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DRAFT SYNTHESIS REPORT:

Draft underlying longer part

(Submitted by the Chairman)

This part of the draft Synthesis Report is submitted to the Session for adoption.

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CLIMATE CHANGE 2001: SYNTHESIS REPORT

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QUESTION 1

What can scientific, technical, and socio-economic analyses contribute to the determination of what constitutes dangerous anthropogenic interference with the climate system as referred to in Article 2 of the Framework Convention on Climate Change?

Box 1-1. Framework Convention on Climate Change, Article 2

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

Paragraph Number | *Reference*

Paragraph	Reference
1.1 ***Natural, technical, and social sciences provide essential evidence needed for decisions on what constitutes "dangerous anthropogenic interference" with the climate system. However, in the end, the decisions are value judgments determined through socio-political processes, taking issues like development, equity, and sustainability into account.*** Scientific evidence helps to reduce uncertainty and increase knowledge, and can serve as an input for considering precautionary measures.[1] Such decisions are based on risk assessment, and lead to risk management choices by decisionmakers, about actions and policies.[2] [FOOTNOTE 1: Conditions which justify the adoption of precautionary measures are described in Article 3.3 of the Framework Convention on Climate Change (FCCC).] [FOOTNOTE 2: The risk associated with an event is most simply defined as the probability of that event, multiplied by the magnitude of its consequence. Various decision frameworks can facilitate climate risk assessment and management. These include, among others, cost-benefit analysis, cost-effectiveness analysis, multi-attribute analysis, and tolerable windows. Such techniques help to differentiate the risk levels associated with alternative futures, but in all cases, the analysis is marked by considerable uncertainties.]	• WGII TAR Section 2.7 • WGIII TAR Chapter 10 (see Table 10.1)
1.2 ***The basis for determining what constitutes "dangerous anthropogenic interference" will vary among regions, depending both on the local nature and consequences of climate change impacts, and also on the mitigative and adaptive capacity available to cope with climate change.*** The consequent types of adaptation responses that will be selected depend on the effectiveness of various adaptation or mitigation responses in reducing vulnerabilities and improving the sustainability of our life-support system. At the same time, the climate change problem requires a collective global determination and actions. There is no universal best set of policies; rather, it is important to consider both the robustness of different policy measures against a range of possible future worlds, and the degree to which such climate-specific policies can be integrated with broader sustainable development policies in particular regions.	
1.3 ***The TAR provides new scientific information and evidence for contributing to the determination of what constitutes "dangerous anthropogenic interference with the climate***	

system" with regard to: (1) the magnitudes and rates of changes in the climate system, (2) the ecological and socio-economic impacts of climate change, and (3) the potential for achieving different levels of concentrations through mitigation and information about how adaptation can reduce vulnerability.

1.4 ***With regard to changes in the climate system, the TAR provides projections of future concentrations of greenhouse gases in the atmosphere, global and regional patterns of temperatures and precipitation, sea levels, and changes in extreme climate events.*** It also explains that possibilities exist for abrupt and irreversible changes in ocean circulation and the major ice sheets.

1.5 ***The TAR reviews the biophysical and socio-economic impacts of climate change.*** The TAR articulates five reasons for concern, regarding:

- Risks to unique and threatened systems
- Risks associated with extreme weather events
- The distribution of impacts
- Aggregate impacts
- Risks of large-scale, high impacts events.

Of great significance here is an assessment of the likelihood of the critical thresholds at which natural and human systems exhibit large-scale, abrupt, or irreversible changes in their response to a changing climate. Since no single indicator (e.g., dollars) captures all relevant dimensions of the impacts, multiple approaches to evaluating impacts are called for.

- WGII TAR Chapter 19

1.6 ***With regard to strategies for addressing climate change, the TAR provides an assessment of the potential for achieving different levels of concentrations through mitigation and information about how adaptation can reduce vulnerability.*** The causality works in both directions. Different stabilization levels result from different emission scenarios, which are connected to underlying development paths. In turn, these development paths strongly affect adaptive capacity in any region. In this way adaptation and mitigation strategies are dynamically connected with changes in the climate system and the prospects for ecosystem adaptation, food production, and sustainable economic development.

- WGII TAR Chapter 18
- WGIII TAR Chapter 2

1.7 ***An integrated view of climate change considers the dynamics of the complete cycle of multiply-linked causes and effects across all sectors.*** Figure 1-1 shows the cycle, from the underlying driving forces of population, economy, technology, and governance, through GHG and other emissions, changes in the physical climate system, biophysical and human impacts, to adaptation and mitigation, and back to the driving forces. The figure presents a schematic view of an ideal "integrated assessment" framework, in which all the parts of the climate change problem interact mutually. Changes in one part of the cycle influence other components in a dynamic manner, through multiple paths. The TAR provides new policy-relevant information and evidence with regard to all quadrants of Figure 1-1. In particular, a new contribution has been to fill in the bottom right-hand quadrant of the figure by exploring alternative development paths and their relationship to greenhouse gas emissions, and by undertaking preliminary work on the linkage between adaptation, mitigation, and development paths. However, the TAR does not achieve a fully integrated assessment of climate change, because of the incomplete state of knowledge.

- SRES
- WGII TAR
- WGIII TAR

[FIGURE 1-1 CAPTION: Schematic and simplified representation of an integrated assessment framework for considering anthropogenic climate change. The arrows show a full clockwise cycle of cause and effect among the four quadrants shown in the figure. Each **socio-economic development path** explored in the SRES, including development of the industrialized countries, has driving forces which give rise to emissions of greenhouse gases, aerosols, and precursors—with CO_2 being the most important. The **emissions accumulate and interact in the atmosphere as concentrations** and disturb the natural balances, depending on physical processes such as solar radiation, cloud formation, and rainfall. The aerosols also give rise to air pollution (e.g., acid rain) that damage human and the natural systems (not shown). The long-term effect is to **change the climate** (the enhanced greenhouse effect). These climate changes, in turn, have **impacts on the natural and human systems**. There is a possibility of some feedback between the changes in these systems and the climate (not shown), such as albedo effects from changing land use, and other, perhaps larger interactions between the systems and atmospheric emissions [e.g., effects of changes in land use (again not shown)]. These changes will ultimately have effects on socio-economic development paths. The development paths also have direct effects on the natural systems (shown by the anti-clockwise arrow from the development box) such as changes in land use leading to deforestation. Several quadrants of the figure are also affected by inputs, such as solar radiation, from the larger systems in which they are located (not shown). This figure illustrates that the various dimensions of the climate change issue exist in a dynamic cycle, characterized by significant time delays. Both emissions and impacts, for example, are linked in complex ways to underlying socio-economic and technological development paths. A major contribution of the TAR has been to explicitly consider the bottom right-hand domain (shown as a rectangle) by examining the relationships between greenhouse gas emissions and development paths (in SRES), and by undertaking preliminary work on the linkage between adaptation, mitigation, and development paths (WGII and III). However, the TAR does not achieve a fully integrated assessment of climate change, since not all components of the cycle were able to be linked dynamically.]

1.8 ***Climate change impacts are part of the larger question of how complex social, economic, and environmental subsystems interact and shape prospects for sustainable development.*** There are multiple links. Economic development affects ecosystem balance and, in turn, is affected by the state of the ecosystem; poverty can be both a result and a cause of environmental degradation; material- and energy-intensive life styles and continued high levels of consumption and rapid population growth are not likely to be consistent with sustainable development paths; and extreme socio-economic inequality within communities and between nations may undermine the social cohesion that would promote sustainability and make policy responses more effective. At the same time, socio-economic and technology policy decisions made for non-climate-related reasons have significant implications for climate policy and climate change impacts, as well as for other environmental issues (see Question 8). In addition, critical impact thresholds, and vulnerability to climate change impacts, are directly connected to social and economic conditions, and institutional capacity.

- WGIII TAR Sections 1.3.4 & 2.2.3
- DES Guidance Paper

1.9 ***As a result, the effectiveness of climate policies can be enhanced when they are integrated with broader strategies designed to make national and regional development paths more sustainable.*** This occurs because climate impacts, climate policy responses, and associated socio-economic development will affect the ability of countries to achieve sustainable development goals, while the pursuit of those goals will in turn affect the opportunities for, and success of, climate policies. In particular, the socio-economic and technological characteristics of different development paths will strongly affect emissions, the rate and magnitude of climate change, climate change impacts, the capability to adapt, and the capacity to mitigate climate. The Special Report on Emissions Scenarios (see Box 3-1) outlined multiple plausible future worlds with different characteristics, each having very different implications for the future climate and for climate policy.

- WGIII TAR Section 10.3.2

1.10 ***The TAR provides information on some aspects of the timing, opportunities, costs, benefits, and impacts of various mitigation and adaptation options.*** It indicates that there are opportunities for countries acting individually, or in cooperation with others, to reduce costs of mitigation and adaptation and realize benefits associated with achieving sustainable development.

FIGURE 1-1

SEE PAGE 2 LINE 48 – PAGE 3 LINE 21 FOR FIGURE CAPTION

Color version can be downloaded at <http://www.metoffice.com/sec5/CR_div/ipcc/wg1/drafts/>
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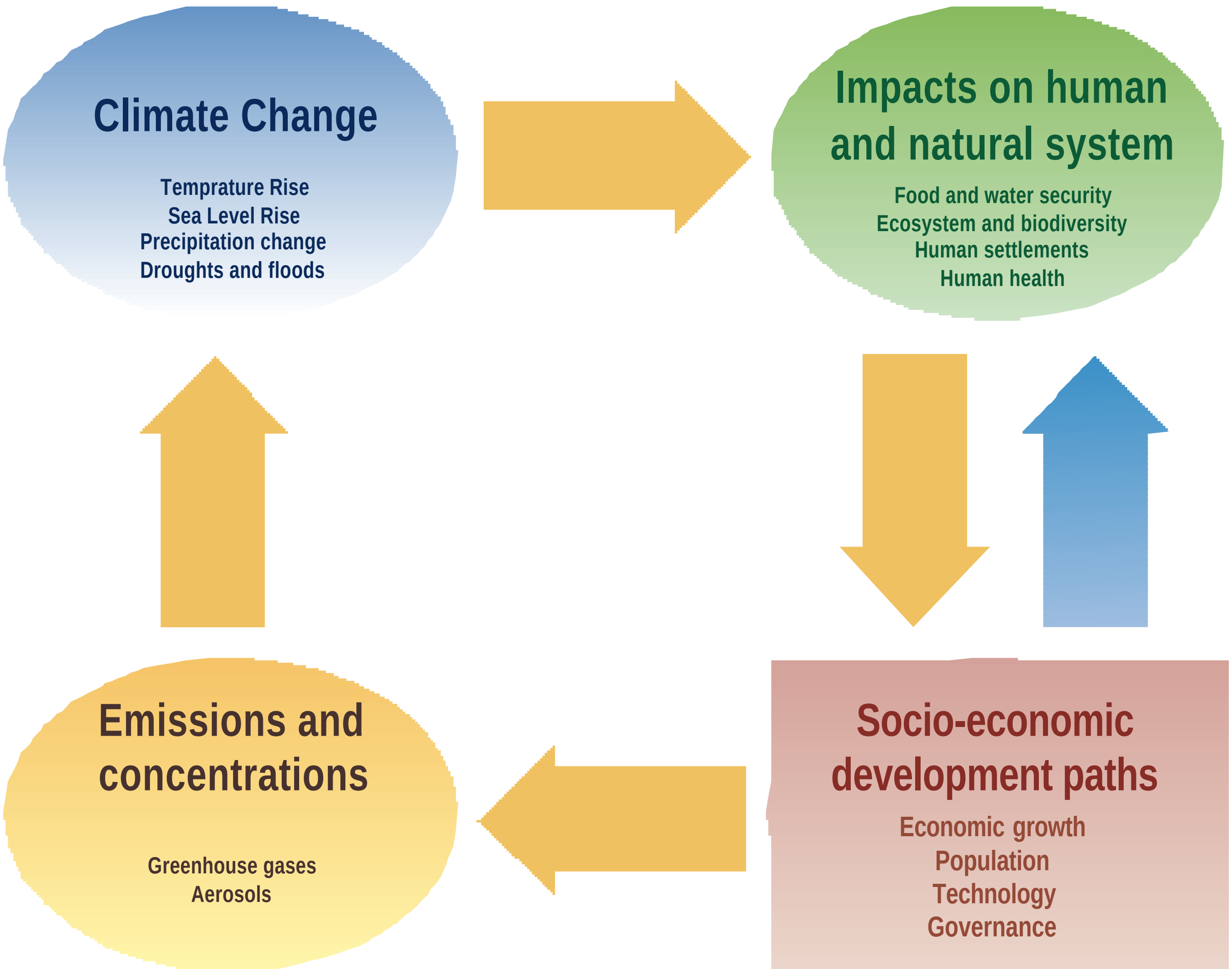

QUESTION 2

What is the evidence for, causes of, and consequences of changes in the Earth's climate since the pre-industrial era? (a) Has the Earth's climate changed since the pre-industrial era at the regional and/or global scale? If so, what part, if any, of the observed changes can be attributed to human influence and what part, if any, can be attributed to natural phenomena? What is the basis for that attribution? (b) What is known about the environmental, social, and economic consequences of climate changes since the pre-industrial era with an emphasis on the last 50 years?

Paragraph Number		*Reference*
2.1	This answer focuses on classical measures of climate (e.g., temperature, precipitation, sea level, plus extreme events including floods, droughts, and storms), on other components of the Earth's climate system (e.g., greenhouse gases and aerosols, ecological systems), and on human health and socio-economic sectors. Climate change as defined in IPCC refers to statistically significant variations that persist for an extended period, typically decades or longer. It includes shifts in the frequency and magnitude of sporadic weather events as well as the slow continuous rise in global mean surface temperature. Thus the discussion here includes climate-weather variations on all temporal and spatial scales, ranging from brief-lived severe storms to seasonal El Niños, decadal droughts, and century shifts in temperature and ice cover. Although short-term climate variations are considered predominantly natural at present, their impacts are discussed in this question because they represent a class of changes that may become more prevalent in a future climate perturbed by human activities (see Question 4). Attribution is used here as the process of establishing the most likely causes for the detected change with some defined level of confidence. The discussion includes climate change that is both attributable to human influence and that may at present be natural but might in the future be attributable to human influence.	
2.2	**The Earth's climate system has demonstrably changed on both global and regional scales since the pre-industrial era, with some of these changes attributable to human influence.**	
2.3	**Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate (see Table 2-1).** [Insert Table 2-1 here]	
2.4	***Concentrations of atmospheric greenhouse gases and their radiative forcings have generally increased over the 20th century as a result of human activities.*** Almost all greenhouse gases reached their highest concentrations yet recorded as of year 2000 during the 1990s and continue to increase (see Figure 2-1). Atmospheric CO_2 and CH_4 have varied substantially during glacial-interglacial cycles over the past 420,000 years, but even the largest of these earlier values are much less than their current atmospheric concentrations. In terms of radiative forcing by greenhouse gases emitted through human activity, CO_2 and CH_4 are the first and second most important, respectively. From 1750 to 2000, the concentration of CO_2 increased by 31 ± 4%, and that of CH_4 rose by 150 ± 25% (see Box 2-1 and Figure 2-1). These rates of increase over the past century are unprecedented when compared with the past 20,000 years for which nearly a continuous record exists. Fossil-fuel burning released on average 5.4 Gt C yr^{-1} during the 1980s, increasing to 6.3 Gt C yr^{-1} during the 1990s. About three-quarters of the increase in atmospheric CO_2 during the 1990s was caused by fossil-fuel burning, with land-use change including deforestation responsible for the rest. Over the 19th	• WGI TAR Chapters 3 & 4 • SRAGA

and much of the 20th century the terrestrial biosphere has been a net source of atmospheric CO_2, but by the 1990s it had become a net sink. The increase in CH_4 can be identified with emissions from energy use, livestock, rice agriculture, and landfills. Increases in the concentrations of other greenhouse gases, particularly tropospheric ozone, the third most important, are directly attributable to fossil-fuel combustion as well as other industrial and agricultural emissions.

[FIGURE 2-1 CAPTION: Records of past changes in atmospheric composition, extending from centuries to millennia, demonstrate the rapid rise in greenhouse gases and sulfate aerosols that is attributable primarily to industrial growth since 1750. Top three panels show increasing atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) over the past 1000 years. Early sporadic data taken from air trapped in ice cores and firn matches up with continuous atmospheric observations from recent decades. These gases are well mixed in the atmosphere, and their concentrations reflect emissions from sources throughout the globe. The estimated positive radiative forcing of the climate system from these gases is indicated on the right-hand scale. Lowest panel shows the concentration of sulfate in ice cores from Greenland (shown by lines for three different cores) from which the episodic effects of volcanic eruptions have been removed. Sulfate aerosols form from SO_2 emissions, deposit readily at the surface, and are not well mixed in the atmosphere. Specifically, the increase in sulfate deposited at Greenland is attributed to SO_2 emissions from the U.S. and Europe (shown as blue dots), and both show a decline in recent decades. Sulfate aerosols produce negative radiative forcing.]

- WGI TAR Figures SPM-2, 3-2b, 4.1ab, 4-2, & 5.4a

Box 2-1 The following words have been used throughout the text of the Synthesis Report to the TAR where appropriate to indicate judgmental estimates of the likelihood probability from WGI: *virtually certain* (greater than 99% chance that a result is true); *very likely* (90-99% chance); *likely* (66-90% chance); *medium likelihood* (33-66% chance); *unlikely* (10-33% chance); *very unlikely*(1-10% chance); *exceptionally unlikely* (less than 1% chance). An explicit uncertainty range (±) is a *likely* range. Judgmental estimates of confidence in a result are taken from WGII: very high (95% or greater), high (67-95%), medium (33-67%), low (5-33%), and very low (5% or less).

2.5 ***The radiative forcing of climate change since the pre-industrial era has likely been positive and driven by human activities.*** Radiative forcing continues to be a useful tool to estimate the global-mean surface temperature response to human and natural perturbations. Greenhouse gases trap the heat radiated from the lower atmosphere and surface of the planet, generating a positive (warming) radiative forcing. Compared with 1750 the radiative forcing in year 2000 from the primary anthropogenic greenhouse gases (CO_2, CH_4, N_2O, halocarbons, tropospheric and stratospheric O_3) is positive and estimated as +2.6 ± 0.3 W m^{-2} (see Figure 2-2; individual ± ranges in forcing treated as *likely* and summed). Aerosols generally enhance the reflection of sunlight and tend to cool the Earth's surface. Compared with 1750, the major anthropogenic aerosols [sulfates, biomass-burning organic, fossil-fuel organic and black carbon (soot)] have a direct radiative forcing that is negative, -0.5 (-0.3 to -0.9) W m^{-2}. Aerosols also have a potentially large and negative forcing from their indirect effects on clouds and hydrological cycle that are estimated to range from 0 to -2 W m^{-2}. Natural agents have contributed small amounts to changes in radiative forcing over the 20th century. For example, changes in the radiant energy emitted from the sun since 1750 are estimated to be +0.3 ± 0.2 W m^{-2} and occurred predominantly during the first half of the 20th century. Stratospheric aerosols from large volcanic eruptions have led to important, but brief-lived, negative forcings, particularly the periods about 1880 to 1920 and 1963 to 1994. The sum of these natural forcings has been negative over the past 2, and possibly even 4, decades; whereas the positive forcing due to well-mixed greenhouse gases has increased rapidly over the past 4 decades.

- WGI TAR Chapter 5
- SRAGA Chapter 6

[FIGURE 2-2 CAPTION: Forcing of the climate system in year 2000 relative to 1750 is dominated by the positive radiative forcing from greenhouse gases, but uncertainties in aerosol indirect effects preclude accurate estimates of the total anthropogenic radiative forcing. Factors external to the climate alter the radiative balance and force climate change: for example, changes in the atmospheric concentration of greenhouse gases and aerosols, formation of contrails and cirrus by aircraft, regional changes (anthropogenic or natural) that alter the generation of airborne dust particles or the reflectance of land (albedo), natural variations in solar output, and irregular, brief-lived stratospheric aerosol layers from large volcanoes (not shown). The magnitude of this forcing is calculated as a global mean radiative forcing in Watts per square meter (W m^{-2}) with positive values warming on average and negative values cooling. The height of a bar indicates a best estimate of the forcing, and the accompanying vertical line, a *likely* range of values. Where no bar is present (mineral dust and aerosol indirect effect) the vertical line only indicates the range in best estimates with no likelihood. One indirect effect of aerosols on the size and number of cloud droplets is shown, but a second indirect effect on cloud lifetime (also negative) is less well understood and not shown. The level of scientific understanding for each type of forcing varies considerably, as noted.]

• WGI TAR Figures SPM-3 & 6-6

2.6 **An increasing body of observations gives a collective picture of a warming world and other changes in the climate system (see Table 2-1).**

2.7 ***The global-average surface temperature has increased from the 1860s to 2000, the period of instrumental record.*** Over the 20th century this increase was 0.6°C with a *very likely* (see Box 2-1) confidence range of 0.4–0.8°C (see Figure 2-3a). It is very likely that the 1990s was the warmest decade, and 1998 the warmest year, of the instrumental record. Extending the instrumental record with proxy data for the Northern Hemisphere indicates that over the past 1000 years the 20th century increase in temperature is likely to have been the largest of any century, and the 1990s was likely the warmest decade (see Figure 2-3b). Insufficient data are available to assess such changes in the Southern Hemisphere. Since 1950 the increase in sea surface temperature is about half that of the mean land surface air temperature, and the nighttime daily minimum temperatures over land have increased on average by about 0.2°C per decade, about twice the corresponding rate of increase in daytime maximum air temperatures. These climate changes have lengthened the frost-free season in many mid- and high-latitude regions.

• WGI TAR SPM & Chapter 2

[FIGURE 2-3 CAPTION: The Earth's surface temperature has increased by about 0.6ºC over the record of direct temperature measurements (1860–2000, top panel), a rise that is unprecedented, at least based on proxy temperature data for the Northern Hemisphere, over the last millennium (bottom panel). In the top panel the global mean surface temperature is shown year-by-year (red bars with *very likely* ranges as thin black whiskers) and approximately decade-by-decade (continuous red line). Analyses take into account data gaps, random instrumental errors and uncertainties, uncertainties in bias corrections in the ocean surface temperature data, and also in adjustments for urbanization over the land. The lower panel merges proxy data (year-by-year blue line with *very likely* ranges as gray band, 50-year-average purple line) and the direct temperature measurements (red line) for the Northern Hemisphere. The proxy data consist of tree rings, corals, ice cores, and historical records that have been calibrated against thermometer data. Insufficient data are available to assess such changes in the Southern Hemisphere.]

• WGI TAR Figures SPM-1, 2-7c, & 2-20

2.8 ***In the lowest 8 km of the atmosphere the global temperature increase from the 1950s to 2000, about 0.1°C per decade, has been similar to that at the surface***. For the period 1979–2000 both satellite and weather balloon measurements show nearly identical warming over North America (0.3ºC per decade) and Europe (0.4ºC per decade) for both surface and lower atmosphere, but distinct differences over some land areas and particularly in the

• WGI TAR SPM & Section 2.2.4

tropical regions (+0.10 ± 0.10°C per decade for surface versus -0.06 ± 0.16°C per decade for the lower atmosphere). Temperatures of the surface and lower atmosphere are influenced differently by factors such as stratospheric ozone depletion, atmospheric aerosols, and the El Niño phenomenon. In addition, spatial sampling techniques can also explain some of the differences in trends, but these differences are not fully resolved.

2.9 **There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.**

2.10 ***The observed warming over the 20th century is unlikely to be entirely natural in origin***. The increase in surface temperatures over the last 100 years is very unlikely to be due to internal variability alone. Reconstructions of climate data for the last 1000 years also indicate that this 20th century warming was unusual and unlikely to be the response to natural forcing alone; that is, volcanic eruptions and variation in solar output do not explain the warming in the latter half of the 20th century (see Figure 2-4a), but they may have contributed to the observed warming in the first half.

- WGI TAR SPM & Chapter 12

[FIGURE 2-4 CAPTION: Natural forcing and internal variability alone cannot explain the rise in global mean surface temperature over the last 50 years, but climate models combining anthropogenic and natural forcing factors match the observed record. Temperature anomalies (°C) from an ensemble of climate model simulations (gray band) are compared with observations (red line) for the period of instrumental record (1860–2000) (from Figure 2-3a). Model simulations in the left panel with only natural forcings (solar output variations and volcanic activity) can explain part of the rise in the first half of the 20th century but not the rise in the last half. Adding the anthropogenic forcing from greenhouse gases and sulfate aerosols to the natural forcing in the right panel can now explain the rapid rise in temperature over the last half of the 20th century. While anthropogenic greenhouse gases and sulfate aerosols are sufficient to explain the observed changes, they do not exclude a possible role for the other non-sulfate aerosols in driving temperature change over the 20th century.]

- WGI TAR Figure 12-7

2.11 ***In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations***. Detection and attribution studies (including greenhouse gases and sulfate aerosols as anthropogenic forcing) consistently find evidence for an anthropogenic signal in the climate record of the last 50 years, despite uncertainties in forcing due to anthropogenic sulfate aerosols and natural factors (volcanoes and solar irradiance). The sulfate and natural forcings are negative over this period and are unlikely to explain the warming (see Figure 2-4a). Most models that take into account both greenhouse gases and sulfate aerosols are consistent with observations over the last 50 years, and the best agreement for the 1860–2000 record is found when the above anthropogenic and natural forcing factors are combined (see Figure 2-4b). This result does not exclude the possibility that other forcings may also contribute. Some anthropogenic factors [e.g., organic carbon, black carbon (soot), biomass aerosols, and some changes in land use], however, have not been used in these detection and attribution studies. Estimates of the magnitude and geographic distribution of these additional anthropogenic forcings vary considerably.

- WGI TAR SPM & Chapter 12

2.12 ***Some other observed changes are in the same direction as simulated in model projections forced with increasing greenhouse gases.*** Most of these changes are regional, and hence it is more difficult to attribute them to the global human influence rather than to internal variations, natural forcings, or regional human activities. For example, the retreat of most non-polar glaciers has occurred in parallel with regional warming but has not been formally attributed.

- WGII TAR Section 4.3.11

2.13 **Changes in sea level, snow cover, ice extent, and precipitation are consistent with a warming climate near the Earth's surface (see Table 2-1).**

2.14 ***It is very likely that the 20th century warming has contributed significantly to the observed rise in global-average sea level and increase in ocean heat content***. Warming drives sea-level rise through thermal expansion of seawater and widespread loss of land ice. Based on the few, very long, tide gauge records, the average annual rise was between 1 and 2 mm during the 20th century and was less during the 19th century (see Figure 2-5). The observed rate of sea level rise during the 20th century is consistent with models. Global ocean heat content has increased since the late 1950s, the period with adequate observations of sub-surface ocean temperatures.

- WGI TAR Sections 2.2.2.5 & 11.2.1

[FIGURE 2-5 CAPTION: A limited number of sites in northern Europe have nearly continuous records of sea level spanning 300 years and show the greatest rise in sea level over the 20th century. Records from Amsterdam, The Netherlands, Brest, France, and Swinoujscie, Poland (formerly Swinemunde, Germany) as well as other sites confirm the accelerated rise in sea level over the 20th century as compared to the 19th.]

- WGI TAR Figure 11-7

2.15 ***Snow cover and ice extent have decreased***. It is very likely that the extent of snow cover has decreased by about 10% since the late 1960s and that the annual duration of lake- and river-ice cover in the mid- and high-latitudes of the Northern Hemisphere has been reduced by about 2 weeks over the 20th century. There has also been a widespread retreat of mountain glaciers in non-polar regions during the 20th century. It is likely that Northern Hemisphere spring and summer sea-ice extent has decreased by about 10 to 15% from the 1950s to 2000 and that Arctic sea-ice thickness has declined by about a 40% during late summer and early autumn in the last 3 decades of the 20th century. While there is no change in overall Antarctic sea-ice extent from 1975 to 2000 in parallel with global warming, regional warming in the Antarctic Peninsula coincided with the collapse of the Prince Gustav and parts of the Larsen ice shelves during the 1990s.

- WGI TAR Chapter 2

2.16 ***Precipitation has very likely increased during the 20th century by 5 to 10% over most mid- and high-latitudes of the Northern Hemisphere continents,*** but in contrast, rainfall has likely decreased by 3% on average over much of the sub-tropical land areas (see Figure 2-6a). Increasing global surface temperatures are very likely to lead to changes in precipitation and atmospheric moisture because of changes in atmospheric circulation, a more active hydrologic cycle, and increases in the water-holding capacity throughout the atmosphere. There has likely been a 2 to 4% increase in the frequency of heavy precipitation events in the mid- and high-latitudes of the Northern Hemisphere over the latter half of the 20th century. There were relatively small long-term increases over the 20th century in land areas experiencing severe drought or severe wetness, but in many regions these changes are dominated by inter-decadal and multi-decadal climate variability with no significant trends evident over the 20th century.

- WGI TAR Sections 2.5, 2.7.2.2, & 2.7.3

[FIGURE 2-6A CAPTION: Precipitation during the 20th century has on average increased over continents outside the tropics but decreased in the desert regions of Africa and South America. While the record shows an overall increase consistent with warmer temperatures and more atmospheric moisture, trends in precipitation vary greatly from region to region and are only available over the 20th century for some continental regions. Over this period, there were relatively small long-term trends in land areas experiencing severe drought or severe wetness, but in many regions these changes are dominated by inter-decadal and multi-decadal climate variability that has no trends evident over the 20th century.]

- WGI TAR Figure 2-25

2.17 **Changes have also occurred in other important aspects of climate (see Table 2-1).**

2.18 **Over the 20th century there has been a consistent, large-scale warming of both the land and ocean surface, with largest increases in temperature over the mid and high latitudes of northern continents.** The warming of land surface faster than ocean surface from 1976 to 2000 (see Figure 2-6b) could be in part a signal of anthropogenic warming; however, a component of the pattern of warming at northern mid-latitudes appears to be related to the North Atlantic and Arctic oscillations in climate. As described below, statistically significant associations between regional warming and observed changes in biological systems have been documented in freshwater, terrestrial, and marine environments on all continents.

- WGI TAR Section 2.2.2.4
- WGII TAR Sections 5.2.1, 5.4, & 6.3

[FIGURE 2-6B CAPTION: A consistent, large-scale warming of both the land and ocean surface occurred over the last quarter of the 20th century, with largest temperature increases over the mid and high latitudes of North America, Europe, and Asia. Large regions of cooling occurred only in parts of the Pacific and Southern Oceans and Antarctica. The warming of land faster than ocean surface could be in part a signal of anthropogenic warming; however, a component of the pattern of warming at northern mid-latitudes appears to be related to the North Atlantic and Arctic oscillations in climate. As described in the text, warming in some regions is linked with observed changes in biological systems on all continents.]

- WGI TAR Figure 2-9d

2.19 ***Warm episodes of the El Niño/Southern Oscillation (ENSO) phenomenon have been more frequent, persistent, and intense since the mid-1970s, compared with the previous 100 years.*** ENSO consistently affects regional variations of precipitation and temperature over much of the tropics, sub-tropics, and some mid-latitude areas. It is not obvious from models, however, that a warmer world would have a greater frequency of occurrence of El Niños.

- WGI TAR Chapter 2

2.20 ***Some important aspects of climate appear <u>not</u> to have changed.*** A few areas of the globe have not warmed in recent decades, mainly over some parts of the Southern Hemisphere oceans and parts of Antarctica (see Figure 2-6b). No significant trends in overall Antarctic sea-ice extent are apparent since 1978, the period of reliable satellite measurements. Current analyses are unable to draw conclusions about the likelihood of changes in storm activity or in the frequency of tornadoes, thunder days, or hail events for the limited regions that have been studied.

- WGI TAR Chapter 2

2.21 **Regional climate shifts over the past 50 years have affected biological and hydrological systems in many parts of the world (see Table 2-1).**

2.22 ***There has been a discernible impact of regional climate change, particularly increases in temperature, on biological systems in the 20th century.*** In many parts of the world the observed changes in these systems, either anthropogenic or natural, are coherent across diverse localities and are consistent in direction with the expected effects of regional changes in temperature. The probability that the observed changes in the expected direction could occur by chance alone is negligible. Such systems include, for example, species distributions, population sizes, and the timing of reproduction or migration events. These observations implicate regional climate change as a prominent contributing causal factor. There have been observed changes in the types (e.g., fires, droughts, blowdowns), intensity, and frequency of disturbances that are affected by regional climatic change (either anthropogenic or natural) and land-use practices, and they in turn affect the productivity of and species composition within an ecosystem, particularly at high latitudes and high altitudes. Frequency of pests and disease outbreaks have also changed especially in forested systems and can be linked to changes in climate. In some regions of Africa, the combination of regional climate changes (ENSO, Sahelian drought) and anthropogenic stresses has led to decreased cereal crop production since 1970. There are some positive aspects of warming, for example, the growing season across Europe has lengthened by about 11 days from 1959 to 1993.

- WGII TAR Figure SPM-2 & Sections 5.4, 5.6.2, 5.6.2.2, 10.1.3.2, 11.2, & 13.1.3.1

2.23 ***Coral reefs are adversely affected by rising sea surface temperatures.*** Increasing sea surface temperatures have been recorded in much of the tropical oceans over the past several decades. Many corals have undergone major, although often partially reversible, bleaching episodes when sea surface temperatures rise by 1°C in any one season; and extensive mortality occurs for a 3°C rise. This typically occurs during El Niño events and is exacerbated by rising sea surface temperatures. These bleaching events are often associated with other stresses such as pollution.	• WGII TAR Sections 6.4.5, & 17.4.2.4.1
2.24 ***Changes in marine systems, particularly fish populations, have been linked to large-scale climate oscillations.*** The El Niño affects fisheries off the coasts of South America and Africa and the decadal oscillations in the Pacific are linked to decline of fisheries off the west coast of North America.	• WGI TAR Section 2.6.3 • WGII TAR Sections 10.2.2.2, 14.1.3, & 15.2.3.3
2.25 ***Changes in stream flow, floods, and droughts have been observed.*** Evidence of regional climate change impacts on elements of the hydrological cycle suggest that warmer temperatures lead to intensification of the hydrological cycle. Peak stream flow has shifted back from spring to late winter in large parts of eastern Europe, European Russia, and North America in the last decades. The increasing frequency of droughts and floods in some areas is related to variations in climate—for example, droughts in Sahel and in northeast and southern Brazil, and floods in Colombia and northwest Peru.	• WGI TAR SPM • WGII TAR SPM, Table 4-6, & Sections 4.3.6, 10.2.1.2, 10.2.5.3, 14.3, & 19.2.2.1
2.26 ***Extreme weather or climatic events cause substantial damage.*** Extreme events are currently a major source of climate-related impacts. For example, heavy losses of human life, property damage, and other environmental damages were recorded during the El Niño of 1997–98. The impacts of climatic extremes and variability are a major concern, and the uneven impacts of climatic hazards raise issues for development and equity.	• WGII TAR SPM & Sections 8.5.4, 14.2.5, & 14.3
2.27 **The socio-economic costs related to weather damage and to variations in climate suggest increasing vulnerability to climate change (see Table 2-1).**	
2.28 ***Extreme weather events worldwide are causing increasing damage.*** Preliminary indications suggest that some social and economic systems have been affected by recent increases in floods and droughts, with apparent increases in insurance losses. Because these systems are also affected by changes in socio-economic factors such as demographic shifts and land-use changes, quantifying the relative impacts of climate change (either anthropogenic or natural) and of socio-economic factors is difficult. For example, direct costs of global catastrophic weather-related losses, corrected for inflation, have risen 10-fold from the 1950s to the 1990s (see Figure 2-7), and costs for non-catastrophic weather events are equivalent. The catastrophic losses over the past 50 years cannot be fully explained by inflation, demographic	• WGII TAR SPM & Section 8.2.1

change, and/or increases in insured value. The number of weather-related catastrophic events has risen three times faster than the number of non-weather-related events, despite generally enhanced disaster preparedness.

[FIGURE 2-7 CAPTION: The economic losses from catastrophic weather events have risen globally 10-fold (inflation-adjusted) from the 1950s to the 1990s, much faster than can be accounted for with simple inflation. The insured portion of these losses rose from a negligible level to about 23% in the 1990s. The total losses from small, non-catastrophic weather-related events (not included here) are equivalent. This rise in weather-related losses over the last half of the 20th century cannot be fully explained by inflation, demographic change, and/or increases in insured value, but quantifying the relative impacts of climate change (either anthropogenic or natural) and of socio-economic factors is difficult.]

- WGII TAR Figure 8-1

2.29 ***Climate-related health effects are observed.*** Many vector-, food-, and water-borne infectious diseases are known to be sensitive to changes in climatic conditions. Extensive experience makes clear that any increase in floods will increase the risk of drowning, diarrheal and respiratory diseases, water-contamination diseases, and in developing countries hunger and malnutrition (high confidence). Heat waves in Europe and North America are associated with a significant increase in urban mortality, but warmer wintertime temperatures also result in reduced wintertime mortality. In some cases health effects are clearly related to recent climate changes, such as in Sweden where tick-borne encephalitis incidence increased after milder winters and moved northward following the increased frequency of milder winters from 1980 to 1994.

- WGII TAR SPM & Sections 9.5.1, 9.7.8, & 13.2.5

2.30 ***The fraction of weather-related losses covered by insurance varies considerably by region***, with insurers paying only 5% of total economic losses today in Asia and South America, 10% in Africa, and about 30% in Australia, Europe, and North and Central America. The fraction covered is typically much higher when just storm losses are considered, but flood- and crop-related losses have much lower coverage. The balance of the losses are absorbed by governments and affected individuals and organizations.

- WGII TAR Section 8.3.3.1

2.31 **The recognition and anticipation of adverse impacts of climate change has led to both public and governmental responses.**

2.32 ***Socioeconomic and policy responses to anticipated changes in the climate system have included various initiatives to mitigate greenhouse gas emissions in the last decade.*** These have included stimulation of the renewable energy market; development of energy efficiency improvement programs enhanced by climate change concerns; integration of climate policies into broader national policies; carbon taxes in several countries; domestic greenhouse gases trading regimes in some countries; national and international voluntary agreements with industries to increase energy efficiency or otherwise decrease greenhouse gas emissions; creation of carbon exchange markets; public and political pressures for utilities to reduce or offset carbon emissions from new energy projects; industry reconnaissance into approaches to offset carbon emissions; and establishment of programs in the developing countries for creating tradable, independently certified sequestration activities.

- WGIII TAR Sections 3.2, 3.4, 3.5, 3.8.4.3, 6.2.2, 6.3.2, & 9.2.1

Table 2-1: *20th century changes in the Earth's atmosphere, climate, and biophysical system.**

Indicator	Observed Changes
Atmospheric concentration of CO_2	280 ppm for 1000-1750 to 368 ppm in 2000 (31±4% increase) [WGI TAR Chapter 3]
Terrestrial biospheric CO_2 uptake	Cumulative source of about 30 GtC between 1800 and 2000; but during the 1990s, a net sink of about 14 GtC (consisting of large global uptake less emissions from deforestation) [SRLUCF Figure 4-4]
Atmospheric concentration of CH_4	700 ppb for 1000-1750 to 1750 ppb in 2000 (150±25% increase) [WGI TAR Chapter 4]
Atmospheric concentration of N_2O	270 ppb for 1000-1750 to 316 ppb in 2000 (17±5% increase) [WGI TAR Chapter 4]
Tropospheric concentration of O_3	Increased by 35±15% from 1750 to 2000, varies with region [WGI TAR Chapter 4]
Stratospheric concentration of O_3	Decreased from 1970 to 2000, varies with altitude and latitude [WGI TAR Chapters 4 & 6]
Global mean surface temperature	Increased by 0.6±0.2°C over the 20th century; land areas warmed more than the oceans (very likely) [WGI TAR Section 2.2.2.1]
Northern Hemisphere surface temperature	Increased over the 20th century greater than during any other century in the last 1000 years; 1990s warmest decade of the millennium (likely) [WGI TAR Section 2.2.2.1]
Diurnal surface temperature range	Decreased from 1950 to 2000 over land: night-time minimum temperatures increased at twice the rate of day-time maximum temperatures (likely) [WGI TAR Section 2.2.2.1]
Hot days / heat index	Increased (likely) [WGI TAR Section 2.7.2.1]
Cold / frost days	Decreased for nearly all land areas during the 20th century (very likely) [WGI TAR Section 2.7.2.1]
Continental precipitation	Increased by 5-10% over the 20th century in the northern hemisphere (very likely), although decreased in some regions, e.g., north and west Africa and parts of the Mediterranean [WGI TAR Section 2.7.2.2]
Heavy precipitation events	Increased at mid- and high northern latitudes (likely) [WGI TAR Section 2.7.2.2]
Global mean sea level	Increased at an average annual rate of 1 to 2 mm during the 20th century [WGI TAR Chapter 11]
Duration of ice cover of rivers and lakes	Decreased by about two weeks over the 20th century in mid- and high latitudes of the Northern Hemisphere (very likely) [WGII TAR Sections 5.7 & 16.1.3.1]
Arctic sea ice extent and thickness	Thinned by 40% in recent decades in late summer to early autumn (likely) and decreased in extent by 10-15% since the 1950s in spring and summer [WGI TAR Section 2.2.5.2; WGII TAR Section 16.1.3.1]
Non-polar glaciers	Wide-spread retreat during the 20th century [WGI TAR Section 2.2.5.3; WGII TAR Section 4.3.11]
Snow cover	Decreased in area by 10% since 1960s (very likely) [WGII TAR Sections 11.2.1.5 & 16.1.3.1]
Permafrost	Thawed, warmed and degraded in parts of the polar regions [WGI TAR Chapter 3]
El-Nino events	Became more frequent, persistent and intense during the last 20-30 years compared to the previous 100 years [WGI TAR Section 7.6.5]
Growing season	Lengthened by about 1-4 days per decade during the last 40 years in the Northern Hemisphere, especially at higher latitudes [WGII TAR Section 5.2.1]
Plant and animal ranges	Shifted poleward and up in elevation, for plants, insects, birds and fish [WGII TAR Sections 5.2, 5.4, 5.9, &16.1.3.1]
Breeding, flowering and migration	Earlier plant flowering, earlier bird arrival, earlier dates of breeding season, earlier emergence of insects in the Northern Hemisphere [WGII TAR Sections 5.2.1, 5.4.1.3, & 13.2.2.2]
Coral reef bleaching	Increased frequency, especially during El-Nino events [WGII TAR Chapter 5]
Weather-related economic losses	Global inflation-adjusted losses rose 14 fold over the last 40 years. [WGII TAR Sections 8.2.1 & 8.2.2]

* This table provides examples of key observed changes and is not an exhaustive list. It includes both changes attributable to anthropogenic climate change and those that may be caused by natural variations or anthropogenic climate change. Confidence levels are reported where they are explicitly assessed by the relevant Working Group.

FIGURE 2-1

SEE PAGE 6 LINES 8–22 FOR FIGURE CAPTION

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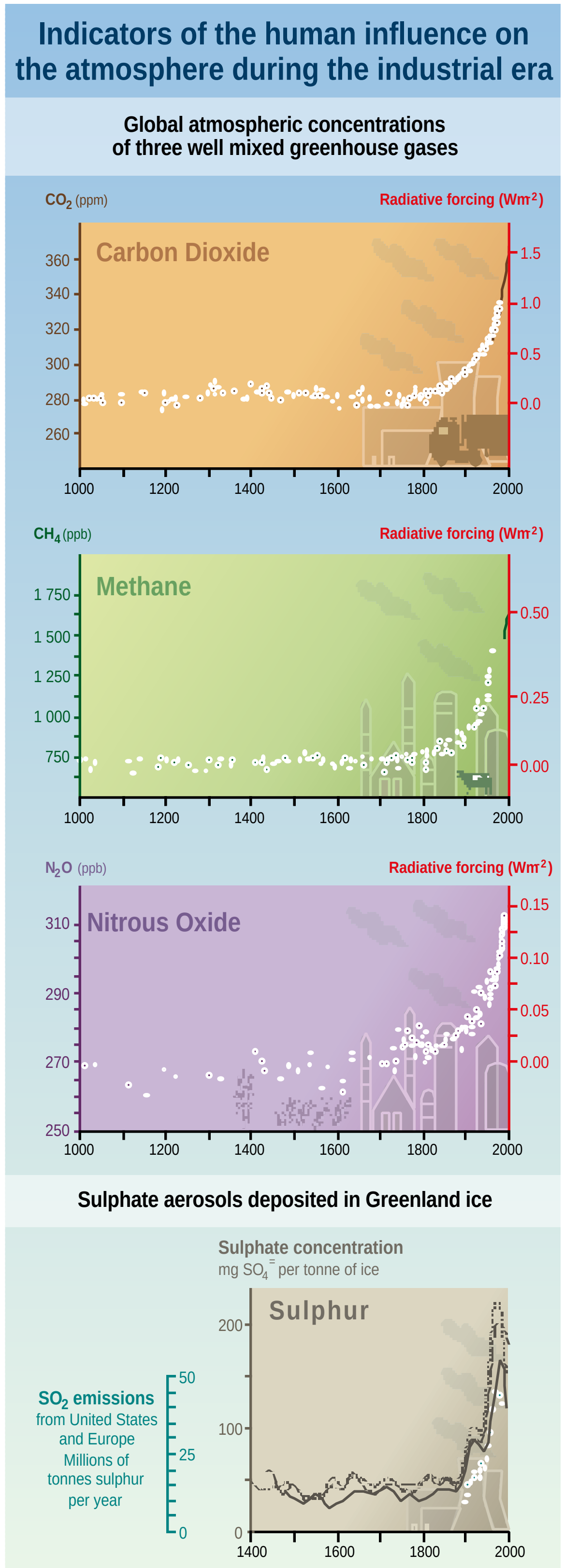

FIGURE 2-2

SEE PAGE 7 LINES 1–17 FOR FIGURE CAPTION

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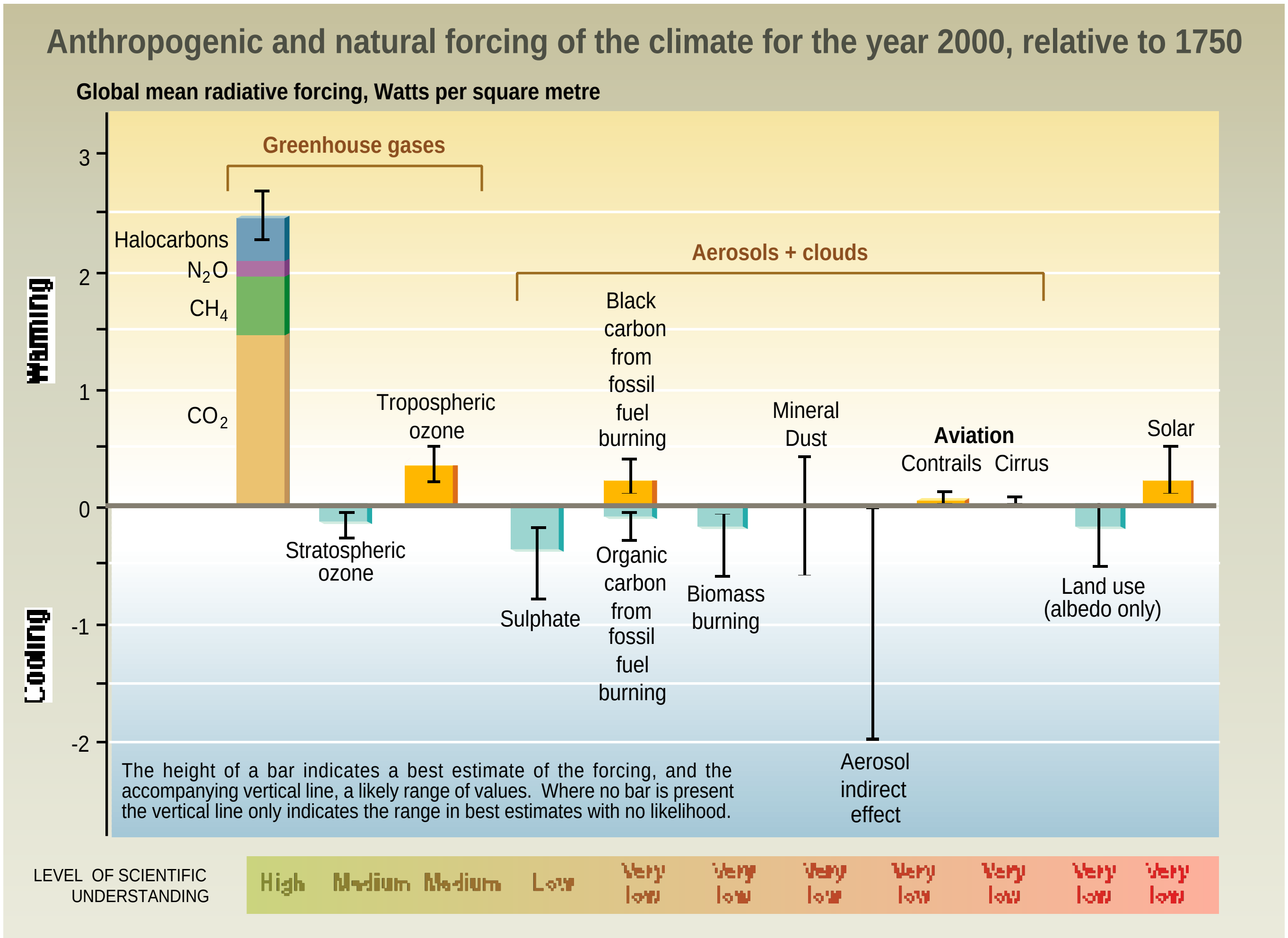

FIGURE 2-3

SEE PAGE 7 LINES 36–48 FOR FIGURE CAPTION

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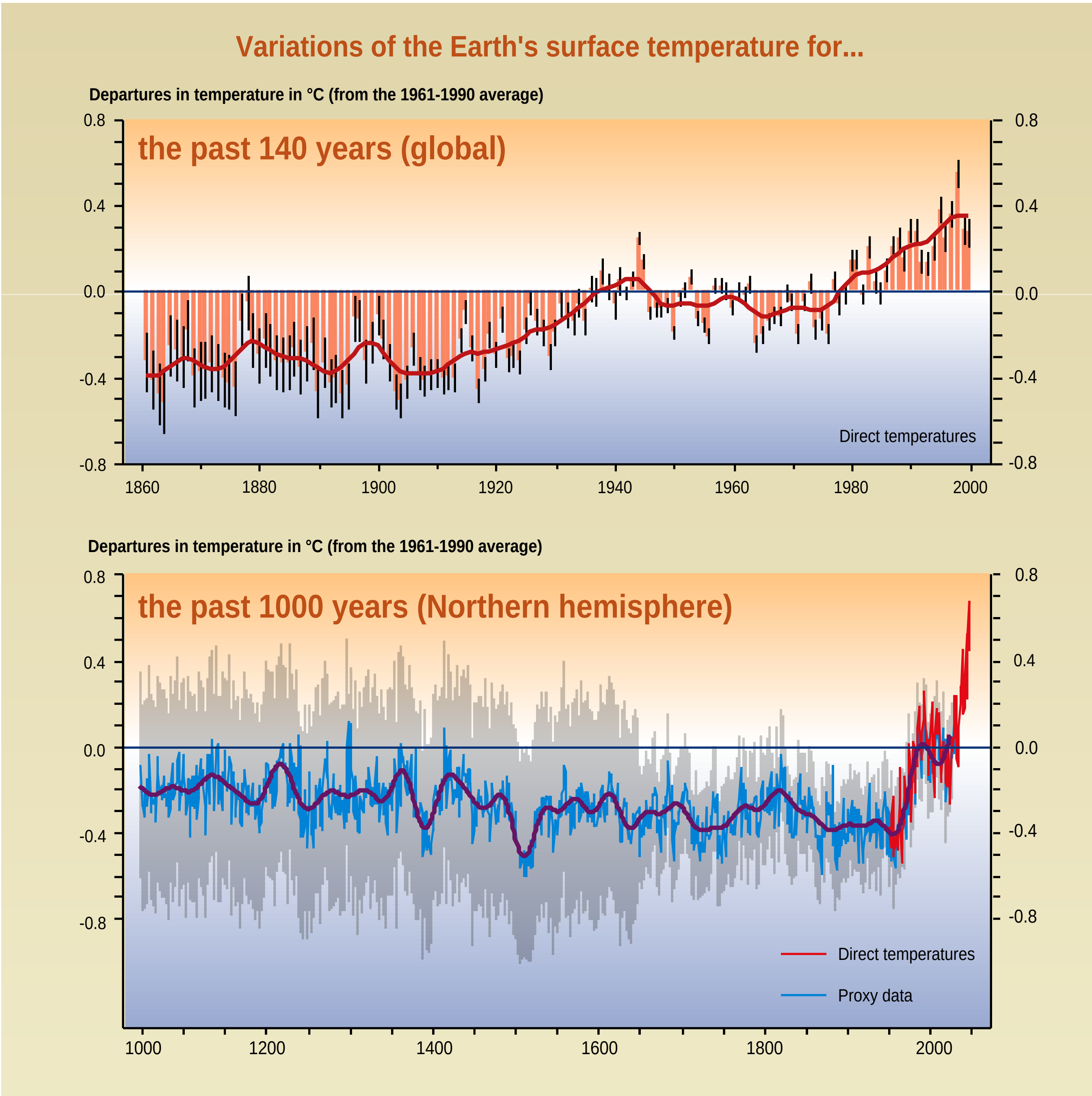

FIGURE 2-4

SEE PAGE 8 LINES 18–29 FOR FIGURE CAPTION

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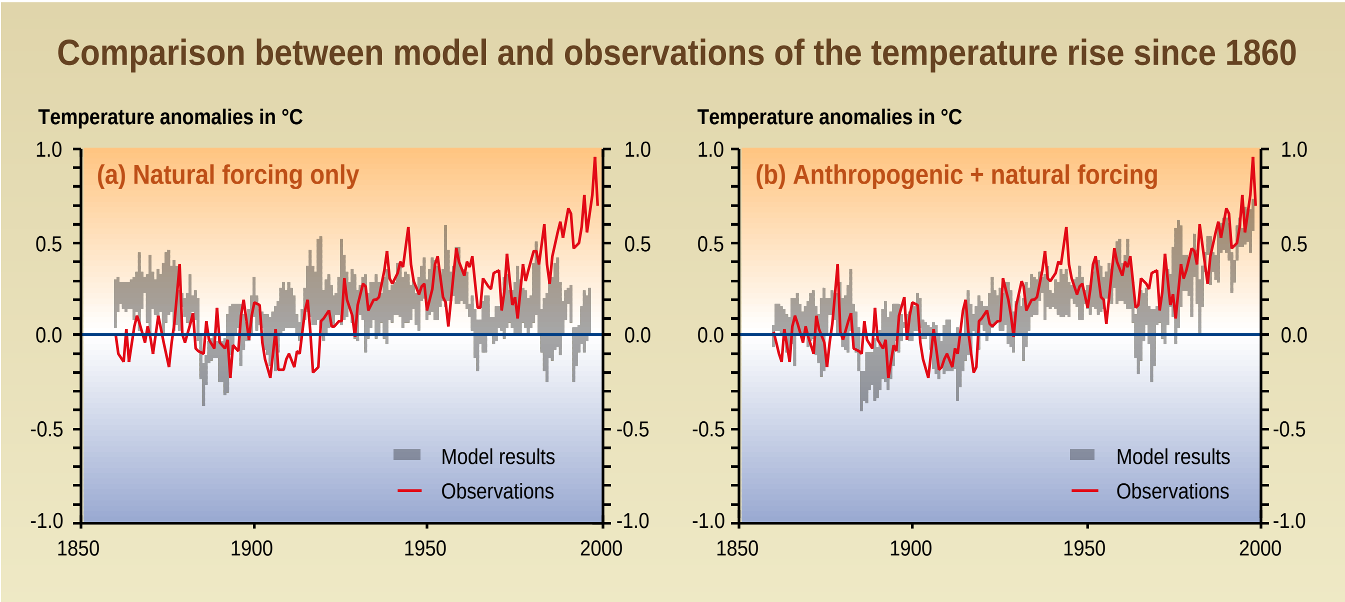

FIGURE 2-5

SEE PAGE 9 LINES 13–17 FOR FIGURE CAPTION

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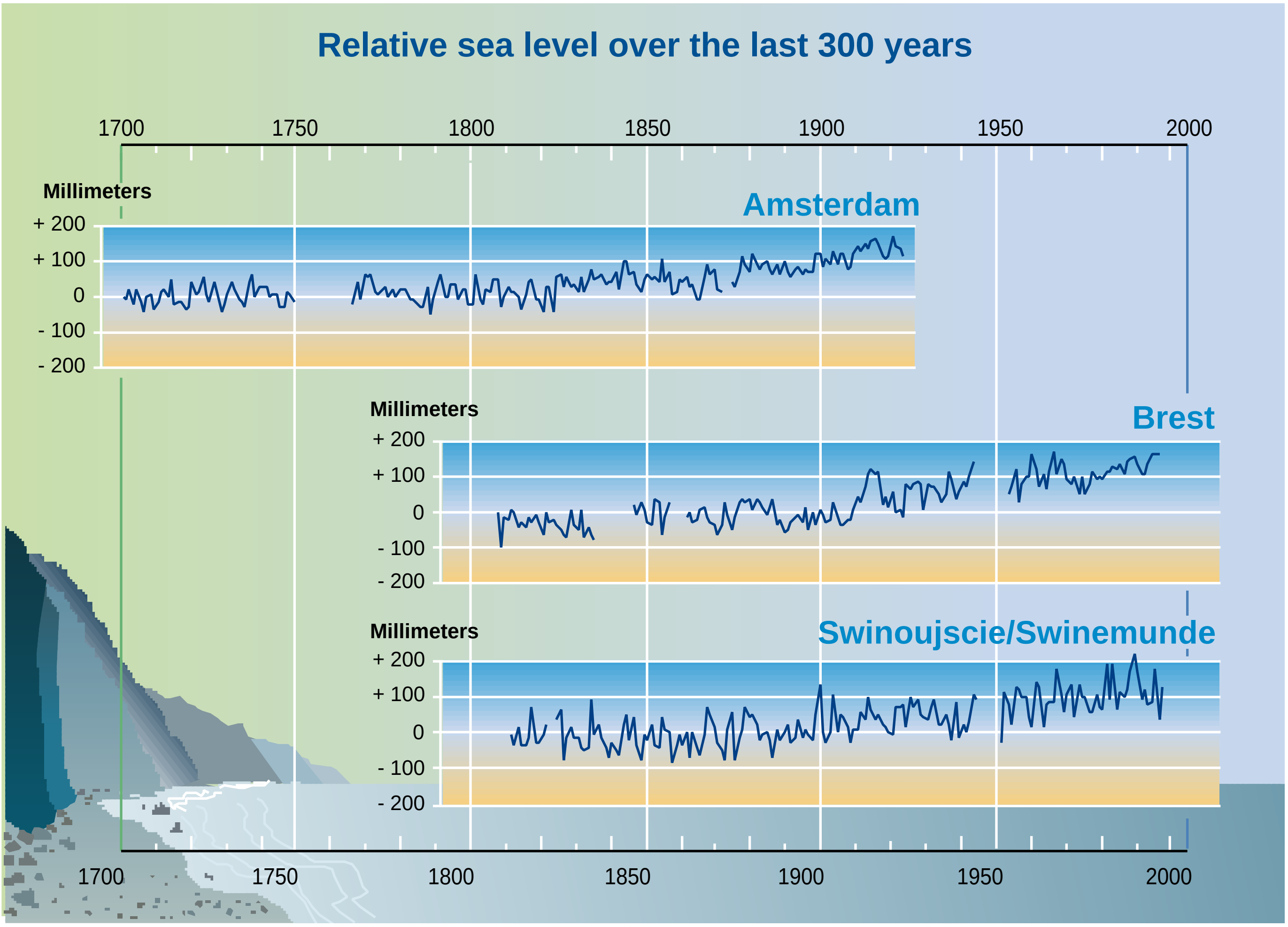

FIGURE 2-6a

SEE PAGE 9 LINES 44–51 FOR FIGURE CAPTION

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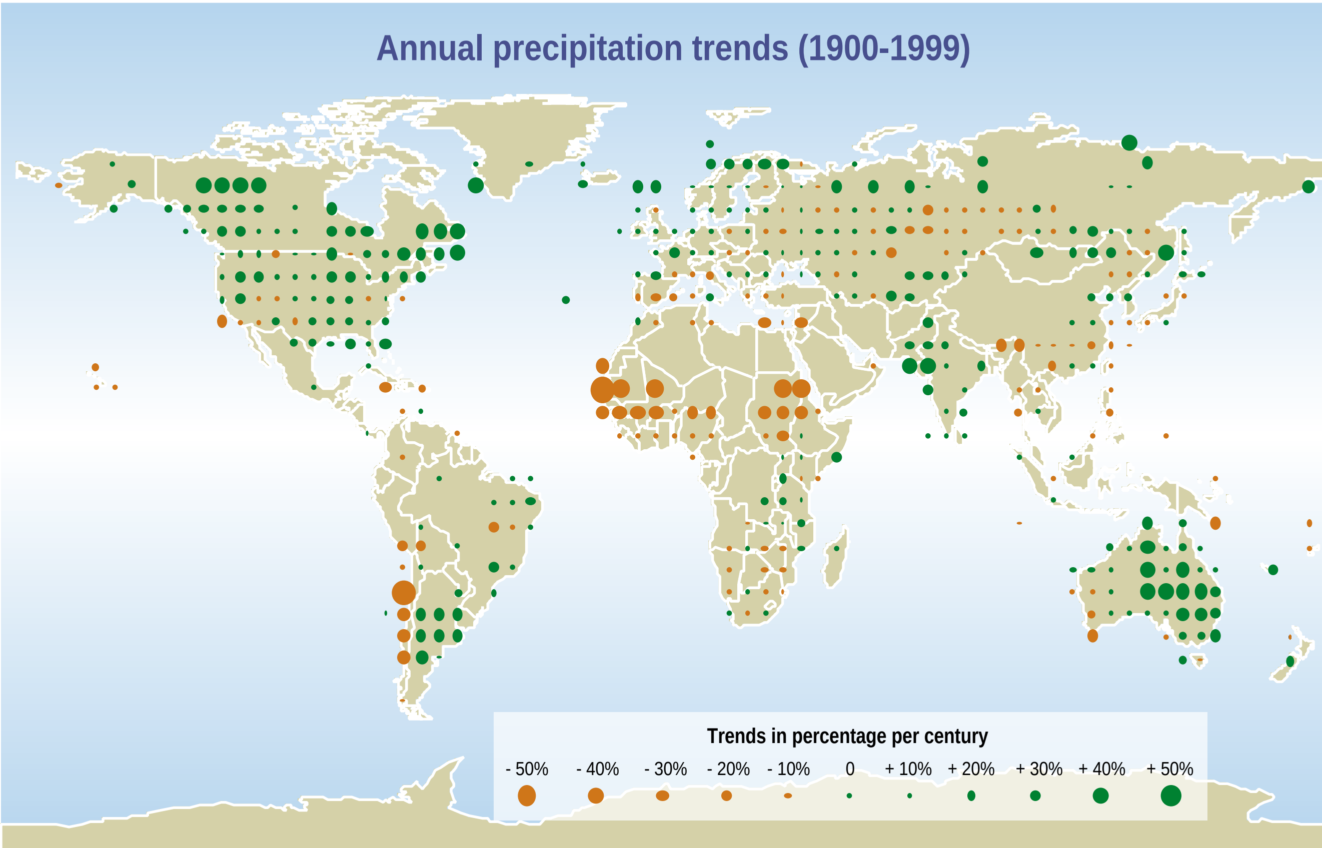

FIGURE 2-6b

SEE PAGE 10 LINES 11–18 FOR FIGURE CAPTION

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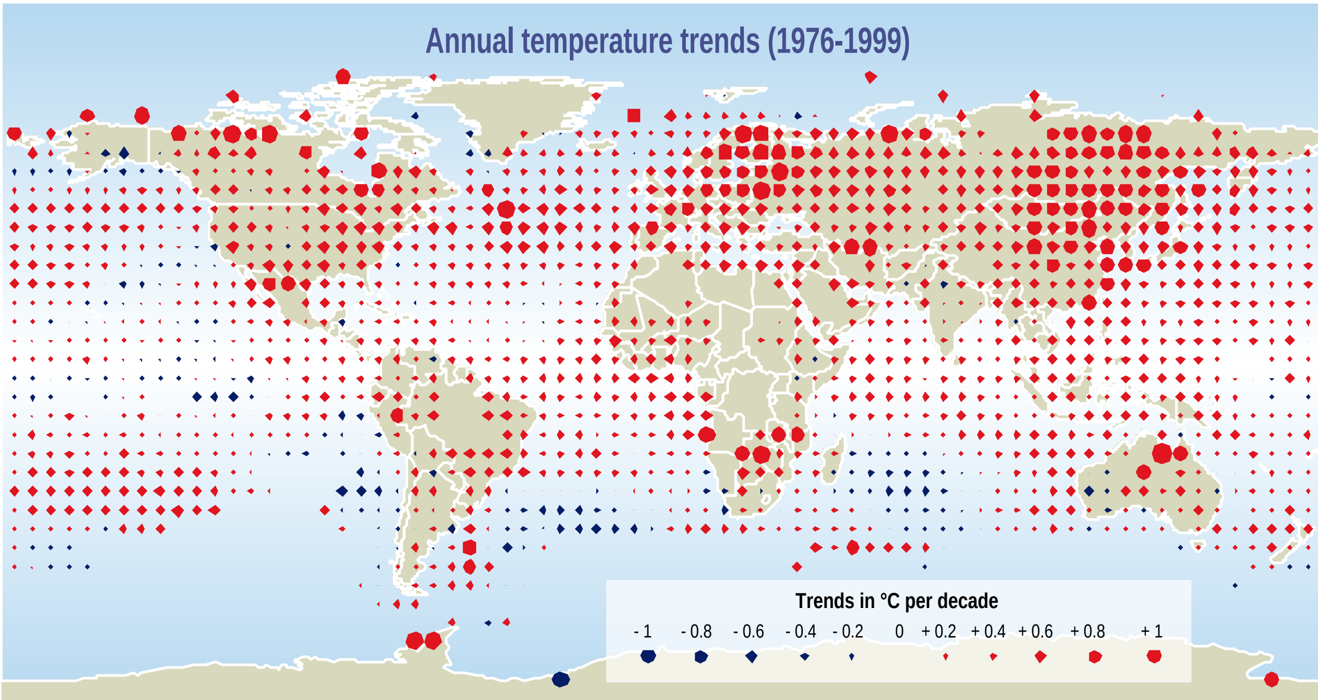

FIGURE 2-7

SEE PAGE 12 LINES 5–12 FOR FIGURE CAPTION

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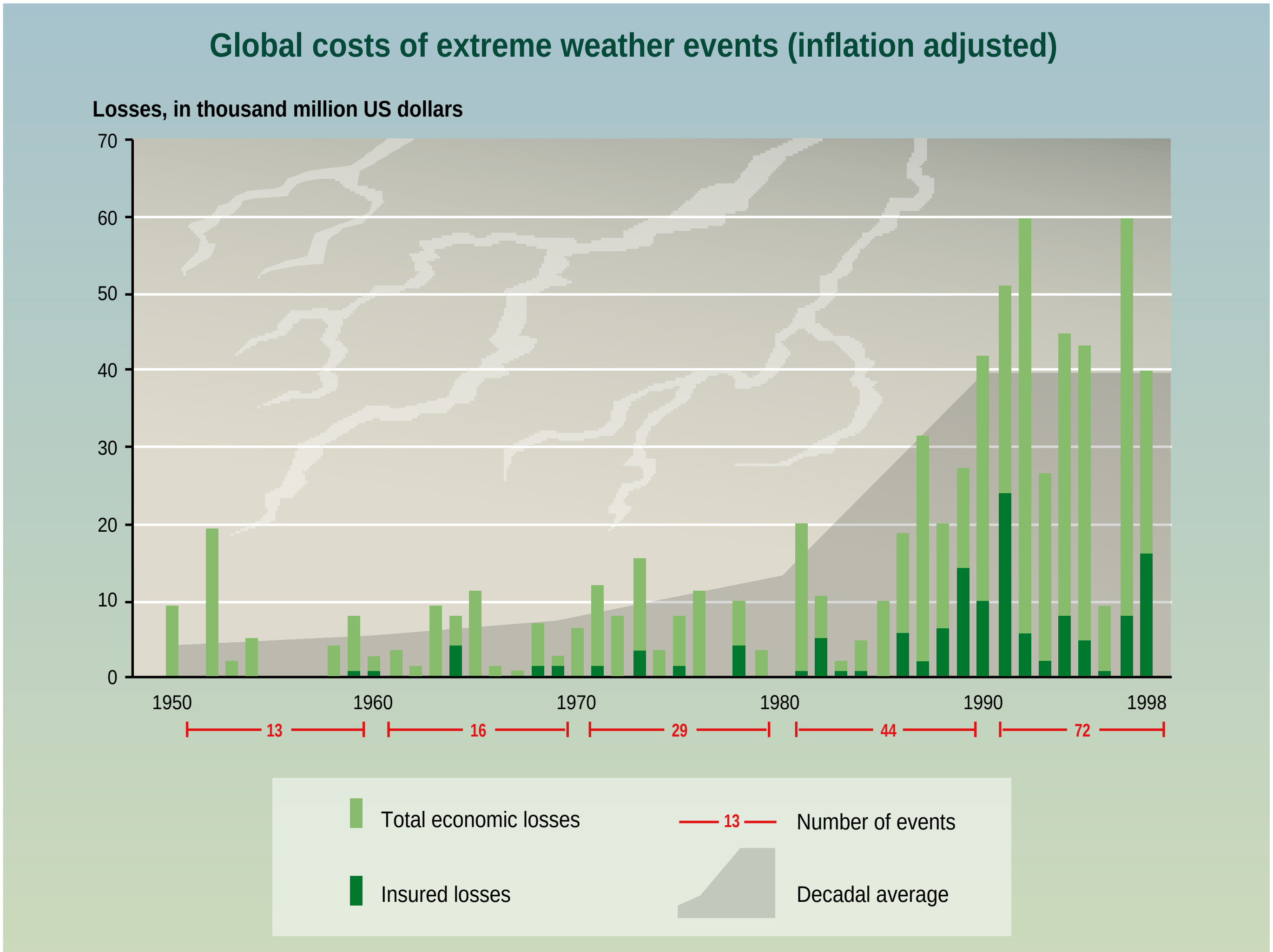

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QUESTION 3

What is known about the regional and global climatic, environmental, and socio-economic consequences in the next 25, 50, and 100 years associated with a range of greenhouse gas emissions arising from scenarios used in the TAR (projections which involve no climate policy intervention)?

To the extent possible evaluate the:

- **Projected changes in atmospheric concentrations, climate, and sea level**
- **Impacts and economic costs and benefits of changes in climate and atmospheric composition on human health, diversity and productivity of ecological systems, and socio-economic sectors (particularly agriculture and water)**
- **The range of options for adaptation, including the costs, benefits, and challenges**
- **Development, sustainability, and equity issues associated with impacts and adaptation at a regional and global level.**

Paragraph Number *Reference*

3.1 The greenhouse gas emissions scenarios used as the basis for the climate projections in the TAR are those contained in the IPCC *Special Report on Emissions Scenarios* (see Box 3-1). Because the SRES scenarios had only been available for a very short time prior to production of the TAR, it was not possible to include impact assessments based on these scenarios. Hence, the impacts assessments in the TAR use climate model results which tend to be based on equilibrium climate change scenarios (e.g., $2xCO_2$), a relatively small number of 1% per year CO_2 increase transient scenarios, or the scenarios used in the Second Assessment Report (i.e., the IS92 series). The challenge in answering this question therefore is to try and map these impact results onto the climate change results, which have used the SRES scenarios. This, by necessity, requires various approximations to be made and in many cases only qualitative conclusions can be drawn. Projections of changes in climate variability, extreme events, and abrupt/non-linear changes are covered in Question 4.

Box 3-1 **Future emissions of greenhouse gases and aerosols due to human activities will alter the atmosphere in ways that are expected to affect the climate.** Changes in climate occur as a result of internal variability of the climate system and external factors (both natural and as a result of human activities). Emissions of greenhouse gases and aerosols due to human activities change the composition of the atmosphere. Future emissions of greenhouse gases and aerosols are determined by driving forces such as population, socio-economic development, and technological change, and hence are highly uncertain. Scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyze how driving forces may influence future emission outcomes and to assess the associated uncertainties. The SRES scenarios, developed to update the IS92 series, consist of six scenario groups, based on narrative storylines, which span a wide range of these driving forces (see Figure 3-1). They are all plausible and internally consistent, and no probabilities of occurrence are assigned. They encompass four combinations of demographic change, social and economic development, and broad economic developments (A1B, A2, B1, B2). Two further scenario groups, A1FI and A1T, explicitly explore alternative energy technology developments to A1B (see Figure 3-1a). The resulting emissions of the greenhouse gases CO_2, CH_4 and N_2O, along with SO_2 which leads to the production of sulfate aerosols, are shown in Figures 3-1b to 3-1e; other gases and particles are also important. These emissions cause changes in the concentrations of these gases and aerosols in the atmosphere. The changes in the concentrations for the SRES scenarios are shown in Figures 3-1f to 3-1i. Note that for gases which stay in the atmosphere for a long period, such as CO_2 shown in panel (f), the atmospheric concentration responds to changes in emissions relatively slowly (e.g., see Figure 5-3); whereas for short-lived gases and aerosols, such as sulfate aerosols shown in panel (i), the atmospheric concentration responds much more quickly. The influence of changes in the concentrations of greenhouse gases and aerosols in the atmosphere on the climate system can broadly be compared using the concept of radiative forcing, which is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system. A positive radiative forcing, such as that produced by increasing concentrations of greenhouse gases, tends to warm the surface, conversely a negative radiative forcing, which can arise from an increase in some types of aerosols such as sulfate aerosols, tends to cool the surface. The radiative forcing resulting from the increasing concentrations in panels (f) to (i) is shown in panel (j). Note that, as with the IS92 scenarios, all combinations of emissions of greenhouse gases and aerosols in the SRES scenarios result in increased radiative forcing.

[FIGURE 3-1 CAPTION: The different socio-economic assumptions underlying the SRES scenarios result in different levels of emissions of greenhouse gases and aerosols. The SRES scenarios do not include additional climate initiatives and no probabilities are assigned. These emissions in turn change the concentration of these gases and aerosols in the atmosphere, leading to changed radiative forcing of the climate system. The highlighted boxes along the top of the figure illustrate how the various aspects relate to the integrated assessment framework for considering climate change (see Figure 1-1).]

- WGI TAR Figures 3.12 & 4.14

3.2 **Carbon dioxide concentrations, global average surface temperature, and sea level are projected to increase under all IPCC emissions scenarios during the 21st century.**

3.3 ***All SRES scenarios result in an increase in the atmospheric concentration of CO_2.*** For the six illustrative SRES scenarios, the projected concentrations of CO_2, the primary anthropogenic greenhouse gas, in 2100 range from 540 to 970 ppm, compared to the pre-industrial concentration of 280 ppm and the concentration of about 368 ppm in 2000 (see Figure 3-1f). These projections include the land and ocean climate feedbacks. Uncertainties, especially regarding the persistence of the present sink processes and the magnitude of the climate feedback from the terrestrial biosphere, cause a variation of about -10 to +30% in the 2100 concentration, around each scenario. The total range is 490 to 1260 ppm (75 to 350% above the 1750 concentration).

3.4 ***Fossil-fuel CO_2 emissions are virtually certain to remain the dominant control over trends in atmospheric CO_2 concentration during this century.*** This is because the projected fossil-fuel emissions exceed the foreseeable biospheric sinks. If, hypothetically, all of the carbon released by historical land-use changes could be restored to the terrestrial biosphere over the course of the century (e.g., by reforestation), CO_2 concentration would be reduced by only 40 to 70 ppm.

- WGI TAR Sections 3.2.2 & 3.7.3

3.5 ***Model calculations of the concentrations of the primary non-CO_2 greenhouse gases by year 2100 vary considerably across the six illustrative SRES scenarios.*** For most cases, A1B, A1T, and B1 have the smallest increases, and A1FI and A2 the largest (see Figures 3-1g and 3-1h).

- WG1 TAR Section 4.4.5 & Box 9.1

3.6 ***The SRES scenarios include the possibility of either increases or decreases in anthropogenic aerosols, depending on the extent of fossil fuel use and policies to abate polluting emissions.*** As seen in Figure 3-1i sulfate aerosol concentrations are projected to fall below present levels by 2100 in all six illustrative SRES scenarios. This would result in warming relative to present day**.** In addition, natural aerosols are projected to increase as a result of changes in climate.

3.7 ***The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100 (see Figure 3-2b)—about two to ten times larger than the central value of observed warming during the last 100 years.*** For the periods 1990 to 2025 and 1990 to 2050 the projected increases are 0.4 to 1.1°C and 0.8 to 2.6°C, respectively. These results are for the full range of 35 SRES scenarios, based on a number of climate models.[1] Temperature increases are projected to be greater than those in the SAR, which were about 1.0 to 3.5°C based on six IS92 scenarios. The higher projected temperatures and the wider range are due primarily to lower projected sulfur dioxide emissions in the SRES scenarios relative to the IS92 scenarios, because of structural changes in the energy system as well as concerns about local and regional air pollution. The projected rate of warming is much larger than the observed changes during the 20th century and is very likely to be without precedent during at least the last 10,000 years, based on palaeoclimate data. For the last 1000 years this is illustrated in Figure 9-2.	• WGI TAR Section 9.3.3 • SRES Section 3.6.4
[FOOTNOTE 1: Complex physically based climate models are the main tool for projecting future climate change. In order to explore the range of scenarios, these are complemented by simple climate models calibrated to yield an equivalent response in temperature and sea level to complex climate models. These projections are obtained using a simple climate model whose climate sensitivity and ocean heat uptake are calibrated to each of seven complex climate models. The climate sensitivity used in the simple model ranges from 1.7 to 4.2°C, which is comparable to the commonly accepted range of 1.5 to 4.5°C. For the atmosphere-ocean general circulation model (AOGCM) experiments for the end of the 21st century (2071 to 2100) compared with 1961 to 1990, the mean warming for SRES scenario A2 is 3.0°C with a range of 1.3 to 4.5°C, while for SRES scenario B2 the mean warming is 2.2°C with a range of 0.9 to 3.4°C. Fast, simplified carbon cycle models are also used in this assessment.]	• WGI TAR Box 3.7
[FIGURE 3-2 CAPTION: Radiative forcing due to the SRES scenarios results in projected increases in temperature and sea level, which in turn will cause impacts. Because the SRES scenarios had only been available for a very short time prior to production of the TAR, the impacts assessments here use climate model results which tend to be based on equilibrium climate change scenarios (e.g., $2xCO_2$), a relatively small number of 1% per year CO_2 increase transient scenarios, or the scenarios used in the Second Assessment Report (i.e., the IS92 series). Impacts in turn can affect socio-economic development paths through, for example, adaptation and mitigation. The highlighted boxes along the top of the figure illustrate how the various aspects relate to the integrated assessment framework for considering climate change (see Figure 1-1).]	• WGI TAR Figures 9.13a, 9.14, & 11.12 • WGII TAR Figure 19-7
3.8 ***By 2100, the range in the surface temperature response across different climate models for the same emissions scenario is comparable to the range across different SRES emissions scenarios for a single climate model.*** Further uncertainties arise due to uncertainties in the radiative forcing. The largest forcing uncertainty is that due to the sulfate aerosols. It should be noted that the temperature projections do not include uncertainties in the modeling of radiative forcing (e.g., aerosol forcing uncertainties).	• WGI TAR Section 9.3.3
3.9 ***Globally averaged precipitation is projected to increase.*** Globally averaged water vapor and evaporation are also projected to increase.	• WGI TAR Section 9.3.1
3.10. ***Global mean sea level is projected to rise by 0.09 to 0.88 meters between 1990 and 2100, for the full range of SRES scenarios (see Figure 3-2c).*** For the periods 1990 to 2025 and 1990 to 2050, the projected rises are 0.03 to 0.14 m and 0.05 to 0.32 m, respectively. This is due primarily to thermal expansion and loss of mass from glaciers and ice caps. The range of sea-	• WGI TAR Section 11.5.1

level rise presented in the SAR was 0.13 to 0.94 m, based on the IS92 scenarios. Despite the higher temperature change projections in this assessment, the sea-level projections are slightly lower, primarily due to the use of improved models, which give a smaller contribution from glaciers and ice sheets.

3.11 **Substantial differences are projected in regional changes in climate and sea level, compared to the global mean change.**

3.12 ***It is very likely that nearly all land areas will warm more rapidly than the global average, particularly those at northern high latitudes in winter.*** Most notable of these is the warming in the northern regions of North America, and northern and central Asia, which exceeds global mean warming in each model by more than 40%. In contrast, the warming is less than the global mean change in south and southeast Asia in summer and in southern South America in winter (see Figure 3-3).

• WGI TAR Section 10.3.2

[FIGURE 3-3 CAPTION: The background shows the annual mean change of temperature (color shading) and its range (isolines) for (a) the SRES scenario A2 and (b) the SRES scenario B2. Both SRES scenarios show the period 2071 to 2100 relative to the period 1961 to 1990, and were performed by AOGCMs. Scenarios A2 and B2 are shown as no AOGCM runs were available for the other SRES scenarios. The boxes show an analysis of inter-model consistency in regional relative warming (i.e., warming relative to each model's global average warming) for (a) the A2 and (b) the B2 scenario. Regions are classified as showing either agreement on warming in excess of 40% above the global mean annual average (*much greater than average warming*), agreement on warming greater than the global mean annual average (*greater than average warming*), agreement on warming less than the global mean annual average (*less than average warming*), or disagreement amongst models on the magnitude of regional relative warming (*inconsistent magnitude of warming*). There is also a category for agreement on cooling (which never occurs). A consistent result from at least seven of the nine models is defined as being necessary for agreement. The global mean annual average warming of the models used span 1.2 to 4.5°C for A2 and 0.9 to 3.4°C for B2, and therefore a regional 40% amplification represents warming ranges of 1.7 to 6.3°C for A2 and 1.3 to 4.7°C for B2.]

• WGI TAR Figures 9.10d & 9.10e, and Box 10.1, Figure 1

3.13 ***At the regional scale, both increases and decreases in precipitation are projected, typically of 5 to 20%.*** It is likely that precipitation will increase in both summer and winter over high latitude regions. In winter, increases are also projected over northern mid-latitudes, tropical Africa and Antarctica, and in summer in southern and eastern Asia. Australia, central America, and southern Africa show consistent decreases in winter rainfall. Larger year-to-year variations in precipitation are very likely over most areas where an increase in mean precipitation is projected (see Figure 3-4).

• WGI TAR Section 10.3.2

[FIGURE 3-4 CAPTION: The background shows the annual mean change of rainfall (color shading) for (a) the SRES scenario A2 and (b) the SRES scenario B2. Both SRES scenarios show the period 2071 to 2100 relative to the period 1961 to 1990, and were performed by AOGCMs. Scenarios A2 and B2 are shown as no AOGCM runs were available for the other SRES scenarios. The boxes show an analysis of inter-model consistency in regional precipitation change. Regions are classified as showing either agreement on increase with an average change of greater than 20% (*large increase*), agreement on increase with an average change between 5 and 20% (*small increase*), agreement on a change between -5 and +5% or agreement with an average change between -5 and +5% (*no change*), agreement on decrease with an average change between -5 and -20% (*small decrease*), agreement on decrease with an average change of more than -20% (*large decrease*), or disagreement (*inconsistent sign*). A consistent result from at least seven of the nine models is defined as being necessary for agreement.]

• WGI TAR Box 10.1, Figure 2

3.14 ***The projected range of regional variation in sea-level change is substantial compared to projected global-average sea-level rise, because the level of the sea at the shoreline is determined by many factors (see Figure 3-5).*** Confidence in the regional distribution of sea-level change from complex models is low because there is little similarity between model results, although nearly all models project greater than average rise in the Arctic Ocean and less than average rise in the Southern Ocean.

- WGI TAR Section 11.5.2

[FIGURE 3-5 CAPTION: What causes sea level to change? The level of the sea at the shoreline is determined by many factors in the global environment that operate on a great range of time scales, from hours (tidal) to millions of years (ocean basin changes due to tectonics and sedimentation). On the time scale of decades to centuries, some of the largest influences on the average levels of the sea are linked to climate and climate change processes.]

- WGI TAR Box TS-2

3.15 ***Glaciers and ice caps are projected to continue their widespread retreat during the 21st century.*** Northern Hemisphere snow cover, permafrost, and sea-ice extent are projected to decrease further. The Antarctic ice sheet is likely to gain mass because of greater precipitation, while the Greenland ice sheet is likely to lose mass because the increase in runoff will exceed the precipitation increase. Concerns that have been expressed about the stability of the West Antarctic ice sheet are covered in Question 4.

- WGI TAR Section 11.5.4

3.16 **Projected climate change will have both beneficial and adverse environmental and socio-economic effects, but the larger the changes in climate the more the adverse effects predominate.**

3.17 ***The impacts of climate change will be more severe the greater the cumulative emissions of greenhouse gases.*** Climate change can have beneficial as well as adverse effects, but adverse effects are projected to predominate for much of the world. The various effects of climate change pose risks that increase with global mean temperature. Many of these risks have been organized into five reasons for concern: threats to endangered species and unique systems, damages from extreme climate events, effects that fall most heavily on developing countries and the poor within countries, global aggregate impacts, and large-scale high impact events (see Box 3-2 and Figure 3-2d). The effects of climate change on human health, ecosystems, food production, water resources, small islands and low-lying coastal regions, and aggregate market activities are summarized below. However, note that future changes in the frequency or intensity of extreme events have not been taken into account in most of these studies.

- WGII TAR Sections 1.2, 19.3, 19.5, & 19.8
- See also Q4

Box 3-2. **Concerns about the risks from climate change rise with temperature.**

- *Unique and threatened systems:* Some changes in species and systems have already been associated with observed changes in climate, and some highly vulnerable species and systems may be at risk of damage or even loss for very small changes in climate. Greater warming would intensify the risks to these species and systems, and place additional ones at risk.
- *Extreme climate events:* Increased frequencies and intensities of some extreme events have already been observed (see Question 2) and are likely to increase with further warming, as would the risks to human life, property, crops, livestock, and ecosystems. These risks increase where development is occurring in inherently dynamic and unstable zones (e.g., river floodplains and low-lying coastal regions) (see also Question 3).
- *Uneven distribution of impacts:* In general, developing countries are at greater risk of adverse impacts from climate change than are developed countries, of which some of the latter may experience market sector benefits for warming less than a few °C. For greater warming, most regions are at risk of predominantly negative effects from climate change. But developing countries generally would continue to be more severely impacted than

- WGII TAR Sections 5.2, 5.4, & 19.3
- WGII TAR Sections 8.5, 15.2, & 19.6
- WGII TAR Section 19.4

developed countries. Within countries, vulnerability varies and the poorest populations often have higher exposure to impacts that threaten their lives and livelihoods.

- *Global aggregate impacts:* Globally aggregated market sector impacts may be positive or negative up to a few °C, though the majority of people may be negatively affected. With greater warming, the risk of negative global market sector impacts increases, and impacts would be predominantly negative for most people. (• WGII TAR Section 19.5)
- *Large-scale, high impact events:* The probability of large-scale, high impact events within a 100-year time horizon such as shutdown of the thermohaline circulation or collapse of the West Antarctic ice sheet is very low for warming less than a few °C. The risk, which is a product of the probabilities of these events and the magnitude of their consequences, is largely unquantified. For greater warming, and over a time horizon longer than 100 years, the probabilities and the risks increase, but by an amount that cannot now be estimated. See also Question 4. (• WGII TAR Section 19.6)

Human Health

3.18 ***Climate change is projected to primarily affect human health adversely, particularly in lower income populations of tropical and subtropical countries.*** Climate change can affect human health through multiple pathways, including direct effects (e.g., increased heat stress but reduced cold stress, loss of life in floods and storms) and indirect effects that operate through infectious disease vectors (e.g., mosquitoes), water-borne pathogens, water quality, air quality, food availability and quality (e.g., decreased protein content in some cereals), population displacement, and economic disruption. Some effects may be beneficial (e.g., reduced cold stress, reduced disease transmission in some cases), but the predominant effect is anticipated to be adverse (see Table 3-1). However, for each anticipated adverse health impact there is a range of social, institutional, technological, and behavioral adaptation options to lessen that impact. Adaptations could, for example, encompass strengthening of the public health infrastructure, health-oriented management of the environment (including air and water quality, food safety, urban and housing design, and surface water management), and the provision of appropriate medical care.

• WGII TAR Sections 5.3, 9.1, 9.5, 9.11, & 9.14

[Insert Table 3-1 here]

Biodiversity and Productivity of Ecological Systems

3.19 ***Diversity in ecological systems is expected to be reduced by climate change and sea-level rise, with an increased risk of extinction of some vulnerable species.*** Significant disruptions of ecosystems from disturbances such as fire, drought, pest infestation, invasion of exotic species, storms, and coral bleaching events are expected to increase (see Table 3-2). The stresses caused by climate change, added to other stresses on ecological systems (e.g., land conversion, land degradation, harvesting, and pollution), threaten substantial damage to or complete loss of some unique ecosystems, and extinction of some critically endangered and endangered species. Coral reefs and atolls, mangroves, boreal and tropical forests, polar and alpine ecosystems, prairie wetlands, and remnant native grasslands are examples of systems threatened by climate change. In some cases the threatened ecosystems are those that could mitigate against some climate change impacts (e.g., coastal systems that buffer the impacts of storms).

• WGII TAR Sections 5.2.2, 5.2.3, 5.4.1, 16.2, 17.2, 19.3.2, & 19.3.3

[Insert Table 3-2 here]

3.20 ***The productivity of ecological systems is highly sensitive to climate change and projections of change in productivity range from increases to decreases.*** Increasing CO_2 concentrations would increase net primary productivity (CO_2 fertilization) and net ecosystem productivity in most vegetation systems, causing carbon to accumulate in vegetation and soils over time.

• WGI TAR Section 3.7

Climate change may either augment or reduce the direct effects of CO_2 on productivity, depending on the type of vegetation, the region, and the scenario of climate change. On a global scale, terrestrial models project that climate change would reduce the rate of uptake of carbon by terrestrial ecosystems, but that they would continue to be a net, but decreasing, sink for carbon through 2100.

- WGII TAR Sections 5.2.2 & 5.6.3

3.21 ***The terrestrial ecosystems at present are a carbon sink that may diminish with increased warming by the end of the 21st century (see Table 3-2).*** The terrestrial ecosystems at present are a sink for carbon due to past land management practices, CO_2 fertilization effect on plant photosynthesis (either directly via increased carbon assimilation, or indirectly through higher water use efficiency), nitrogen deposition (especially in the northern hemisphere), and climate change. This sink is projected to be maintained over the next few decades but may diminish and even become a source with increased warming towards the end of the 21st century due to an increase in plant and soil respiration and changes in disturbance regimes (e.g., fire and insect outbreaks) mediated through climate change.

- WGI TAR Section 3.2.2
- WGII TAR Sections 5.2, 5.5, 5.6, & 5.9
- SRLUCF Section 1.4

Agriculture

3.22 ***Models of cereal crops indicate that in temperate areas yields increase for small increases in temperature but decrease with larger temperature changes. In most tropical and subtropical regions yields are projected to decrease for almost any increase in temperature.*** In mid-latitudes, crop models indicate that warming of less than a few °C and the associated increase in CO_2 concentrations will lead to generally positive responses and generally negative responses with greater warming. In tropical agricultural areas, similar assessments indicate that yields of some crops would decrease with even minimal increases in temperature because they are near their maximum temperature tolerance. Where there is also a large decrease in rainfall in subtropical and tropical dryland/rainfed systems, crop yields would be even more adversely affected. Assessments that include autonomous agronomic adaptation (e.g., changes in planting times and crop varieties) tend to project yields less adversely affected by climate change than without adaptation. These assessments include the effects of CO_2 fertilization but not technological innovations or changes in the impacts of pests and diseases, degradation of soil and water resources, or climate extremes. The ability of livestock producers to adapt their herds to the physiological stresses associated with climate change is poorly known. Warming of more than a few °C is projected to increase food prices globally, and may increase the risk of hunger in vulnerable populations.

- WGII TAR Sections 5.3.4, 5.3.5, 5.3.6, & 9.9

[Insert Table 3-3 here]

Water

3.23 ***Projected climate change would exacerbate water shortage and quality problems in many water-stressed countries but alleviate it in some other countries.*** Climate change is projected to reduce streamflow and groundwater recharge in many parts of the world (e.g., in central Asia, southern Africa, the area around the Mediterranean), but may increase it in some other areas. Several hundred million to a few billion people are projected to suffer a supply reduction of 10% or more by 2050 for climate change projections corresponding to 1% per year increase in CO_2 emissions (see Table 3-4). The effects of climate changes on water scarcity, water quality, and the frequency and intensity of floods and droughts will intensify challenges for water and flood management. Unmanaged and poorly managed water systems are the most vulnerable to adverse effects of climate change.

- WGI TAR Section 9.3.6
- WGII TAR Sections 4.3, 4.4, 4.5.2, & 4.6

[Insert Table 3-4 here]

Small Islands and Low-Lying Coasts

3.24 ***Populations that inhabit small islands and/or low-lying coasts are at particular risk of severe social and economic effects***. Projected sea-level rise would inundate significant portions of many small, low-lying islands and deltas, resulting in displacement of populations and loss of infrastructure and/or substantial efforts and costs to protect vulnerable coastal areas. Resources critical to island and coastal societies and economies such as freshwater, fisheries, coral reefs and atolls, beaches, and wildlife habitat would also be at risk.

- WGII TAR Sections 7.2.2, 17.2, & 19.3.4

3.25 ***Projected sea-level rise will increase the average annual number of people flooded in coastal storm surges.*** The areas of greatest absolute increase in populations at risk are southern Asia and southeast Asia, with lesser but significant increases in eastern Africa, western Africa, and the Mediterranean from Turkey to Algeria. Significant portions of many highly populated coastal cities are also vulnerable to permanent land submergence and especially to more frequent coastal flooding superimposed on surge heights, due to sea-level rise. These estimates assume no change in the frequency or intensity of storms, which could exacerbate the effects of sea-level rise on flooding risks in some areas.

- WGII TAR Sections 6.5.1, 7.2.2, & 17.2.2

Aggregate Market Effects

3.26 ***Net market sector effects are expected to be negative in most developing countries, but mixed for developed countries.*** The effects of climate change will have market sector effects by changing the abundance, quality, and prices of food, fiber, water, and other goods and services (see Table 3-5). In addition, climate change can have market effects through changes in energy demand, hydropower supply, transportation, tourism and construction, damages to property and insurance losses from extreme climate events, loss of coastal land from sea-level rise, location and relocation decisions for development and populations, and the resource needs and costs of adapting to climate change. Estimates of net market effects from a few published studies, aggregated across sectors and to national or regional scales, indicate losses for most developing countries and regions studied. Both gains and losses are estimated for developed countries and regions for increases in global mean temperature of up to a few °C. Economic losses are estimated for developed countries at larger temperature increases. When aggregated to a global scale, world gross domestic product (GDP) would change by ± a few percent for global mean temperature increases of up to a few °C, and increasing net losses for larger increases in temperature. Confidence in estimates of market effects for individual countries is generally *low*, and the various omissions are likely to result in underestimates of economic losses and overestimates of economic gains.

- WGII TAR Sections 6.5, 7.2, 7.3, 8.3, 18.3.4, 18.4.3, 19.4.1, 19.4.2, 19.4.3, & 19.5

[Insert Table 3-5 here]

3.27 **Adaptation can partially offset adverse effects of climate change, and can also produce immediate benefits.**

3.28 ***Numerous possible adaptation options for responding to climate change have been identified, but evaluation of their benefits and costs is incomplete and quantitative estimates are few.*** Adaptation to climate change can take many forms, including actions taken by people with the intent of lessening impacts or utilizing new opportunities, and structural and functional changes in natural systems made in response to changes in pressures. The focus in this report is on the adaptive actions of people. The range of options includes reactive adaptations (actions taken concurrent with changed conditions and without prior preparation) and planned adaptations (actions taken either concurrent with or in anticipation of changed

- WGII TAR Sections 18.2.3 & 18.3.5

conditions, but with prior preparation). Adaptations can be taken by private entities (e.g., individuals, households, or business firms) or by public entities (e.g., local, state, or national government agencies). Examples of identified options are listed in Table 3-6. The benefits and costs of adaptation options, evaluation of which is incomplete, will also vary across regions and entities. Despite the incomplete and evolving state of knowledge about adaptation, a number of robust findings have been derived and are summarized below.

[Insert Table 3-6 here]

3.29 ***Scenarios of greater and more rapid climate change pose greater challenges for adaptation and greater risks of damages than do scenarios of lesser and slower change.*** Key features of climate change to be adapted to include the magnitudes and rates of changes in climate extremes, variability, and mean conditions. Systems and communities have evolved capabilities to cope with a range of climate variability within which the risks of damage are relatively low and ability to recover is high. Changes in climate that result in increased frequency of events that fall outside the historic range with which systems have coped, however, increase the risk of severe damages and incomplete recovery or collapse of the system. Changes in mean conditions (e.g., increases in average temperature), even in the absence of changes in variance, can bring increases in the frequencies of some events (e.g., more frequent heat waves) that exceed the coping range, and decreases in the frequencies of others (e.g., less frequent cold spells) (see Question 4 and Figure 4-1).

- WGII TAR Sections 18.2.2, 18.3.3, & 18.3.5

3.30 ***Enhancement of adaptive capacity can extend or shift ranges for coping with variability and extremes to generate benefits in the present and future.*** Many of the adaptation options listed in Table 3-6 are presently employed to cope with current climate variability and extremes, and their expanded use can enhance both current and future capacity to cope. But the future success of such efforts are expected to be less the greater are the magnitudes and rates of the changes.

- WGII TAR Sections 18.2.2 & 18.3.5

3.31 ***The potential direct benefits of adaptation are substantial and take the form of reduced adverse and enhanced beneficial impacts of climate change.*** Results of studies of future impacts of climate change indicate the potential for adaptation to substantially reduce many of the adverse impacts and enhance beneficial impacts. For example, analyses of coastal flood risks from storm surges estimate that climate change-driven sea-level rise would increase the average annual number of people flooded many-fold if coastal flood protection is unchanged from the present. But if coastal flood protection is enhanced in proportion to future GDP growth, the projected increase is cut by as much as two-thirds (see Figure 3-6). However, estimates such as these indicate only potential benefits from adaptation, not the likely benefits—as analyses generally use arbitrary assumptions about adaptation options and obstacles, often omit consideration of changes in climate extremes and variability, and do not account for imperfect foresight.

- WGII TAR Sections 5.3.4, 6.5.1, & 18.3.2

[FIGURE 3-6 CAPTION: Adaptation and the average annual number of people flooded by coastal storm surges, projection for 2080s. The left two bars show the average annual number of people projected to be flooded by coastal storm surges in 2080 for present sea level and for a rise in sea level of ~40 cm, assuming that coastal protection is unchanged from the present and a moderate population increase. The right two bars show the same, but assuming that coastal protection is enhanced in proportion to GDP growth.]

- WGII TAR Section 6.5.1

3.32 ***Estimates of the costs of adaptation are few; the available estimates indicate that costs are highly sensitive to decision criteria for the selection and timing of specific adaptation measures.*** The costs of measures to protect coastal areas from sea-level rise are perhaps the best studied to date. Evaluated measures include construction of "hard structures" such as dikes, levees, and seawalls, and the use of "soft structures" such as nourishment of beaches

- WGII TAR Sections 6.5.2 & 18.4.3

with sand and dune restoration. Estimates of the costs of protecting coasts vary depending on assumptions about what decisions will be made regarding the extent of the coastline to be protected, the types of structures to be used, the timing of their implementation (which is influenced by the rate of sea-level rise), and discount rates. Different assumptions about these factors yield estimates for protection of U.S. coasts from 0.5-m sea-level rise by 2100 that range from US$20 billion to US$150 billion in present value.

3.33 **Climate change is expected to negatively impact development, sustainability and equity.**

3.34 ***The impacts of climate change are likely to fall disproportionately upon the poorest countries and the poorest persons within countries, and thereby exacerbate inequities in health status and access to adequate food, clean water, and other resources.*** As already noted, populations in developing countries are generally expected to be exposed to relatively high risks of adverse impacts from climate change on human health, water supplies, agricultural productivity, property, and other resources. Poverty, lack of training and education, lack of infrastructure, lack of access to technologies, lack of diversity in income opportunities, degraded natural resource base, misplaced incentives, inadequate legal framework, and struggling public and private institutions create conditions of low adaptive capacity in most developing countries. The exposures and low capacity to adapt combine to make populations in developing countries generally more vulnerable than populations in developed countries.

- WGII TAR Sections 18.5.1, 18.5.2, & 18.5.3

3.35 ***Non-sustainable resource use adds to the vulnerability to climate change.*** Conversion of natural habitat to human uses, high harvesting rates of resources from the environment, cultivation and grazing practices that fail to protect soils from degradation, and pollution of air and water can reduce the robustness of systems to cope with variations or change in climate, and the resilience of systems to recover from declines. Such pressures make systems, and the populations that derive goods, services, and livelihoods from them, highly vulnerable to climate change. These pressures are present in developed as well as developing countries, but satisfying development goals in ways that do not place non-sustainable pressures on systems pose a particular dilemma for developing countries.

- WGII TAR Sections 1.2.2, 4.7, 5.1, 6.4.4, & 6.3.4

3.36 ***Hazards associated with climate change can undermine progress toward sustainable development.*** More frequent and intensified droughts can exacerbate land degradation. Increases in heavy precipitation events can increase flooding, landslides, and mudslides, the destruction from which can set back development efforts by years in some instances. Advances in health and nutritional status could be set back in some areas by climate change impacts on human health and agriculture. Hazards such as these can also be exacerbated by further development in inherently dynamic and unstable zones (e.g., floodplains, barrier beaches, low-lying coasts, and deforested steep slopes).

- WGII TAR Section 18.6.1

3.37 ***Climate change can detract from the effectiveness of development projects if not taken into account.*** Development projects often involve investments in infrastructure, institutions, and human capital for the management of climate-sensitive resources such as water, hydropower, agricultural lands, and forests. The performance of these projects can be affected by climate variability and change, yet these factors are given little consideration in the design of projects. Analyses have shown that flexibility to perform well under a wider range of climate conditions can be built into projects at modest incremental costs in some instances, and that greater flexibility has immediate value because of risks from present climate variability.

- WGII TAR Section 18.6.1

3.38 ***Many of the requirements for enhancing capacity to adapt to climate change are similar to those for promoting sustainable development.*** Examples of common requirements for enhancing adaptive capacity and sustainable development include increasing access to resources and lowering inequities in access, reducing poverty, improving education and

- WGII TAR Section 18.6.1

training, investing in infrastructure, involving concerned parties in managing local resources, and raising institutional capacities and efficiencies. Additionally, initiatives to slow habitat conversion, manage harvesting practices to better protect the resource, adopt cultivation and grazing practices that protect soils, and better regulate the discharge of pollutants can reduce vulnerabilities to climate change while moving toward more sustainable use of resources.

Table 3-1: *Human health consequences of climate change if no climate policy interventions are made.*

	2025	**2050**	**2100**
CO_2 Concentration[a]	415–460 ppm	460–625 ppm	475–1100 ppm
Global Mean Temperature Change from 1990[b]	0.4–1.1°C	0.8–2.6°C	1.4–5.8°C
Global Mean Sea-Level Rise from 1990[b]	2–15 cm	5–30 cm	10–90 cm
Human Health Effects[c]			
Heat stress and winter mortality [WGII TAR Section 9.4]	1) Increase in heat related deaths and illness (high confidence[d]) 2) Decrease in winter deaths in some temperate regions (high confidence[d])	1) Thermal stress effects amplified (high confidence[d])	· Thermal stress effects amplified (high confidence[d])
Infectious disease [WGII TAR Section 9.7]		· Expansion of areas of potential transmission of malaria and dengue (medium-to-high confidence [d]).	· Further expansion of areas of potential transmission (medium-to-high confidence [d]).
Floods, storms [WGII TAR Sections 3.8.5 & 9.5]	3) Increase in deaths, injuries, infections associated with extreme weather (medium confidence[d])	2) Greater increases in deaths, injuries, infections (medium confidence[d]).	1) Greater increases in deaths, injuries, infections (medium confidence[d])
Nutrition [WGII TAR Sections 5.3.6 & 9.9]	4) Poor are vulnerable to increased risk of hunger, but state of science is very incomplete.	3) Poor remain vulnerable to increased risk of hunger.	· Poor remain vulnerable to increased risk of hunger.

[a] The reported ranges for carbon dioxide concentration correspond to the minimum and maximum values estimated with a fast carbon cycle model for the 35 SRES projections of greenhouse gas emissions. See WGI TAR Section 1 3.7.3.

[b] The reported ranges for global mean temperature change and global mean sea-level rise correspond to the minimum and maximum values estimated with a simple climate model for the 35 SRES projections of greenhouse gas and sulfur dioxide emissions. See WGI TAR Sections 9.3.3 and 11.5.1.

[c] Summary statements about market effects of climate change in 2025, 2050, and 2100 are inferred from Working Group II's assessment of studies that investigate the impacts of scenarios other than the SRES projections as studies that use the SRES projections have not been published yet. Estimates of the impacts of climate change vary by region and are highly sensitive to estimates of regional and seasonal patterns of temperature and precipitation changes, changes in the frequencies or intensities of climate extremes, and rates of change. Estimates of impacts are also highly sensitive to assumptions about characteristics of future societies and the extent and effectiveness of future adaptations to climate change. In consequence, summary statements about the impacts of climate change in 2025, 2050, and 2100 must necessarily be general and qualitative. The statements in the table are considered to be valid for a broad range of scenarios. Note, however, that few studies have investigated the effects of climate changes that would accompany global temperature increases near the upper end of the range reported for 2100.

[d] Judgments of confidence use the following scale: *very high* (95% or greater), *high* (67-95%), *medium* (33-67%), *low* (5-33%), and *very low* (5% or less). See WGII TAR Technical Summary and Section 1.4.

[e] Aggregate market effects represent the net effects of estimated economic gains and losses summed across market sectors such as agriculture, commercial forestry, energy, water, and construction. The estimates generally exclude the effects of changes in climate variability and extremes, do not account for the effects of different rates of change, and only partially account for impacts on goods and services that are not traded in markets. These omissions are likely to result in underestimates of economic losses and overestimates of economic gains. Estimates of aggregate impacts are controversial because they treat gains for some as canceling out losses for others and because the weights that are used to aggregate across individuals are necessarily subjective.

Table 3-2: *Ecosystem effects of climate change if no climate policy interventions are made.**

	2025	**2050**	**2100**
CO_2 Concentration[a]	415–460 ppm	460–625 ppm	475–1100 ppm
Global Mean Temperature Change from 1990[b]	0.4–1.1°C	0.8–2.6°C	1.4–5.8°C
Global Mean Sea Level Rise from 1990[b]	2–15 cm	5–30 cm	10–90 cm
Ecosystem Effects[c]			
Corals [WGII TAR Sections 6.4.5, 12.4.7, & 17.2.4]	· Increase in frequency of coral bleaching and death of corals (high confidence[d]).	· More extensive coral bleaching and death (high confidence[d]).	· More extensive coral bleaching and death (high confidence[d]). · Reduced species biodiversity and fish yields from reefs (medium confidence[d]).
Coastal Wetlands and Shorelines [WGII TAR Sections 6.4.2 & 6.4.4]	· Loss of some coastal wetlands to sea level rise (medium confidence[d]). · Increased erosion of shorelines (medium confidence[d]).	· More extensive loss of coastal wetlands (medium confidence[d]). · Further erosion of shorelines (medium confidence[d]).	· Further loss of coastal wetlands (medium confidence[d]). · Further erosion of shorelines (medium confidence[d]).
Terrestrial ecosystems [WGII TAR Sections 5.2.1, 5.4.1, 5.4.3, 5.6.2, 16.1.3, & 19.2]	· Lengthening of growing season in mid and high latitudes; shifts in ranges of plant and animal species (high confidence[d])[e] · Increase in net primary productivity of many mid- and high-latitude forests (medium confidence[d]).	· Increase in frequency of ecosystem disturbance by fire and insect pests (high confidence[d]). · Extinction of some endangered species; many others pushed closer to extinction (high confidence[d]).	· Loss of unique habitats and their endemic species (e.g. vegetation of Cape region of South Africa and some cloud forests) (medium confidence[d]).
Ice environments [WGI TAR Sections 2.2.5 & 11.5; WGII TAR Sections 4.3.11, 11.2.1, 16.1.3, 16.2.1, 16.2.4, & 16.2.7]	· Retreat of glaciers, decreased sea ice extent, thawing of some permafrost, longer ice free seasons on rivers and lakes (high confidence[d]).[e]	· Extensive Arctic sea ice reduction, benefiting shipping but harming wildlife (e.g. seals, polar bears, walrus) (medium confidence[d]) · Ground subsidence leading to infrastructure damage (high confidence[d]).	· Substantial loss of ice volume from glaciers, particularly tropical glaciers (high confidence[d]).

* Refer to the footnotes accompanying Table 3-1.

Table 3-3: *Agricultural effects of climate change if no climate policy interventions are made.**

	2025	**2050**	**2100**
CO_2 Concentration[a]	415–460 ppm	460–625 ppm	475–1100 ppm
Global Mean Temperature Change from 1990[b]	0.4-1.1°C	0.8-2.6°C	1.4-5.8°C
Global Mean Sea Level Rise from 1990[b]	2–15 cm	5–30 cm	10–90 cm
Agricultural Effects[c]			
Average crop yields[d] [WGII TAR Sections 5.3.6, 10.2.2, 11.2.2, 12.5, 13.2.3, & 14.2.2, 15.2.3]	· Cereal crop yields increase in many mid- and high-latitude regions (low-to-medium confidence[e]). · Cereal crop yields decrease in most tropical and sub-tropical regions (low-to-medium confidence[e]).	· Mixed effects on cereal yields in mid- latitude regions. · More pronounced cereal yield decreases in tropical and sub-tropical regions (low-to-medium confidence[e]).	· General reduction in cereal yields in most mid-latitude regions for warming of more than a few degrees (low-to-medium confidence[e]).
Extreme low and high temperatures [WGII TAR Section 5.3.3]	· Reduced frost damage to some crops (high confidence[e]). · Increased heat stress damage to some crops (high confidence[e]). · Increased heat stress in livestock (high confidence[e]).	· Effects of changes in extreme temperatures amplified (high confidence[e]).	· Effects of changes in extreme temperatures amplified (high confidence[e]).
Incomes and prices [WGII TAR Sections 5.3.5 & 5.3.6]		· Incomes of poor farmers in developing countries decrease (low-to-medium confidence[e]).	· Food prices increase relative to projections that exclude climate change (low-to-medium confidence[e])

* Refer to the footnotes accompanying Table 3-1.

Table 3-4: *Water resource effects of climate change if no climate policy interventions are made.**

	2025	2050	2100
CO_2 Concentration[a]	415–460 ppm	460–625 ppm	475–1100 ppm
Global Mean Temperature Change from 1990[b]	0.4–1.1°C	0.8–2.6°C	1.4-5.8°C
Global Mean Sea Level Rise from 1990[b]	2–15 cm	5–30 cm	10–90 cm
Water Resource Effects			
Water supply [WGII TAR Sections 4.3.6 & 4.5.2]	· Peak river flow shifts from spring toward winter in basins where snowfall is an important source of water (high confidence[d]).	· Water supply decreased in many water-stressed countries, increased in some other water-stressed countries (high confidence [d]).	· Water supply effects amplified (high confidence [d]).
Water quality [WGII TAR Section 4.3.10]	· Water quality degraded by higher temperatures (high confidence [d]). · Water quality changes modified by changes in water flow volume (high confidence [d]). · Increase in salt-water intrusion into coastal aquifers due to sea level rise (medium confidence [d]).	· Water quality effects amplified (high confidence [d]).	· Water quality effects amplified (high confidence [d]).
Water demand [WGII TAR Section 4.4.3]	· Water demand for irrigation will respond to changes in climate; higher temperatures will tend to increase demand (high confidence [d])	· Water demand effects amplified (high confidence [d]).	· Water demand effects amplified (high confidence [d]).
Extreme events [WGI TAR SPM; WGII TAR SPM]	· Increased flood damage due to more intense precipitation events (high confidence [d]) · Increased drought frequency (high confidence [d])	· Further increase in flood damage (high confidence [d]) · Further increase in drought events and their impacts.	· Flood damage several fold higher than “no climate change scenarios”

* Refer to the footnotes accompanying Table 3-1.

Table 3-5: *Other market sector effects of climate change if no climate policy interventions are made.**

	2025	**2050**	**2100**
CO_2 Concentration[a]	415–460 ppm	460–625 ppm	475–1100 ppm
Global Mean Temperature Change from 1990[b]	0.4–1.1°C	0.8–2.6°C	1.4–5.8°C
Global Mean Sea Level Rise from 1990[b]	2–15 cm	5–30 cm	10–90 cm
Other Market Sector Effects[c]			
Energy [WGII TAR Section 7.3]	1) Decreased energy demand for heating buildings (high confidence[d]). 2) Increased energy demand for cooling buildings (high confidence[d]).	· Energy demand effects amplified (high confidence[d]).	1) Energy demand effects amplified (high confidence[d]).
Financial sector [WGII TAR Section 8.3]		· Increased insurance prices and reduced insurance availability (high confidence[d]).	· Effects on financial sector amplified.
Aggregate market effects[e] [WGII TAR Section 19.4]	· Net market sector losses in many developing countries (low confidence[d]). · Mixture of market gains and losses in developed countries (low confidence[d]).	1) Losses in developing countries amplified (medium confidence[d]). 2) Gains diminished and losses amplified in developed countries (medium confidence[d]).	2) Losses in developing countries amplified (medium confidence[d]). 3) Net market sector losses in developed countries form warming of more than a few degrees (medium confidence[d]).

* Refer to the footnotes accompanying Table 3-1.

Table 3-6: *Examples of adaptation options for selected sectors.*

Sector/System	Adaptation Options
Water [WGII TAR Sections 4.6 & 7.5.3; WGII SAR Sections 10.6.4 & 14.4]	· Increase water-use efficiency with "demand-side" management (e.g., pricing incentives, regulations, technology standards). · Increase water supply, or reliability of water supply, with "supply-side" management (e.g., construct new water storage and diversion infrastructure). · Change institutional and legal framework to facilitate transfer of water among users (e.g., establish water markets). · Reduce nutrient loadings of rivers and protect/augment streamside vegetation to offset eutrophying effects of higher water temperatures. · Reform flood management plans to reduce downstream flood peaks; reduce paved surfaces and use vegetation to reduce storm runoff and increase water infiltration. · Reevaluate design criteria of dams, levees other infrastructure for flood protection.
Food and Fiber [WGII TAR Sections 5.3.4 & 5.3.5; WGII SAR Sections 2.9, 4.4.4, 13.9, & 15.6; SRTT Section 11.2.1]	· Change timing of planting, harvesting, other management activities. · Use minimum tillage and other practices to improve nutrient and moisture retention in soils, prevent soil erosion. · Alter animal stocking rates on rangelands. · Switch to crops or crop cultivars that are less water demanding, more tolerant of heat, drought and pests. · Conduct research to develop new cultivars. · Promote agro-forestry in dryland areas, including establishment of village woodlots and use of shrubs and trees for fodder. · Shorten wood harvest rotations; replant with mix of tree species to increase diversity and flexibility. · Assist natural migration of tree species with connected protected areas and transplanting. · Improve training and education of rural work forces. · Establish or expand programs to provide secure food supplies as insurance against local supply disruptions. · Reform policies that encourage inefficient, non-sustainable or risky farming, grazing, and forestry practices (e.g., subsidies for crops, crop insurance, water).
Coastal Areas, Marine Fisheries [WGII TAR Sections 6.6 & 7.5.3; WGII SAR Section 16.3; SRTT Section 15.4]	· Prevent or phase-out development in coastal areas vulnerable to erosion, inundation, and storm-surge flooding. · Use "hard" (dikes, levees, seawalls) or "soft" (beach nourishment, dune and wetland restoration, afforestation) structures to protect coasts. · Implement storm warning systems and evacuation plans. · Protect and restore wetlands, estuaries, and floodplains to preserve essential habitat for fisheries. · Modify and strengthen fisheries management institutions and policies to promote conservation of fisheries. · Conduct research and monitoring to better support integrated management of fisheries.
Human Health [WGII TAR Sections 7.5.3 & 9.11; WGII SAR Section 12.5; SRTT Section 14.4]	· Rebuild and improve public health infrastructure. · Improve epidemic preparedness and develop capacities for epidemic forecasting and early warning. · Monitor environmental, biological and health status. · Improve housing, sanitation, and water quality. · Urban designs to reduce heat island effect (e.g., use of vegetation and light colored surfaces). · Public education to promote behaviors that reduce health risks.
Financial Services [WGII TAR Section 8.3.4]	· Risk spreading through private and public insurance and reinsurance. · Risk reduction through building codes and other standards set or influenced by financial sector as requirements for insurance or credit.

FIGURE 3-1 (LEFT PANEL OF 2-PAGE SPREAD)

SEE PAGE 24 LINES 15–21 FOR FIGURE CAPTION

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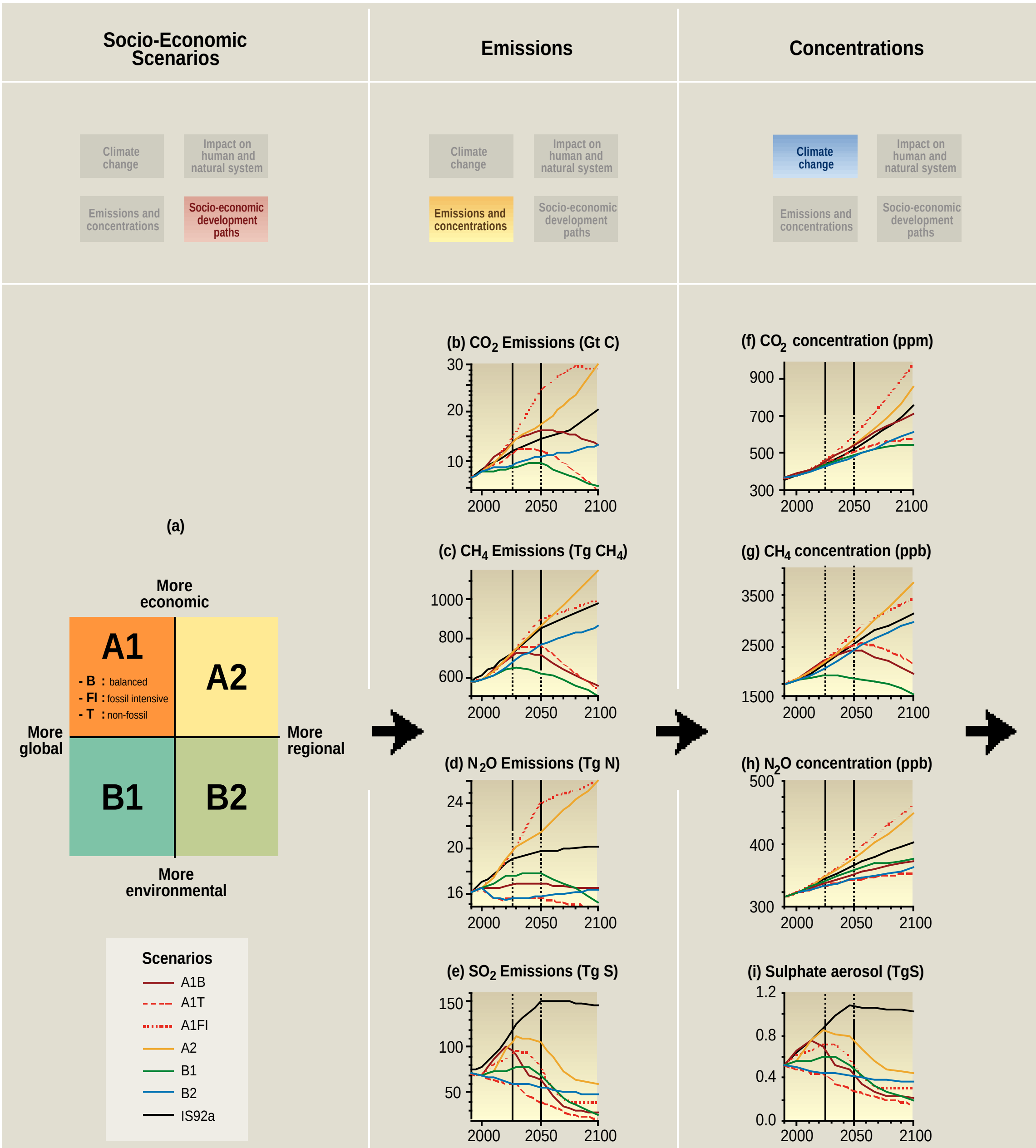

SCENARIOS

A1 FI, A1 T and A1 B

The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1 FI), non-fossil energy sources (A1 T), or a balance across all sources (A1 B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvment rates apply to all energy supply and end use technologies).

FIGURE 3-2 (RIGHT PANEL OF 2-PAGE SPREAD)

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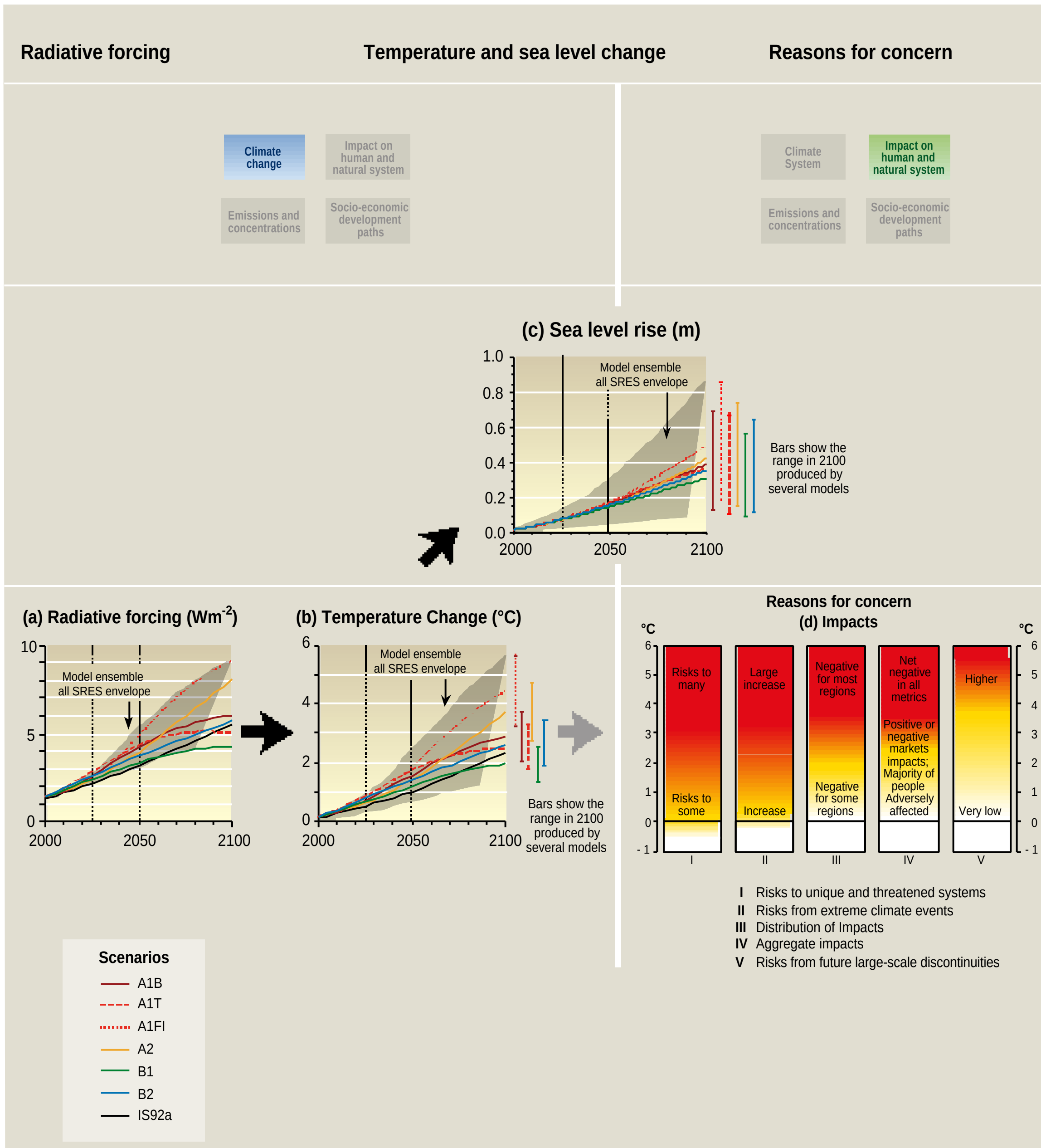

D E C R I P T I O N S

A2

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1

The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environment sustainability, including improved equity, but without additional climate initiatives.

B2

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

FIGURE 3-3

SEE PAGE 26 LINES 16–32 FOR FIGURE CAPTION

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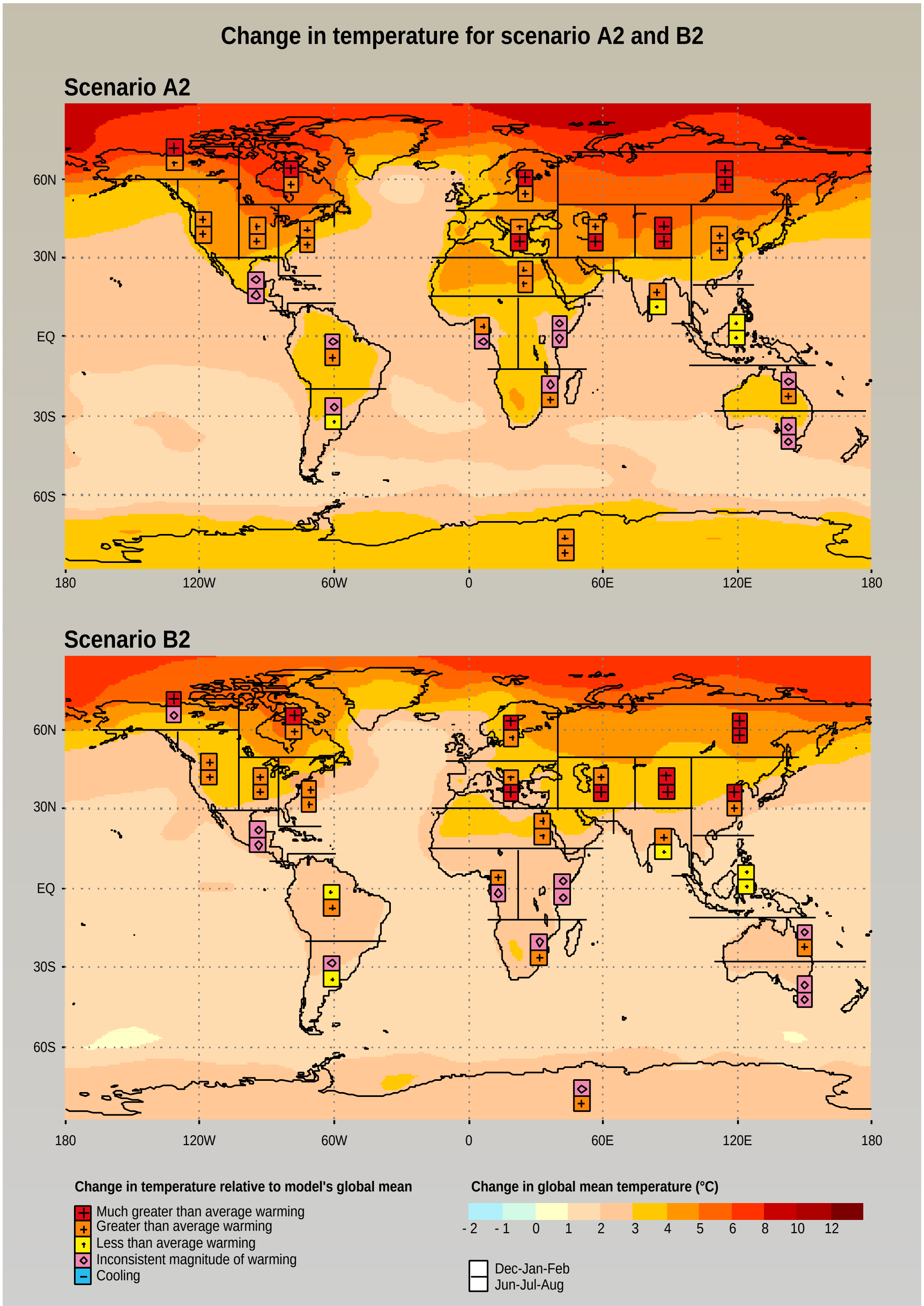

FIGURE 3-4

SEE PAGE 26 LINES 42–54 FOR FIGURE CAPTION

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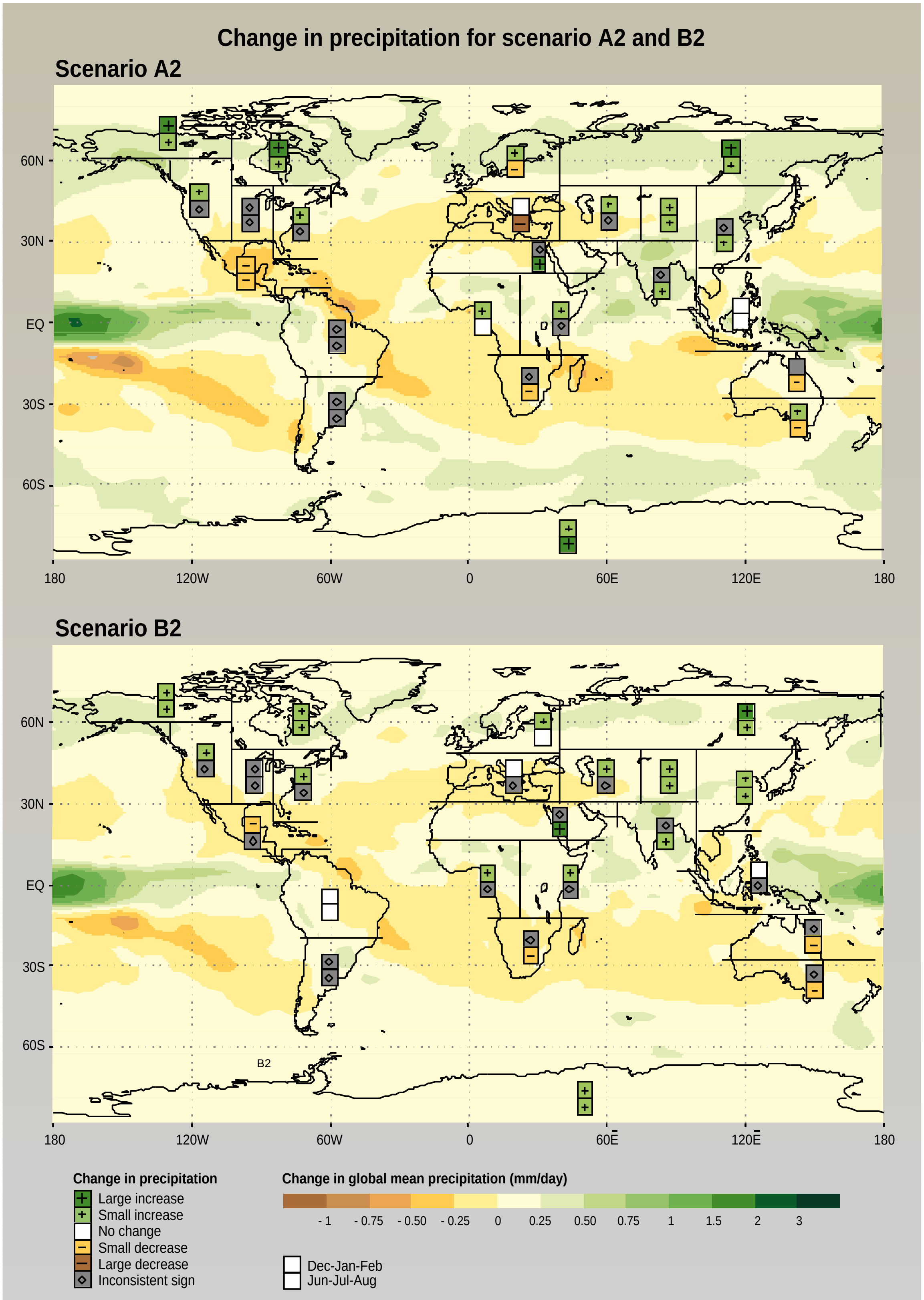

FIGURE 3-5

SEE PAGE 27 LINES 9–14 FOR FIGURE CAPTION

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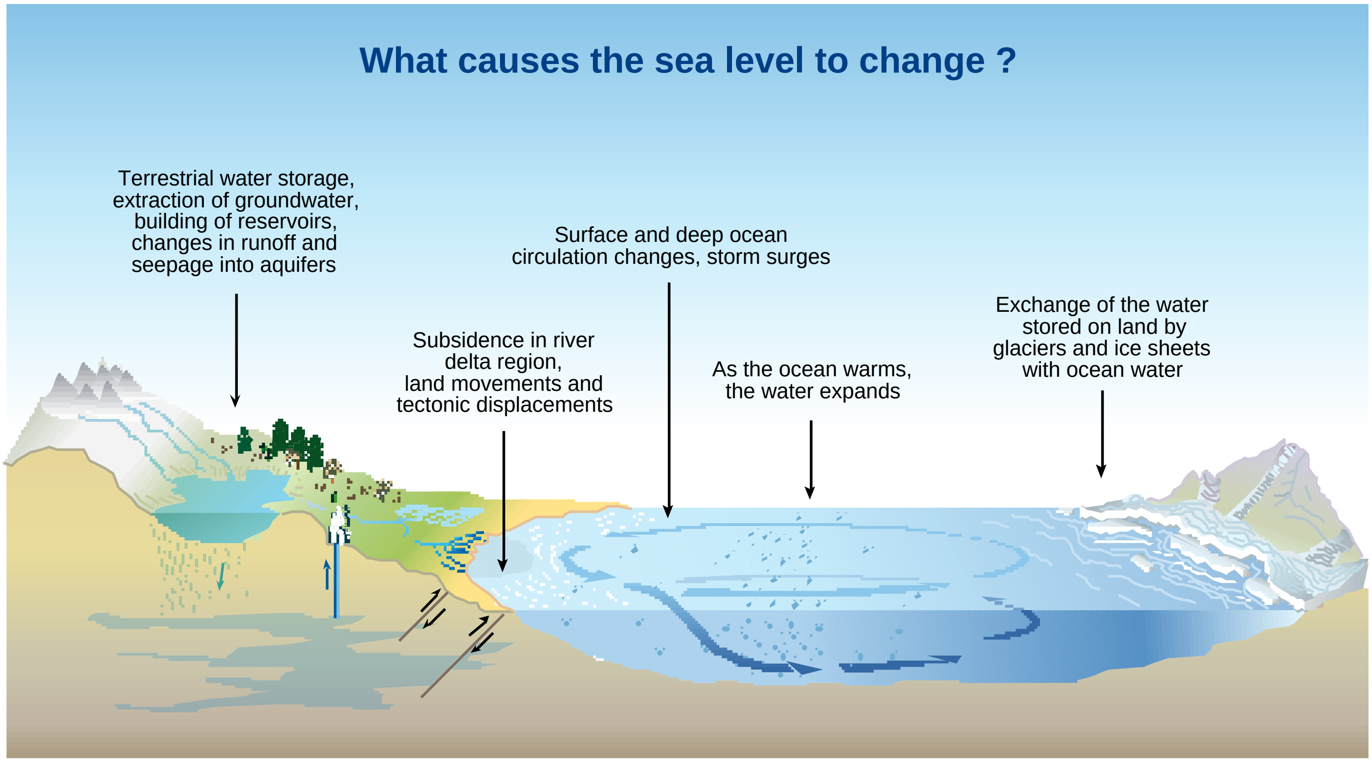

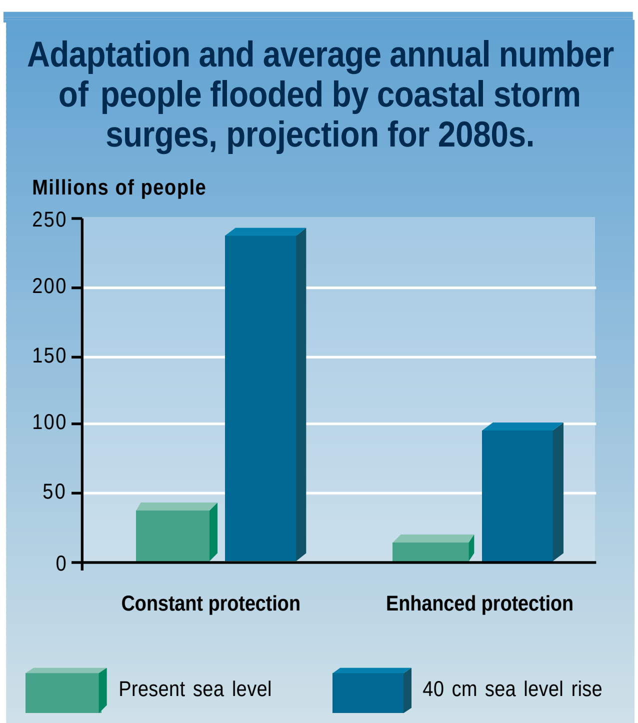

FIGURE 3-6

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QUESTION 4

What is known about the influence of the increasing atmospheric concentrations of greenhouse gases and aerosols, and the projected human-induced change in climate regionally and globally on:

- **a. The frequency and magnitude of climate fluctuations, including daily, seasonal, inter-annual, and decadal variability, such as the El Niño Southern Oscillation cycles and others?**
- **b. The duration, location, frequency, and intensity of extreme events such as heat waves, droughts, floods, heavy precipitation, avalanches, storms, tornadoes, and tropical cyclones?**
- **c. The risk of abrupt/non-linear changes in, among others, the sources and sinks of greenhouse gases, ocean circulation, and the extent of polar ice and permafrost? If so, can the risk be quantified?**
- **d. The risk of abrupt or non-linear changes in ecological systems?**

Paragraph Number		*Reference*
4.1	This answer focuses on projected changes in the frequency and magnitude of climate fluctuations. Particular emphasis is placed on changes in the frequency, magnitude, and duration of climatic extremes, which represent important climate change risks for ecological systems and socio-economic sectors. Projected abrupt or other non-linear changes in the biophysical system are discussed here; the gradual changes in the physical, biological, and social systems are discussed in Question 3.	
4.2	**The duration, location, frequency, and intensity of extreme climatic events is likely to change and would result in mostly adverse impacts on biophysical systems.**	
4.3	Natural circulation patterns, such as the El Niño Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO), play a fundamental role in global climate and its short-term (daily, intra- and inter-annual) and longer term (decadal) variability. Climate change may manifest itself as a shift in means as well as a change in preference of specific climate regimes that could result in changes in the variance and frequency of extremes of climatic variables (see Figure 4-1).	• WGI TAR Sections 1.2 & 2.7
	[FIGURE 4-1 CAPTION: Schematic diagrams showing the effect on extreme events when (a) mean temperature increases in summer, leading to more record hot weather; (b) the mean temperature and its variance increases, leading to much more record hot weather; (c) the variance of precipitation increases without an increase in the mean, leading to more intense rainfall events and longer dry spells; and (d) the mean precipitation and its variance increases, potentially changing the distribution function and leading to much more intense rainfall events and more dry spells.]	• WGI TAR Figure 2.32
4.4	***More hot days and heat waves and fewer cold and frost days are likely.*** Increases in the mean and in the variance of temperature will lead to an increase in more hot weather and record hot weather, with fewer frost days and cold waves (see Figure 4-1a,b). A number of models show a generally decreased daily variability of surface air temperature in winter and increased daily variability in summer in Northern Hemisphere land areas. The changes in temperature extremes are likely to result in increased crop and livestock losses, decreases in water run-off, higher energy use for cooling and lower for heating, and increased human morbidity and heat-stress-related mortality. Fewer frost days will result in decreased cold-related human morbidity and mortality, and decreased risk of damage to a number of crops, though the risk to other crops may increase. Benefits to agriculture from a small temperature increase could result in small increases in the gross domestic product (GDP) in temperate zone countries (see Table 4-1).	• WGI TAR Sections 9.3.6 & 10.3.2 • WGII TAR Sections 5.3, 9.4.2, & 19.5

[Insert Table 4-1 here]

4.5 ***The amplitude and frequency of extreme precipitation events is very likely to increase over many areas*** and the return period for extreme precipitation events are projected to decrease (see Figure 4-1c,d). This is likely to lead to more frequent floods and landslides with attendant loss of life, health impacts (epidemics, water contamination, infectious diseases, food poisoning), property damage, loss to infrastructure and settlements, soil erosion, pollution loads, insurance and agriculture losses amongst others. A general drying of the mid-continental areas during summer is likely to lead to increases in summer droughts and could increase the risk of wild fires. This is due to a combination of increased temperature and potential evaporation that is not balanced by increases in precipitation.

- WGI TAR Section 9.3.6
- WGII TAR Chapters 4/9, & Section 5.3

4.6 ***The majority of models project a more El Niño-like condition in the tropical Pacific,*** with the central and eastern equatorial Pacific sea surface temperatures warming more than the western equatorial Pacific and with a corresponding mean eastward shift of precipitation. These changes could result in increased frequency of floods and droughts and lead to other changes such as increases in the frequency of wildfires. There is no clear agreement concerning the changes in frequency or structure of other naturally occurring modes of variability such as the NAO.

- WGI TAR Section 9.3.5
- WGII TAR Section 14.1.3

4.7 ***High-resolution modeling studies suggest that the peak precipitation intensity of tropical cyclones may increase*** by 5–10% and precipitation rates may increase by 20–30%, but none of the studies suggest that the locations of the tropical cyclones will change.

- WGI TAR Box 10.2

4.8 ***There is insufficient information on how very small-scale phenomena may change.*** Very small-scale phenomena such as thunderstorms, tornadoes, hail, and lightning are not simulated in global models.

- WGI TAR Section 9.3.6

4.9 **The risk of abrupt or other non-linear changes in the sources and sinks of greenhouse gases, ocean circulation, and the extent of continental ice sheets and permafrost appear unlikely within the 21st century, but the probability of such changes increases as the rate, magnitude, and duration of climate change increases.**

4.10 The climate system involves many processes that interact in complex non-linear ways, which can give rise to thresholds (thus potentially abrupt changes) in the climate system that could be crossed if the system were perturbed sufficiently. These abrupt and other non-linear changes include large climate-induced increase in greenhouse gas emissions from terrestrial ecosystems, a collapse of the thermohaline circulation (THC; see Figure 4-2), and disintegration of the Antarctic and the Greenland ice sheets. Some of these changes have low probability of occurrence during the 21st century; however, greenhouse gas forcing in the 21st century could set in motion changes that could lead to such transitions in subsequent centuries (see Question 5). Some of these changes (e.g., to THC) could be irreversible over centuries to millenia. There is a large degree of uncertainty about the mechanisms involved and about the likelihood or time scales of such changes; however, there is evidence from polar ice cores of atmospheric regimes changing within a few years and large-scale hemispheric changes as fast as a few decades with large consequences on the biophysical systems.

- WGI TAR Sections 7.3, 9.3.4, & 11.5.4
- WGII TAR Sections 5.2 & 5.8
- SRLUCF Chapters 3 & 4

[FIGURE 4-2 CAPTION: Schematic illustration of the global circulation system in the world ocean consisting of major north-south thermohaline circulation routes in each ocean basin joining in the Southern Ocean. Warm surface currents and cold deep currents are connected in the few areas of deepwater formation in the high latitudes of the Atlantic and around Antarctica (blue), where the major ocean-to-atmosphere heat transfer occurs. This current system contributes substantially to the transport and redistribution of heat (e.g., the poleward flowing currents in the North Atlantic warm northwestern Europe by up to 10°C). Model simulations indicate that the North Atlantic branch of this circulation system is particularly vulnerable to changes in atmospheric temperature and in the hydrological cycle. Such perturbations caused by global warming could disrupt the current system, which would have a strong impact on regional-to-hemispheric climate.]

4.11 ***Large climate-induced increases in greenhouse gas emissions due to large-scale changes in vegetation may be possible.*** Global warming interacting with other environmental stresses and human activity could lead to the rapid breakdown of existing ecosystems. Examples include drying of the tundra, boreal and tropical forests, and their associated peatlands leaving them susceptible to fires. Such breakdowns could induce further climate change through increased emissions of carbon dioxide and other greenhouse gases from plants and soil and changes in surface properties and albedo.

- WGII TAR Sections 5.2, 5.8, & 5.9
- SRLUCF Chapters 3 & 4

4.12 ***Large, rapid increases in atmospheric methane either from reductions in the atmospheric chemical sink or from release of buried reservoirs appear exceptionally unlikely.*** The rapid increase in methane lifetime possible with large emissions of tropospheric pollutants does not occur within the range of SRES scenarios. The methane reservoir buried in solid hydrate deposits under permafrost and ocean sediments is enormous, more than a 1000-fold the current atmospheric content. A proposed climate feedback occurs when the hydrates decompose in response to warming and release large amounts of methane; however, most of the methane gas released from the solid form is decomposed by bacteria in the sediments and water column, thus limiting the amount emitted to the atmosphere unless explosive ebullient emissions occur. This mechanism has not been quantified, and there is no evidence for rapid, massive methane release in the record of atmospheric methane over the past 420,000 years during the large temperature and sea-level variations of the glacial-interglacial period.

- WGI TAR Section 4.2.1.1

4.13 ***Most models project a weakening of the ocean thermohaline circulation, which leads to a reduction of the heat transport into high latitudes of Europe (see Figure 4-2).*** However, even in models where the thermohaline circulation weakens, there is still a warming over Europe due to increased greenhouse gases. The current projections do not exhibit a complete shutdown of the thermohaline circulation by 2100. Beyond 2100, there is some evidence to suggest that the thermohaline circulation could completely, and possibly irreversibly, shut down in either hemisphere if the change in radiative forcing is large enough and applied long enough. Models indicate that a decrease in the THC reduces its resilience to perturbations (i.e., a once-reduced THC appears to be less stable and a shutdown can become more likely).

- WGI TAR SPM and Sections 7.3 & 9.3.4

4.14 ***The Antarctic ice sheet is likely to increase slightly in mass during the 21st century but the West Antarctic ice sheet could lose mass over the next 1000 years with an associated sea-level rise of several meters***. Concerns have been expressed about the stability of the West Antarctic ice sheet (WAIS) because it is grounded below sea level. However, loss of grounded ice leading to substantial sea-level rise from this source is widely agreed to be unlikely during the 21st century. Current climate and ice dynamic models project that over the next 100 years the Antarctic ice sheet as a whole is likely to gain mass because of a projected increase in precipitation, contributing to a decrease of 1 cm to sea level. Over the next 1000 years, these models project that the WAIS could contribute up to 3 m to sea-level rise. However, the dynamics of the WAIS are still not sufficiently understood to make projections, especially on the longer time scales (see Questions 3 and 5).

- WGI TAR Section 11.5.4

4.15 ***The Greenland ice sheet is likely to lose mass during the 21st century and contribute a few cm to sea-level rise.*** Over the 21st century, the Greenland ice sheet is likely to lose mass because the projected increase in runoff will exceed the increase in precipitation but contribute only about 10 cm to the total sea-level rise. A sustained localized warming of 3.0 to 5.5°C over Greenland could result in a sea-level rise of 1 to 3 m over the next 1000 years (see Question 3).

• WGI TAR Section 11.5.4

4.16 ***Pronounced changes in permafrost temperature, surface morphology, and distribution are expected***. Permafrost currently underlies 24.5% of the exposed land area of the Northern Hemisphere. Under climatic warming, much of this terrain would be vulnerable to subsidence, particularly in areas of relatively warm, discontinuous permafrost. The area of the Northern Hemisphere occupied by permafrost could eventually be reduced by 12–22% of its current extent and could eventually disappear from half the present-day Canadian permafrost region. The changes on the southern limit may become obvious by the late 21st century but some thick ice-rich permafrost could persist in relict form for centuries or millennia. Thawing of ice-rich permafrost can be accompanied by mass movements and subsidence of the surface, possibly increasing the sediment loads in water courses and causing damage to the infrastructure in developed regions. Depending on the precipitation regime and drainage conditions, degradation of permafrost could lead to changes from forest to bogs, grasslands, and wetland ecosystems and could cause major erosion problems and landslides.

• WGII TAR Sections 16.1 & 16.2

4.17 **Many natural and managed ecosystems may change abruptly or non-linearly during the 21st century.**

4.18 ***Abrupt changes could impact adversely on many ecosystems, which would affect their biodiversity and function.*** For example, sustained increases in water temperatures of as little as 1°C, alone or in combination with any of several stresses (e.g., pollution, siltation), can lead to corals ejecting their algae (coral bleaching; see Figure 4-3 and Question 2), the eventual death of the corals, and a possible loss of biodiversity. Climate change will shift suitable habitats for many organisms polewards or to higher altitudes in mountainous areas. Increased disturbances, along with the shift in habitats and the more restrictive conditions necessary for establishment of species, could result in new plant and animal assemblages that are less diverse, have "weedy" species, and have increased risk of extinction and potential loss of biodiversity (see Question 5).

• WGII TAR Sections 5.2, 6.4.5, & 17.4.2.4

[FIGURE 4-3 CAPTION: The diversity of corals could be affected with the branching corals (e.g., staghorn coral) decreasing or becoming locally extinct, as they tend to be more severely affected by increases in sea surface temperatures, and the massive corals (e.g., brain corals) increasing.]

• WGII TAR Section 17.2.4

4.19 ***Ecological systems have many interacting non-linear processes and are thus subject to abrupt changes and threshold effects arising from relatively small changes in driving variables, such as climate.*** For example:

- Experimental and modeling work shows that, with increasing atmospheric CO_2, rice growth increases non-linearly, while water-use efficiency increases near current growing temperatures but declines rapidly with increasing temperatures. The success in forming grains is also sensitive to a threshold temperature of 26°C and grain yield falls by about 10% for every degree increase above 26°C during the flowering and pollination process. The outcome of the interactions between these non-linear processes depends on the precise field growing conditions; in some areas yield will increase under projected climate change, including elevated CO_2, but with slightly higher temperatures this could rapidly change to decreased yields. For some parts of the world, this is one possible

• WGII TAR Sections 11.2 & 11.3

mechanism by which areas become unsuitable for a particular crop, necessitating a switch to some other crop or crops.

- Mangroves occupy a transition zone between sea and land that is set by a balance between the erosional processes from the sea, which might be expected to increase with sea-level rise, and siltation processes from land, which could also increase through climate change but also other human activities (e.g., coastal development). The impact on the mangrove forests will be determined by the balance between these two processes, which will determine whether mangrove systems migrate landward or seaward.

- WGII TAR Sections 5.3, 10.2.2, 15.2, & 17.2

4.20 ***Human activities, leading to large-scale changes in vegetation cover, could affect regional climate*.** Changes in land surface characteristics, such as those created by land cover, can modify energy, water, and gas fluxes and affect atmospheric composition creating changes in local/regional climate and thus changing the disturbance regime (e.g., in the Arctic). In areas without surface water (typically semi-arid or arid), evapotranspiration and the albedo affect the local hydrologic cycle and thus a reduction in vegetative cover could lead to reduced precipitation at local/regional scale and change the frequency and persistence of droughts.

- WGII TAR Sections 1.3.1, 3.7, 5.2, 5.9, 10.2.6.3, & 14.2.1.1

Table 4-1: *Examples of climate variability and extreme climate events and examples of their impacts (WGII TAR Table SPM-1).*

Projected Changes during the 21st Century in Extreme Climate Phenomena and their Likelihood	**Representative Examples of Projected Impacts[a] (all high confidence of occurrence in some areas)**
Higher maximum temperatures, more hot days and heat waves[b] over nearly all land areas (*very likely*)	• Increased incidence of death and serious illness in older age groups and urban poor • Increased heat stress in livestock and wildlife • Shift in tourist destinations • Increased risk of damage to a number of crops • Increased electric cooling demand and reduced energy supply reliability
Higher (Increasing) minimum temperatures, fewer cold days, frost days and cold waves[b] over nearly all land areas (*very likely*)	• Decreased cold-related human morbidity and mortality • Decreased risk of damage to a number of crops, and increased risk to others • Extended range and activity of some pest and disease vectors • Reduced heating energy demand
More intense precipitation events (*very likely*, over many areas)	• Increased flood, landslide, avalanche, and mudslide damage • Increased soil erosion • Increased flood runoff could increase recharge of some floodplain aquifers • Increased pressure on government and private flood insurance systems and disaster relief
Increased summer drying over most mid-latitude continental interiors and associated risk of drought (*likely*)	• Decreased crop yields • Increased damage to building foundations caused by ground 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*, over some areas)[c]	• Increased risks to human life, risk of infectious disease epidemics and many other risks • Increased coastal erosion and damage to coastal buildings and infrastructure • Increased damage to coastal ecosystems such as coral reefs and mangroves
Intensified droughts and floods associated with El Niño events in many different regions (*likely*) (see also under droughts and intense precipitation events)	• Decreased agricultural and rangeland productivity in drought- and flood-prone regions • Decreased hydro-power potential in drought-prone regions
Increased Asian summer monsoon precipitation variability (likely)	• Increase in flood and drought magnitude and damages in temperate and tropical Asia
Increased intensity of mid-latitude storms (Little agreement between current models)[b]	• Increased risks to human life and health • Increased property and infrastructure losses • Increased damage to coastal ecosystems

[a] These impacts can be lessened by appropriate response measures.
[b] Information from WGI TAR Technical Summary (Section F.5).
[c] Changes in regional distribution of tropical cyclones are possible but have not been established.

FIGURE 4-1

SEE PAGE 45 LINES 34–40 FOR FIGURE CAPTION

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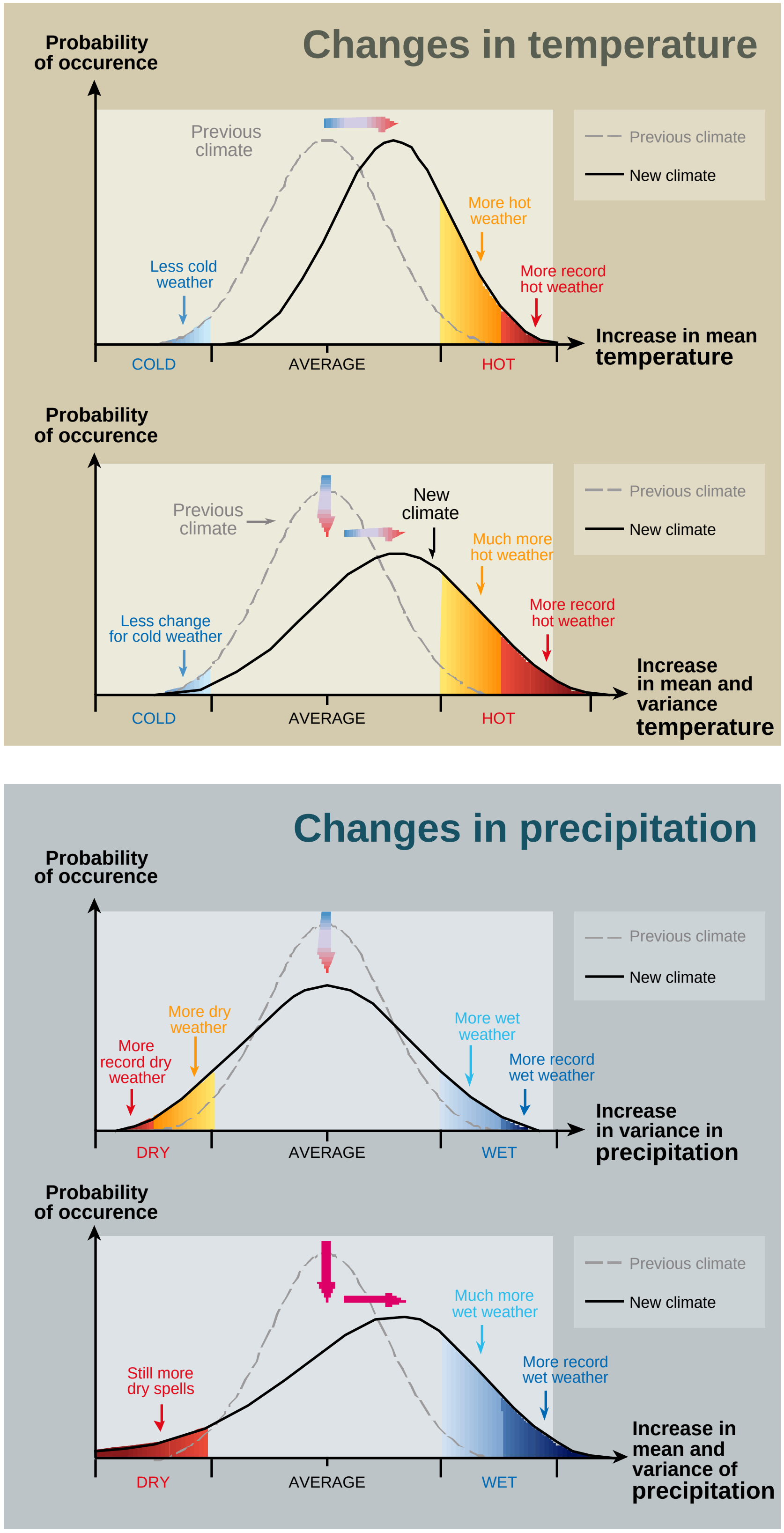

FIGURE 4-2

SEE PAGE 46 LINE 53 – PAGE 47 LINE 9 FOR FIGURE CAPTION

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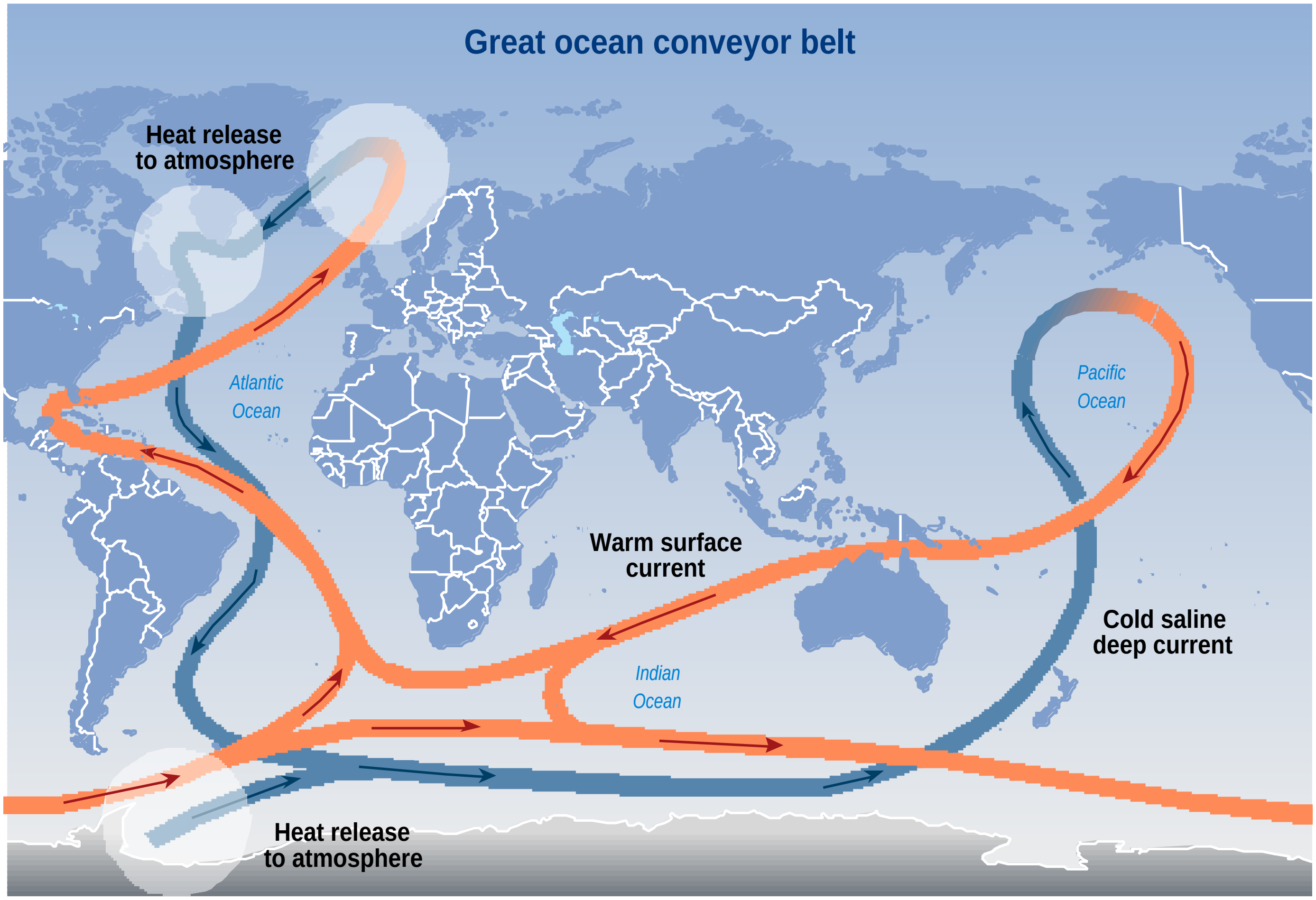

FIGURE 4-3

SEE PAGE 48 LINES 37–40 FOR FIGURE CAPTION

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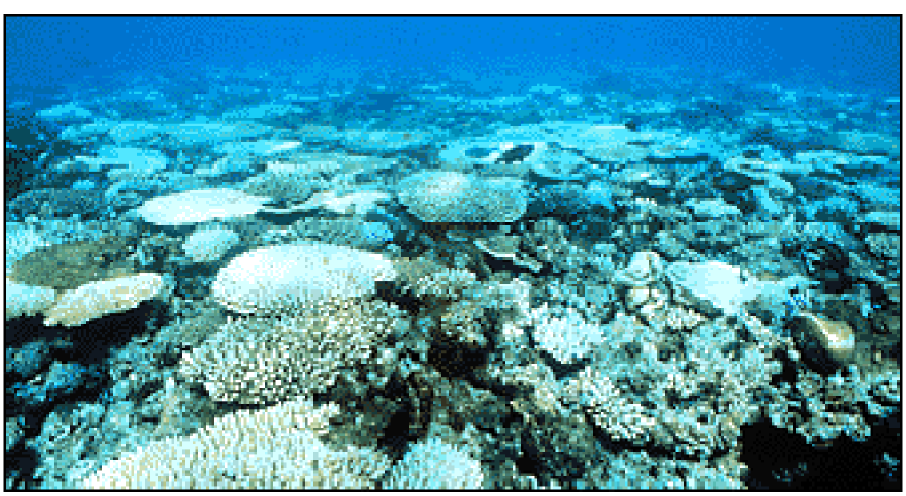

QUESTION 5

What is known about the inertia and time scales associated with the changes in the climate system, ecological systems, and socio-economic sectors and their interactions?

Paragraph Number *Reference*

This question response discusses issues resulting from time scales associated with important processes in the interacting atmospheric, climatic, biological, and human systems (the components of the Earth system depicted in Figure 5-1).

Box 5-1 The terms "time scale" and "inertia" have no generally accepted meaning across all the disciplines involved in the TAR. The following definitions are applied for the purpose of responding to this question:

- "**Time scale**" is the time required for a perturbation in a process to show at least half of its final effect. The time scales of some key Earth system processes are shown in Figure 5-1.
- "**Inertia**" means a delay, slowness, or resistance in the response of climate, biological, or human systems to factors that alter their rate of change, including continuation of change in the system after the cause of that change has been removed.

These are only two of several concepts used in the literature to describe the responses of complex, non-linear, adaptive systems to external forcing.

[FIGURE 5-1 CAPTION: The characteristic time scales of some key processes in the atmosphere (blue), climate (red), biological (green), and human (purple) subsystems of the Earth system. "Time scale" is defined here as the time needed for at least half of the consequences of a change in a driver of the process to have been expressed. Problems of adaptation arise when response processes (such as the migration of plants) are much slower than driving processes (the change in temperature). Inter-generational equity problems arise for all processes with time scales greater than a human generation, since a large part of the consequences of activities of a given generation will be borne by future generations.]

Reference:
- WGI TAR Chapters 3, 4, 7, & 11
- WGII TAR Chapter 5
- WGIII TAR Chapters 5 & 6

The first section of this response gives examples of inertia and varying time scales in the atmosphere, climate, ecological, and socio-economic systems. The second section describes situations where parts of the Earth system may fail to return to its former state within time scales of multiple human generations after the driving forces leading to change are reduced or removed. The third section explores how the effects of inertia may influence decisions regarding the mitigation of, or adaptation to, climate change.

5.1 **Inertia is widespread in the Earth system, with some important processes having impacts that persist for centuries or millennia.**

5.2 ***The combined effect of the interacting inertias of the various component processes is that stabilization of the climate and climate-impacted systems will only be achieved long after anthropogenic emissions of greenhouse gases have been reduced.*** The perturbation of the atmosphere, climate, and oceans resulting from carbon dioxide (CO_2) already emitted due to

Reference:
- WGI TAR Figures 9.16 &

human activities since 1750 will persist for centuries because it triggers a redistribution of carbon between large biospheric reservoirs with slow turnover (see Figures 5-2 and 5-4). The future atmospheric concentration of CO_2 is projected to remain near the highest level reached for centuries, since natural processes can only return the concentration to pre-industrial levels over geological time scales. Inertia also implies that avoidance of emissions of long-lived greenhouse gases has long-lasting benefits. The atmospheric concentrations of short-lived gases such as methane (CH_4) respond rapidly to emission reductions.

9.19, & Sections 3.7, 3.13, 4.2, 11.15, 11.16

[FIGURE 5-2 CAPTION: Time scales of response to reductions in CO_2 emissions by parts of the climate system. After CO_2 emissions are reduced and atmospheric concentrations stabilize, surface air temperature continues to rise slowly for a few centuries. Thermal expansion of the ocean continues long after CO_2 emissions have been reduced, and melting of ice sheets continues to contribute to sea-level rise for several millennia. Stabilization at any level between 450 and 1000 ppm shows broadly similar time courses, but the amplitude of change becomes progressively larger. The curves illustrated are based on stabilization of atmospheric CO_2 at 550 ppm, while the given time ranges are for stabilization from 450 to 1000 ppm. When emissions are reduced sooner, the time scales of response will be shorter and magnitudes of change are less.]

- WGI TAR Sections 3.7, 9.3, & 11.5

5.3 ***The oceans and cryosphere (ice caps, ice sheets, glaciers, and permafrost) are the main sources of physical inertia in the climate system for time scales up to a thousand years***. Due to the great mass, thickness, and thermal capacity of the oceans and cryosphere, linked ocean-climate models predict that the average temperature of the atmosphere near the Earth's surface will take hundreds of years to finally approach the new "equilibrium" temperature following a change in radiative forcing. Penetration of heat into the upper "mixed layer" of the ocean is relatively rapid, but transport of heat into the deep ocean is slow. An associated consequence is that human-induced sea-level rise will continue inexorably for many centuries after the atmospheric concentration of greenhouse gases has been stabilized.

- WGI TAR Figures TS-26, 9.1, 9.24 & 11.16,& Sections 1.1.2, 7.3.1-3, 7.5, & 11.5.4

5.4 ***The lower the stabilization target for atmospheric CO_2, the sooner CO_2 levels would need to decrease to meet it.*** If emissions were held at today's levels, the atmospheric concentration of CO_2 would continue to rise, for millennia (see Figure 5-3). Stabilization at any level up to and beyond 1000 ppm requires ultimate reduction of net emissions to a small fraction of the current emission level. Keeping the atmospheric concentration of CO_2 below 450 ppm is only possible if emissions of CO_2 fall below 1990 levels within the period 2010 to 2040, below 550 ppm by 2040 to 2100**,** at 650 ppm by 2090 to 2150, at 750 ppm by 2150 to 2190, and at 1000 ppm by 2180 to 2380 (see Figure 6-1). These time constraints are partly due to the rate of CO_2 uptake by the ocean, which is limited by the slow transport of material between the surface and deep waters. There is sufficient uptake capacity in the ocean to incorporate 70 to 80% of foreseeable anthropogenic CO_2 emissions to the atmosphere, but this would take several centuries. Interaction with ocean sediments has the potential to remove up to a further 15% over a period of 5000 years (see Figure 5-3).

- WGI TAR Section 3.7

[FIGURE 5-3 CAPTION: Stabilizing CO_2 *emissions* at current levels will result in a continously rising atmospheric CO_2 *concentration* and temperature. Stabilization of atmospheric CO_2 and temperature change will eventually require the emissions to drop well below current levels. In all three panels the red curves illustrate the result of emissions fixed at the level projected by WRE 550 for year 2000 (which is slightly higher than the actual emissions for 2000), while the blue curves are the result of emissions following the WRE 550 stabilization scenario. Both cases are illustrative only: Constant emissions are unattainable in the short term, and no preference is expressed for the WRE 550 scenario over others. Other

- WGI TAR Sections 3.7 & 9

stabilization scenarios are illustrated in Figure 6-1. Figure 5-3 was constructed using the models described in TAR WGI 3.7 and 9. The climate model had a temperature sensitivity of 2.5°C. The effects of non-CO_2 greenhouse gases and aerosols are not included in either the constant emissions or WRE 550 example.]

5.5 ***A delay between biospheric carbon uptake and carbon release is manifest as a temporary net sink.*** The present terrestrial carbon sink is partly a product of the time lag between photosynthetic carbon uptake and carbon release when plants eventually die and decay. For example, the sink resulting from regrowth of forests on agricultural lands abandoned over the last century in the northern hemisphere will decline as the forests reach their mature biomass, growth slows, and death increases. Enhancement of plant carbon uptake due to CO_2 or nitrogen fertilization will eventually saturate, then decomposition of the increased biomass will catch up. Climate change is likely to increase disturbance and decomposition rates in the future. Models project that the terrestrial carbon sink will peak, then level off or decrease. The peak could be passed within the 21st century under most model projections. Projections of the terrestrial carbon sink strength beyond a few decades remain uncertain (Figure 5-4).

- WGI TAR Sections 3.2.2 & 3.7.1

[FIGURE 5-4 CAPTION: The time scales of major processes within the global carbon cycle leads to a long perturbation lifetime of CO_2 in the atmosphere, and the development of ocean and land sinks when the atmospheric CO_2 concentration rose above its pre-1750 equilibrium level. The land sink is partly due to rapid, enhanced CO_2 uptake through plant growth, with a delay before this carbon is returned to the atmosphere via the decay of plant material and soil organic matter. Several other processes contribute to whether the land is a source or sink: The main ones are changes in land use and disturbance, climate, and nitrogen fertilization. A range of models (identified by their acronyms in the panel) project a continued increase in the strength of the land sink for several decades, then a leveling off or decline late in the 21st century (panel a). The ocean sink is due to dissolution of CO_2 in the surface ocean and subsequent mixing into deep waters. Ocean models project that the ocean sink will persist for centuries, but will take up a declining proportion of CO_2 emissions (panel b).]

- WGI TAR Figure 3.10

5.6 ***When subjected to rapid climate change, ecological systems are likely to be disrupted as a consequence of the differences in response times within the system.*** The loss of sustainability may not be immediately apparent, and the consequences for ecosystem services are little known and hard to predict**.** Climate change may lead to conditions unsuitable for the establishment of key species, but the slow and delayed response of long-lived plants hides the importance of the change until the already-established individuals die or are killed in a disturbance. For example, for climate change of the degree possible within the 21st century, it is likely, in some forests, that when a stand is disturbed by fire, wind, pests, or harvesting, instead of the community regenerating as in the past, species may be lost or replaced by different species.

- WGII TAR Section 5.2

5.7 ***Humans have shown a capacity to adapt to long-term mean climate conditions, but there is less success in adapting to extremes and to year-to-year variations in climatic conditions.*** Climatic changes in the next 100 years are expected to exceed any experienced in the history of modern societies. The magnitude and rate of these changes will pose a major challenge for humanity. The time needed for socio-economic adaptation varies from years to decades, depending on the sector and the resources available to assist the transition. There is inertia in decisionmaking in the area of mitigation, and in implementing those decisions, of the order of decades. The fact that adaptation and mitigation decisions are generally not made by the same entities compounds the difficulties inherent in the identification and implementation of the best possible combination of strategies, and hence contributes to the delays of climate change response.

- WGII TAR Sections 1.2 & 18.2.5
- WGIII TAR Secion 10.4.2

5.8 ***There is a delay of years to decades between perceiving a need, researching and developing a technological solution, scaling it up, and implementing it.*** The delay in the "technology pipeline" can be shortened by anticipating needs through the application of foresight, and thus developing technologies in advance. The response of technological development to energy price changes has historically been relatively rapid (typically, less than 5 years elapses between a price shock and the response in terms of patenting activity and introduction of new model offerings) but its diffusion takes much longer. The diffusion rate often depends on the rate of retirement of previously installed equipment. Early deployment of rapidly improving technologies allows learning-curve cost reductions (learning by doing), without premature lock-in to existing, low-efficiency technology. The rate of technology diffusion is strongly dependent not only on economic feasibility but also on socio-economic pressures. For some technologies, such as the adoption of new crop varieties, the availability of, and information on, pre-existing adaptation options allows for rapid adaptation. In many regions, however, population pressures on limited land and water resources, government policies impeding change, or limited access to information or financial resources make adaptation difficult and slow. Optimal adaptation to climate change trends, such as more frequent droughts, may be delayed if they are considered to be due to natural variability, while they might actually be related to climate change. Conversely, maladaptation can occur if climate variability is mistaken for a trend.

- WGII TAR Sections 1.4.1, 12.8.4, & 18.3.5
- WGIII TAR Chapter 5 & Sections 6.5.3.2 & 10.4

5.9 ***Social structures and personal values interact with society's physical infrastructure, institutions, and the technologies embodied within them, and the combined system evolves relatively slowly.*** This is particularly obvious, for instance, in relation to the impact of urban design and infrastructure on energy consumption for heating, cooling, and transport. Markets sometimes "lock in" to technologies and practices that are sub-optimal because of the investment in supporting infrastructure, which block out alternatives. Diffusion of most innovations comes up against people's traditional preferences and other social and cultural barriers. Unless advantages are very clear, social or behavioral changes on the part of technology users may require generations. Energy use, greenhouse gas mitigation, and cost minimization are peripheral interests in most people's everyday lives. Their consumption patterns are driven not only by demographic, economic and technological change, resource availability, infrastructure, and time constraints, but also by motivation, habit, need, compulsion, social structures, and other factors.

- WGIII TAR Sections 3.8.6, 5.2, 5.3, & 10.3
- SRTT SPM & Chapter 4 ES

5.10 ***Social and economic time scales are not fixed: They are sensitive to social and economic forces, and could be reduced by policy actions.*** Behavioral and technological changes can occur rapidly under severe economic conditions. For example, the oil crises of the 1970s triggered societal interest in energy conservation and alternative sources of energy, and the economy in most Organisation for Economic Cooperation and Development (OECD) countries deviated strongly from the traditional tie between energy consumption and economic development growth rates (see Figure 5-5). Economic reform, inducing fast growth in China in the begin of the 1980s, is an example of the effect of policy change. Another example is the observed reduction in CO_2 emissions caused by the disruption of the economy of the Former Soviet Union (FSU) countries in 1988. The response in all cases was very rapid (within a few years). The converse is also apparently true: In situations where pressure to change is small, inertia is large. This has implicitly been assumed to be the case in the SRES scenarios, since they do not consider major stresses, such as economic recession, large-scale conflict, or collapses in food stocks and associated human suffering, which are inherently difficult to forecast. That is why most greenhouse gas stabilization scenarios may require proper policies to be achieved.

- WGII SAR Section 20.1
- WGIII TAR Chapter 2, & Sections 3.1 & 10.1.4.3

[FIGURE 5-5 CAPTION: The response of the energy system, as indicated by per capita emission of CO_2 to economic changes such as the "oil crisis," significant economic policy

- WGII SAR

changes in China, and the end of former Soviet Union can be almost without inertia if the shock is large. The "oil crisis"—during which energy prices rose substantially over a short period of time—led to an almost immediate and sustained divergence of the formerly closely linked emission per capita and GDP per capita in most developed countries (Japan and United States are shown). Economic reform in China in 1980 induced significant economic growth without a proportional increase in CO_2 emission. At the breakup of the FSU, the two indicators remained closely linked, leading the emission to drop rapidly in tandem with declining per capita GDP. The GDP per capita for each of the countries can be read from the righthand side vertical axis with the following metric: United States divide by 1.31; FSU divide by 2.05; Japan divide by 0.72; and China divide by 1.80.]

Figure 20-2
- WGIII TAR Table 3.1

5.11 ***Stabilization of atmospheric CO_2 concentration at levels below about 600 ppm is only possible with reductions in carbon intensity and/or energy intensity greater than have been achieved historically.*** This implies shifts toward alternative development pathways with new social, institutional, and technological configurations that address environmental constraints. Low historical rates of improvement in energy intensity (energy use per unit GDP) reflect the relatively low priority placed on energy efficiency by most producers and users of technology. By contrast, labor productivity increased at higher rates over the period 1980–1992. The historically recorded annual rates of improvement of global energy intensity (1 to 1.5% per annum) would have to be increased and maintained over long time frames to achieve stabilization of CO_2 concentrations at about 600 ppm or below (see Figure 5-6). Carbon intensity (carbon per unit energy produced) reduction rates would eventually have to change by even more [e.g., up to 1.5% per annum (the historical baseline is 0.3 to 0.4% per annum)]. In reality, both energy intensity and carbon intensity are likely to continue to improve, but greenhouse gas stabilization requires that at least one of them do so at a rate much higher than historically achieved. The lower the stabilization target and the higher the level of baseline emissions, the larger the CO_2 divergence from the baseline that is needed, and the earlier it should occur.

- WGI TAR Section 9.3.3
- WGIII TAR Section 2.5
- SRES Sections 3.3 & 3.3.4.7

[FIGURE 5-6 CAPTION: (a) The required rate of decrease in energy intensity (energy per unit GDP) in order to meet given CO_2 concentration stabilization targets is within the range of historically achieved rates for stabilization above 550 ppm, and possibly even at 450 ppm, but (b) the required rate of improvement in carbon intensity (C emissions per unit energy) to stabilize at levels below about 600 ppm is higher than the historically achieved rates. As a consequence, the cost of mitigation rises as the stabilization level decreases, and does so more steeply below a target of about 600 ppm than above (see Figure 7-5).]

5.12 **Some Earth system changes are intrinsically irreversible, or are effectively irreversible over many human lifetimes.**

5.13 ***There are two types of apparent irreversibility.*** One derives from processes that will eventually return to their pre-disturbance state, but take centuries to millennia to do so; and the other from crossing a threshold beyond which the system no longer spontaneously returns to the previous state. An example of effective irreversibility due to slow processes is the partial melting of the Greenland ice sheet. Another is the projected rise in mean sea level, partly as a result of melting of the cryosphere, but primarily due to thermal expansion of the oceans. The world is already committed to some sea-level rise as a consequence of the surface atmospheric warming that has occurred over the past century. An example of an intrinsically irreversible change due to crossing a threshold is the extinction of species, resulting from a combination of climate change and habitat loss.

- WGI TAR Chapter 11
- WGII TAR Chapter 5, & Sections 16.2.1 & 17.2.1

5.14 ***The location of a threshold, and the resistance to change in its vicinity, can be affected by the rate at which the threshold is approached.*** Model results indicate that a threshold may exist in the ocean thermohaline circulation (see Question 4) such that a transition to a new ocean circulation, as occurred during the emergence from the last glacial period, could be induced. While such a transition is unlikely during the 21st century, some models suggest that it would be irreversible (i.e., the new circulation would persist even after the perturbation disappeared). For slower rates of warming, the thermohaline circulation would likely gradually adjust and thresholds may not be crossed. This implies that the greenhouse gas emission trajectory is important in determining the evolution of the thermohaline circulation. When a system approaches a threshold, as is the case for a weakening thermohaline circulation under global warming, resilience to perturbations decreases.

- WGI TAR Sections 1.4.3.5, 2.4.3, 7.3.7, & 9.3.4.3

5.15 ***Higher rates of warming and the compounded effects of multiple stresses increase the likelihood of a threshold crossing***. An example of an ecological threshold is provided by the migration of plant species as they respond to a changing climate. Fossil records indicate that the maximum rate at which most plant species have migrated in the past is about 1 km yr^{-1}. Known constraints imposed by the dispersal process (e.g., the mean period between germination and the production of seeds, and the mean distance that an individual seed can travel) suggest that, without human intervention, many species would not be able to keep up with the rate of movement of their preferred climatic niche projected for the 21st century, even if there were no barriers to their movement imposed by land use. An example of a socio-economic threshold is provided by conflicts in already-stressed situations—for example, a river basin shared by several nations with competition for a limited water resource. Further pressure from an environmental stress such as reduced stream flow could trigger more severe conflict. If impacted systems are not fully understood, the presence of a threshold may not be apparent until it is reached.

- WGII SAR Ecology Primer
- SRES Box 4.2
- WGII TAR Sections 1.2.1.2, 4.7.3, & 5.2
- WGIII TAR TS 2.3

5.16 **The presence of inertia and time lags has strong bearing on the timing and degree of mitigation of and adaptation to climate change.**

5.17 ***As a result of the time lags and inertias inherent in the Earth system, including its social components, some of the consequences of actions taken, or not taken, will only be felt many years in the future***. For example, the differences in the initial trajectories of the various SRES and stabilization scenarios are small, but the outcomes in terms of the long-term climate are large. The choice of development path has consequences at all the affected time scales; thus, long-term total costs and benefits may differ considerably from short-term ones.

5.18 ***In the presence of inertia, well-founded actions to adapt to or mitigate climate change are more effective, and under some circumstances may be cheaper, if taken earlier rather than later.*** Time lags provide a breathing space between emissions and impacts, thus allowing time for planned adaptation. The inertia of technology development and capital stock replacement is an important argument for gradual mitigation. The essential point of inertia in economic structures and processes is that deviation from any given trend incurs costs, and these costs rise with the speed of deviations (e.g., the costs of early retirement of carbon-intensive facilities). However, earlier mitigation action may reduce the risk of incurring severe lasting or irreversible impacts and also decreases vulnerability to climate variability in the short term (see paragraph 7.6), while reducing the need for more rapid mitigation later. Accelerated action may help to drive down the costs of mitigation and adaptation in the long term by accelerating technology development and the early realization of benefits currently obscured by market imperfections. Abatement over the next few years is economically valuable if there is a significant probability of having to stay below ceilings that would otherwise be reached within the characteristic time scales of the systems producing greenhouse gases. Climate change mitigation decisions depend on the interplay of inertia and

- WGII TAR Sections 1.3.4 & 2.7.1
- WGIII TAR Chapter 2 ES, & Sections 10.1 & 10.4.2

	uncertainty, resulting in a sequential decisionmaking process. Foresight and early adaptation will be most advantageous in sectors with long-lived infrastructure, such as dams and bridges, and large social inertia, such as misallocated property rights. Anticipatory adaptive action can be very cost-effective if the anticipated trend materializes.	
5.19	***The existence of time lags, inertia, and irreversibility in the Earth system means that a mitigation action or technology development can have different outcomes, depending on when it is taken.*** For example, in one model analysis of the hypothetical effect of reducing anthropogenic greenhouse gas emissions to zero in 1995 on sea-level rise during the 21st century in the Pacific showed that the sea-level rise that would inevitably occur due to warming incurred to that date (5–12 cm) would be substantially less than if the same emission reduction occurred in 2020 (14–32 cm). This demonstrates the increasing commitment to future sea-level rise due to past and present emissions, and the effect of delaying the hypothetical emissions reduction.	• WGII TAR Section 17.2.1
5.20	***Technological inertia in less-developed countries can be reduced through "leapfrogging" (i.e., adopting anticipative strategies to avoid the problems faced today by industrial societies).*** It cannot be assumed that developing countries will automatically follow the past development paths of industrialized countries. For example, some developing countries have bypassed land-lines for communication, and proceeded directly to cellular phones. Developing countries could avoid the past energy-inefficient practices of developed countries by adopting technologies that use energy in a more sustainable way, recycling more wastes and products, and handling residual wastes in a more acceptable manner. This may be easier to achieve in new infrastructure and energy systems in developing countries since large investments are needed in any case. Transfer of technology between countries and regions can reduce technological inertia (see paragraph 7.3).	• WGII TAR Chapter 2 • WGIII TAR Section 10.3 • SRTT SPM • SRES Section 3.3.4.8
5.21	***Inertia in the socio-economic and biophysical systems increases the need for caution in setting targets for avoiding "dangerous interference in the climate system."*** Stabilization target levels of, for instance, atmospheric CO_2, temperature change, or sea-level rise may be affected by: • The timelag between the decision to adopt a target level and the deployment of mechanisms to achieve it • The inertia of the climate system, which will carry it beyond the point at which mitigation action is initiated • The uncertainty of dynamics, measurement, and internal variability associated with the target and the approach to it. Hedging strategies and sequential decisionmaking may be appropriate in the face of these issues of inertia and uncertainty. Important differences exist between optimal strategies for mitigation (which is a global issue) and adaptation (which is primarily a local issue). Both issues involve time lags and inertia, with inertia suggesting a generally greater sense of urgency for mitigation.	• WGII TAR Section 2.7.1 • WGIII TAR Sections 10.1.4.1 & 10.4.3

FIGURE 5-1

SEE PAGE 53 LINES 26–33 FOR FIGURE CAPTION

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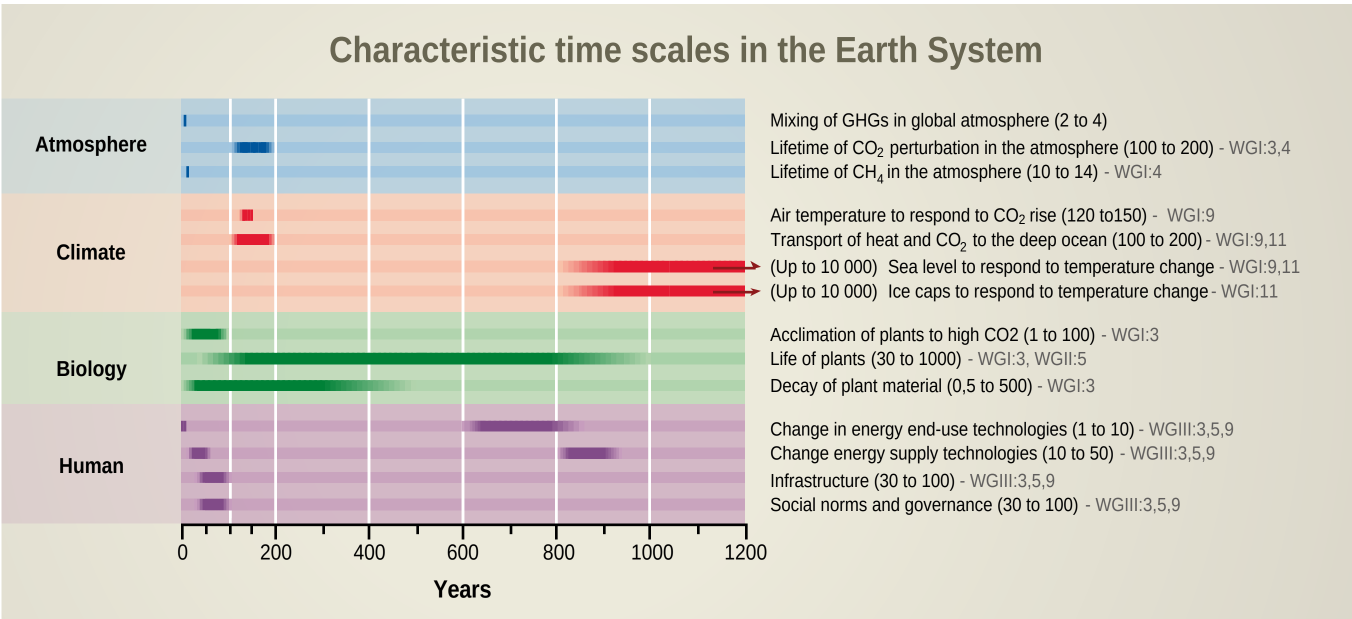

FIGURE 5-2

SEE PAGE 54 LINES 9-18 FOR FIGURE CAPTION

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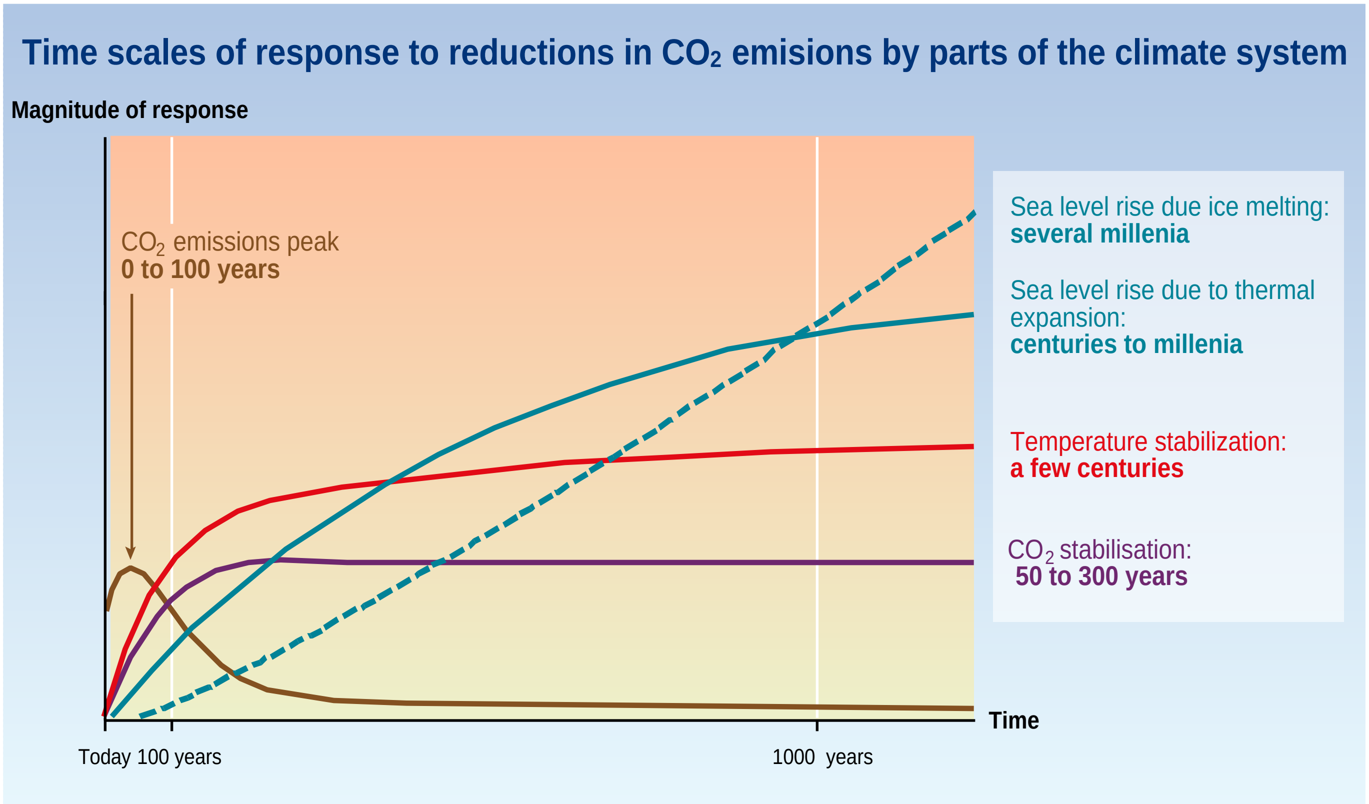

FIGURE 5-3

SEE PAGE 54 LINE 47 – PAGE 55 LINE 4 FOR FIGURE CAPTION

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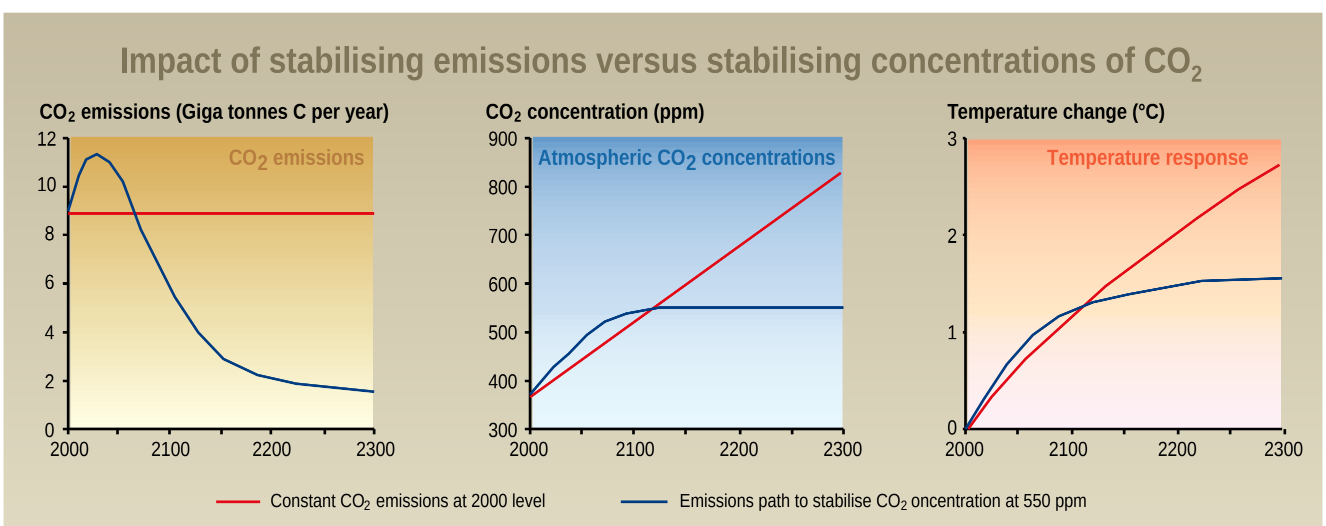

FIGURE 5-4

SEE PAGE 55 LINES 18–29 FOR FIGURE CAPTION

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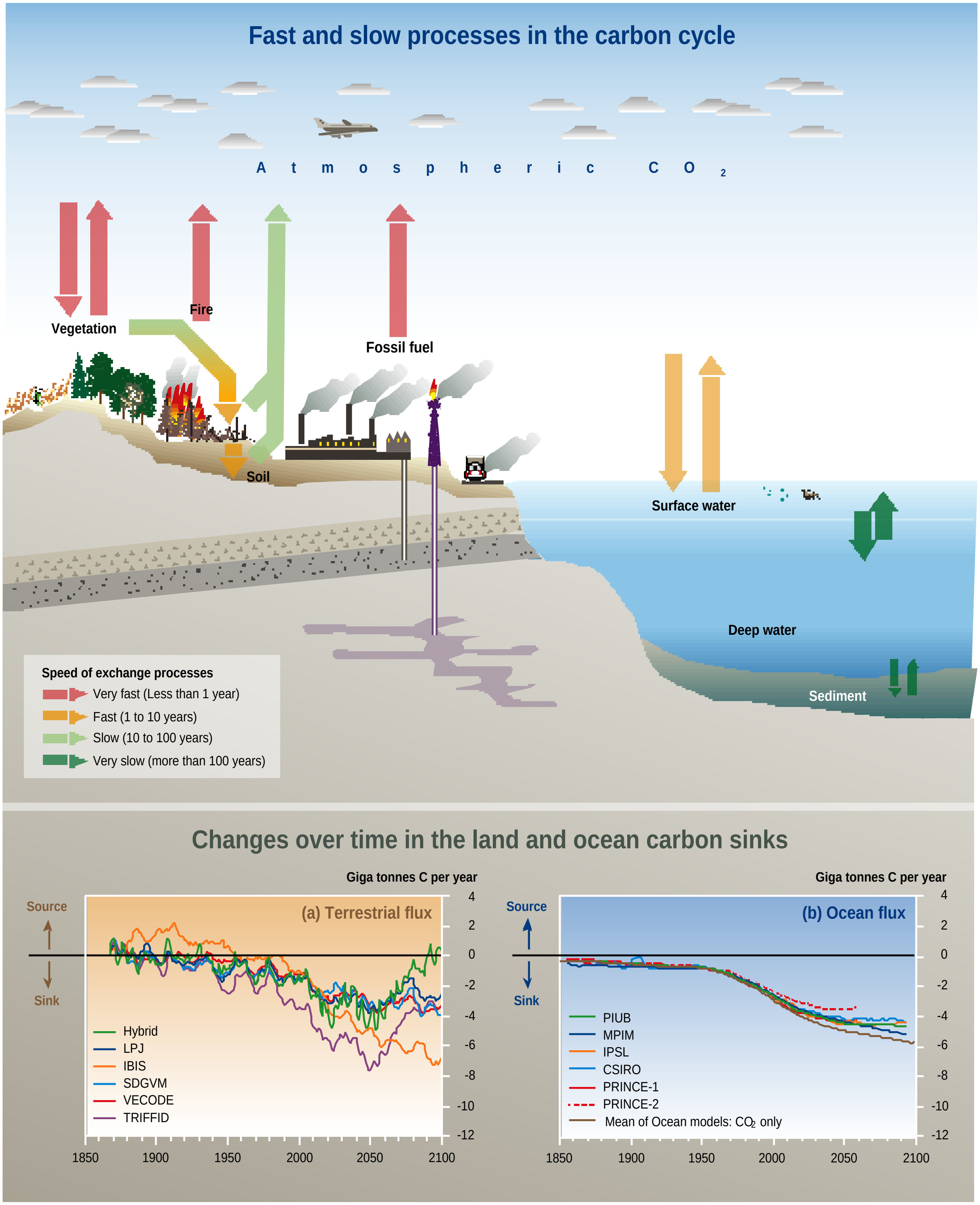

FIGURE 5-5

SEE PAGE 56 LINE 52 – PAGE 57 LINE 10 FOR FIGURE CAPTION

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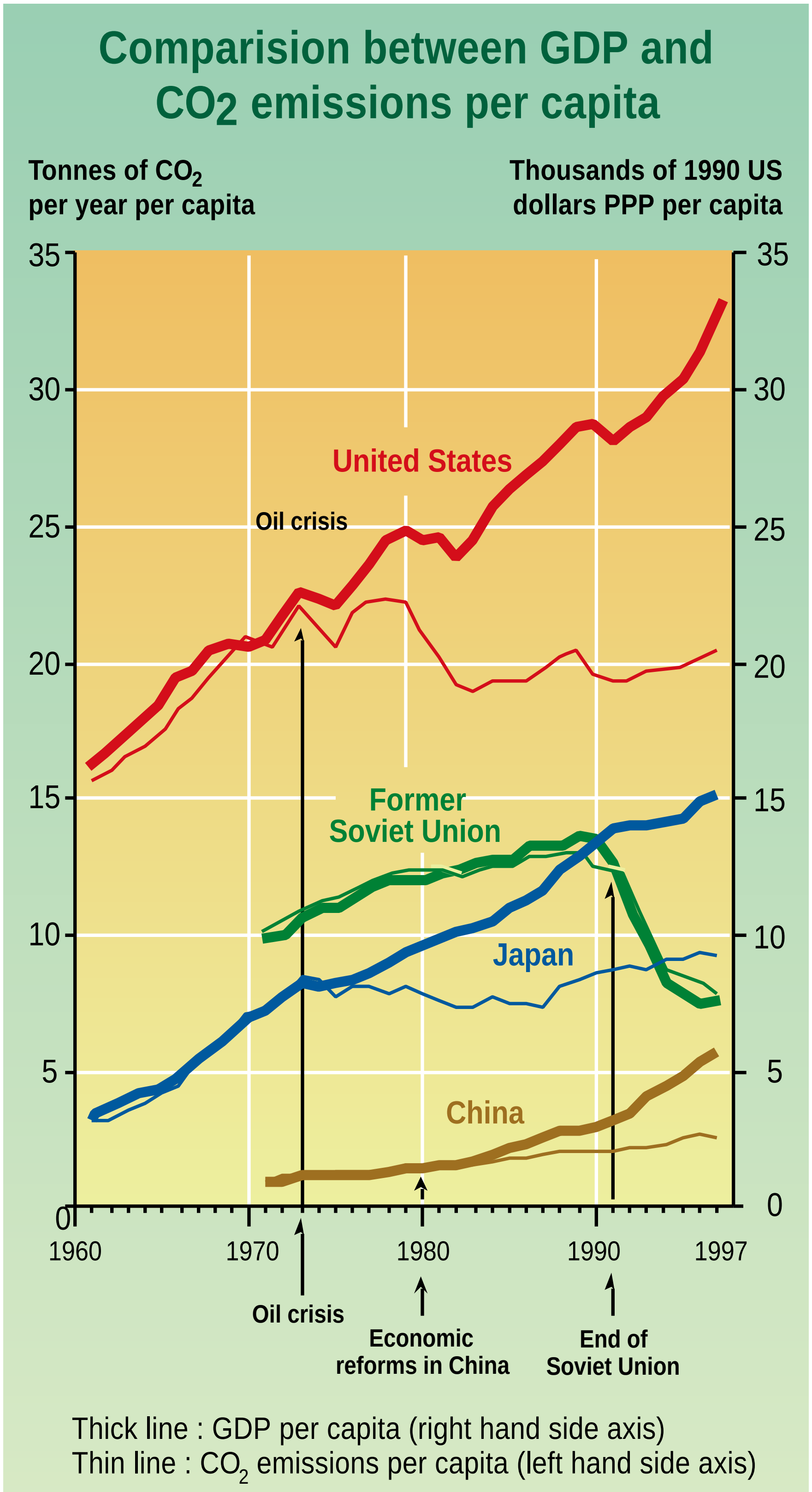

FIGURE 5-6

SEE PAGE 57 LINES 30–36 FOR FIGURE CAPTION

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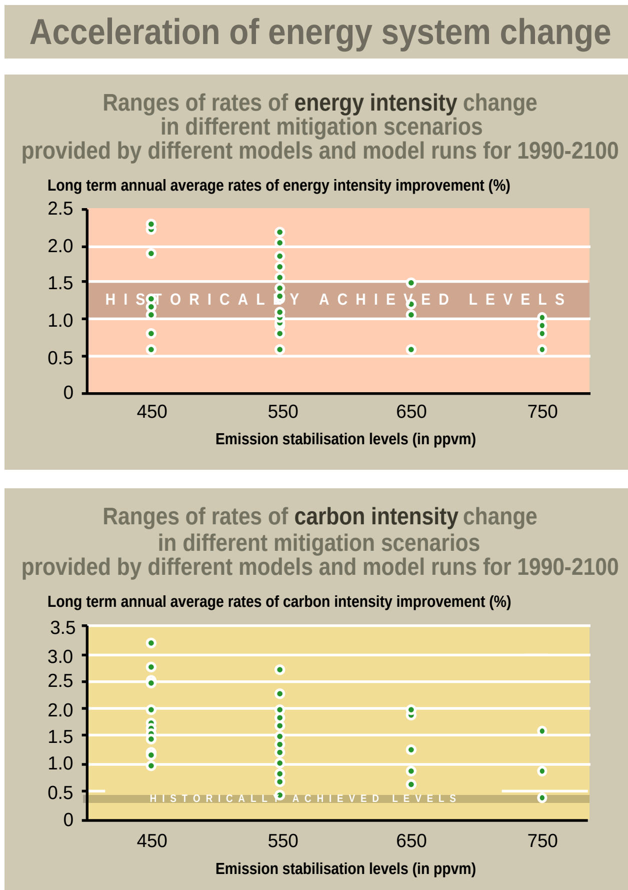

QUESTION 6

a) How does the extent and timing of the introduction of a range of emissions reduction actions determine and affect the rate, magnitude, and impacts of climate change, and affect the global and regional economy, taking into account the historical and current emissions?

b) What is known from sensitivity studies about regional and global climatic, environmental, and socio-economic consequences of stabilizing the atmospheric concentrations of greenhouse gases (in carbon dioxide equivalents), at a range of levels from today's to double that level or more, taking into account to the extent possible the effects of aerosols? For each stabilization scenario, including different pathways to stabilization, evaluate the range of costs and benefits, relative to the range of scenarios considered in Question 3, in terms of:

- **Projected changes in atmospheric concentrations, climate, and sea level, including changes beyond 100 years**
- **Impacts and economic costs and benefits of changes in climate and atmospheric composition on human health, diversity and productivity of ecological systems, and socio-economic sectors (particularly agriculture and water)**
- **The range of options for adaptation, including the costs, benefits, and challenges**
- **The range of technologies, policies, and practices that could be used to achieve each of the stabilization levels, with an evaluation of the national and global costs and benefits, and an assessment of how these costs and benefits would compare, either qualitatively or quantitatively, to the avoided environmental harm that would be achieved by the emissions reductions**
- **Development, sustainability, and equity issues associated with impacts, adaptation, and mitigation at a regional and global level.**

Paragraph Number		*Reference*
6.1	The climatic, environmental, and socio-economic consequences of greenhouse gas emissions were assessed in Question 3 for scenarios that do not include any climate policy interventions. These same issues are addressed here in Question 6, but this time to assess the benefits that would result from a set of climate policy interventions. Among emission reduction scenarios considered are scenarios that would achieve stabilization of CO_2 concentrations in the atmosphere. The role of adaptation as a complement to mitigation and the potential contributions of reducing emissions to the goals of sustainable development and equity are evaluated. The policies and technologies that might be used to implement the emission reductions and their costs are considered in Question 7.	
6.2	**The rate and magnitude of warming and sea-level rise can be lessened by reducing greenhouse gas emissions.**	
6.3	***Slowing of warming and sea-level rise during the 21st century would be larger the deeper are reductions in greenhouse gas emissions, the earlier they are introduced, and the longer they are sustained.*** Estimates have been made of the global mean temperature and sea-level rise effects of a 2% per year reduction in CO_2 emissions by developed countries over the period 2000 to 2100, assuming that developing countries do not reduce their emissions.[1] Under these assumptions, global emissions and the atmospheric concentration of CO_2 grow throughout the century but at a diminished rate compared to scenarios that assume no actions to reduce developed country emissions. The effects of the emission limit accrue slowly but build with time. By 2030, the projected concentration of CO_2 in the atmosphere is reduced roughly 20% relative to the IS92a scenario of unabated emissions, which diminishes warming and sea-level rise by a small amount within this time frame. By 2100 the projected CO_2	• IPCC Tech Paper 4

concentration is reduced by 35% relative to the IS92a scenario, projected global mean warming reduced by 25%, and projected sea-level rise reduced by 20%. Analyses of CO_2 emission reductions of 1% per year by developed countries indicate that the lesser reductions would yield smaller reductions in CO_2 concentration, temperature change, and sea-level rise. Actions such as these taken now would have a greater effect at 2100 than the same emissions reductions implemented at a later time.

[FOOTNOTE 1: Emissions by developed countries of greenhouse gases other than CO_2 are assumed to be unabated from the IS92 scenario projections in these analyses. Developing country emissions of CO_2 and other greenhouse gases are assumed to follow the IS92 scenario projections. The temperature projections were made with a simple climate model that did not include aerosols. The IS92 scenarios are described in the IPCC *Special Report on Radiative Forcing of Climate Change*.]

6.4 ***To stabilize the atmospheric concentration of CO_2 at a level from 450 to 1000 ppm, global emissions can initially continue to increase from present levels, but eventually growth must be halted and emissions substantially reduced below current levels.*** Carbon cycle models have been used to estimate time paths of CO_2 emissions that would result in stabilization of the concentration of CO_2 in the atmosphere at levels ranging from 450 to 1000 ppm (see Figure 6-1)—the lower the target CO_2 concentration, the sooner must emissions growth cease. The estimates of emissions that would stabilize CO_2 concentration at 450, 650, and 1000 ppm peak within, respectively, 1 to 2 decades, 3 to 4 decades, and roughly a century. From those time periods, stabilization would require CO_2 emissions to decline and eventually, after many centuries, reach and be sustained at the level of persistent natural sinks, which is a very small fraction of current emissions. CO_2 emissions for the SRES A2, A1B, and B1 scenarios through 2100, which do not include any policy interventions to limit emissions, are included in Figure 6-1a for comparison to the stabilization scenarios. CO_2 emissions under the A2 scenario increase throughout the 21st century and would result in CO_2 concentrations that rise at an increasing rate. CO_2 emissions under the A1B scenario peak near 2050 and then decline. This scenario is projected to result in CO_2 concentrations that grow at a decreasing rate on a path above the path for eventual stabilization at 1000 ppm. CO_2 emissions for the B1 scenario rise more slowly than for A1B and then decrease such that the projected CO2 concentration closely follows the path for eventual stabilization at 550 ppm.

- WGI TAR Section 3.7.3.4

[FIGURE 6-1 CAPTION: Stabilizing the concentration of CO_2 in the atmosphere would eventually require substantial reductions of emissions below current levels and would slow the rate of warming.

(a) *CO_2 emissions.* The time paths of CO_2 emissions that would lead to stabilization of the concentration of CO_2 in the atmosphere at 450, 550, 650, 750, and 1000 ppm are estimated for the WRE scenarios using carbon cycle models. Lower CO_2 concentration targets would require an earlier halt of emissions growth and earlier decreases to levels below current emissions. The shaded area illustrates uncertainty in estimating $C0_2$ emissions corresponding to specified concentration time paths, as represented in carbon cycle models. Also shown for comparison are CO_2 emissions for three of the SRES scenarios (A1B, A2, and B1), which do not include greenhouse gas emission limits.

(b) *CO_2 concentrations.* The CO_2 concentrations specified for the WRE scenarios gradually approach stabilized levels that range from 450 to 1000 ppm. Also shown for comparison are estimates of CO_2 concentrations that would result from three of the SRES projections of emissions (A1B, A2, and B1).

(c) *Global mean temperature changes.* The colored lines show the global mean temperature changes for each WRE scenario as estimated with a simple climate model using average values of climate parameters. Estimated warming slows as growth in the atmospheric concentration of CO_2 slows and warming continues after the time at which the CO_2

- WGI TAR Sections 3.7.3 & 9.3.3
- IPCC Tech Paper 3

concentration is stabilized (indicated by black spots) but at a much diminished rate. The shaded area indicates the range of temperature changes estimated for the WRE scenarios when low and high values of climate parameters are used. The dashed lines show the temperature changes projected for the S scenarios, an alternate set of CO_2 stabilization scenarios [not shown in panels (a) or (b)]. Estimates of warming for both the WRE and S scenarios are made assuming that emissions of gases other than CO_2 follow the A1B scenario until 2100 and are constant thereafter. The colored bars on the righthand side show, for each WRE scenario, the uncertainty represented by the climate model at 2350 and the diamonds on the righthand side show the equilibrium (very long-term) warming for each scenario using average climate parameters. Also shown are temperature increases in 2100 estimated for the SRES emission scenarios A1B, A2, and B1 (indicated by red crosses).]

6.5 ***There is a wide band of uncertainty in the amount of warming that would result from any stabilized greenhouse gas concentration.*** Estimates of global mean temperature change for scenarios that would stabilize the concentration of CO_2 at different levels, and hold them constant through 2350, are presented in Figure 6-1c. The estimates use a range of values for climate sensitivity from 1.7 to 4.2ºC. The uncertainty about climate sensitivity yields a wide range of estimates of temperature change that would result from emissions that would lead to a selected stabilization level. This is shown more clearly in Figure 6-2, which maps eventual CO_2 stabilization levels against the corresponding range of temperature change that is estimated to be realized in 2100 and at long-run equilibrium. To estimate temperature changes for these scenarios, it is assumed that emissions of greenhouse gases other than CO_2 would follow the SRES A1B scenario until 2100 and that emissions of these gases would be constant thereafter. Different assumptions about emissions of other greenhouse gases would result in different estimates of warming for each CO_2 stabilization level.

- WGI TAR Section 9.3.3

[FIGURE 6-2 CAPTION: Stabilizing CO_2 concentrations would lessen warming but by an uncertain amount. Temperature changes in (a) 2100 and (b) at long-run equilibrium are estimated using a simple climate model for the WRE scenarios, which eventually would stabilize atmospheric CO_2 concentrations at levels ranging from 450 to 1000 ppm. The estimates are made using a simple climate model and it is assumed that emissions of gases other than CO_2 follow the SRES A1B projection until 2100 and that emissions of these gases would be constant thereafter. The low and high estimates for each stabilization level assume a climate sensitivity of 1.7 and 4.2ºC, respectively. The center line is an average of the low and high estimates.]

- WGI TAR Section 9.3.3

6.6 ***Emission reductions that would eventually stabilize the atmospheric concentration of CO_2 at a level below 1000 ppm are estimated to limit global mean temperature increase to 3.5ºC or less through the year 2100.*** Global average surface temperature is estimated to increase 1.2 to 3.5ºC by 2100 for scenarios that would limit CO_2 emissions so as to eventually stabilize the concentration of CO_2 at a level from 450 to 1000 ppm. In comparison, estimates of warming by 2100 for the SRES projections range from 1.4 to 5.8ºC (see Question 3). All of the CO_2 stabilization scenarios analyzed would avoid much of the upper end of the SRES range of warming projected for 2100, taking into account uncertainty about climate sensitivity. Results from the only comprehensive climate model that has been used to analyze the regional effects of stabilizing CO_2 concentrations project that regionally averaged temperature changes would be similar in geographic pattern but less in magnitude than those projected for a baseline scenario with a 1% per year increase in CO_2 emissions from 1990.[2]

- WGI TAR Section 9.3.3

[FOOTNOTE 2: This rate of emission growth closely approximates the IS92a emission scenario.]

6.7 ***Different time paths of emissions that lead to a common stabilization target yield different time paths of temperature change.*** Different time paths of CO_2 emissions can attain a

- WGI TAR

specified target for stabilization of atmospheric CO_2 concentration. For CO_2 stabilization targets of 450, 550, 650, and 750 ppm, two sets of emission time paths have been analyzed in previous IPCC reports and are referred to as the S and WRE time paths.[3] The WRE time paths allow higher emissions in early decades than do the S time paths, but then must require lower emissions in later decades to achieve a specified stabilization target. This deferment of emission reductions in the WRE time paths is estimated to reduce mitigation costs (see Question 7) but would result in a more rapid rate of warming initially. The difference in temperature projections for the two sets of pathways is 0.2ºC or less in 2050, when the difference is most pronounced. Beyond 2100, the temperature changes of the WRE and S profiles converge. The temperature projections for the S and WRE time paths are compared in Figure 6-1c. — Section 9.3.3.1

[FOOTNOTE 3: The S and WRE time paths are discussed in the WGI SAR and are described in more detail in IPCC Technical Paper 3.]

6.8 ***Global mean surface temperature would continue to rise for many decades after stabilization of greenhouse gas concentrations.*** Owing to the large inertia of the ocean (see Question 5), temperatures are projected to continue to rise after stabilization of greenhouse gas concentrations, though at a rate that is slower than is projected for the period prior to stabilization and that diminishes with time. The theoretical equilibrium temperature, which would take many centuries to reach, varies from 1.4 to 4.0°C for stabilization at 450 ppm and 3.4 to 8.9°C for stabilization at 1000 ppm (see Figure 6-2b). — • WGI TAR Section 9.3.3 & Table 9.3

6.9 ***Sea level and ice sheets would continue to respond to warming for many centuries after greenhouse gas concentrations have been stabilized (see Question 5).*** Model estimates of very long run sea-level rise from thermal expansion alone range from 0.5 to 2 m for stabilization of CO_2 concentration at 560 ppm (double the pre-industrial concentration) and 1 to 4 m for stabilization at 1120 ppm (quadruple the pre-industrial concentration). For sustained stabilization of CO_2 concentration above 560 ppm, estimates from ice sheet models indicate that the Greenland ice sheet could melt completely and add substantially to sea-level rise, potentially up to 7 m over thousands of years. Current models also suggest that the West Antarctic ice sheet could contribute up to 3 m to sea-level rise over the next 1000 years, but such results are strongly dependent on model assumptions regarding climate change scenarios, ice dynamics, and other factors. — • WGI TAR SPM & Section 11.5.4

6.10 **Reducing emissions of greenhouse gases to stabilize their atmospheric concentrations would delay and reduce damages caused by climate change.**

6.11 ***Benefits of limiting greenhouse gas emissions are determined, in part, by the socio-economic development pathway, the stringency of the emission limits, and the sensitivity of the climate system to changes in greenhouse gas concentrations.*** By slowing the rate of accumulation of greenhouse gases in the atmosphere, and thereby slowing the rate of increase in global mean temperature and sea level, the pressures on natural and human systems from climate change would build more slowly and allow more time for adaptation. This is expected to yield environmental and socio-economic benefits. Figure 6-3 presents a summary of climate change risks or reasons for concern (see Box 5-2) juxtaposed against the ranges of global mean temperature change in 2100 that have been estimated for different scenarios.[4] Stabilizing the concentration of CO_2 in the atmosphere is expected to generate benefits by avoiding risks associated with global temperature increases of 3.5ºC and higher by 2100—the more stringent the stabilization target, the greater the avoided risks and the greater the expected benefits. — • WGII TAR Sections 1.4.3.5, 19.6.3.2, & 19.8.2

[FOOTNOTE 4: Climate change impacts will vary by region and sector or system and the impacts will be influenced by regional and seasonal changes in mean temperature and precipitation, climate variability, the frequencies and intensities of extreme climate events, and sea-level rise. Global mean temperature change is used as a summary measure of the pressures exerted by climate change.]

[FIGURE 6-3 CAPTION: Risks of climate change damages would be reduced by stabilizing CO_2 concentrations. The risks of adverse impacts from climate change are depicted for different magnitudes of global mean temperature change, where global mean temperature change is used as a proxy for the magnitude of climate change. Estimates of global mean temperature change in 2100 are shown on the righthand side of the figure for scenarios that would lead to stabilization of the atmospheric concentration of CO_2, as well as for the full set of SRES projections. Risks associated with warming above 3.5ºC by 2100 would be avoided by stabilizing CO_2 concentration at or below 1000 ppm. White indicates neutral or small negative or small positive impacts or risks; yellow indicates negative impacts for some systems or low risks; and red means negative impacts or risks that are more widespread and/or greater in magnitude. The assessment of impacts or risks takes into account only the magnitude of change and not the rate of change. Global mean annual temperature change is used as a proxy for the magnitude of climate change, but impacts would be a function of, among other factors, the magnitude and rate of global and regional changes in mean climate, climate variability and extreme climate phenomena, social and economic conditions, and adaptation.]

- WGI TAR Section 9.3.3
- WGII TAR Section 19.8.2

6.12 ***Comprehensive, quantitative estimates of the benefits of reducing greenhouse gas emissions do not exist.*** While advances have been made in understanding the qualitative character of the impacts of future climate change, the impacts that would result under different scenarios are incompletely quantified. Because of uncertainty in climate sensitivity, and uncertainty about the geographic and seasonal patterns of changes in temperatures, precipitation, and other climate variables and phenomena, the impacts of scenarios that include and exclude greenhouse gas emission limits cannot be uniquely determined and compared. There are also uncertainties about the sensitivities and adaptive capacities of potentially impacted systems now and in the future to changes in climate. In addition, impacts such as the degradation or loss of unique habitats, species extinction, and changes in human health risks are not readily expressed in units that can be directly compared to each other, across regions, or to estimates of the costs of mitigation. Because of these limitations in the presently available information, the benefits of different stabilization targets, or different emission pathways to a stabilization target, can only be characterized in general terms.

- WGII TAR Sections 19.4 & 19.5

6.13 **Adaptation is a necessary strategy at all scales to complement climate change mitigation efforts.**

6.14 ***Adaptation can complement mitigation in a cost-effective strategy to reduce climate change risks.*** Reductions of greenhouse gas emissions, even stabilization of their concentrations in the atmosphere, will neither altogether prevent climate change and sea-level rise, nor their impacts. As a result, many reactive adaptations will occur in response to the changing climate and rising seas. In addition, the development of planned adaptation strategies to address risks and utilize opportunities can complement mitigation actions to lessen climate change impacts. However, adaptation would entail costs and cannot prevent all damages. Adaptation in combination with mitigation can be a more cost-effective approach to reducing the impacts of climate change than either applied alone. The potential for adaptation to substantially reduce many of the adverse impacts of climate change was assessed in Question 3. Because there are overlapping ranges of global temperature increases associated with the various stabilization levels (see Figure 6-1c), many adaptation options will be appropriate for a range of stabilization levels. Improved knowledge will narrow the uncertainties associated with particular stabilization levels and identification of appropriate adaptation strategies.

- WGII TAR Sections 1.4.4.2, 18.3.5, & 18.4.1

6.15 ***Adaptation costs and challenges can be lessened by mitigation of climate change.*** Greenhouse gas emission reductions would reduce the magnitude and rate of changes to be adapted to, possibly including changes in the frequencies and intensities of extreme events. The smaller changes to which systems would be exposed, and slower pace at which stresses would increase, would allow more time for adaptation and lessen the degree to which current practices for coping with climate variability and extremes might need to be modified (see Question 3). More aggressive mitigation efforts will therefore reduce adaptation costs to attain a specified level of effectiveness.

- WGII TAR Section 18.2.2

6.16 **Mitigation and adaptation actions can advance sustainable development and reduce inequities.**

6.17 ***Reducing climate change risks through mitigation and adaptation actions can contribute to sustainable development objectives.*** As described in Question 3, risks associated with climate change have the potential to undermine progress toward sustainable development (e.g., damages from extreme climate events, water shortage and degraded water quality, food supply disruptions and hunger, land degradation, and diminished human health). By reducing these risks, climate change mitigation and adaptation policies can, if appropriately designed, improve the prospects for sustainable development.[5]

[FOOTNOTE 5: The relationship between mitigation actions themselves and sustainable development and equity are addressed in Question 7. The relationships among adaptation, sustainable development, and equity are covered in Question 3.]

- WGII TAR Section 18.6.1

6.18 ***Climate change pressures can exacerbate inequities between poor and wealthier countries; lessening these pressures can reduce these inequities.*** People in developing countries, particularly the poorest people in these countries, are considered to be more vulnerable to climate change than people in developed countries (see Question 3). Reducing the rate of warming and sea-level rise and increasing the capacity to adapt to climate change would lessen many of the impacts that are otherwise expected to fall most heavily on vulnerable populations in developing countries.

- WGII TAR Sections 18.5.3 & 19.4

6.19 ***Reducing and slowing climate change can also promote intergenerational equity.*** Emissions of the present generation will affect many future generations because of inertia in the atmosphere-ocean-climate system and the long-lived and sometimes irreversible effects of climate change on the environment. Future generations are generally anticipated to be wealthier, better educated and informed, and technologically more advanced than the present generation and consequently better able to adapt in many respects. But the changes set in motion in coming decades will accumulate and some could reach magnitudes that would severely test the abilities of many societies to cope. For irreversible impacts, such as the extinction of species or loss of unique ecosystems, there are no adaptation responses that can fully remedy the losses. Mitigating climate change would lessen the risks to future generations from the actions of the present generation.

- WGII TAR Sections 1.2 & 18.5.2

FIGURE 6-1

SEE PAGE 66 LINE 36 – PAGE 67 LINE 11 FOR FIGURE CAPTION

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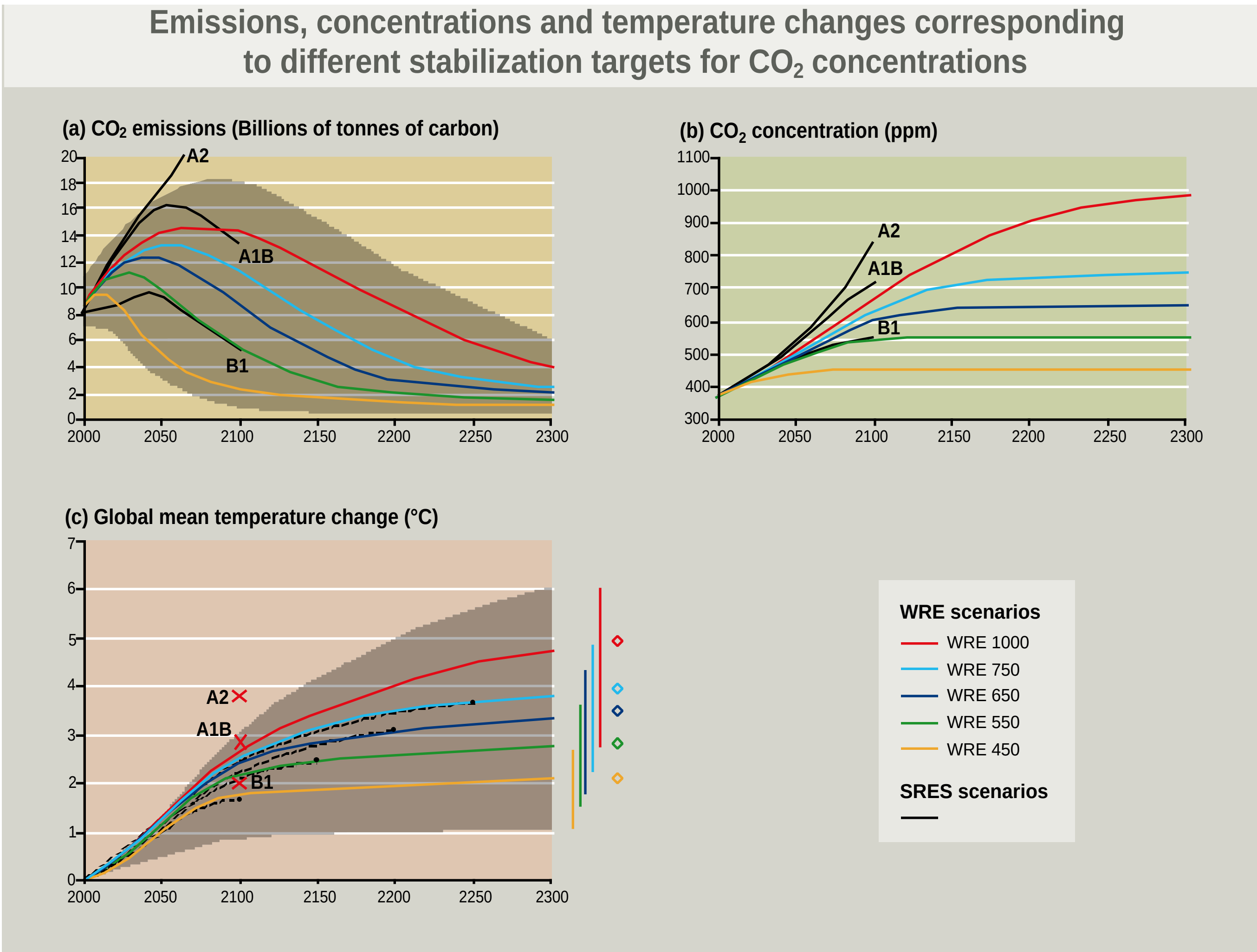

FIGURE 6-2

SEE PAGE 67 LINES 27–35 FOR FIGURE CAPTION

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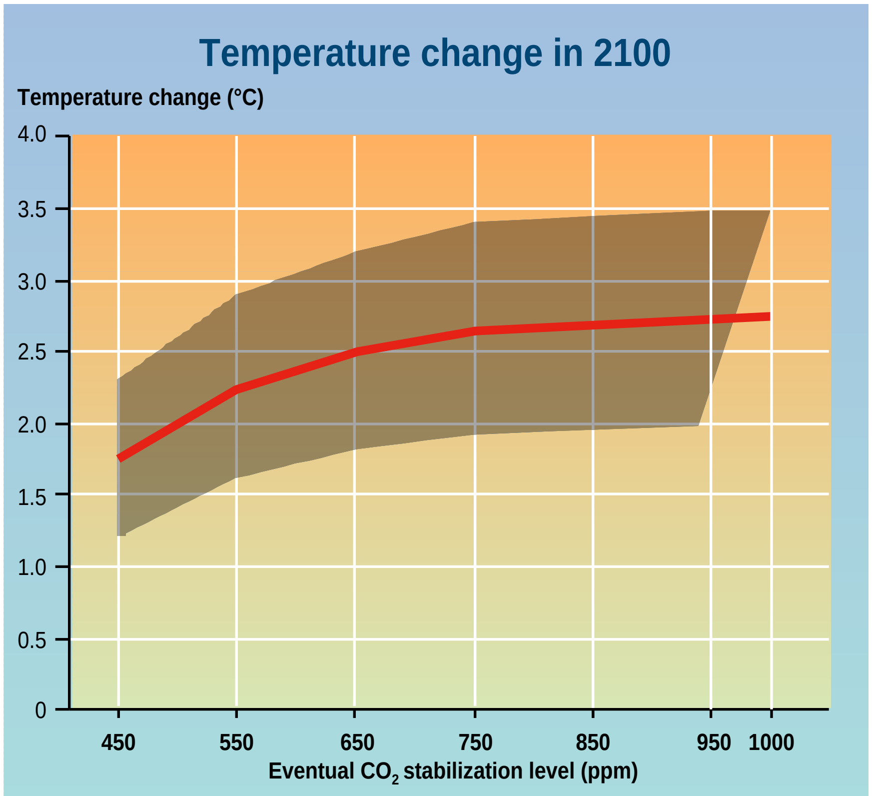

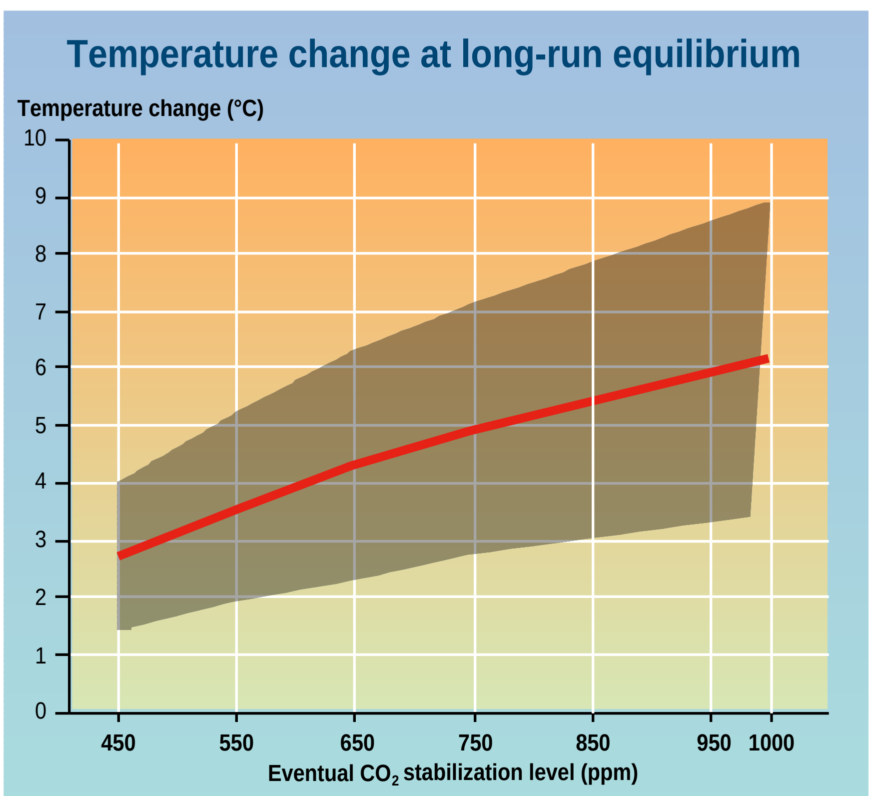

FIGURE 6-3

SEE PAGE 69 LINES 5–20 FOR FIGURE CAPTION

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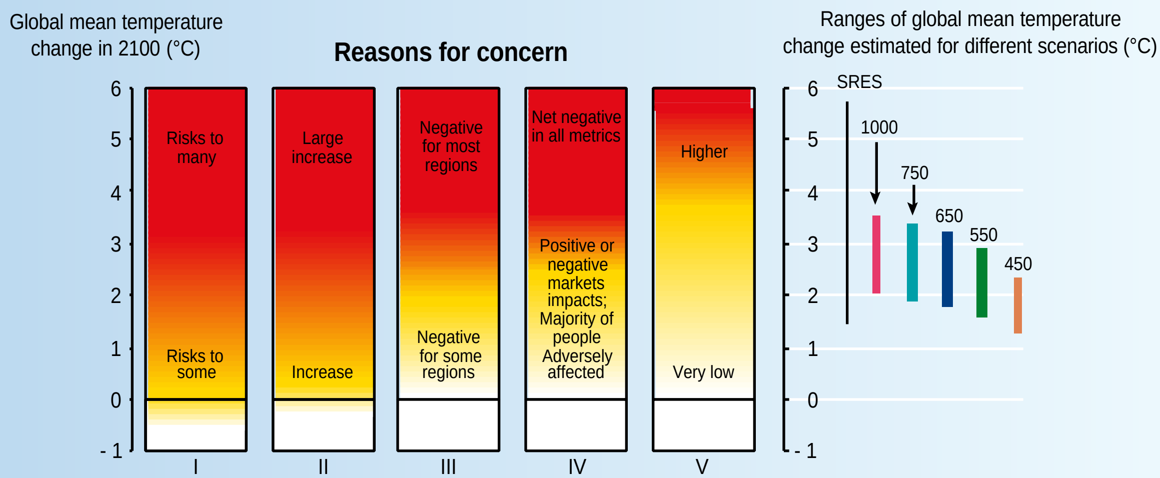
Risks of climate change damages would be reduced by stabilizing CO_2 concentrations



I. Unique and Threatened Systems

Extinction of species.

Loss of unique habitats, coastal wetlands.

Bleaching and death of coral.

II. Extreme Climate Events

Health, property and environmental impacts from increased frequency and intensity of some climate extremes.

III. Distribution of Impacts

Cereal crop yield changes that vary from increases to decreases across regions but which are estimated to decrease in most tropical and subtropical regions.

Decrease in water availability in some water-stressed countries, increase in others.

Greater risks to health in developing countries than in developed countries.

Net market sector losses estimated for many developing countries; mixed effects estimated for developed countries up to a few degrees warming and negative effects for greater warming.

IV. Global aggregate impacts

Estimates of globally aggregated net market sector impacts are positive and negative up to a few degrees warming and negative for greater warming.

More people adversely affected than beneficially affected even for warming less than a few degrees.

V. Large Scale, High Impact Events

Significant slowing of thermohaline circulation possible by 2100.

Melting and collapse of ice sheets adding substantially to sea level rise (very low likelihood before 2100; likelihood higher on multi-century timescale).

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QUESTION 7

What is known about the potential for, and costs and benefits of, and time frame for reducing greenhouse gas emissions?

- **What would be the economic and social costs and benefits and equity implications of options for policies and measures, and the mechanisms of the Kyoto Protocol, that might be considered to address climate change regionally and globally?**
- **What portfolios of options of research and development, investments, and other policies might be considered that would be most effective to enhance the development and deployment of technologies that address climate change?**
- **What kind of economic and other policy options might be considered to remove existing and potential barriers and to stimulate private- and public-sector technology transfer and deployment among countries, and what effect might these have on projected emissions?**
- **How does the timing of the options contained in the above affect associated economic costs and benefits, and the atmospheric concentrations of greenhouse gases over the next century and beyond?**

Paragraph Number | *Reference*

7.1 This question focuses on the potential for, and costs of, mitigation both in the near and long term. The issue of the primary mitigation benefits (the avoided costs and damages of slowing climate change) is addressed in Questions 5 and 6, and that of ancillary mitigation benefits is addressed in this response and the one to Question 8. This response describes a variety of factors that contribute to significant differences and uncertainties in the quantitative estimates of the costs of mitigation options. The SAR described two categories of approaches to estimating costs: bottom-up approaches, that often assess near-term cost and potential, and are built up from assessments of specific technologies and sectors; and top-down approaches, which proceed from macroeconomic relationships. These two approaches lead to differences in the estimates of costs, which have been narrowed since the SAR. The response below reports on cost estimates from both approaches for the near term, and from the top-down approach for the long term. Mitigation options and their potential to reduce greenhouse gas emissions and sequester carbon are discussed first. This is followed by a discussion of the costs for achieving emissions reductions to meet near-term emissions constraints, and long-term stabilization goals, and the timing of reductions to achieve such goals. This response concludes with a discussion of equity as it relates to climate change mitigation.

7.2 **Potential, barriers, opportunities, policies, and costs of reducing greenhouse gas emissions in the near term.**

7.3 **Significant technological and biological potential exists for near-term mitigation.**

7.4 ***Significant technical progress relevant to greenhouse gas emissions reduction has been made since the SAR in 1995, and has been faster than anticipated.*** Advances are taking place in a wide range of technologies at different stages of development—for example, the market introduction of wind turbines; the rapid elimination of industrial by-product gases, such as N_2O from adipic acid production and perfluorocarbons from aluminum production; efficient hybrid engine cars; the advancement of fuel cell technology; and the demonstration of underground CO_2 storage. Technological options for emission reduction include improved efficiency of end-use devices and energy conversion technologies, shift to zero and low-carbon energy technologies, improved energy management, reduction of industrial by-product and process gas emissions, and carbon removal and storage. Table 7-1 summarizes the results from many sectoral studies, largely at the project, national, and regional level with

Reference: • WGIII TAR SPM Para7, Sections 3.3-3.8, & Chapter 3 App.

some at the global levels, providing estimates of potential greenhouse gas emissions reductions to the 2010 and 2020 time frame.

[Insert Table 7-1 here]

7.5 ***Forests, agricultural lands, and other terrestrial ecosystems offer significant carbon mitigation potential. Conservation and sequestration of carbon, although not necessarily permanent, may allow time for other options to be further developed and implemented (Table 7-2).*** Biological mitigation can occur by three strategies: a) conservation of existing carbon pools, b) sequestration by increasing the size of carbon pools, and c) substitution of sustainably produced biological products (e.g., wood for energy-intensive construction products and biomass for fossil fuels). Conservation of threatened carbon pools may help to avoid emissions, if leakage can be prevented, and can only become sustainable if the socio-economic drivers for deforestation and other losses of carbon pools can be addressed. Sequestration reflects the biological dynamics of growth, often starting slowly, passing through a maximum, and then declining over decades to centuries. The potential of biological mitigation options is on the order of 100 Gt C (cumulative) by 2050, equivalent to about 10 to 20% of projected fossil fuel emissions during that period, although there are substantial uncertainties associated with this estimate. Realization of this potential depends upon land and water availability as well as the rates of adoption of land management practices.

- WGIII SPM Para8 & Sections 3.6.4.3 & 6.4
- SRLUCF

[Insert Table 7-2 here]

7.6 **Adoption of even cost-effective greenhouse gas-reducing technologies and measures may require overcoming barriers through the implementation of policy measures.**

7.7 ***The successful implementation of greenhouse gas mitigation options needs to overcome many technical, economic, political, cultural, social, behavioral, and/or institutional barriers that prevent the full exploitation of the technological, economic, and social opportunities of these mitigation options (Figure 7-1).*** The potential mitigation opportunities and types of barriers vary by region and sector, and over time. This is caused by a wide variation in mitigation capacity. The poor in any country are faced with limited opportunities to adopt technologies or change their social behavior, particularly if they are not part of a cash economy. Most countries could benefit from innovative financing and institutional reform and removing barriers to trade. In the developed countries, future opportunities lie primarily in removing social and behavioral barriers; in countries with economies in transition, in price rationalization; and in developing countries, in price rationalization, increased access to data and information, availability of advanced technologies, financial resources, and training and capacity building. Opportunities for any given country, however, might be found in the removal of any combination of barriers.

- WGIII TAR SPM Para17 & Sections 1.5, 5.3, & 5.4

[FIGURE 7-1 CAPTION: Penetration of environmentally sound technologies (including practices): a conceptual framework. Various barriers prevent the different potentials from being realized. Opportunities exist to overcome barriers through innovative projects, programs, and financing arrangements. An action can address more than one barrier. Actions may be pursued to address barriers at all levels simultaneously. Their implementation may require public policies, measures, and instruments. The socio-economic potential may lie anywhere in the space between the economic and technological potential.]

7.8 ***National responses to climate change can be more effective if deployed as a portfolio of policy instruments to limit or reduce greenhouse gas emissions.*** The portfolio of national climate policy instruments may include — according to national circumstances — emissions/carbon/energy taxes, tradable or non-tradable permits, provision and/or removal of subsidies, deposit/refund systems, technology or performance standards, energy mix

- WGIII TAR SPM Para18 &

requirements, product bans, voluntary agreements, information campaigns, environmental labeling, government spending and investment, and support for research and development (R&D). The literature in general gives no preference for any particular policy instrument. (Sections 5.3, 5.4, & 6.2)

7.9 ***Coordinated actions among countries and sectors may help to reduce mitigation cost, address competitiveness concerns, potential conflicts with international trade rules, and carbon leakage. A group of countries that wants to limit its collective greenhouse gas emissions could agree to implement well-designed international instruments.*** Instruments assessed in the WGIII TAR, and being developed in the Kyoto Protocol, are emissions trading, Joint Implementation (JI), and the Clean Development Mechanism (CDM). Other international instruments also assessed in this report include coordinated or harmonized emission/carbon/energy taxes, an emission/carbon/energy tax, technology and product standards, voluntary agreements with industries, direct transfers of financial resources and technology, and coordinated creation of enabling environments such as reduction of fossil-fuel subsidies. Some of these have been considered only in some regions to date.

- WGIII TAR SPM Para20 & Sections 6.3, 6.4, & 10.2

7.10 **Transfer of technologies between countries and regions would widen the choice of options at the regional level, and economies of scale and learning will lower the costs of their adoption.**

7.11 ***Adequate human and organizational capacity at every stage can increase the flow, and improve the quality, of technologies transferred within and across countries.*** The transfer of environmentally sound technologies has come to be seen as a major element of global strategies to achieve sustainable development and climate change mitigation. The local availability of technical, business, management, and regulatory skills can enhance the flow of international capital, helping to promote technology transfer. Technical skills are enhanced by the creation of competence in associated services, organizational know-how, and capacity improvement to formulate and enforce regulations. Capacity building is a continuous process that needs to keep up with the evolution of mitigation options as they respond to technological and social changes.

- WGIII TAR Sections 2.3.2, 2.4.5, 2.5.1, & 2.5.2
- SRTT SPM

7.12 ***Governments through sound economic policy and regulatory frameworks, transparency, and political stability can create an enabling environment for private- and public-sector technology transfers.*** At the macro-level actions to consider include, reform of the legal system, protection of intellectual property rights, open and competitive markets, reduced corruption, discouragement of restrictive business practices, reform of export credit, political risk insurance, reduction of tied aid, development of physical and communications infrastructure, and improvement of macroeconomic stability. At the sectoral and project levels, actions include fuel and electricity price rationalization, energy industry institutional reform, improving land tenure, transparent project approval procedures, ensuring assessment of local technology needs and social impact of technologies, cross-country R&D on innovative technologies, and demonstration programs.

- SRTT SPM

7.13 ***Networking among private and public stakeholders, and focusing on products and techniques with multiple ancillary benefits, that meet or adapt to local needs and priorities foster effective technology transfer.*** National systems of innovation (NSI) can help achieve this through activities such as (a) strengthening educational institutions; (b) collection, assessment, and dissemination of technical, commercial, financial, and legal information; (c) technology assessment, demonstration projects, and extension services; (d) supporting market intermediary organizations; and (e) innovative financial mechanisms. Increasing flows of national and multilateral assistance can help to mobilize and multiply additional financial resources, including official development assistance, to support NSI activities.

- SRTT SPM

7.14 **An increasing scale of international co-operation, such as emissions trading and technology transfer, will lower mitigation costs**

7.15 A large number of studies using both top-down and bottom-up approaches (see Box 7-1 for definitions) report on the costs of greenhouse gas mitigation. Estimates of the costs of limiting fossil-fuel greenhouse gas emissions vary widely and depend on choice of methodologies, underlying assumptions, emissions scenarios, policy instruments, reporting year, and other criteria.

Box 7-1 **Bottom-up and top-down approaches to cost estimates and the importance of uncertainties.** Bottom-up models incorporate detailed studies of engineering costs of a wide range of available and anticipated technologies, and describe energy consumption in great detail. However, they typically incorporate relatively little detail on non-energy consumer behavior and interactions with other sectors of the economy. The costs estimated by bottom-up models can range from negative values (due to the adoption of "no-regrets" options) to positive values. Negative costs indicate that the direct energy benefits of a mitigation option exceed its direct costs (net capital, operating, and maintenance costs). Market and institutional barriers, however, can prevent or delay the adoption of cost-effective options. Inclusion of implementation and policy costs would add to the costs estimated by bottom-up models.

Top-down models are aggregate models of the economy that often draw on analysis of historical trends and relationships to predict the large-scale interactions between sectors of the economy, especially the interactions between the energy sector and the rest of the economy. Top-down models typically incorporate relatively little detail on energy consumption and technological change. The costs estimated by top-down models usually range from zero to positive values. This is because negative cost options estimated in bottom-up models are assumed to be adopted in both the baseline and policy scenarios. This is an important factor in the differences in the estimates from these two types of models.

An increasing scale of international cooperation lowers mitigation costs. Estimates of mitigation costs assessed in the TAR are converging between bottom-up engineering-oriented analyses under the hypothetical assumption of full world-wide implementation of all mitigation opportunities cited below, and top-down global economic analyses under the hypothetical assumption of full global emissions trading. The lesson to be learned from these analyses is the greater the level of international collaboration, the greater the opportunities to lower mitigation costs.

However, a great deal of uncertainty surrounds both the bottom-up and top-down cost estimates reported. No analysis incorporates all relevant factors. The inclusion of multiple greenhouse gases, sinks, ancillary benefits, efficient tax revenue recycling, induced technical change, international emissions trading, CDM, and JI can lower costs. On the other hand, limitations on the use of market mechanisms, inclusion of ancillary costs, and ineffective tax recycling measures can have a counter effect. The reported analyses also ignore short-term macro shocks to the economy.

- WGIII SAR Chapter 8
- WGIII TAR Chapters 3 & 8

7.16 ***Bottom-up assessments (see Box 7-1) of specific technologies and sectors suggest that half of the potential emissions reductions noted in Table 7-1 may be achieved by 2020 with direct benefits exceeding direct costs, and the other half at a net direct cost of up to US$100/t C_{eq} (at 1998 prices). However, for reasons described below, the realized potential may be different.*** These cost estimates are derived using discount rates in the range of 5 to 12%, consistent with public-sector discount rates. Private internal rates of return vary greatly, and are often significantly higher, affecting the rate of adoption of these technologies by private entities. In addition, these assessments do not take into account: (a) additional implementation costs, which in some cases may be substantial; (b) the possible need for supporting policies; and (c) the increased costs of R&D and technology transfer.

- WGIII TAR SPM Para7, Para17, Para18, & Sections 1.5, 3.3-3.8, 5.3, 5.4, & 6.2

7.17 ***Cost estimates using bottom-up analyses reported to date for biological mitigation vary significantly from US$0.1/t C to about US$20/t C in several tropical countries and from US$20/t C to US$100/t C in non-tropical countries.*** The cost calculations do not cover, in many instances, *inter alia*, costs for infrastructure, appropriate discounting, monitoring, data collection and implementation costs, opportunity costs of land and maintenance, or other recurring costs, which are often excluded or overlooked. The lower end of the range is assessed to be biased downwards, but understanding and treatment of costs is improving over time.

- WGIII TAR SPM Para8 & Sections 4.3-4.4

7.18 ***Projections of abatement cost of near-term policy options implemented domestically for meeting a given near-term CO_2 emissions target as reported by several models[1] of the global economy (top-down models) vary within and across regions (solid lines Figure 7-2).*** Reasons for the differentiation among models within regions is due to varying assumptions about future gross domestic product (GDP) growth rates, carbon intensity, and energy intensity (different socio-economic development paths). The same reasons also apply to differences across regions. These models assume that national policy instruments are efficient and consistent with international policy instruments. That is, they assume that reductions are made through the use of market mechanisms (e.g, cap and trade) within each region. To the extent that regions employ a mix of market mechanisms and command and control policies, costs will likely be higher. On the other hand, inclusion of carbon sinks, non-CO_2 greenhouse gases, induced technical change, ancillary benefits, or targeted revenue recycling could reduce costs.

- WGIII TAR Chapter 8

[FOOTNOTE 1: The above-referenced models report results for Energy Modeling Forum (EMF) scenarios examining the benefits of emissions trading. For the analyses reported here, these models exclude sinks, multiple gases, ancillary benefits, macroeconomic shocks, and induced technical change, but include lump sum tax revenue recycling. No-regrets options not listed above are included in the model baseline.]

[FIGURE 7-2 CAPTION: Global model projections of mitigation costs of meeting Kyoto targets expressed as GDP losses in Annex II in 2010. The global models used in this EMF study dissagregate the world into regions. The projections reported in the figure are for four regions, which constitute Annex II. The models examined two scenarios. In the first, each region must make the prescribed reduction in the absence of international trade in carbon emissions rights (solid lines). In the second, full Annex B trading is permitted (dashed lines). For each region, the maximum, minimum, and average of the model projections are shown.]

- WGIII TAR Section 8.3.1.1

7.19 ***The models used in the above study show that the Kyoto mechanisms are important in controlling risks of high costs in given countries, and thus could complement domestic policy mechanisms, and could minimize risks of inequitable international impacts.*** For example, the dotted lines in Figure 7-2 show that the national marginal costs to meet the Kyoto targets range from about US$20/t C up to US$600/t C without Annex B trading, and range from about US$15/t C up to US$150/t C with Annex B trading.[2] The cost reductions from Annex B trading will depend on the details of implementation, including the compatibility of domestic and international mechanisms, constraints, and transaction costs. The following is indicative of the broad variation in the change in GDP[3] reported for Annex B countries:

- *For Annex II countries, the above modeling studies show GDP losses, compared to projected levels in 2010.* Figure 7-2 indicates that in the absence of Annex B trading losses range from 0.2 to 2% of GDP. With Annex B trading losses range form 0.1 to 1% of GDP. National studies, which explore a more diverse set of policy packages and take account of specific national circumstances, vary even more widely.
- *For most economies in transition, GDP effects range from negligible to a several percent increase, reflecting opportunities for energy efficiency improvements not available to*

- WGIII TAR SPM Para13 & Sections 7.3, 8.3, 9.2, & 10.2

Annex II countries. Under assumptions of drastic energy-efficiency improvement and/or continuing economic recessions in some countries, the assigned amounts may exceed projected emissions in the first commitment period. In this case, models show increased GDP due to revenues from trading assigned amounts. However, for some economies in transition, implementing the Kyoto Protocol will have similar impact on GDP as for Annex II countries.

[FOOTNOTE 2: In the hypothetical case of full global emissions trading, marginal cost estimates drop to US$5-90/t C, similar to the positive marginal cost estimates for potential emissions reductions from the bottom-up studies quoted above.]

[FOOTNOTE 3: GDP is an oft-used but incomplete measure of welfare (see TAR WGIII Chapter 7).]

7.20 ***Emission constraints in Annex I countries have well-established, albeit varied, "spill-over" effects[4] on non-Annex I countries.***

- *Oil-exporting, non-Annex I countries: Analyses report costs differently, including, inter alia, reductions in projected GDP and reductions in projected oil revenues*.[5] The study reporting the lowest costs shows reductions of 0.2% of projected GDP with no emissions trading, and less than 0.05% of projected GDP with Annex B emissions trading in 2010.[6] The study reporting the highest costs shows reductions of 25% of projected oil revenues with no emissions trading, and 13% of projected oil revenues with Annex B emissions trading in 2010. These studies do not consider policies and measures[7] other than Annex B emissions trading, which could lessen the impact on non-Annex I, oil-exporting countries, and therefore tend to overstate both the costs to these countries and overall costs. The effects on these countries can be further reduced by removal of subsidies for fossil fuels, energy tax restructuring according to carbon content, increased use of natural gas, and diversification of the economies of non-Annex I, oil-exporting countries.
- *Other non-Annex I countries**:** They may be adversely affected by reductions in demand for their exports to Organisation for Economic Cooperation and Development (OECD) nations and by the price increase of those carbon-intensive and other products they continue to import. These countries may benefit from the reduction in fuel prices, increased exports of carbon-intensive products, and the transfer of environmentally sound technologies and know-how.* The net balance for a given country depends on which of these factors dominates. Because of these complexities, the breakdown of winners and losers remains uncertain.
- *Carbon leakage: The possible relocation of some carbon-intensive industries to non-Annex I countries and wider impacts on trade flows in response to changing prices may lead to leakage on the order of 5-20%.[8]* Exemptions (e.g., for energy-intensive industries) make the higher model estimates for carbon leakage unlikely, but would raise aggregate costs. The transfer of environmentally sound technologies and know-how, not included in models, may lead to lower leakage and especially on the longer term may more than offset the leakage.

- WGIII TAR SPM Para16 & Sections 8.3.2, 9.3.1, & 9.3.2

[FOOTNOTE 4: Spill-over effects incorporate only economic, not environmental, effects.]

[FOOTNOTE 5: Details of the six studies reviewed are found in WGIII TAR Table 9.4.]

[FOOTNOTE 6: These estimated costs can be expressed as differences in GDP growth rates over the period 2000–2010. With no emissions trading, GDP growth rate is reduced by 0.02 percentage points/year; with Annex B emissions trading, growth rate is reduced by less than 0.005 percentage points/year.]

[FOOTNOTE 7: These policies and measures include those for non-CO_2 gases and non-energy sources of all gases; offsets from sinks; industry restructuring (e.g., from energy producer to supplier of energy services); use of OPEC's market power; and actions (e.g., of Annex B Parties) related to funding, insurance, and the transfer of technology. In addition, the studies typically do not include the following policies and effects that can reduce the total cost of mitigation: the use of tax revenues to reduce tax burdens or finance other mitigation measures; environmental ancillary benefits of reductions in fossil-fuel use; and induced technical change from mitigation policies.]

[FOOTNOTE 8: Carbon leakage is defined here as the increase in emissions in non-Annex B countries due to implementation of reductions in Annex B, expressed as a percentage of Annex B reductions.]

7.21 ***Some sources of greenhouse gas emissions can be limited at no, or negative, net social cost to the extent that policies can exploit no-regret opportunities. This may be achieved by removal of market imperfections, accounting for ancillary benefits (see Question 8), and recycling revenues to finance reductions in distortionary taxes ("double dividend").***

- *Market imperfections*. Reduction of existing market or institutional failures and other barriers that impede adoption of cost-effective emission reduction measures can lower private costs compared to current practice. This can also reduce private costs overall.
- *Ancillary benefits.* Climate change mitigation measures will have effects on other societal issues. For example, reducing carbon emissions in many cases will result in the simultaneous reduction in local and regional air pollution. It is likely that mitigation strategies will also affect transportation, agriculture, land-use practices, and waste management and will have an impact on other issues of social concern, such as employment, and energy security. However, not all of the effects will be positive; careful policy selection and design can better ensure positive effects and minimize negative impacts. In some cases, the magnitude of ancillary benefits of mitigation may be comparable to the costs of the mitigating measures, adding to the no-regret potential, although estimates are difficult to make and vary widely.
- *Double dividend.* Instruments (such as taxes or auctioned permits) provide revenues to the government. If used to finance reductions in existing distortionary taxes ("revenue recycling"), these revenues reduce the economic cost of achieving greenhouse gas reductions. The magnitude of this offset depends on the existing tax structure, type of tax cuts, labor market conditions, and method of recycling. Under some circumstances, it is possible that the economic benefits may exceed the costs of mitigation.

- WGIII TAR Chapter 5 & Sections 7.3.3, 8.2.2, 8.2.4, 9.2.1, 9.2.2, 9.2.4, & 9.2.8
- WGII TAR Section 1.6.2

7.22 **Potential, barriers, opportunities, policies, and costs of stabilizing atmospheric greenhouse gas concentrations in the <u>long term</u>.**

7.23 **Cost of stabilization depends on both the target and the emissions pathway.**

7.24 ***There is no single path to a low-emission future, and countries and regions will have to choose their own path. Most model results indicate that known technological options[9] could achieve a broad range of atmospheric CO_2 stabilization levels, such as 550 ppmv, 450 ppmv, or below over the next 100 years or more, but implementation would require associated socio-economic and institutional changes.*** To achieve stabilization at these levels, the scenarios suggest that a very significant reduction in world carbon emissions per unit of GDP from 1990 levels will be necessary. For the crucial energy sector, almost all greenhouse gas mitigation and concentration stabilization scenarios are characterized by the introduction of efficient technologies for both energy use and supply, and of low- or no-carbon energy. However, no single technology option will provide all of the emissions reductions needed for stabilization. Reduction options in non-energy sources and non-CO_2 greenhouse gases will also provide significant potential for reducing emissions.

- WGIII TAR Sections 2.3.2, 2.4.5, 2.5.1, 2.5.2, & 3.5, & Chapter 3 App.

[FOOTNOTE 9: "Known technological options" refer to technologies that exist in operation or pilot plant stage today, as referenced in the mitigation scenarios discussed in this report. It does not include any new technologies that will require drastic technological breakthroughs. In this way it can be considered to be a conservative estimate, considering the length of the scenario period.]

7.25 ***The development and diffusion of new environmentally sound technology can substantially reduce the costs of stabilizing concentrations at a given level.*** A substantial body of work has considered the implication of technology development and diffusion on the cost of meeting alternative emissions-mitigation obligations. The principal conclusion is that the cost of emissions mitigation depends crucially on the ability to develop and deploy new technology. The value of successful technology diffusion appears to be large with the value depending on the magnitude and timing of emissions mitigation, and on the assumed reference scenario.

- WGIII TAR Chapter 10
- WGIII SAR Chapter 9

7.26 ***The pathway to stabilization can be as important as the stabilization target itself in determining mitigation cost.*** Economic modeling studies completed since the SAR indicate that a gradual near-term transition from the world's present energy system towards a less carbon-emitting economy minimizes costs associated with premature retirement of existing capital stock. It also provides time for investment in technology development and diffusion, and may reduce the risk of lock-in to early versions of rapidly developing low-emission technology. On the other hand, more rapid near-term action would decrease environmental and human risks associated with rapid climatic changes, as well as minimizing potential implications of inertia in climate and ecological systems (see Question 5). It would also stimulate more rapid deployment of existing low-emission technologies and provide strong near-term incentives to future technological changes that may help reduce the risks of lock-in to carbon-intensive technologies. It also would give greater scope for later tightening of targets should that be deemed desirable in light of evolving scientific understanding.

- WGIII TAR SPM Para22 & Sections 2.3.2, 2.6.3, 8.4.2, 10.4.2, & 10.4.3

7.27 ***Cost-effectiveness studies with a century time scale estimate that the mitigation costs of stabilizing CO_2 concentrations in the atmosphere increase as the concentration stabilization level declines. Different baselines can have a strong influence on absolute costs. While there is a moderate increase in the costs when passing from a 750 ppmv to a 550 ppmv concentration stabilization level, there is a larger increase in costs passing from 550 ppmv to 450 ppmv (see Figure 7-3) unless the emissions in the baseline scenario are very low (see Figure 7-4).*** In no case did the stabilization scenarios lead to significant declines in global GDP growth rates over this century. The losses, however, did vary across regions and time. These results, however, do not incorporate carbon sequestration and gases other than CO_2, and did not examine the possible effect of more ambitious targets on induced technological change. Costs associated with each concentration level depend on numerous factors including the rate of discount, distribution of emission reductions over time, policies and measures employed, and particularly the choice of the baseline scenario: For scenarios characterized by a focus on local and regional sustainable development for example, total costs of stabilizing at a particular level are significantly lower than for other scenarios.

- WGIII TAR SPM Para14 & Sections 2.5.2, 8.4.1, 8.4.3, & 10.4.6

[FIGURE 7-3 CAPTION: The mitigation costs (1990 US$, present value discounted at 5% per year for 1990–2100) of stabilizing CO_2 concentrations at 450-750 ppmv are calculated using three global models. Ancillary benefits are not included. In each instance, costs were calculated based on two emission pathways for achieving the prescribed target: WGI or S and WRE. The bar chart shows cumulative carbon emissions between 1990 and 2100. Cumulative future emissions until carbon budget ceiling is reached. These cumulative emissions are reported above the bars in Gt C.]

[FIGURE 7-4 CAPTION: Relationship in 2050 between the relative GDP reduction, the scenario group, and the stabilization level. The reduction in GDP tends to increase with the stringency of the stabilization level. But the costs are very sensitive to the choice of the baseline scenario.]

- WGIII TAR Figure 8.18

7.28 **Energy R&D and social learning can contribute to the flow and adoption of improved energy technologies throughout the 21st century.**

7.29 ***Lower emissions scenarios require different patterns of energy resource development and an increase in energy R&D to assist accelerating the development and deployment of advanced environmentally sound energy technologies.*** Fossil-fuel resources will not limit carbon emissions during the 21st century (see Figure 7-5). The carbon in proven conventional oil and gas reserves is much less, however, than the cumulative carbon emissions associated with stabilization of carbon dioxide at levels of 450 ppmv or higher.[10] Changes will occur in the global energy mix during the 21st century irrespective of climate change, among other reasons, because the carbon in proven conventional oil and gas reserves, or in conventional oil resources, is limited. The choice of energy mix and associated technologies and investments—either more in the direction of exploitation of unconventional oil and gas resources, or in the direction of non-fossil energy sources, or fossil energy technology with carbon capture and storage—will determine whether, and if so, at what level and cost, greenhouse concentrations can be stabilized.

- WGIII TAR Sections 2.5.1, 2.5.2, 3.8.2, & 8.3

[FOOTNOTE 10: The reference to a particular concentration level does not imply an agreed-upon desirability of stabilization at this level.]

[FIGURE 7-5 CAPTION: Carbon in oil, gas, and coal reserves and resources compared with historic fossil-fuel carbon emissions 1860–1998, and with cumulative carbon emissions from a range of SRES scenarios and TAR stabilization scenarios up until 2100. Data for current reserves and resources are shown in the lefthand columns. Unconventional oil and gas includes tar sands, shale oil, other heavy oil, coal bed methane, deep geopressured gas, gas in acquifers, etc. Gas hydrates (clathrates) that amount to an estimated 12,000 Gt C are not shown. The scenario columns show both SRES reference scenarios as well as scenarios that lead to stabilization of CO_2 concentrations at a range of levels. Note that if by 2100 cumulative emissions associated with SRES scenarios are equal to or smaller than those for stabilization scenarios, this does not imply that these scenarios equally lead to stabilization.]

- WGIII TAR Section 3.8.1

7.30 ***The decline in energy R&D expenditure is inconsistent with the goal of accelerating the development and deployment of advanced energy technologies.*** Energy-related R&D expenditure by Annex II governments increased dramatically after the 1970 oil price increases, but as a group it has decreased steadily in real terms since the early 1980s. In some countries the decrease has been as great as 75%. The support for energy conservation and renewable energy R&D has increased. However, other important energy technologies relevant to climate change, such as, for example, commercial biomass and carbon capture and storage, remain minor constituents of the energy R&D portfolio.

- SRTT Section 2.3

7.31 ***Social learning and innovation and changes in institutional structure could contribute to climate change mitigation.*** Changes in collective rules and individual behaviors may have significant effects on greenhouse gas emissions, but take place within a complex institutional, regulatory, and legal setting. Several studies suggest that current incentive systems can encourage resource-intensive production and consumption patterns that increase greenhouse gas emissions in all sectors (e.g., transport and housing). In the shorter term, there are opportunities to influence through social innovations individual and organizational behaviors. In the longer term, such innovations in combination with technological change may further enhance socio-economic potential, particularly if preferences and cultural norms shift

- WGIII TAR SPM Para10, & Sections 1.4.3, 5.3.7, 10.3.2,

	towards a lower emitting and sustainable behaviors. These innovations frequently meet with resistance, which may be addressed by encouraging greater public participation in the decisionmaking processes. This can help contribute to new approaches to sustainability and equity.	& 10.3.4
7.32	**Integrating near- and long-term considerations**	
7.33	**Climate change decisionmaking is a sequential process under uncertainty. Decisionmaking at any point in time entails balancing the risks of either insufficient or excessive action.**	
7.34	***Development of a prudent risk management strategy involves careful consideration of the consequences (both environmental and economic), their likelihood, and society's attitude toward risk.*** The latter is likely to vary from country to country and perhaps even from generation to generation. This report therefore confirms the SAR finding that the value of better information about climate change processes and impacts and society's responses to them is likely to be great. Decisions about near-term climate policies are in the process of being made while the concentration stabilization target is still being debated. The literature suggests a step-by-step resolution aimed at stabilizing greenhouse gas concentrations. This will also involve balancing the risks of either insufficient or excessive action. The relevant question is not "what is the best course for the next 100 years," but rather "what is the best course for the near term given the expected long-term climate change and accompanying uncertainties."	• WGIII TAR SPM Para21 & Section 10.4.3
7.35	***Stabilizing atmospheric concentrations would depend upon emissions reductions beyond those agreed to in the Kyoto Protocol.*** Most post-SRES scenario analysis suggests that achievement of stabilization at 450 ppmv may require emission reductions during the period 2008–2012 in Annex I countries that are significantly stronger than the Kyoto Protocol commitments. This analysis also suggests that achieving the aggregate Kyoto commitments may be consistent with trajectories that achieve stabilization at 550 ppmv or higher. Other analyses suggest a more gradual departure from emissions baselines even for 450 ppmv followed by sharper reductions in subsequent budget periods. The appropriate path is influenced by the representation of inertia in the system and expectations about how initial reductions by Annex I countries may relate to the strength and scope of emissions limitation in subsequent periods.	• WGIII TAR Section 2.5.2 & Chapter 8
7.36	**Climate change mitigation raises both interregional and inter-temporal equity considerations.**	
7.37	***Differences in the distribution of technological, natural, and financial resources among and within nations and regions, and between generations, as well as differences in mitigation costs, are often key considerations in the analysis of climate change mitigation options.*** Much of the debate about the future differentiation of contributions of countries to mitigation and related equity issues also considers these circumstances.[11] The challenge of addressing climate change raises an important issue of equity, namely the extent to which the impacts of climate change or mitigation policies ameliorate or exacerbate inequities both within and across nations and regions, and between generations. Findings with respect to these different aspects of equity include: • *Equity within nations: Most studies show that the distributional effects of a carbon tax are regressive unless the tax revenues are used either directly or indirectly in favor of the low-income groups; the regressive aspect can be totally or partially compensated by a revenue-recycling policy.* • *Equity across nations and regions: Greenhouse gas stabilization scenarios assessed in this report assume that developed countries and countries with economies in transition*	• WGIII TAR Sections 1.3, 2.5.2, 8.2.2, 10.2, & 10.4.5

limit and reduce their greenhouse gas emissions first. Emissions from all regions diverge from baselines at some point**.** Global emissions diverge earlier and to a greater extent as stabilization levels are lower or underlying scenarios are higher.[12] Another aspect of equity across nations and regions is that mitigation of climate change can offset inequities that would be exacerbated by the impacts of climate change (see Question 6.4).

- *Equity between generations: Stabilization of concentrations depends more upon cumulative than annual emissions; emissions reductions by any generation will reduce the need for those by future generations.*[13] Intergenerational equity can be promoted by reducing climate change impacts through mitigation of climate change by any generation, since not only would impacts—which are expected to affect especially those with the fewest resources—be reduced, but also subsequent generations will have less climate change to adapt to (see Question 6.4).

[FOOTNOTE 11: Approaches to equity have been classified into a variety of categories, including those based on allocation, outcome, process, rights, liability, poverty, and opportunity, reflecting the diverse expectations of fairness used to judge policy processes and the corresponding outcomes.]

[FOOTNOTE 12: Such scenarios are uncertain, and do not provide information on equity implications and how such changes may be achieved or who may bear any costs incurred.]

[FOOTNOTE 13: See above for other aspects of timing of greenhouse gas emissions reductions.]

Table 7-1: *Estimates of potential global greenhouse gas emission reductions in 2010 and in 2020.*

Sector	Historic Emissions in 1990 [$MtC_{eq.}$/yr]	Historic C_{eq} Annual Growth Rate in 1990-1995 [%]	Potential Emission Reductions in 2010 [$MtC_{eq.}$/yr]	Potential Emission Reductions in 2020 [$MtC_{eq.}$/yr]	Net Direct Costs per Tonne of Carbon Avoided
Buildings[a] CO_2 only	1650	1.0	700-750	1000-1100	Most reductions are available at negative net direct costs.
Transport CO_2 only	1080	2.4	100-300	300-700	Most studies indicate net direct costs less than $25/tC but two suggest net direct costs will exceed $50/tC.
Industry CO_2 only -energy efficiency: -material efficiency:	2300	0.4	 300-500 ~200	 700-900 ~600	More than half available at net negative direct costs. Costs are uncertain.
Industry Non-CO_2 gases	170		~100	~100	N_2O emissions reduction costs are $0-$10/$tC_{eq.}$.
Agriculture[b] CO_2 only Non-CO_2 gases	 210 1250-2800	n.a	150-300	350-750	Most reductions will cost between $0-100/$tC_{eq.}$ with limited opportunities for negative net direct cost options
Waste[b] CH_4 only	240	1.0	~200	~200	About 75% of the savings as methane recovery from landfills at net negative direct cost; 25% at a cost of $20/$tC_{eq.}$.
Montreal Protocol replacement applications Non-CO_2 gases	0	n.a.	~100	n.a.	About half of reductions due to difference in study baseline and SRES baseline values. Remaining half of the reductions available at net direct costs below $200/$tC_{eq.}$.
Energy supply and conversion[c] CO_2 only	(1620)	1.5	50-150	350-700	Limited net negative direct cost options exist; many options are available for less than $100/$tC_{eq}$.
Total	6,900-8,400[d]		1,900-2,600[e]	3,600-5,050[e]	

[a] Buildings include appliances, buildings, and the building shell.

[b] The range for agriculture is mainly caused by large uncertainties about CH_4, N_2O and soil related emissions of CO_2. Waste is dominated by methane landfill and the other sectors could be estimated with more precision as they are dominated by fossil CO_2.

[c] Included in sector values above. Reductions include electricity generation options only (fuel switching to gas/nuclear, CO_2 capture and storage, improved power station efficiencies, and renewables).

[d] Total includes all sectors reviewed in Chapter 3 for all six gases. It excludes non-energy related sources of CO_2 (cement production, 160MtC; gas flaring, 60MtC; and land use change, 600-1400MtC) and energy used for conversion of fuels in the end-use sector totals (630MtC). If petroleum refining and coke oven gas were added, global 1990 CO_2 emissions of 7100MtC would increase by 12%. Note that forestry emissions and their carbon sink mitigation options are not included.

[e] The baseline SRES scenarios (for six gases included in the Kyoto Protocol) project a range of emissions of 11,500-14,000 MtC_{eq} for 2010 and of 12,000-16,000MtC_{eq} for 2020. The emissions reduction estimates are most compatible with baseline emissions trends in the SRES-B2 scenario. The potential reductions take into account regular turn-over of capital stock. They are not limited to cost-effective options, but exclude options with costs above US$100/$tC_{eq}$ (except for Montreal Protocol gases) or options that will not be adopted through the use of generally accepted policies.

Table 7-2: *Estimates of potential global greenhouse gas emission reductions in 2010: land use, land-use change, and forestry.*

Categories of Mitigation Options	**Potential Emission Reductions in 2010 [MtC/yr]**	**Potential Emission Reductions [MtC]**	
Afforestation/Reforestation (AR)[a]	197–584		Includes carbon in above and below-ground biomass. Excludes carbon in soils and in dead organic matter.
Reducing Deforestation (D)[b]		1788	Potential for reducing deforestation is very uncertain for the tropics and could be in error by as much as ±50%.
Improved management within a land use (IM)[c]	570		Assumed to be the best available suite of management practices for each land use and climatic zone.
Land-use change (LC)[c]	435		
Total	1202–1589	1788	

[a] Source: SRLUCF Table SPM-3. Based on IPCC definitional scenario. Information is not available for other definitional scenarios. Potential refers to the estimated average stock change (Mt C).
[b] Source: SRLUCF Table SPM-3. Based on IPCC definitional scenario. Information is not available for other definitional scenarios. Potential refers to the estimated range of accounted average stock change 2008-2012 (Mt C/yr^{-1}).
[c] Source: SRLUCF Table SPM-4. Potential refers to the estimated net change in carbon stocks in 2010 (Mt C/yr^{-1}). The list of activities is not exclusive or complete, and it is unlikely that all countries will apply all activities. Some of these estimates reflect considerable uncertainty.

FIGURE 7-1

SEE PAGE 76 LINES 42–48 FOR FIGURE CAPTION

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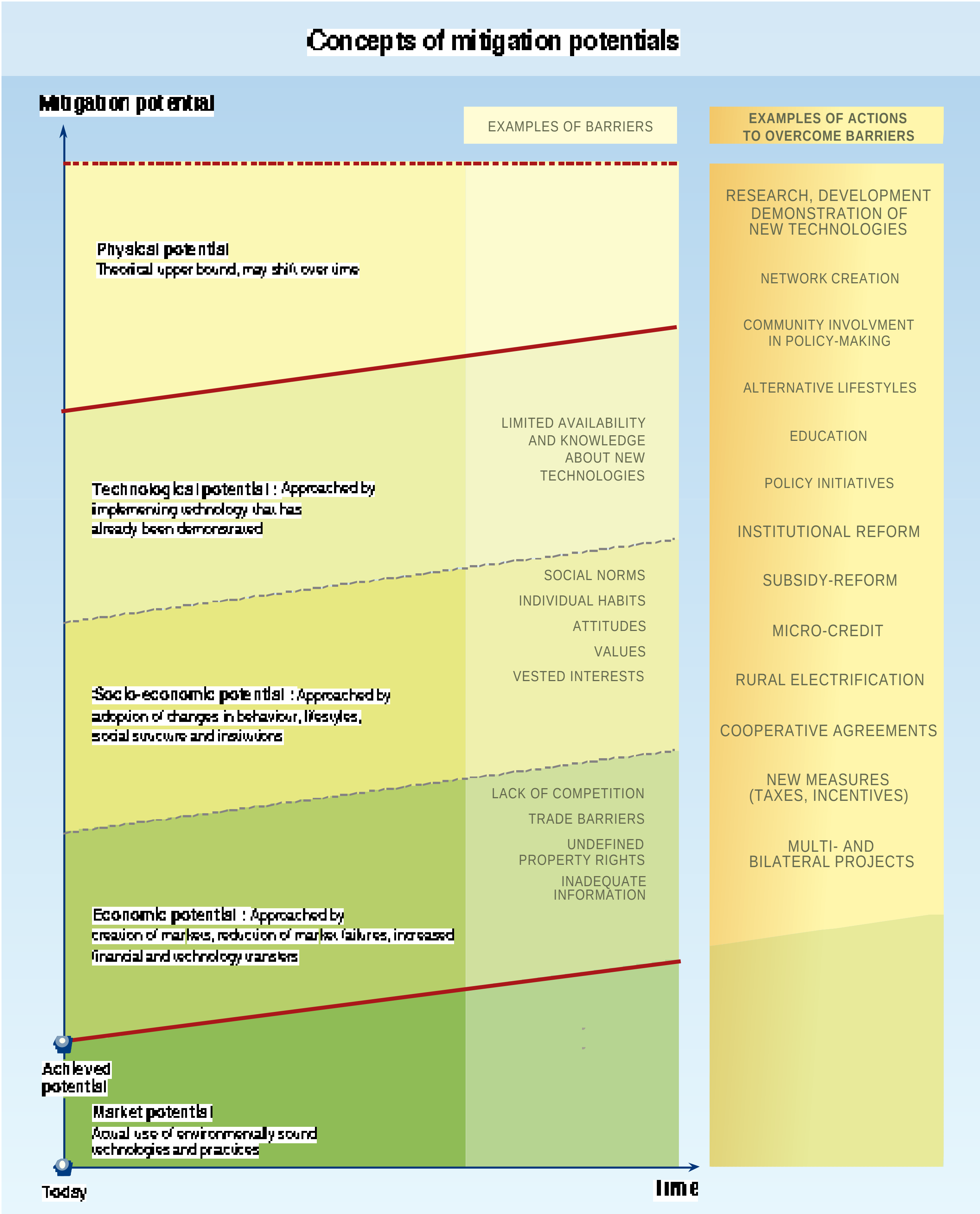

FIGURE 7-2

SEE PAGE 79 LINES 30–36 FOR FIGURE CAPTION

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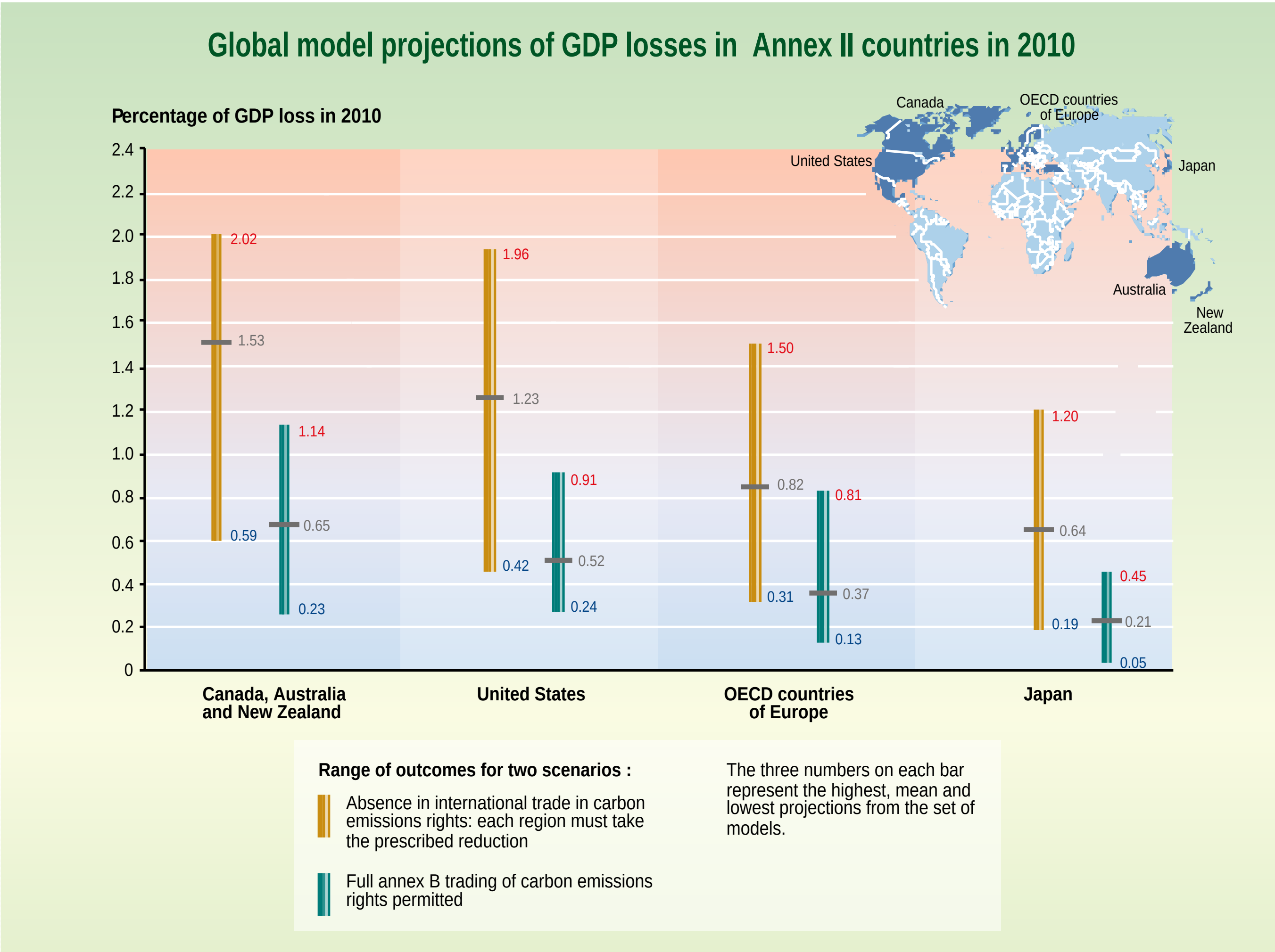

FIGURE 7-3

SEE PAGE 82 LINES 47–53 FOR FIGURE CAPTION

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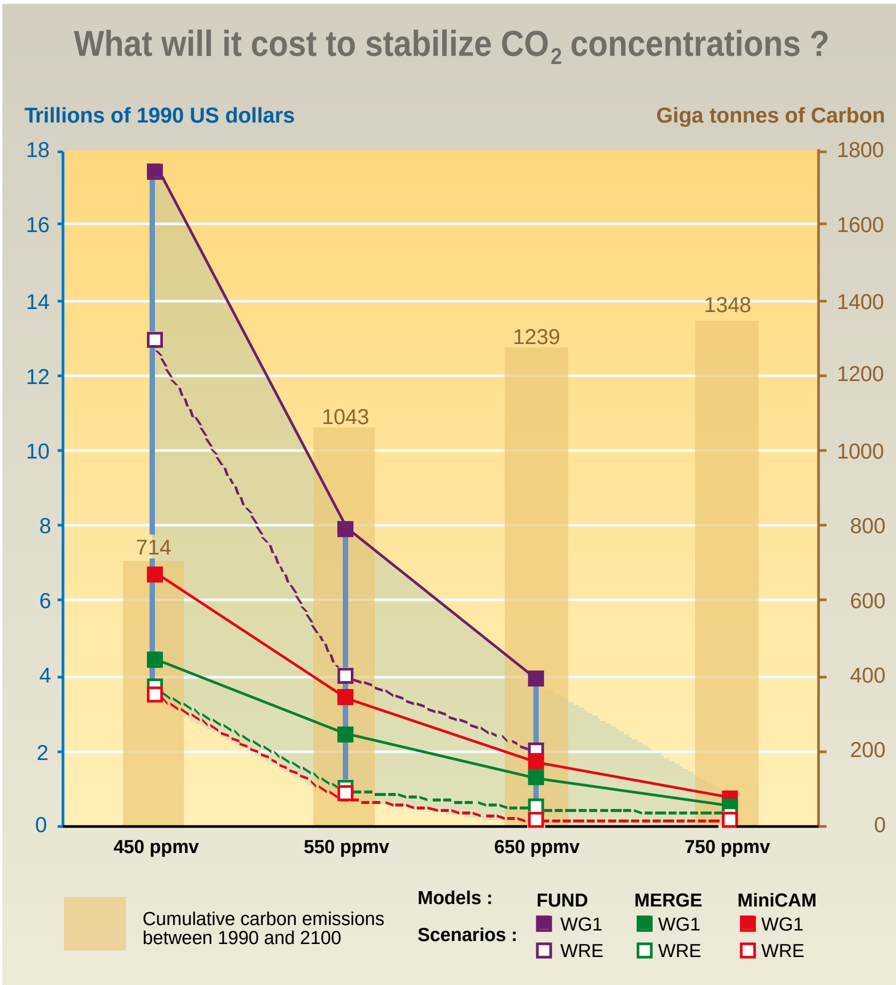

FIGURE 7-4

SEE PAGE 83 LINES 1–4 FOR FIGURE CAPTION

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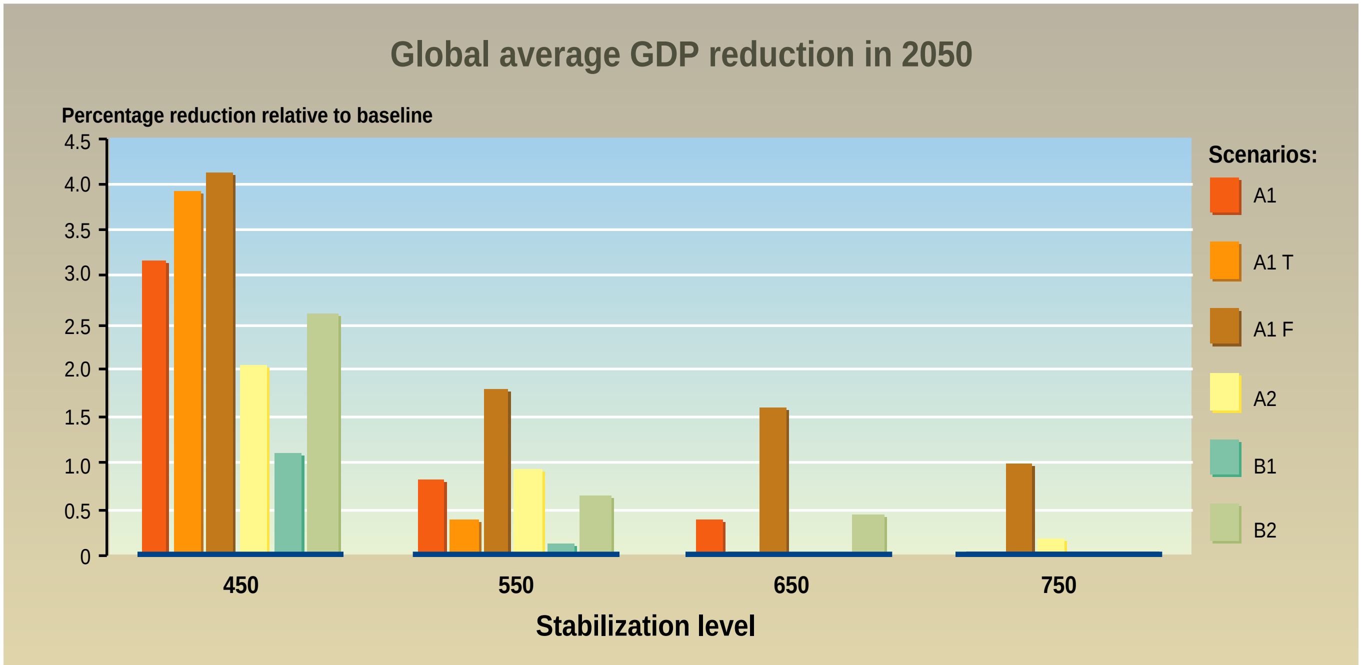

FIGURE 7-5

SEE PAGE 83 LINES 26–35 FOR FIGURE CAPTION

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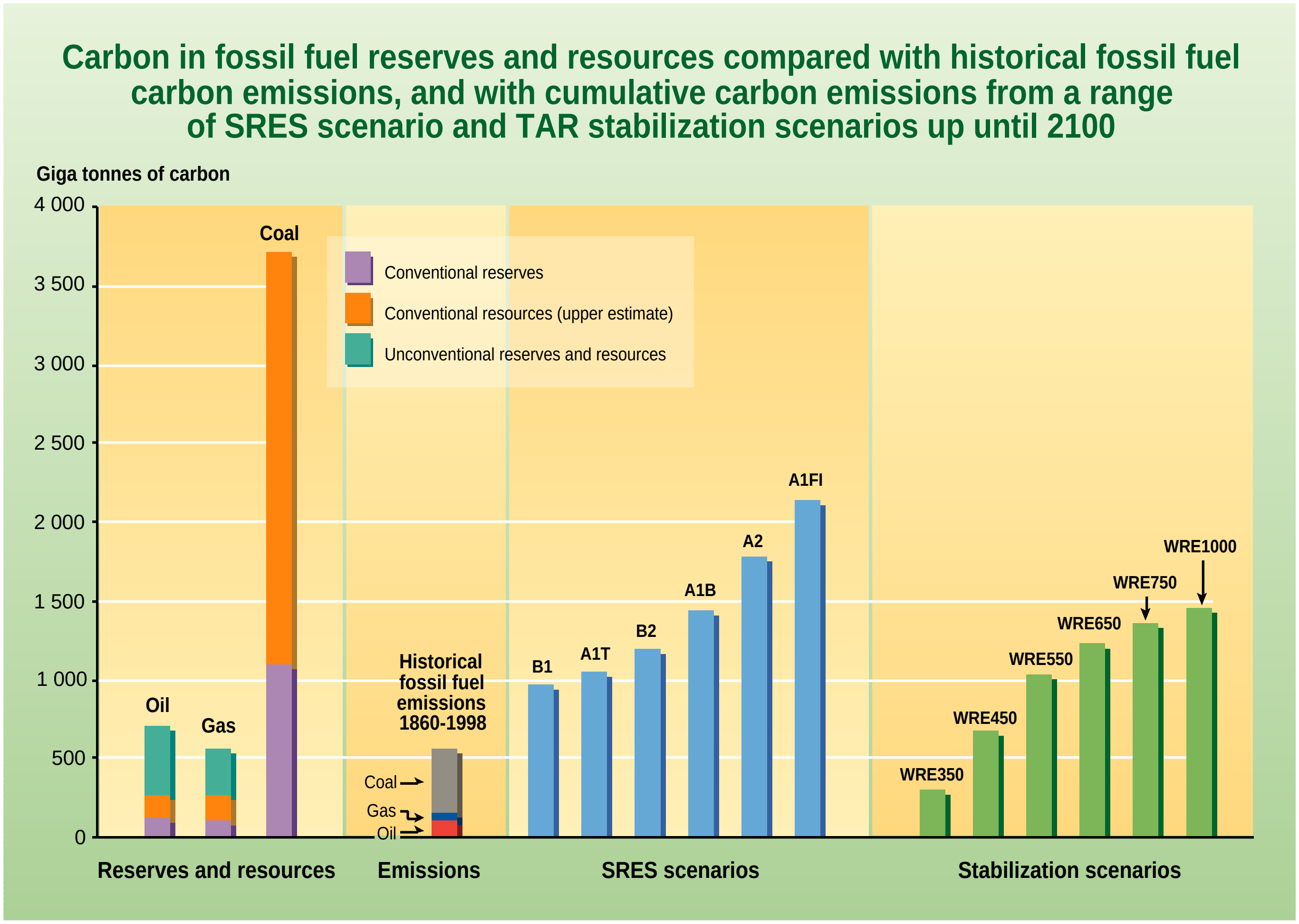

QUESTION 8

What is known about the interactions between projected human-induced changes in climate and other environmental issues (e.g., urban air pollution, regional acid deposition, loss of biological diversity, stratospheric ozone depletion, and desertification and land degradation)? What is known about environmental, social, and economic costs and benefits and implications of these interactions for integrating climate change response strategies in an equitable manner into broad sustainable development strategies at the local, regional, and global scales?

Paragraph Number		*Reference*
8.1	The answer to this question recognizes two major points. The first is that the human impacts on the environment are manifested in several issues, many driven by common factors associated with the meeting of human needs. The second is that many of these issues—their causes and impacts—are biogeophysically and socio-economically interrelated. With a central emphasis on climate change, this answer assesses the current understanding of the interrelations between the causes and impacts of the key environmental issues of today. To that is added a summary of the now largely separate policy approaches to these issues. In so doing, this answer frames how choices associated with one issue may positively or negatively influence another. With such knowledge, there is the prospect of efficient integrated approaches.	
8.2	**Local, regional, and global environmental issues often combine in ways that jointly affect the sustainable meeting of human needs.**	
8.3	***Meeting human needs is degrading the environment in many instances, and environmental degradation is hampering the meeting of human needs.*** Society has a range of socio-economic paths to development; however, these will only be sustainable if due consideration is given to the environment. Environmental degradation is already evident at the local, regional, and global scale, such as urban air pollution, scarcity of freshwater, deforestation, desertification, acid deposition, loss of biological diversity, land degradation, stratospheric ozone depletion, and climate change. Very frequently, addressing human needs causes or exacerbates several environmental problems, which may increase the vulnerability to climatic changes. For example, with the aim of higher agricultural production, there is increased use of nitrogeneous fertilizers, irrigation, and conversion of forested areas to croplands. But, these agricultural activities can affect the Earth's climate through release of greenhouse gases, degrade land by erosion and salinization, and reduce biodiversity. In turn, an environmental change can impact meeting human needs. For example, agricultural productivity can be adversely affected by changes in the magnitude and pattern of rainfall, and human health in an urban environment can be impacted by heat waves.	• WGI TAR Sections 3.4, 4.1, & 5.2 • WGII TAR Sections 4.1, 5.1, 5.2, & 7.5.4
8.4	***Just as different environmental problems are often caused by the same underlying driving forces (economic growth, population size, patterns of consumption, and choice of technologies), common barriers inhibit solutions to a variety of environmental and socio-economic issues.*** Approaches to the amelioration of environmental issues are hampered by many of the same barriers, for example: • Increased demand for natural resources and energy • Market imperfections, including subsidies that lead to the inefficient use of resources and act as a barrier to the market penetration of environmentally friendly technologies; the lack of recognition of the true value of natural resources; failure to appropriate the global	• WGIII TAR Chapter 5

values of natural resources to the local level; and failure to internalize the costs of environmental degradation into the market price of a resource

- Inefficient use of technologies and inadequate investment in research and development for the technologies of the future
- Institutional failures to manage adequately the use of natural resources and energy.

8.5 **Several environmental issues that traditionally have been viewed as separate are indeed linked with climate change via common biogeochemical and socio-economic processes.**

8.6 Figure 8-1 illustrates the interconnectivity of several environmental issues. The summary below delineates how climate change is closely interlinked with many of these issues.

[FIGURE 8-1 CAPTION: Linkages among environmental issues. Climate, defined as the balance between the radiation energy from external (Sun) and internal (Earth and its atmosphere) sources, is controlled by geochemical proceses and cycles resulting from the interplay among the environment's components involved, as affected by human action. The scheme shows some of these issues. There are a number of feedback loops in the interactions among climate, biodiversity, and forests. For simplicity, the single double-ended arrows between issues represent some of the linkages involved. For example, biological and ecological processes play an important role in modulating the Earth's climate at both regional and global scale by controlling the amounts of water vapor and other greenhouse gases that enter into or are depleted from the atmosphere. Changes in climate affect the boundaries, composition, and functioning of ecological systems, including forests, and changes in the structure and functioning of forests affect the Earth's climate system through changes in the biogeochemical cycles, particularly cycles of carbon and nitrogen. There are other linkages such as the connection between air quality and forestry, directly or through acid precipitation, which for simplicity are not shown here.]

<u>Urban Ozone Pollution and Climate Change</u>

8.7 ***Urban ozone pollution and the emissions that drive it are important contributors to global climate change.*** The same pollutants that generate surface ozone pollution (nitrogen oxides, carbon monoxide, and volatile organic compounds) also contribute to the rise in global tropospheric ozone, making it the third most important contributor to radiative forcing after carbon dioxide and methane (see Figure 2-2). In some regions emissions of ozone precursor substances are controlled by regional environmental treaties (see Table 8-3).

- WGI TAR Section 4.2.3

8.8 ***Global climate changes and rising tropospheric ozone levels may exacerbate urban air pollution problems.*** Projections based on some SRES scenarios show increases in tropospheric ozone of more than 40 ppb over most of the Northern Hemisphere mid-latitudes. Such increases would approximately double the baseline levels of ozone entering many metropolitan regions, substantially degrading air quality. Climate change would affect the meteorological conditions (regional temperature, cloud cover, and surface wind) that influence photochemistry, and the occurrence of major pollution episodes. While warmer temperatures would generally contribute to more urban ozone, the change in frequency and intensity of pollution episodes has not been evaluated. Adverse health effects attributable to urban air quality would be exacerbated by increases in heat waves that would accompany anthropogenic climate change.

- WGI TAR Section 4.6
- WGII TAR Sections 7.2.2.3 & 9.6

<u>Acid Deposition and Climate Change</u>

8.9 ***The sulfate aerosols formed from sulfur emissions from the burning of fossil fuels lead to both acid deposition and a cooling of the climate system.*** Acid deposition can have adverse impacts on both terrestrial and aquatic ecosystems and cause damage to many materials.

- WGI TAR Sections

	Some of these impacts could be exacerbated by climate change. As a result, actions to reduce sulfur emissions have been taken in many countries, and declines in sulfate deposition have been observed in some regions in recent years (see Table 8-3). In the SRES scenarios, this situation has led to projections of future sulfate aerosol abundances that are lower than those in the SAR. This has led, in turn, to less-negative projections for the radiative forcing by aerosols, hence less of a cooling effect to the greenhouse gas-induced warming.	5.2, 5.3, 6.7, 6.8, & 6.15
	<u>Stratospheric Ozone Depletion and Climate Change</u>	
8.10	***Depletion of the stratospheric ozone layer leads to a cooling of the climate system.*** During the last 2 decades, the observed losses of stratospheric ozone have decreased the downward infrared emissions to the troposphere from the (now colder) lower stratosphere. This ozone depletion also has allowed for increased penetration of UV-B radiation, with harmful effects on human and animal health, plants, etc. Stratospheric ozone depletion has also altered tropospheric ozone concentrations, and, by allowing more ultraviolet sunlight into the troposphere, it has led to more rapid photochemical destruction of methane thereby reducing its radiative forcing.	• WGI TAR Sections 4.2.2 & 6.4
8.11	***Many of the halocarbons that cause depletion of the ozone layer are also important greenhouse gases.*** Chlorofluorocarbons (CFCs), for example, add a notable fraction to the total positive radiative forcing since the pre-industrial era. The negative radiative forcing from the associated stratospheric ozone depletion (noted above) reduces this by about half. The Montreal Protocol will eventually eliminate both of these radiative-forcing contributions. However, one class of substitutes for the now-banned CFCs is hydrofluorocarbons (HFCs), which are among the greenhouse gases listed under the Kyoto Protocol. Therefore consideration under the latter protocol could potentially conflict with the needs of the former, underscoring the value of communication.	• WGI TAR Sections 4.2.2 & 6.3.3
8.12	***Climate change will alter the temperature and wind patterns of the stratosphere, possibly enhancing chlorofluorocarbon depletion of stratospheric ozone over the next 50 years.*** Increases in greenhouse gases lead in general to a colder stratosphere, which alters stratospheric chemistry. Some studies predict that current rates of climate change will result in significant increases in the depletion of the Arctic stratospheric ozone layer over the next decade before chlorofluorocarbon concentrations have declined substantially. Although many climate/ozone-layer feedbacks have been identified, no quantitative consensus is reached in this assessment.	• WGI TAR Section 4.5.2
	<u>Biodiversity, Agriculture, and Forestry and Climate Change</u>	
8.13	***Terrestrial and marine ecosystems are closely linked to changes in climate and vice versa.*** Changes in climate and in atmospheric concentrations of carbon dioxide cause changes in the biodiversity and function of some ecosystems. In turn, ecosystem changes influence the land-atmosphere exchange of radiatively active gases (e.g., carbon dioxide, methane, and nitrous oxide) and of water and energy, and change surface albedo. Therefore, understanding these combined effects and feedbacks are a requisite for evaluating the future state of the atmosphere and the natural systems and their biodiversity.	• WGI TAR Section 4.5.3
8.14	***Natural climate variations have illustrated the impacts of climate change on natural and managed ecosystems.*** The examples of floods, droughts, and heat waves are etched into human history. Further, the warming events associated with El Niño illustrate that changes in climate patterns adversely impact fish, marine mammals, and coastal and ocean biodiversity. Coastal ecosystems—such as coral reefs, salt marshes, and mangrove forests—are affected by sea-level rise, warming ocean temperatures, and changes in storm frequency and intensity.	• WGII TAR Chapters 5 & 6

Table 8-1 gives main implications of climate change for natural ecosystems at the regional scale.

[Insert Table 8-1 here]

8.15 ***Climate change is but one of many stresses on managed and unmanaged ecosystems.*** Land-use change, resource demands, deposition of nutrients and pollutants, harvesting, grazing, habitat fragmentation and loss, and invasive species are major stressors on ecosystems. They can lead to species extinction, resulting in irreversible losses of biodiversity. Therefore, climate change constitutes an additional stress and could change or endanger ecosystems and the many services they provide. As a result, the impact of climate change will be influenced by management of natural resources, adaptation, and interaction with other pressures. Figure 8-2 exemplifies the manner in which climate change interacts with other factors in food supply and demand.

- WGII TAR Chapter 5
- WGIII TAR Chapter 4

[FIGURE 8-2 CAPTION: Linkages among food production and global environmental issues. Increasing food demand by an explosively growing world population calls for larger food production. This, in turn, brings a series of implications in the use of land, such as converting wildlands to croplands (extensification), using chemical fertilizers to increase yields (intensification), and using irrigation to increase yield or enabling cultivation in otherwise non-usable land. Expanding the land under cultivation results in loss of biodiversity, as ecosystems are converted to fields growing only a few species (usually exotics). Change of forests to agriculture brings a net loss of carbon to the atmosphere, as trees are replaced by grasses or crops. This clearing also increases flooding probability, as the agricultural systems retain less precipitation than forests. Intensification of crop production can involve a variety of chemical treatments, most of them being nitrogen fertilizers bringing the side effect of release of nitrogen gas compounds (some of which are strong greenhouse gases) to the atmosphere and nitrogen runoff into watersheds, with many environmental and health implications. The expansion of irrigation affects the supply of freshwater for other uses, leading to shortages and conflicts over water-use rights. Any strategy for meeting the need for increased agricultural production has the potential to increase global rates of biodiversity loss, climate change, and desertification.]

8.16 ***Climate change can influence the movement and survival of species in natural ecosystems.*** Populations of many species are already threatened with extinction and are expected to be placed at greater risk by the stresses of changing climate, rendering portions of current habitat unsuitable. Vegetation-distribution models since the SAR suggest that a mass ecosystem or biome movement is most unlikely to occur because of different climate tolerance of the species involved, different migration abilities, and the effects of invading species. Lastly, in a related sense, climate change can enhance the spreading of pests and diseases, thereby affecting both natural ecosystems, crops, and livestock.

- WGII TAR Section 5.2
- WGIII TAR Section 5.4

8.17 ***Carbon storage capacities of natural and managed ecosystems, particularly forests, influence impacts and feedbacks with climate change.*** For example, forests, agriculture, and other terrestrial ecosystems offer a significant, often temporary, carbon mitigation potential. This terrestrial sink has occurred along with the emissions into the atmosphere from land-use change. Terrestrial ecosystem degradation may be exacerbated by climate change, affect the storage of carbon, and may add to the stresses resulting from the current deforestation practices. It should be noted that, if the carbon-conserving practices are discontinued, carbon dioxide emissions in the future will be higher. For example, abandoning fire control in forest or reverting from direct seeding to intensive tillage in agriculture may result in rapid loss of part, at least, of the carbon accumulated during previous decades.

- WGIII TAR Chapter 4 ES
- SRLUCF SPM Paras 8 & 9

<u>Land Degradation and Desertification and Climate Change</u>

8.18 ***Projected levels of climate change would exacerbate the continuation of land degradation and desertification that has occurred over the past few centuries in many areas.*** Land-use conversion and the intensive use of land, particularly in the world's arid and semi-arid regions, has resulted in decreased soil fertility and increased land degradation and desertification. The changes have been large enough to be apparent from satellite images. Land degradation already affects more than 900 million people in 100 countries, most of them among the less-developed nations. The TAR projections using the SRES scenarios indicate increased droughts, higher intensity of rainfall, more irregular rainfall patterns, and more frequent tropical summer drought in the mid-latitude continental interiors. The systems that likely would be impacted include those with scarce water resources, rangelands, and land subsidence (see Table 8-2). Because land degradation already affects one-quarter of the world soil resources, the annual recorded losses of millions of hectares would significantly undermine economies and create some irreversible situations.

- WGI TAR Section 2.7.3.3
- WGII TAR Table SPM-1 & Sections 3.2.3 & 5.5

[Insert Table 8-2]

<u>Freshwater and Climate Change</u>

8.19 ***All three classes of freshwater problems—having too little, too much, and too dirty water—may be exacerbated by climate change.*** Freshwater is essential for human health, food production, and sanitation, as well as for manufacturing and other industrial uses and sustaining ecosystems. There are several indicators of water resources stress. When withdrawals are greater than 20% of the total renewable resources, water stress often is a limiting factor on development. Withdrawals of 40% or more represent high stress. Similarly, water stress may be a problem if a country or region has less than 1700 m^3 yr^{-1} of water per capita. In 1990 approximately one-third of the world's population lived in countries using more than 20% of their water resources, and by 2025 about 60% of a larger total would be living in such a stressed country, only because of population growth. Higher temperatures could increase such stress conditions. However, adaptation through appropriate water management practices can reduce the adverse impacts. While climate change is just one of the stresses on water resources in this increasingly populated world, it is clear that it is an important one (see Table 8-2). The TAR projections using the SRES scenarios of future climate indicate a tendency for increased flood and drought risks for many areas under most scenarios. Decreases of water availability in parts of a warmer world are projected in areas like southern Africa and countries around the Mediterranean. Because of sea-level rise, many coastal systems will experience saltwater intrusion into fresh groundwater and encroachment of tidal water into estuaries and river systems, with consequential effects on freshwater availability.

- WGII TAR Sections 4.1 & 4.5.2

8.20 ***Water managers in some countries are beginning to consider climate change explicitly, although methodologies for doing so are not yet well defined.*** By its nature, water management is based around minimization of risks and adaptation to changing circumstances, now also changing climate. There has been a gradual shift from "supply-side" approaches (i.e., providing water to satisfy demands by increased capacity reservoirs or structural flood defenses) towards "demand-side" approaches (i.e., trimming demands adequately to match water availability, using water more efficiently, and non-structural means of preparedness to floods and droughts).

- WGII TAR Section 4.2.4

8.21 **Interactions between climate change and other environmental problems offer opportunities to capture synergies in developing response options, enhancing benefits, and reducing costs (see Figure 1-1).**

8.22 ***By capturing synergies, some greenhouse gas mitigation actions may yield extensive ancillary benefits for several other environmental problems, but also trade-offs may occur.*** Examples include, *inter alia*, reduction of negative environmental impacts such as urban air pollution and acid deposition; protecting forests, soils, and watersheds; reducing distortionary subsidies and taxes, and inducing more efficient technological change and diffusion, contributing to wider goals of sustainable development. However, dependent on the way climate change or other environmental problems are addressed, and the degree to which inter-linking issues are taken into account, significant trade-offs may occur and unanticipated costs may be incurred. For example, policy options to reduce greenhouse gas emissions from the energy and land-use sectors can have both positive and negative effects on other environmental problems:

- In the energy sector, reducing greenhouse gas emissions by moving to energy-efficient and low- or zero-carbon technologies can also reduce urban pollution. Increased use of biomass as a substitute for fossil fuel could have positive or negative impacts on soils, biodiversity, and water availability depending on the land use it replaces and the management regime.
- In the land-use sector, conservation of biological carbon pools not only prevents carbon from being emitted into the atmosphere, it also can have a favorable effect on soil productivity, prevent biodiversity loss, and reduce air pollution problems from biomass burning. Carbon sequestration by plantation forestry can enhance carbon sinks and protect soils and watersheds, but—if developed improperly—may have negative effects on biodiversity and water availibility.

- WGIII TAR Sections 3.6.4, 4.4.2, 8.2.4, & 9.2.5

8.23 ***Conversely, addressing environmental problems other than climate change can have ancillary climate benefits, but the linkages between the various problems may also lead to trade-offs.*** Examples include:

- There are likely to be substantial greenhouse gas benefits from policies aimed at reducing air pollution. For example, increasing pollution is often associated with the rapidly growing transportation sector in all regions, involving emissions of particulate matter and precursors of ozone pollution. Addressing these emissions to reduce the impacts on human health, agriculture, and forestry through increasing energy efficiency or penetration of non-fossil-fuel energy can also reduce greenhouse gas emissions.
- Controlling sulfur emissions has positive impacts on human health and vegetation, but sulfate aerosols partly offset the warming effect of greenhouse gases and therefore control of sulfur emissions can amplify possible climate change. If sulfur emissions are controlled through desulfurization of flue gases at power plants, an energy penalty results, with associated increase of greenhouse gas emissions.

- WGIII TAR Sections 2.4 & 9.2.8
- SRES

8.24 ***Adopting state-of-the-art environmentally sound technologies and practices offer particular opportunities for environmentally sound development while avoiding greenhouse gas-intensive activities.*** For example, the application of supply- and demand-side energy-efficient technologies simultaneously reduces various energy-related environmental impacts and can lower the pressure on energy investments, reduce public investments, improve export competitiveness, and enlarge energy reserves. The adoption of more sustainable agricultural practices (e.g., in Africa) illustrates the mutually reinforcing effects of climate change mitigation, environmental protection, and long-term economic benefits. The introduction or expansion of agroforestry and low-fertilizer agriculture can improve food security and at the same time reduce greenhouse gas emissions. More decentralized development patterns based on a stronger role for small- and medium-sized cities can decrease the rural exodus, reduce needs for transportation, and allow the use of modern technologies (bio-fuel, solar energy, wind, and small-scale hydropower) to tap the large reserves of natural resources.

- WGII TAR Section 7.5.4
- WGIII TAR Section 10.3.2

8.25 ***Reducing vulnerability to climate change can often reduce vulnerability to other environmental stresses and vice versa.*** Examples include, *inter alia*: • *Protecting threatened ecosystems*. Removing societal stresses and managing resources in a sustainable manner may help unique and threatened systems also to cope with the additional stress posed by climate change. Accounting for potential climatic changes and integration with socio-economic needs and development plans can make biodiversity conservation strategies and climate change adaptation measures more effective. • *Land-use management*. Addressing or avoiding land degradation also decreases vulnerability to climate change, especially when response strategies consider the social and economic factors defining the land use practices together with the additional risks imposed by climate change. In regions where deforestation is progressing and leading to carbon loss and increased peak runoff, restoring vegetation by reforestation (and when possible by afforestation) and revegetation can help to combat desertification. • *Freshwater management*. Problems with availability, abundance, and pollution of freshwater, which are often caused by demographic and development pressures, can be exacerbated by climate change. Reducing vulnerability to water stress (e.g., by water conservation, water-demand management, and more efficient water use) also reduces vulnerability to additional stress by climate change.	• WGII TAR Sections 4.1, 4.2, & 7.5.4
8.26 ***Approaches that exploit synergies between environmental policies and key national socio-economic objectives like growth and equity could help mitigate and reduce vulnerability to climate change, as well as promote sustainable development.*** Sustainable development is closely linked with the environmental, social, and economic components defining the status of each community. The interconnections among the elements of sustainable development are reflected in Figure 8-3, illustrating that important issues such as climate change, sustainability, poverty, and equity can be related to all three components. Just as climate policies can yield ancillary benefits that improve well-being, non-climate socio-economic policies may bring climate benefits. Utilizing such ancillary benefits would aid in making development more sustainable. Complex interactions among environmental, social, and economic challenges exist, and therefore none of these three types of problems can be resolved in isolation. [FIGURE 8-3 CAPTION: Key elements of sustainable development and interconnections. The vertices of the triangle represent the three major dimensions or domains of sustainable development: economic, social, and environmental. The economic domain is geared mainly towards improving human welfare, primarily through increases in the consumption of goods and services. The environmental domain focuses on protection of the integrity and resilience of ecological systems. The social domain emphasizes the strengthening of human relationships and achievement of individual and group aspirations. Examples of linkages between the three domains are shown along the sides of the triangle. Important issues such as climate change, poverty, equity, and sustainability lie within the triangle and interact with all three domains.]	• WGIII TAR Sections 1.3.4, 2.2.3, & 10.3.2 • DES Guidance Paper
8.27 ***Countries with limited economic resources, low levels of technology, poor information systems, inadequate infrastructure, unstable and weak institutions, and inequitable empowerment and access to resources are not only highly vulnerable to climate change but also to other environmental problems, and at the same time have little capacity to adapt to these changing circumstances and/or mitigate them.*** The capacity of these countries to adapt and mitigate can be enhanced when climate policies are integrated with non-climate objectives of national policy development and turned into broad transition strategies to achieve the long-term social and technological changes required by both sustainable development and climate change mitigation.	• WGII TAR Chapter 18 • WGIII TAR SPM Para19 & Sections

		2.2.3, 2.4.4, 2.4.5, 2.5.1, 10.3.2, & 10.3.4
8.28	***A great deal of interaction exists among the environmental issues that Multilateral Environmental Agreements address, and synergies can be exploited in their implementation.*** Global environmental problems are addressed in a range of individual conventions and instruments—the Vienna Convention and its Montreal Protocol, the UNFCCC and the Kyoto Protocol, the United Nations Convention on Biological Diversity (CBD), the United Nations Convention to Combat Desertification (UNCCD), and the Forestry principles—as well as a range of regional agreements, such as the Convention on Long-Range Transboundary Air Pollution (LRTAP). Table 8-3 provides a list of such conventions and instruments. They contain similar requirements concerning common shared or coordinated governmental and civil institutions to enact the general objectives; formulation of strategies and action plans as a framework for country level-implementation; collection of data and processing information and new and strengthened capacities for both human resources and institutional structures; and reporting obligations. They also specify the level at which scientific assessment synergies can be exploited (see Box 8-1). [Insert Table 8-3 here]	• WGIII TAR Section 10.3.2
Box 8-1	**Assessing climate change and stratospheric ozone depletion.** The Ozone Scientific Assessment Panel of the Montreal Protocol and the IPCC have had integrated assessment activities regarding the state of understanding of the coupling of the stratospheric ozone layer and the climate system. For the past several years, the Scientific Assessments of Ozone Depletion have included the climate relevance of ozone-depleting gases. Further these assessments have included how current and future climate change and greenhouse gas abundances can influence ozone layer recovery. The IPCC has assessed the climate-cooling tendency due to ozone layer depletion. In addition, joint activities have been undertaken such as the assessment of the climate and ozone-layer impacts of aviation and how the mitigative needs of the Montreal Protocol for substitutes for ozone-depleting gases (notably HFCs) could be impacted by potential decisions about the global warming properties of these gases. These assessments provide information on how decisions and actions regarding one issue would influence the other, and they foster effective dialog between the policy frameworks.	• WGI TAR Sections 4.2, 5.5, 6.13, & 7.2 • WGIII TAR Chapter 3 App. • SRAGA Section 4.2

Table 8-1: *Examples for observed and projected regional implications of climate change on natural ecosystems, biodiversity, and food supply.*

Region	**Impacts**	**Reference Section in WGII TAR**
Africa	• Irreversible losses of biodiversity could be accelerated with climate change. • Significant extinctions of plant and animal species are projected and would impact rural livelihoods, tourism, and genetic resources (medium confidence).	TS 5.1.3 & Section 10.2.3.2
Asia	• Climate change would exacerbate threats on biodiversity that are currently due to land-use/cover and population pressure. • Decreases in agricultural productivity and aquaculture due to thermal and water stress, sea-level rise, floods and droughts, and tropical cyclones would diminish in many countries of arid, tropical, and temperate Asia; agriculture would expand and increase in productivity in northern areas (medium confidence). • Climate change would exacerbate threat to biodiversity due to land-use and land-cover change and population pressure (medium confidence). Sea-level rise would put ecological security at risk including mangroves and coral reefs (high confidence),	TS 5.2.2 & 5.2.6, & Section 11.2.1
Australia New Zealand	• A warming of 1ºC would threaten the survival of species currently near the upper limit of their temperature range, notably in marginal alpine regions. • Some species with restricted climatic niches and that are unable to migrate due to fragmentation of the landscape soil differences or topography could become endangered or extinct (high confidence). Australian ecosystems that are particularly vulnerable to climate change include coral reefs, arid and semi-arid habitats in southwest and inland Australia, and Australian alpine systems. Freshwater wetlands in coastal zones in both Australia and New Zealand are vulnerable, and some New Zealand ecosystems are vulnerable to accelerated invasion by weeds.	TS 5.3.2 & Sections 12.4.2, 12.4.4, 12.4.5, & 12.4.7
Europe	• Natural ecosystems will change due to increasing temperature and atmospheric concentration of CO_2. Diversity in nature reserves is under threat of rapid change. Loss of important habitats (wetlands, tundra, and isolated habitats) would threaten some species, including rare/endemic species and migratory birds. • There will be some broadly positive effects on agriculture in northern Europe (medium confidence); productivity will decrease in southern and eastern Europe.	TS 5.4.2 & 5.4.3, & Sections 13.2.1.4, 13.2.2.1, & 13.2.2.3-5

Table 8-1 (continued)

Region	Impacts	Reference Section in WGII TAR
Latin America	• It is well-established that Latin America accounts for one of the Earth's largest concentration of biodiversity and the impacts of climate change can be expected to increase the risk of biodiversity loss (high confidence). • Yields of important crops are projected to decrease in many locations even when the effects of CO_2 are taken into account; subsistence farming in some regions could be threatened (high confidence).	TS 5.5.2 & 5.5.4, & Section 14.2.1
North America	• There is a strong evidence that climate change can lead to the loss of specific ecosystem types [e.g., high alpine areas and specific coastal (salt marshes and inland prairie "potholes") wetlands] (high confidence). • Some crops would benefit from modest warming accompanied by increasing CO_2, but effect would vary among crops and regions (high confidence), including declines due to drought in some areas of Canada's Prairies and the U.S. Great Plains, potential increased food production in areas of Canada north of current production areas, and increased warm temperate mixed forest production (medium confidence). However, benefits for crops would decline at an increasing rate and possibly become a net loss with further warming (medium confidence). • Unique natural ecosystems such as prairie wetlands, alpine tundra, and coldwater ecosystems will be at risk and effective adaptation is unlikely (medium confidence).	TS 5.6.5 & 5.6.4, & Section 15.2.2
Arctic	• The Arctic is extremely vulnerable to climate change, and major physical, ecological, and economic impacts are expected to appear rapidly.	TS 5.7 & Sections 16.2.5.3, 16.2.7.1, & 16.2.8.1
Antarctic	• In the Antarctic projected climate change will generate impacts that will be realized slowly (high confidence). • Warmer temperatures and reduced ice extent are likely to produce long-term changes in the physical oceanography and ecology of the Southern Ocean, with intensified biological activity and increase growth rate of fish.	TS 5.7 & Sections 16.2.3 & 16.2.4.2
Small Islands	• Projected future climate change and sea-level rise will affect shifts in species composition and competition. It is estimated that one out of every three (30%) known threatened plants are islands endemics, while 23% of bird species are threatened. Coral reefs, mangroves, and sea grass beds that often rely on stable environmental conditions will be adversely by rising air and sea temperatures and sea-level rise (medium confidence). • Declines in coastal ecosystem would negatively impact reef fish and threaten reef fisheries (medium confidence).	TS 5.8 & Sections 17.2.4 & 17.2.5

Table 8-2: *Examples of regional impacts of climate change on water resources, land degradation, and desertification.*

Region	**Projections**	**Reference Section in WGII TAR**
Africa	• Changes in rainfall and intensified land use would exacerbate the desertification processes. Desertification would be exacerbated by reduction in the average annual rainfall, runoff, and soil moisture in countries of West African Sahel, and northern and southern Africa (medium confidence). Increases in droughts and other extreme events would add to stresses on water resources, food security, and human health, and would constrain development in the region (high confidence).	TS 5.1.6, SPM Table-2, Chapter 10 ES
Asia	• Water shortage—already a limiting factor for ecosystems, food and fiber production, human settlements, and human health—may be exacerbated by climate change. Runoff and water availability may decrease in arid and semi-arid Asia but increase in northern Asia (medium confidence). Reduced soil moisture in summer would exacerbate land degradation and desertification in arid and semi-arid regions.	TS 5.2.3 & Sections 11.1.1 & 11.3.2
Australia New Zealand	• Interannual variability due to ENSO leads to major floods and droughts in Australia and New Zealand. Such variations are expected to continue under enhanced greenhouse gas conditions, but possibly with greater hydrological extremes. • Water is likely to be a key issue due to projected drying trends over much of the region and change to a more El Niño-like event state. Water quality would be affected, and more intense rainfall events would increase fast runoff, soil erosion, and sediment loading. Eutrophication is a major water quality problem in Australia.	TS 5.3 & 5.3.5, & Sections 12.1.5.3 & 12.3.4
Europe	• Summer runoff, water availability, and soil moisture are likely to decrease in southern Europe, and would widen the gap between the north and south. Flood hazards will increase across much of Europe (high confidence); risk would be substantial for coastal areas where flooding will increase erosion and result in loss of wetlands. • Half of alpine glaciers and large permafrost areas could disappear by the end of the 21st century (medium confidence).	TS 5.4.1 & Chapter 13 ES
Latin America	• Some studies based on model experiments suggest that under climate change the hydrological cycle would be more intense, with changes in the distribution of extreme rainfall, wet spells, and dry spells. Frequent severe drought in Mexico during the last decade coincides with some of these model findings. El Niño is related to dry conditions in northeastern Brazil, northern Amazons, and the Peruvian-Bolivian altiplano. Southern Brazil and northwestern Peru exhibit anomalous wet conditions during these periods. • Loss and retreat of glaciers would adversely impact runoff and water supply in areas where snowmelt is an important water resource (high confidence).	TS 5.5.1 & Chapter 14 ES
North America	• Snowmelt-dominated watersheds in western North America will experience earlier spring peak flows (high confidence) and possible reduction in summer flow (high confidence); adaptive responses may offset some, but not all, of the impacts on water resources and aquatic ecosystems (medium confidence).	SPM Table-2 & TS 5.6.2
Small Islands	• Islands with very limited water supplies are highly vulnerable to the impacts of climate change on the water balance (high confidence).	SPM Table-2 & TS 5.8.4

Table 8-3: *Selected international environmental treaties.*

Convention on Fishing and Conservation of the Living Resources of the High Seas	Geneva, 1958
The Antarctic Treaty − Protocol to the Antarctic Treaty on Environmental Protection	Washington, 1959 Madrid, 1991
Convention on Wetlands of International Importance especially as Waterfowl Habitat − Protocol to Amend the Convention on Wetlands of International Importance Especially as Waterfowl Habitat	Ramsar, 1971 Paris, 1982
International Convention for the Prevention of Pollution from Ships	London, 1973
Convention on International Trade on Endangered Species of Wild Fauna and Flora	Washington, 1973
Convention on the Prevention of Marine Pollution from Land-based Sources	June 1974
Convention on the Conservation of Migratory Species of Wild Animals	Bonn, 1979
UN/ECE Convention on Long-Range Transboundary Air Pollution − Protocol on Long-Term Financing of Cooperative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP) − Protocol on the Reduction of Sulfur Emissions or their Transboundary Fluxes by at least 30% − Protocol Concerning the Control of Emissions of Nitrogen or their Transboundary Fluxes − Protocol Concerning the Control of Emissions of Volatile Organic Compounds or their Transboundary Fluxes − Protocol on Further Reduction of Sulfur Emission − Protocol on Heavy Metals − Protocol on Persistent Organic Pollutants − Protocol to Abate Acidification, Eutrophication, and Ground-level Ozone	Geneva, 1979 Geneva, 1984 Helsinki, 1985 Sofia, 1988 Geneva, 1991 Oslo, 1994 Aarhus, 1998 Aarhus, 1998 Gothenburg, 1999
United Nation Convention on the Law of the Sea	Montego Bay, 1982
Vienna Convention for the Protection of the Ozone Layer − Montreal Protocol on Substances that Deplete the Ozone Layer	Vienna, 1985 Montreal, 1987
Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal − Amendment to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal	Basel, 1989 Geneva, 1995
UN/ECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes	Helsinki, 1992
United Nation Framework Convention on Climate Change − Kyoto Protocol to the United Nation Framework Convention on Climate Change	New York, 1992 Kyoto, 1997
Convention on Biological Diversity − Cartagena Protocol on Biosafety to the Convention on Biological Diversity	Rio de Janeiro, 1992 Montreal, 2000
United Nations Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification. Particularly in Africa	Paris, 1994
Stockholm Convention on Persistent Organic Pollutants	Stockholm, 2001
United Nations Forum on Forests[a]	New York, 2001

[a] This reference is included in view of the importance of international efforts towards a treaty on the issue of forests and their environmental value.

FIGURE 8-1

SEE PAGE 94 LINES 13–27 FOR FIGURE CAPTION

Color version can be downloaded at <http://www.metoffice.com/sec5/CR_div/ipcc/wg1/drafts/>
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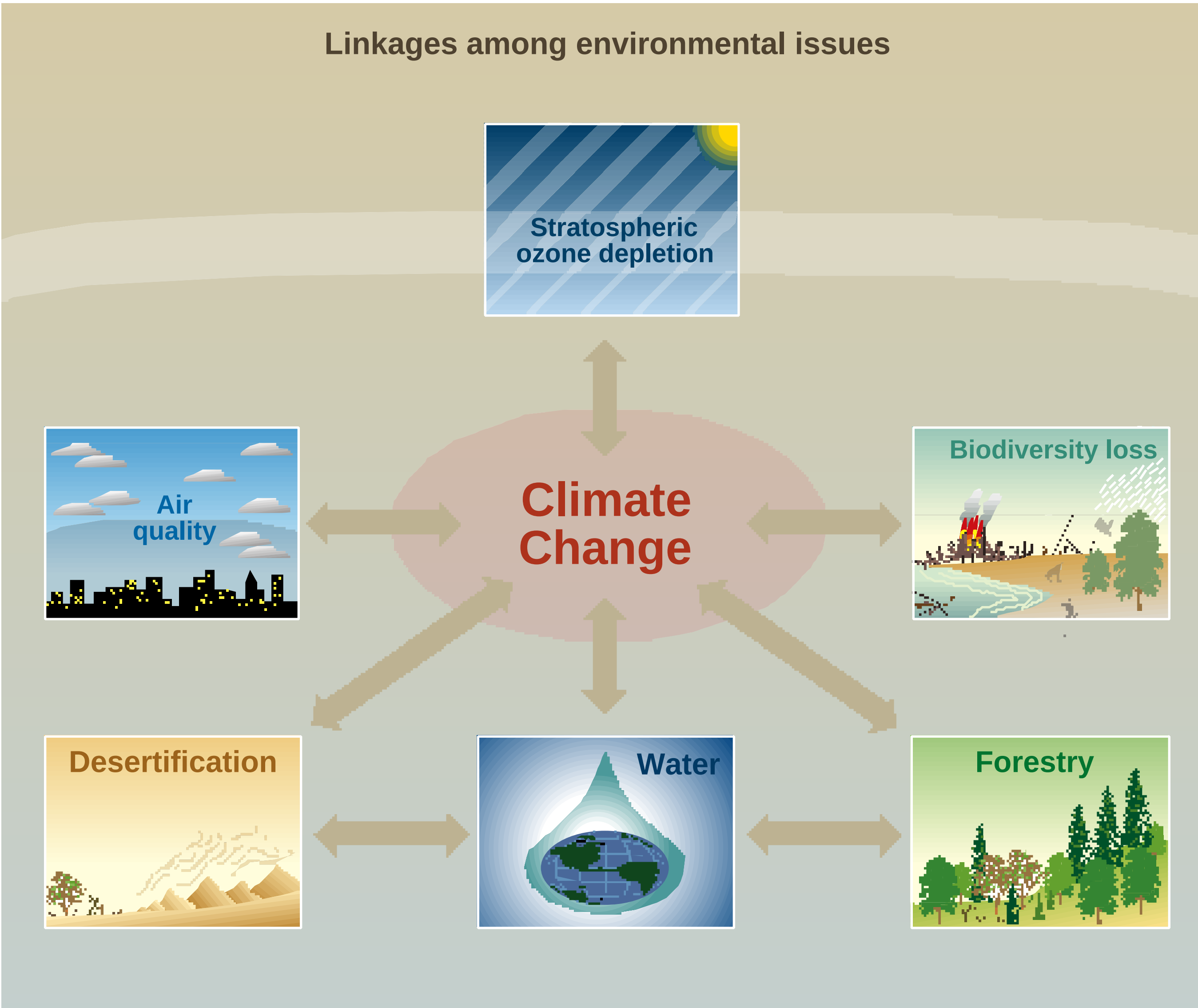

FIGURE 8-2

SEE PAGE 96 LINES 16–32 FOR FIGURE CAPTION

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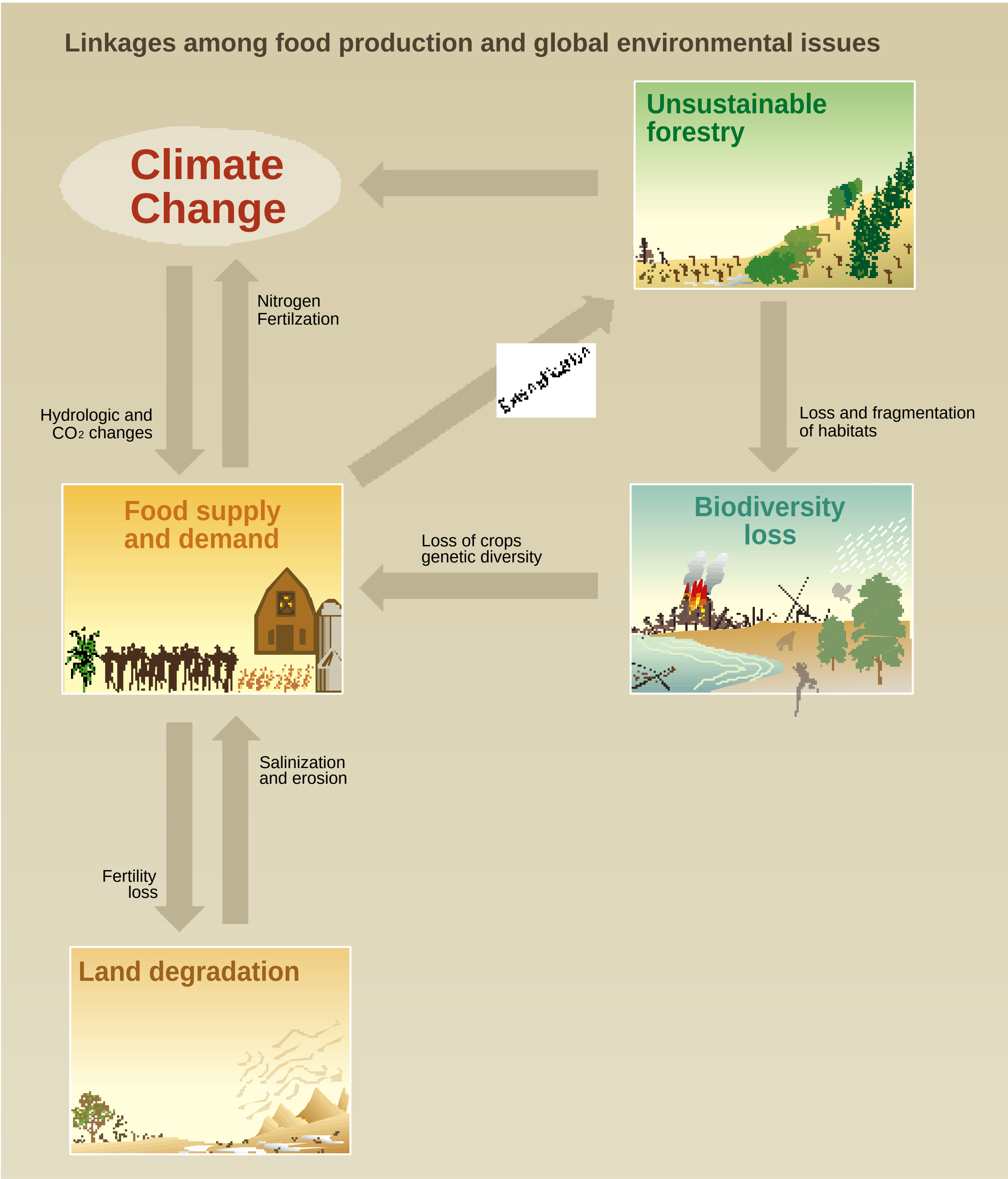

FIGURE 8-3

SEE PAGE 99 LINES 33–42 FOR FIGURE CAPTION

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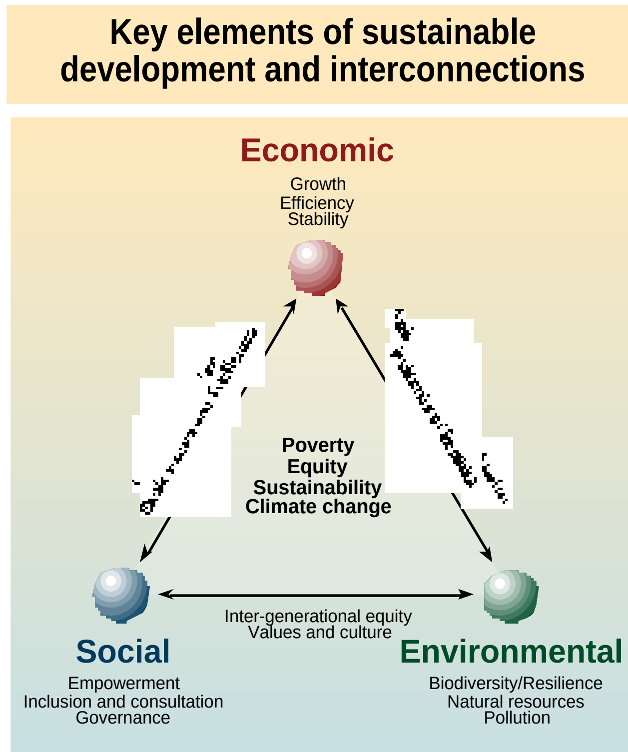

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QUESTION 9

What are the most robust findings and key uncertainties regarding attribution of climate change and regarding model projections of:

- **Future emissions of greenhouse gases and aerosols?**
- **Future concentrations of greenhouse gases and aerosols?**
- **Future changes in regional and global climate?**
- **Regional and global impacts of climate change?**
- **Costs and benefits of mitigation and adaptation options?**

Paragraph Number		*Reference*
	<u>Introduction</u>	
9.1	***The understanding of climate change, its impacts, and the options to mitigate and adapt is developed through multi- and interdisciplinary research and monitoring in an integrated assessment framework.*** As understanding deepens, some findings become more robust and some uncertainties emerge as critical for informed policy formulation. Some uncertainties arise from a lack of data and a lack of understanding of key processes and from disagreement about what is known or even knowable. Other uncertainties are associated with predicting social and personal behavior in response to information and events. The uncertainties tend to escalate with the complexity of the problem, as additional elements are introduced to include a more comprehensive range of physical, technical, social, and political impacts and policy responses. The climate responds to human influence without deliberation or choice; but human society can respond to climate change deliberately, making choices between different options. An objective of the TAR and other IPCC reports is to explore, assess, quantify, and, if possible, reduce these uncertainties.	• Q1.7
9.2	***A robust finding for climate change is defined as one that holds under a variety of approaches, methods, models, and assumptions and one that is expected to be relatively insensitive to uncertainties***. A robust finding can be expected to fall into the categories of “well-established” and “established-but-incomplete” in the literature. Robustness is different from likelihood: A finding that an outcome is “exceptionally unlikely” may be just as robust as the finding that it is “virtually certain.” A major development in the TAR is that of the multiple alternative pathways for emissions and concentrations of greenhouse gases as represented by the SRES. Robust findings are those that are maintained under a wide range of these possible worlds.	
9.3	***Key uncertainties in this context are those which, if reduced, may lead to new and policy-relevant robust findings.*** These findings may, in turn, lead to better or more of the information that underpins policymaking. The uncertainties can never be fully resolved, but often they can be bounded by more evidence and understanding, particularly in the search for consistent outcomes or robust conclusions.	
9.4	**Robust findings and key uncertainties can be brought together in the context of an integrated assessment framework.**	
9.5	***The integrated assessment framework described in this report is used to bring together the robust findings and key uncertainties in the model projections.*** Such a framework can encompass all the disciplines involved in understanding the climate, the biosphere, and human society. It emphasizes the linkages between the systems described in the different	• Q1.7

Working Group reports of the TAR as well as considers linkages between climate change and other environmental issues, and helps to identify gaps in knowledge. It suggests how key uncertainties can affect the whole picture. Figure 9-1 elaborates upon Figure 1-1, and shows how adaptation and mitigation can be integrated into the assessment.

[FIGURE 9-1 CAPTION: This illustration shows how adaptation and mitigation can be included in Figure 1-1 in a schematic representation for considering anthropogenic climate change, but without any feedbacks (which are described in the caption to Figure 1-1).

To illustrate ***adaptation*** to climate change, take the inevitable rise in sea levels over the next 100 years. The human and natural systems will have to adapt to the rise, and development will be affected. The adaptation will be both autonomous, such as households protecting their homes from local flooding, and via government initiatives, such as more flood defenses in areas threatened by higher sea levels. These adaptation actions will reduce (but cannot entirely avoid) some of the impacts of climate change on these systems and on development, shown by the narrower arrows compared to those of Figure 1-1. The actions provide additional benefits but also entail costs. Net climate change costs are total adaptation benefits less adaptation costs, plus the costs of the unavoided impacts.

Mitigation of greenhouse gas emissions is unlike adaptation in that it reduces emissions at the start of the cycle (hence the narrower arrows compared to those in Figure 1-1). It reduces concentrations and climate change. It further reduces the need for adaptation (not shown), the impacts of climate change, and the effects on socio-economic development. It is also different in that mitigation is a global problem with local implications, but requiring global action, whereas adaptation is mainly a local problem. The primary benefit of mitigation is avoided climate change, but it also has costs (e.g., higher energy prices). In addition, mitigation gives rise to ancillary benefits (e.g., reduced air pollution leading to improvements in human health, or more rural employment in biomass projects).

A fully integrated approach to climate change assessment would consider the whole cycle dynamically with all the feedbacks but this could not be accomplished in the TAR.]

9.6 Many of the ***robust findings*** as listed below are concerned with the existence of a climate response to human activities and the sign of the response. Many of the ***key uncertainties*** are concerned with the quantification of the magnitude and/or the timing of the response and the potential effects of improving methods and relaxing assumptions.

<u>Attribution of Climate Change</u>

9.7 **There is now stronger evidence for a human influence of the global climate.**

9.8 ***An increasing body of observations gives a collective picture of a warming world and modeling studies indicate that most of the observed warming at the Earth's surface over the last 50 years is likely to have been due to human activities.*** Globally, the 1990s were very likely to have been the warmest decade in the instrumental record (i.e., since 1861). For the Northern Hemisphere, the magnitude of the warming in the last 100 years is likely to be the largest of any century during the past 1000 years. Observations, together with model simulations, provide stronger evidence that most of the warming observed over the last 50 years is attributable to the increase in greenhouse gas concentrations. The observations also provide increased confidence in the ability of models to project future climate change. Better quantification of the human influence depends on reducing the ***key uncertainties*** relating to the magnitude and character of natural variability, cloud feedbacks, and the magnitude of climate forcings due to anthropogenic aerosols (particularly indirect effects) and natural effects.

- Q2.7, & 2.10-11

Future Emissions and Concentrations of Greenhouse Gases and Aerosols

9.9 **Human activities increase the atmospheric concentrations of greenhouse gases.**

9.10 ***Since 1750 (i.e., the beginning of the Industrial Revolution), the atmospheric concentration of CO_2 (the largest contributor to anthropogenic radiative forcing) has increased by 31% due to human activities, and all SRES scenarios project substantial increases in the future (see Figure 9-2).*** Other greenhouse gases have also increased in concentrations since 1750 (e.g., CH_4 by 150%, N_2O by 17%). The present CO_2 concentration has not been exceeded during the past 420,000 years (the span measurable in ice cores) and likely not during the past 20 million years. The rate of increase is unprecedented relative to any sustained global changes over at least the last 20,000 years. In projections of greenhouse gas concentrations based on the set of SRES scenarios (for details see Box 3-1), CO_2 concentrations continue to grow to 2100. All SRES scenarios show reductions in SO_2 emissions (precursor for sulfate aerosols) by 2100 compared with 2000. ***Key uncertainties*** are inherent in the assumptions that underlie the wide range of future emissions in the SRES scenarios and therefore the quantification of future concentrations. These uncertainties relate to population growth, technological progress, economic growth, and governance structures, which are particularly difficult to quantify. Further, inadequate emission scenarios have been available of ozone and aerosol precursors. Smaller uncertainties arise from lack of understanding of all the factors inherent in modeling the carbon cycle. Accounting for all these uncertainties leads to a range of CO_2 concentrations in 2100 between about 490 and 1260 ppm (compared to the pre-industrial concentration of about 280 ppm and about 368 ppm in 2000). • Q2.4 & 3.3

[FIGURE 9-2 CAPTION: Observations of atmospheric CO_2 concentration from 1000 to 2000 from ice core and firn data supplemented with data from direct atmospheric samples over the past few decades. From 2000 to 2100 are shown projections of CO_2 concentrations based on the six illustrative SRES scenarios and IS92a (for comparison with the SAR).] • WGI TAR SPM Figures 2a & 5b

9.11 ***Fossil fuel CO_2 emissions are virtually certain to remain the dominant influence on the trends in CO_2 concentrations over the 21st century.*** This is implied by the range of SRES scenarios in which projected fossil-fuel emissions exceed the foreseeable biospheric sources and sinks for CO_2. It is estimated that, even if all the carbon so far released by land-use changes could be restored to the terrestrial biosphere (e.g., by reforestation), CO_2 concentration would be reduced by only 40 to 70 ppm. There are key uncertainties in the influence of changing land use and biospheric feedbacks on the uptake, storage, and release of carbon that in turn could influence CO_2 concentrations. • Q3.4 & 4.11-12

Future Changes in Regional and Global Climate

9.12 **The climate has changed during the 20th century; larger changes are projected for the 21st century.**

9.13 ***Under all SRES scenarios, projections show the global average surface temperature continuing to rise during the 21st century at rates of rise that are very likely to be without precedent during the last 10,000 years, based on paleoclimate data (see Figure 9-3).*** It is likely that nearly all land areas will warm more rapidly than the global average, particularly those at high northern latitudes in the cold season. There are very likely to be more hot days, fewer frost days and a reduced diurnal temperature range. • Q3.7, 3.12, & 4.4

[FIGURE 9-3 CAPTION: From 1000–1860, observations of variations in average surface temperature of the Northern Hemisphere (adequate data from the Southern Hemisphere not • WGI TAR available) constructed from proxy data (tree rings, corals, ice cores, and historical records). The line shows the 50-yr average, the grey region the 95% confidence limit in the annual data. From 1860–2000 are shown variations in observations of global and annual averaged surface temperature from the instrumental record; the line shows the decadal average. From 2000–2100 are shown projections of globally averaged surface temperature for the six illustrative SRES scenarios and IS92a as estimated by a model with average climate sensitivity. The grey region "several models all SRES envelope" shows the range of results from the full range of 35 SRES scenarios in addition to those from a range of models with different climate sensitivities.] SPM Figures 1b & 5d

9.14 ***In a warmer world the hydrological cycle will become more intense.*** Global average precipitation is projected to increase. More intense precipitation events (hence flooding) are very likely over many areas. Increased summer drying and associated risk of drought is likely over most mid-latitude continental interiors. Even with little or no change in El Niño amplitude, global warming is likely to lead to greater extremes of drying and heavy rainfall, and increase the risk of droughts and floods that occur with El Niño events in many different regions.

- Q3.9, 3.13, & 4.5-6

9.15 ***In a warmer world the sea-level will rise, primarily due to thermal expansion and loss of mass from glaciers and ice caps, the rise being continued for hundreds of years even after stabilization of greenhouse gas concentrations***. This is due to the long time scales on which the deep ocean adjusts to climate change. Ice sheets will continue to react to climate change for thousands of years. Models project that a local warming (annually averaged) of larger than 3ºC, sustained for many millennia, would lead to virtually a complete melting of the Greenland ice sheet with a resulting sea-level rise of about 7 m.

- Q3.10, 3.15, 4.15, & 5.3

9.16 ***Key uncertainties*** that influence the quantification and the detail of future projections of climate change are those associated with the SRES scenarios and also those associated with the modeling of climate change, in particular those that concern the understanding of key feedback processes in the climate system, especially those involving clouds and aerosols (including their indirect forcing). Allowing for these uncertainties leads to a range of projections of surface temperature increase 1990–2100 of 1.4 to 5.8ºC (see Figure 9-2) and of sea-level rise from 0.09 to 0.88 m. The range of values in the global averaged temperature projections includes some allowances for these uncertainties. ***Key uncertainties*** also affect the detail of regional climate change and its impacts because of the limited capabilities of the regional models and the global models driving them and inconsistencies in results between different models especially in some areas and in precipitation.

- Q3.7 & 3.10

Regional and Global Impacts of Climate Change

9.17 **Climate change leads to global and regional impacts that are more negative than positive.**

- Q3.16-17 & Box 3-2

9.18 ***Regional changes in climate, particularly increases in temperature, have already affected and will continue to affect a diverse set of physical and biological systems in many parts of the world.*** Examples of observed changes include shrinkage of glaciers, reductions in seasonal snow cover, thawing of permafrost, later freezing and earlier break-up of ice on rivers and lakes, loss of Arctic sea ice, lengthening of mid- to high-latitude growing seasons, poleward and altitudinal shifts of plant and animal ranges, changes in the seasonal progression of some plants and animals, declines in some plant and animal populations, and damage to coral reefs. These observed rates of change would be expected to increase in the future represented by any of the SRES scenarios, for which the warming trends for the 21st century are two to ten times those observed for the 20th century.

- Q3.15 & 3.19-21

9.19 ***Diversity in ecological systems is expected to be reduced by climate change and sea-level rise, with an increased risk of extinction of some vulnerable species.*** Natural systems at risk include glaciers, coral reefs and atolls, mangroves, boreal and tropical forests, polar and alpine ecosystems, prairie wetlands, and remnant native grasslands. While some species may increase in abundance or range, climate change will increase existing risks of extinction of some more vulnerable species and loss of biodiversity. It is *well-established* that the geographical extent of the damage or loss, and the number of systems affected, will increase with the magnitude and rate of climate change.

- Q3.19

9.20 ***Projected changes in climate extremes could have major consequences especially on water and food security and on health.*** The vulnerability of human societies and natural systems to climate extremes is demonstrated by the damage, hardship, and death caused by events such as droughts, floods, heat waves, avalanches, landslides, and windstorms, which have shown an increasing trend during recent decades. The impact of such events falls disproportionately on developing countries and on the poor. While there are uncertainties attached to estimates of such changes, some extreme events are projected to increase in frequency and/or severity during the 21st century due to changes in the mean and/or variability of climate. These increases combined with increased water stress (occurring already because of increasing demand) will impact food security and health especially in many developing countries. Conversely, the frequency and magnitude of extreme low temperature events, such as cold spells, is projected to decrease in the future, with both positive and negative impacts.

- Q3.18 & 3.22-23

9.21 ***Populations that inhabit small islands and low-lying coasts are at particular risk of severe social and economic effects.*** Tens of millions of people living in deltas, low-lying coastal areas, and on small islands will face risk of displacement by sea-level rise. Further negative impacts will be increased by saltwater intrusion and flooding due to storm surges and loss of coastal wetlands and slowing down of river discharges.

- Q3.24-25

9.22 ***Key uncertainties*** in the identification and quantification of impacts arise from the lack of reliable local or regional detail in climate projections especially in the projection of extremes, inadequate accounting in impacts assessments for the effects of changes in extremes and disasters, limited knowledge of some non-linear processes and feedbacks, uncertainties in the costing of the damage due to climate impacts, lack of both relevant data and understanding of key processes in different regions, and uncertainties in assessing and predicting the response of ecological and socio-economic systems to the combined effect of climate change and other stresses such as land-use change, local pollution, etc.

- Q4.10, 4.13-14, & 4.18-19

Costs and Benefits of Adaptation and Mitigation Options

9.23 **Adaptation is a necessity; its cost can be reduced by anticipation, analysis, and planning.**

9.24 ***Adaptation is no longer an option, it is a necessity, given that climate changes and related impacts are already occurring. Anticipatory and reactive adaptation, which will vary with location and sector, has the potential to reduce many of the adverse impacts of climate change and to enhance beneficial impacts.*** However, its potential is much more limited for natural systems than for human systems. The capacity of different regions to adapt to climate change depends highly upon their current and future states of socio-economic development and their exposure to climate stress. Therefore the potential for adaptation is more limited for developing countries, which are projected to be the most adversely affected. Adaptation appears to be easier if the climate changes are modest and/or gradual rather than large and/or abrupt. If climate changes more rapidly than expected in any region, especially with respect

- Q3.28-29 & 3.34

to climate extremes, then the potential of adaptation to diminish vulnerability of human systems will be lessened.

9.25 ***The costs of adaptation can be reduced by anticipation and planned action, and many costs may be relatively small, especially when adaptation policies and measures contribute to other goals of sustainable development.*** • Q3.32 & 3.38

9.26 ***Key uncertainties*** regarding adaptations relate to the inadequate representation by models of local changes, lack of foresight, inadequate knowledge of benefits and costs, possible side-effects including acceptability and speed of implementation, various barriers to adaptation, and more limited opportunities and capacities for adaptation in developing countries. • Q3.28

9.27 **The primary economic benefits of mitigation are the *avoided* costs associated with the adverse impacts of climate change.**

9.28 ***Comprehensive, quantitative estimates of global primary benefits of mitigating climate change do not exist.*** For mean temperature increases over 3ºC relative to 1990, impacts are predominantly adverse, and so net primary benefits of mitigation are positive. A key uncertainty is the net balance of adverse and beneficial impacts of climate change for temperature increases less than about 2 to 3ºC. These averages conceal wide regional variations.

- Q6.10-11
- WGII TAR SPM Section 5

9.29 **Mitigation generates costs and ancillary benefits.**

9.30 ***Major reductions in global greenhouse gas emissions would be necessary to achieve stabilization of their concentrations***. For example, for the most important anthropogenic greenhouse gas, carbon cycle models indicate that stabilization of atmospheric CO_2 concentrations at 450, 650, or 1000 ppm would require global anthropogenic CO_2 emissions to decline below 1990 levels, within a few decades, about a century, or about two centuries, respectively, and continue to decrease steadily thereafter. Eventually stabilization would require CO_2 emissions to decline to a very small fraction of current global emissions. The ***key uncertainties*** here relate to the possibilities of climate change feedbacks and alternative development pathways. • Q6.4

9.31 ***Mitigation costs and benefits vary widely across sectors, countries, and development paths***. In general it is easier to identify sectors, such as coal, possibly oil and gas, and some energy-intensive sectors that are very likely to suffer an economic disadvantage from mitigation. Their economic losses are more immediate, more concentrated, and more certain. The sectors that are likely to benefit include renewable energy and services. Different countries and development paths have widely different energy structures, so they too have different costs and benefits from mitigation. Carbon taxes can have negative income effects on low-income groups unless the tax revenues are used directly or indirectly to compensate such effects. A ***key uncertainty*** for policy is whether effective, efficient, and equitable schemes can be developed to manage and reduce the losses and enhance the benefits.

- Q7.15, 7.18, & 7.37
- WGIII TAR SPM Para15

9.32 ***Changes will occur in the global energy mix irrespective of climate change, offering an opportunity for the introduction of new sources of energy during the 21st century.*** The technological options chosen to meet this new energy demand will determine at what level and cost greenhouse gas concentrations can be stabilized. ***Key uncertainties*** are the future relative prices of energy and carbon-based fuels, and the relative technical and economic attractiveness of non-fossil-fuel energy alternatives compared with unconventional oil and gas resources.

- Q7.29
- WGIII TAR SPM Para6

9.33 ***Significant progress in energy-saving and low-carbon technologies has been made since 1995, and the progress has been faster than anticipated in the SAR***. Net emission reductions could be achieved through, *inter alia*, improved techniques in production and use of energy, shifts to low- or no-carbon technologies, CO_2 removal and storage, and improved land-use and forestry practices, and movement to more sustainable lifestyles. Significant progress is taking place in the development of wind turbines, solar energy, hybrid engine cars, fuel cells, and underground CO_2 storage. ***Key uncertainties*** are (a) the likelihood of technological breakthroughs leading to substantial reductions in costs and rapid take-up of low-carbon processes and products, and (b) the future scale of private and public research and development expenditures on these technologies.

- Q7.4
- WGIII TAR SPM Para7

9.34 ***Mitigation costs can be substantially reduced and sometimes turned into net benefits through a portfolio of policy instruments (including those that help to overcome barriers).*** The costs of mitigation are strongly affected by development paths, with those paths involving substantial increases in greenhouse gas emissions requiring more mitigation to reach a stabilization target, and hence higher costs. These costs can be reduced or even turned into net benefits with a portfolio of policy instruments to the extent that policies can exploit "no-regrets" opportunities in the following areas.

- *Technological options*. Technological options may achieve global emissions reductions of 1.9–2.6 Gt C_{eq} yr^{-1} by 2010 and 3.6–5.0 Gt C_{eq} yr^{-1} by 2020. Half of these reductions may be realized with direct benefits exceeding direct costs, and the other half at a net direct cost of up to US$100/t C_{eq} (at 1998 prices).[1] ***Key uncertainties*** are the extent and nature of any barriers that impede adoption of cost-effective options, and the costs of overcoming the barriers.
- *Ancillary benefits*. Depending on factors (such as location of the greenhouse gas emissions, the prevailing local climate, and the population density, composition, and health) the magnitude of the ancillary benefits of mitigation may be comparable to the costs of the mitigating policies and measures. ***Key uncertainties*** are the magnitude and location of these benefits involving the scientific assessment and valuation of health risks of air pollution, particularly those involving fine aerosols and particles.
- *Double dividends*. Some mitigation policies, such as carbon taxes or auctioned emission permits, raise revenues that can be used to reduce existing distortionary taxes. ***Key uncertainties*** regarding the overall net costs of mitigation vary between countries, depending on the existing tax structure the extent of the distortion and the type of tax cuts that are acceptable.

[FOOTNOTE 1: These cost estimates are derived using discount rates in the range of 5 to 12%, consistent with public-sector discount rates. Private internal rates of return vary greatly and are often significantly higher.]

- Q7.7-8, 7.16, 7.21, & 7.25
- WGIII TAR SPM Paras 6&11, & Sections 3.9, 7.3.3, 7.3.4, 8.2.2, 8.2.4, 9.2.1, 9.2.2, & 9.2.8

9.35 ***Emissions trading reduces costs of mitigation.*** Global modeling studies, with results depending strongly upon assumptions, project that costs of mitigation based on Kyoto targets are likely to be reduced by full carbon-permit trading within the Annex B[2] group of countries. *Annex I OECD[3] countries* may expect aggregate costs to be reduced by about half through full permit trading. *Annex I economies-in-transition* are projected to be unaffected or to gain several percent increase in GDP. *Oil-exporting, non-Annex I countries* may also expect similar reductions in costs under such trading. The aggregate effects of trading are expected to be positive for *other non-Annex I countries.* Those countries that may expect a loss or gain without Annex I trading may expect a smaller change with trading. A ***key uncertainty*** is the extent of the underlying costs, which vary widely across countries, and how these cost estimates will be changed (a) when methods are improved and (b) when some of the assumptions of the models are relaxed. Such assumptions are concerned with:

- Allowance for exemptions in the emission-permit trading in concert with other policies and measures

- Q7.19-20
- WGIII TAR SPM Paras 3, 11-12, & 24

- Consideration of various market failures
- Allowance for induced technical change
- Inclusion of ancillary benefits
- Opportunities for double dividends
- Inclusion of policies for non-CO_2 greenhouse gases and non-energy sources of all greenhouse gases (e.g., methane from agriculture)
- Offsets from sinks.

[FOOTNOTE 2: *Annex B countries.* Group of countries included in Annex B of the Kyoto Protocol that have agreed to a target for their greenhouse gas emissions, including all the Annex I countries (as amended in 1998) but Turkey and Belarus.]

[FOOTNOTE 3: *Annex I countries.* Group of countries included in Annex I to the UNFCCC, including all developed countries in the OECD and economies-in-transition.]

9.36 ***Stabilization could be achieved with hardly noticeable effects on global GDP growth averaged over the 21st century.*** The *highest* cost of stabilization at different levels 450 to 750 ppm across all models and post-SRES scenarios is a reduction in global GDP growth 2000–2100 of 0.06% per year. The average reduction is 0.003% per year. These reductions are hardly noticeable in the context of projections of the growth rates of global GDP of some 2 to 3% per year over a century. However mitigation costs may be significant for particular sectors and countries over some periods. ***Costs of stabilization tend to rise as stabilization levels are reduced***.

- Q7.27
- WGIII TAR Section 8.4.3

9.37 ***Unexpected public policies ("quick fixes") with sudden short-term effects may cost economies much more than expected policies with gradual effects***. A ***key uncertainty*** in the magnitude of the costs lies in the existence of well-designed contingency plans in the event of policy shifts (e.g., as a result of a sudden shift in public perception of the climate change). Other key uncertainties for costs lie in the possibilities of the rapid short-term effects including, or leading to, abrupt reductions in costs of low-carbon processes and products, and/or shifts towards low-emission technologies, and/or changes towards more sustainable lifestyles.

- Q7.26
- WGIII TAR Sections TS10.4, 8.3.1.1, & 10.4.3

9.38 ***Near-term action in mitigation and adaptation would reduce risks.*** Because of the long time lags associated both with the climate system (e.g., ~100 years for atmospheric CO_2) and with human response, near-term action in mitigation and adaptation would reduce risks.

- Q3.16-33 & 4.17-20

9.39 ***The effectiveness of mitigation would be increased and its costs reduced if climate policies could be integrated and harmonized with non-climate policies for sustainable development.*** Some future paths that focus on the social, economic, and environmental elements of sustainable development may result in lower greenhouse gas emissions than other paths, so that the level of additional policies and measures required for a particular level of stabilization and any associated costs can also be lower. A ***key uncertainty*** is the lack of appropriate knowledge on the interactions between climate change and other environmental issues and the related socio-economic implications. A related issue is the pace of change in integrating the main global conventions and protocols associated with climate change (e.g., those involving world trade, transboundary pollution, biodiversity, desertification, stratospheric ozone depletion, health, and food security). It is also uncertain at which rate individual countries will integrate sustainable development concepts into policymaking processes.

- Q1.9 & 8.21-28

9.40 ***Development paths that meet sustainable development objectives may result in lower levels of greenhouse gas emissions***. Key choices about future development paths and the future of

- WGIII TAR

the climate are being made now in both developed and developing countries. Information is available to help decisionmakers evaluate benefits and costs from adaptation and mitigation over a range of options and sustainable development pathways. Anticipated adaptation could be much less costly than reactive adaptation. Mitigation of climate change can reduce and postpone the impacts, lowering the damages and giving human societies as well as animals and plants more time to adapt.	SPM Para4
9.41 ***Significant progress has been made in the TAR in many aspects of the knowledge required to understand climate change and the human response to it.*** However, there remain major gaps where further work is required, in particular in: • The understanding and prediction of climate extremes • The quantification of the damage from climate change impacts at the global, regional, and local levels • The development of effective, efficient, and equitable adaptation and mitigation policies • The integration of all aspects of the climate change issue into strategies for sustainable development.	• WGI TAR SPM (p.11) • WGII TAR SPM Sec6 • WGIII TAR SPM Para24

FIGURE 9-1

SEE PAGE 110 LINES 6–28 FOR FIGURE CAPTION

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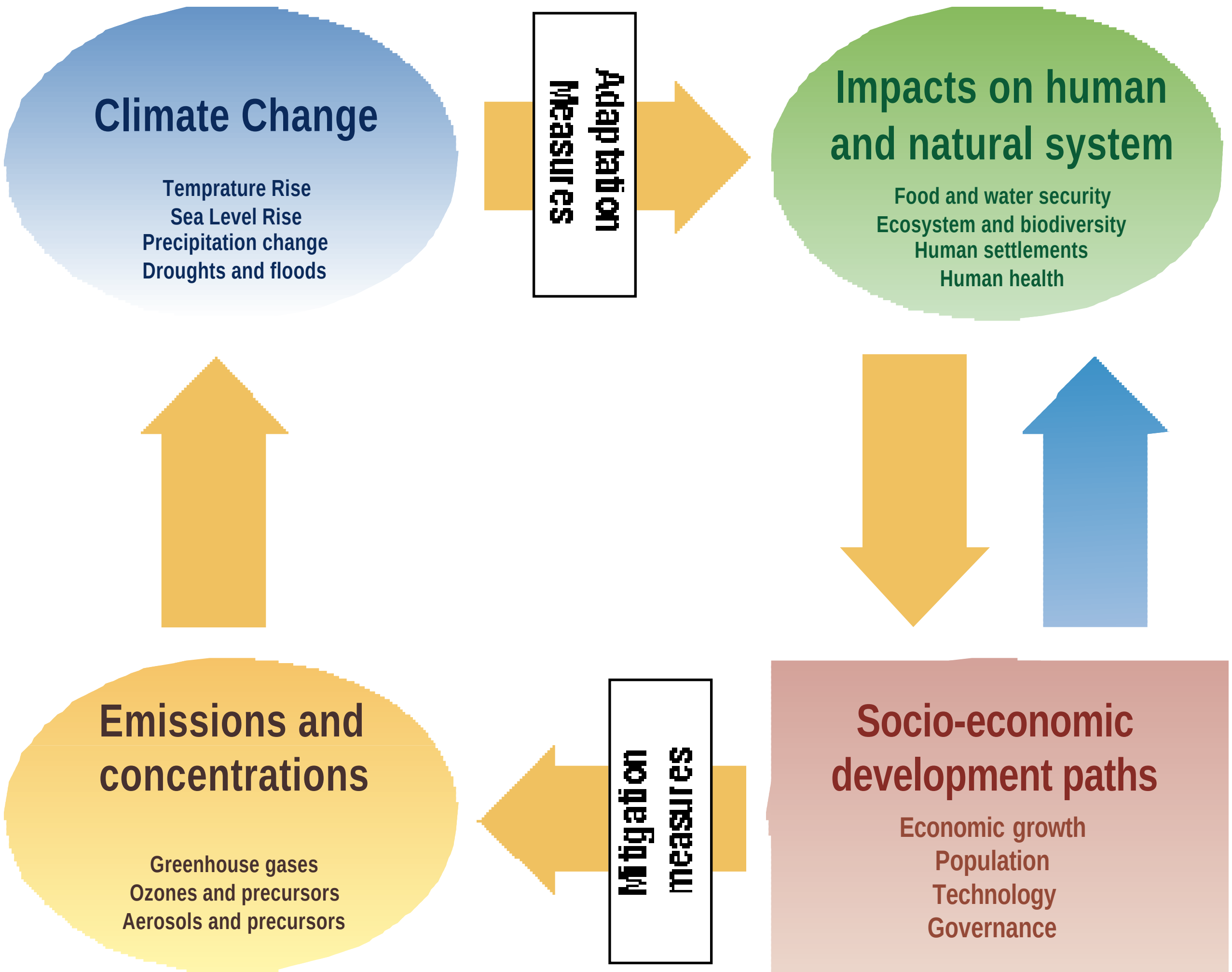

FIGURE 9-2

SEE PAGE 111 LINES 26–29 FOR FIGURE CAPTION

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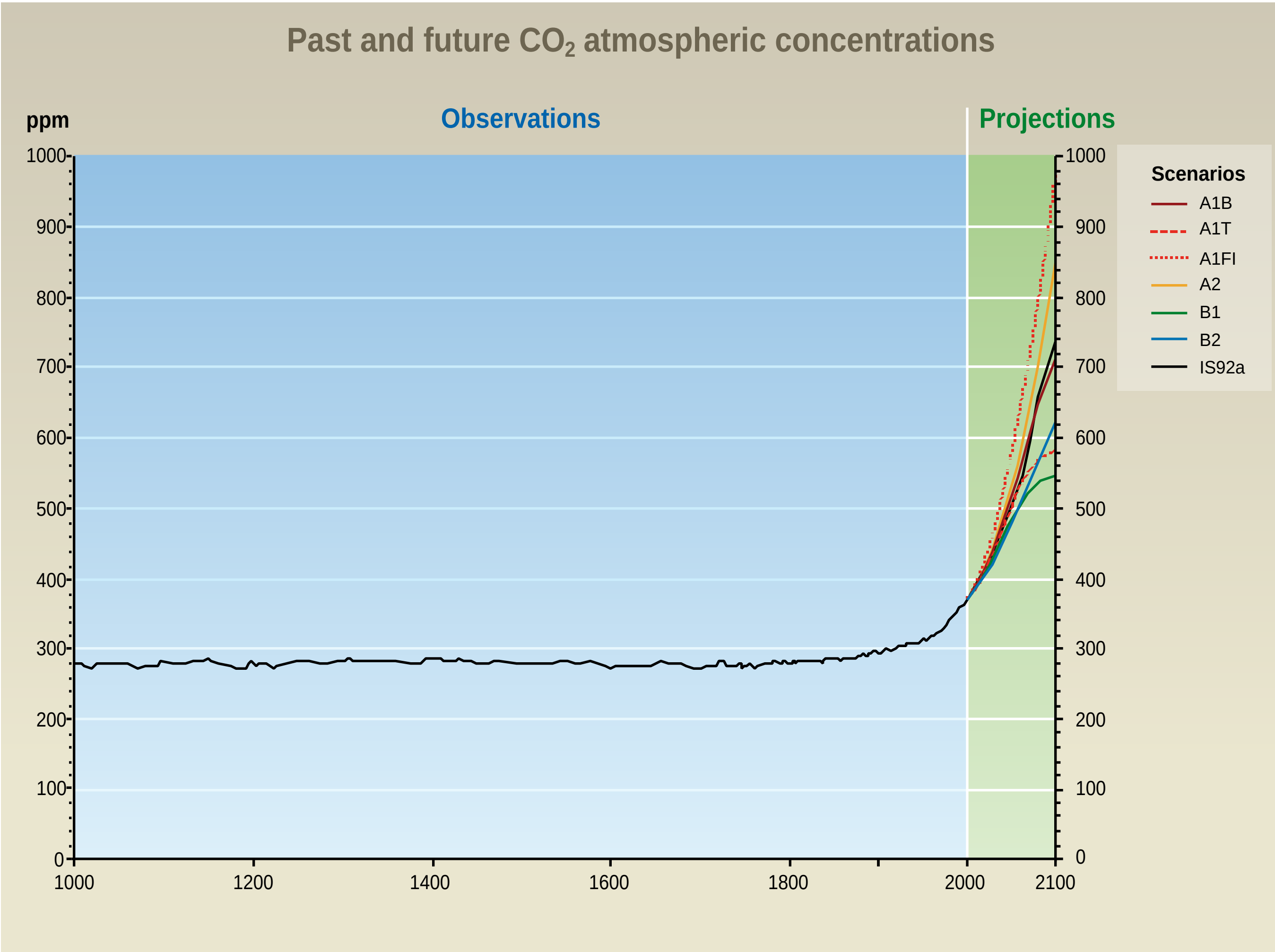

FIGURE 9-3

SEE PAGE 111 LINE 53 – PAGE 112 LINE 9 FOR FIGURE CAPTION

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