtained with station starting and ending dates as in observations, while open circles are obtained with all stations continuing operation once begun. Source: Milly et al. 2002.

Milly, Figure 2

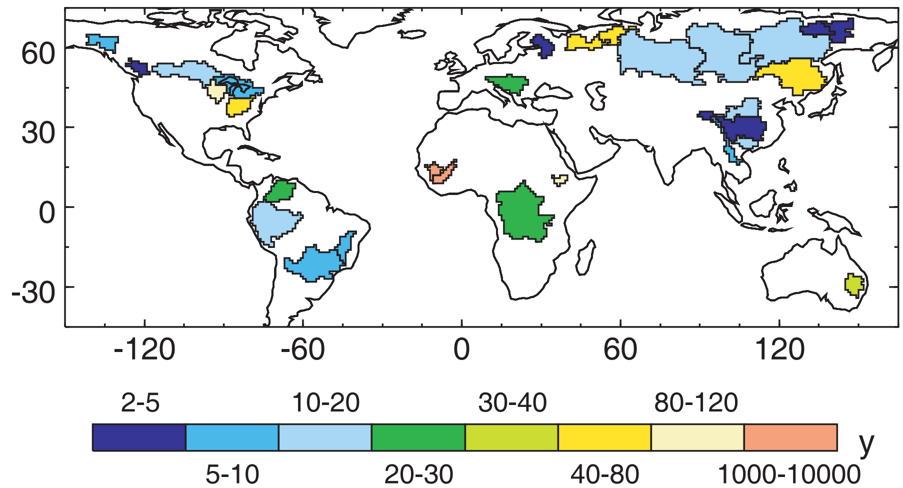


Fig. 7. Map showing gauged drainage areas and flood-risk sensitivities. Color indicates the modeled return period, under idealized CO_2 quadrupling, of the flood magnitude associated with a 100-year flood before the CO_2 increase. Source: Milly et al. 2002).

Groisman et al. (2005) present evidence for increasing occurrence of intense precipitation events (upper 0.3%) for many extratropical regions, but they note that it is difficult to relate the changes in very heavy precipitation directly to changes in flooding. Knutson and Tuleya's (2004) simulations of hurricanes under CO2-warmed climate conditions, with a 20% increase in storm core rainfall for a 1.75°C SST warming, suggests the possibility of a future trend in hurricane-related precipitation rates. Groisman et al. (2004) report that no change can be detected at this time in hurricane-related precipitation along the southeast coast of the U.S. However, they did not assess whether the *per storm* precipitation has changed. Local precipitation totals from hurricanes are strongly influenced by the storm translation speed as well as storm-relative precipitation rates.

Pielke and Downton (2000) find that both precipitation increases and societal factors (population and wealth) have contributed to the increase in U.S. flood damages in recent decades. They found that 2-day heavy rainfall events and the number of wet days were two climate statistics that were more closely linked to flood damage than other measures they examined. They noted a trend, correlated to the increase in these precipitation measures, in damage per capita, but not in damage per unit wealth.

In summary, the analyses by Milly et al. and Pielke and Downton suggest that climate factors may be at least partially responsible for the observed increase in flood occurrence and flood damages in recent decades, although based on the latter study of U.S. damages, societal factors are likely to be most important.

2. What are the implications of these understandings, both for research and policy?

Societal factors (coastal population growth, increased development of more expensive infrastructure at the coast, etc.) have almost certainly been the key drivers of the strong, systematic rise in total U.S. hurricane damages over the past several decades. One implication of this is that research to understand these drivers and how to best reduce vulnerability to hurricane damage is a worthwhile undertaking. There is probably much "low-hanging fruit" to be harvested in this regard, if the goal is to reduce the aggregate amount of hurricane damage in the future, relative to a "business as usual" scenario. Consumers, businesses (e.g., insurers) and policymakers could benefit from such studies, particularly since wide-spread adoption of damage-reducing preventative measures will likely require proactive measures from these stakeholders.

The possibility of substantial long-term increases in historical PDI in several basins, including the Atlantic, and the possibility of even greater increases in the future imply that this topic also deserves considerable attention from the hurricane and climate research communities at this time. The lack of a long-term trend in U.S. landfalling TC statistics could reflect a signal-to-noise issue, as Emanuel (2005b) suggests, or could be indicative of greater data problems in the basin-wide statistics as compared to the U.S. landfalling TC statistics. In general, the causes of the differing behavior between all-basin and landfalling TCs need to be resolved.

Despite the evidence that societal factors have almost certainly been the key drivers of the sharp rise in total hurricane damages in the U.S. in recent decades, there is some ambiguity arising regarding the interpretation of the past two very damaging seasons. In addition, the (highly uncertain) future projections of increases in hurricane intensities and perhaps other TC metrics imply that climate change could lead to additional damage potential for whatever coastal infrastructure exists at a given point in the future. For example, Emanuel (2005a) reports roughly a doubling of PDI accumulated over the Atlantic and Northwest Pacific basins in the last 30 years, associated with roughly an 0.5ºC SST increase. If future PDI changes were to scale with future SST changes in that manner, it seems likely that a climate change signal in landfalling PDI will eventually emerge, even for the U.S. landfalling hurricanes, unless there is a strong mitigating effect from changes in storm tracks, or other factors. It is important to note that SST increases in the Atlantic during the 21st century are likely to be much more substantial, perhaps by a factor of four (e.g., Knutson and Tuleya 2004), than the warming that occurred in the 20th century. Future sea level rise associated with anthropogenic climate warming, a process which apparently has a very long equilibration time scale (e.g. centuries to millennia) will almost certainly further exacerbate coastal flooding problems from a given hurricane to some degree, unless substantial damage mitigation steps are undertaken. Subsiding land in some coastal regions due to various natural and anthropogenic influences can also exacerbate this problem.

From a research perspective, the implications include the need for improved climate-quality monitoring and for improved historical and "paleoclimate-proxy" tropical cyclone data bases. These will provide better information for assessing future changes, and more reliable statistical assessments of past changes in hurricane activity, including land fall, in all basins. Specific examples include the need to reanalyze tropical cyclone data bases in all basins, and not just the Atlantic. Greater efforts should be made to provide researchers with access to original "raw" historical observations rather than derived quantities, concerning past tropical cyclones (Emanuel, personal communication). Consideration should be given to initiating or resuming aircraft reconnaissance of hurricanes outside of the Atlantic basin. For example, aircraft reconnaissance was conducted in the NW Pacific basin beginning in the 1940s, but was discontinued in 1987. Aircraft reconnaissance could provide more reliable intensity estimates than are now possible using satellite-only methods. Another example is paleotempestology research, which attempts to use information in the geological record, such as overwash deposits in near coastal lakes, to infer pre-historic hurricane activity.

In general, hurricane-climate research is expected to progress most rapidly when a combination of theory, modeling, and observations are brought to bear on the problem.

References

Emanuel, K. A., 2005a: Increasing destructiveness of tropical cyclones over the past 30 years. Nature, **436,** 686-688.

Emanuel, K. A., 2005b: Emanuel replies. *Nature*, **438**, E13, doi:10.1038/nature04427.

Emanuel, K. (2006), Environmental influences on tropical cyclone variability and trends. Proceedings of 27th AMS Conference on Hurricanes and Tropical Meteorology, #4.2. Available online at: http://ams.confex.com/ams/pdfpapers/107575.pdf.

Groisman, P. Y., R. W. Knight, T. R., Karl, D. R. Easterling, B. Sun, and J. H. Lawrimore, 2004: Contemporary changes of the hydrological cycle over the contiguous United States: trends derived from *in situ* observations. *J. Climate*, **18**(9), 1326-1350.

Groisman, P. Y., R. W. Knight, D. R. Easterling, T. R. Karl, G. C. Hegerl, and V. N. Razuvaev, 2005: Trends in Intense Precipitation in the Climate Record. *J. Climate*, **18**(9), 1326-1350.

Knutson, T. R., and Co-authors, 2006: Assessment of Twentieth-Century Regional Surface Temperature Trends Using the GFDL CM2 Coupled Models. *J. Climate*, **19**(9), 1624-1651.

Knutson, T. K., and R. E. Tuleya, 2004: Impact of CO2-induced warming on simulated hurricane intensity and precipitation: Sensitivity to the choice of climate model and convective parameterization. *J. Climate*, **17**(18), 3477-3495.

Landsea, C. W., 2005. Hurricanes and global warming. *Nature*, **438**, E11-E12, doi:10.1038/nature04477.

Milly, P. C. D., R. T. Wetherald, K. A. Dunne, and T. L. Delworth, 2002: Increasing risk of great floods in a changing climate. *Nature*, **415**(6871), 514-517.

Milly, P. C. D., K. A. Dunne, and A. V. Vecchia, 2005: Global pattern of trends in streamflow and water availability in a changing climate. *Nature*, **438**(7066), 347-350.

Pielke Jr., R.A. and M.W. Downton, 2000. Precipitation and Damaging Floods: Trends in the United States, 1932-97. *J. Climate*, 13(20), 3625-3637.

Pielke, Jr., R. A., and C. W. Landsea, 1998: Normalized U.S. hurricane damage, 1925-1995. *Wea. And Forecast.*, **13**, 621-631.

The Search for Trends in a Global Catalogue of Normalized Weather-Related Catastrophe Losses

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Abstract

In order to evaluate potential trends in global natural catastrophe losses it is important to compensate for changes in asset values and exposures over time. A study has been undertaken to create a Global Normalized Catastrophe Catalogue covering weather-related catastrophe losses in the principal developed (Australia, Canada, Europe, Japan, South Korea, US) and developing (Caribbean, Central America, China, India, the Philippines) regions of the world. We have attempted to survey losses from 1950 to 2005 although data availability means that for many regions even for the largest events the record is incomplete before the 1970s. After 1970 when the global record becomes more comprehensive we find evidence of an annual upward trend for normalized losses of 2% per year) that corresponds with a period of rising global temperatures. However over this same period, in some regions, including Australia, India and the Philippines normalized losses have declined. The significance of the trend in global normalized losses is dominated by the affect of the 2004 and 2005 Atlantic hurricane seasons as well as by the bias in US wealth relative to other developing regions. What is presented here provides a short summary of the global results of this study. Full results are in course of publication also covering individual peril regions and the exploration of correlations with global temperatures.

Introduction

Economic losses attributed to natural disasters have increased from US $75.5 billion in the 1960s to $659.9 billion in the 1990s (a compound annual growth rate of 8%). Private sector data also shows rising insured losses over a similar period. Both reinsurers and some climate scientists have argued that these increases demonstrate a link between anthropogenically induced global warming and catastrophe losses. However, failing to adjust for time-variant economic factors yields loss amounts that are not directly comparable and a pronounced upward trend through time for purely economic reasons.

To allow for a comparison of losses over time many previous studies have adjusted past catastrophe losses to account for changes in monetary value in the form of inflation. However in most countries far larger changes have resulted from variations in wealth and the numbers and values of properties located in the path of the catastrophes. A full normalization of losses, which has been undertaken for the United States hurricane and flood, also includes the affect of changes in wealth and population to express losses in constant dollars. These previous national US assessments, as well as those for normalized Cuban hurricane losses, have failed to show an upward trend in losses over time, but this was before the remarkable hurricane losses of 2004 and 2005.

In order to assess global trends over time we set out to compile a database of normalized economic losses attributed to weather-related catastrophes from 1950 to 2005 from a large and representative sample of geographic regions. Regions were selected which had a reasonable centralization of catastrophe loss information as well as a broad range of peril types: tropical cyclone, extratropical cyclone, thunderstorm, hailstorm, wildfire and flood. The surveyed regions also span high and low latitude areas.

Although global in scope, this study does not cover all regions. We have, for example, not included losses from Africa or South America; first because these continents are more affected by persistent climatological catastrophes (in particular drought) than sudden-onset weather-related catastrophes. Also the core economic loss data, in particular for much of Africa, is simply unavailable. However, the surveyed area includes the large majority of the world's asset exposure (and the majority of the population).

Methodology

We normalize losses to 2005 USD by adjusting for changes in wealth (GDP per capita in USD), inflation and population. This methodology is consistent with that used by Pielke and Landsea (1998) and is given below:

$$NL2005 = L_y * (W2005/W_y) * (I2005)/I_y) * (P2005/P_y),$$

where normalized losses in 2005 USD (NL2005) equal the product of losses in year y and the change ratios in wealth (W), inflation (I) and population (P). Where GDP per capita is expressed in nominal terms we omit the inflation multiplier.

Data

We researched and compiled the best available economic loss data from international agencies, national databases, insurance trade associations and reinsurers as well as RMS internal figures. Data quality varies by region. Table 1 indicates coverage by region and hazard type. The final column indicates our assessment of the reliability of the estimates. In cases where the quality of insured loss data exceeds that of economic losses we have estimated economic losses based upon insurance coverage ratios for the affected region and hazard type from contemporary insurance penetration rates.

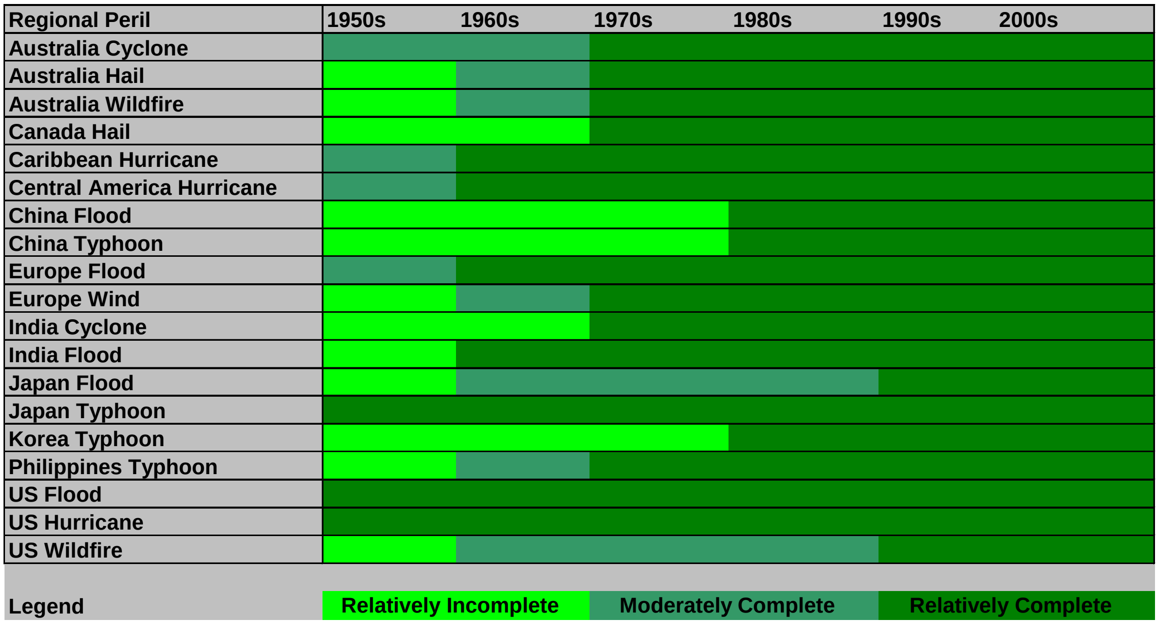
Table 1: Survey Coverage and Data Confidence

Region	Hazards	Data Confidence Level
Australia	Hail, Typhoon, Wildfire	H
Canada	Hail, Ice	M* - H
Caribbean	Hurricane	M
Central America	Hurricane	M
China	Flood, Typhoon	L* - M
Europe	Flood, Wind	H
India	Flood, Cyclone	L* - M
Japan	Flood, Typhoon	L * - M
Korea	Typhoon	L-M
Philippines	Typhoon	M
United States	Flood, Hurricane, Ice, Wildfire	H

* Data incomplete

Data sets from a number of territories are clearly incomplete through the 1950s and 1960s as shown in Figure 1 which presents relative data completeness by decade. For this reason any assessment of global trends prior to the 1970s has to omit a number of important contributory regions.

Figure 1. Data Completeness by Decade



The cumulative normalized losses for each year since 1950 are shown as a graph in Fig 1.

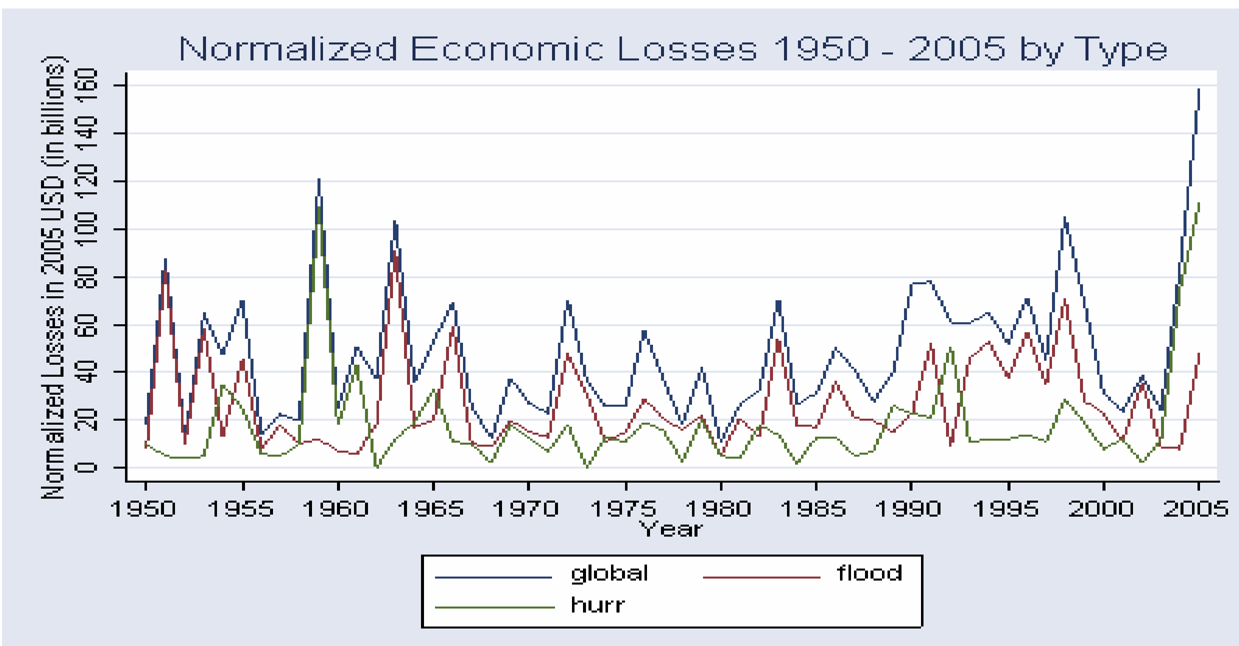


Fig 1 – Normalized economic losses for tropical cyclone, flood (storm surge and inland) and across all weather related perils, 1950-2005.

Caveats

There are four issues which merit discussion before proceeding to the results:

i) The term 'economic loss' defies precise definition and is likely to have become broader over time. Today's estimates include direct damages such as physical damage to infrastructure, crops, housing, etc. and indirect damages such as loss of revenue, unemployment and market destabilization. For example, Indonesia's losses from the 2004 tsunami include an estimated $1.53 billion USD for initial reduction in economic activity. As there is no systematic way to standardize loss estimates over time we proceed with the caveat that recent loss estimates may report a more comprehensive and therefore higher economic loss.

ii) The reporting of economic loss estimates tends to improve with the size of the event and over time. Recent losses are almost everywhere better recorded due to improvements in communications, literacy, news coverage and insurance penetration. Failing to account for the summation of small to mid-size event losses below a certain monetary threshold (e.g. $1 billion USD) will certainly affect aggregated loss estimates for most countries in earlier decades, which is why the focus here has been the largest losses.

iii) The method of normalization employed here assumes a constant vulnerability through time. For wind and hail, vulnerability reflects the susceptibility of buildings to direct damage, while for flood and wildfire it is the degree to which communities have been protected from risk (with flood defenses and fire breaks). The bias of assuming constant vulnerability is strongest where substantial adaptation (mitigation) has occurred, as for normalizing 1950s and 1960s storm surge losses in northern Europe, 1950s and 1960s storm surge and river flood events in Japan or 1970s wind loss events in Australia. However for most perils and regions, such as US hurricane, real reductions in vulnerability have been modest. The question of testing the degree to which the affects of adaptation can be demonstrated from the normalized losses is considered further in the Discussion section.

iv) The normalization methodology employed uses national statistics to compute the multipliers. Previous US normalizations use State and County level data to normalize losses. With the benefit of county level resolution in the US we can see that the population growth rate between certain coastal, hazard-prone regions such as Florida is understated by using the national average. However, we consider the large-scale migration to hazardous coastal areas seen in the US to be the exception. In the developing countries we survey, industrialization has led to migration to urban areas, which generally have lower risk profiles than rural areas. In other countries there has been a greater balance between urban and coastal migration patterns.

Trend Analysis

To test for a trend in normalized losses over time we perform a linear regression of normalized economic losses on the year. The model is given below in equation 1.

(1) $$NL_y = \alpha + \beta_1 YEAR_{y} + \varepsilon_y$$

Normalized losses (NL) in year y are determined by the loss year (YEAR) *y*, where ε is the error term. If time is a significant determinant of loss level we would expect the year to be statistically significant. The coefficient sign will indicate the direction of the trend.

We fit the regression twice using global normalized loss estimates as well as hazard type and regional subsets, first with data from 1950 – 2005 and then with data from 1970 - 2005.

Due to the large impact of Katrina, 2005 losses are nearly four standard deviations from the mean and exert an upward pull on the overall trend. To separate out the affect of Katrina on the overall results we ran the regression separately with Katrina losses removed.

Table 1: OLS Regression of Normalized Losses on Year

Survey Group	Time Period	
	1950 – 2005	1970 – 2005
Global Losses	379.26 (241.9)	1251.08*** (423.45)
Global Losses (Katrina Removed)	220.24 (210.62)	855.22** (330.28)

** Significant at 5%, ***Significant at 1% ^ at 0.055

When analyzed over the full survey period (1950 – 2005) the year is not statistically significant for global normalized losses. However, it is significant with a positive coefficient for normalized losses for specific regions such as Canada at 10%, Korea at 5%, and China at 1% (in all of which the earlier record is known to be incomplete). The coefficient is negative (but not significant) for Australia, Europe, India, Japan and the Philippines.

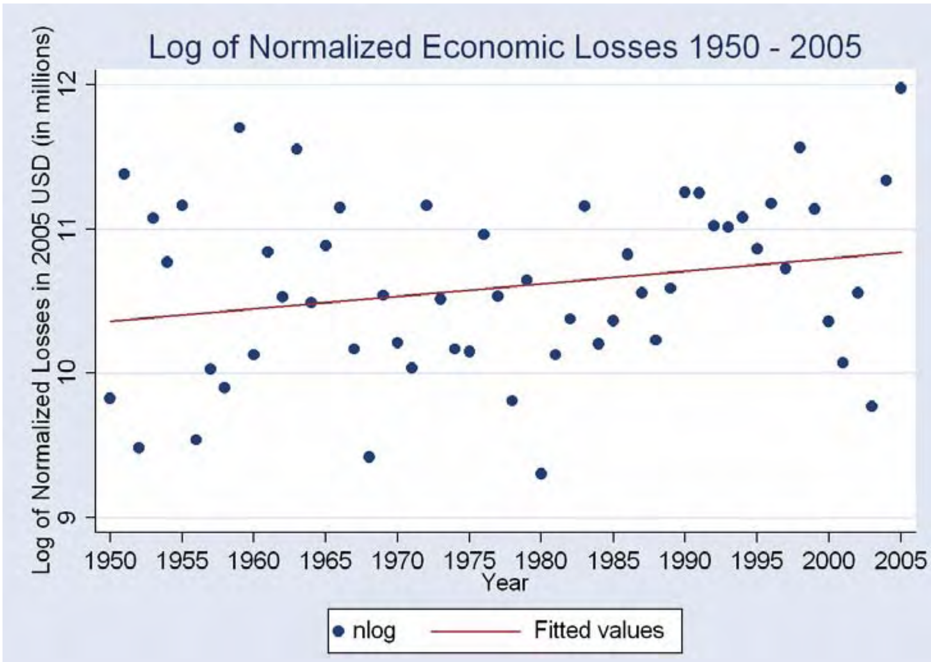


Fig 2: Trend line of Log of Normalized Economic 'Global' Losses relative to year since 1950

For the more complete 1970-2005 survey period, the year is significant with a positive coefficient for (i.e. increase in) global losses at 1% with an R2 value of 0.20 (5% with Katrina excluded), China at 1% (although again the early part of the record is likely to be incomplete), global tropical cyclones at 5% (both with and without Katrina losses) and for Caribbean losses at 10%. However, there is a decreasing trend in normalized losses for Australia at 10%, the Philippines at 5% and India at 1% (all located around the eastern Indian Ocean).

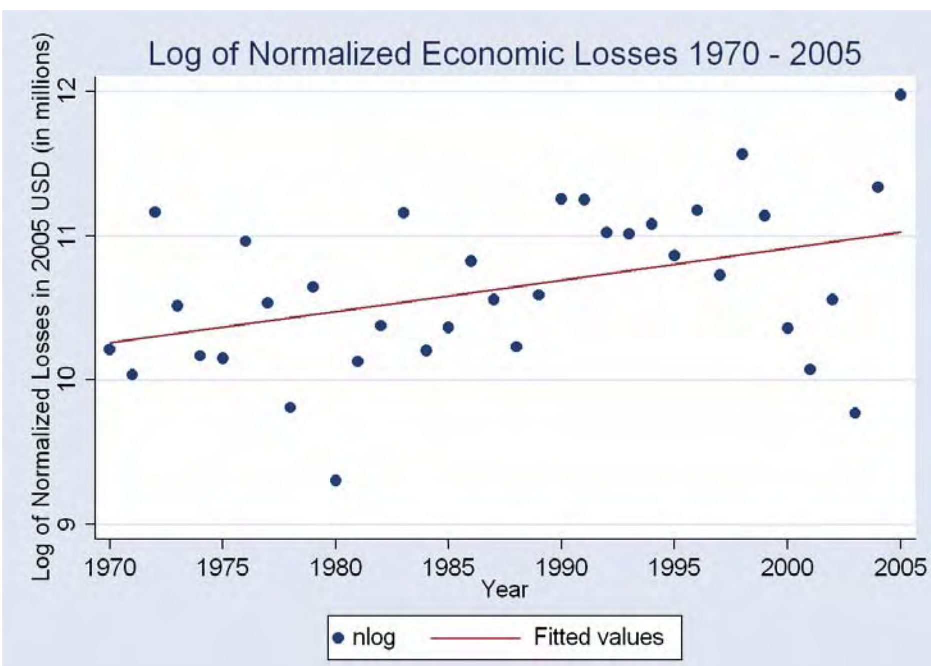


Fig 3: Trend line of Log of Normalized Economic 'Global' Losses relative to year since 1970

Discussion

Before attempting to consider the implications of these findings we should first explore potential reasons for trends within the dataset. As already noted our methodology does not normalize for changes in the vulnerability of buildings nor does our regression control for improved mitigation, as around reducing flood risk.   However, there are several clear regional examples of declining loss trends since 1950 which merit comment. In Europe and Japan extensive investments in coastal flood defenses, in particular during the 1960s, have been well documented and the actual losses from events such as Typhoon Vera or the 1953 and 1962 North Sea storm surges would in consequence be significantly reduced below the normalized values if they recurred today. For flood in Europe the top three loss years all occur by 1966 and recent flood years have reached less than half the value of the high loss years in the first 20 years of the record.

While improved flood mitigation can help explain some part of the reduction of catastrophic flood losses since the 1950s other causes must be sought in explaining the upward trend in global losses seen since the 1970s.

Before concluding that these loss results demonstrate a strong rising trend in normalized catastrophe losses, we performed some simple tests to explore the sensitivity of this result.

> The first test involved exploring whether such a trend could have been identified before the 2004 and 2005 loss years, with their heavy contribution from hurricanes in the US. The results of excluding these loss years show a reduction in the significance of the trend. Had we executed this study in 2003 we would have found no evidence to suggest an upward loss trend from 1950 and weaker evidence (at 10%) from 1970 onwards.
>
> The second test involved removing the record of flood losses in China, in particular because it is likely to be incomplete prior to the 1980s. This also has the impact of the reducing the significance for a post 1970 trend in worldwide normalized losses - but which is still significant at 10%.

The importance of the contribution of the 2004 and 2005 US hurricane highlights the difficulty inherent in compounding global losses from nations with very different asset levels as wealthier nations will inevitably have higher nominal loss totals. Record years for hazard losses in a developing region would not have exerted such a strong pull on trend significance. For illustrative purposes we re-normalized each region's normalized losses by multiplying by the ratio of US GDP per capita to regional GDP per capita. This crude modification approximates a homogenous distribution of wealth. This adjustment yields results which are significant at 5% from 1950 onwards, but not significant when isolated from 1970 – 2005.

References

1) United Nations Development Programme (UNDP). 2004. "Reducing Disaster Risk: A Challenge for Development." http://www.undp.org/bcpr/disred/rdr.htm

2) Munich Re Group. 2005. "Annual Review: Natural Catastrophes 2004." WKD Offsetdruck GmbH. Munich.

3) Swiss Reinsurance Company. 2005. Sigma: No.1 2005. "Natural Catastrophes and Man-made Disasters in 2004." Swiss Reinsurance Company. Economic Research & Consulting. Zurich.

4) International Panel on Climate Change (IPCC). 2001. "IPCC Third Assessment Report – Climate Change 2001." http://www.ipcc.ch/pub/reports.htm

5 Pielke, Roger A. Jr. and Christopher Landsea. 1998. "Normalized Hurricane Damage in the United States: 1925 – 95." *Weather and Forecasting*. September 1998. pp. 621 - 631

6) Collins, Douglas J. and Stephen P. Lowe. 2001. "A Macro Validation Dataset for U.S. Hurricane Models." http://www.casact.org/pubs/forum/01wforum/01wf217.pdf

7) National Oceanic & Atmospheric Administration (NOAA). 2005. "The Deadliest, Costliest, and Most Intense United States Tropical Cyclones From 1851 to 2004 (And Other Frequently Requested Hurricane Facts)." http://www.tpc.ncep.noaa.gov/pdf/NWS-TPC-4.pdf.

8) Pielke, Jr., R.A., M.W. Downton, and J.Z. Barnard Miller, 2002: *Flood Damage in the United States, 1926-2000: A Reanalysis of National Weather Service Estimates*. Boulder, CO: UCAR.

9) Pielke, R.A., Jr., and Jose Ribeira, Christopher Landsea, Mario L. Fernández, and Roberta Klein. 2003. "Hurricane Vulnerability in Latin America and the Caribbean: Normalized Damage and Loss Potentials." *Natural Hazards Review*. August 2003. pp. 101 – 114

WHITE PAPER PREPARED FOR WORKSHOP ON CLIMATE CHANGE AND DISASTER LOSSES: UNDERSTANDING AND ATTRIBUTION TRENDS AND PROJECTIONS

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Summary

- Climate change is real, and has a significant human component related to greenhouse gases, as summarized by the IPCC's Working Group I. Nothing in this white paper contradicts this work.
- Global disaster losses have increased.
- The increase in disaster losses is primarily due to floods and storms.
- Scientists have not yet attributed changes in floods and storms to human causes. However, there is evidence for the detection of trends in some phenomena, especially tropical cyclones.
- Some long-term disaster loss records are of suitable quality for research purposes.
- Long-term records of disaster losses indicate that the overwhelming factors responsible for increasing disaster losses are a result of societal change and development.
- Looking to the future, societal change will continue to be the dominant factor in increasing disaster losses. This conclusion is robust to a wide range of climate change scenarios. Identifying the signal of human-caused climate change in disaster loss trends will remain difficult for decades to come.

Global disaster losses have increased.

A wide range of datasets from around the world paint a consistent picture: Disaster losses have been increases rapidly in recent decades. Figure 1 below was produced by Munich Re and is illustrative of the more general conclusions (Munich Re, 2005).

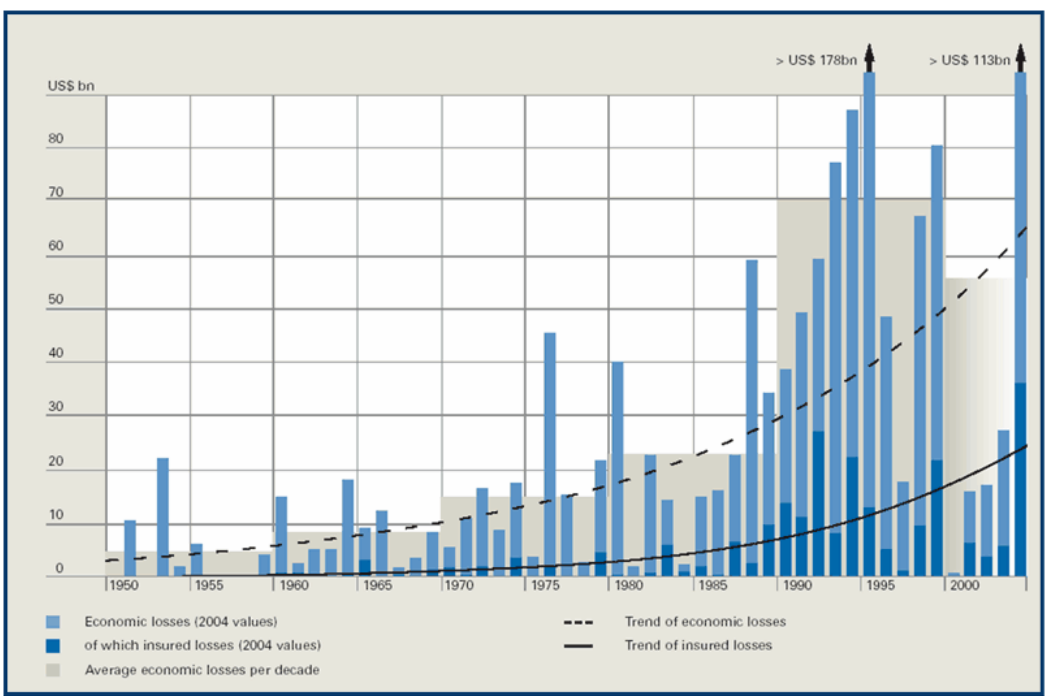


Figure 1. Global trend in disaster losses.

It is important to recognize that disaster losses do not increase in every region at a constant rate. Some regions may see decreasing trends. Disaster losses typically come in discrete, large values and the trend record is driven by the increase in the costs of the largest disasters, such as hurricanes in the United States.

The increase in disaster losses is primarily due to floods and storms.

The trend of increasing disaster losses has been driven largely by damage associated with floods and storms. Figure 2 (right) indicates that the vast majority of insured losses are the result of floods and storms (Association of British Insurers, 2005).

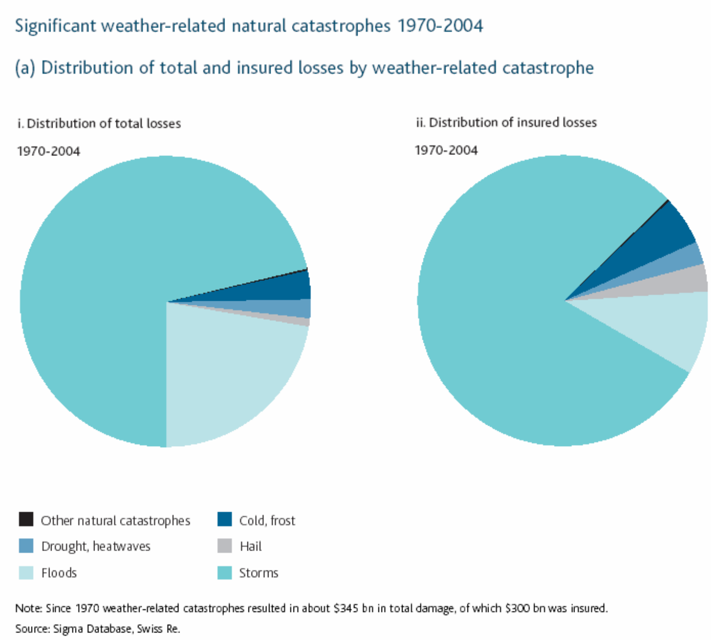


Figure 2. Distribution of insured losses 1970-2004, ABI, 2005.

The three figures below (3a, b, 3c) show for the decades of the 1990s the distribution of disasters by phenomena in terms of the number of disasters, total damage, an loss of life.[1] A consistent picture emerges from this data for atmospheric-related disasters – floods and wind storms are the primary phenomena responsible for disasters around the world according to each of these metrics.

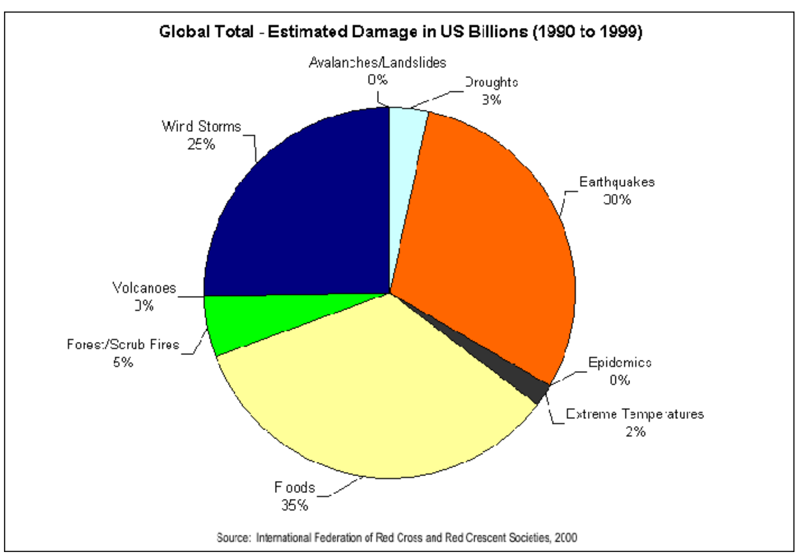
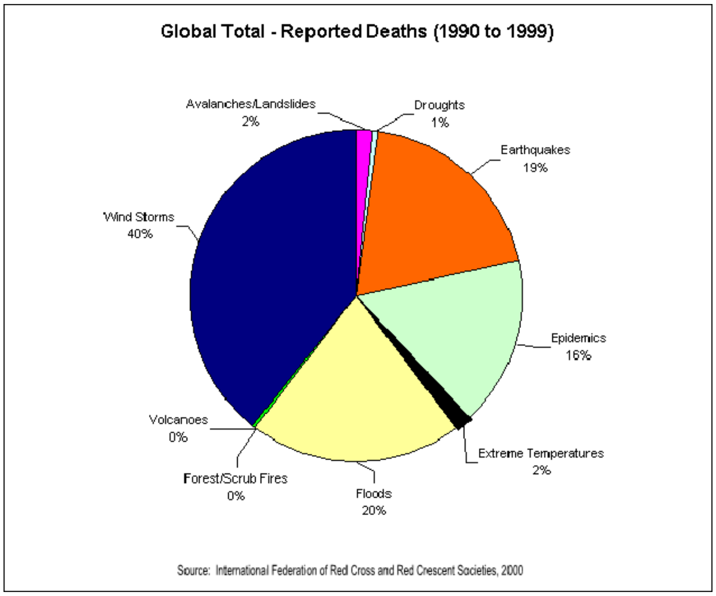
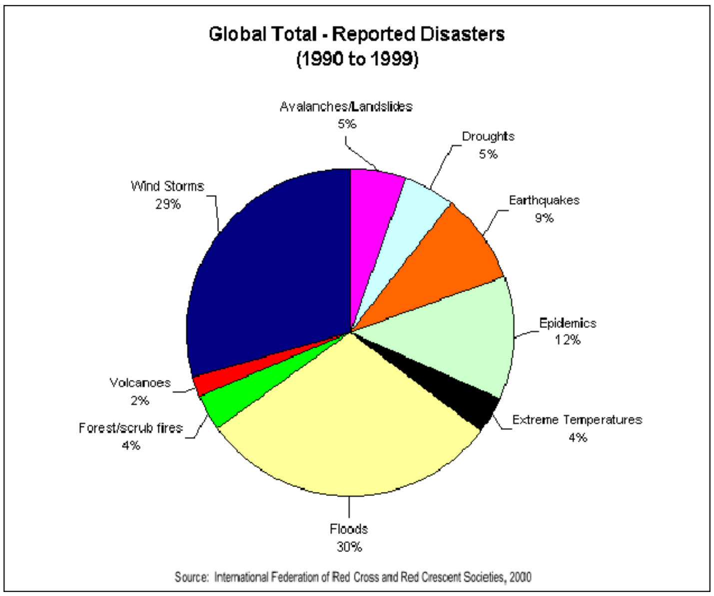


Figure 3a. IFRC, 2000. Total disaster losses in the 1990s by cause.

[1] Data from the Red Cross World Disasters Report (International Federation of Red Cross and Red Crescent Societies, 2000).





Figures 3b and 3c. Total deaths and number of disasters by cause during the 1990s. IFRC, 2000.

Scientists have not yet attributed changes in floods and storms to human causes. However, there is evidence for the detection of trends in some phenomena, especially tropical cyclones.

The most recent IPCC report took a close look at research on extreme weather events and found little evidence for changes over time (IPCC, 2001). Consider that over recent decades, the IPCC found no long-term global trends in extra-tropical cyclones (i.e., winter storms), in "droughts or wet spells," or in "tornados, hail, and other severe weather." No research (that I am aware of) has been published that would overturn these conclusions. In the absence of global trends in these weather events, they cannot be identified as being responsible for any part of the growing global economic toll. Regional trends may paint a different picture, however, in this context as well detection of trends and attribution to human causes remains incomplete.

<u>Tropical Cyclones</u>

Research on tropical cyclones has advanced rapidly since the last IPCC. In 2005 Massachusetts Institute of Technology's Kerry Emanuel published a study in the journal Nature that described an increase in the intensity of hurricanes in the North Atlantic and North Pacific (Emanuel, 2005). Another prominent study by Webster et al. has found an increase in the proportion of the strongest storms since 1970 (Webster et al., 2005). These two papers, published in the midst of a record Atlantic hurricane season in terms of both activity and damages have prompted much discussion about trends in tropical cyclone behavior.

However, it is important to recognize that neither of these papers focused on attribution. Emanuel (2005) expressed some uncertainty as to the factors responsible for the trends presented in that paper, stating "*Whatever the cause*, the near doubling of power dissipation over the period of record should be a matter of some concern" (emphasis added). Webster et al. (2005) even go so far as to observe that "attribution of the 30-year trends to global warming would require a longer global data record and, especially, a deeper understanding of the role of hurricanes in the general circulation of the atmosphere and ocean, even in the present climate state." And both the Emanuel and Webster et al. papers have prompted a vigorous discussion with responses to each subsequently published by Landsea (2005) and Chan (2006), respectively.

A vigorous debate continues within the community about the trends themselves. These studies are complemented by a new paper forthcoming in *Geophysical Research Letters* in May, 2006 which find no trends in global tropical cyclone intensity from 1986-2005, with the exception of a dramatic increase in intense storms in the Atlantic Basin (Klotzbach, 2006a). Its author concludes,

> These findings indicate that there has been very little trend in global tropical cyclone activity over the past twenty years, and therefore, that a large portion of the dramatic increasing trend found by Webster et al. [2005] and Emanuel [2005] is likely due to the diminished quality of the datasets before the middle 1980s. One would expect that if the results of Webster et al. and Emanuel were accurate reflections of what is going on in the climate system, than a similar trend would be found over the past twenty years, especially since SSTs have warmed considerably (about 0.2°C – 0.4°C) during this time period (Klotzbach, 2006b).

Given these various results, a position paper by the World Meteorological Organization's Commission on Atmospheric Sciences, its Tropical Meteorology Research Program Panel (whose authorship included Emanuel, Holland, Knutson, Landsea, among other prominent scientists) concluded:

> The research issues discussed here are in a fluid state and are the subject of much current investigation. Given time the problem of causes and attribution of the events of 2004-2005 will be discussed and argued in the refereed scientific literature. Prior to this happening it is not possible to make any authoritative comment (WMO/CAS, 2006).

Disaster losses related to tropical cyclones are discussed in some detail below. However, it seems reasonable to conclude that, at the present time, while detection of trends in tropical cyclone behavior may yet achieve a scientific consensus, attribution of such trends to human causes remains to be settled in the scientific literature. This area of science is undergoing rapid change as new research results are published, so it may be that detection and attribution will soon be unambiguously achieved. But until that occurs claims of definitive detection and attribution are premature, and thus so too would be any definitive link between trends in damage and human effects on tropical cyclones. In any case, this issue is largely moot as will be shown below, there are no long term trends in damages related to tropical cyclones – in the U.S., Caribbean, or India.

Floods

The IPCC did find "a widespread increase in heavy and extreme precipitation events in regions where total precipitation has increased, e.g., the mid- and high latitudes of the Northern Hemisphere". (IPCC, 2001) But, at the same time, the IPCC warned that "an increase (or decrease) in heavy precipitation events may not necessarily translate into annual peak (or low) river levels". Indeed, while the IPCC found some changes in streamflow, it did not identify changes in streamflow extremes (i.e., floods), and concluded on a regional basis that, "Even if a trend is identified, it may be difficult to attribute it to global warming because of other changes that are continuing in a catchment."

Since the IPCC was published it does not appear that uncertainties have been resolved one way or another. For example, a recent (2005) study by the International Ad Hoc Detection and Attribution Group, published in the Journal of Climate, was unable to detect a greenhouse gas signal in global precipitation (International Ad Hoc Detection and Attribution Group, 2005). And research on trends in precipitation appears to have mixed results, e.g., with one recent study finding no global trends: "Increased precipitation in some regions is balanced by decreased precipitation in other regions, and the global average change is near zero; " (Smith et al., 2006) Yet another recent study reaches a different conclusion, "Data are often incomplete in spatial and temporal domains and regional analyses are variable and sometimes contradictory; however, the weight of evidence indicates an ongoing intensification of the water cycle." (Huntington, 2006)

But in this case, like that in the case of tropical cyclones, a close look at the damage data does not indicate that climate trends play anything more than a very minor role (if any) in the global increase is disaster losses related to floods.

Some long-term disaster loss records are of suitable quality for research purposes.

We have intensively studied disaster loss data in the United States (Downton et al., 2005; Downton and Pielke, 2005). In particular we have reconstructed the record of flood losses kept by the U.S. National Weather Service and compared the updated loss figures with those collected independently by states. We found very large disagreements on loss totals for small events, but much lower disagreement for losses which totaled more than $500 million. We also found no reason to believe that errors in these estimates of disaster losses contain systematic biases over time. Thus, it is appropriate to conclude:

- Disaster loss data collected by the U.S. NWS is appropriate for seeking to identify climate trends.
- Estimates for large events may contain errors of, on average, 40% when compared to independently collected estimates for the same event.
- However, these errors tend to even out over time and space. There is no reason to believe that a longitudinal bias exists in the errors.
- Extreme caution should be applied when aggregating loss datasets collected in different places for different purposes.
- If loss datasets are combined for purposes of discerning climate trends, we recommend that it is absolutely essential to at the same time study each loss database independently for purposes of quality control and bias, and to conduct analyses of the role of climate trends in the region where the losses occurred.

Long-term records of disaster losses indicate that the overwhelming factors responsible for increasing disaster losses are a result of societal change and development.

<u>Floods</u>

Using the dataset described in the previous section, Figure 4a from our research shows how flood damage has increased dramatically in the United States, but Figure 4b shows that it has stayed almost constant when growing national wealth is considered.

This analysis indicates that the entire trend in losses is removed once one accounts for the growth in wealth. However, there are some indications that increasing precipitation is related to increasing damages. In a 2000 study, using an earlier version of the NWS flood loss dataset, we found a relationship between precipitation trends and damages (Pielke and Downton, 2000). The relationships were strongest when we focused at the regional scale and identified metrics of

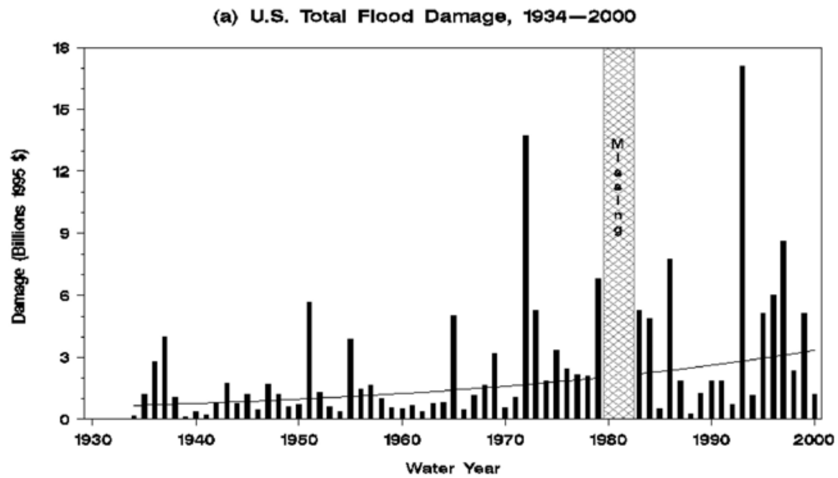


Figure 4a. Trends in U.S. flood damage, 1934-2000, adjusted for inflation.
http://www.flooddamagedata.org.

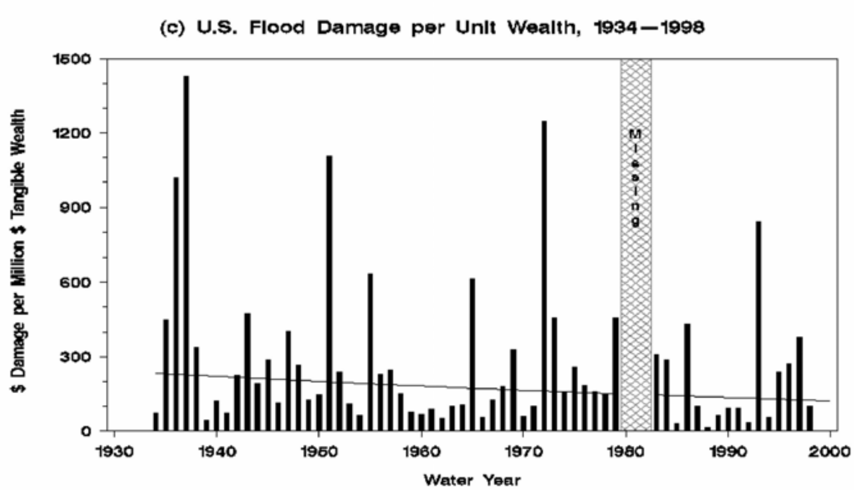


Figure 4b. Trends in U.S. flood damage per unit of wealth, 1934-1998.
http://www.flooddamagedata.org.

precipitation most closely related to the regional hydrologic and societal characteristics associated with flood damage. As the scale increases from the regional to the national, the relationship between various metrics of precipitation and damage becomes weaker. I would hypothesize that this relationship would change similarly when one goes from the national to global scale. In any case, the relationship of precipitation trends to damage is dwarfed by the overwhelming influence of societal changes as drivers of increasing flood losses.[2]

Tropical Cyclones

The case of hurricane impacts in the United States is similarly instructive. Consider economic damage (adjusted for inflation) related to hurricane landfalls in the United States, 1900–2005, as shown in Figure 5. Although damage is growing in both frequency and intensity, this trend does not reflect increased frequency or strength of hurricanes. In fact, while hurricane frequencies have varied a great deal over the past 100 + years, they have not increased in recent decades in parallel with increasing damages. To the contrary, although damage increased during the 1970s and 1980s, hurricane activity was considerably lower than in previous decades.

[2] The UK Foresight project on flooding came to similar conclusions, http://www.foresight.gov.uk/Previous_Projects/Flood_and_Coastal_Defence/index.html

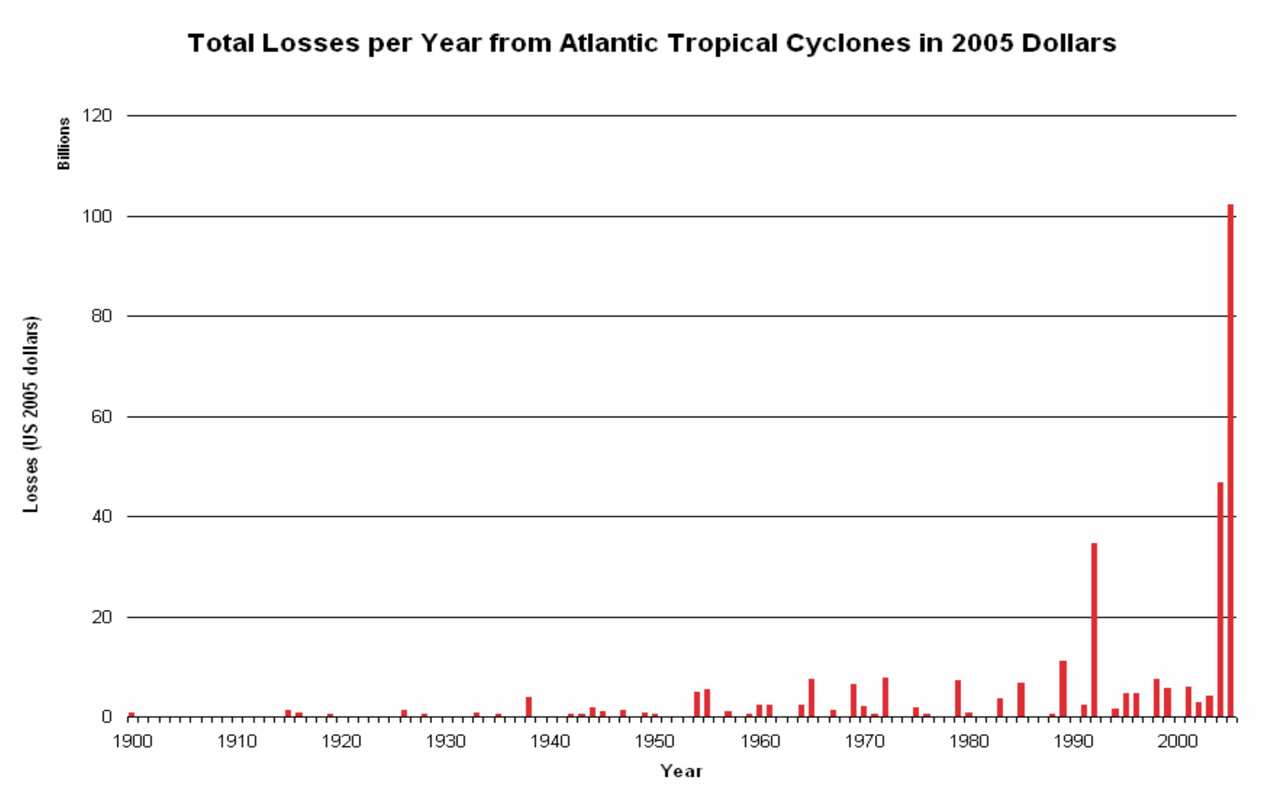


Figure 5. Trend in U.S. hurricane damage, 1900-2005. Source: NOAA/NHC

To explain the increase in damage, it is therefore necessary to consider factors other than variability or change in climate. Society has changed enormously during the past century and coastal development has taken pace at an incredible pace.

Given the significance of societal change in trends of hurricane damage, one way to present a more accurate perspective on such trends is to consider how past storms would affect present society. We developed a methodology for ''normalizing'' past hurricane damage to present day values (using wealth, population, and inflation). (Pielke and Landsea, 1998) Figure 6 shows the historical losses of Figure 5 normalized to 2005 values. The normalized record shows that the impacts of Hurricane Andrew, at close to $53 billion (2005 values) (unpublished analysis by author, updated from Pielke and Landsea, 1998), would have been far surpassed by the Great Miami Hurricane of 1926, which would have caused an estimated $137 billion damage had it occurred in 2005, exceeding similarly accounted costs of Katrina. We can have some confidence that the normalized loss record accounts for societal changes because, unlike the unadjusted data, the adjusted damage data accurately reflect well-understood patterns of climate variability, such as the signal of El Niño and La Niña in hurricane frequencies (Katz, 2002).

Figure 6 shows no longitudinal trend in losses related to tropical cyclones, even with the extreme losses of 2004 and 2005. Kerry Emanuel, who has documented an increase in hurricane intensities in the Atlantic Basin accepts this conclusion. He writes on his website, "There is a huge upward trend in hurricane damage in the U.S., but all or almost all of this is due to increasing coastal population and building in hurricane-prone areas. When this increase in population and wealth is accounted for, there is no discernible trend left in the hurricane damage data." (Emanuel, 2006) A comment that I wrote in response to Emanuel's paper (2005), also published in Nature, provided evidence that indicated that once U.S. hurricane damage was adjusted to reflect societal changes, there was no trend of increasing damages over the twentieth century or an increase in damages per storm (Pielke, 2005).

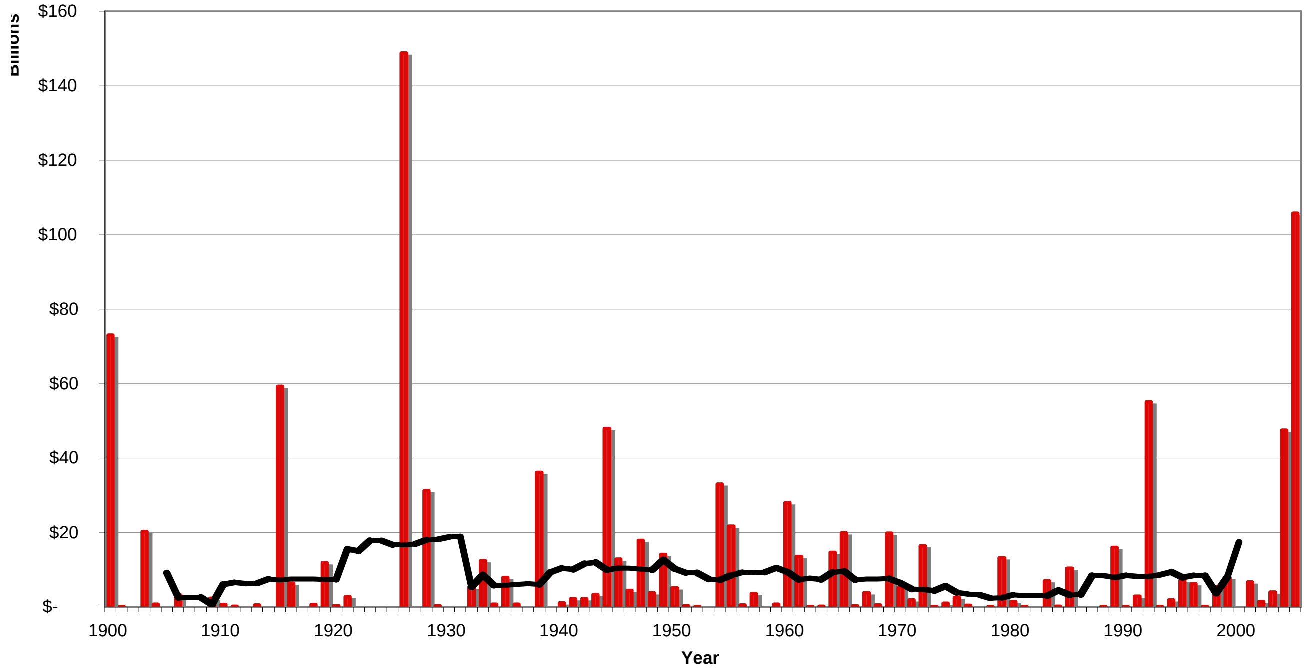


Figure 6. Estimated hurricane damages 1900-2005 if storms of the past made landfall with coastal development of 2005. Source: Roger A. Pielke, Jr., work in progress

Similar conclusions have been reached in studies that looked at Latin America and the Caribbean (Pielke et al., 2003), and well as in an India case study (Raghavan and Rajesh, 2003).

Of course, the case studies discussed above focus only on the United States and do not provide a global perspective. However, a very large portion of the trend in global losses is from the United States, and in particular from hurricane losses. A focus on death or other human impacts would necessarily result in a different focus, perhaps with different conclusions. As an operating hypothesis, the results from the case studies discussed above provide suggest that research in Europe and Asia, in particular, might focus on identifying disaster datasets of suitable quality for such research and efforts to quantitatively disaggregate the role of population growth and wealth in regional trends in disaster losses.

What About the Conclusion of the IPCC 2001 WG II?

One important reason for some confusion among scientists stems from a claim made by the IPCC Working Group II attributing some part of the trend of increasing disaster losses to changes in climate. (IPCC, 2001) However, upon closer look, the claim seems unfounded. The IPCC relied on a report published in 2000 by Munich Re that found that global disasters resulted in $636 billion in losses in the 1990s compared with $315 billion in the 1970s, after adjusting for changes in population and wealth. (Munich Re, 2000) The Munich Re report concludes that disaster costs have increased by a factor of two (i.e., 636/315), independent of societal changes, and the IPCC suggests that climate change is responsible for the difference.

Methodologically, the calculation is suspect for a number of reasons. First, Munich Re provides neither their methods nor data. Second, Munich Re admits that data on changes in wealth are not available around the world and changes in GDP are not always a good proxy for data on wealth. Third, Munich Re's data apparently includes weather and non-weather events (e.g., it appears to also include earthquake damages).

But assuming that all of the issues raised above can be overcome, and in the end there remains a 2-to-1 ratio. The fact is that the large decadal variability in disaster losses makes it quite dodgy to assert a trend by comparing two different ten-year periods over a period of 30 years. This can be illustrated with an example from our database of hurricane losses. If we adjust the hurricane loss data, accounting for trends in population, wealth, and inflation, to 2005 values and then compare decades (data can be seen in Figure 6), we see some interesting things.

First, the ratio of the 1990s to the 1970s is quite similar to the Munich Re analysis, 2.1 ($87B/$41B). But if we look at other decadal comparisons, the picture looks quite different, the 1990s to the 1940s = 0.8 ($87B/$110B) compared to the 1990s to the 1920s = 0.5 ($87B/$184B). The bottom line is that the 2000 Munich Re analysis, which provided some valuable insights on disasters to be sure, tells us nothing about the attribution of the causes for increasing disasters, yet its results were used by the IPCC to suggest otherwise.

Looking to the future, societal change will continue to be the dominant factor in increasing disaster losses. This conclusion is robust to a wide range of climate change scenarios.

It goes beyond the scope of the present workshop to focus on the future. However, it should be simply noted that societal change will continue, of course, with dramatic implications for continued increases in disaster losses. In this context, identifying the signal of human-caused climate change will require that two conditions be met:

1. Scientific evidence of both the detection and attribution of trends in extreme events (i.e., storms and floods) to human-caused climate change.
2. A signal of such changes evident in the disaster loss record that is significant in the context of societal change, and importantly, in the context of the inherently noisy data of disaster losses.

Until that time occurs, it is premature to suggest that the observed large increase in disaster losses is related to anything other than increasing population at risk possessing ever-greater amounts of wealth at risk of loss. The bottom line is that identifying the signal of human-caused climate change in disaster loss trends will remain difficult for decades to come.

References

Association of British Insurers, 2005. June 2005 Summary Report: Financial Risks of Climate Change, http://www.abi.org.uk/Display/File/Child/552/Financial_Risks_of_Climate_Change.pdf.

Chan, J. C. L. 2006. Comment on "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment," Science, 311:1713, http://www.sciencemag.org/cgi/content/full/311/5768/1713b.

Downton, M. and R. A. Pielke, Jr., 2005. How Accurate are Disaster Loss Data? The Case of U.S. Flood Damage, Natural Hazards, Vol. 35, No. 2, pp. 211-228, http://sciencepolicy.colorado.edu/admin/publication_files/resource-796-2005.31.pdf.

Downton, M., J. Z. B. Miller and R. A. Pielke, Jr., 2005. Reanalysis of U.S. National Weather Service Flood Loss Database, Natural Hazards Review, Vol. 6, pp. 13-22, http://sciencepolicy.colorado.edu/admin/publication_files/resource-487-2005.16.pdf.

Emanuel, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. Nature, Vol. 436, pp. 686–688.

Emanuel, K. 2006. Anthropogenic Effects on Tropical Cyclone Activity, http://wind.mit.edu/%7Eemanuel/anthro2.htm.

Huntington, T. C., 2006. Evidence for intensification of the global water cycle: Review and synthesis, Journal of Hydrology, Vol. 319, pp. 83-95.

International Ad Hoc Detection and Attribution Group, 2005. Detecting and attributing external influences on the climate system: A review of recent advances. Journal of Climate, Vol.18, pp. 1291–1314.

International Federation of Red Cross and Red Crescent Societies, 2000. World Disasters Report 2000, Geneva, 240 p., http://www.ifrc.org/publicat/catalog/autogen/4517.asp.

IPCC. 2001. Climate Change 2001. The Scientific Basis. Contributions of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, and D. Xiaosu). Cambridge University Press, United Kingdom, 881 pp.

Katz, R.W., 2002. Stochastic modeling of hurricane damage. Journal of Applied Meteorology, Vol. 41, pp. 754-762, http://www.isse.ucar.edu/HP_rick/pdf/damage.pdf.

Klotzbach, P.J., 2006a (submitted). Trends in Global Tropical Cyclone Activity over the Past Twenty Years (1986-2005), Geophysical Research Letters, http://tropical.atmos.colostate.edu/Includes/Documents/Publications/klotzbach2006.pdf.

Klotzbach, P.J., 2006b (submitted). Talking Points: Trends in Global Tropical Cyclone Activity over the Past Twenty Years (1986-2005), Geophysical Research Letters, http://tropical.atmos.colostate.edu/Includes/Documents/Publications/klotzbach2006_talkingpoints.pdf.

Landsea, C. W., 2005. Hurricanes and global warming, Nature, Vol. 438, pp. E11-13. http://www.aoml.noaa.gov/hrd/Landsea/landseanaturepublished.pdf

Munich Re, 2000. Topics, 2000: Natural Catastrophes, The Current Position. Munich Reinsurance (Munich Re), Munich, Germany, http://www.munichre.com/publications/302-02354_en.pdf?rdm=80335.

Munich Re, 2005. Annual Review: Natural Catastrophes 2004, http://www.munichre.com/publications/302-04321_en.pdf?rdm=71234%20.

Pielke, Jr., R. A. and C. W. Landsea, 1998. Normalized Hurricane Damages in the United States: 1925-95. Weather and Forecasting, American Meteorological Society, Vol. 13, pp. 621-631, http://sciencepolicy.colorado.edu/admin/publication_files/resource-168-1998.11.pdf.

Pielke, Jr., R. A. and M.W. Downton, 2000. Precipitation and Damaging Floods: Trends in the United States, 1932-97. Journal of Climate, Vol.13, No. 20, pp. 3625-3637, http://sciencepolicy.colorado.edu/admin/publication_files/resource-60-2000.11.pdf.

Pielke, Jr., R.A., J. Rubiera, C. Landsea, M. Fernandez, and R.A. Klein, 2003. Hurricane Vulnerability in Latin America and the Caribbean, Natural Hazards Review, Vol. 4, pp. 101-114, http://sciencepolicy.colorado.edu/admin/publication_files/resource-1769-2003.21.pdf.

Pielke, Jr., R. A., 2005. Are there trends in hurricane destruction? Nature, Vol. 438, December, pp. E11, http://sciencepolicy.colorado.edu/admin/publication_files/resource-1890-2005.48.pdf.

Raghavan, S., and S. Rajesh, 2003. Trends in tropical cyclone impact: A study in Andhra Pradesh, India, Bulletin of the American Meteorological Society, Vol. 84, pp. 635–644.

Smith, T. M., X. Yin, and A. Gruber, 2006. Variations in annual global precipitation (1979–2004), based on the Global Precipitation Climatology Project 2.5° analysis, Geophysical Research Letters, Vol. 33, L06705, doi:10.1029/2005GL025393, http://www.agu.org/pubs/crossref/2006/2005GL025393.shtml.

Webster, P.J., G.J. Holland, J.A. Curry, and H.R. Chang, 2005. Changes in tropical cyclone number, duration, and intensity in a warming Environment. Science, Vol. 309, pp. 1844–1846.

WMO/CAS, 2006. Statement on Tropical Cyclones and Climate Change, WMO/CAS Tropical Meteorology Research Program, Steering Committee for Project TC-2: Scientific Assessment of Climate Change Effects on Tropical Cyclones, http://www.bom.gov.au/info/CAS-statement.pdf.

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1. **What factors account for the dramatically increasing costs of weather-related disasters (specifically, floods and storms) in recent decades?**

While the socio-economic Impact of weather-related hazards has undeniably increased tremendously in the past few decades, the reasons are to be looked for in social, political and economic factors rather than in the meteorological phenomena themselves.

2. **What are the implications of these understandings, for both research and policy?**

The following are needed:

1) Continued research for understanding the meteorological phenomena and the mechanisms of damage including the likely effects of climate change.
2) Pro-active preparedness for disaster mitigation which will include engineering, social and legal measures.

I attach a background paper setting out the basis for these answers.

First question: What factors account for the dramatically increasing costs of weather-related disasters (specifically, floods and storms) in recent decades?

While the socio-economic Impact of weather-related hazards has undeniably increased tremendously in the past few decades, the reasons for the increase are to be looked for in social, political and economic factors rather than in the meteorological phenomena themselves. I shall confine myself to tropical cyclones, which are the most hazardous weather phenomena and floods which are the most disastrous weather-related events. I am illustrating with two recent examples from India.

Tropical Cyclones

Andhra Pradesh (location shown in Fig. 1) is one of the most cyclone-prone states in India with a coastline of about 1030 km. Reliable meteorological as well as economic data are available since about 1970. From a study of the tropical cyclones hitting the state in the period 1971-2000 it was shown by Raghavan and Rajesh (2003) that there was no trend of increase of frequency or intensity of tropical cyclones (actually there was a negative trend within these three decades) but the estimated damage was increasing over the period. Normalisation of the damage for inflation, increase in population and economic activity in the region showed that there was no trend in the normalised damage figures. This agrees with similar studies in the USA (Pielke and Landsea, 1998). The study could not be extended to other coastal states in India because of difficulties in getting reliable damage data although reliable meteorological data are available. There is however no reason to expect a very different result in those states. Actual damage in future cyclones is expected to increase further.

I have also examined the attention given by administrators to *preparedness* for disastrous events and for *post-disaster relief*. The figures for Andhra Pradesh (source: Government of Andhra Pradesh) are as below.

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EXPENDITURE[2]	Indian Rupees Crore (Crore means 10^7)
Relief expenditure after the event (including cyclones, floods and droughts), from 1979-80 to 1999-2000.	**2781**
Damage estimated to have occurred in one single tropical cyclone in 1996	**6129**
expenditure on preparedness before each event	**Not available**
World Bank-aided Project in the nineties mostly on infrastructure development	**801**

The fact that data on expenditure incurred on preparedness were not even available except for the World Bank project outlay, shows that much more importance is attached to relief after the event rather than proactive preparedness *before* it. This attitude is understandable in the sociopolitical context and is not confined to Andhra Pradesh. One has only to draw a parallel to the state of preparedness in New Orleans, USA, before Hurricane Katrina, despite elaborate plans being available.

Although in recent decades, awareness on cyclone preparedness has improved in this region, there is a "Fading Memory Syndrome", which results in slackness in disaster preparedness if there is no cyclone affecting an area for a few years (Raghavan and Sen Sarma, 2000). The phenomenal damage and deaths in the "super cyclone" (defined as one with maximum sustained surface wind of 62 m s^{-1} or more; in this case 72 m s^{-1}) which struck the Indian State of Orissa in October 1999, may be largely attributed to want of preparedness.

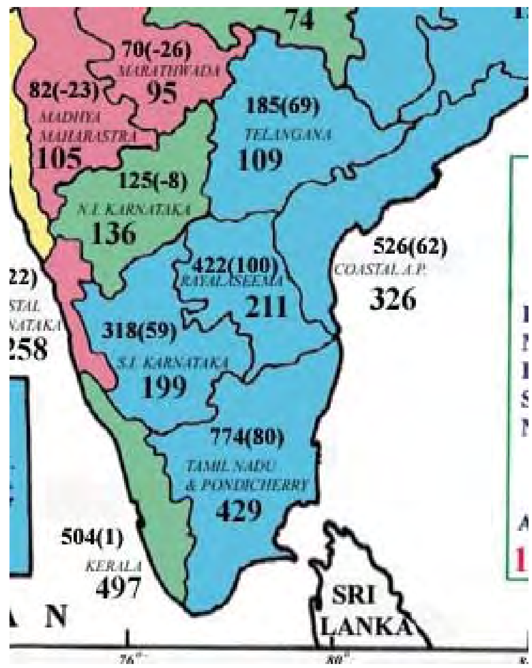

Fig. 1 Map of peninsular India showing location of "coastal Andhra Pradesh" and "Tamil Nadu and Pondicherry" on the east coast. The rainfall figures for the latter are 774 mm from October to December, 2005 which is 80% above the normal figure of 429 mm. – figure courtesy India Meteorological Department.

Floods

Floods occur every year in several parts of India especially during the monsoon months (June to September). In the southernmost state of Tamil Nadu (see Fig. 1) the major part of the rainfall occurs in the October to December season which is locally called the "northeast monsoon" season. In the period October to December 2005 there was a total rainfall of 774 mm which is about two standard deviations above the normal of 429 mm. The rain resulted from several low pressure systems moving in from the Bay of Bengal, some of which attained cyclonic storm intensity (wind speed greater than 17 m s^{-1}) while at sea but weakened before landfall. Hence the damage due to these events was entirely by flooding and not wind or storm surge. According to media and official reports the entire state had unprecedented floods affecting various districts. The rainfall however, was *not* unprecedented. The year 1946 had higher rainfall and five other years in the 20th century had comparable rainfall, but the floods were not serious in those years.

Unlike in the case of tropical cyclones, floods in India have been increasing over the years in severity and area affected, but the causes are not meteorological.

It was found in this case that the floods were largely man-made and attributable to the following causes.

1. Drainages were blocked over the years in the name of development.

[2] At present 45 Indian Rupees are equal to a US Dollar but the exchange rate has varied considerably over the years. Hence conversion of the above figures to US Dollars may be misleading.

2. Large numbers of water storage ponds built in previous centuries for storing rain water for irrigation, were allowed to be silted up or even destroyed by building over them or encroaching on them.
3. Rivers and canals which were navigable even 50 years ago were encroached upon or filled with sewage and garbage. There were even "university" and "government" buildings built over some river beds.
4. Destruction of wetlands e.g. coastal mangrove swamps[3].
5. Encroachments were encouraged or subsidised by governments over the years, to meet real or contrived demands from various sections of society[4].

It is true that for an accurate assessment of floods, complete information on intensity and duration of each spell of rainfall should be examined (e.g. Trenberth et al., 2003), but it is clearly established in this case that the above human-made causes were dominant.

Other Phenomena

There may be other adverse weather phenomena which may themselves be increasing because of "climate change" but even in these cases human activities may often be major contributors. Examples are large-scale deforestation, depletion of ground water, widespread mining and other land use changes.

Causes

Scientific opinion on whether tropical cyclones are increasing in frequency or intensity and whether such increase is due to "global warming" is inconclusive. The work of Emanuel (2005) and Webster et al. (2005) is often cited (in many cases, out of context), in support of the contention that cyclones are increasing due to global warming. According to Emanuel, the "potential destructiveness" of hurricanes increased markedly since the mid-1970s. He concluded that future warming may lead to an upward trend in tropical cyclone *destructive potential*, and—taking into account an increasing coastal population— a substantial increase in hurricane-related losses in the twenty-first century. He did *not* find any increase in number of cyclones. Note that the increase in losses is attributed not just to the intensity of the cyclones but also to societal factors such as increase in coastal population. Also note that most cyclones do not reach the maximum potential intensity given by theory. Emanuel has also said that it is absurd to think that the Katrina disaster is due to global warming. http://wind.mit.edu/~emanuel/anthro2.htm) But this part is conveniently forgotten.

Webster et al. (2005) examined data of the past 35 years and found that the number of cyclones and cyclone days have increased in the North Atlantic during the past decade but this is not the case in all other ocean basins. A large increase was seen in the number and proportion of intense hurricanes (categories 4 and 5) in all basins but the maximum intensity remained unchanged over 35 years. These increases are attributed by them to increasing sea surface temperature. But (and this part often goes unnoticed) the authors say "*attribution of the 30-year trends to global warming would require a longer global data record and, especially, a deeper understanding of the role of hurricanes in the general circulation of the atmosphere and ocean, even in the present climate state".*

It has been pointed out by Patrick Michaels (of the University of Virginia) http://www.tcsdaily.com/article.aspx?id=091605F that in the Atlantic where good data are available for earlier years also, just the opposite occurred in the period 1945 to 1970 i.e. there was a greater number of intense hurricanes than in the period 1970 to 1994. Gray (2006) is of the view that "the large increase in Atlantic hurricane frequency and strength of intensity since 1995 is natural and is a result of the large increase in the Atlantic thermohaline circulation (THC)". Pielke et al. (2005) also state that the claims of linkage with global warming are premature.

[3] It was found that damage due to the tsunami of 26 December 2004 was minimal in those coastal areas where mangroves were intact compared to severe impact in other areas where they had been destroyed –Swaminathan (2005).

[4] Some of the encroaching structures were demolished after the floods.

The Association of British Insurers (2005) report on "Financial Risks of Climate Change" states "To date, these trends in the number of events and total losses over time have been driven predominantly by socio-economic factors, including population growth, concentration of population in urban areas and rising amounts of increasingly valuable assets in areas prone to storm and flood risk. There have also been improvements in monitoring capabilities, so that more events are now identified and recorded each year".

The projections for the future (based on assumptions of climate change) are sensitive to the model used and vary widely. Therefore, they do not necessarily reflect reality. For example, Knutson and Tuleya (2004) estimate a 6% increase in hurricane wind speeds by 2080. This is disputed by others (e.g. Michaels et al, 2005). According to Pielke et al., (2005), even if this increase is there, the increase by now would have been 0.5 to 1 m s^{-1} , which is smaller than the error in satellite techniques of estimating wind speed and it is also small in comparison with inter-decadal changes.

In the absence of clarity about whether observed increase in incidence of events is due to climate change or periodical oscillations of meteorological and oceanographic parameters the assumptions in the model projections can be counter-productive. An example is the widespread assumption that drought in Asia and Africa would be the consequence of the 1997 El Niño in many regions including India and southern Africa. That did not happen. In southern Africa, people made decisions based on the likelihood of drought, such as not planting, that ultimately hurt them (Dilley 2002).

Answer to the first Question:

Hence it is my submission that the observed increase in ***impact*** *of severe weather events is attributable largely to human-made social, political and economic causes and not due to any increase in the events themselves.*

Second Question: What are the implications of these understandings, for both research and policy? Are we doing enough to minimize the impact of severe weather phenomena?

Attribution of the increases to global warming or to natural causes is often used as an excuse for inaction by branding the events as "acts of God" (see e.g. Kennedy, 2006). Instead of worrying about whether the events will increase due to climate change the more appropriate and immediate question to ask ourselves is "*Are we doing enough to minimise the* ***impact*** *of severe weather phenomena?*". It is amply evident that we are not.

Relief vs Preparedness:

Palliative "relief" measures after each severe weather event are undertaken at great cost. Pro-active preparedness measures, though less expensive, and more durable, are given less importance and are often totally neglected. Relief measures in the limelight are politically rewarding while preparedness involves hard work behind the scenes. While better preparedness cannot totally avoid damage or relief expenditure, it can mitigate human suffering as well as economic damage. By preparedness we mean the various aspects which may have different relative priorities in different parts of the world.

Preparedness may consist of:

1. Improvement of physical infrastructure e.g. better construction, better roads, drainage, water storage facilities, reliable communication networks[5].
2. Creation of awareness of risks.
3. Discouragement or prevention of unwise land use, preservation of coastal wetlands and shelter belts[6].

[5] A recent development in India is a scheme to disseminate disaster warnings automatically through mobile phone networks which have a large penetration in rural areas.

[6] In India the Government had banned all construction within 500 meters of the shoreline. This ban was violated almost all over the country. Based on the recommendations of a committee which went into this (Swaminathan, 2005), it is now proposed to define areas available for development near the coast on "scientific principles".

These aspects have been studied extensively and there are no technical difficulties in implementing preparedness schemes. The impediments are socio-political e.g. how to overcome conflicting interests, population pressures and so on.

Insurance:

Insurance is one area which needs development in many parts of the world. For example in India, government property is not insured (as a policy) and insurance of private property in rural areas especially agricultural crops is almost non-existent. In the absence of insurance, the Governments step in and provide ad hoc relief after each event. This results in uneven and wasteful deployment of funds and blame games between various agencies and affected people. It also makes the assessment of losses difficult. An insurance policy linked to regulations of land use is desirable.

Answer to the second question:

The following are needed:

(1) *Continued research for understanding the meteorological phenomena and the mechanisms of damage including the likely effects of climate change.*

(2) *Pro-active preparedness for disaster mitigation which will include engineering, social and legal measures.*

References

Association of British Insurers (ABI) , 2005, "Financial risks of climate change", Summary Report, 40 pp., http://www.abi.org.uk

Emanuel K., 2005, "Increasing destructiveness of tropical cyclones over the past 30 years", *Nature*, 436, 686-688.

Gray W.M., 2006, "Global warming and hurricanes", Paper 4C.1, *27th Conference on Hurricanes and Tropical Meteorology*, 23-28 April 2006, Amer. Meteor. Soc.

Dilley M., 2002, "The use of climate information and seasonal prediction to prevent disasters", *WMO Bull.*, **51**, 1, 42-48.

Kennedy D., 2006**, "**Acts of God?"", Editorial, *Science*, Vol. 311. no. 5759, p. 303

Knutson T.R. and R. E. Tuleya, 2004, "Impact of CO2-Induced Warming on Simulated Hurricane Intensity and Precipitation: Sensitivity to the Choice of Climate Model and Convective Parameterization", J. C l i m a t e, 17,18, 3477-3495.

Michaels P.J., P.C. Knappenberger and C. Landsea, 2005, , Comments on "Impacts of CO_2- Induced Warming on Simulated Hurricane Intensity and Precipitation: Sensitivity to the Choice of Climate Model and Convective Scheme", ***J. Climate:*** **18,. 23, 5179–5182.**

Pielke, R. A. Jr., and C. W. Landsea, 1998, "Normalized hurricane damages in the United States: 1925–95", *Weather Forecasting,* **13**, 621–631.

Pielke, R. A. Jr., C. W. Landsea, M. Mayfield, J. Laver and R. Pasch, 2005, "Hurricanes and global warming", Bull. Amer. Meteor. Soc., 86, 11, 1571-1575.

Raghavan S. and S. Rajesh, 2003, "Trends in tropical cyclone impact:: A study in Andhra Pradesh, India", *Bull. Amer. Meteor. Soc.*, **84**, 635-644.

Raghavan S. and A. K. Sen Sarma, 2000: Tropical cyclone impacts in India and neighbourhood. *Storms,* Vol. 1, R. A. Pielke Sr. and R. A. Pielke Jr., Eds., Routledge , 339–356.

Swaminathan M.S., 2005, Report of the Committee to review the Coastal Regulation Zone Notification, 1991, February 2005, 122 pages pdf file http://mpcb.mah.nic.in/mczma/swaminathan-1.pdf.

Webster P. J., G. J. Holland, J. A. Curry, and H.-R. Chang, 2005, "Changes in Tropical Cyclone, Number, Duration, and Intensity in a Warming Environment", *Science*, **309**, 1844-1846.

White Paper: Gerd Tetzlaff

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1. **What accounts for the dramatically increasing costs of weather-related disasters (specifically floods and storms) in recent decades?**

Weather and damage changes are implied to be of global character. Weather systems and their changes occur regionally and often are different from region to region, these differences not smoothing out when going to a global scale. The same is true for damage. Economic and social systems show even higher degrees of regional and temporal differentiation. Whether the spatial patterns of weather patterns match the ones of the economic ones within any given time interval could be investigated with enough high quality data being available.

Moving back and forth in time in steps of decades means to assure the quality of the data used for any comparison purposes. The quality of weather data is rather well known. However, weather damage comes with rare weather events, with limited accuracy of the occurrence frequency data. Most societies have regulations that ensure the existence of protective systems to reduce damage. In principle that would mean damage only to occur if threshold values are exceeded. In practice damage occurs gradually and already at values far below design thresholds because of error, negligence, or ageing. The threshold values and their enforcement strongly influences the relation between size of a weather event and damage. Future data solely rely on climate model results with error estimates of modest accuracies. Economic analyses are usually confined to one particular country. To produce long time series is not simple (Maddison 2003). The results available show quite some variety in the economic structure and their changes, being different also from country to country. When a retrospective analysis for Germany is extended over 100 years or longer it means to go through 5 major political and economic systems, and quite substantial changes in the country's size and population. This becomes evident when looking at economic indicators such as national wealth, natural capital, fixed assets, human resources, gross domestic product, capital productivity, capital intensity, interest rates, and inflation rates. These parameters show country-specific and parameter-specific different and specific changes. This makes the formulation of the relation between the size of a rare weather event and the economic damage complicated and inaccurate, and there are few concrete analyses available in this field, and in there no systematic error estimates are given.

The methods that different nations apply to combine and employ their assets to generate well-being after a weather event are multifold, each one itself complex. Unquestionably, human resources is the major contributor to national wealth and usually left almost unharmed after a weather event. Damage caused by weather events is inflicted to a major proportion on fixed assets (Kunte et al. 1998). It is however plausible that the use of economic damage or cost as a proxy for rare weather event data is possible only with very limited reliability, in the end probably not allowing to draw any globally and century-long valid conclusions on a quantitative relation between rare weather events and damage.

2. **What are the implications of these understandings, for both research and policy?**

Although it might be difficult to make use of national economic data as proxy for weather data, there remains the challenge to anticipate future changes for each nation separately. Whether global indicators of the past allow extrapolations into the national future seems to be doubtful. Research needs to develop methods to quantify errors of past and future national weather and national economic changes, both separately and together. It may be that scenario techniques are closest to allow results.

Policies –on a national basis- need to acknowledge that the whole spectrum of future changes needs a variety of adaptation strategies, integrating projected weather changes into them.

References

Kunte A., Hamilton K., Dixon J., and Clemens M. : Estimatind National Wealth : Methodology and Results. World Bank ESD Papers 57, 1998, 53 p.

Maddison A. : The World Economy : Historical Statistics. OECD Development Centre, 2003, 274p.

Factors affecting economic losses from tropical storms in the Cayman Islands

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Summary

The purpose of this paper is to provide an overview of some of the societal factors that influence vulnerability to storms in the Cayman Islands. Specifically the paper considers how changes in the economy, society and government institutions have affected adaptive capacity and vulnerability. These changes have both enabled and disabled preparedness for storms. The paper concludes that the adaptive capacity of the islands depends on the ability of both the government and individuals to balance the consequences of increasing wealth and economic growth, with changes in social structure and institutional capacity to respond.

Introduction to tropical storms in the Cayman Islands

The three Cayman Islands (Grand Cayman, Cayman Brac and Little Cayman) fall within the Caribbean hurricane belt and are seasonally affected by tropical depressions, tropical storms and tropical cyclones (hurricanes). Between 1886 and 1996, 128 tropical storms passed within 250 km of the Cayman Islands during the Atlantic Hurricane Season, which generally runs from June to November (Minor and Murphy, 1999). From 1887 to 1987, 4.3 tropical storms passed within 50 miles of Grand Cayman, and a tropical storm passed directly over Grand Cayman every 12.5 years (Clark, 1988). The recent storms affecting the Cayman Islands (specifically Grand Cayman – weather station identifier: MWCR) are shown in Table 1.

Table 1. Major topical storms affecting the Cayman Islands in recent years

Date	Wind speed (mph)	Category[1]	CPOA[2] (miles)	Name
15-Sep-55	98	h2	15	Hilda
14-Aug-69	58	ts	43	Camille
19-Sep-75	40	ts	36	Eloise
07-Aug-80	155	h5	54	Allen
07-May-81	40	ts	36	Arlene
05-Nov-81	86	h1	17	Katrina
13-Sep-88	144	h4	23	Gilbert
19-Sep-02	69	ts	52	Isidore
12-Aug-04	92	h1	32	Charley
12-Sep-04	155	h5	28	Ivan

Notes: [1] ts = tropical storm, h = hurricane, numbers refer to Saffir-Simpson scale

[2] Closest point of approach to weather station (in miles)

Source: http://stormcarib.com/climatology/MWCR_all_isl.htm, accessed May 31st, 2006

Little information exists to show the impacts of these storms on the Cayman Islands. Reporting has historically focussed on deaths and community coping mechanisms, such as 'The 32 Storm' a compilation of recollections of the 1932 storm which killed 67 people and damaged many homes (McLaughlin 1994), or more recently on the very short term economic impact of Hurricane Ivan on the Cayman Islands (ECLAC 2005). There is very little documentation of the effects of past storms, of the changing response to storms by different groups in the Cayman Islands, or of the long term economic effects of the storms on the islands.

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Changing economic losses from weather-related disasters in recent decades

Following Wisner at al (2004) I start with the premise that hazards, in this case tropical storms, do not automatically lead to disasters. Disasters, and the costs associated with damage from them, occur when a vulnerable community is affected by the hazard. A tropical storm that does not make landfall does not generally create large economic losses. As Pielke and Landsea (1998) argue, societal factors such as increasing population density in hazard-prone areas and increasing wealth have increased the economic losses associated with tropical storms. This paper explores in more detail the societal factors that have increased and decreased the ability of the Cayman Islands to respond to tropical storms over recent decades. The focus is on changes in some aspects of society, the economy and government and their influence on vulnerability.

The IPCC (2001) note that vulnerability is influenced by three elements: the character, magnitude and rate of climate variation to which a system is exposed; the sensitivity of the system to the exposure; and the adaptive capacity of the system. Empirical evidence suggests that exposure to hazards comprises only a small part of vulnerability and that socio-economic factors that reduce community resilience are more important elements in increasing vulnerability (Adger and Brooks, 2003; Few, 2003; Jessamy and Turner, 2003; Pelling, 1997). Clearly the issue of how best to manage socio-economic drivers of vulnerability is an important element in planning for hazards and reducing economic losses. The relationship between vulnerability and economic losses from storms is not proven in this paper, it is assumed to be proportional, i.e. as vulnerability increases, so do economic losses generated from hazards. The causes of the changing vulnerability in the Cayman Islands are discussed below.

Economic factors influencing vulnerability

As a result of various government initiatives in the 1960s (specifically innovative taxation and banking laws) coupled with an investment in tourism infrastructure, the Cayman Islands have experienced a booming economy since the 1970s (Johnson 2001). Data from the Cayman Islands Government Compendium of Statistics (2000) reveal that domestic electricity consumption (in megawatt hours) which is a useful proxy for income and also levels of consumption of white goods, rose over a 25 year period, at an average rate of 7% per annum, from 1.95 Mwhrs per person in 1975, to 9.23Mwhrs per person in 2000. Imports of goods rose at an average rate of 13% from CI$12.5mn in 1972 to CI$558.7mn in 2000 (in current prices), see Figure 1.

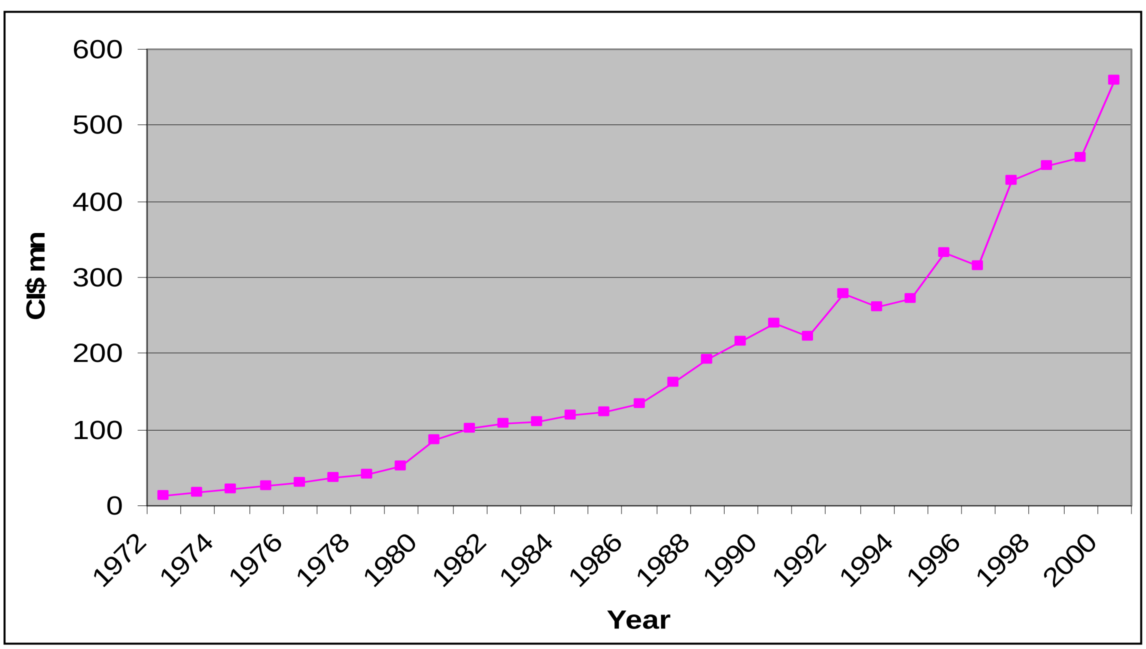

Figure 1. Cayman Islands Imports (cif), in CI$ mn 1972 - 2000
Source: Government of the Cayman Islands (2000)

Even when adjusted for inflation, per capita imports reveal an upward trend, see Figure 2, suggesting that since the 1970's Caymanians have increased their consumption of imported goods, which account for almost all consumption locally. This suggests that that there has been an increase in the financial wealth of the country.

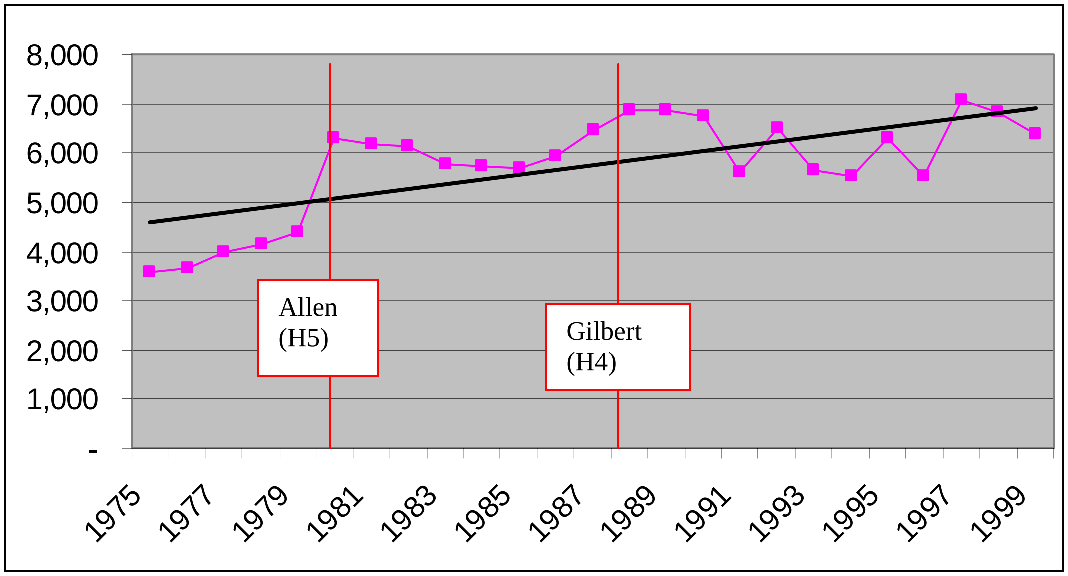

Figure 2. Inflation adjusted per capita imports (CI$ 1984 prices)

While energy consumption, imports, car registrations, value of land transfers and other indicators of wealth rose, so too did the number of businesses selling to the tourism and banking sectors. Figure 3 shows the number of tourism related businesses in operation from 1975 to 2004.

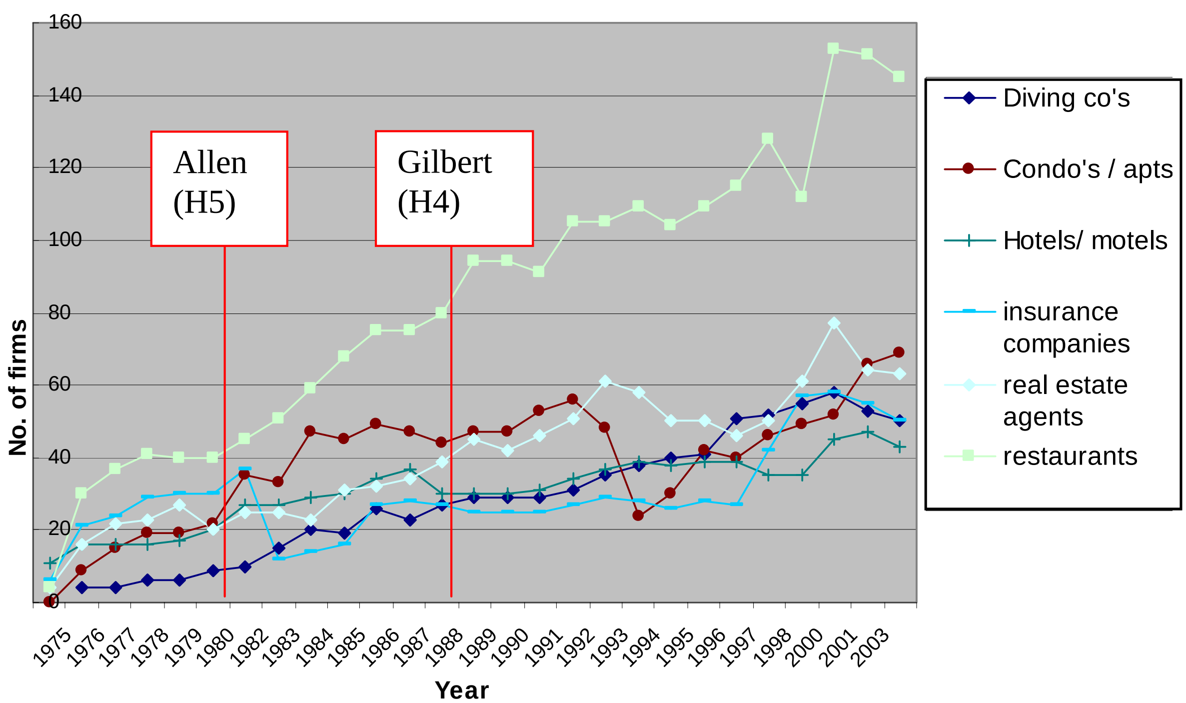

Figure 3. Numbers of firms by sector, in the Cayman Islands 1975-2003

Source: Cable and Wireless telephone directories for the Cayman Islands from 1966 - 2004[2]

[2] There are many problems with these data, hence this figure can only be considered illustrative.

Despite some slowdowns, the main direction of the Cayman Islands economy for the past 40 years has been upwards. It can be assumed from work by Pielke and others that this increase in wealth has increased the vulnerability of the islands to economic losses from storm damage.

Government factors influencing vulnerability

Since the 1970s the Cayman Islands' Government has made significant investments in hurricane preparedness through increased awareness, improved communication, better use of plans and thorough testing of drills, plans and preparedness skills. For a detailed description of the changes that have occurred in the Cayman Islands see Tompkins (2005).

The investment of resources by the government in national hurricane preparedness planning has shown some signs of reducing the sensitivity of the government to hurricane impacts. A government engineer interviewed in Tompkins (2005) reports that:

> "In 1988 prior to Gilbert we did our first Hurricane Preparedness Exercise. We were disorganised because it was our first attempt. It took us 16 hours to get 70% of the hurricane shutters onto the government buildings complete. Even so this exercise helped us when Gilbert hit. Even though we weren't as effective as we are now, we were better prepared than we were before we did the preparedness exercise. Since then we have held an exercise every year. We can now protect all Government buildings in 6 hours. The Andrew's, Gilbert's, Michelle's and Mitch's have helped to keep us focussed and prepared".

This shift in behaviour and increase in preparedness by the Cayman Islands' Government appears due to the emergence of group action, led by a champion, supporting changes in legislation[3] and changes in the organisation and structure of the government institutions dealing with hazards[4]. Anticipatory national level planning for hurricanes appears to have increased the effectiveness of the government response, thereby reducing damages from hurricane impacts. Similarly national prioritisation of hurricanes may have encouraged individuals in wider civil society to engage in preparedness and hence reduce the wider social impacts of hurricanes.

Social factors influencing vulnerability

There are social consequences associated with rapid economic growth. In the Cayman Islands, the growing economy has been supported by an influx of largely temporary migrant workers at all levels of society. The immigrant population rose from 15% of the population in 1975 to 47% by 2000. The majority of immigrants come from outside the Caribbean region have little or no experience of tropical storms Due to the low-lying nature of the islands the principal threats to the Cayman Islands from storms are wind, windborne debris and storm surge (Minor and Murphy 1999). Local rhymes, radio broadcasts and the flying of flags from government house are used to inform people about the threats from storms and the need to prepare. In the aftermath of Hurricane Ivan in 2004, it became very apparent that the traditional mechanisms for passing on knowledge about storms and storm preparedness missed this group and many were entirely unprepared for what happened.

The population more than doubled between 1980 and 2000 (when it reached 41,800). With this growth came the demand for more housing, and the expansion into low-lying areas, areas known to be vulnerable to storm surge and in areas covered by mangroves. This pattern of social expansion, leading to destruction of a protective environment (i.e. mangroves, sea grasses and coral reefs) is not unique to the Cayman Islands.

[3] An enhanced Building Code in 1995/6 and changes to the Development and Planning Regulations to increase waterfront set back in beach front areas in 2002.

[4] One: the evolution of the small Natural Resources Unit with 4 staff, to a formal Department of Environment with 26 staff, and a recognised role in the Ministry of Tourism, Environment, Development and Commerce. Two: the creation and mainstreaming of the National Hurricane Committee which coordinates the Cayman Islands' hurricane preparedness and response activities.

A further social factor that appears to be influencing social coping capacity is the uptake of insurance. The increasing uptake of insurance appears to be having two effects on behaviour in the Cayman Islands. The first is to stop self-protecting behaviour which might reduce the impacts (i.e. moral hazard), the second is to lead individuals to re-build houses in areas to be well known for experiencing significant storm damage, relying on the insurers to underwrite this risky behaviour. All of these factors are likely to increase the exposure of individuals to storm damage.

Implications of these societal factors for both research and policy

Changes in the economy, society and government clearly have affected the Cayman Islands ability to cope with hazards. Some of these changes have eroded ability to cope with hazards and others have enhanced it. Research and policy action in the following four areas may assist in our understanding of how and why some societies face lower levels of economic losses from hazards, when faced with the same population density and income levels, than others.

1. What is not known is the quantitative impact of societal factors on each other, or on general vulnerability to hazards. This leads to the question: can small changes in legislation or institutional preparedness offset the economic losses caused by increases in wealth? An interesting question for researchers would be to identify the degree to which these offsets can be made, if at all, or if increases in wealth in hazard-prone areas only ever lead to increases in economic losses from damage. Policy makers need to retain their focus on increasing preparedness of the government and enhancing ability to respond to hazards.
2. A second area of interest relates to information. Clearly some individuals expose themselves to higher levels of storm risk, either because of poverty, lack of information, lack of understanding of the information, or deliberate choice. To prevent this behaviour, very different policy initiatives are required to tackle each of the issues. The challenge for researchers and policy makers is to identify more specifically what is causing individuals to increase or reduce their exposure to hazards, and then to identify mechanisms to change their behaviour.
3. A third area of interest relates to knowledge transfer. Why do some societies and communities with high levels of exposure suffer different levels of economic losses? Are there generic lessons that can be transferred between communities, or even between nations, other than the importance of the disaster risk management approach?
4. Finally, how can the problem of moral hazard be managed? There are already different approaches to dealing with moral hazard in the UK, the US and Canada. Some universal lessons on best practice would be useful.

References

Adger, W.N. and Brooks, N., 2002. Does Global Environmental Change Cause Vulnerability to Disaster. In: Pelling, M. (Eds.), Natural Disaster and Development in a Globalising World. Routledge

Clark, R. R., 1988. Investigation of Erosion Conditions on the Seven Mile Beach, Grand Cayman. Florida Department of Natural Resources, Division of Beaches and Shores. Tallahassee, FL.

ECLAC (2005). The impact of hurricane Ivan in the Cayman Islands. Mexico City, ECLAC and UNDP: 82.

Few, R., 2003. Flooding, vulnerability and coping strategies: local response to a global threat. Progress in Development Studies 3, 43-58.

Government of the Cayman Islands (2000) Compendium of Statistics. Government of the Cayman Islands, Cayman Islands, BWI.

Jessamy, V.R. and Turner, R.K., 2003. Modelling community response and perception to natural hazards: lessons learnt from Hurricane Lenny 1999. CSERGE Working Paper EDM 03-06, 24.

Johnson, V., 2004. As I see it, a history of the financial sector in the Cayman Islands.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. (Eds.), 2001. Climate Change 2001: Impacts, Adaptation, Vulnerability. Contribution of Working Group II. Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA.

McLaughlin, H. R., Ed. (1994). The '32 Storm; eye-witness accounts and official reports of the worst natural disaster in the history of the Cayman Islands. Grand Cayman, Cayman Islands National Archive.

Minor, J.E. and Murphy, P., 1999. The Hurricane Risk for the Cayman Islands, British West Indies, APEC Consulting Engineers Ltd, George Town, Grand Cayman.

Pelling, M., 1999. The political ecology of flood hazard in urban Guyana. Geoforum 30, 249-261.

Pielke Jr., R.A. and Landsea, C.W., 1998. Normalized hurricane damages in the United States, 1925 - 1995. Weather and forecasting 13, 621-631.

Tompkins, E.L., 2005. Planning for climate change in small islands: Insights from national hurricane preparedness in the Cayman Islands. Global Environmental Change 15, 139-143.

Wisner, B., Blaikie, P., Cannon, T. and Davis, I., 2004. At Risk. Natural hazards, people's vulnerability and disasters. Routledge, London, pp 471.

Regional storm climate and related marine hazards in the NE Atlantic

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Storms represent a major environmental threat. They are associated with abundant rainfall and excessive wind force. Wind storms cause different types of damages on land and on sea; on land, houses and other constructions may be damaged; also trees may break in larger numbers in forests. In the sea, wind pushes water masses towards the coasts, where the water levels may become dangerously high, overwhelm coastal defense and inundate low-lying coastal areas; also the surface of the sea is affected – wind waves are created, which eventually transform into swell. Obviously, ocean waves represent a major threat for shipping, off-shore activities and coastal defense.

We review a number of questions related to windstorms in the North East Atlantic and Northern European region, namely

1. ***How to determine decadal and longer variations in the storm climate?*** The methodical problem is that many variables, which seem to be well suited for this purpose, are available only for a too short period or suffer from *inhomogeneities*, i.e., their trends are contaminated by signals related to the observation process (instrumentation, practice, or environment). From air pressure readings at a weather station and characteristics of water levels at a tide gauge useful indicators may be derived.
2. ***How has the storm climate developed in the last few decades and last few centuries?*** It turns out that an increase in storm activity over the considered region (NE Atlantic, N Europe) took place for a few decades since about the 1960s, which had replaced a downward trend since about 1900. When considering air pressure readings at two stations in Sweden since about 1800 no significant changes could be found.
3. ***How is storm climate variability linked to hemispheric temperature variations?*** Sometimes it is argued that a general warming would lead to an increase of water vapor in the atmosphere, thus a warming would provide more “fuel” for the formation of storms. This hypothesis is examined in the framework of a millennium simulation with a state-of-the-art climate model, which was run with reconstructed natural and anthropogenic forcing since 1000 bp, and extended until the year 2100 assuming scenarios for future greenhouse gas emissions. It turns out that during preindustrial and industrial times (i.e., until about the end of the 20century), the hypothesized link could not be detected, even if significant temperature fluctuations were simulated; only when greenhouse gas concentrations strongly increased, a parallel development of NE Atlantic storm intensity and hemispheric temperature emerged.
4. ***How did wind storm impact on storm surges and ocean waves develop in the past decades, and what may happen in the expected course of anthropogenic climate change?*** Regionally detailed reconstructions of surface winds since about 1960 have been used to run dynamical models of water levels, currents and ocean waves in the North Sea. Changes were found to be consistent with the changes of storm activity, namely a general increase since 1960 to the mid 1990s and thereafter a decline – apart of the Southern North Sea, where the upward trend is still going on. Scenarios prepared by a chain of assumed emissions, global and regional climate models point to a slightly more violent future of storminess, storm

surges and waves in the North Sea. For the end of the century an intensification of up to 10% is envisaged, mostly independently of the emission scenario used. When not only the change in windiness but also the enlarged volume of the ocean is considered, then, for extreme water levels, an increase of 20 cm in 2030 and of 50 cm in 2085 along the German Bight coast line are reasonable guesses for future conditions.

1. How to determine decadal and longer variations in the storm climate?

A major problem with determining changes in windiness represents the homogeneity, or more precisely the lack of homogeneity, of observed time series. The term "inhomogeneity" refers to the presence of contaminations in a data set, so that the meteorological data, which are supposed to describe the meteorological conditions and their changes over time, are actually a mix of the looked-after signal and a variety of factors reflecting changing environmental conditions, changing instruments and observation practices (Karl et al., 1993).

For instance, pressure readings usually depend not very much on the specifics of the location (apart of the height) and have been recorded over long periods of time with rather similar instruments, namely the mercury barometer. A rather different example represents wind measurements which depend very strongly on the details of the surrounding, in particular the exposition and obstacles. Also instruments and observation practices have changed frequently. This is in particular so with wind observations and wind estimates over sea.

Figure 1 displays a series of examples:

(a) shows the frequency of strong wind events in the city of Hamburg (Germany) per decade of years. Obviously a very strong decline took place from the 1940s to the 1950s – the explanation is that the instrument was moved from the harbor to the airport. This is a very obvious examples; the second example has been mistaken for evidence of a worsening storm climate in Northern Europe.

(b) displays the frequency of recorded stormy days (with wind speed ≥21 m/s) in Kullaberg (south-western Sweden; after Pruszak and Zawadzka (2005). Seemingly, in later years the number of such events was considerably more frequent than in earlier years. A closer inspection of the record reveals that a severe wind storm damaged the surrounding forest in 1969, so that the locally recorded winds became stronger after the wind break and the associated reduction of surface roughness. We will later see that proxies of storminess indicate no such change in that area.

(c) is an example with marine winds from the Pacific. There, the stationary weather station (ship) P is located that is taking quality controlled wind observations. From the COADS data set, many other wind reports are available from ship (of opportunity) observations originating from a series of grid boxes surrounding the position of the weather station. However, when the ship observations are averaged for each year, and compared to the quality controlled data form the ocean weather station, a discrepancy emerges – the ship data indicate an upward trend, while station P reports variable but by and large stationary conditions. Obviously, the COADS data are not homogeneous.

Thus, direct observations of wind are almost never helpful to assess changes in windiness for decades of years. As an alternative, a number of proxies representative for the strength of windiness or storminess in a season or a year have been suggested and tested. They are mainly based on pressure readings. Specifically spatial and temporal pressure differences are in use, but also the frequency of low pressure occurrences.

(a) Schmidt and von Storch (1993) have suggested the calculation of geostrophic winds form triangles of pressure readings; in this way, one (or possibly more) geostrophic wind-speed per day is obtained for given location. From the distribution of all numbers within one season, or a year, high percentiles are derived as proxies for storminess. Figure 2 shows a comparison of percentiles derived from geostrophic wind estimates and local wind observations for a few years in modern times, and a remarkably linear link is found – suggestive that any change in real wind percentiles would be reflected in changes of the geostrophic wind and vice versa (Kaas et al., 1996). Thus, time series of the geostrophic wind percentiles are considered as proxies of wind- and storm conditions change in the course of time (Schmidt and von Storch, 1993; Alexandersson et al., 19998, 2000). Typically used percentiles are 95% or 99%.

(b) An alternative proxy based on spatial differences of pressure readings is the annual frequency of days, when the geostrophic wind is larger than, say, 25 m/s.

(c) Two alternative proxies are based on local pressure observations, reflecting the experience that stormy weather is associated with low pressure and a fall of the barometer reading (Kaas et al., 1996). This proxy has the advantage that it is available for very long time at some locations (Bärring and von Storch, 2004).

(d) A totally different proxy is derived from short-term water variations at a tide gauge. Water levels at tide gauges are often changed by local water works but also by slow variations related to geological phenomena. Therefore, first the annual mean height tide is determined, and then the variations of the high tide relative to this mean high tide are considered (Pfizenmayer, 1997; von Storch and Reichardt, 1997).

With these proxies, an assessment of past storminess in Northern Europe is possible (see next chapter). The different indices are mostly consistent among, with the exception of the number of deep pressure readings as the following table of correlation coefficients demonstrates (95% and 99% stand for the 95%ile and the 99%ile of seasonal geostrophic wind; #F_{25} for the seasonal frequency of events with geostrophic winds stronger than 25 m/s, #$|\Delta_p|$ for the seasonal frequency of a pressure fall of 16 hPa within 24 hours, and #p<980 hPa for the frequency of barometer readings of less than 980 hPa)

correlations	**95%**	**#F_{25}**	**#$\|\Delta_p\|$**	**#p<980 hPa**
99%	0.75	0.90	0.38	0.08
95%		0.64	0.44	0.15
#F_{25}			0.35	0.07
#$\|\Delta_p\|$				0.35

For historical times, when barometers where not yet available, historical accounts help to assess wind conditions, for instance repair costs of Dikes in Holland during the 17th century (de Kraker, 1999) or sailing times of supply ships on pre-determined routes (e.g., Garcia et al., 2000).

2. How has the storm climate in the Northeast Atlantic developed in the last few decades and last few centuries?

Serious efforts to study changing storminess on the NE Atlantic began in the early 1990s, when meteorologists noticed a roughening of storm and wave conditions. Wave observations from light houses and ships (Hogben, 1994;

Cardone et al., 1990; Carter and Draper, 1988) described a roughening since the 1950s, and an analysis of deep pressure systems in operational weather maps indicated a steady increase of such lows since the 1930s (Schinke et al., 1992). Unfortunately, these analyses all suffered from the problems described above, namely either an insufficient length of data series or compromised homogeneity. For instance, the skill of describing weather details in weather maps has steadily improved in the course of time, because of more and better data reported to the weather services and improved analysis practices. For instance, for the case of global re-analysis the improvement related to the advent of satellite data on Southern Hemisphere analysis is described by Kistler et al.(2001). Another example on the effect of better data coverage is provided by Landsea et al. (2004) for an example of a tropical storm.

The breakthrough came when the proxies defined in the previous section were introduced, mostly in the EU project WASA (WASA, 1998). Alexandersson et al. (1998, 2000) assembled homogeneous series of air pressure readings from 1880 for a variety of locations covering most of Northern Europe. They calculated 99%iles of geostrophic winds from a number of station triangles. After some normalization and averaging they derived proxy time series for the greater Baltic Sea region and for the Greater North Sea region. The time series are shown in Figure 3. According to this proxy, the storm activity intensified indeed between 1960 and 1995[1], but from the beginning of the record until about1960 there was a long period of declining storminess, and since about 1995 the trend is in most areas of the NE Atlantic reversed (Weisse et al., 2005).

A similar result is obtained when analyzing the record of high water tides in Den Helder and Esbjerg, two harbours at the Dutch and Danish North Sea coast (Pfizenmayer, 1997). Figure 4 displays two statistics for each of the two tide gauges, the annual man high tide and the annual 99%iles of the deviations of the high tide form the annual mean. The former, the annual mean, is influenced by a number of non-storm related processes, in particular water works, geological changes (land sinking) and global man sea level rise. Both locations exhibit a marked increase in mean high tide, but the rate of increase is different at the two locations, which is likely related to different regional processes related to water works and costal defence measures. The two other curves in Figure 4 display the temporal development of the 99%iles (after subtraction of the annual mean); again, an increase is found for the period 1960 to the 1990s, which is, however, not significant when compared to the development prior to 1960.

The 1960-1995 increase in NE Atlantic storminess appears also as non-dramatic, when an even longer time window is considered, namely homogenized local air pressure readings at two locations in Sweden, Lund and Stockholm, which have been recorded since the early 1800s and earlier (Bärring and von Storch, 2004;). The number of deep pressure systems as well as the number of pressure falls of 16 hPa and more within 12 hours (not shown) is remarkably stationary since the beginning of the barometer measurements. This is remarkably in view of the marked increase in regional temperatures, e.g., the winter mean temperatures for Denmark.

3. How is storm climate variability linked to hemispheric temperature variations?

The link between decadal and centennial variations of mean temperature and storminess has hardly been studied because of the lack of sufficient data. However, climate models exposed to variable solar, volcanic and greenhouse gas forcing provide good data, to study such links. This was done by Fischer-Bruns et al. (2002, 2005), who counted for each model's grid box the annual frequency of gales in a simulation beginning in 1550 and extending to 2100 (using the IPCC A2 scenario for 2000-2100). They found no obvious link between hemispheric mean temperatures for historical times (not shown); only during the anthropogenic climate change in the 21st century a

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[1] Interestingly, in the early 1990s there were widespread claims in Northern Europe (e.g., Berz, 1993; Berz and Conrad, 1994) that there was a significant increase in storminess, which would be consistent with anthropogenic climate change. Following this logic, one would had to assume that the trend would continue into the future, and thus wind-related risks would increase and cause problems for the insurance industry.

parallel development of storminess and temperature is simulated, which is associated mainly with a spatial displacement of the storm track to the Northeast and not a major intensification.

The lack of a link of mean temperatures and the level of storminess during historical times is demonstrated by Figure 5, which shows the spatial pattern of the difference of temperature and of storm frequency (given as number of gales per year and grid box) during the Late Maunder Minimum (1675-1710) and the pre-industrial period of the simulation (1550-1850). The Late Maunder Minimum was a the coldest period of the Little Ice Age, at least in Europe, and the model simulation indicates that this cooling was of almost global extent, affecting all of the Northern Hemisphere. This period was, at least in the model, not associated with a reduced level of storminess in the North Atlantic or in the North Pacific.

Thus, neither the admittedly very limited empirical evidence discussed in the previous section nor the modelling study by Fischer-Bruns et al. (2002, 2005) support the hypothesis that a general warming would lead via increased availability of humidity to a roughened storm climate.

4. How did wind storm impact on storm surges and ocean waves develop in the past decades, and what may happen in the expected course of anthropogenic climate change?

Changes in storminess have a significant impact on a variety of socio-economic relevant activities and risks. An economic segment obviously sensitive to changes in the risk of wind- related damages is the insurance industry (Berz, 1993; Berz and Conrad, 1994)[2]. Other relevant aspects are related to ocean waves and storm surges, and their impact on off-shore activities, shipping, and coastal structures.

Using proxies, as described in the previous sections, indicates that a systematic roughening of storm-related risks has not happened in the past 200 years, or so. On the other hand, a worsening has taken place in the past 50 years, and data during that period are good enough to examine the changes of storm surge and ocean wave statistics.

The availability of good weather analyses – on the global basis for instance the NCEP re-analyses (Kalnay et al., 1996) and, for the European region, dynamical downscaling of this reanalysis (Feser et al. 2001) – allow a detailed analysis of changing ocean wave and storm surge conditions. To do so, 6-hourly (or even more frequent) wind- and air pressure analyses are used to run ocean wave (Günther et al., 1998; Sterl et al., 1998) and storm surge models (Flather et al., 1998b; Langenberg et al., 1999). In this way, homogeneous estimates of changes in the past 50, or so, years, can be constructed (Weisse and Plüß, 2005). Using the same models, also scenarios of expected climate change can be processed with respect to windstorms, ocean waves and storm surges (e.g., Flather et al., 1998a; Kauker, 1998; Debernard et al., 2003; Woth et al., 2005; Woth, 2005, Lowe and Gregory, 2001, 2005).

Along these lines, the „Feser“-analyses have been used to examine changes in patterns of storminess (Weisse et al., 2005). In most parts of the Northeast Atlantic, storminess – given as annual frequency of gales per grid box – increased until the early 1990s, south of about 50°N there was a decrease (Figure 6). This pattern reversed almost completely in the early 1990s apart of the southern North Sea, where the trend towards more storms continued, albeit somewhat decelerated towards the end of the period, at least until 2002 Accordingly, simulations of high tide statistics reveal an increase of water levels of a few mm/year, both in the seasonal mean as well as in the high levels relative to the mean (Weisse and Plüß, 2005, Aspelien, 2006), in particular along the German Bight coast line.

Furthermore, in the HIPOCAS project (Soares et al., 2002) statistics of ocean (surface) waves have been derived.

[2] One should, however, not accept an assertion of the insurance industry as an unbiased and objective description of the situation without careful analysis – overestimating the risks involved does in general not harm the economic interests of an insurance company.

Extreme wave heights have increased in the Southeastern North Sea within the period 1958-2002 by rate of up to 1.8 cm/yr while for much of the UK coast a decrease is found. The increase in the Southeastern North Sea, however, is not constant in time. The frequency of high wave events has increased until about 1985-1990 and remained almost constant since that time (Weisse and Guenther, in prep.). This development closely follows that of storm activity (Weisse et al. 2005).

Scenarios of future wind conditions have been derived by several groups. The most useful is possibly the set of simulations with the model of the Swedish Rossby Center, which features not only an atmospheric component but also lakes and a dynamical description of the Baltic Sea (Räisänen et al., 2004). This model was run with boundary conditions taken form two global climate models; also the effect of two different emission scenarios has been simulated. In these simulations, strong westerly wind events are intensified by less than 10% at the end of the 21st century (Woth, 2005).

These changes of wind speed will have an effect on both North Sea storm surges and wave conditions. For the storm surges along the North Sea coast line, an intensification is expected, which may amount to an increase of 30 cm, or so, to the end of the century (Figure 7a). To this wind-related change the mean level has to be added, so that for maximum values of 50 cm along the German Bight are plausible estimates for the increase of water levels during heavy storm surges. In the Elbe estuary, larger values up to 70 cm are derived. These numbers are associated with a wide range of uncertainty (± 50 cm) (Grossmann et al., 2006).

Scenarios of future wave conditions show large differences in the spatial patterns and the amplitude of the climate change signals. There is, however, agreement among models and scenarios that extreme wave heights may increase by up to 30 cm (7% of present values) in the Southeastern North Sea by 2085 (Weisse und Grabemann, in prep., Fig 7b).

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References

Alexandersson, H., T. Schmith, K. Iden and H. Tuomenvirta, 1998: Long-term trend variations of the storm climate over NW Europe. The Global Atmos. Oc. System 6, 97-120.

Alexandersson, H., T. Schmith, K. Iden and H. Tuomenvirta, 2000: Trends of storms in NW Europe derived from an updated pressure data set. Clim. Res. 14:71-73.

Aspelien, T., 2006: The use of long-term observations in combination with modelling and their effect on the estimation of the North Sea storm surge climate. PhD thesis, Hamburg, 106pp.

Bärring, L. and H. von Storch, 2004: Northern European storminess since about 1800. Geophys. Res. Letters 31, L20202, doi:10.1029/2004GL020441, 1-4.

Berz, G., 1993: Global Warming and the insurance industry. Interdisciplinary Science Review 18 (2), 120-125.

Berz, G. and K. Conrad, 1994: Stormy weather: The mounting windstorm risk and consequences for the insurance industry. Ecodecision 12, 65-68.

Cardone, V.J., Greenwood, J.G. and M.A. Cane, 1990: On trends in historical marine data. J. Climate 3, 113-127.

Carter, D.J.T. and L. Draper, 1988: Has the northeast Atlantic be come rougher? Nature 322: 494.

Debernard J, Sætra Ø, Røed LP, 2003: Future wind, wave and storm surge climate in the northern North Atlantic. CR 23:39-49.

De Kraker, A.M.J., 1999: A method to assess the impact of high tides, storms and storm surges as vital elements in climate history. The case of stormy weather and dikes in the Northern part of Flanders, 1488-1609. Climatic Change 43: 287-302.

Feser, F., R. Weisse and H. von Storch, 2001: Multidecadal atmospheric modelling for Europe yields multi-purpose data. EOS 82, 305+310.

Fischer-Bruns, I., U. Cubasch, H. von Storch, E. Zorita, J. F. Gonzáles-Rouco and J. Luterbacher, 2002: Modelling the Late Maunder Minimum with a 3-dimensional OAGCM, CLIVAR exchanges 7, 59-61.

Fischer-Bruns, I., H. von Storch, F. González-Rouco and E. Zorita, 2005: Modelling the variability of midlatitude storm activity on decadal to century time scales. Clim. Dyn. 25: 461-476, DOI 10.1007/s00382-005-0036-1.

Flather, R.A. and J.A. Smith, 1998a: First estimates of changes in extreme storm surge elevation due to doubling CO2. Global Atm. Oc. System, 6, 193-208.

Flather, R.A., J.A. Smith, J.D. Richards, C. Bell, and D.L. Blackman, 1998b: Direct estimates of extreme storm surge elevations from a 40 year numerical model simulation and from observations. Global Atm. Oc. System, 6, 165-176.

Gaslikova,L., 2006: High-resolution wave climate analysis in the Helgoland area. PhD thesis, U Hamburg, 102pp.

García, R., L. Gimeno, E. Hernández, R. Prieto and P. Ribera, 2000: Reconstruction of North Atlantic atmospheric circulation in the 16th, 17th and 18th centuries from historical sources. Clim. Res. 14, 147-151.

Grossmann, I., K. Woth and H. von Storch, 2006: Localization of global climate change: Storm surge scenarios for Hamburg in 2030 and 2085. submitted.

Günther, H., W. Rosenthal, M. Stawarz, Carretero, J.C., M. Gomez, I. Lozano, O. Serano and M. Reistad, 1998: The wave climate of the Northeast Atlantic over the period 1955-1994: The WASA wave hindcast. Global Atm. Oc. System,6, 121-163.

Hogben, N, 1994: Increases in wave heights over the North Atlantic: A review of the evidence and some implications for the naval architect. Trans. Roy. Inst. Naval Arch. W5, 93-101.

Kaas, E., T-S. Li, T. Schmith, 1996: Statistical hindcast of wind climatology in the North Atlantic and northwestern European region. Clim. Res., 7, pp 97-110.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne and D. Joseph, 1996: The NCEP/NCAR 40-Year Reanalysis Project. Bulletin of the American Meteorological Society, Vol. 77, No. 3, 437-471.

Karl, T.R., R.G. Quayle and P.Y. Groisman, 1993: Detecting climate variations and change: New challenges for observing and data management systems. J. Climate 6, 1481-1494.

Kauker, F., 1998: Regionalization of climate model results for the North Sea. PhD thesis University of Hamburg, 109 pp., GKSS 99/E/6.

Kistler, R., E. Kalnay, W. Collins, S. Saha, G. White, J. Woollen, M. Chelliah, W. Ebisuzaki, M. Kanamitsu, V. Kousky, H. van den Dool, R. Jenne and M. Fiorino, 2001: The NCEP/NCAR 50-year reanalysis. Bull Amer. Meteor. Soc. 82: 247-267.

Landsea, C. W., C. Anderson, N. Charles, G. Clark, J. Dunion, J. Fernandez-Partagas, P. Hungerford, C. Neumann, and M. Zimmer, 2004: The Atlantic hurricane database re-analysis project: Documentation for the1851-1910 alterations and additions to the HURDAT database. In: R. J. Murname and K.-B. Liu (eds): *Hurricanes and Typhoons: Past, Present and Future*, Eds., Columbia University Press, 177-221.

Langenberg, H., A. Pfizenmayer, H. von Storch and J. Sündermann, 1999: Storm related sea level variations along the North Sea coast: natural variability and anthropogenic change.- Cont. Shelf Res. 19: 821-842.

Lowe, J.A., and J.M. Gregory, 2005: The effects of climate change on storm surges around the United Kingdom. Phil. Trans. R. Soc. A 363: 1313-1328. DOI:10.1098/rsta.2005.1570.

Lowe, J.A., J.M. Gregory and R.A. Flather, 2001: Changes in the occurrence of storm surges in the United Kingdom under a future climate scenario using a dynamic storm surge model driven by the Hadley center climate models, *Clim. Dyn.*, 18: 197 – 188.

Pfizenmayer, A., 1997: Zusammenhang zwischen der niederfrequenten Variabilität in der grossräumigen atmosphärischen Zirkulation und den Extremwasserständen an der Nordseeküste. Diplomarbeit Institut für Geographie Universität Stuttgart

Pruszak, Z., and E. Zawadzka, 2005: Vulnerability of Poland's coast to sea level rise. Coastal Eng. J. 47, 131-155.

Räisänen, J., U. Hansson, A. Ullerstig, R. Döscher, L.P. Graham, C. Jones, H.E.M. Meier, P. Samuelsson and U. Willén, 2004: European climate in the late twenty-first century: regional simulations with two driving global models and two forcing scenarios. Clim. Dyn., 22, 13 – 31 ,doi 10.1007/s00382-003-0365-x.

Schinke, H., 1992: Zum Auftreten von Zyklonen mit niedrigen Kerndrücken im atlantisch-europäischen Raum von 1930 bis 1991. Wiss. Zeitschrift der Humboldt Universität zu Berlin, R. Mathematik/Naturwiss. 41, 17-28.

Schmidt, H. and H. von Storch, 1993: German Bight storms analyzed. - Nature 365, 791.

Soares, C.D., R. Weisse, J.C. Carretero and E. Alvarez, 2002: A 40 year hindcast of wind, sea level and waves in European waters. Proceedings of the 21st International Conference on Offshore Mechanics and Artic Engineering, Oslo, Norway, American Soc. of Mechanical Engineers, OMAE 2002-28604.

Sterl, A., G. Komen and P.D. Cotton, 1998: Fifteen years of global wave hindcasts using winds from the European Centre for Medium Range Weather reanalysis: Validating the reanalyzed winds and assessing the wave climate. J. Geophys Res. 103, C3, 5477 - 5492.

von Storch, H. and H. Reichardt 1997: A scenario of storm surge statistics for the German Bight at the expected time of doubled atmospheric carbon dioxide concentration. - J. Climate 10, 2653-2662.

Wang, X. L. and F.W. Zwiers, and V.R. Swail, 2004: North Atlantic Ocean wave climate change scenarios for the twenty-first century, J Climate 17, 2368-2383.

WASA, 1998: Changing waves and storms in the Northeast Atlantic? - Bull. Amer. Met. Soc. 79, 741-760.

Weisse, R. and A. Plüß, 2005: Storm related sea level variations along the North Sea Coast as simulated by a high-resolution model 1958-2002, Ocean Dynamics, DOI: 10.1007/s10236-005-0037-y.

Weisse, R., H. von Storch and F. Feser, 2005: Northeast Atlantic and North Sea storminess as simulated by a regional climate model 1958-2001 and comparison with observations. J. Climate 18, 465-479.

Woth, K., R. Weisse and H. von Storch, 2005: Dynamical modelling of North Sea storm surge extremes under climate change conditions - an ensemble study. Ocean Dyn. DOI 10.1007/s10236-005-0024-3.

Woth K., 2005: Projections of North Sea storm surge extremes in a warmer climate: How important are the RCM driving GCM and the chosen scenario? Geophys Res Lett: 32, L22708, doi: 10.1029/2005GL023762.

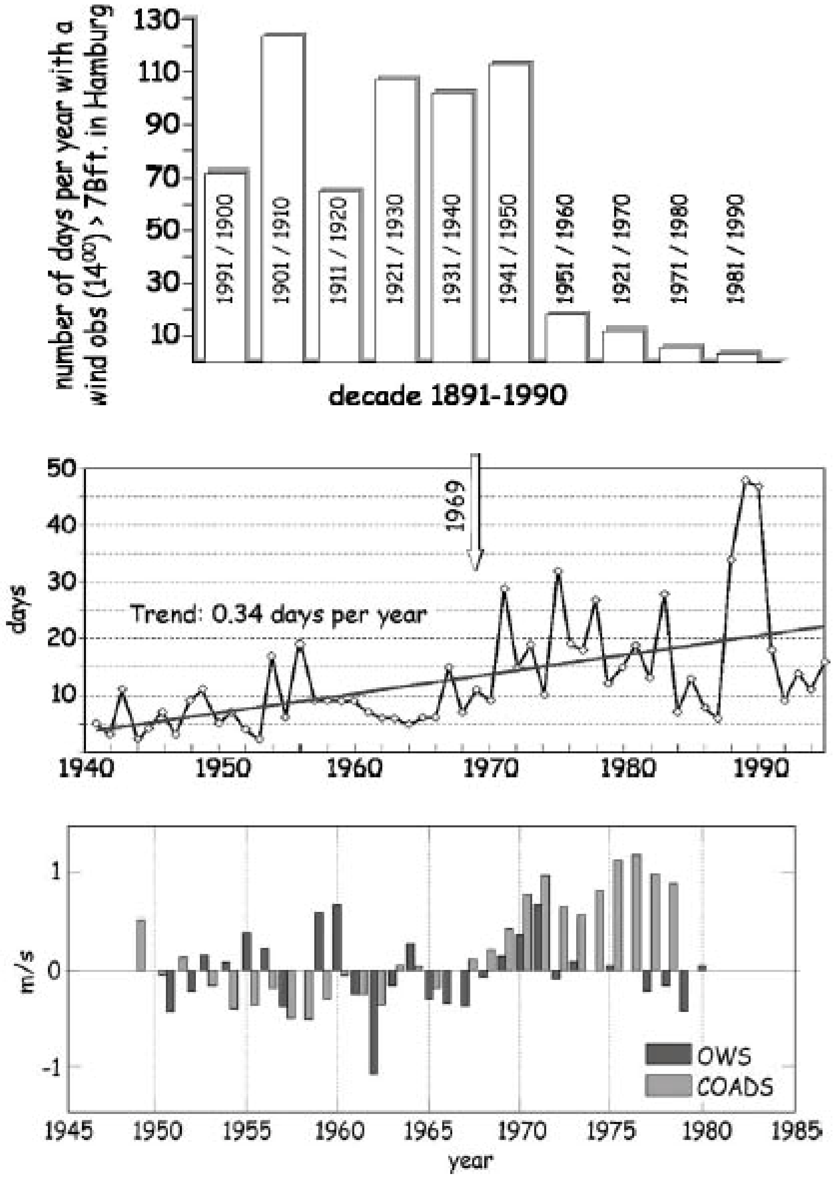

Fig. 1

(a) Reported number of days per years with wind speed of 7 Bft and more in Hamburg. In the early 1950s the observation was moved form the harbour to the airport. (After Schmidt, pers. communication).

(b) Time series of frequency of stormy days (days per year with wind speed ≥21 m/s) in Kullaberg (south-western Sweden), after Pruszak and Zawadzka (2005).

(c) Estimated changes in mean wind speed in the North Pacific in the area of ocean weather station OWS P. Data from the ocean weather station are marked as "OWS" (ocean weather ship), and those from the ships of opportunity in the vicinity of OWS as "COADS". (After Isemer, pers. communication)

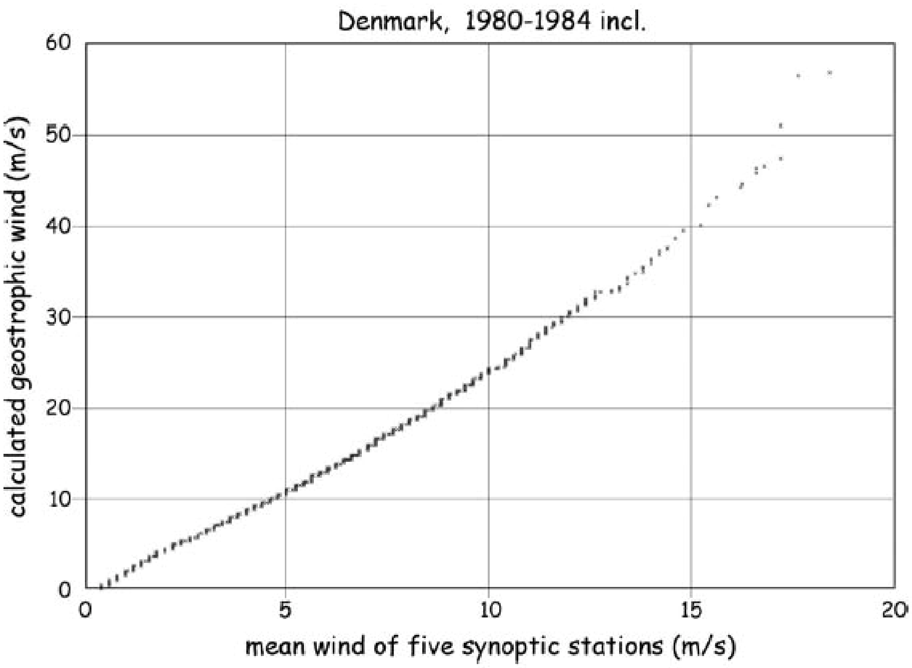

Fig. 2 Percentile-percentile plot of daily wind speed and geostrophic wind speeds at oen location derived form 5 years of data. (Kaas et al., 1996)

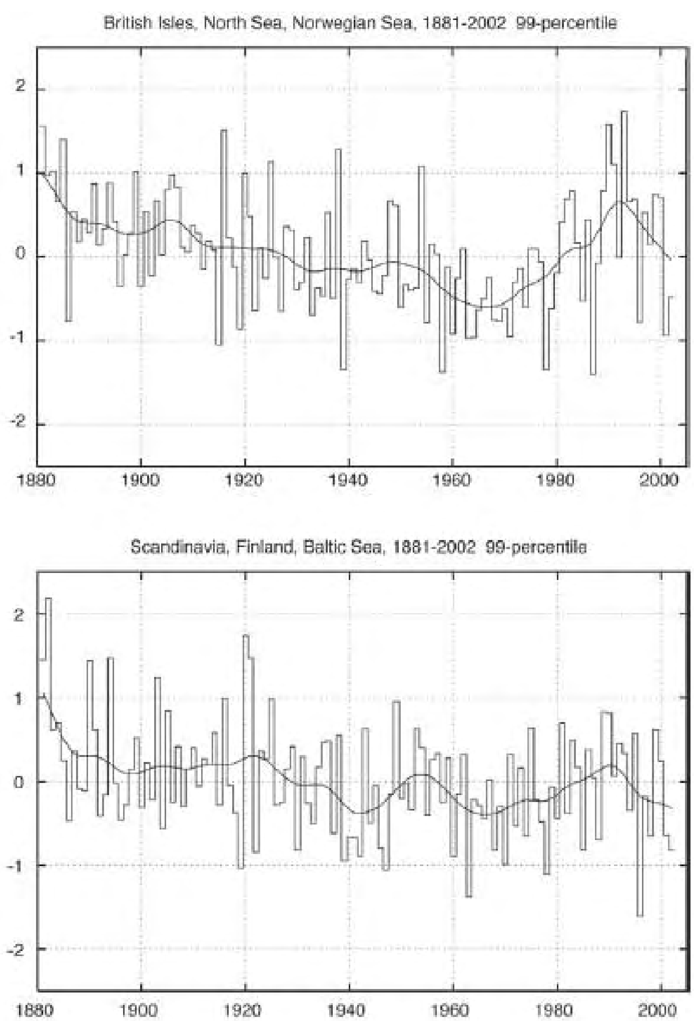

Fig. 3 Storm indicator derived from intra-annual percentiles of geostrophic winds derived form a series of triangles of stations for the greater North Sea (top) and the greater Baltic Sea region (bottom). Updated version of diagram provided by Alexandersson (2000).

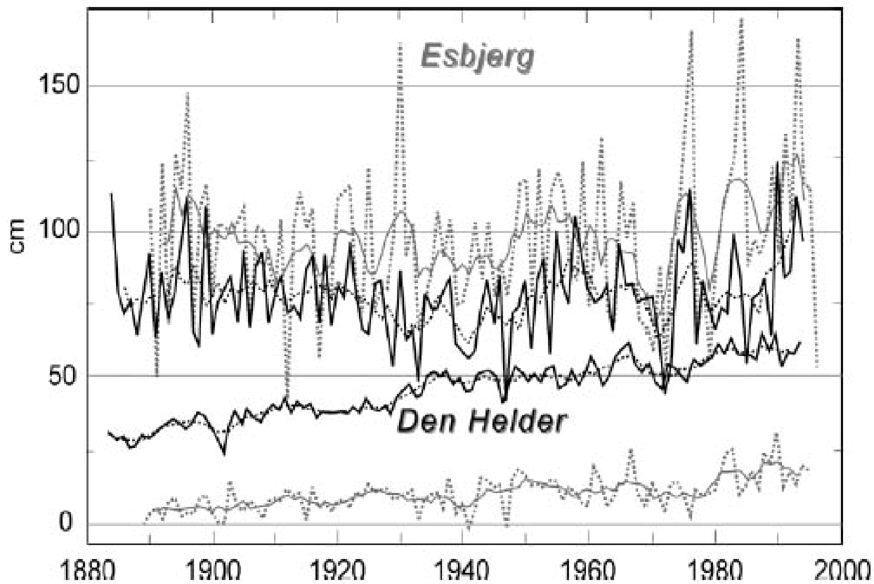

Fig. 4 Changing intraseasonal statistics of high tide water levels at Esbjerg (Denmark) and Den Helder (The Netherlands) since the late 19th century. The lower two curves display the seasonal means, and the upper two curves the 99%iles of intraseasonal variatons relative to the seasonal mean. The former reflect the presence of all kind of climatic as well as local effects, while the latter is a proxy for regional storm activity. After Pfizenmayer (1997).

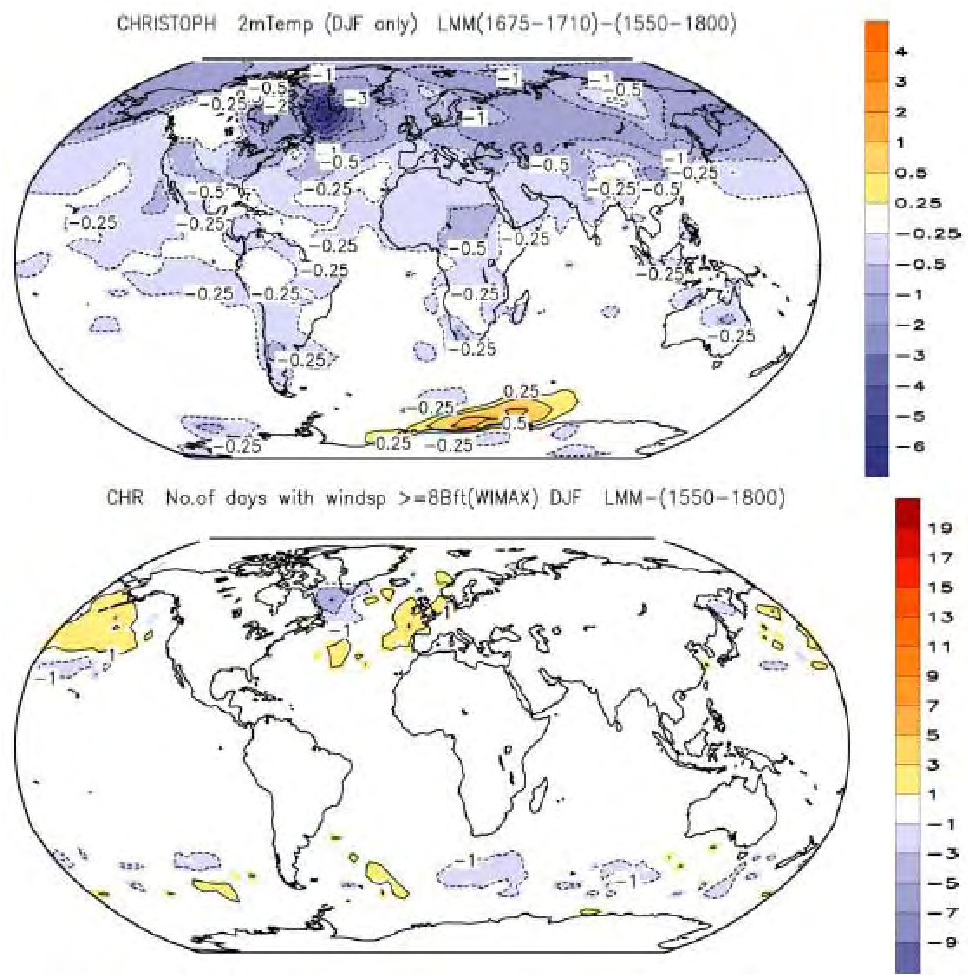

Fig. 5 Simulated differences in winter between the "Late Maunder Minimum" (LMM, 1675-1710) and the pre-industrial time (1550-1800) – in terms of air temperature (top, K) and in terms of number of gale days (wind speed 8 Bft and more). Note that the LMM is portrayed by the model as particularly cold, but the storm activity shows little changes. Courtesy: Irene Fischer-Bruns.

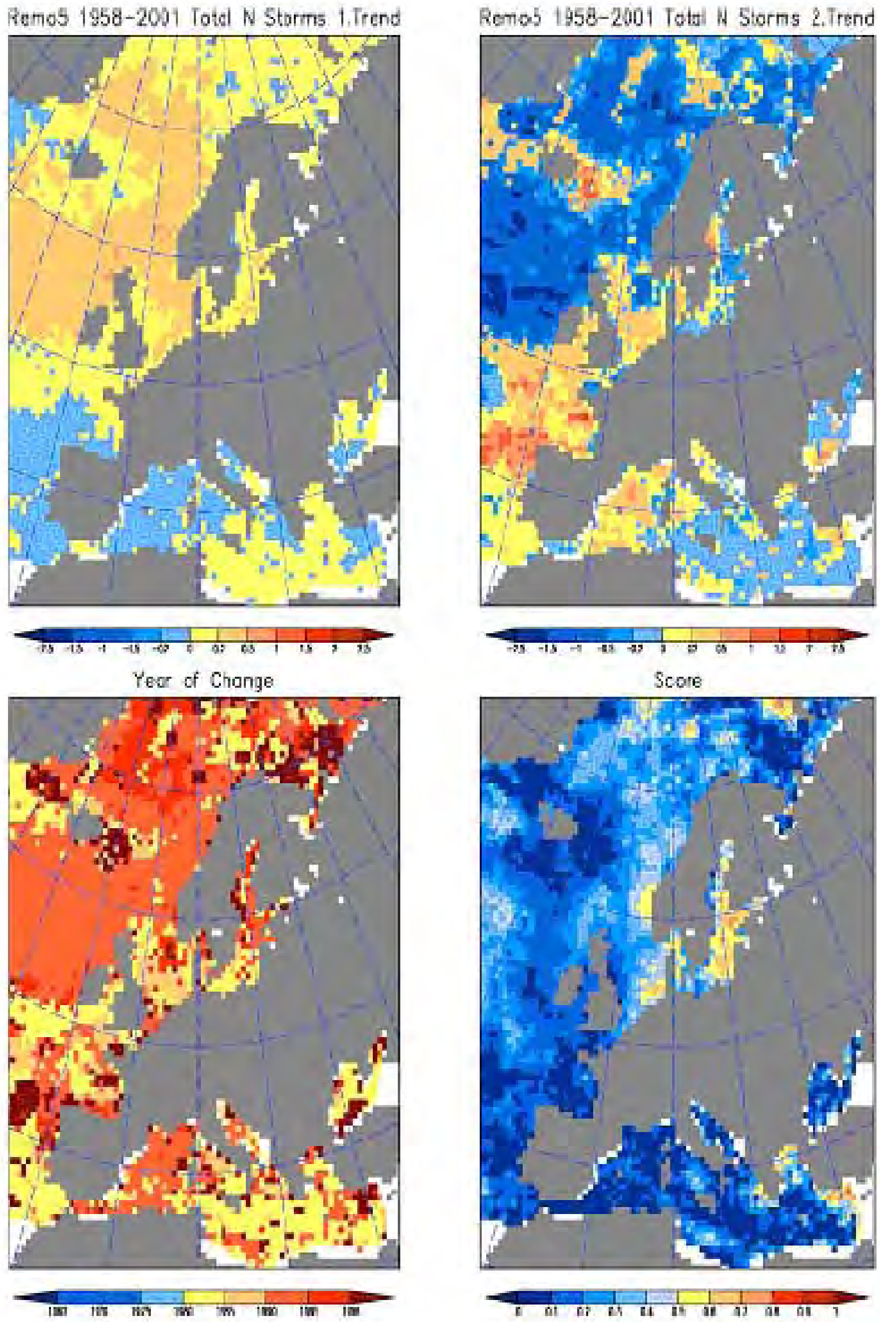

Fig. 6 Piecewise linear trends in the total number of storms per year with maximum wind speeds exceeding 17.2 m s1. (a) Linear trend for the 1958–T period; (b) linear trend for the T–2001 period. Units in both cases are number of storms per year. (c) Year T at which a change in trends is indicated by the statistical model. (d) Brier skill score of the bi-linear trend fitting the data as compared to using one trend. (Weisse et al., 2005)

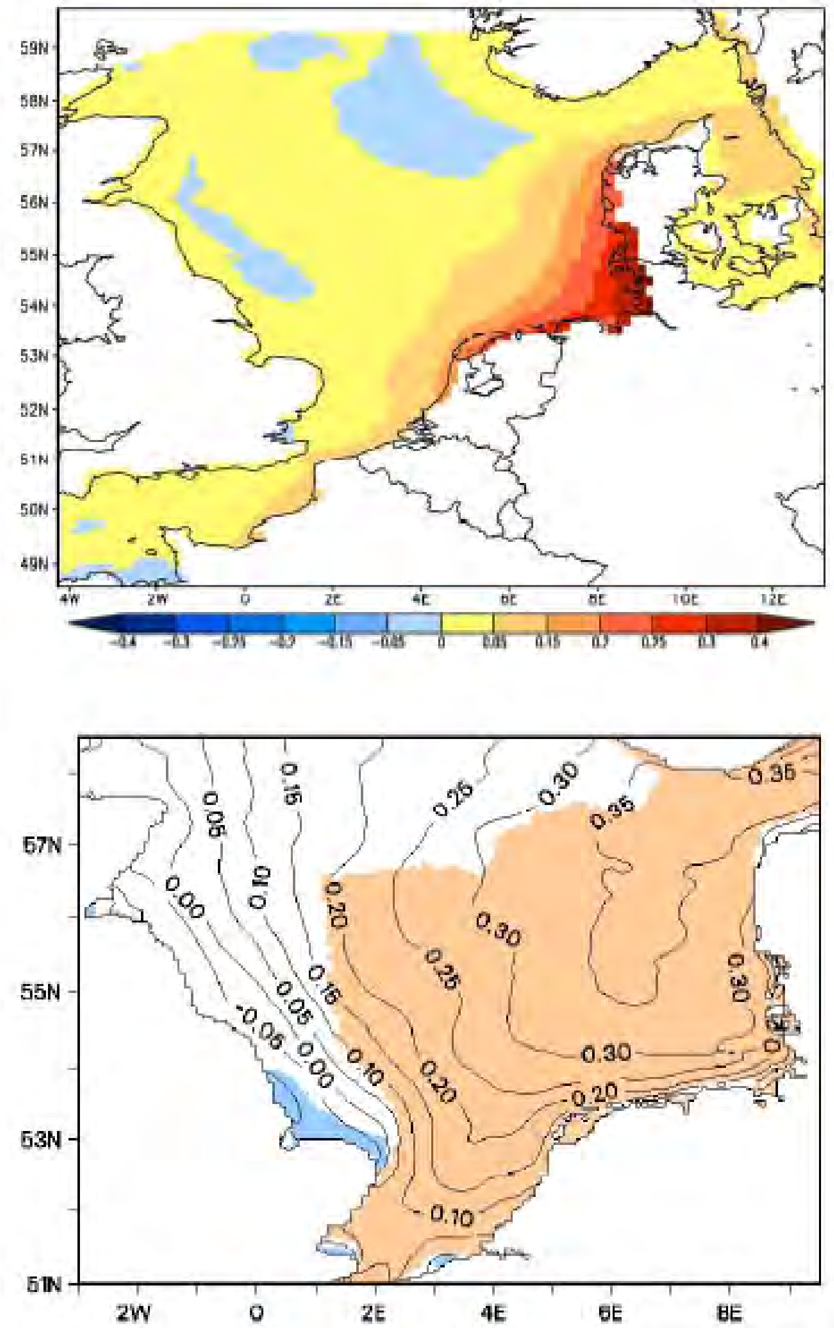

Fig. 7 Expected changes in wind-related storm surge heights (top; maximum averaged across many years, RCAO model) and ocean wave heights (bottom¸ change of 99-percentile; averaged across a series of simulations using different models and both emission scenarios A2 and B2. Shading indicates areas where signals from all models and scenarios have the same sign; red-positive, blue-negative.) in the North Sea at the end of the 21st century (emission scenario A2). Units: m. Courtesy Katja Woth and Iris Grabemann.

FACTOR ANALYSIS OF DISASTER LOSSES: CHINA CASE STUDY

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1. Introduction

As reported by the Ministry of Civil Affairs, China, the central government agency responsible for disaster management and mitigation (Jia, 2005) for the past 15 years, about 370 million people annually have been affected by various kinds of natural hazards, and thousands have lost their lives in China. Moreover, over the same period of time, about 4 million buildings and 500 million hectares of crops were destroyed, with direct economic losses of more than 120 billion US dollars each year on average (Figure 1). In the 1990s, disaster losses increased by 40% compared with the 1980s. Among all kinds of natural hazards that occurred, losses caused by floods, droughts and earthquakes were 80 to 90% of the losses, which was about 3 to 6% of GDP.

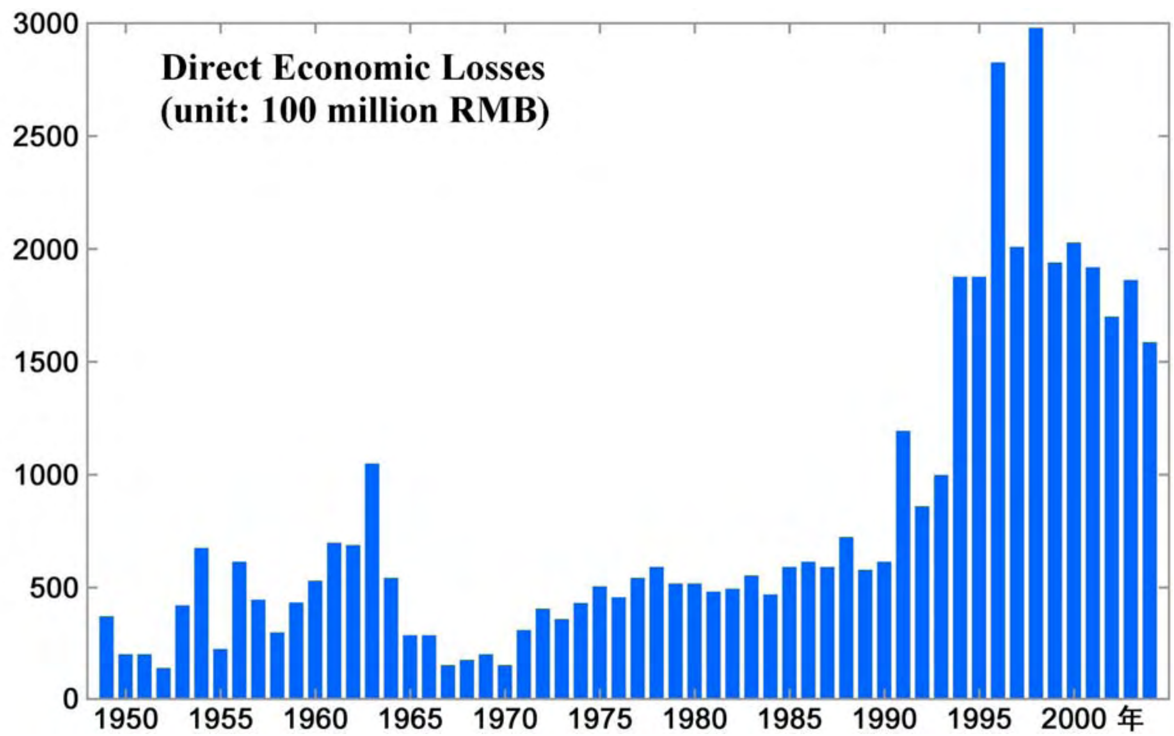

Figure 1. Direct Economic Losses Due to All Natural Hazards in China (Source: China National Disaster Research Group, 2000; China National Climate Center, 2005)

Floods and storms have been recognized as major hazards in China for more than 3,000 years, since agriculture always plays a dominant role in China's economy and society. For example, as historical records show, the Yellow river in northern China has flooded more than 1,500 times during the past 2,000 years and affected more than 250,000 square kilometers. Figures 2a, 2b, 2c and 2d show the time series of direct economic losses, populations affected, the area of affected crops, and the buildings that were destroyed by major floods and storms in China from 1990 to 2005.

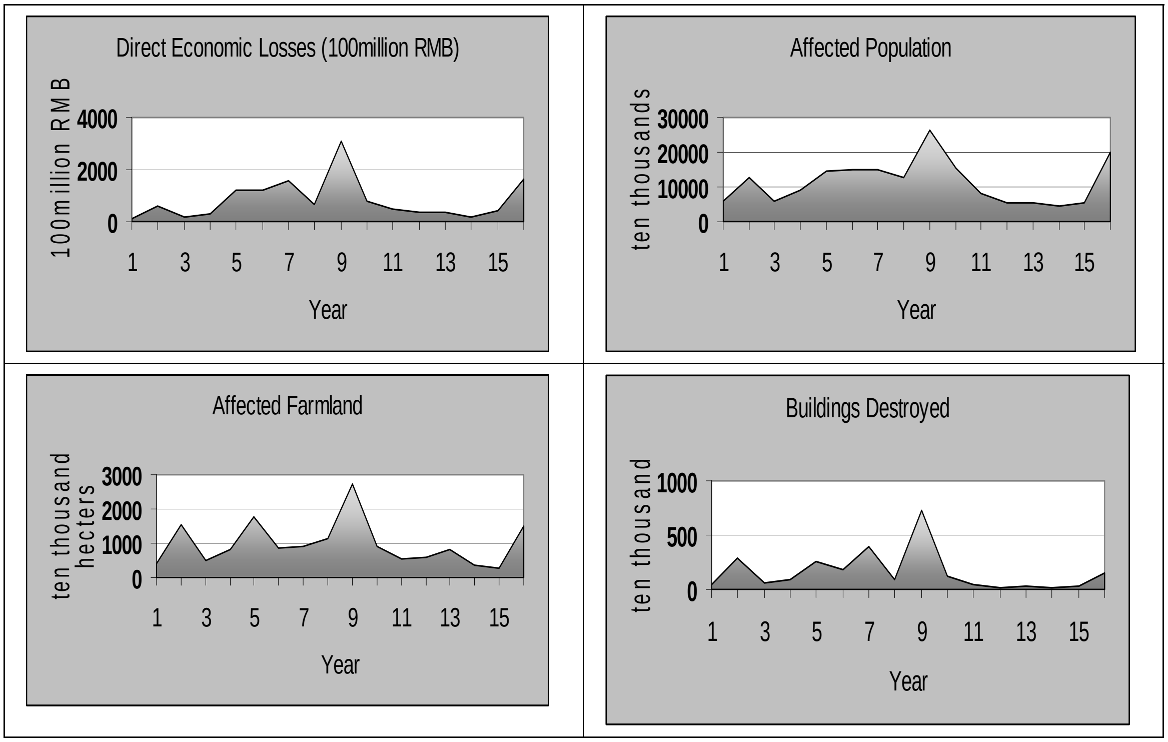

Figure 2. Time series of a) direct economic losses; b) affected population; c) affected farmland; d) number of buildings destroyed. (Source: Guo et al., 2005 and Ministry of Water Resources, 2006)

China's complex geological topography and various climatic conditions render the country extremely vulnerable to hydrological hazards, including floods and storms. In general, the topography of China can be divided into three distinct steps: from the high mountains in the west, to many hills and flat valleys in the middle of the country, and ending in fertile deltas and vast flat alluvial plains in the east (Figure 3a). Most major rivers which originate from the high mountains in the west flow eastward, accelerating from the first step to the second step. The water then suddenly slows down when it enters the third step before flowing into the ocean.

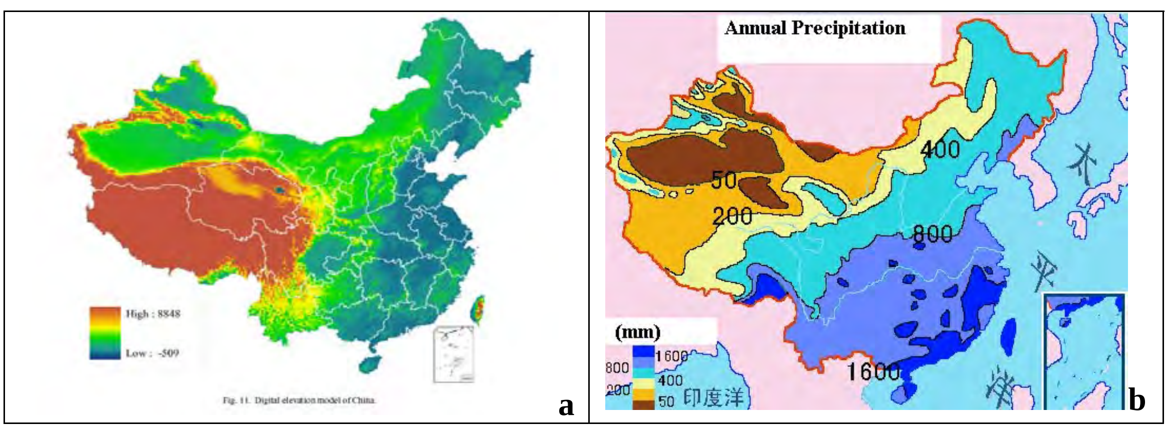

Figure 3 a) Topography of China; **b)** Annual Precipitation Distribution in China

Although China's territory covers many different climate zones defined as torrid, subtropical, warm-temperate and temperate, most portions of the east and middle regions in China are governed by the monsoon climate, which brings significant spatial and temporal variations in rainfall patterns which peak in summer and are concentrated along the Yangtze river basin (Figure 3b).

2. Factors causing increased losses due to floods and storms

China has had the largest population and the fastest economic growth rate in the world for the past twenty-five years. It is not surprising that the major factors related to increased losses caused by floods and storms, as in other developed and developing countries around the world, can be traced to the increase in both population and wealth, as pointed out by Pielke Jr. and Landsea (1998) and others (e.g., Loster, 1999).

a. Population Increase

The population of mainland China surpassed 1.3 billion on Jan. 6, 2005, according to China's National Statistics Bureau (NSB) (Xinhua News, 2005). The increase in population, as shown in Figure 4, is not evenly distributed around the country. Most of the increase has occurred in eastern China partly due to migration from rural to urban areas, which also has experienced the fastest economic development

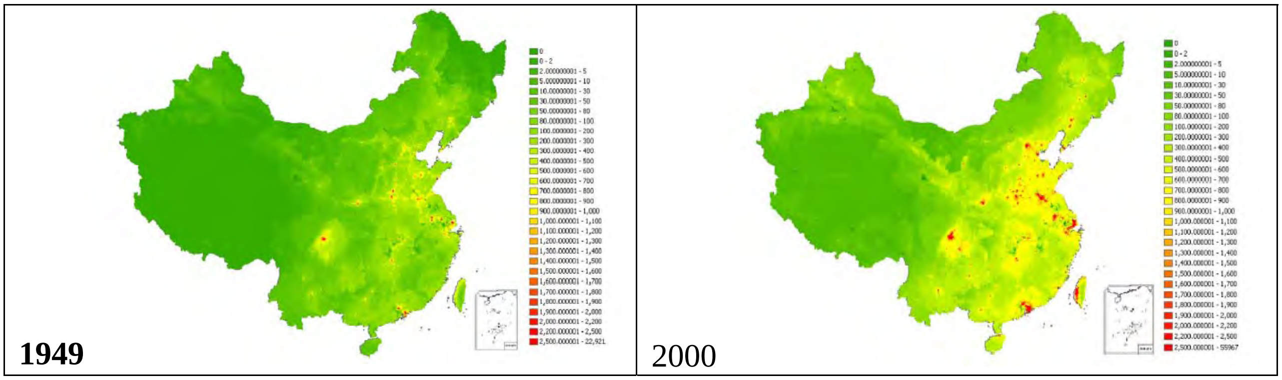

Figure 4. The population distribution of China in 1949 (left) and 2000 (right) in unit of persons per square kilometer. (Source: Tian et.al., 2004)

b. Wealth Increase

China has achieved remarkable progress in economic development since its reform and opening policy adapted in 1979. According to the statistics, the average growth rate of Chinese GDP was as high as 8.2% from 1979-2005 (National Statistic Bureau, 2005). China has become the world's fifth-largest economy in terms of GDP and has moved to the rank of a middle-income country, according to GDP per capita measures (exceeding $1,000 US dollars in 2003). It is a miracle that China has kept a high economic record for such a long time. With such high growth in the economy, the Chinese people have also become richer. For example, the number of wealthy people, each with more than $1 million US dollars in assets, has increased more than 12% every year (Merrylin Group, 2004). Meanwhile, a sizeable middle class is starting to emerge. The income increase in urban areas has kept a similar tempo with the growth of the national economy, with an increase in average employee salary of 16-33% in the past five years.

Although further studies need to be carried out in order to determine a reliable trend in China's flood and storm damage, based on a normalization of the damages that takes inflation into account, as well as changes in population and wealth, the increase of population and wealth obviously plays an important role in the increasing trend of losses. The other factors which have been considered in China, however, are highly dependent on the differing interests of numerous government agencies.

Factor 1: Weak Capacity in Hydrological Management (emphasized by Ministry of Water Resources)

For more than 50 years, China has built and reinforced over 270,000 km dikes of various standards, constructed more than 10,000 km of sea dikes, built 85,000 reservoirs of large, medium and small size with the total storage of 518.4 billion m3, and developed 97 flood detention and storage zones for major rivers, including the Yangtze river, Yellow river, Huai river and Hai river with a total area of 30,000 km2 and total volume of 107.8 billion m3.

However, not only most projects along the major rivers were constructed with only a standard of withstanding the worst flood that might be expected over a ten to twenty year period but also after many years of mismanagement and overuse, it is estimated that at least 40% of these hydrological engineering projects are presently in various degrees of malfunction. As pointed out by the Ministry of Water Resources,

> *"The changes of flood control situation in China are mainly indicated as (a) the decline of the flood carrying capacities in river courses and flood detention capacities in wetlands which caused the flood stages higher and higher at the same discharge; (b) Flood-protected areas rely more on dikes for their safety that aggravate hardships in flood fighting; (c) inundated areas caused by river outflows have decreased, but that caused by local rainstorms increased; (d) the densities of inhabitants and properties in flood prone areas increased sharply, which have aggrandized flood damages and emerged the scarcity of flood-protected level in urban areas; (e) casualties in flood plains decreased, but the rate of casualties caused by torrents and mud-rock flows in gullies and valleys, and storm surges along coastlands increased; (f) the conflicts among different regions during flood control operations aggravated and hardness in harmonizing enlarged; (g) the management and maintenance of the flood control engineering system becomes more important, and demands on information system and decision-support system increased, and so on." (Cheng Xiaotao, Ministry of Water Resources, 2005)*

Since more than 70% of total national fixed assets, 44% of the total population, one-third of the farmland, several hundred cities, and a huge number of heavy industrial facilities and infrastructures are downstream of many rivers, the potential for increased losses caused by floods and storms is very high without appropriate prevention and mitigation management plans.

Factor 2 Environmental Degradation (emphasized by National Environmental Protection Bureau)

During the past 25 years, with increasing economic development but protection of the natural environment lagging behind, 70% of the rivers in China are now polluted. The major pollution sources come from municipal and industrial waste water and overuse of pesticides in agriculture. For example, in 2004, among a total of 661 cities, only 55% of them have waste water processing facilities and among these facilities, the efficient treatment rate is only 45.7%. As a result, when even small-scale floods and storms occur, polluted water from upstream flows downstream and can cause considerable damage to the agriculture and tourism businesses, as well as short-term and long-term impacts on the health of human beings and ecosystems.

The areas of land degradation, which leads to soil erosion in many river basins, are also increasing. Currently, more than 37% of the total land surface in mainland China suffers various kinds of land degradation problems, of which about 50% is directly caused by floods and storms (National Environmental Protection Bureau, 2005). Moreover, with the national policy of speeding up urbanization, many wetlands and lakes which used to be buffer zones for floods have been transferred to industrial use or replaced by apartment buildings. For example, in Shanghai more than 25% of water surface has been lost due to urban development (People's Daily, 2003). As a result, in combination with increasing sediment deposition due to the soil erosion and land reclamation, many lakes and reservoirs have lost their capacities to hold floodwaters (Shankman and Liang, 2003).

Factor 3 Climate Change (emphasized by China Meteorological Administration)

Although northern China is still suffering from a long-lasting period of droughts starting in the 1980s, there is a trend toward in increase in annual precipitation in southern China, as shown in Figure 5 (Zhai and Wang, China National Climate Center, 2003). For the future, an increase of precipitation in China is also predicted by the IPCC based on different scenarios (IPCC, 2003). More precipitation in China usually means more floods and more frequent storms.

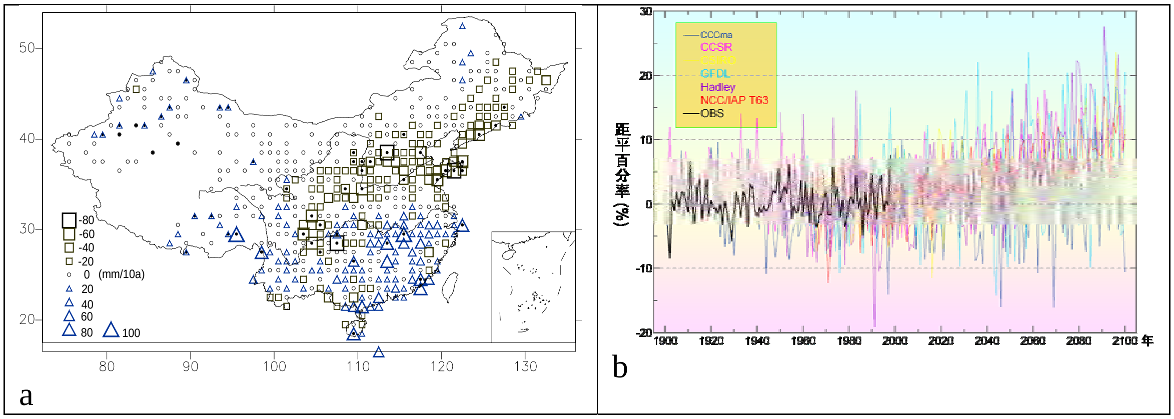

Figure 5. a) The trend of annual precipitation over China in the last 50 years (Zhai and Wang, China National Climate Center, 2003); **b)** IPCC prediction based on different scenarios (IPCC, 2003)

Factor 4 Political Game (stated by overseas scholars)

"A man who wishes to run the country well should give priority to flood control" is a saying handed down from generation to generation in the Chinese nation. Leaders, on the other hand, have often used flood disasters as an opportunity to show the people how powerful they are and to test how much control they can gain by moving resources around. As pointed out by overseas Chinese scholars, a large amount of the losses during the Great Yangtze River Floods in 1998 was mainly due to wrong decisions made by the leaders from the central government, who wanted to use the opportunity to test both the loyalty of the military and the strength of their power (Wang, 2005).

3. Implications for Research and Policy

For researchers:

First, many floods and storms should not only be categorized based on physical characteristics, such as wind speed and pressure as in the case of typhoons, but the social and economic impacts should also be considered. For example, in the Korean cases of Super-typhoons Rusa and Maemi, we found that "the significant differences in their physical characteristics led to different damages to the society" (Ye, 2005).

Second, a reliable, up-to-date monitoring, early warning and assessment system is needed. Again, in our Korea super-typhoon case study, it was found that the government agencies used either averaged data or out-of-date information when they dealt with these extreme events.

Third, since it is impossible for scientists to single out factors responsible for increases in flood and storm losses, future research on these issues should not only include the scientific community in different disciplines but also, and even more importantly, government decision makers, city managers, community organizations, planners, and insurance companies.

For policy makers:

First, as we discussed above, it is clear that different government agencies have their own needs and different working priorities when dealing with flood and storm disasters. Therefore, improving capacity of communication and sharing information among these government agencies is a must, at least in China's case.

Second, a third party, for example, insurance companies, should play an important role in government assessments when decisions on hydro-meteorological issues are being made, such as major river diversions and other mega-scale hydrological engineering projects.

Third, floods and storms are repeating natural events. Humans dealt with these natural hazards even before the dawn of civilization. Looking back into the history of other countries, one can easily find many similar lessons that have been learned and so many social, economic and political solutions that have been identified. The question is, as Glantz asked in his UN 16-country study on the impacts of El Nino, "Why are many of those solutions known by governments, researchers, and individuals learned but not yet applied?" (Glantz, 2001)

References:

Cheng, X.T., 2005: Changes of Flood Control Situation in China and Adjustments of Flood Management Strategies. *Water International*, Vol. 30, No. 1, P108-113.

Shankman, D. and Q.L., Liang, 2003: Landscape Changes and Increasing Flood Frequency in China's Poyang Lake Region. *Professional Geographer*, P 435- 445, Vol. 55. No. 4, 2003.

Glantz, M.H, 2001: Once burned, twice shy? – Lessons learned from the 1997-98 El Nino, United Nations University.

Jia, Z.B., 2005: Speech on the Asian Conference on Disaster Reduction Conference, Beijing, September 20-21, 2005.

Loster, T., 1999: Flood trends and global change. Conference on Global Change and Catastrophe Risk Management. IIASA.

Guangzhou 21st Century Business Herald, 2004: China has 236,000 "rich people". September 14, 2004.

People's Daily, 2003: Shanghai speeding up urbanization. May 8, 2003.

Pielke, Jr., R. A. and C. W. Landsea 1998: "Normalized Hurricane Damages in the United States: 1925-1995," *Weather and Forecasting*, 13: 621-631.

Tian, X.Y., et al., 2004: Surface modelling of human population distribution in China. *Ecological Modelling* 181 (2005) 461–478.

Wang, W.L., 2005: How to determine the severity of floods in China (in Chinese) http://www.observechina.net/info/artshow.asp?ID=35581.

Ye, Q., 2005: Typhoon Rusa and Super-Typhoon Maemi in Korea. (http://www.ccb.ucar.edu/superstorm/ss-korea-v1.pdf).

DISASTER'S IMPACT: UNDERSTANDING AND ATTRIBUTING TRENDS AND PROJECTIONS OF DAMAGE AND LOSSES. THE ECLAC PERSPECTIVE

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Are there lessons to be learned from the recent disasters at the global scale? Are the numbers of disasters increasing and is their impact more severe? Is there a difference to be established among hazard exposure and the resilience, fragility and brittleness of human-made vulnerabilities? How do countries and societies manage risk, transfer it or disperse it. ECLAC has observed an increase in disasters' costs in recent decades. Not only has the replacement value gone upwards, given the global increase in a number of inputs' prices and materials.

1. Factors account for the increased costs of disasters in recent decades according to the research to ECLAC's experience

On the basis or recent years' analysis of disasters in Latin America and the Caribbean, particularly the 2004 and 2005 hurricane seasons (in the Caribbean and in Mexico and Central America) and ECLAC's involvement in supporting the World Bank's damage and needs assessment in the Indian Ocean countries after the tsunami, some trends are discernible in this increase that bear stressing:

a) Demographic growth and the increased localization of human settlements near coastlines and river basins.

b) Faster growth in the number of disasters associated with hydrometeorological phenomena rather than derived from volcanic or seismic activity (the 2004 Indian Ocean tsunami being a very severe and very long return period phenomenon).

c) Increased sophistication and cost of infrastructure in vulnerable areas without appropriate risk reduction measures (for example increased agricultural production in floodplains and slopes without appropriate risk reduction techniques).

d) Increase environmental degradation leading to increased exposure with insufficient defense mechanisms and natural environmental barriers to mitigate the impact of natural phenomena (hydro or geomorphologic).

e) Climate variability cycles, larger variations of climate variables (rainfall, seasonal extremes, etc.), and climate change measured in such variables as seawater temperature, rainfall, drought and air temperature means as well as wind speed of extreme events are associated with impacts on non-adapted infrastructures.

f) Development of new sectoral activities –such as tourism—that are located in highly exposed areas (particularly in beaches and coastlines of islands and territories prone to recurrent phenomena such as cyclones, hurricanes and tropical storms).

g) Increased value added of economic activities that do not incorporate risk reduction financing as part of their financial, social and environmental viability and sustainability analysis.

h) Differentiated social and economic impact in terms of asset losses, income and livelihoods in rural and urban areas, primary (agriculture, commodities, extraction industries such as mining, etc.), secondary (industrial production, industrial processing, manufacture, etc.) and tertiary (services, such as transport, communications and telecom., tourism, financial sector, commerce and trade, e-commerce and information technology), as well as income strata, age groups and gender.

i) In spite of higher insured claims, in developing countries insured damage and losses are still a small percentage of total impact.

j) Globalization of information and improved assessment techniques also explain a more visible quantified impact and the inclusion of such previously non considered costs such as environmental, gender and cultural damage and losses.

There is a growing literature that covers research on possible scenarios of climate change in the next 10 to 50 years, which would have severe consequences on human life and human activity.[1] ECLAC has a cumulative experience in disaster's impact assessment that started in Central America in the mid nineteen seventies. Given the nature of the developing countries of Central America and the Caribbean: the hazards faced, the high levels of vulnerability, the extreme exposure associated with both their geographic location and patterns of production and levels of development, major catastrophes overwhelm their capacity to respond. The fact that disasters surpass their response mechanisms is particularly acute not only in the emergency and immediate response phase but mostly in their resilience and need for external resources to undertake their reconstruction processes. This latter consideration led to the affected countries' governments to request ECLAC –as an intergovernmental technical cooperation part of the United Nations—to assist them in assessing the damages, losses and needs generated by disasters in order to validate or support their request for international assistance. Since the first assessment in 1973 to the latter ones in 2005, ECLAC has developed a methodology to assess in a systematic way damages (as impacts on assets and capital) and losses (as impacts on flows in terms of income, expenditures and value added that reflects on economic variables) that has increasingly being recognised, now being a part of the PROVENTION and World Bank's toolkit.

In response to several countries and institutions both in the Latin American, Caribbean and Southeast Asian regions, ECLAC carried out in 2004 and 2005 such assessments. In 2004, in association with other national, regional and international institutions, comprehensive assessments in six countries (Bahamas, Cayman Islands, Dominican Republic, Grenada and Jamaica). In 2005 participated –at the request of the World Bank—in the assessment of the Indian Ocean Tsunami, and with regional and international institutions in Central America and the Caribbean floods in Guyana and the impacts of hurricanes Emily, Stan and Wilma over a number of countries –namely Guatemala, El Salvador and Mexico. Additionally the ECLAC's assessment methodology is becoming a tool to assess the impact of climate change and potential adaptation measures and policies. [2]

The partial figure of damage and losses –in terms of assets lost, destroyed or harmed and of economic flows interrupted, increased or altered due to the damage—reaches an amount of more than US$ 6,000 million dollars. If the reported damage in Cuba (US$ 1,500 million) and in the state of Florida due to the four hurricanes is combined, the figure climbs to US$ 37,600 million.

In summary, the cases analyzed by ECLAC this year show that 76% of the total impact was constituted by actual physical damage to assets (houses, businesses, roads and bridges, utilities, schools, hospitals and clinics, etc.), which imply losses in terms of flows of more that US$ 1,454 million.

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[1] The author is one of numerous researchers involved in the fourth IPCC assessment. For a possible scenario of climate change see http://www.ems.org/climate/pentagon_climate_change.html.

[2] These studies may be downloaded at: http://www.eclac.cl/mexico, under recent documents. They are the following:

- Bahamas, "Hurricanes Frances and Jeanne in 2004: Their Impact in The Commonwealth of the Bahamas" (LC/MEX/L.642/Rev.2, LC/CAR/L.23/Rev.2), 8 December 2004
- Cayman Islands, "The Impact of Hurricane Ivan in the Cayman Islands" (LC/MEX/L.645/Rev.1, LC/CAR/L.25/Rev.1) 8 December 2004
- Dominican Republic, "Los efectos socioeconómicos del huracán Jeanne en la República Dominicana" (LC/MEX/L.638), 3 November 2004
- Grenada : "Macro-Socio-Economic Assessment of the Damages Caused by Hurricane Ivan" (as part of a OECS led mission), September 7th, 2004
- Haiti : « Le cyclone Jeanne en Haïti: dégâts et effets sur les Départements du Nord-Ouest et de l'Artibonite : approfondissement de la vulnérabilité » (LC/MEX/L648, LC/CAR/L27), March 2005
- Jamaica: "Assessment of the socioeconomic and environmental impact of Hurricane Ivan on Jamaica" (LC/MEX/L.636, LC/CAR/L.22), 20 October 2004

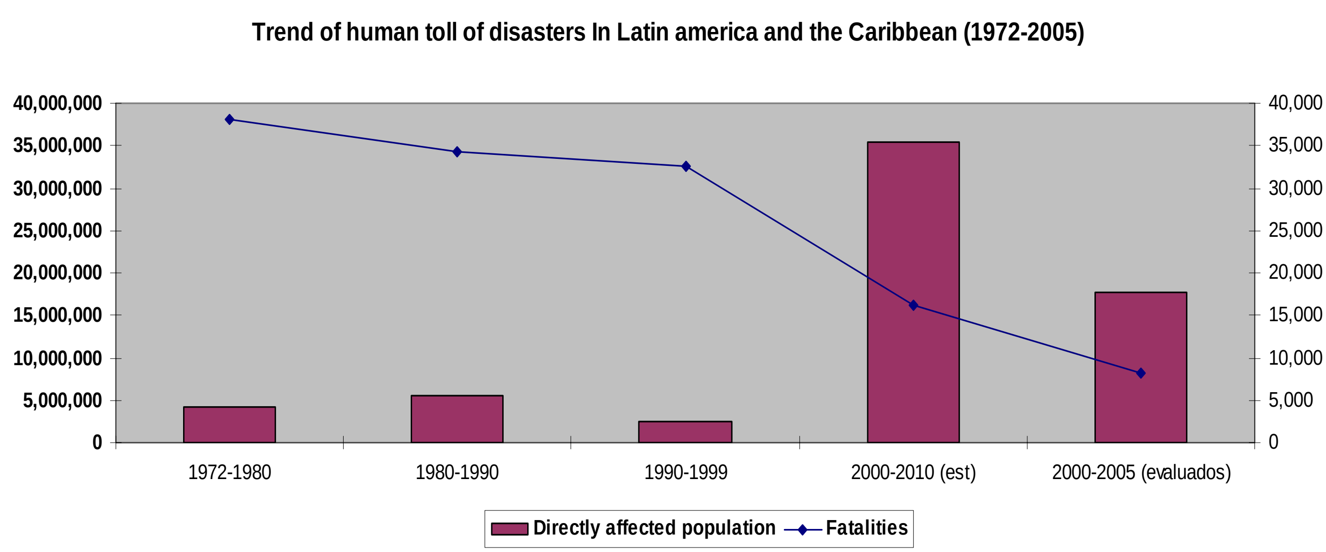
By sector, most of the damage affected the social sectors (47.5%) and productive activities (both goods and services, 35.2%, namely tourism). Damage and losses to infrastructure and utilities such as electricity, water and sanitation, and transport represent 15.6%, and the direct environmental impact, since most of natural resources are expected to recuperate, is 1.3%. This, nevertheless, does not imply that environmental action in terms of clean up, restoration and preservation of habitats and better environmental management is of lesser importance. In reality the amount of accountable damage pointedly signals that environmental assets and their services do not receive adequate valuation. The impact in terms of GDP is quite severe in most cases: 212% in Grenada and 138% in the Cayman Islands.

If the impact suffered by other territories and countries not appraised such as the Netherlands Antilles, parts of Mexico or the State of Florida, is added, damage would certainly exceed the total figure indicated of US$ 37,600 million, once the impact in the overall economic performance of these economies is taken into account. As pointed out and is well known, in the more developed territories and countries insurance coverage and national response capabilities will compensate for the losses in the short to medium term but will, nevertheless, mark this season as one where the issue of sustainability of the present patterns of physical and spatial settlements will have to be reassessed in order to prepare these territories to move from prevention of unexpected events to adaptation to ever increasing damage if no appropriate measures are taken.

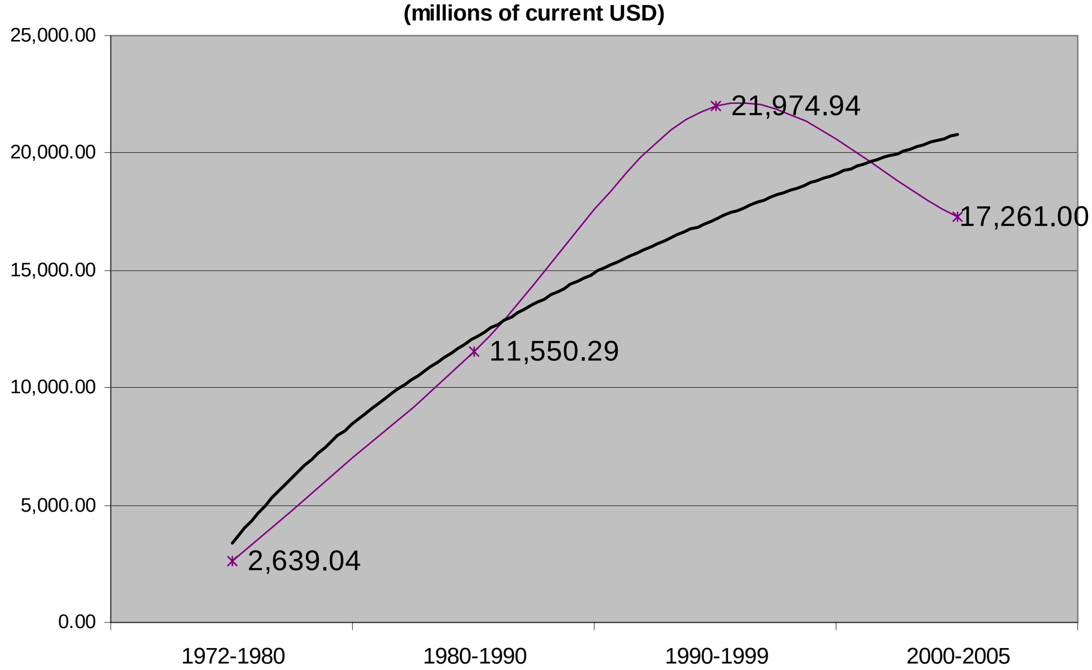
However, from a social point of view the most severe socioeconomic and human toll, was concentrated in the least developed, smaller countries affected, whose capability to rebuild and return to the path of growth and development is limited given the lack of appropriate insurance coverage, institutional response and preventive policies. This is particularly the case of Haiti and Grenada, but other economies with fragile environment and indebted or weakly performing economies were burdened by the severity of the events. In Grenada the total impact was estimated to be almost US$ 889 million, which is equivalent to more than twice (2.12 times) the current value of last year's GDP.

An additional relevant conclusion is that even though most damage occurs in the private sector, it falls on Governments to take care of and assist those segments of the population with lower income, which are highly dependent on basic agricultural or fishing activities that are affected. Productive activities rank high in the amount of damage and losses and in some cases the ensuing losses (economic flows affected) will persist for a long period of time, in some instance years. Infrastructure vulnerability is enhanced by poor environmental management and environmental degradation, leading to high productive risks and huge human suffering.

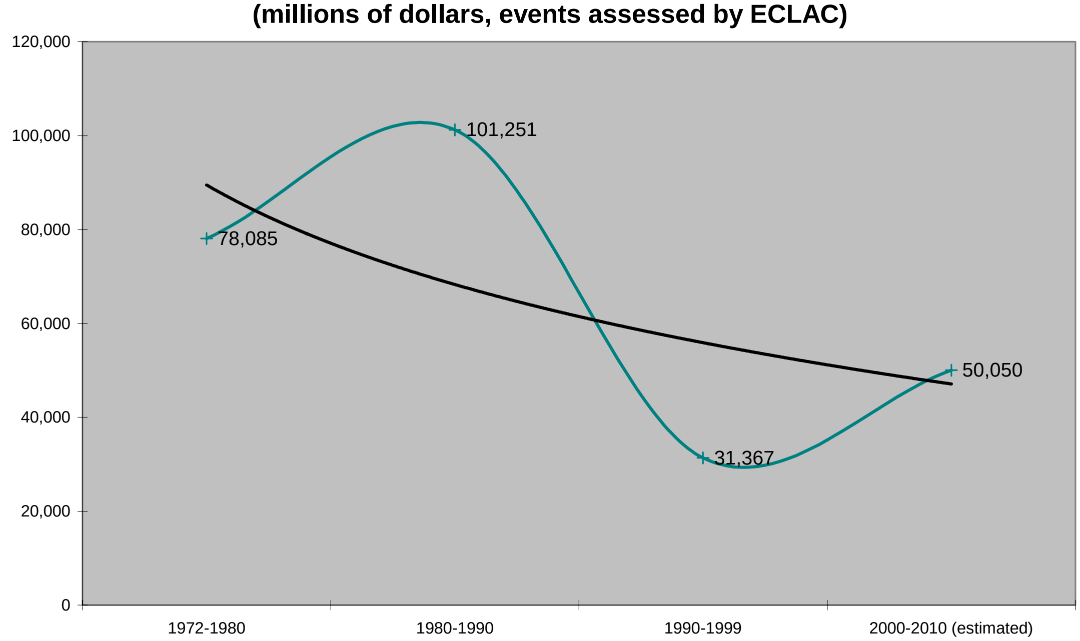
Some figures that come out of recent assessments done by ECLAC:



HISTORIC EVOLUTION OF DISASTER DAMAGE IN LATIN AMERICA AND THE CARIBBEAN (1972-2004) (millions of current USD)



Latin America and the Caribbean: Trend in major disasters impact, constant 2004 value (millions of dollars, events assessed by ECLAC)



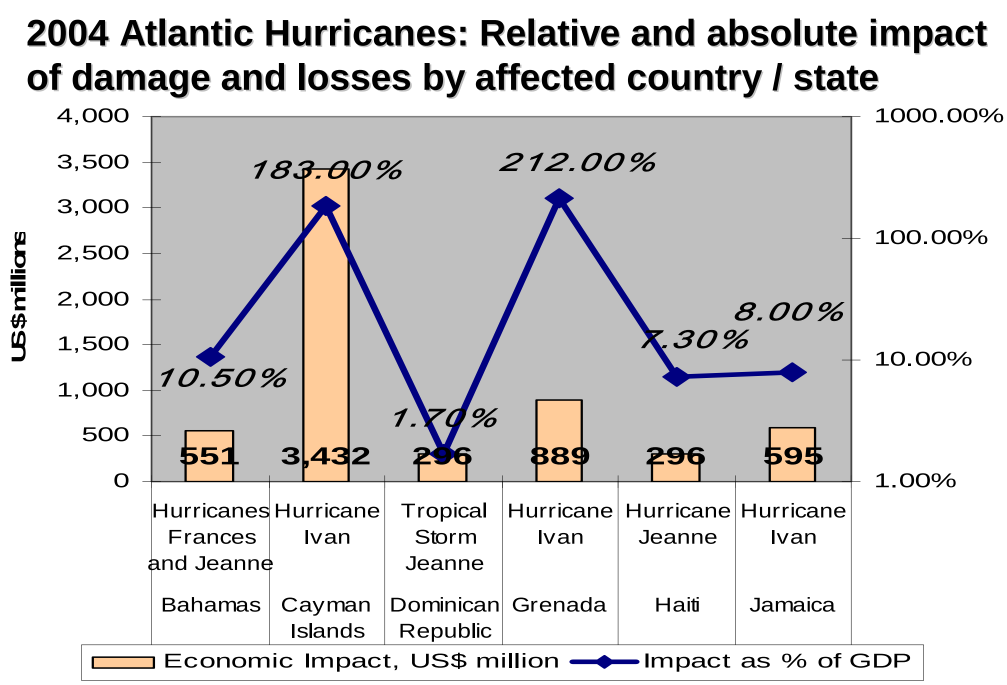
IMPACT OF DISASTERS IN LATIN AMERICA AND THE CARIBBEAN – 1972-2005 (based on ECLAC assessments)						
PERIOD	AFFECTED POPULATION		TOTAL IMPACT (CONSTANT 2004 VALUE)			
	Deaths	Directly affected population	TOTAL	DAMAGE (to assets)	LOSSES (in flows)	External impact
1972-2005	115,176	35,463,890	232,259.40	150,335.00	80,424.30	77,221.00
YEARLY AVERAGE (on the basis of ECLAC assessed disasters in Latin America and the Caribbean)	3,490	1,074,663	7,038.20	4,555.60	2,437.10	2,340.00

The Caribbean 2004 hurricane season exemplifies different experiences in terms of damage, losses and response that are relevant to the sustainability and capacity to mitigate and adapt to extreme events, even more so than the tsunami.

Economic impact of 2004 Hurricane Season (based on assessments made by ECLAC)

Island / State	Economic Impact, US$ million	Natural Event
Total of ECLAC assessed damage and losses	6,059	Ivan, Frances and Jeanne a/
Bahamas	551	Hurricanes Frances and Jeanne
Cayman Islands	3,432	Hurricane Ivan
Dominican Republic	296	Tropical Storm Jeanne
Grenada	889	Hurricane Ivan
Haiti	296	Hurricane JeannE
Jamaica	595	Hurricane Ivan
Florida	30,000	Jeanne, Charley and Frances
Cuba	1,500	Hurricanes Ivan and Charley
Total (including Cuba and Florida)	37,559	

Source: ECLAC



The 2004 and 2005 hurricane season further show that built vulnerability is not necessarily development related but more closely associated with inappropriate risk appropriation and valuation and with costlier infrastructure, more value added related infrastructure and negative externalities being not assumed by the industrial and commercial sectors. Additionally it shows that the government's assessment of risk and their preparedness to face its consequences and reduce risk is also not necessarily related to levels of industrialization.

2005 Atlantic Hurricane season			**Deaths**	**Directly affected population**	**Total impact (millions of USD)**	**Damage (to assets)**	**Losses (in flows)**
Date	**Location**	**Type of event**	**Population**		**Total impact (millions of USD)**		
January	Guyana	Flood due to intense rainfall in December/January period in coastal floodplains in Georgetown and Albion	34.0	274,774.0	465.1	418.3	46.8
October	Guatemala	Torrential rains, tropical storm Stan	1,583.0	474,821.0	988.3	421.1	567.2
October	El Salvador	Torrential rains, tropical storm Stan, and Ilamatepec (Santa Ana) volcano eruption	69.0	72,141.0	355.7	196.2	159.5
July-September	United States b/	Dennis, Katrina, Rita	1,698.0	900,000.0	200,000.0	65,000.0	135,000.0
July-September	Mexico b/	Emily, Stan, Wilma, etc.	98.0	2,942,119.0	4,642.0	2,098.0	2,543.0
		Emily	4.0	63,300.0	413.2	322.8	90.4
August	Cuba b/	Dennis	16.0	2,500,000.0	1,400.0	950.0	450.0
Other events a/			1,134.0	3,474,389.0	150.0	100.0	50.0
TOTAL	***Assessed by ECLAC***		***1,690.0***	***885,036.0***	***2,222.0***	***1,358.0***	***864.0***
TOTAL (not including United States)			***2,938.0***	***9,801,544.0***	***8,414.3***	***4,506.4***	***3,906.9***
TOTAL (IN CLUDING UNITED STATES)			**4,636.0**	**10,701,544.0**	**208,414.3**	**69,506.4**	**138,906.9**

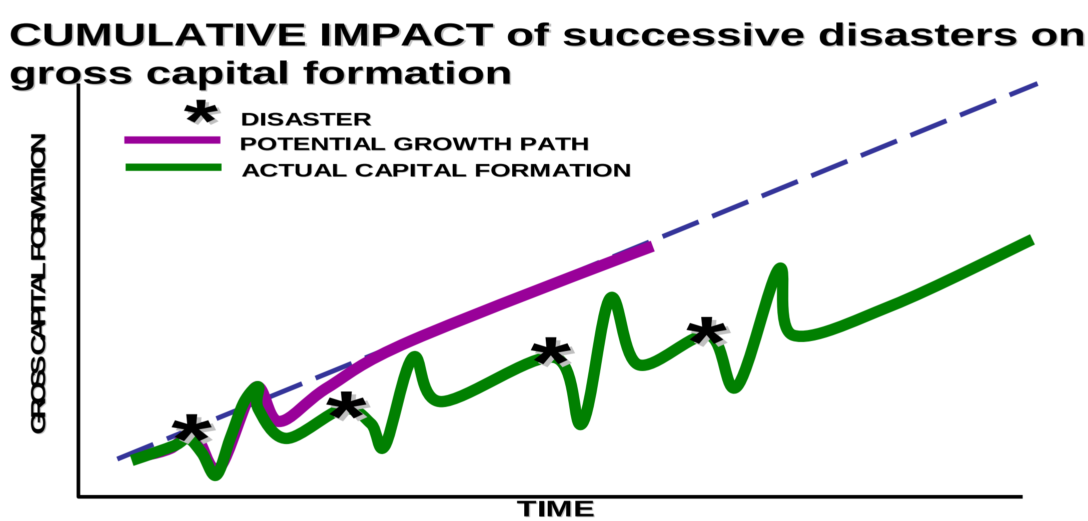
Just as accountability in public spending is linked to transparency, risk transfer must be linked to risk appropriation. It is still dramatically true that risk transfer tends to be made on false premises: instead of having a larger number of financial instruments of risk transfer, society tends to transfer its losses and disaster related damage to the state.

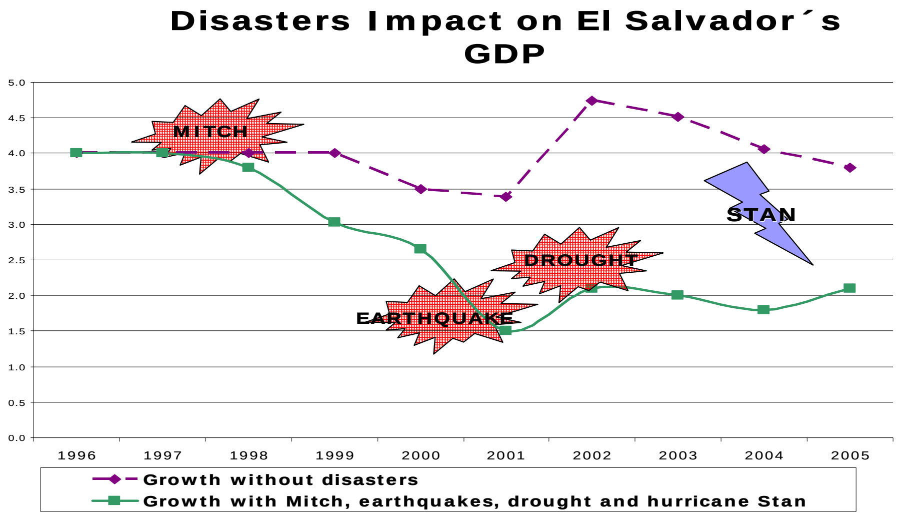
Some comments are also possible in the context of the type of disasters that are being faced and the type of damage they cause.

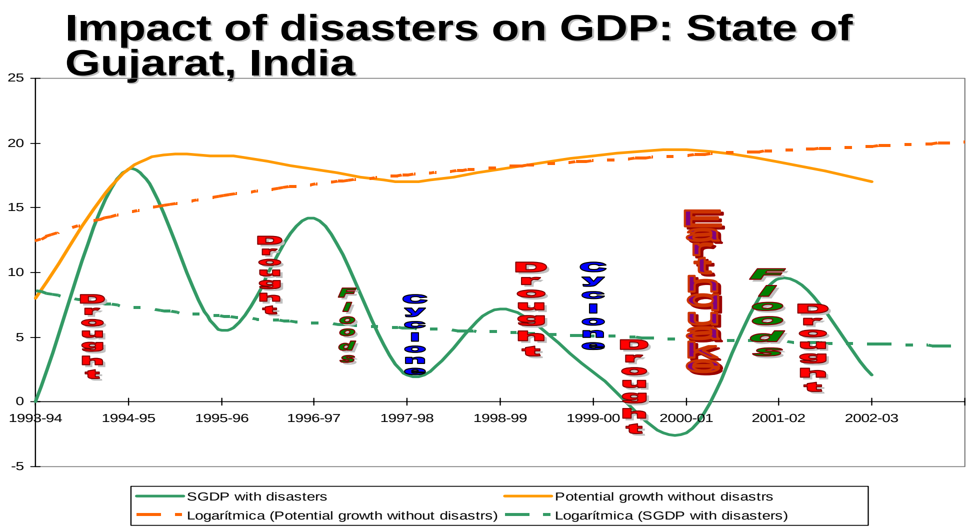
Geomorphologic events (seismic, volcanic, etc.) or non climate related have larger damage than losses –affect more severely infrastructure but cause relatively less losses than climatic ones. Nevertheless the number and impact of meteorological or climate related ones –including drought—seems to be growing, according to recently assessed disasters. The table summarizes the composition of disasters assessed by ECLAC over the years.

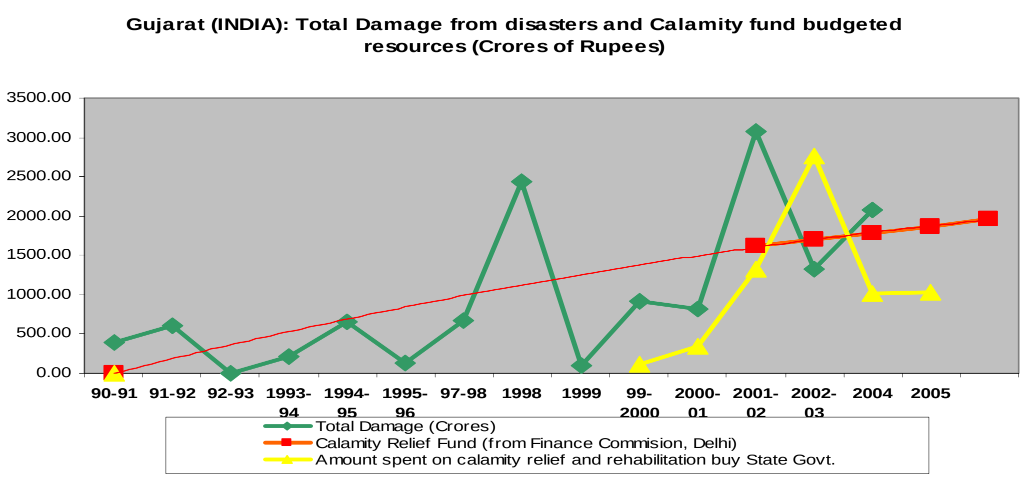
DIFFERENT IMPACTS OF DIFFERENT EVENTS (as observed in ECLAC assessments, 1972-2005)						
	AFFECTED POPULATION		TOTAL IMPACT (constant 2004 prices)			
	Deaths	Directly affected population	TOTAL	DAMAGE (to assets)	LOSSES (in flows)	External sector impact
METEOROLOGICAL (CLIMATIC) EVENTS	50,424	24,945,145	118,926	73,382	43,304	35,600
GEOMORPHOLOGICAL (SISMIC, VOLCANIC) EVENTS	64,752	10,518,745	113,334	76,953	37,120	41,621
Droughts	35	2,200,000	10,599	5,888	4,712	3,141
TOTAL ASSESSED EVENTS	115,176	35,463,890	232,259.40	150,335.00	80,424.30	77,221.00
Meteorological as % of total	44%	70%	51%	49%	54%	46%
Droughts as % of total	0.07%	8.82%	8.91%	8.02%	10.88%	8.82%
Damage composition						
Total				64.70%	34.60%	33.20%
Meteorological or climatic				61.70%	36.40%	29.90%
Non-climatic				67.90%	32.80%	36.70%
Droughts				55.50%	44.50%	29.60%

Trends of disaster's recurrence and impact and their implication for the economic dynamism of a country and its development path are illustrated in recent cases such as El Salvador and others. The following graphs correlate disasters relative damage and its implication for development over time.

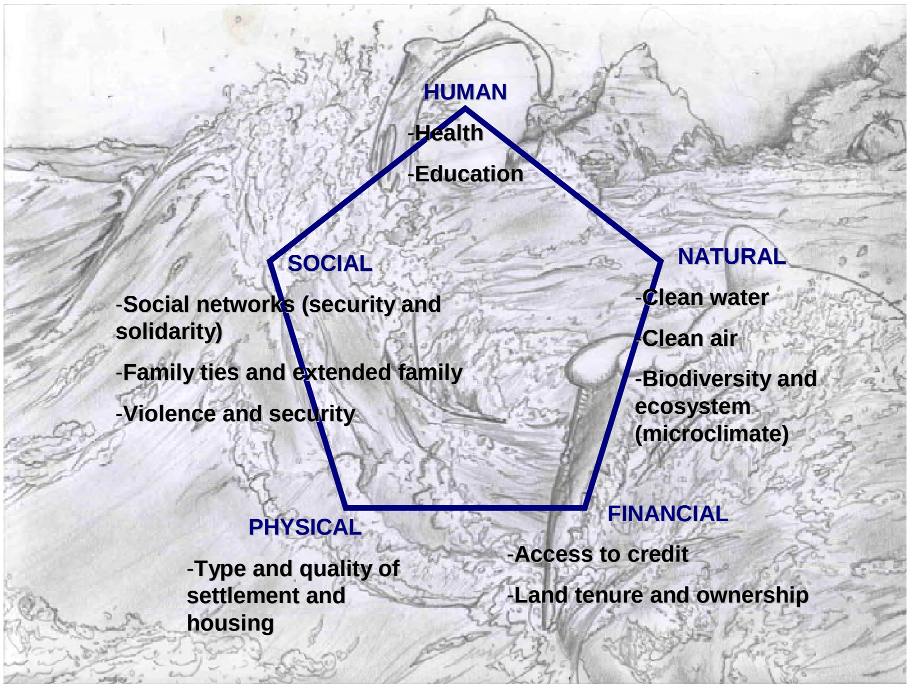


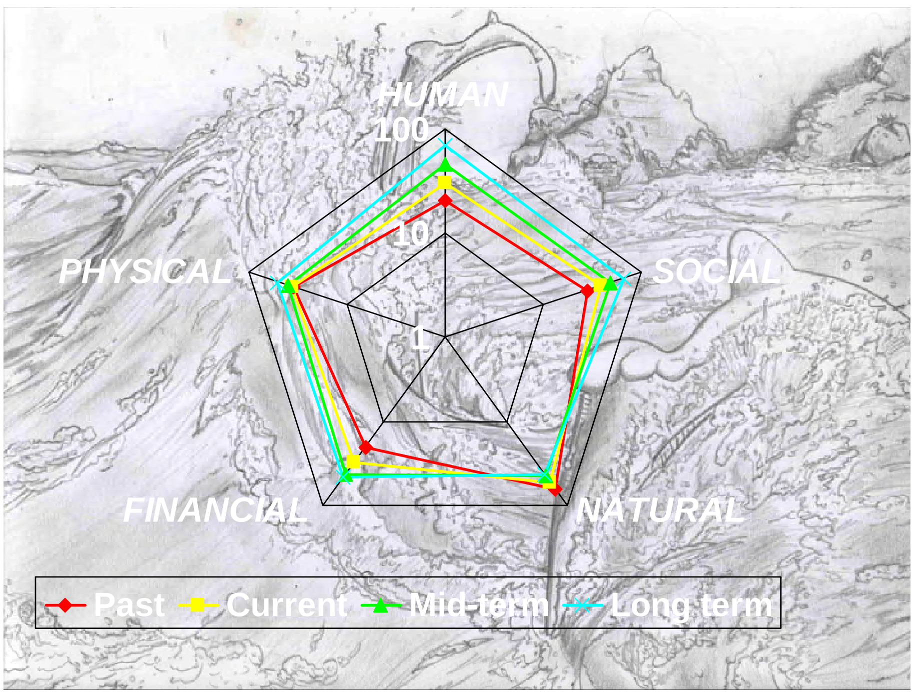






The effect, of a cumulative nature, that disasters have distorts, transforms and changes the development pattern of a society. If natural, human, physical and political factors are considered, their evolution will be affected by disasters in such a way that is not appropriate to consider such events as merely external shocks: they become –due to their recurrence and lingering effects—an intrinsic element of the process that has to be tackled. That is to say that in modeling a disaster's impact, as could be done by the use of econometric models be they general or of partial equilibrium, the disaster becomes over time an endogenous variable.





Post-disaster needs must be seen in a wider context: extreme events may be drivers for change. In brief the experience of re-insurers is a good example of financial adaptation to change. It seems a lot more difficult to promote the social adaptation to changing vulnerabilities and exposure. In that sense both the Asian tsunami and the "Katrina effect" seem relevant: extreme events for which society had not adapted. In the first instance due.

Risk transfer becomes a crucial element in disaster reduction. Traditionally it has been made in what may be categorized as a spurious way, by not internalizing risk as part of the viability (economic, financial, social, environmental) and having private investment externalize risk to society at large, placing demands on government. Similarly, countries, particularly developing countries with high vulnerability and insufficient resources to sustain their development process, transfer risk to the international community. Thus the balance of resources from the international community and governments concentrates heavily in response and reconstruction investment, rather than on risk reduction, prevention, mitigation and adaptation. On the other hand, the "virtuous" alternatives to risk transfer imply recognizing risk and accepting responsibility in facing it, at both the individual and institutional levels. Thus disaster reduction requires, first, appropriation and responsibility which come from appropriate regulatory and institutional frameworks and, second, economic and financial instruments that provide leverage to attain the risk reduction goals. Such instruments are relevant as part of macroeconomic policies of compensation and development. In a concrete sense, appropriate investment in risk management and transfer will generate pre-disaster leverage and reduce damage (in a manner similar to anti-cyclical policies such as price compensation funds for commodities). But that is only part of the risk management equation. The other is more at the microlevel, focusing on having investors internalize risk (invest in its reduction on the basis of the profitability of not losing such investment in the face of disasters) instead of externalizing it to the rest of society. Also at the micro level, governments – as part of appropriate social policy – should generate resources and community based resilience. It seems fair to say that state-assisted responsibility and solidarity are needed instead of irresponsible charitable and paternalistic responses. The use of community-based institutions and instruments such as microcredit associations, self-help groups, community women groups has been successful in some instances, namely in some countries in Asia and is worth pursuing.

2. Some implications of these understandings, for both research and policy

Recent ECLACs experience points out to information requirements and technical and analytical gaps that require further research and attention. On the basis of this observation, some of the most pressing research priorities are listed.

b) Risk appropriation and risk transfer,

c) The state's responsibility vs. the individual and social responsibility to reduce risk.

d) Better assessment of risk as the complex result of hazards, recurrence, vulnerability and exposure.

e) The correlation of built risk with demographic, economic and social variables.

f) Moral hazard assumed by states and inappropriate protection.

g) Development goals, such as poverty reduction or the United Nations Millenium

h) Development Goals or the World Bank's Poverty Reduction initatives and the negative impact that disasters have on them. While it is still true that the composition of damage shows that in developing countries human costs are higher than economic ones, it is also true that development related investment is lost at higher rates and in relative terms economic losses are also higher in those countries. That is to say that even though in absolute terms economic losses are larger in industrialized countries, once they are measured relatively to GDP or the overall economic assets of countries, it is the developing ones that suffer most while they are also the leas covered by insurance, contingency funds or other such risk bearing and risk transfer instruments.

Recent literature and studies produced by ECLAC

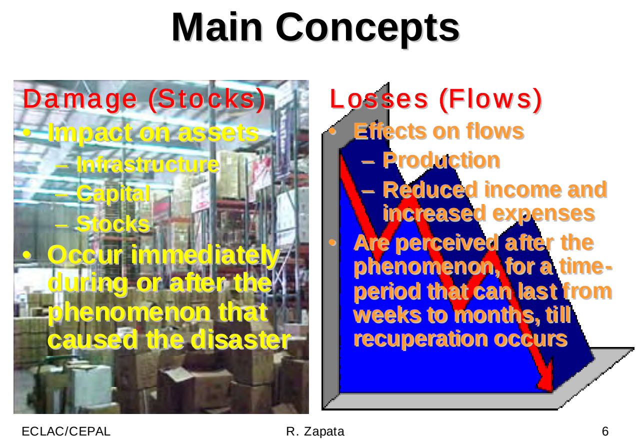
The list includes not only recently completed studies but new or forthcoming work.

- ECLAC updated (2003/4 Handbook, http://www.eclac.cl/mexico)
- Valuation of cultural assets (K. Vespars, ECLAC, draft, 2005)
- The 2004 hurricanes in the Caribbean and the Tsunami in the Indian Ocean. Lessons and policy challenges for development and disaster reduction (Ricardo Zapata Martí, LC/MEX/L.672, August 2005, Estudios y perspectivas series No. 35
- Economic impact of the 26 December 2004 Indian Ocean disaster (Asian Disaster Preparedness Center (ADPC),

prepared by Roberto Jovel, 2005, non-published)

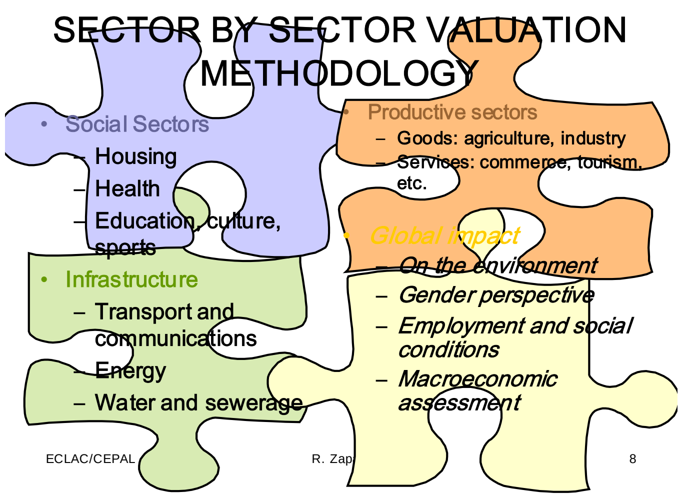
- Efectos en Guatemala de las lluvias torrenciales y la tormenta tropical Stan, octubre del 2005 y Perfiles de proyecto, LC/MEX/R.895, Noviembre de 2005
- Efectos en El Salvador de las lluvias torrenciales, tormenta tropical Stan y erupción del volcán Ilamatepec (Santa Ana) octubre del 2005 y Perfiles de proyecto. LC/MEX/R.892, November 2005
- Características e impacto socioeconómico del huracán "Emily" en Quintana Roo, Yucatán, Tamaulipas y Nuevo León en Julio de 2005, LC/MEX/L.693, December 2005
- See also 2004 Assessments in the Caribbean (Grenada, Bahamas, Cayman, Dominican Republic, Gonaives/Haiti, Jamaica and in Guyana (both 2005 and 2006) (http://www.eclac.cl/mexico)
- Drought in Belize in 2004-2005an assessment of its economic impact, A report prepared by International Consultant Roberto Jovel, for use in a training seminar on the assessment of disaster impact, held in Belmopan, January 2006.
- Natural Disaster Assessments case studies in Southeast Asia, presented to the REGIONAL WORKSHOP ON METHODOLOGIES TO ASSESS SOCIO-ECONOMIC IMPACTS OF NATURAL DISASTERS, 19 - 21 October 2005
- United Nations Conference Centre, Bangkok, undertaken under an ESCAP/BCPR/ECLAC project.
- Methodological proposal of country studies for IDB project on indicators of disaster management and ris indicators, and First reports on national case studies on disaster’s impact and risk management infrastructure for Mexico, Chile, Colombia, Nicaragua and Jamaica (http://www3.cepal.org.mx/iadb-eclac-project)

What is the methodology?



The socioeconomic and environmental impact evaluation methodology has been developed in Latin America by ECLAC[3] since the mid 1970s (the first requirement made by a government to have an assessment was the case of the 1972 earthquake in Managua, Nicaragua.

The main concepts used in a systemic sectoral approach are of a stock flow analysis. This entails first assessing the damage (partial or total) in assets, i.e. quantifying firstly the physical damage as miles or km. of road, miles or meters of bridges, number, type and size of buildings (i.e. houses, schools, hospitals, factories, warehouses, churches, museums, etc.); machinery, stocks of production, land for agricultural use, forest and natural reserves, beaches and ecological systems such as coral reefs; number of classrooms, hospital beds, etc. The valuation of these may be calculated in terms of present actuarial or book value (for insurance purposes, for example); at replacement value (current market value of construction of similar structures), real estate value, proxy prices in the case of environmental assets in terms of services rendered by asset damaged or lost. Valuation may also be attempted in terms of reconstruction that introduces hazard mitigation, vulnerability reduction or risk management measures.

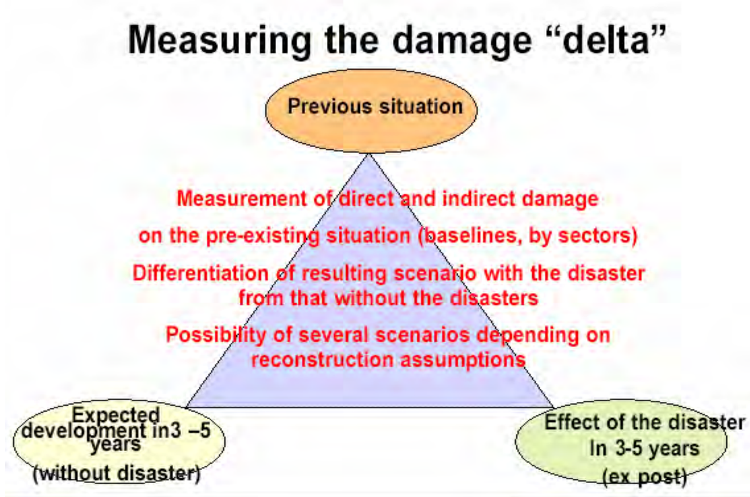


Once damage and its value are established, the economic consequences of that damage are assessed in terms of flows affected, sector by sector. These refer to the current value of production lost, reduced or deferred; additional production, distribution and marketing of production, trade in goods and services, increased government expenditures, and public service utilities (either provided privately or by the state); and reduced income both at the personal and entrepreneurial level as well as in terms of public finances. Reduced income to the state will be associated with reduced economic activities, special tax holidays given due to the disaster which can be of a general nature (reduction or elimination of import duties for example) or location specific to favour the disaster area. Other potential flow impacts could occur in the external sector, such a reduced exports or increased imports, and on the financial side, transfers received (be it private as remittances from nationals abroad or public as charitable contributions), new donations and grants as well as reconstruction credits. On the plus side also should be considered insurance and reinsurance payments from overseas. The sum of damage and losses, sector by sector, constitute the total impact of a disaster.

***Damage** (direct impact) refers to the impact on assets, stock, and property, valued at agreed replacement (as opposed to reconstruction) unit prices. The assessment should consider the level of damage, i.e., whether an asset can be rehabilitated/repaired, or has completely destroyed.*
***Losses** (indirect impact) refer to flows that will be affected, such as reduced income, increased expenditure, etc. over the time period until the assets are recovered. These will be quantified at present value of such flows.*

[3] See http://www.eclac./mexico, under "desastres". Handbook for the evaluation of the socioeconomic and environmental impact of disasters (LC/MEX/G.5, July 2003) available at the following web pages: http://www.eclac.cl/mexico, ("desastres"), http://www.worldbank.org/hazards/knowledge/other_res.htm, and http://www.proventionconsortium.org/toolkit.htm.

These impacts, assessed sector by sector, as flows variations resulting from the disaster, are then used–in their value added component—to estimate the macroeconomic impact of the disaster. The purpose of such an exercise is to establish the gap –or delta— that the economy as a whole and its components will experience. In fact three alternate situations are analyzed: the pre-disaster situation and trend (baseline situation), the non-disaster expected performance, and the post-disaster impact. This impact, in its entirety, without any potential reconstruction or response, constitutes the base scenario. To consider the reconstruction needs (as distinct and different from damage and losses) several possible scenarios may be considered on the basis of the system's absorptive capacity, that is, the resources available for reconstruction (from insurance and reinsurance, contingency or emergency funds, or credit available). Alternatively the base scenario serves to establish the financial gap to be filled, considering the reconstruction strategy (and its cost) that is put forward by the relevant stakeholders.



What is the use or purpose of the evaluation?

The general purpose of the evaluations is to provide a preliminary assessment of the damage and losses after a disaster in order to identify immediate recovery and longer-term reconstruction needs, and to determine the economic and financial implications of the event. The assessment's conceptual basis is a stock/flow analysis that evaluates effects (i) on physical assets that will have to be repaired, restored, replaced or discounted in the future and (ii) on flows that that will not be produced until certain assets are repaired or rebuilt.

The end product will be a consolidated summary of damage and losses that provide the extent and breadth of a disaster's impact, in quantitative, sector by sector, geographically specific terms that are stratified by affected groups, stemming from information compiled immediately after the event. It should not be considered a definitive assessment, but rather a preliminary understanding, compiled in a timely manner, to inform urgent recovery efforts. This quantification offers two further results: a determination of the relative size of impacts on relevant economic variables (by use of macroeconomic analysis and scenario modelling under different assumptions for the reconstruction potential and needs); and an analysis of the resource gap that these reconstruction scenarios pose to the government and to the affected population.

Use of Assessment Report

The evaluation's most important function is to provide decision-makers and stakeholders with a quantitative basis to request recovery funding assistance, and to design a reconstruction strategy. The quantification, given its sector by sector nature, allows for concrete, specific proposals for action in sector or geographic terms. It is a tool for determining priorities (importance vs. urgency) and sequencing (timeline for reconstruction process), i.e. to restore livelihood through income and employment while physical reconstruction of housing, production, and infrastructure proceed.

How to proceed: when and how the methodology is applied

Past experience indicates several needs. First, a team must be established to collect, organize, and analyze the necessary sector by sector information, from profiling existing baseline to superimposing damage and losses with a unified and comparable approach. The team should be multidisciplinary and inter-institutional, with clearly designated focal points to compile and present the data in a comparable manner –so that they can be summarized and factored into a macroeconomic scenario exercise. Each focal point should have common terms of reference. The global analysts (e.g.

macroeconomists, environmental economists, gender experts) will proceed to use the emerging data of damage and losses to: contrast the disaster scenarios to the non-disaster trend; make environmentally related damage and losses visible; and differentiate men and women's impact and roles in the post-disaster process.

Second, a deadline must be established to submit the final report deadlines for submission of sector data (quantification in standardized format with agreed common criteria) and accompanying descriptive text must be set depending on the final deadline. The description will include not only narratives of the event's impact on the sector but also the criteria and assumptions made to establish damage and loss figures.

Third, a deadline must be set for completion of a global analysis, and this deadline must be discussed and made compatible with a strategic reconstruction proposal. Caveats as to accuracy of available data, methodological considerations and assumptions made must be specifically addressed. The timing for the assessment should be such that, without losing its timeliness, it does not interfere with the ongoing emergency, particularly the search and rescue, although thinking of the future in terms of the needs for the reconstruction process is an immediate task to be pursued since some actions are required to be undertaken promptly, especially those related to providing housing solutions, health and education services, and recovery strategy. Additionally, discussion of the future serves as a therapeutic measure to overcome trauma. The main concern is that it does not interfere with immediate life-saving activities and emergency relief operations.

Each sector team should consult and exchange information with each other to avoid duplication, share data of common interest or of interest in more than one sector, and identify information gaps or lack of information. The sector specialist will not only gather information on baselines and the disaster's impact on them (i.e. damage and losses), but on reconstruction needs in the form of sectoral strategic responses. These can be used as input to develop an overall reconstruction strategy and possibly project proposals.

The strategic proposal will include a framework for action, based on pre-existing policies or development strategies, focusing on adaptation of the latter to the needs for the reconstruction, prioritize and sequence the process, define resource gaps to be filled from government, private and external sources, and profile execution processes in which affected populations and other stakeholders can play key roles in reconstruction.

APPENDIX A

Participant List and Biographies

**WOT = Workshop Organizing Team*

Christoph Bals
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Christoph Bals is the executive director policy of the NGO Gemanwatch, were he is a founding member (1991). He was among the initiators of European Business Council for Sustainable Energy, the pro-Kyoto-campaign "e-mission55", and the initiative for climate consicous flying "atmosfair". He has been on the board of the "Foundation for Sustainability" since 1998. He is one of the three NGO-representatives in the German government's working group on emission trading AGE) since 1998; and a member of the advisory group of most ambitious German green investment index (NAI); in 2003 and 2004 he was in the National Advisory Committee for the Renewables 2004. Bals headed different successful campaigns (Rio Konkret, Climate Responsibility Campaign). Bals studied theology (in which he received his diploma), economics and philosophy in Munich, Belfast, Erfurt, and Bamberg.

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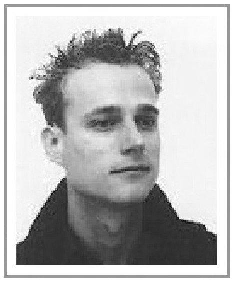

Laurens Bouwer has been employed at the Institute for Environmental Studies since 1999. His work at the institute covers many aspects of global change, but in particular the relationship between climate change and water resources management. He has been working on the hydrological impacts of climate variability and climate change on river basins. He was a lead author for a chapter on the financial services sector in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), and he is an expert reviewer for the IPCC Fourth Assessment Report. He was involved in the Dialogue on Water and Climate for subjects relating to insurance and risk management in the water sector. Recently, Laurens started working on a PhD that deals with the impacts of climate change on disaster losses.

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Rudolf Brázdil is a professor of physical geography in the Masaryk University of Brno, the Czech Republic. He is doing research in instrumental and historical climatology with a special attention to climate variability and change as well as to climatic anomalies and weather extremes. In 1985, 1988 and 1990 he participated in polar expeditions to Spitsbergen. In 1992/1993 he was an invited professor at the ETH Zürich, Switzerland. He is a chairman of the Czech National Geographic Committee and a full member of Commission on Climatology of the International Geographical Union.

Harold Brooks
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Harold Brooks is a research meteorologist and Head of the Mesoscale Applications Group at the National Severe Storms Laboratory (NSSL) in Norman, Oklahoma. He grew up in Saint Louis, Missouri. As an undergraduate, he majored in physics and math at William Jewell College, with a year at the University of Cambridge studying Archaeology and Anthropology. He has a Ph.D. from the University of Illinois and a M.A. from Columbia University. After graduating from Illinois, he was a National Research Council Research Associate at NSSL and joined the permanent staff there in 1992. During his career, his work has focused on why, when, and where severe thunderstorms occur and what their effects are, and on how to evaluate weather forecasts. In 2002, he received the United States Department of Commerce's Silver Medal for his work on the distribution of severe thunderstorms in the United States. Currently, he is Co-Chief Editor of the American Meteorological Society's journal, Weather and Forecasting, and is a member of the World Meteorological Organization's Joint Working Group on Verification.

Ian Burton (*WOT)
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Ian Burton is a Scientist Emeritus with the Meteorological Service of Canada; an Emeritus Professor at the University of Toronto, and a Fellow of the Royal Society of Canada. He now works as an independent scholar and consultant in climate change and natural hazards with particular interest in adaptation and the science-policy interface. He is currently a Lead Author in the IPCC 4th assessment.

Ryan Crompton
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Ryan Crompton obtained both his BSc (Advanced Mathematics) (2001) and Postgraduate Diploma in Accounting (2003) from Macquarie University. He joined Risk Frontiers at the completion of his studies and is responsible for the research and development work associated with Risk Frontiers' tropical cyclone loss estimation model (CyclAUS).

Other recent work includes a report prepared for the Insurance Council of Australia in which various indexation methods were explored and applied to their historical list of insured natural disaster losses. Other interests include the pricing and structure of catastrophe bonds, and he has previous experience in numerical ocean modelling and the analysis of mining risk.

Andrew Dlugolecki
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Andrew Dlugolecki is now a Visiting Research Fellow at the Climatic Research Unit, University of East Anglia, a director of the Carbon Disclosure Project, and advisor on climate change to UNEP Finance Initiative.

Andrew worked for 27 years in Aviva insurance egroup, in a number of senior technical and operational posts, starting with General Accident in 1973, and retiring from the position of Director of General Insurance Development in December 2000. He served as the chief author on Financial Services and later reviewer for the Intergovernmental Panel on Climate Change in its Second, Third and Fourth (due 2007) Assessment Reports in Working Group 2, and carried out similar duties for official UK and EU reviews of climate change. He also chaired two studies of climate change by the Chartered Insurance Institute (1994 and 2001), and is currently recruiting the writing team for a third report due in 2007.

Andrew obtained BSc (Hons) in Pure Mathematics at Edinburgh (1970), MA in Operational Research at Lancaster (1971), and PhD in Technological Economics at Stirling (1978), and is Fellow of Chartered Insurance Institute (1990), and Fellow of Royal Meteorological Society (1992).

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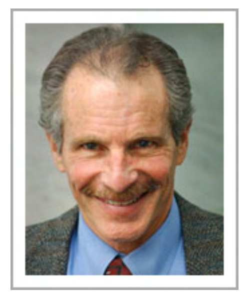

Paul R. Epstein, M.D., M.P.H. is Associate Director of the Center for Health and the Global Environment at Harvard Medical School and is a medical doctor trained in tropical public health. Paul has worked in medical, teaching and research capacities in Africa, Asia and Latin America and, in 1993, coordinated an eight-part series on Health and Climate Change for the British medical journal, Lancet. He has worked with the Intergovernmental Panel on Climate Change (IPCC), the National Academy of Sciences (NAS), the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) to assess the health impacts of climate change and develop health applications of climate forecasting and remote sensing. He also served as a reviewer for the Health chapter of the Millenium Ecosystem Assessment, and was the lead author of *Climate Change Futures: Health, Ecological and Economic Dimensions*, a report released on November 1, 2005 after a three-year collaboration between the Center for Health and the Global Environment, Swiss Re and the United Nations Development Programme.

Eberhard Faust (*WOT)
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Eberhard Faust, a geoecologist and theologian, is head of the climate risks, geo risks research division at Munich Reinsurance Company. Prior to this, Eberhard worked at Deutsche Rückversicherung, Düsseldorf where he was an expert on natural perils (windstorm and climate risks). His research background is in software engineering, modelling of natural perils, natural hazards risk management. Eberhard received his M.Sc. in Geoecology from University of Bayreuth and his Ph.D. in Theology from University of Heidelberg.

Indur Goklany

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Indur Goklany, who is Assistant Director for Science and Technology Policy at the U.S. Department of the Interior's Office of Policy Analysis, has worked for over thirty years on a variety of developmental, natural resource and environmental issues with the U.S. federal government, the State of Michigan, the private sector, and various think tanks. He has researched and written widely on science-related public policy issues pertaining to the relationships between human well-being, economic development and technological change; hunger; biotechnology; sustainable development; the precautionary principle, air quality; and climate change. He has a bachelor's degree from the Indian Institute of Technology, Bombay, and master's and doctorate degrees from Michigan State University (all in electrical engineering). He is the author of The Precautionary Principle: A Critical Appraisal of Environmental Risk Analysis (Washington, DC: Cato Institute, 2001).

Maryam Golnaraghi

Natural Disaster Prevention and Mitigation Programme, World Meteorological Organization (WMO)
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In September 2004, Dr. Golnaraghi joined WMO to head up its new crosscutting Natural Disaster Prevention and Mitigation (DPM) Programme. Dr. Golnaraghi is the WMO focal point on all disaster prevention and mitigation activities for weather, water and climate-related hazards. She is coordinating WMO's activities related to the International Strategy for Disaster Reduction (ISDR) System. Through development of a coordinated approach among WMO's 10 Scientific and Technical Programmes and WMO's constituent bodies, Dr. Golnaraghi is working to ensure that WMO is contributing in a systematic and sustainable manner to strengthening of national capacities for observing, monitoring, detecting, early warnings and mapping of hydro-meteorological hazards. She is working to establish new organizational partnerships for WMO to ensure optimal utilization of WMO's scientific and technical capacities in disaster risk reduction decision process at national, regional and international levels. Dr. Golnaraghi coordinates WMO's contributions to the establishment of the Tsunami Early Warning System (TEWS) in the Indian Ocean and other regions at risk. In this capacity she also works with the Office of the UN Special Envoy on Tsunami Recovery, Former President Clinton.

From 1993 to 1995, Dr. Golnaraghi worked at Harvard University, as a postdoctoral fellow; and later as research associate at the Harvard Business School. In 1996, she founded Climate Risk Solutions, Inc., a consulting company working with the private sector, the government and the U.S. research community, providing innovative risk management solutions based on the latest scientific and technological developments in the field of weather and climate for public- and private-sector decision-making and public/private partnerships. Since 1993, she served as Principal Investigator on numerous projects with the U.S. National Oceanic and Atmospheric Administration, related to applications of climate information and forecasting technologies. Dr. Golnaraghi also worked extensively in the area of weather derivatives, involving technical capacity building in energy and financial corporations for access to and utilization of climate information. From 2000 to 2004, as a full-time consultant with Air Worldwide Corporation, she oversaw the development of AIR's climate business unit and the development of its operational climate forecasting system in support of the-state-of-the-Art risk modelling tools of AIR. Dr. Golnaraghi has advised over 70 companies in the insurance/reinsurance, energy and agriculture sectors and has authored various articles in technical, policy and business journals. She also severed as the executive editor of The Climate Report, a quarterly publication of CRS.

Hervé Grenier
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Hervé Grenier has been employed at AXE Re since 2002. He holds a masters's degree in meterology from University of Paris VI and a PhD degree in atmospheric sciences from Université of Louvain in Belgium. Prior to joining at AXA Re, he successively worked as a research scientist at the University of Washington in Seattle for three years and at the French National Center for meteorological research in Toulouse for 2 years. His research involved developing physical parameterizations for cloudy boundary layer turbulence and tropical shallow convection, and sensitivity of climate simulations to these physical parameterizations.

In the weather derivatives department of AXA Re, he was originally responsible for providing expertise regarding the underwriting of weather derivatives, and developing tools to efficiently manage the exposure. He is now mostly involved in the risk modelling department of the company, in charge of studying climate hazards variability and providing guidance for the management of the property book of business.

Bhola R. Gurjar (*WOT)
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Bhola Gurjar is on the faculty of the Civil Engineering department of India's premier technological institution, Indian Institute of Technology in Roorkee. He has extensive industrial, teaching, training and research experience. His present research interests include atmospheric emissions and climate change; environmental impact and risk assessment; air and water pollution; and integrated cross-disciplinary study of science and policy issues of the environment, health, energy, economy, entrepreneurship, technology, infrastructure and resources – particularly from the global change, sustainable development and risk governance perspectives.

He is co-author/co-editor of five books, and has a number of research papers to his credit. He has received several awards and fellowships including the prestigious Advanced Postdoctoral Research Fellowship of the Max Planck Society, which was awarded to him to work at the Max Planck Institute for Chemistry, for three years. Based on his outstanding research work at the MPIC–Mainz, the Scientific Steering Committee of the global change SysTem for Analysis, Research and Training, Wash., D.C., honored him with the 2004 START Young Scientist Award. To learn more: http://www.iitr.ernet.in/departments/CE/people/faculty/facthtml/bholafce.htm.

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Armin Haas is a senior researcher currently working in PIK's research group "Global Financial Transition" led by Carlo Jaeger. When he joined PIK in 2000, he first worked on the transition of the global energy system.

Armin has been trained as an economist at the University of Karlsruhe, Germany. In his Ph.D. thesis, he applied stochastic dynamics to cartel theory. His other fields of research have been the credit mechanism that allocates resources in real economies, and the improvement of stakeholder dialogues for managing climate risks. As an innovative tool for climate communications, he co-authored the climate board game "Winds of Change".

Armin contributes to the management of the European Climate Forum. He is founding member of the Munich Climate Insurance Initiative. In Fall 2006, he started a project on mainstreaming the management of climate risks by German financial service providers. His special interest lies with Bayesian techniques for managing climate risks.

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Jaakko Helminen is a Senior meteorologist at the Finnish Meteorological Institute in Helsinki, Finland. He has with the Finnish Meteorological Institute since 1983. His main area of specification is in meteorology, mathematics (calculus of probability), statistics, and project management. From 2001-2005, Jaakko was a leader for the WMO/CCI/CLIPS/OPAG3 Expert Team on End-User Liaison. Since 2004, he has been a member of the Scientific Organizing Committee of the WMO Conference on Climate Variability and Change: Understanding the Uncertainties and Managing the Risks and chairman of the Local Organizing Committee of the WMO Conference on Climate Variability and Change: Understanding the Uncertainties and Managing the Risks (17-21.July 2006 at Dipoli, Espoo, Finland). He has bachelor's, master's and doctorate degrees from University of Helsinki (all in Meteorology).

Peter Höppe (Workshop Co-Organizer, *WOT)
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Peter Höppe has been Munich Re's head of Geo Risks Research since 2004. Prior to this, Peter was a tenured lecturer and senior lecturer at the Institute of Occupational and Environmental Medicine and Institute of Bioclimatology and Applied Meteorology, at Ludwig Maximilian University in Munich. Peter's main areas of research are the effects of atmospheric processes (heat/cold, UV radiation, air pressure fluctuations) and air pollutants (ozone, particles) on humans; assessment of environmental risks. From 1999-2002, Peter was president of the International Society of Biometeorology and also a board member for the German Meteorological Society. Peter studied meteorology at LMU and received his Ph.D. in physics and a second Ph.D. in human biology.

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Shi Jun is an engineer in Shanghai Climate Center, Shanghai Meteorological Bureau, China. From 1995 to 2002, he was a student in the Northeast Forestry University, Haerbin, China, where he studied forestry and ecology and received his bachelor and master degree in 1999 and 2002 respectively. He received his doctoral degree of science from the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences in 2005, with the research direction of global change and terrestrial carbon cycle. Now he focuses his research on regional climate change and meteorological disaster.

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Claudia Kemfert is Professor of Energy Economics at Humboldt University of Berlin and Head of the department "Energy, Transportation and Environment" at the German Institute of Economic Research in Berlin.

Claudia studied economics at Oldenburg, Bielefeld Germany and Stanford University, United States. She worked for the Fondazione Eni Enrico Mattei (FEEM) in Italy and Stuttgart University, Institute for Rational Energy Use. Claudia gave lectures at the universities of St. Petersburg from 2003/04, Moscow from 2000/01 and Siena in 1998, and from 2002/03. She also acts as an external expert for the World bank and United Nations. Claudia is in the editorial board of Energy Economics and GAIA. She is scientific advisor of the Austrian Institute of Economics, WIFO and member of the sustainability advisory council of the state Baden-Württemberg, Germany. Her research activities concentrate on the evaluation of climate and energy policy strategies.

Richard J.T. Klein (*WOT)
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Richard J.T. Klein is a senior research fellow at the Stockholm Environment Institute (SEI) in Sweden and a visiting researcher at the Potsdam Institute for Climate Impact Research (PIK) in Germany. At SEI he leads the Stockholm-based Climate and Energy team and co-ordinates climate policy research across all SEI centres. He also directs the joint PIK-SEI research project Formal Approaches to Vulnerability Assessment that Informs Adaptation (FAVAIA).

Until mid-2006 Richard was group leader and deputy head of the department of Global Change and Social Systems at PIK. From 2001 to 2004 he co-directed the award-winning interdisciplinary project Environmental Vulnerability Assessment (EVA), upon which in 2005 he initiated FAVAIA. Within EVA and FAVAIA he successfully managed externally-funded research projects and activities with a total budget of over € 3 million.

Richard has fourteen years of experience as a researcher and senior researcher on societal vulnerability and adaptation to climate variability and change. He has been a principal investigator in a number of collaborative projects, including WISE, DINAS-COAST (which he co-ordinated), ATEAM, Security Diagrams, cCASHh, NeWater and ADAM. In addition, he has provided research and consultancy services to UNDP, UNEP, UNFCCC, GEF, World Bank, OECD, WHO, IUCN, Germanwatch, the European Commission and the governments of the Netherlands, Germany, Norway and the United Arab Emirates. He has been a lead author in the IPCC Second and Third Assessment Reports and the Millennium Ecosystem Assessment, and a co-ordinating lead author in the IPCC Special Report on Technology Transfer and the Fourth Assessment Report. He co-organised the seminal IPCC Workshop on Adaptation in 1998 and the Potsdam Workshop on Adaptive Capacity and Development in 2001.

Richard holds a PhD (magna cum laude) in environmental geography (Christian-Albrechts-Universität zu Kiel), as well as master's degrees (distinction) in quaternary geology (Vrije Universiteit Amsterdam) and environmental sciences (University of East Anglia). To date he has produced over sixty journal articles, book chapters and reports, edited a book and two special journal issues and contributed to numerous national and international workshops and conferences. He has supervised one MSc student and currently has supervising responsibilities for six PhD students.

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Thomas Knutson has been a Research Meteorologist at the Geophysical Fluid Dynamics Laboratory (GFDL) since 1990. GFDL, which is part of the National Oceanic and Atmospheric Administration, is one of the world's leading climate modeling centers.

Mr. Knutson has authored several studies in major scientific journals on the potential impact of climate change on hurricane intensities and hurricane-related precipitation. He is currently serving on the World Meteorological Organization Steering Committee for Project TC-2: Scientific Assessment of Climate Change Effects on Tropical Cyclones.

His other research interests include climate change detection, and comparison of observed and simulated regional surface temperature trends.

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Chairman of Munich Re Foundation since 2004, Thomas Loster has been a member of Geo Risks Research Department at Munich Reinsurance Company since 1988. During this time, Thomas was involved with the development of Section “Digital Cartography”, creator and editor of periodical publication Topics geo–Annual Review: Natural Catastrophes, head of division “Flooding”, head of NatCatSERVICE®, and head of Weather/Climate Risks Research. Thomas received his degree in geography at Ludwig-Maximilians-University.

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Robert Muir-Wood heads the Research Group within RMS with the mission to design enhanced methodologies for natural catastrophe modeling and develop models for new areas of risk. He has more than 20 years experience in developing probabilistic catastrophe models for hurricane windstorm and flood in Europe Japan North America Caribbean and Australia. Author of six books many scientific publications and numerous articles he has also been the technical lead on a number of Catastrophe risk securitization transactions. He is also a Lead Author covering issues around Climate Change and Catastrophe risk occurrence relevant to the insurance and finance sectors for the next (4th) 2007 IPCC Assessment Report.

Gunilla Öberg
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Gunilla Öberg is Professor at Linköping University (LiU) and Director of the Centre for Climate Science and Policy Research. Important parts of the institute's research are the MISTRA financed research project "Climate Science and Policy Beyond 2012+ as well as a research project that focus on communication in relation to the follow up of the Swedish Environmental Goals. Gunilla is in charge of the group at LiU that focus on the biogeochemistry of chlorine. Among other tasks can be mentioned, Gunilla teaches at the Environmental Science Programme at LiU Norrköping. Gunilla is also an affiliated professor at University of Colorado at Boulder, USA, adjunct professor at Xinjiang University, PR China, board member of Malmö University as well as of the County administrative board of Östergötland, both Sweden.

Jean Palutikof (*unable to attend*)
IPCC WGII TSU
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Jean Palutikof is Head of the Technical Support Unit, IPCC Working Group II. She is based in the Hadley Centre for Climate Prediction and Research, the Met Office. Prior to joining the Met Office, she was a Professor in the School of Environmental Sciences, and Director of Climatic Research Unit, at University of East Anglia. Her research interests focus on climate change impacts, and the application of climatic data to economic and planning issues. She co-ordinated the EU-funded MICE project (Modelling the Impacts of Climate Extremes) and was a partner in the PRUDENCE project (Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects). She worked for a number of years on the MEDALUS projects, constructing scenarios of regional climate change for the Mediterranean, for application to research on desertification. She was a Lead Author for Working Group II of the IPCC Third Assessment Report. She has edited three books, and published over two hundred articles and papers on climate change.

Roger Pielke, Jr. (Workshop Co-Organizer, *WOT)
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Roger A. Pielke, Jr. has been on the faculty of the University of Colorado since 2001 and is a Professor in the Environmental Studies Program and a Fellow of the Cooperative Institute for Research in the Environmental Sciences (CIRES). At CIRES, Roger serves as the Director of the Center for Science and Technology Policy Research. Roger's current areas of interest include understanding disasters and climate change, the politicization of science, decision making under uncertainty, and policy education for scientists. In 2000, Roger received the Sigma Xi Distinguished Lectureship Award and in 2001, he received the Outstanding Graduate Advisor Award by students in the University of Colorado's Department of Political Science. Before joining the University of Colorado, from 1993-2001 Roger was a Scientist at the National Center for Atmospheric Research. Roger sits on the editorial boards of Policy Sciences, Bulletin of the American Meteorological Society, Environmental Science and Policy, Darwin, Water Resources Research, and Natural Hazards Review. He sits on various advisory committees, is author of numerous articles and essays, and is also author, co-author or co-editor of four books. He is the author of a forthcoming book titled: The Honest Broker: Making Sense of Science in Policy and Politics to be published by Cambridge University Press in early 2007.

S. Raghavan (*unable to attend*)
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S. Raghavan is a former Deputy Director-General of Meteorology, of the India Meteorological Department. He has worked mainly in the areas: Tropical Cyclone prediction and warning, Techno-Economic analysis of the Meteorological Component of the Indian Space Programme, Meteorological Instruments and Observations, Radar Meteorology, Radar-Satellite estimation of precipitation, and Radio wave Propagation.

Raghavan has published a book "Radar Meteorology", and has also contributed a chapter in a two-volume book on "Storms". Raghavan also published 70 research papers.

Currently, Raghavan is Consultant to the Indian Space Research Organisation and is associated with several Universities as guest lecturer. He was also the Principal Investigator of a Research Project at the National MST Radar Facility (now National Atmospheric Research Laboratory).

Silvio Schmidt
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Silvio Schmidt is a PhD-student at the German Institute for Economic Research, Berlin (DIW) since 2005. He studied at the University of Tübingen and the University of Nanjing, P.R. China and received his graduate degree in economics from the University of Tübingen in 2002.

Since 2002 he works for Munich Reinsurance Company, since 2004 as environmental expert in the Department for Geo Risks Research and Environmental Management.

Silvio Schmidt take part in a research project cooperation between DIW and MunichRe and works for his PhD-thesis on loss trends of natural catastrophes and assessments to the economic impact of climate change.

Gerd Tetzlaff
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Gerd Tetzlaff is a full Professor and founding director of the meteorology department at the Universität Leipzig. Prior to his appointment at Universität Leipzig, Gerd was lecturer and assistant professor (tenure) at Universität Hannover. His research interests include extreme events of wind and precipitation, boundary layer meteorology (experimental and modelling), and high atmosphere. Gerd is vice chair of DKKV and GeoUnion. He on the council for IUGG, secretary general of GeoRiskCommission, national representative of IAMAS, on the Deutscher Wetterdienst scientific advisory board, and is also senate of the Leibniz Society and Universität Leipzig. From 1995-2001, Gerd was co-editor of promet and Metorological Zeitschrift. He is on the board of directors for the German Wind Energy Institute and Meteorologische Zeitschrift. Gerd received his master's in Meteorology from Freie Universität Berlin and his Ph.D. and DSc. (Habilitation) in meteorologay from Universität Hannover.

Emma Tompkins (∗WOT)
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Emma Tompkins is a research fellow at University of Oxford's Centre for the Environment and Tyndall Centre for Climate Change. Emma's previous experience has been in multi-disciplinary projects. Her specialisation is in institutional adaptation to environmental change, environmental management, participatory approaches, integrated and inclusive coastal zone management, multi-criteria analysis (MCA), contingent valuation methods, stakeholder analysis and conflict management. Her research interest lies in developing a theory of adaptive capacity to climate change. This are of research includes understanding the determinants of adaptive capacity; what motivates individuals and societies to respond to natural hazards; and identifying the linkages between adaptive and mitigative capacity.

Hans von Storch (∗WOT)
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Hans von Storch is director of Institute of Coastal Research of the GKSS Research Centre and professor at the Meteorological Institute of the University of Hamburg. From 1987 - 1995, he was Senior Scientist and leader of the "Statistical Analysis and Modelling" group at the Max Planck-Institut for Meteorology (Hasselmann division). In 1996, Hans von Storch became director of the Institute of Hydrophysics at the GKSS Research Centre and professor at the Meteorological Department of the University of Hamburg. In 2001, the Institute of Hydrophysics became part of the Institute of Coastal Research. Within that institute, he is director of the division "Systems Analysis and Modelling".

His research interests are climate diagnostics and statistical climatology, specifically detection and attribution of anthropogenic climate change, variability and change in storminess and related marine variables (storm surges, ocean waves), regional climate change; use of paleo proxy data to study climate variability and change, transdisciplinary context.

Hans has published eleven books, and numerous articles and is in charge of a number of projects. He is member of the advisory boards of *Journal of Climate* and Meteorologische Zeitschrift, *Annals of Geophysics*, and organizor of the GKSS School on Environmental Research. He is also a member of the steering committee of the International Meeting on Statistical Climatology and of the committee for the Eduard Brückner award.

Hans studied mathematics, physics and Danish at the University of Hamburg, and received a diploma in mathematics in 1976. While a student he also worked as a programmer at the Department of Oceanography. He went on to receive his Ph.D. from the Meteorological Department of the University of Hamburg in 1979, and his "Habilitation" in 1985.

Koko Warner
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Koko Warner serves as an senior scientific advisor at the United Nations University Institute for Environment and Human Security (UNU-EHS). She coordinates the Munich Re Foundation Chair on Social Vulnerability. Prior to joining the UNU, Warner was an economist research scholar at the Natural Hazards Department at the World Institute for Disaster Risk Management (DRM) in Davos, Switzerland. Dr. Warner has worked for the past seven years on the economic and societal impacts of climate change and natural catastrophes in developing countries.

Warner's research has focused on policy and financial instruments to reduce and transfer disaster risk. Warner's research identifies existing incentive structures for decision makers, and explores financial services that can provide efficient risk transfer and encourage prudent risk reduction measures. In 2004 and 2003, her work focused on operational policies for natural disaster management at major international financial institutions, upon infrastructure loan portfolios and the reduction of infrastructure vulnerability, and strategies for reducing poverty and infrastructure vulnerability to climate change. Past work quantified the macroeconomic effects of potential capital stock exposure to catastrophe loss. This research focused on alternatives to finance weather-related catastrophe risk.

Koko Warner is a member of the Munich Climate Insurance Initiative (MCII). She received her doctoral degree in economics, and currently also serves as an assistant professor at the University of Richmond's Emergency Service Management graduate program.

Martin Weymann
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Martin Weymann is a Sustainability and Emerging Risk Advisor within Risk Management Division. In his current function he contributes to the identification, assessment, evaluation and business implementation of emerging risks within the company. Climate change and its impacts to the reinsurance industry was one of the main topics he was involved over the past years since he joined Swiss Re in 2002. Through joining the International Graduate Programme in 2002, he worked also in Asset Management and Corporate Underwriting.

Martin holds an master in environmental sciences from ETH Zurich with specialization in environmental physics, water and climate. He finished his studies with a diploma thesis in the field of radioactive tracers, climate change and mathematical modelling. Additionally, he was an assistant for system analysis and scenario planning at ETH Zurich.

Angelika Wirtz (∗WOT)
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Angelika Wirtz has been working with Munich Reinsurance Company for 23 years. Angelika is responsible for the Munich Re NatCat*SERVICE*® and is chief editor of Munich Re's annual review of natural catastrophes "Topics Geo".

The MRNatCat*SERVICE*® is based on a comprehensive data base where natural disasters and loss events are analysed and documented. Detailed information on the location, date and duration of events is stored and all relevant facts are summarized in a brief description, which provides a simple and quick overview of the dimensions of each loss event. Statistics are also provided on damaged or destroyed buildings, affected infrastructure, damage to lifeline network, agricultural damage and the number of victims. The NatCat*SERVICE*® also includes a record of insured and overall losses which are of vital importance for analysing and determining trends.

Anita Wreford
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Anita Wreford is a senior research associate at the Tyndall Centre at the UEA in Norwich UK. She is currently working on a project assessing the economic impacts of climate change in Europe focusing particularly on extreme events.

Qian Ye (∗WOT)
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Qian Ye, after obtained his Ph.D. degree in Satellite Climatology from Oregon State University in 1993 and worked with NOAA and Chinese Academy of Sciences for seven years, is now working in Center for Capacity Building, National Center for Atmospheric Research in the field of weather and climate related impacts on society. He has worked with Dr. Michael Glantz, CCB director, to promote an education and training program so called Climate Affairs Program around the world, especially in Asia including China, Great Central Asia and Southeast Asia. He has worked with China Meteorological Administration and universities as well as local and national government agencies to develop social and economic impact research programs around China. He is also working with China National IHDP committee as deputy general secretary and with Chinese Academy of Meteorological Sciences as President assistant. Currently, he is leading an international research team to conduct a social and economic impact assessment project for WMO/WCRP Beijing 2008 Olympics Forecasting Demonstration Program. As a special advisor for the newly established China Weather TV, he is helping CWTV to develop a research program on better disseminating natural hazard information based on different technologies including traditional media such as TV, radio and newspapers as well as new media such as internet, cell phones and satellite radios.

Ricardo Zapata-Marti
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Ricardo Zapata-Marti is currently Focal Point for Disaster Evaluation at the Subregional Headquarters in Mexico of the United Nations Economic Commission for Latin America and the Caribbean.

Professionally Ricardo has worked for the UN/ECLAC since 1975. Previously he was editor and researcher at the Special Projects Department of the Mexico office of the a major international editorial house (1968-1969); Assistant researcher, Economics Department, Universidad Católica del Perú (1972-73); Assistant professor, Economics Department, same institution (1972-73); Lecturer on Macroeconomic Theory and International Trade, Universidad Católica de Guayaquil (Ecuador) (1974-75); Columnist and editor, "El Comercio" daily newspaper, Quito (Ecuador) (1973-1975); contributor and executive editor, "Vistazo" weekly newsmagazine, Guayaquil (Ecuador) (1974-1975).

His areas of expertise are in economic matters, international trade, and economic and social impact of natural disasters.

In the United Nations Economic Commission for Latin America and the Caribbean, he worked at the Joint ECLAC/FAO Agricultural Division (Santiago, Chile), 1976-81; was Trade Officer, Subregional Office for the Caribbean (Trinidad y Tabago), 1981-83; Economic Affairs Officer, Join ECLAC/FAO Agriculture Unit, subregional Headquarters in Mexico 1983-1987, Chief, International Trade Unit at the same office, 1987-2005, and since 1989 to date has been the Focal Point for Disaster Evaluation of ECLAC. In those capacities he has represented ECLAC at numerous events, conferences and intergovernmental meetings.

Ricardo has participated in a number of conferences, symposia, seminars, on trade issues and on the valuation and socio-economic impact of natural disasters. Among the latter he attended the United Nations World Conference on Natural Disaster Reduction, held in Yokohama, Japan, in 1994, International Forum that took place at the end of the International Decade for the Reduction of Natural Disasters (Geneva, July 1999), and the Second World Conference on Natural Disasters, held in Kobe, Hyogo, Japan, in 2005.

In the field of disasters he has led numerous assessment missions in the Latin American and Caribbean region, coordinated the current edition of the ECLAC methodology for disaster evaluation (published in 2004), provided technical assistance to the World Bank's Hazard Risk Management Team (including the assessments of the 2004 Tsunami in Indonesia and India), and coordinated technical cooperation projects between ECLAC and the Interamerican Development Bank and the United Nations Development Programme Among the latter he attended the United Nations World Conference on Natural Disaster Reduction, held in Yokohama, Japan, in 1994, and the International Forum that took place at the end of the International Decade for the Reduction of Natural Disasters (Geneva, July 1999).

Logistics & Organizing Team

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Appendix B

Workshop Agenda

Day 1

Wednesday, 24 May 2006

4:00pm WOT Executive session

7:00pm Informal evening reception

Thursday, 25 May 2006

8:45am *Gutshof-Saal Room*
Welcome, Introductions, Goals

9:00am Peter Höppe

9:15am Roger Pielke, Jr.

Part I: Trends in Extreme Weather Events
Richard J. T. Klein, Chair

9:30am Tropical Cyclones
- 5 minute perspectives
  - Faust, Knutson, Grenier

10:30am Break

11:00am Extra-tropical and Convective Storms, Floods
- 5 minute perspectives
  - von Storch, Brooks, Brazdil

12:30pm Lunch

2:00pm Discussion on Trends in Extreme Weather Events
Hans von Storch, Chair

Part II: Trends in Damage
Andrew Dlugolecki, Chair

2:45pm Tropical Storms
- 5 minute perspectives
  - Faust, Pielke, Jr., Crompton

3:45pm Break

4:30pm Extratropical and Convective Storms, Floods
- 5 minute perspectives
  - Bouwer, Ye, Kemfert, Weymann

5:15pm Discussion on Trends in Damage
Thomas Loster, Chair

6:00pm Adjourn

7:00pm Reception

7:30pm Dinner

Workshop Agenda

Day 2

Friday, 26 May 2006

Part III: Data Issues -- Extreme Weather Events and Damage
Emma Tompkins, Chair

9:00am Event Data
- 5 minute perspectives
  - Brazdil, Helminen, von Storch

9:45am Impacts Data
- 5 minute perspectives
  - Wirtz, Schmidt, Gurjar

10:30am Break

11:00am Discussion on Data Issues
Harold Brooks, Chair

Part IV: Synthesis
Peter Höppe and Roger Pielke, Jr., Co-Chairs

11:30am Initial Remarks
- 5 minute perspectives
  - Epstein, Burton, Goklany, Jun
  - Dlugolecki, Muir-Wood, Palutikof, Zapata-Marti

12:30pm Lunch

2:00pm Synthesis Forum
Peter Höppe and Roger Pielke, Jr., Co-Chairs

5:00pm Closing remarks and Adjourn

Saturday, 27 May 2006

9:30am Workshop Organizing Team Executive Session

Workshop on Climate Change and Disaster Losses:
Understanding and Attributing Trends and Projections

http://sciencepolicy.colorado.edu/sparc/research/projects/extreme_events/munich_workshop/index.html