Topic 1 – Observed changes in climate and its effects
(31 August 2007)

1.1 Observations of climate change

Since the TAR, progress in understanding how climate is changing in space and time has been gained through improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements. {WGI SPM}

Definitions of climate change

Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (Figure 1.1). {WGI 3.2, 4.8, 5.2, SPM}

Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 1906-2005 linear trend of global surface temperature was 0.74 [0.56 to 0.92]°C per century (Figure 1.1). The linear warming trend over the 50 years 1956-2005 (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the 100 years 1906-2005. {WGI 3.2, SPM}

The temperature increase is widespread over the globe, and is greater at higher northern latitudes (Figure 1.2). Average Arctic temperatures have increased at almost twice the global average rate in the past 100 years. Land regions have warmed at a faster rate than the oceans. Surface air temperatures over land have increased at about 0.27ºC per decade in the past two decades, with the greatest warming in winter and spring in the Northern Hemisphere. Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000 m and that the ocean has been taking up over 80% of the heat being added to the climate system. New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates similar to those observed in surface temperature. {WGI 3.2, 3.4, 5.2, 5.5, SPM}

Observed decreases in snow and ice extent are consistent with warming (Figure 1.1). Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. Mountain glaciers and snow cover on average have declined in both hemispheres. The maximum areal extent of seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with decreases in spring of up to 15%. Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic by up to 3°C. {WGI 3.2, 4.5, 4.6, 4.7, 4.8, 5.5, SPM}

Increases in sea level are also consistent with warming (Figure 1.1). Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003 and at an average rate of about 3.1 [2.4 to 3.8] mm per year from 1993 to 2003. Whether this faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer term trend is unclear. Since 1993 thermal expansion of the oceans has contributed about 57% of the sum of the estimated individual contributions to the sea level rise, with decreases in glaciers and ice-caps contributing about 28% and losses from the polar ice sheets contributing the remainder. From 1993 to 2003 the sum of these climate contributions is consistent within uncertainties with the total sea level rise that is directly observed. {WGI 4.6, 4.8, 5.5, SPM, Table SPM.1}

Changes in temperature, sea level and Northern Hemisphere snow cover

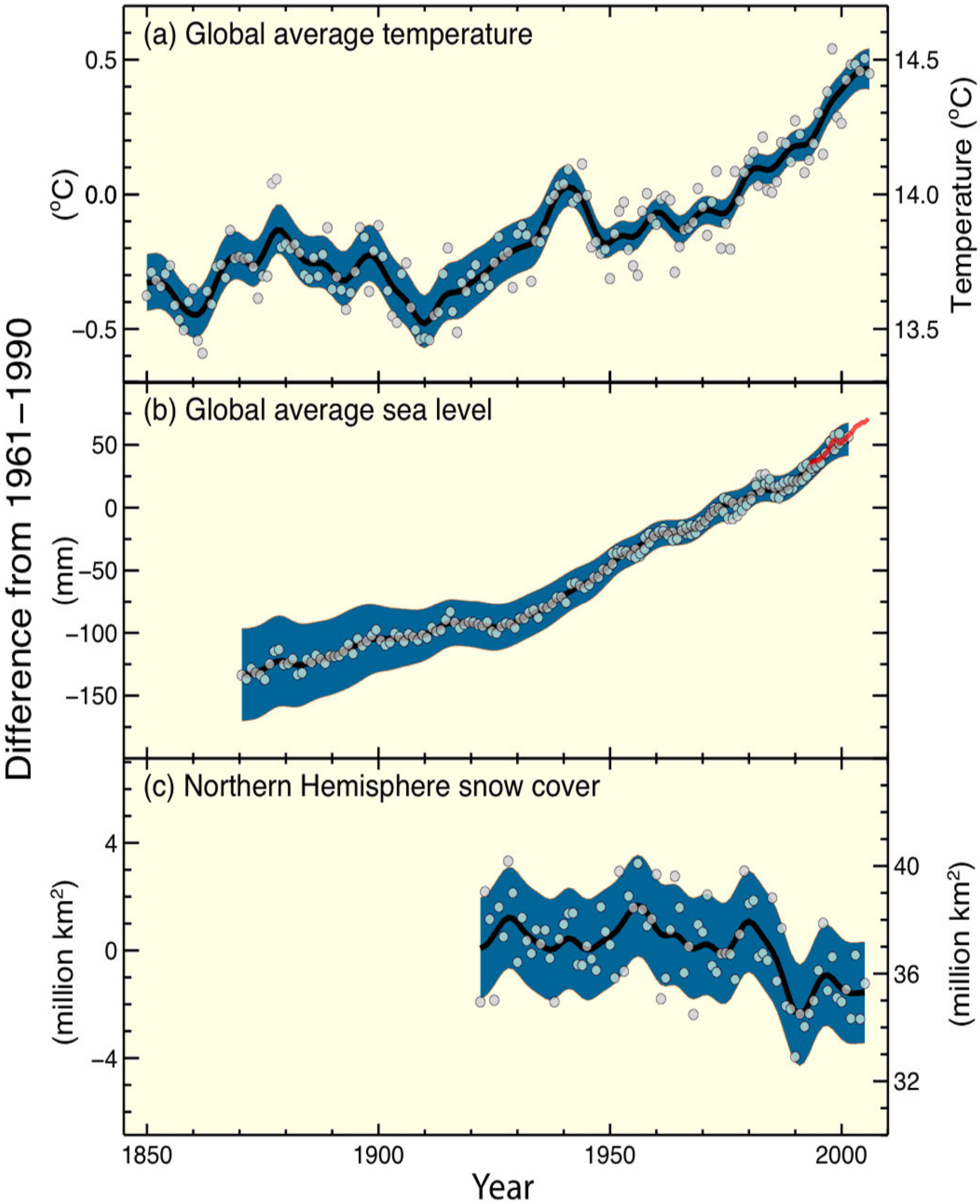

Figure 1.1. Observed changes in (a) global average surface temperature; (b) global average sea level rise from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {WGI FAQ 3.1 Figure 1, Figure 4.2 and Figure 5.13, Figure SPM.3}

At continental, regional, and ocean basin scales, numerous changes in other aspects of climate have also been observed. Trends from 1900 to 2005 have been observed in precipitation amount in many large regions. Over this period, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia whereas precipitation declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. The area affected by drought has *likely*[2] increased in many regions since the 1970s. {WGI 3.3, 3.9, SPM}

Some extreme weather events have changed in frequency or intensity:

- It is *very likely* that cold days, cold nights and frosts have become less frequent over most land areas, while hot days and hot nights have become more frequent. {WGI 3.8, SPM}
- It is *likely* that heat waves have become more frequent over most land areas. {WGI 3.8, SPM}
- It is *likely* that the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas. {WGI 3.8, 3.9, SPM}
- It is *likely* that the incidence of extreme high sea level (excluding tsunamis) has increased at a broad range of sites worldwide since 1975. {WGI 5.5, SPM}

There is observational evidence for an increase in intense tropical cyclone activity in the North Atlantic since about 1970, and suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. {WGI 3.8, SPM}

Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years. {WGI 6.6, SPM}

1.2 Observed effects of climate changes

The statements presented here are based largely on data sets that cover the period since 1970. The number of studies of observed trends in the physical and biological environment and their relationship to regional climate changes has increased greatly since the TAR. The quality of the data sets has also improved. There is a notable lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries. {WGII SPM}

These studies have allowed a broader and more confident assessment of the relationship between observed warming and impacts than was made in the TAR. That Assessment concluded that "there is *high confidence*[2] that recent regional changes in temperature have had discernible impacts on physical and biological systems". {WGII SPM}

Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. {WGII SPM}

There is *high confidence* that natural systems related to snow, ice and frozen ground (including permafrost) are affected. Examples are:

- enlargement and increased numbers of glacial lakes {WGII 1.3, SPM}

[2] Likelihood and confidence statements in italics represent calibrated expressions of uncertainty and confidence. See Box 'Treatment of uncertainty' in the Introduction for an explanation of these terms.

- increasing ground instability in permafrost regions, and rock avalanches in mountain regions {WGII 1.3, SPM}
- changes in some Arctic and Antarctic flora and fauna, including those in sea-ice biomes, and predators at high levels of the food web. {WGII 1.3, 4.4, 15.4, SPM}

Based on growing evidence, there is *high confidence* that the following effects on hydrological systems are occurring: increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers; and warming of lakes and rivers in many regions, with effects on thermal structure and water quality. {WGII 1.3, 15.2, SPM}

There is *very high confidence*, based on more evidence from a wider range of species, that recent warming is strongly affecting terrestrial biological systems**,** including such changes as: earlier timing of spring events, such as leaf-unfolding, bird migration and egg-laying; and poleward and upward shifts in ranges in plant and animal species. Based on satellite observations since the early 1980s, there is *high confidence* that there has been a trend in many regions towards earlier 'greening' of vegetation in the spring linked to longer thermal growing seasons due to recent warming. {WGII 1.3, 8.2, 14.2, SPM}

There is *high confidence*, based on substantial new evidence, that observed changes in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels, and circulation. These include: shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans; increases in algal and zooplankton abundance in high-latitude and high-altitude lakes; and range changes and earlier fish migrations in rivers. While there is increasing evidence for climate change impacts on coral reefs, separating the impacts of climate-related stresses from other stresses (e.g. over-fishing and pollution) is difficult. {WGII 1.3, SPM}

Increasing atmospheric carbon dioxide (CO_2) concentrations lead to increasing acidification of the oceans. The average pH of near-surface seawater has fallen by 0.1 units since pre-industrial times, i.e. a 30% increase in the concentration of hydrogen ions in the near-surface seawater. However, the effects of observed ocean acidification on the marine biosphere are as yet undocumented. {WGI SPM, 5.4; WGII 1.3, SPM}

Other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers. {WGII SPM}

Effects of temperature increases have been documented with *medium confidence* in the following managed and human systems:

- agricultural and forestry management at Northern Hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbances of forests due to fires and pests {WGII 1.3, SPM}
- some aspects of human health, such as increased heat-related mortality in Europe, changes in infectious disease vectors in parts of Europe, and earlier onset of and increases in seasonal production of allergenic pollen season in Northern Hemisphere high and mid-latitudes {WGII 1.3, 8.2, 8.ES, SPM}
- some human activities in the Arctic (e.g. hunting and shorter travel seasons over snow and ice) and in lower-elevation alpine areas (such as limitations in mountain sports). {WGII 1.3, SPM}

Sea level rise and human development are together contributing to losses of coastal wetlands and mangroves and increasing damage from coastal flooding in many areas. However, based on the published literature, the impacts have not yet become established trends. {WGII 1.3, 1.ES, SPM}

1.3 Consistency of changes in physical and biological systems with warming

Changes in the ocean and on land, including observed decreases in snow cover and Northern Hemisphere sea ice extent, thinner sea ice, shorter freezing seasons of lake and river ice, glacier melt, decreases in permafrost extent, increases in soil temperatures and borehole temperature profiles, and sea level rise, provide additional evidence that the world is warming. {WGI 3.9}

Of the more than 29,000 observational data series, from 75 studies, that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming (Figure 1.2 and Table 1.1). {WGII 1.4, SPM}

Changes in physical and biological systems and surface temperature 1970-2004

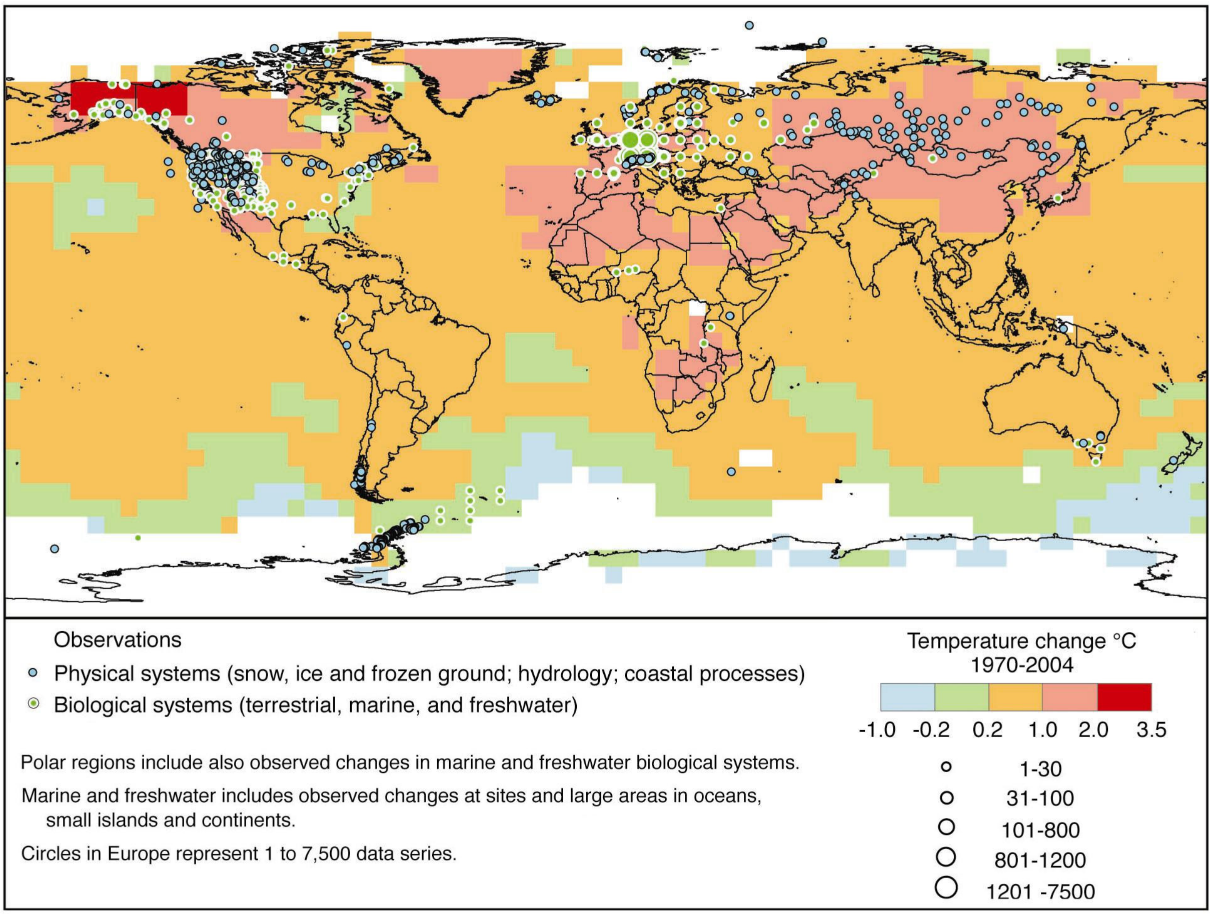

Figure 1.2. Locations of statistically significant changes in observations of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine, and freshwater biological systems) are shown together with surface temperature changes over the period 1970-2004 (from the GHCN-ERSST dataset). White regions do not contain sufficient observational climate data to estimate a temperature trend. A subset of about 29,000 data series was selected from about 80,000 data series from 577

studies. These met the following criteria: (1) ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies. The selected subset is from about 75 studies (of which ~70 are new since the TAR); about 28,000 data series are from European studies. Regions without dots have no time-series that meet the criteria; in these regions physical and biological systems may or may not be changing but are not documented. {WGII Figure SPM.1, 1.4, Figure 1.8}

Table 1.1. Number of physical and biological data series with significant changes and the percentage of those consistent with warming for terrestrial systems, and marine and freshwater systems. {WGII SPM, Figure SPM.1, 1.4, Figure 1.9}

	physical data series		biological data series	
	number of significant data series	% consistent with warming	number of significant data series	% consistent with warming
Terrestrial systems	764	94	28,586	90
Marine and freshwater systems	1	100	85	99

1.4 Some aspects of climate have not been observed to change

Some aspects of climate appear not to have changed, and for some data inadequacies mean that it cannot be determined if they are changing. Antarctic sea ice extent shows inter-annual variability and localised changes but no statistically significant average multi-decadal trend, consistent with the lack of rise in near-surface atmospheric temperatures averaged across the continent. There is insufficient evidence to determine whether trends exist in some other variables, for example the meridional overturning circulation of the global ocean or small-scale phenomena such as tornadoes, hail, lightning and dust-storms. There is no clear trend in the annual numbers of tropical cyclones. {WGI 3.2, 3.8, 4.4, 5.3, SPM}