Climate Change 2001: Synthesis Report

Synthesis Report

An Assessment of the Intergovernmental Panel on Climate Change

This underlying report, approved paragraph by paragraph at IPCC Plenary XVIII (Wembley, United Kingdom, 24-29 September 2001), represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Third Assessment Report.

Based on a draft prepared by:

Core Writing Team

Robert T. Watson, Daniel L. Albritton, Terry Barker, Igor A. Bashmakov, Osvaldo Canziani, Renate Christ, Ulrich Cubasch, Ogunlade Davidson, Habiba Gitay, David Griggs, Kirsten Halsnaes, John Houghton, Joanna House, Zbigniew Kundzewicz, Murari Lal, Neil Leary, Christopher Magadza, James J. McCarthy, John F.B. Mitchell, Jose Roberto Moreira, Mohan Munasinghe, Ian Noble, Rajendra Pachauri, Barrie Pittock, Michael Prather, Richard G. Richels, John B. Robinson, Jayant Sathaye, Stephen Schneider, Robert Scholes, Thomas Stocker, Narasimhan Sundararaman, Rob Swart, Tomihiro Taniguchi, and D. Zhou

Extended Team

Q.K. Ahmad, Oleg Anisimov, Nigel Arnell, Fons Baede, Tariq Banuri, Leonard Bernstein, Daniel H. Bouille, Timothy Carter, Catrinus J. Jepma, Liu Chunzhen, John Church, Stewart Cohen, Paul Desanker, William Easterling, Chris Folland, Filippo Giorgi, Jonathan Gregory, Joanna Haigh, Hideo Harasawa, Bruce Hewitson, Jean-Charles Hourcade, Mike Hulme, Tom Karl, Pekka E. Kauppi, Rik Leemans, Anil Markandya, Luis Jose Mata, Bryant McAvaney, Anthony McMichael, Linda Mearns, Jerry Meehl, Gylvan Meira-Filho, Evan Mills, William R. Moomaw, Berrien Moore, Tsuneyuki Morita, M.J. Mwandosya, Leonard Nurse, Martin Parry, Joyce Penner, Colin Prentice, Venkatachalam Ramaswamy, Sarah Raper, Jim Salinger, Michael Scott, Roger A. Sedjo, Priyaradshi R. Shukla, Barry Smit, Joel Smith, Leena Srivastava, Ron Stouffer, Kanako Tanaka, Ferenc L. Toth, Kevin Trenberth, Alla Tsyban, John P. Weyant, Tom Wilbanks, Francis Zwiers, and many IPCC authors

Review Editors

Susan Barrell, Rick Bradley, Eduardo Calvo, Ian Carruthers, Oyvind Christophersen, Yuri Izrael, Eberhard Jochem, Fortunat Joos, Martin Manning, Bert Metz, Alionne Ndiaye, Buruhani Nyenzi, Ramon Pichs-Madruga, Richard Odingo, Michel Petit, Jan Pretel, Armando Ramirez, Jose Romero, John Stone, R.T.M. Sutamihardja, David Warrilow, Ding Yihui, and John Zillman

Question 1

Q1

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?

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."

1.1 **Natural, technical, and social sciences can provide essential information and evidence needed for decisions on what constitutes "dangerous anthropogenic interference" with the climate system. At the same time, such decisions are value judgments determined through socio-political processes, taking into account considerations such as development, equity, and sustainability, as well as uncertainties and risk.** Scientific evidence helps to reduce uncertainty and increase knowledge, and can serve as an input for considering precautionary measures.[1] Decisions are based on risk assessment, and lead to risk management choices by decision makers, about actions and policies.[2]

WGII TAR Section 2.7 & WGIII TAR Chapter 10

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 adaptive capacity available to cope with climate change. It also depends upon mitigative capacity, since the magnitude and the rate of change are both important.** 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 life-support systems. There is no universally applicable 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.

WGII TAR Chapter 18 & WGIII TAR Chapter 10

1.3 **The Third Assessment Report (TAR) provides an assessment of new scientific information and evidence as an input for policy makers in their 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 a broad range of levels of concentrations through mitigation and information about how adaptation can reduce vulnerability.

WGI TAR, WGII TAR, & WGIII TAR

1.4 **With regard to the magnitudes and rates of changes in the climate system, the TAR provides scenario-based projections of future concentrations of greenhouse gases in the atmosphere, global and regional patterns of changes and rates of change in temperature, precipitation, and sea level, and changes in extreme climate events.** It also examines possibilities for abrupt and irreversible changes in ocean circulation and the major ice sheets.

WGI TAR

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-impact 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., a monetary unit) captures

WGII TAR Chapter 19

[1] Conditions that justify the adoption of precautionary measures are described in Article 3.3 of the United Nations Framework Convention on Climate Change (UNFCCC).

[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 analyses are marked by considerable uncertainties.

the range of relevant risks presented by climate change, a variety of analytical approaches and criteria are required to assess impacts and facilitate decisions about risk management.

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 interlinked causes and effects across all sectors concerned. Figure 1-1 shows the cycle, from the underlying driving forces of population, economy, technology, and governance, through greenhouse gas 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 assesses 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 righthand 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.

WGII TAR Chapters 1 & 19, WGIII TAR Chapter 1, & SRES

1.8 **Climate change decision making is essentially a sequential process under general uncertainties.** Decision making has to deal with uncertainties including the risk of non-linear and/or irreversible changes and entails balancing the risk of either insufficient or excessive action, and involves careful consideration of the consequences (both environmental and economic), their likelihood, and society's attitude towards risk. The latter is likely to vary from country to country and from generation to generation. The relevant question is "what is the best course for the near term given the expected long-term climate change and accompanying uncertainties."

WGI TAR, WGII TAR, & WGIII TAR Section 10.1.4

1.9 **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 supported by non-renewable resources 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 environmental, social, and economic conditions and institutional capacity.

WGII TAR

1.10 **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 of the impacts of natural

WGIII TAR Section 10.3.2

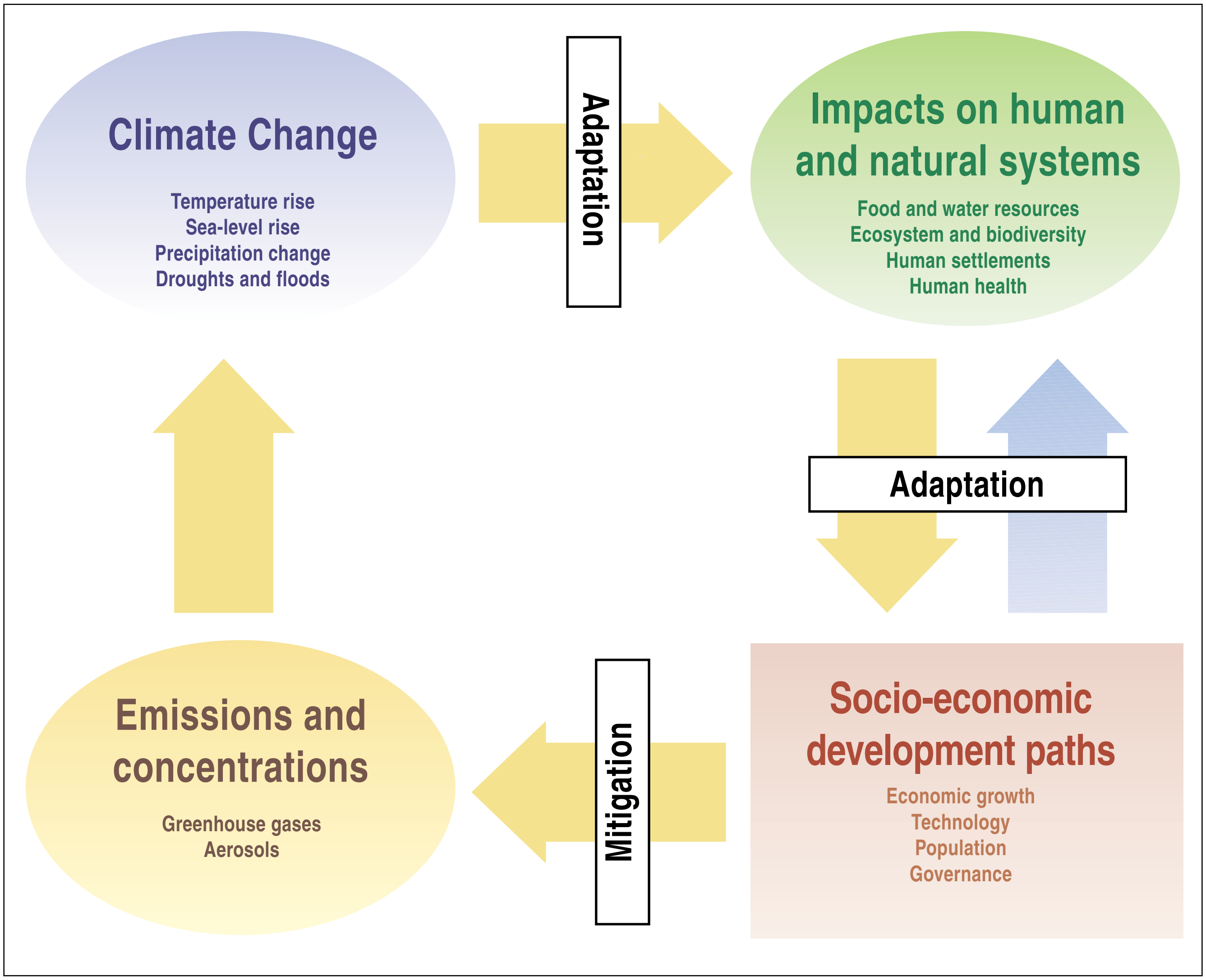


Figure 1-1: Climate change – an integrated framework. Schematic and simplified representation of an integrated assessment framework for considering anthropogenic climate change. The yellow arrows show a full clockwise cycle of cause and effect among the four quadrants shown in the figure, while the blue arrow indicates the societal response to climate change impacts. For both developed and developing countries, each **socio-economic development path** explored in the *Special Report on Emissions Scenarios* has driving forces which give rise to emissions of greenhouse gases, aerosols, and precursors—with carbon dioxide (CO_2) being the most important. The greenhouse gas **emissions accumulate in the atmosphere, changing concentrations** and disturbing 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 enhanced greenhouse effect will initiate **climate changes** well into the future with associated **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. 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 righthand domain (shown as a rectangle) by examining the relationships between greenhouse gas emissions and development paths (in SRES), and by assessing preliminary work on the linkage between adaptation, mitigation, and development paths (WGII and WGIII). 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. Adaptation and mitigation are shown as modifying the effects shown in the figure.

climate variation and changes, 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* (SRES, 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.

1.11 **The TAR assesses available information on 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.

WGII TAR Chapter 18, WGIII TAR Chapters 8, 9, & 10, & SRES

Question 2

Q2

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?

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 Niño events, 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 both climate change that is attributable to human influence and climate change that may at present be natural but might in the future be modified through human influence (see Box 3-1).

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 activities.**

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).**

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 recorded levels in the 1990s and continue to increase (see Figure 2-1). Atmospheric carbon dioxide (CO_2) and methane (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 the years 1750 to 2000, the concentration of CO_2 increased by 31±4%, and that of CH_4 rose by 151±25% (see Box 2-1 and Figure 2-1). These rates of increase are unprecedented. 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 and much of the 20th century the terrestrial biosphere has been a net source of atmospheric CO_2, but before the end of the 20th century 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 (O_3), the third most important—are directly attributable to fossil-fuel combustion as well as other industrial and agricultural emissions.

WGI TAR Chapters 3 & 4, & SRAGA

Box 2-1 Confidence and likelihood statements.

Where appropriate, the authors of the Third Assessment Report assigned confidence levels that represent their collective judgment in the validity of a conclusion based on observational evidence, modeling results, and theory that they have examined. The following words have been used throughout the text of the Synthesis Report to the TAR relating to WGI findings: *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); and *exceptionally unlikely* (less than 1% chance). An explicit uncertainty range (±) is a *likely* range. Estimates of confidence relating to WGII findings are: *very high* (95% or greater), *high* (67–95%), *medium* (33–67%), *low* (5–33%), and *very low* (5% or less). No confidence levels were assigned in WGIII.

WGI TAR SPM & WGII TAR SPM

Table 2-1 20th century changes in the Earth's atmosphere, climate, and biophysical system.[a]	
Indicator	***Observed Changes***
Concentration indicators	
Atmospheric concentration of CO_2	280 ppm for the period 1000–1750 to 368 ppm in year 2000 (31±4% increase). [WGI TAR Chapter 3]
Terrestrial biospheric CO_2 exchange	Cumulative source of about 30 Gt C between the years 1800 and 2000; but during the 1990s, a net sink of about 14±7 Gt C. [WG1 TAR Chapter 3 & SRLULUCF]
Atmospheric concentration of CH_4	700 ppb for the period 1000–1750 to 1,750 ppb in year 2000 (151±25% increase). [WGI TAR Chapter 4]
Atmospheric concentration of N_2O	270 ppb for the period 1000–1750 to 316 ppb in year 2000 (17±5% increase). [WGI TAR Chapter 4]
Tropospheric concentration of O_3	Increased by 35±15% from the years 1750 to 2000, varies with region. [WGI TAR Chapter 4]
Stratospheric concentration of O_3	Decreased over the years 1970 to 2000, varies with altitude and latitude. [WGI TAR Chapters 4 & 6]
Atmospheric concentrations of HFCs, PFCs, and SF_6	Increased globally over the last 50 years. [WGI TAR Chapter 4]
Weather indicators	
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 2.2.2.3]
Northern Hemisphere surface temperature	Increase over the 20th century greater than during any other century in the last 1,000 years; 1990s warmest decade of the millennium (*likely*). [WGI TAR Chapter 2 ES & Section 2.3.2.2]
Diurnal surface temperature range	Decreased over the years 1950 to 2000 over land: nighttime minimum temperatures increased at twice the rate of daytime 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 Chapter 2 ES & Section 2.5.2]
Heavy precipitation events	Increased at mid- and high northern latitudes (*likely*). [WGI TAR Section 2.7.2.2]
Frequency and severity of drought	Increased summer drying and associated incidence of drought in a few areas (*likely*). In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts have been observed to increase in recent decades. [WGII TAR Sections 10.1.3 & 11.1.2]

2.5 **The radiative forcing from the increase in anthropogenic greenhouse gases since the pre-industrial era is positive (warming) with a small uncertainty range; that from the direct effects of aerosols is negative (cooling) and smaller; whereas the negative forcing from the indirect effects of aerosols (on clouds and the hydrologic cycle) might be large but is not well quantified.** Key anthropogenic and natural factors causing a change in radiative forcing from year 1750 to year 2000 are shown in Figure 2-2, where the factors whose radiative forcing can be quantified are marked by wide, colored bars. Only some of the aerosol effects are estimated here and denoted as ranges. Other factors besides atmospheric constituents—solar irradiance and land-use change—are also shown. Stratospheric aerosols from large volcanic eruptions have led to important, but brief-lived, negative forcings (particularly the periods 1880–1920 and 1960–1994), which are not important over the time scale since the pre-industrial era and not shown. The sum of

WGI TAR Chapter 5 & 6, & SRAGA Chapter 6

Table 2-1 20th century changes in the Earth's atmosphere, climate, and biophysical system.[a] (continued)

Indicator	*Observed Changes*
Biological and physical indicators	
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 2 weeks over the 20th century in mid- and high latitudes of the Northern Hemisphere (*very likely*). [WGI TAR Chapter 2 ES & Section 2.2.5.5, & 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	Widespread retreat during the 20th century. [WGI TAR Section 2.2.5.4 & WGII TAR Section 4.3.11]
Snow cover	Decreased in area by 10% since global observations became available from satellites in the 1960s (*very likely*). [WGI TAR Section 2.2.5.1]
Permafrost	Thawed, warmed, and degraded in parts of the polar, sub-polar, and mountainous regions. [WGI TAR Sections 2.2.5.3 & 11.2.5, & WGII TAR Section 16.1.3.1]
El Niño events	Became more frequent, persistent, and intense during the last 20 to 30 years compared to the previous 100 years. [WGI TAR Section 7.6.5]
Growing season	Lengthened by about 1 to 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, and earlier emergence of insects in the Northern Hemisphere. [WGII TAR Sections 5.2.1 & 5.4.3]
Coral reef bleaching	Increased frequency, especially during El Niño events. [WGII TAR Section 6.3.8]
Economic indicators	
Weather-related economic losses	Global inflation-adjusted losses rose an order of magnitude over the last 40 years (see Figure 2-7). Part of the observed upward trend is linked to socio-economic factors and part is linked to climatic factors. [WGII TAR Sections 8.2.1 & 8.2.2]

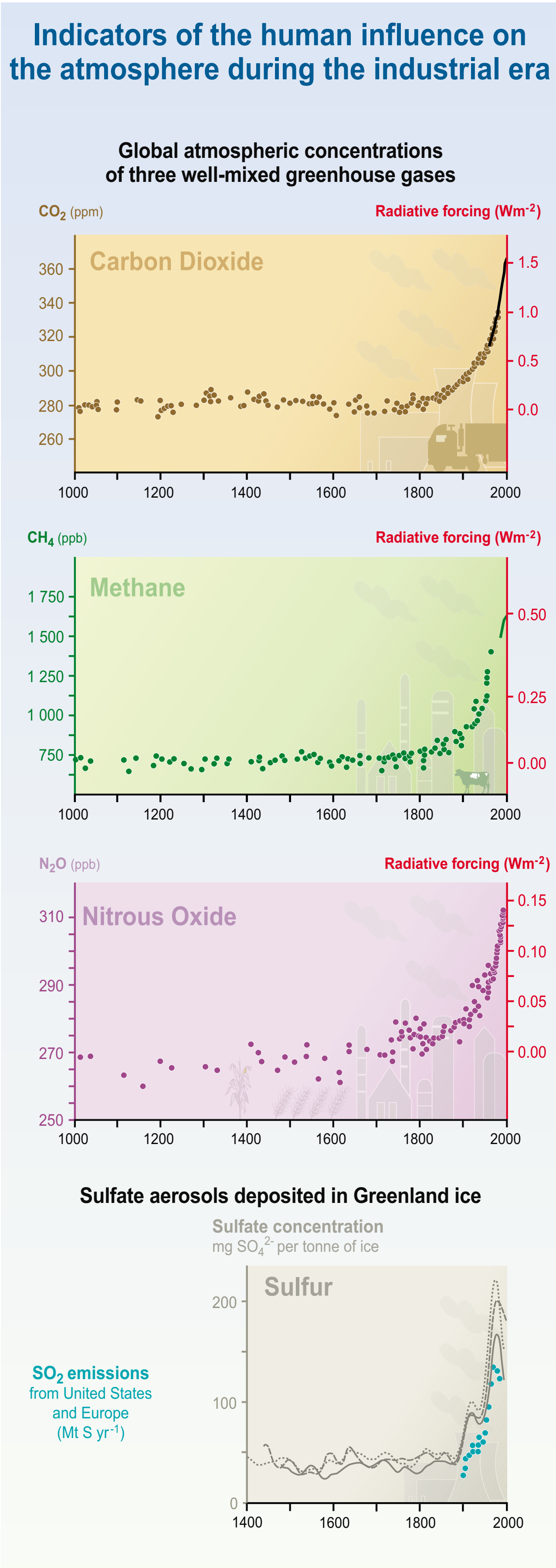
[a] This table provides examples of key observed changes and is not an exhaustive list. It includes both changes attributable to anthropogenic climate change and those that may be caused by natural variations or anthropogenic climate change. Confidence levels are reported where they are explicitly assessed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

quantified factors in Figure 2-2 (greenhouse gases, aerosols and clouds, land-use (albedo), and solar irradiance) is positive, but this does not include the potentially large, negative forcing from aerosol indirect effects. The total change in radiative forcing since the pre-industrial era continues to be a useful tool to estimate, to a first order, the global mean surface temperature response to human and natural perturbations; however, the sum of forcings is not necessarily an indicator of the detailed aspects of the potential climate responses such as regional climate change. For the last half of the 20th century (not shown), the positive forcing due to well-mixed greenhouse gases has increased rapidly over the past 4 decades, while in contrast the sum of natural forcings has been negative over the past 2 and possibly even 4 decades.

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 the year 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 2-3).

WGI TAR SPM & WGI TAR Sections 2.2.2, 2.3.2, & 2.7.2



WGI TAR Figures SPM-2, 3-2b, 4-1a, 4-1b, 4-2, & 5-4a

Figure 2-1: Records of past changes in atmospheric composition over the last millennium demonstrate the rapid rise in greenhouse gases and sulfate aerosols that is attributable primarily to industrial growth since 1750. The top three panels show increasing atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) over the past 1,000 years. Early sporadic data taken from air trapped in ice (symbols) matches up with continuous atmospheric observations from recent decades (solid lines). These gases are well mixed in the atmosphere, and their concentrations reflect emissions from sources throughout the globe. The estimated positive radiative forcing from these gases is indicated on the righthand scale. The 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 sulfur dioxide (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 symbols), and both show a decline in recent decades. Sulfate aerosols produce negative radiative forcing.

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 1,000 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 2-3). Insufficient data are available in the Southern Hemisphere prior to the year 1860 to compare the recent warming with changes over the last 1,000 years. Since the year 1950, the increase in sea surface temperature is about half that of the mean land surface air temperature. During this period the nighttime daily minimum temperatures over land have increased on average by about 0.2°C per decade, about twice the corresponding

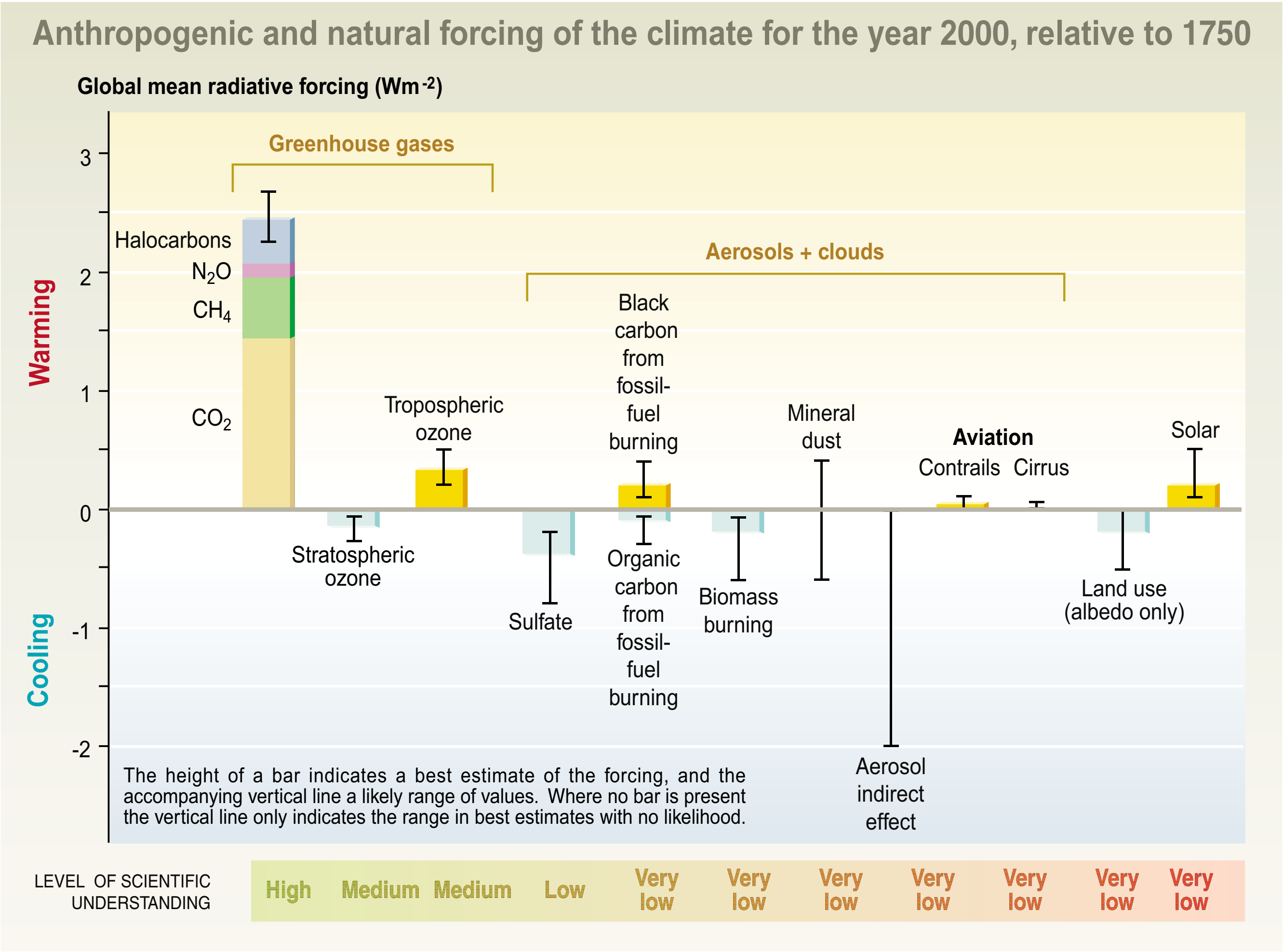
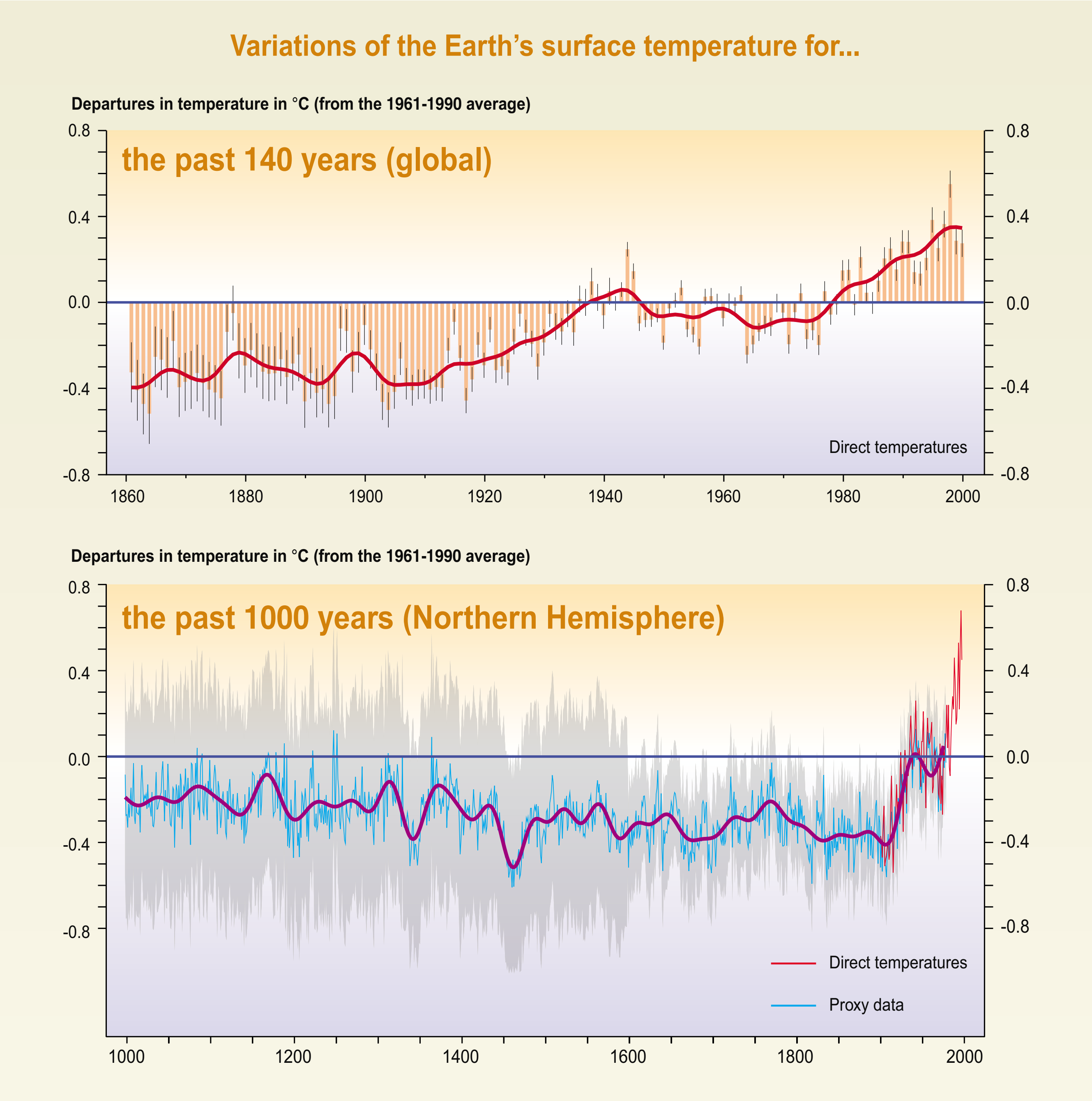


Figure 2-2: The influence of external factors on climate can be broadly compared using the concept of radiative forcing. These radiative forcings arise from changes in the atmospheric composition, alteration of surface reflectance by land use, and variation in the output of the sun. Except for solar variation, some form of human activity is linked to each. The rectangular bars represent estimates of the contributions of these forcings, some of which yield warming and some cooling. Forcing due to episodic volcanic events, which lead to a negative forcing lasting only for a few years, is not shown. The indirect effect of aerosols shown is their effect on the size and number of cloud droplets. A second indirect effect of aerosols on clouds, namely their effect on cloud lifetime, which would also lead to a negative forcing, is not shown. Effects of aviation on greenhouse gases are included in the individual bars. The vertical line about the rectangular bars indicates a range of estimates, guided by the spread in the published values of the forcings and physical understanding. Some of the forcings possess a much greater degree of certainty than others. A vertical line without a rectangular bar denotes a forcing for which no best estimate can be given owing to large uncertainties. The overall level of scientific understanding for each forcing varies considerably, as noted. Some of the radiative forcing agents are well mixed over the globe, such as CO_2, thereby perturbing the global heat balance. Others represent perturbations with stronger regional signatures because of their spatial distribution, such as aerosols. Radiative forcing continues to be a useful tool to estimate, to a first order, the relative climate impacts such as the relative global mean surface temperature response due to radiatively induced perturbations, but these global mean forcing estimates are not necessarily indicators of the detailed aspects of the potential climate responses (e.g., regional climate change).

WGI TAR SPM, WGI TAR Chapter 6 ES, & WGI TAR Figures SPM-3 & 6-6

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 Figures SPM-1, 2-7c, & 2-20

Figure 2-3: 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 grey 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.

2.8 **In the lowest 8 km of the atmosphere the global temperature increase from the 1950s to the year 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 (0.3°C per decade) and Europe (0.4°C per decade) for both surface and lower atmosphere, but distinct differences over some land areas and particularly in the 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.

WGI TAR SPM & WGI TAR Section 2.2.4

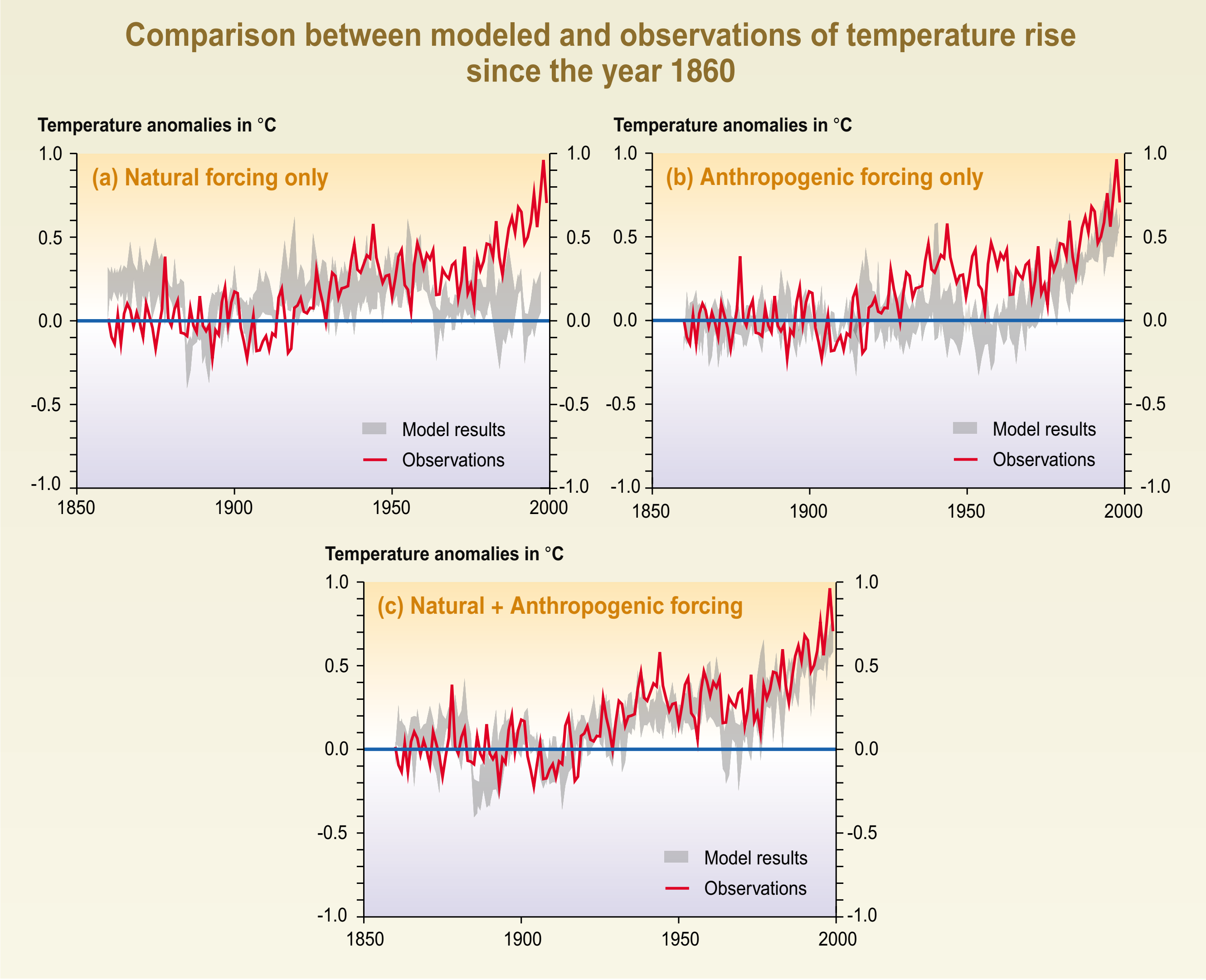


Figure 2-4: Simulating the Earth's temperature variations and comparing the results to the measured changes can provide insight into the underlying causes of the major changes. A climate model can be used to simulate the temperature changes that occur from both natural and anthropogenic causes. The simulations represented by the band in (a) were done with only natural forcings: solar variation and volcanic activity. Those encompassed by the band in (b) were done with anthropogenic forcings: greenhouse gases and an estimate of sulfate aerosols. Those encompassed by the band in (c) were done with both natural and anthropogenic forcings included. From (b), it can be seen that the inclusion of anthropogenic forcings provides a plausible explanation for a substantial part of the observed temperature changes over the past century, but the best match with observations is obtained in (c) when both natural and anthropogenic factors are included. These results show that the forcings included are sufficient to explain the observed changes, but do not exclude the possibility that other forcings may have also contributed. Similar results to those in (b) are obtained with other models with anthropogenic forcing.

WGI TAR Figure 12-7

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 1,000 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 irradiance 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 & WGI TAR Chapter 12

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 35 to 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 cannot explain the warming (see Figure 2-4a); whereas most of these studies find that, over the last 50 years, the estimated rate and magnitude of warming due to increasing greenhouse gases alone are comparable with, or larger than, the observed warming (Figure 2-4b). The best agreement for the 1860–2000 record is found when the above anthropogenic and natural forcing factors are combined (see Figure 2-4c). This result does not exclude the possibility that other forcings may also contribute, and some known anthropogenic factors (e.g., organic carbon, black carbon (soot), biomass aerosols, and some changes in land use) 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 & WGI TAR Chapter 12

2.12 **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).** Some of these changes are regional and some may be due to internal climate variations, natural forcings, or regional human activities rather than attributed solely to global human influence.

WGI TAR SPM & WGII TAR Section 4.3.11

2.13 **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 tide gauge records, after correcting for land movements, the average annual rise was between 1 and 2 mm during the 20th century. The very few long records show that it was less during the 19th century (see Figure 2-5). Within present uncertainties, observations and models are both consistent with a lack of significant acceleration of sea-level rise during the 20th century. 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 subsurface ocean temperatures.

WGI TAR Sections 2.2.2.5, 11.2, & 11.3.2

2.14 **Snow cover and ice extent have decreased.** It is very likely that the extent of snow cover has decreased by about 10% on average in the Northern Hemisphere since the late 1960s (mainly through springtime changes over America and Eurasia) 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 the year 2000 and that Arctic sea-ice thickness has declined by about 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 1978 to 2000 in

WGI TAR Section 2.2.5

parallel with global mean surface temperature increase, regional warming in the Antarctic Peninsula coincided with the collapse of the Prince Gustav and parts of the Larsen ice shelves during the 1990s, but the loss of these ice shelves has had little direct impact.

2.15 **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 subtropical land areas (see Figure 2-6a). Increasing global mean surface temperature is 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

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

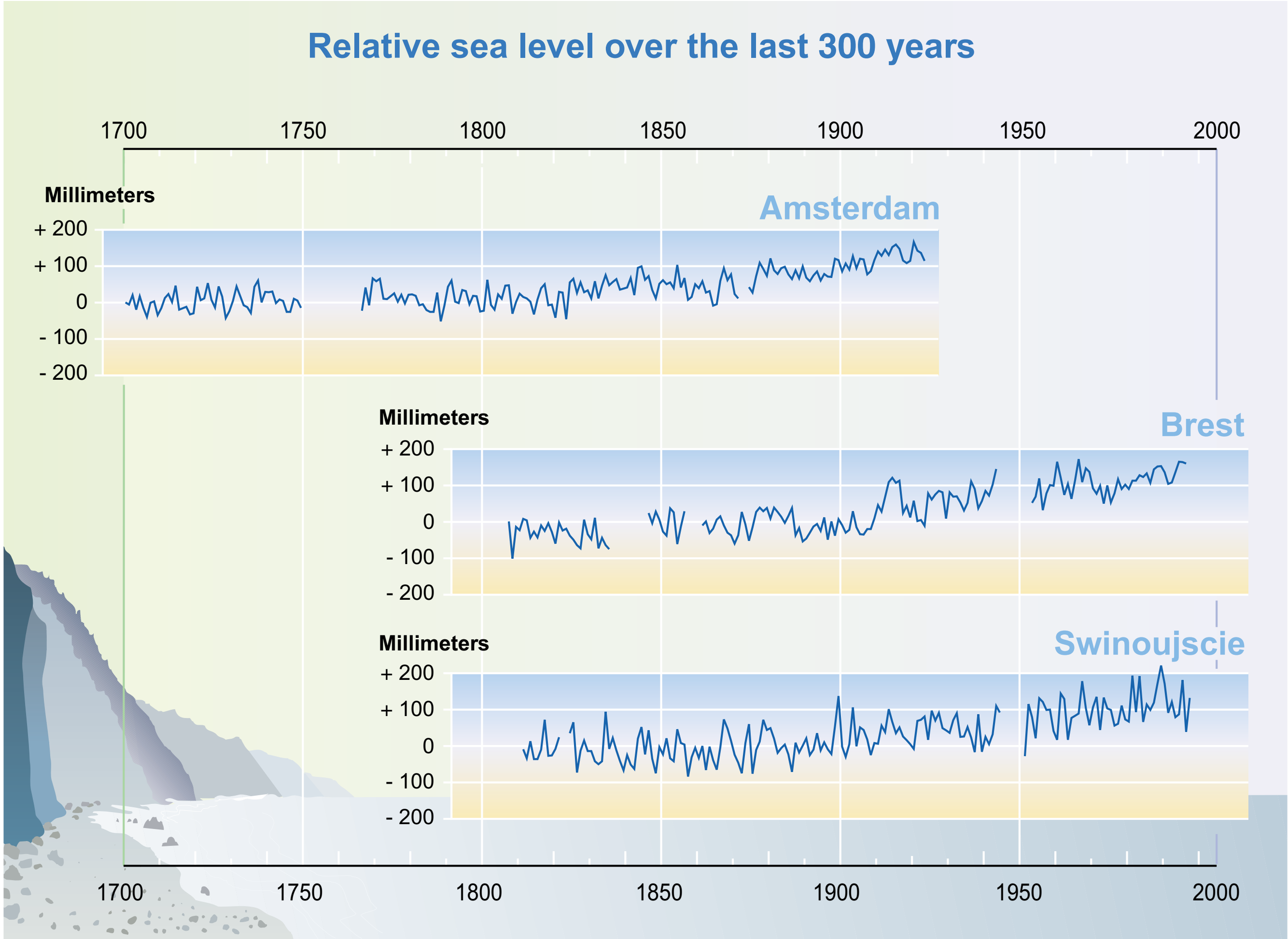


Figure 2-5: A limited number of sites in Europe have nearly continuous records of sea level spanning 300 years and show the greatest rise in sea level over the 20th century. Records shown from Amsterdam, The Netherlands, Brest, France, and Swinoujscie, Poland, as well as other sites, confirm the accelerated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

WGI TAR Figure 11-7

2.17 **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 the years 1976 to 2000 (see Figure 2-6b) is consistent both with the observed changes in natural climate variations, such as the North Atlantic and Arctic Oscillations, and with the modeled pattern of greenhouse gas warming. 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 Sections 2.2.2, 2.6.3, & 2.6.5, & WGII TAR Section 6.3

2.18 **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, subtropics, 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 Niño events.

WGI TAR Section 2.6.2

2.19 **Some important aspects of climate appear *not* 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). Antarctic sea-ice extent has stayed almost stable or even increased since 1978, the period of reliable satellite measurements. Current analyses are unable to draw conclusions about the likelihood of

WGI TAR Sections 2.2.2, 2.2.5, & 2.7.3

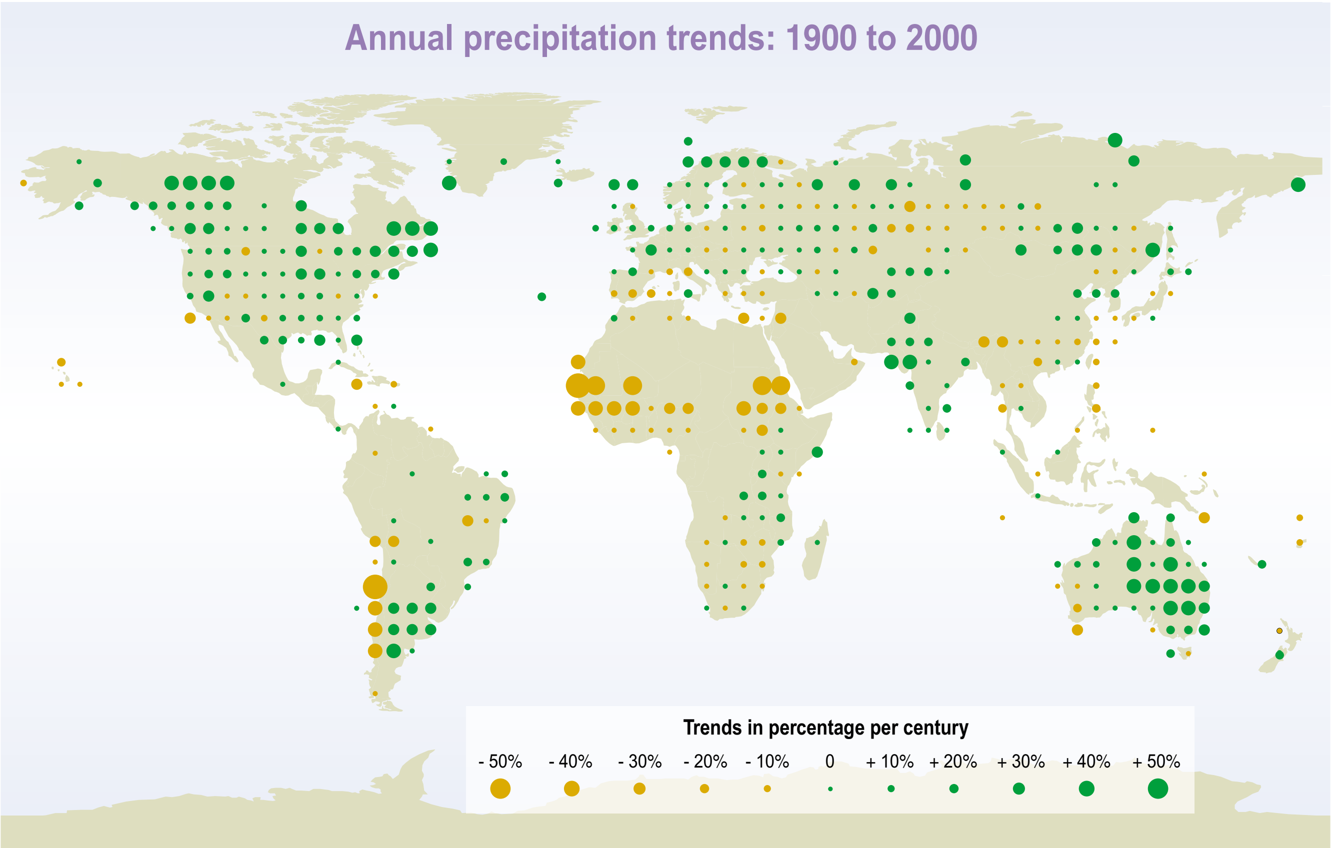


Figure 2-6a: Precipitation during the 20th century has on average increased over continents outside the tropics but decreased in the desert regions of Africa and South America. While the record shows an overall increase consistent with warmer temperatures and more atmospheric moisture, trends in precipitation 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

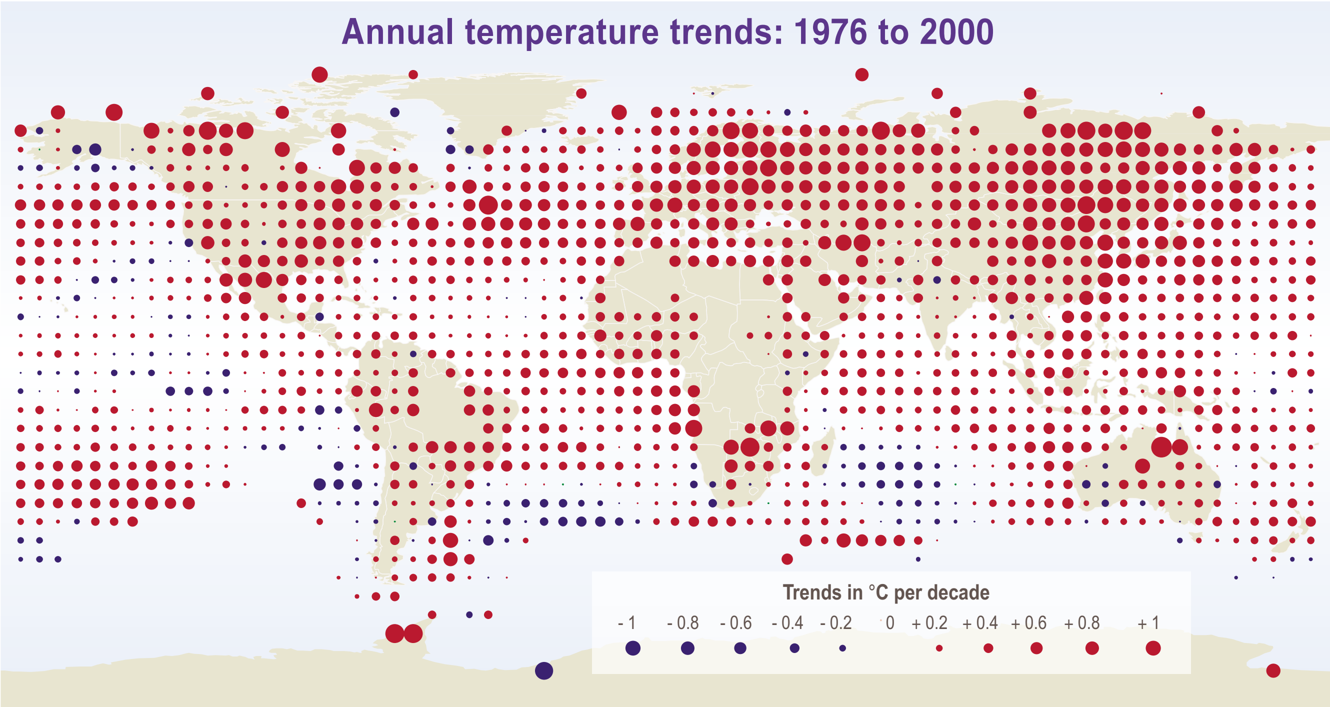


Figure 2-6b: A consistent, large-scale warming of both the land and ocean surface occurred over the last quarter of the 20th century, with largest temperature increases over the mid- and high latitudes of North America, Europe, and Asia. Large regions of cooling occurred only in parts of the Pacific and Southern Oceans and Antarctica. The warming of land faster than ocean surface is consistent both with the observed changes in natural climate variations such as the North Atlantic and Arctic Oscillations and with the modeled pattern of greenhouse-gas warming. 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

changes in the frequency of tornadoes, thunder days, or hail events for the limited regions that have been studied. In addition, insufficient data and conflicting analyses prevent an assessment of changes in intensities of tropical and extra-tropical cyclones and severe local storm activity in the mid-latitudes.

2.20 Observed changes in regional climate over the past 50 years have affected biological and hydrological systems in many parts of the world (see Table 2-1).

2.21 **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[3], 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 (with no reference to magnitude) 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,

WGII TAR Sections 5.4, 5.6.2, 10.1.3.2, 11.2, 13.1.3.1, & 13.2.4.1, & WGII TAR Figure SPM-1

[3] There are 44 regional studies of over 400 plants and animals, which varied in length from about 20 to 50 years, mainly from North America, Europe, and the southern polar region. There are 16 regional studies covering about 100 physical processes over most regions of the world, which varied in length from about 20 to 150 years.

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 (Sahelian drought) and anthropogenic stresses has led to decreased cereal crop production since the year 1970. There are some positive aspects of warming: For example, the growing season across Europe has lengthened by about 11 days from the years 1959 to 1993, and energy consumption for heating in winter has decreased.

2.22 **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.

WGI TAR Section 2.2.2.2 & WGII TAR Sections 6.4.5 & 17.2.4.1

2.23 **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

2.24 **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 Section 2.7.3.3, WGII TAR SPM, WGII TAR Sections 4.3.6, 10.2.1.2, 14.3, & 19.2.2.1, & WGII TAR Table 4-1

2.25 **There are preliminary indications that some human systems have been affected by recent increases in floods and droughts. The rising socio-economic costs related to weather damage and to regional variations in climate suggest increasing vulnerability to climate change (see Table 2-1).**

2.26 **Extreme weather or climatic events cause substantial, and increasing, 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 event of the years 1997–1998. The impacts of climatic extremes and variability are a major concern. Preliminary indications suggest that some social and economic systems have been affected by recent increases in floods and droughts, with increases in economic losses for catastrophic weather events. 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 an order of magnitude from the 1950s to the 1990s (see Figure 2-7), and costs for non-catastrophic weather events have grown similarly. 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. Part of this observed upward trend in weather-related losses over the past 50 years is linked to socio-economic factors (e.g., population growth, increased wealth, urbanization in vulnerable areas), and part is linked to regional climatic factors (e.g., changes in precipitation, flooding events).

WGII TAR SPM & WGII TAR Sections 8.2 & 14.3

2.27 **The fraction of weather-related losses covered by insurance varies considerably by region,** and the uneven impacts of climatic hazards raise issues for development and equity. Insurers pay 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 Sections 8.3.3.1 & 8.5.4

2.28 **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

WGII TAR SPM & WGII TAR Sections 9.5.1, 9.7.8, 10.2.4, & 13.2.5

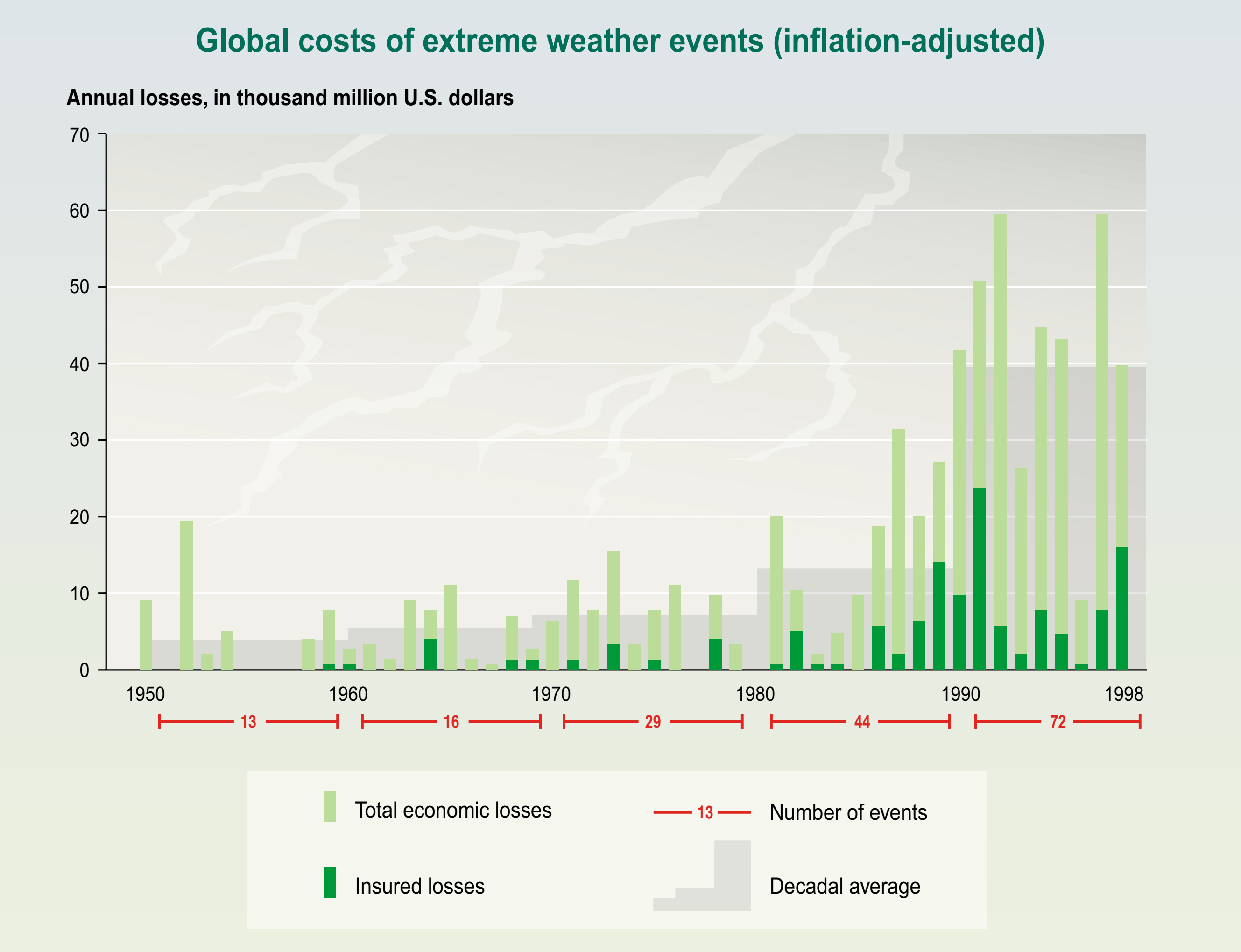


Figure 2-7: The economic losses from catastrophic weather events have risen globally 10-fold (inflation-adjusted) from the 1950s to the 1990s, much faster than can be accounted for with simple inflation. The insured portion of these losses rose from a negligible level to about 23% in the 1990s. The total losses from small, non-catastrophic weather-related events (not included here) are similar. Part of this observed upward trend in weather-related disaster losses over the past 50 years is linked to socio-economic factors (e.g., population growth, increased wealth, urbanization in vulnerable areas), and part is linked to regional climatic factors (e.g., changes in precipitation, flooding events).

WGII TAR Figure 8-1

incidence increased after milder winters and moved northward following the increased frequency of milder winters over the years 1980 to 1994.

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

2.30 **As a consequence of observed and anticipated climate change, socio-economic and policy responses have occurred 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 to assist the developing and least developed countries reduce vulnerabilities and adapt to climate change and engage in mitigation activities.

WGIII TAR Sections 3.2, 3.4-5, 3.8.4, 6.2.2, 6.3.2, & 9.2.1

Question 3

Q3

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.

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 that tend to be based on equilibrium climate change scenarios (e.g., $2xCO_2$), a relatively small number of experiments using a 1% per year CO_2 increase transient scenario, 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 technological 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.

WGI TAR Chapters 3, 4, 5, & 6

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

3.3 **All SRES emissions 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 the year 2100 range from 540 to 970 ppm, compared to about 280 ppm in the pre-industrial era and about 368 ppm in the year 2000 (see Figure 3-1f). These projections include the land and ocean climate feedbacks. The different socio-economic assumptions (demographic, social, economic, and technological) result in different levels of future greenhouse gases and aerosols. Further uncertainties, especially regarding the persistence of the present removal processes (carbon sinks) and the magnitude of the climate feedback on the terrestrial biosphere, cause a variation of about –10 to +30% in the year 2100 concentration, around each scenario. The total range is 490 to 1,260 ppm (75 to 350% above the year 1750 (pre-industrial) concentration).

WGI TAR Section 3.7.3.3

3.4 **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).

WGI TAR Section 4.4.5 & WGI TAR Box 9.1

3.5 **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 (e.g., sea salt, dust, and emissions leading to sulfate and carbon aerosols) are projected to increase as a result of changes in climate.

WGI TAR Section 5.5 & SRES Section 3.6.4

3.6 **The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100 (see Figure 3-1k). This is about two to ten times larger than the central value of observed warming over the 20th century and the projected rate of warming is very likely to be without precedent during at least the last 10,000 years, based on paleoclimate data (see Figure 9-1).** 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.[4] 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 SO_2 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.

WGI TAR Section 9.3.3

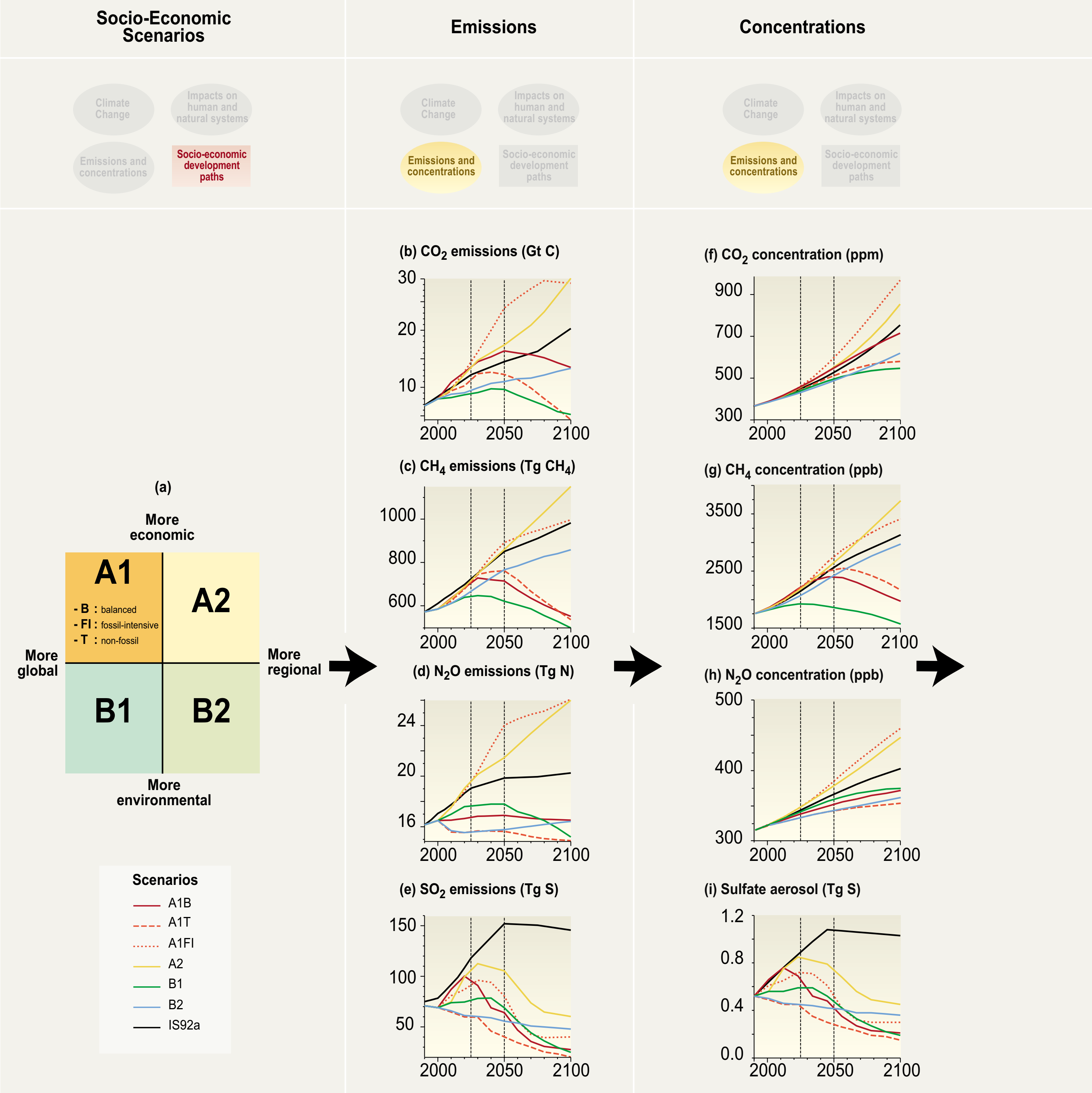
3.7 **By 2100, the range in the surface temperature response across different climate models for the same emissions scenario is comparable to the range across different SRES emissions scenarios for a single climate model.** Figure 3-1 shows that the SRES scenarios with the highest emissions result in the largest projected temperature increases. Further uncertainties arise due to uncertainties in the radiative forcing. The largest forcing uncertainty is that due to the sulfate aerosols.

WGI TAR Section 9.3.3

Figure 3-1: The different socio-economic assumptions underlying the SRES scenarios result in different levels of future emissions of greenhouse gases and aerosols. These emissions in turn change the concentration of these gases and aerosols in the atmosphere, leading to changed radiative forcing of the climate system. Radiative forcing due to the SRES scenarios results in projected increases in temperature and sea level, which in turn will cause impacts. The SRES scenarios do not include additional climate initiatives and no probabilities of occurrence are assigned. 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 experiments using a 1% per year CO_2 increase transient scenario, 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 3.12, 4.14, 5.13, 9.13, 9.14, & 11.12, WGII TAR Figure 19-7, & SRES Figures SPM-2, SPM-5, SPM-6, & TS-10

[4] 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 (years 2071 to 2100) compared with the period 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.



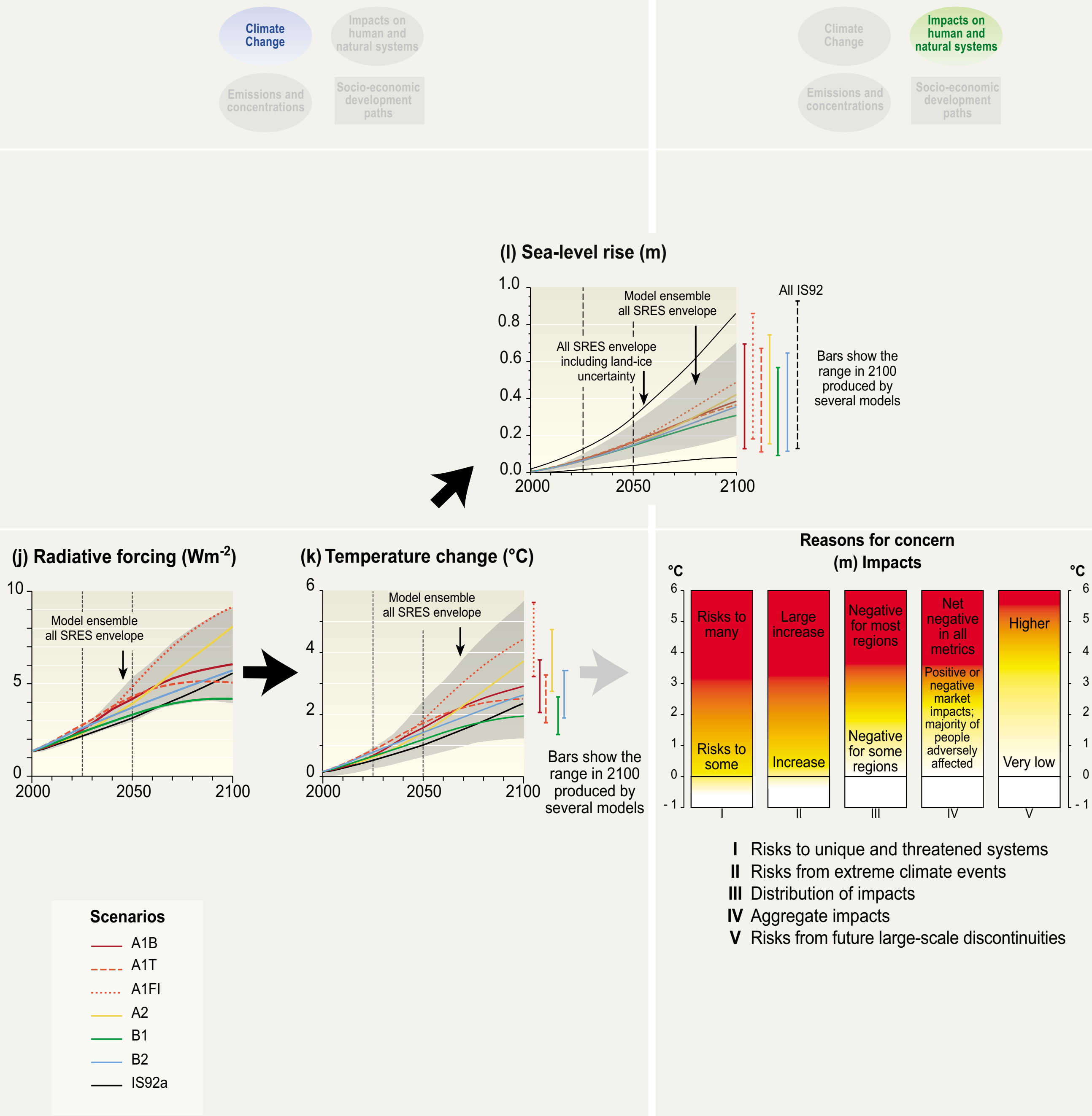
A1FI, A1T, and A1B

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 (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (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).

Radiative Forcing

Temperature and Sea-Level Change

Reasons for Concern



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 environmental 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.

3.8 **Globally averaged annual precipitation is projected to increase during the 21st century.** Globally averaged water vapor and evaporation are also projected to increase.

WGI TAR Section 9.3.1

3.9 **Global mean sea level is projected to rise by 0.09 to 0.88 m between the years 1990 and 2100, for the full range of SRES scenarios (see Figure 3-1l).** 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-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.

WGI TAR Section 11.5.1

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

3.11 **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 3-2).

WGI TAR Section 10.3.2

3.12 **At the regional scale, both increases and decreases in precipitation are projected, typically of 5 to 20%.** It is likely that precipitation will increase over high latitude regions in both summer and winter. Increases are also projected over northern mid-latitudes, tropical Africa and Antarctica in winter, and in southern and eastern Asia in summer. 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 3-3).

WGI TAR Section 10.3.2

3.13 **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 3-4).** 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

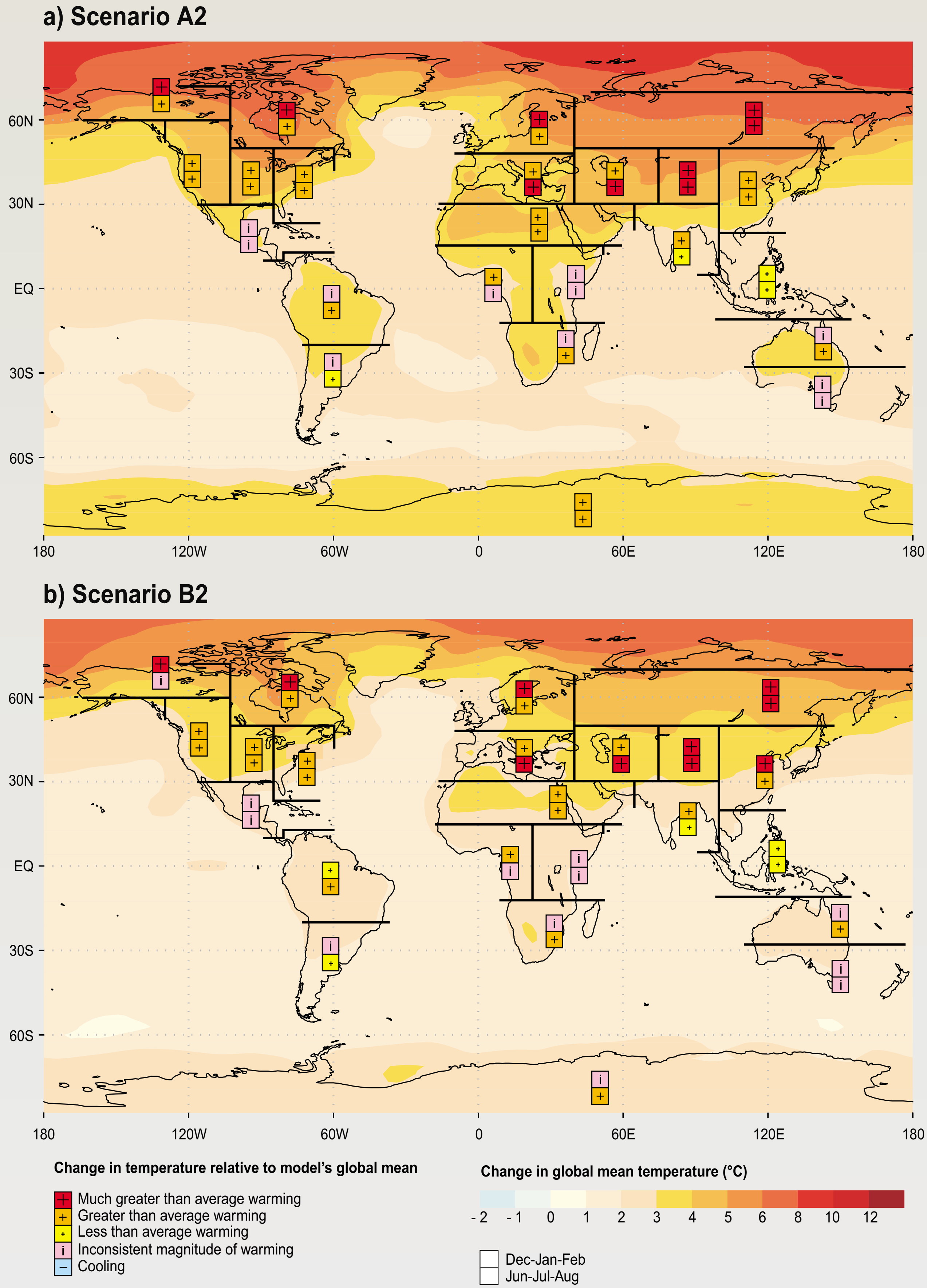
3.14 **Glaciers and ice caps are projected to continue their widespread retreat during the 21st century.** Northern Hemisphere snow cover, permafrost, and sea-ice extent are projected to decrease further. The Antarctic ice sheet is likely to gain mass because of greater precipitation, while the Greenland 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

→ **Figure 3-2: The background shows the annual mean change of temperature (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 relative warming (i.e., warming relative to each model's global average warming) for the same scenarios. 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 (this category 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, & WGI TAR Box 10.1 (Figure 1)

Change in temperature for scenarios A2 and B2



Change in precipitation for scenarios A2 and B2

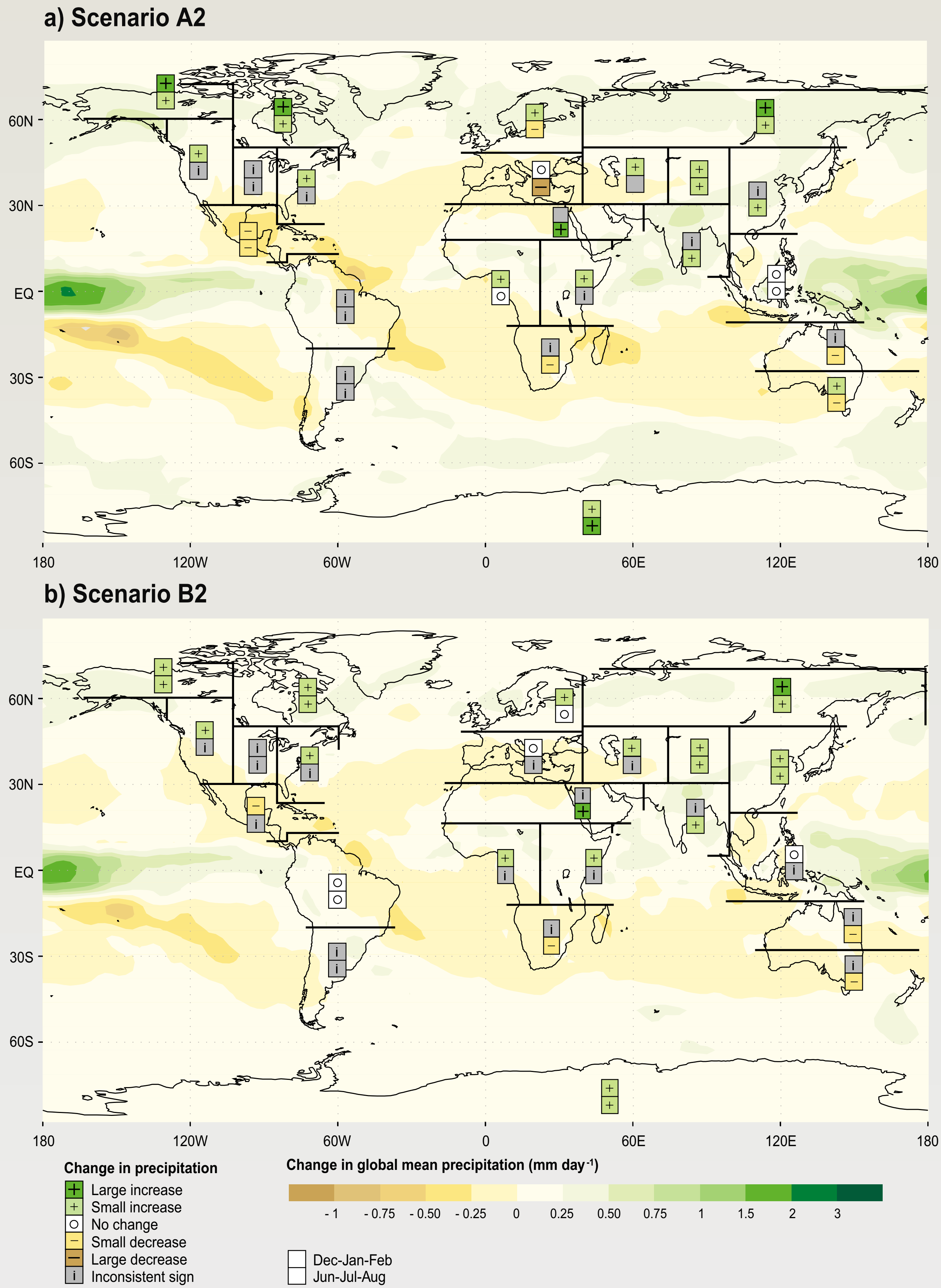


Figure 3-3: The background shows the annual mean change of rainfall (color shading) for (a) the SRES scenario A2 and (b) the SRES scenario B2. Both SRES scenarios show the period 2071 to 2100 relative to the period 1961 to 1990, and were performed by AOGCMs. Scenarios A2 and B2 are shown as no AOGCM 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)

3.15 Projected climate change will have beneficial and adverse environmental and socio-economic effects, but the larger the changes and rate of change in climate, the more the adverse effects predominate.

3.16 **The impacts of climate change will be more severe the greater the cumulative emissions of greenhouse gases (*medium confidence*).** 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 3-1). 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 (see also Question 4).

WGII TAR Sections 1.2, 19.3, 19.5, & 19.8

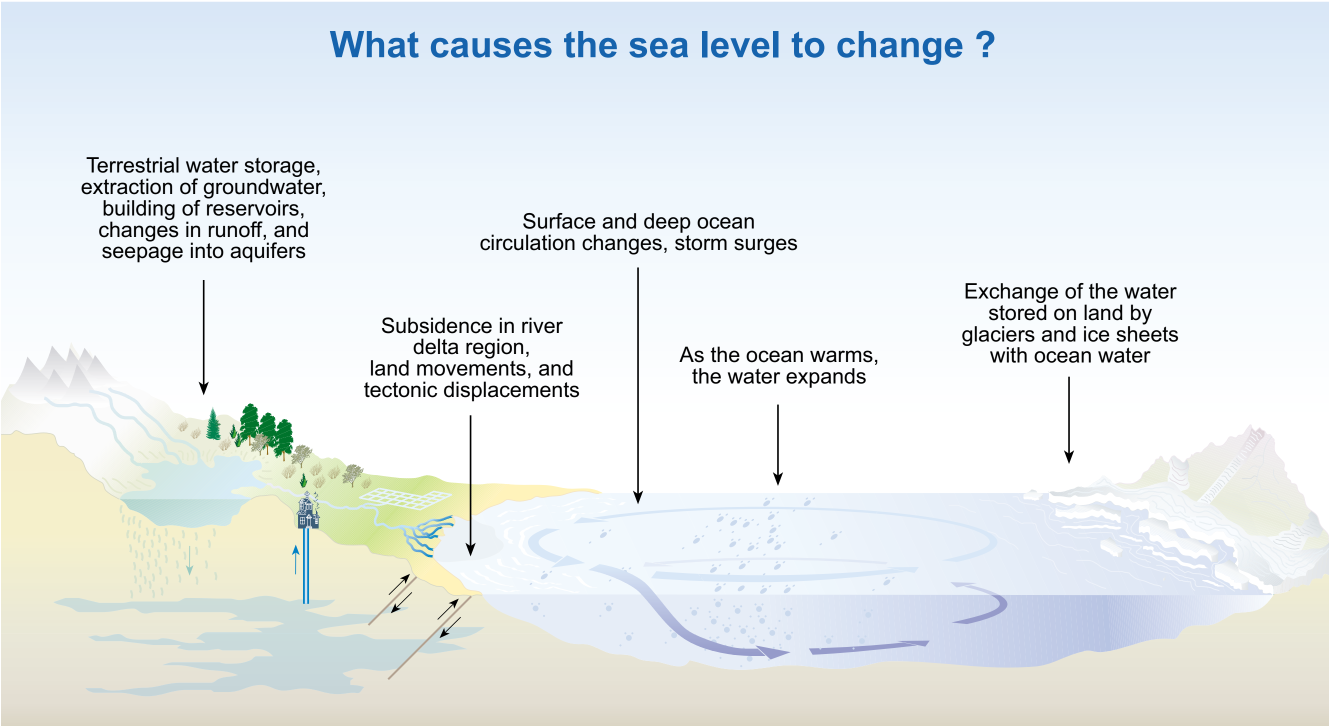


Figure 3-4: The level of the sea at the shoreline is determined by many factors in the global environment that operate on a great range of time scales, from hours (tidal) to millions of years (ocean basin changes due to tectonics and sedimentation). On the time scale of decades to centuries, some of the largest influences on the average levels of the sea are linked to climate and climate change processes.

WGI TAR Box TS-2

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 4).
- *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 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.
- *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 Sections 5.2, 5.4, & 19.3

WGII TAR Sections 15.2 & 19.6

WGII TAR Section 19.4

WGII TAR Section 19.5

WGII TAR Section 19.6

Human Health

3.17 **Overall climate change is projected to increase threats to human health, particularly in lower income populations predominantly within tropical/subtropical countries.** Climate change can affect human health through multiple pathways, including direct effects (e.g., reduced cold stress in temperate countries but increased heat stress, loss of life in floods and storms) and indirect effects that operate through changes in the ranges of disease vectors (e.g., mosquitoes)[5], water-borne pathogens, water quality, air quality, food availability and quality (e.g., decreased protein content in some cereals), population displacement, and economic disruption (*medium to high confidence*). Some effects may be beneficial (e.g., reduced cold stress, and reduced disease transmission in some cases), but the predominant effect is anticipated to be adverse (see Table 3-1). Actual impacts will be strongly influenced by local environmental conditions and socio-economic circumstances, and 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

Biodiversity and Productivity of Ecological Systems

3.18 **Diversity in ecological systems is expected to be affected by climate change and sea-level rise, with an increased risk of extinction of some vulnerable species (*high confidence*).** Significant disruptions of ecosystems from disturbances such as fire, drought, pest infestation, invasion of 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

WGII TAR Sections 5.2.3, 5.4.1, 16.2, 17.2, & 19.3.2-3

[5] Eight studies have modeled the effects of climate change on these diseases, five on malaria and three on dengue. Seven use a biological or process-based approach, and one uses an empirical, statistical approach.

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

	2025	***2050***	***2100***
CO_2 concentration[a]	405–460 ppm	445–640 ppm	540–970 ppm
Global mean temperature change from the year 1990[b]	0.4–1.1°C	0.8–2.6°C	1.4–5.8°C
Global mean sea-level rise from the year 1990[b]	3–14 cm	5–32 cm	9–88 cm
Human Health Effects[c]			
Heat stress and winter mortality [WGII TAR Section 9.4]	Increase in heat-related deaths and illness (*high confidence*[d]). Decrease in winter deaths in some temperate regions (*high confidence*[d]).	Thermal stress effects amplified (*high confidence*[d]).	Thermal stress effects amplified (*high confidence*[d]).
Vector- and water-borne diseases [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 and storms [WGII TAR Sections 3.8.5 & 9.5]	Increase in deaths, injuries, and infections associated with extreme weather (*medium confidence*[d]).	Greater increases in deaths, injuries, and infections (*medium confidence*[d]).	Greater increases in deaths, injuries, and infections (*medium confidence*[d]).
Nutrition [WGII TAR Sections 5.3.6 & 9.9]	Poor are vulnerable to increased risk of hunger, but state of science very incomplete.	Poor remain vulnerable to increased risk of hunger.	Poor remain vulnerable to increased risk of hunger.

[a] The reported ranges for CO_2 concentration are estimated with fast carbon cycle models for the six illustrative SRES scenarios and 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 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 SO_2 emissions. See WGI TAR Sections 9.3.3 and 11.5.1.
[c] Summary statements about effects of climate change in the years 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 the years 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 the year 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 Box 1-1.

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). Possible adaptation methods to reduce the loss of biodiversity include the establishment of refuges, parks and reserves with corridors to allow migration of species, and the use of captive breeding and translocation of species.

3.19 **The productivity of ecological systems is highly sensitive to climate change and projections of change in productivity range from increases to decreases (*medium confidence*).** 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. 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.

WGI TAR Section 3.7 & WGII TAR Sections 5.2.2 & 5.6.3

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

	2025	***2050***	***2100***
CO_2 concentration[a]	405–460 ppm	445–640 ppm	540–970 ppm
Global mean temperature change from the year 1990[b]	0.4–1.1°C	0.8–2.6°C	1.4–5.8°C
Global mean sea-level rise from the year 1990[b]	3–14 cm	5–32 cm	9–88 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,f] 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]). Increase in net primary productivity may or may not continue. Increase in frequency of ecosystem disturbance by fire and insect pests (*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]). Increase in frequency of ecosystem disturbance by fire and insect pests (*high 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]).[f]	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 footnotes a-d accompanying Table 3-1.
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.
f These effects have already been observed and are expected to continue [TAR WGII Sections 5.2.1, 5.4.3, 16.1.3, & 19.2].

3.20 **The terrestrial ecosystems at present are a carbon sink which may diminish with increased warming by the end of the 21st century (see Table 3-2) (*medium confidence*).** The terrestrial ecosystems at present are a sink for carbon. This is partly a result of delays between enhanced plant growth and plant death and decay. Current enhanced plant growth is partly due to fertilization effects of elevated CO_2 on plant photosynthesis (either directly via increased carbon assimilation, or indirectly through higher water-use efficiency), nitrogen deposition (especially in the Northern Hemisphere), climate change, and land-use practices over past decades. The uptake will decline as forests reach maturity, fertilization effects saturate and decomposition catches up with growth, and possibly through changes in disturbance regimes (e.g., fire and insect outbreaks) mediated through climate change. Some global models project that the net uptake of carbon by terrestrial ecosystems

WGI TAR Section 3.2.2, WGII TAR Sections 5.2, 5.5-6, & 5.9, & SRLULUCF Section 1.4

will increase during the first half of the 21st century but may diminish and even become a source with increased warming towards the end of the 21st century.

Agriculture

3.21 **Models of cereal crops indicate that in some temperate areas potential yields increase for small increases in temperature but decrease with larger temperature changes (*medium to low confidence*). In most tropical and subtropical regions potential yields are projected to decrease for most projected increases in temperature (*medium confidence*) (see Table 3-3).** 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 a few °C or more is projected to increase food prices globally, and may increase the risk of hunger in vulnerable populations (*low confidence*).

WGII TAR Sections 5.3.4-6, & 9.9

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

	2025	***2050***	***2100***
CO_2 concentration[a]	405–460 ppm	445–640 ppm	540–970 ppm
Global mean temperature change from the year 1990[b]	0.4–1.1°C	0.8–2.6°C	1.4–5.8°C
Global mean sea-level rise from the year 1990[b]	3–14 cm	5–32 cm	9–88 cm
Agricultural Effects[c]			
Average crop yields[g] [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*[d]). Cereal crop yields decrease in most tropical and subtropical regions (*low to medium confidence*[d]).	Mixed effects on cereal yields in mid-latitude regions. More pronounced cereal yield decreases in tropical and subtropical regions (*low to medium confidence*[d]).	General reduction in cereal yields in most mid-latitude regions for warming of more than a few °C (*low to medium confidence*[d]).
Extreme low and high temperatures [WGII TAR Section 5.3.3]	Reduced frost damage to some crops (*high confidence*[d]). Increased heat stress damage to some crops (*high confidence*[d]). Increased heat stress in livestock (*high confidence*[d]).	Effects of changes in extreme temperatures amplified (*high confidence*[d]).	Effects of changes in extreme temperatures amplified (*high confidence*[d]).
Incomes and prices [WGII TAR Sections 5.3.5-6]		Incomes of poor farmers in developing countries decrease (*low to medium confidence*[d]).	Food prices increase relative to projections that exclude climate change (*low to medium confidence*[d]).

* Refer to footnotes a-d accompanying Table 3-1.
[g] These estimates are based on the sensitivity of the present agricultural practices to climate change, allowing (in most cases) for adaptations based on shifting use of only existing technologies.

Water

3.22 **Projected climate change would exacerbate water shortage and quality problems in many water-scarce areas of the world, but alleviate it in some other areas.** Demand for water is generally increasing due to population growth and economic development, but is falling in some countries because of increased efficiency of use. Climate change is projected to reduce streamflow and groundwater recharge in many parts of the world but to increase it in some other areas (*medium confidence*). The amount of change varies among scenarios partly because of differences in projected rainfall (especially rainfall intensity) and partly because of differences in projected evaporation. Projected streamflow changes under two climate change scenarios are shown in Figure 3-5. Several hundred million to a few billion people are projected to suffer a supply reduction of 10% or more by the year 2050 for climate change projections corresponding to 1% per year increase in CO_2 emissions (see Table 3-4). Freshwater quality generally would be degraded by higher water temperatures (*high confidence*), but this may be offset by increased flows in some regions. 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, 4.5.2, & 4.6

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

	2025	***2050***	***2100***
CO_2 concentration[a]	405–460 ppm	445–640 ppm	540–970 ppm
Global mean temperature change from the year 1990[b]	0.4–1.1°C	0.8–2.6°C	1.4–5.8°C
Global mean sea-level rise from the year 1990[b]	3–14 cm	5–32 cm	9–88 cm
Water Resource Effects[c]			
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. Water quality changes modified by changes in water flow volume. Increase in saltwater intrusion into coastal aquifers due to sea-level rise (*medium confidence*[d]).	Water quality degraded by higher temperatures(*high confidence*[d]). Water quality changes modified by changes in water flow volume (*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 footnotes a-d accompanying Table 3-1.

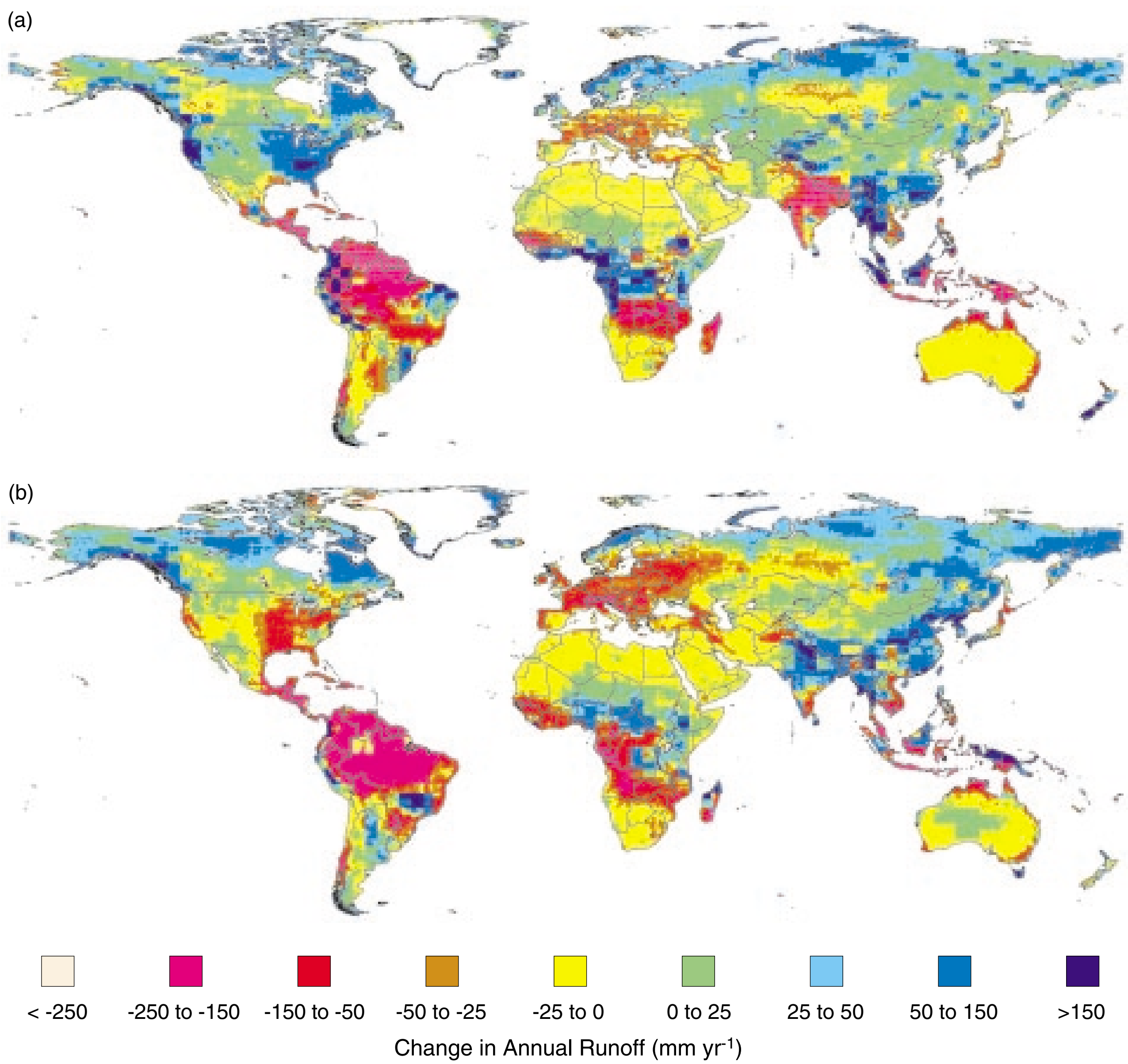


Figure 3-5: Projected changes in average annual water runoff by the year 2050, relative to average runoff for the period 1961–1990, largely follow projected changes in precipitation. Changes in runoff are calculated with a hydrologic model using as inputs climate projections from two versions of the Hadley Centre AOGCM for a scenario of 1% per year increase in effective CO_2 concentration in the atmosphere: (a) HadCM2 ensemble mean and (b) HadCM3. Projected increases in runoff in high latitudes and southeast Asia, and decreases in central Asia, the area around the Mediterranean, southern Africa, and Australia are broadly consistent across the Hadley Centre experiments, and with the precipitation projections of other AOGCM experiments. For other areas of the world, changes in precipitation and runoff are scenario- and model-dependent.

WGII TAR Section 4.3.6

Small Islands and Low-Lying Coasts

3.23 **Populations that inhabit small islands and/or low-lying coastal areas are at particular risk of severe social and economic effects from sea-level rise and storm surges.** Many human settlements will face increased risk of coastal flooding and erosion, and tens of millions of people living in deltas, low-lying coastal areas, and on small islands will face the risk of displacement of populations and loss of infrastructure and/or substantial efforts and costs to protect vulnerable coastal areas. Resources critical

WGII TAR Sections 7.2.2, 17.2, & 19.3.4

to island and coastal populations such as freshwater, fisheries, coral reefs and atolls, beaches, and wildlife habitat would also be at risk.

3.24 **Projected sea-level rise will increase the average annual number of people flooded in coastal storm surges (*high confidence*).** 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

Market Effects

3.25 **The aggregated market sector effects, measured as changes in gross domestic product (GDP), are estimated to be negative for many developing countries for all magnitudes of global mean temperature increases studied (*low confidence*), and are estimated to be mixed for developed countries for up to a few °C warming (*low confidence*) and negative for warming beyond a few °C (*medium to low confidence*).** 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

WGII TAR Sections 6.5, 7.2-3, 8.3, 18.3.4, 18.4.3, 19.4.1-3, & 19.5

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

	2025	***2050***	***2100***
CO_2 concentration[a]	405–460 ppm	445–640 ppm	540–970 ppm
Global mean temperature change from the year 1990[b]	0.4–1.1°C	0.8–2.6°C	1.4–5.8°C
Global mean sea-level rise from the year 1990[b]	3–14 cm	5–32 cm	9–88 cm
Other Market Sector Effects[c]			
Energy [WGII TAR Section 7.3]	Decreased energy demand for heating buildings (*high confidence*[d]). Increased energy demand for cooling buildings (*high confidence*[d]).	Energy demand effects amplified (*high confidence*[d]).	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 Sections 19.4-5]	Net market sector losses in many developing countries (*low confidence*[d]). Mixture of market gains and losses in developed countries (*low confidence*[d]).	Losses in developing countries amplified (*medium confidence*[d]). Gains diminished and losses amplified in developed countries (*medium confidence*[d]).	Losses in developing countries amplified (*medium confidence*[d]). Net market sector losses in developed countries from warming of more than a few °C (*medium confidence*[d]).

* Refer to footnotes a-d accompanying Table 3-1 and footnote e accompanying Table 3-2.

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 GDP would change by plus or minus a few percent for global mean temperature increases of up to a few °C, with increasing net losses for larger increases in temperature. The estimates generally exclude the effects of changes in climate variability and extremes, do not account for the effects of different rates of climate change, only partially account for impacts on goods and services that are not traded in markets, and treat gains for some as canceling out losses for others. Therefore, 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.

3.26 Adaptation has the potential to reduce adverse effects of climate change and can often produce immediate ancillary benefits, but will not prevent all damages.

3.27 **Numerous possible adaptation options for responding to climate change have been identified that can reduce adverse and enhance beneficial impacts of climate change, but will incur costs.** Quantitative evaluation of their benefits and costs and how they vary across regions and entities is incomplete. 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 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 summarized.

WGII TAR Sections 18.2.3 & 18.3.5

3.28 **Greater and more rapid climate change would pose greater challenges for adaptation and greater risks of damages than would 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. Natural and human systems 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 lead to 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

3.29 **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 such efforts may not be as effective in the future as the amount and rate of climate change increase.

WGII TAR Sections 18.2.2 & 18.3.5

3.30 **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

WGII TAR Sections 5.3.4, 6.5.1, & 18.3.2

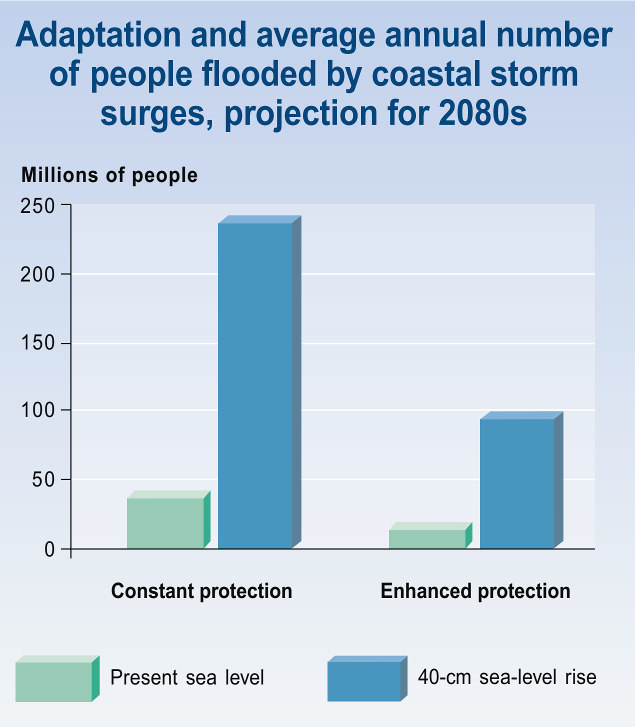
Table 3-6 Examples of adaptation options for selected sectors.

Sector/System	***Adaptation Options***
Water [WGII TAR Sections 4.6 & 7.5.4; 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, and other infrastructure for flood protection.
Food and fiber [WGII TAR Sections 5.3.4-5; WGII SAR Sections 2.9, 4.4.4, 13.9, & 15.6; SRTT Section 11.2.1]	Change timing of planting, harvesting, and other management activities. Use minimum tillage and other practices to improve nutrient and moisture retention in soils and to prevent soil erosion. Alter animal stocking rates on rangelands. Switch to crops or crop cultivars that are less water-demanding and more tolerant of heat, drought, and pests. Conduct research to develop new cultivars. Promote agroforestry in dryland areas, including establishment of village woodlots and use of shrubs and trees for fodder. Replant with mix of tree species to increase diversity and flexibility. Promote revegetation and reforestation initiatives. 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 and marine fisheries [WGII TAR Sections 6.6 & 7.5.4; 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 7.5.4 & 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. Integrate urban designs to reduce heat island effect (e.g., use of vegetation and light colored surfaces). Conduct 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.

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.

3.31 **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

WGII TAR Sections 6.5.2 & 18.4.3



WGII TAR Section 6.5.1

Figure 3-6: Adaptation and the average annual number of people flooded by coastal storm surges, projection for the 2080s. The left two bars show the average annual number of people projected to be flooded by coastal storm surges in the year 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.

of "hard structures" such as dikes, levees, and seawalls, and the use of "soft structures" such as nourishment of beaches 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 the year 2100 that range from US$20 billion to US$150 billion in present value.

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

WGII TAR Sections 18.5.1-3

3.33 **The impacts of climate change will fall disproportionately upon developing countries and the poor persons within all 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 1.2.2, 4.7, 5.1, 6.3.4, & 6.4.4

3.34 **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.

3.35 **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

3.36 **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 change and increased climate variability, 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

3.37 **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 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.

WGII TAR Section 18.6.1

Question 4

Q4

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?

4.1 This answer focuses on projected changes in the frequency and magnitude of climate fluctuations as a result of increasing concentrations of greenhouse gases and aerosols. 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 **Models project that increasing atmospheric concentrations of greenhouse gases will result in changes in daily, seasonal, inter-annual, and decadal variability.** There is projected to be a decrease in diurnal temperature range in many areas, with nighttime lows increasing more than daytime highs. A number of models show a general decrease of daily variability of surface air temperature in winter and increased daily variability in summer in the Northern Hemisphere land areas. Current projections show little change or a small increase in amplitude for El Niño events over the next 100 years. Many models show a more El Niño-like mean response in the tropical Pacific, with the central and eastern equatorial Pacific sea surface temperatures projected to warm more than the western equatorial Pacific and with a corresponding mean eastward shift of precipitation. Even with little or no change in El Niño strength, 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. There is no clear agreement between models concerning the changes in frequency or structure of other naturally occurring atmosphere-ocean circulation pattern such as the North Atlantic Oscillation (NAO).

WGI TAR Sections 9.3.5-6, & WGII TAR Section 14.1.3

4.3 **The duration, location, frequency, and intensity of extreme weather and climate events are likely to very likely to change, and would result in mostly adverse impacts on biophysical systems.**

4.4 Natural circulation patterns, such as ENSO and NAO, play a fundamental role in global climate and its short-term (daily, intra- and inter-annual) and longer term (decadal to multi-decadal) variability. Climate change may manifest itself as a shift in means as well as a change in preference of specific climate circulation patterns that could result in changes in the variance and frequency of extremes of climatic variables (see Figure 4-1).

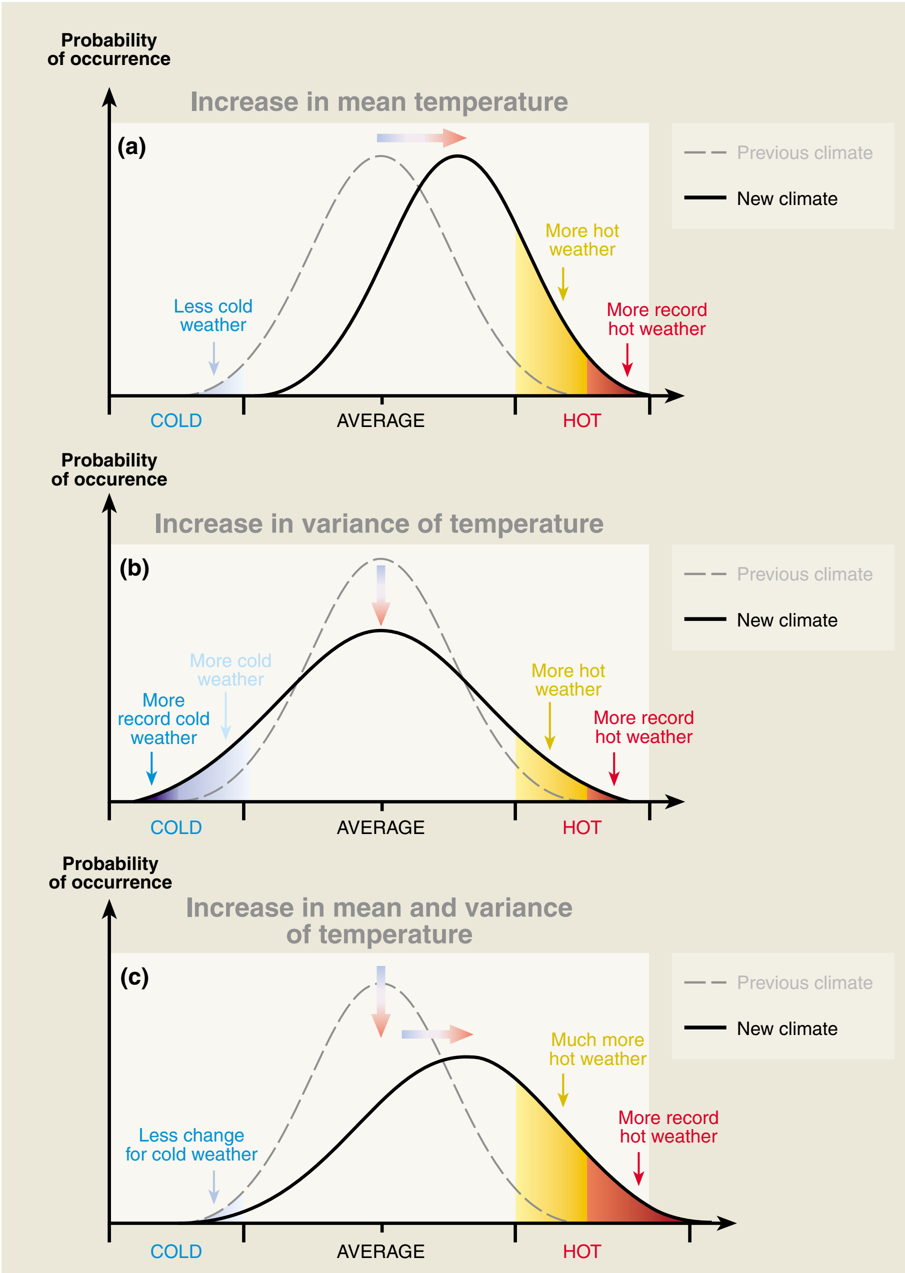
WGI TAR Sections 1.2 & 2.7

4.5 **More hot days and heat waves and fewer cold and frost days are very likely over nearly all land areas.** Increases in mean temperature will lead to increases in 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, higher energy use for cooling and lower for heating, and increased human morbidity and heat-stress-related mortality (see Table 4-1). 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 GDP of temperate zone countries.

WGI TAR Sections 9.3.6 & 10.3.2, & WGII TAR Sections 5.3, 9.4.2, & 19.5

4.6 **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. This would lead to more frequent floods and landslides with attendant loss of life, health impacts (e.g., epidemics, 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 general drying is due to a combination of increased temperature and potential evaporation that is not balanced by increases in precipitation. It is likely that global warming will lead to an increase in the variability of Asian summer monsoon precipitation.

WGI TAR Section 9.3.6 & WGII TAR Sections 4.3.8, 9.5.3, 9.7.10, & 9.8



WGI TAR Figure 2.32

Figure 4-1: Schematic diagrams showing the effects on extreme temperatures when (a) the mean increases, leading to more record hot weather, (b) the variance increases, and (c) when both the mean and variance increase, leading to much more record hot weather.

4.7 **High resolution modeling studies suggest that over some areas the peak wind intensity of tropical cyclones is likely to increase** by 5 to 10% and precipitation rates may increase by 20 to 30%, but none of the studies suggest that the locations of the tropical cyclones will change. There is little consistent modeling evidence for changes in the frequency of tropical cyclones.

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, hailstorms, and lightning are not simulated in global climate models.

WGI TAR Section 9.3.6

4.9 **Greenhouse gas forcing in the 21st century could set in motion large-scale, high-impact, non-linear, and potentially abrupt changes in physical and biological systems over the coming decades to millennia, with a wide range of associated likelihoods.**

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.

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 millennia. 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; & SRLULUCF Chapters 3 & 4

4.11 **Large climate-induced increases in greenhouse gas emissions due to large-scale changes in soils and vegetation may be possible in the 21st century.** 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,

WGII TAR Sections 5.2, 5.8, & 5.9; & SRLULUCF Chapters 3 & 4

boreal and tropical forests, and their associated peatlands leaving them susceptible to fires. Such breakdowns could induce further climate change through increased emissions of CO_2 and other greenhouse gases from plants and soil and changes in surface properties and albedo.

4.12 **Large, rapid increases in atmospheric CH_4 either from reductions in the atmospheric chemical sink or from release of buried CH_4 reservoirs appear exceptionally unlikely.** The rapid increase in CH_4 lifetime possible with large emissions of tropospheric pollutants does not occur within the range of SRES scenarios. The CH_4 reservoir buried in solid hydrate deposits under permafrost and ocean sediments is enormous, more than 1,000-fold the current atmospheric content. A proposed climate feedback occurs when the hydrates decompose in response to warming and release large amounts of CH_4; however, most of the CH_4 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. The feedback has not been quantified, but there are no observations to support a rapid, massive CH_4 release in the record of atmospheric CH_4 over the past 50,000 years.

WGI TAR Section 4.2.1.1

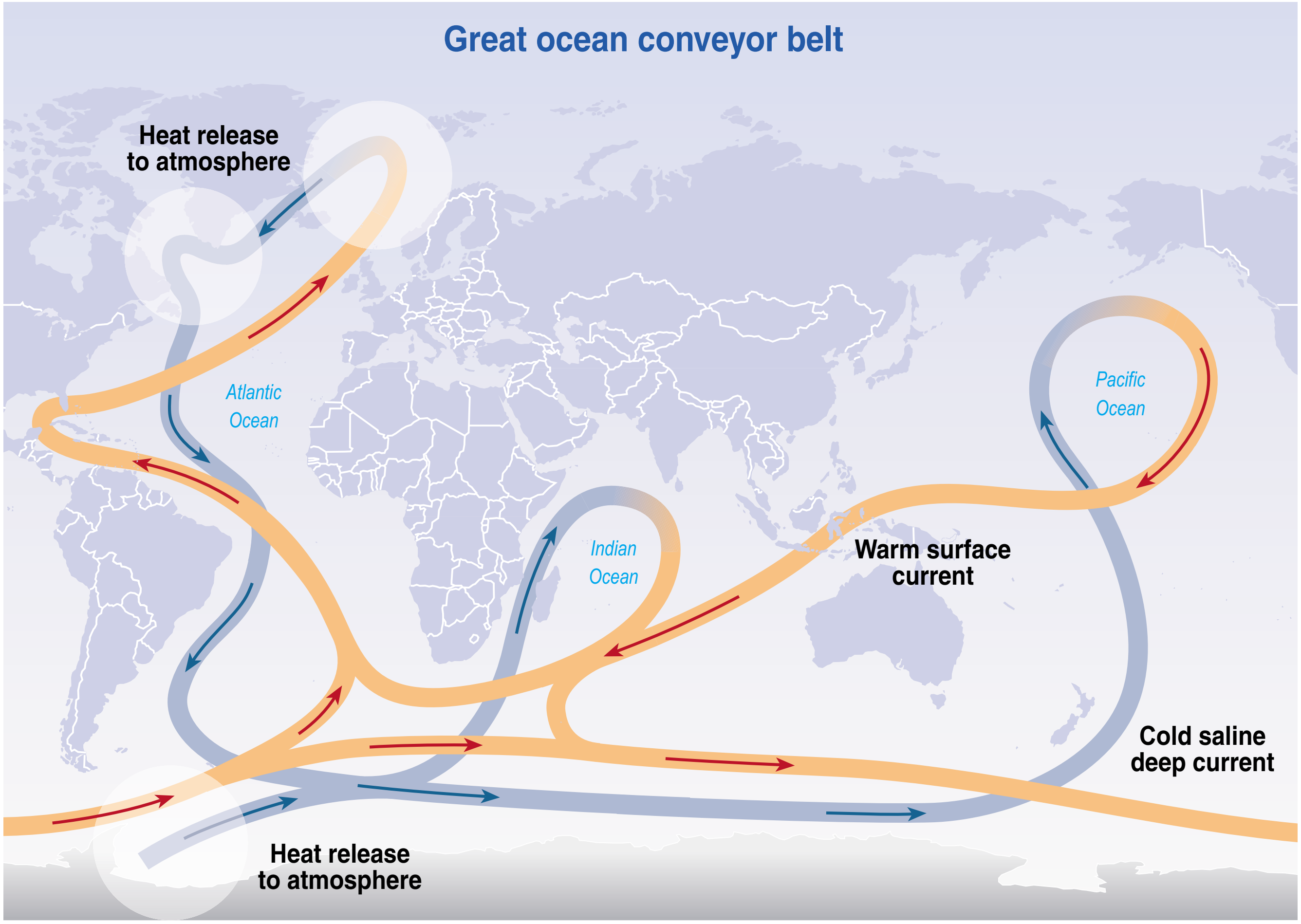


Figure 4-2: Schematic illustration of the global circulation system in the world ocean consisting of major north-south thermohaline circulation routes in each ocean basin joining in the Antarctic circumpolar circulation. Warm surface currents and cold deep currents are connected in the few areas of deepwater 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. Note that this is a schematic diagram and it does not give the exact locations of the water currents that form part of the THC.

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 THC weakens, there is still a warming over Europe due to increased concentrations of greenhouse gases. The current projections do not exhibit a complete shutdown of THC by the year 2100. Beyond the year 2100, some models suggest that THC 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 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 & WGI TAR Sections 7.3 & 9.3.4

4.14 **The Antarctic ice sheet as a whole is likely to increase in mass during the 21st century. However, the West Antarctic ice sheet could lose mass over the next 1,000 years with an associated sea-level rise of several meters, but there is an incomplete understanding of some of the underlying processes.** Concerns have been expressed about the stability of the West Antarctic ice sheet 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 very 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 relative decrease of several centimeters to sea level. Over the next 1,000 years, these models project that the West Antarctic ice sheet could contribute up to 3 m to sea-level rise.

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 centimeters 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 and contribute 10 cm maximum to the total sea-level rise. The ice sheets will continue to react to climate warming and contribute to sea-level rise for thousands of years after climate has stabilized. Climate models indicate that the local warming over Greenland is likely to be one to three times the global average. Ice sheet models project that a local warming of larger than 3°C, if sustained for thousands of years, would lead to virtually a complete melting of the Greenland ice sheet with a resulting sea-level rise of about 7 m. A local warming of 5.5°C, if sustained for 1,000 years, would likely result in a contribution from Greenland of about 3 m to sea-level rise (see Question 3).

WGI TAR Section 11.5.4

4.16 **Pronounced changes in permafrost temperature, surface morphology, and distribution are expected in the 21st century.** 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 to 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 emission of greenhouse gases, conversion of forest to bogs, grasslands, or wetland ecosystems and could cause major erosion problems and landslides.

WGII TAR Sections 16.1-2

4.17 Many natural and managed ecosystems may change abruptly or non-linearly during the 21st century. The greater the magnitude and rate of the change, the greater the risk of adverse impacts.

4.18 **Changes in climate could increase the risk of abrupt and non-linear changes in many ecosystems, which would affect their biodiversity, productivity, and**

WGII TAR Sections 5.2, 6.4.5, & 17.2.4

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., excessive pollution and 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 also shift suitable habitats for many terrestrial and marine organisms polewards or terrestrial ones to higher altitudes in mountainous areas. Increased disturbances along with the shift in habitats and the more restrictive conditions needed for establishment of species could lead to abrupt and rapid breakdown of terrestrial and marine ecosystems, which could result in new plant and animal assemblages that are less diverse, that include more "weedy" species, and that increase risk of extinctions (see Question 3).

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:

- Temperature increase beyond a threshold, which varies by crop and variety, can affect key development stages of some crops and result in severe losses in crop yields. Examples of key development stages and their critical thresholds include spikelet sterility in rice (e.g., temperatures greater than 35°C for more than 1 hour during the flowering and pollination process greatly reduce flower formation and eventually grain production), loss of pollen viability in maize (>35°C), reversal of cold-hardening in wheat (>30°C for more than 8 hours), and reduced formation of tubers and tuber bulking in potatoes (>20°C). Yield losses in these crops can be severe if temperatures exceed critical limits for even short periods.
- Mangroves occupy a transition zone between sea and land that is set by a balance between the erosional processes from the sea and siltation processes from land. The erosional

WGII SAR Sections 13.2.2 & 13.6.2

WGII TAR Sections 5.3, 10.2.2, 15.2, & 17.2

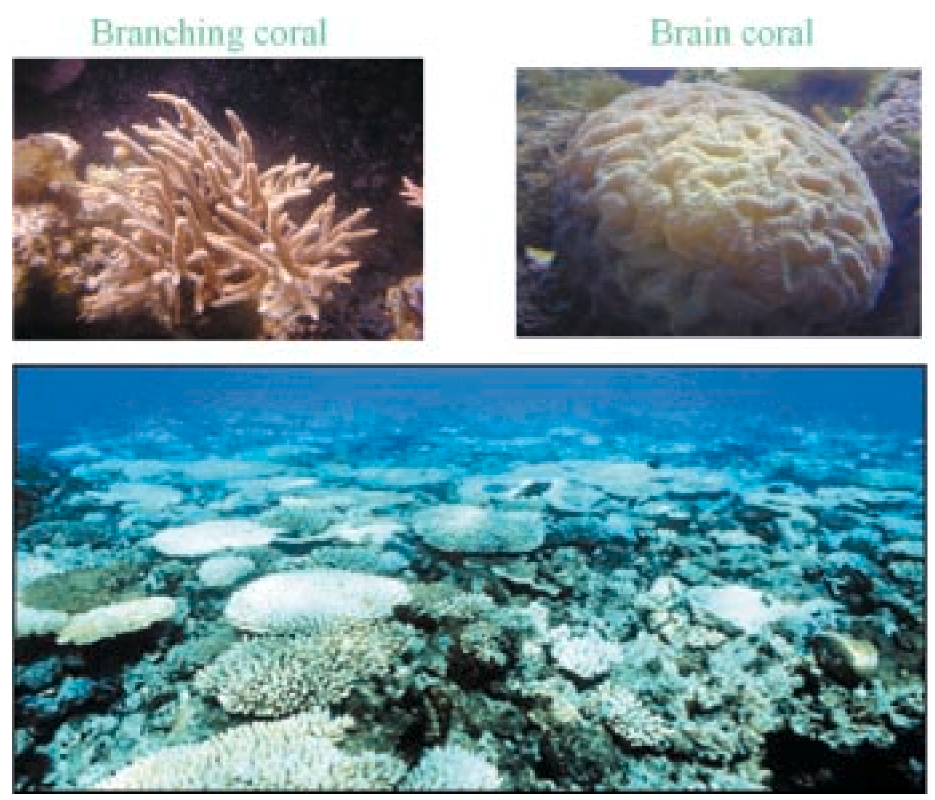


Figure 4-3: The diversity of corals could be affected with the branching corals (e.g., staghorn coral) decreasing or becoming locally extinct as they tend to be more severely affected by increases in sea surface temperatures, and the massive corals (e.g., brain corals) increasing.

WGII TAR Section 17.2.4

processes from the sea might be expected to increase with sea-level rise, and the siltation processes through climate change and other human activities (e.g., coastal development). Thus, 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.

4.20 **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 albedo affect the local hydrologic cycle, thus a reduction in vegetative cover could lead to reduced precipitation at the local/regional scale and change the frequency and persistence of droughts.

WGII TAR Sections 1.3.1, 5.2, 5.9, 10.2.6.3, 13.2.2, 13.6.2, & 14.2.1

Question 5

Q5

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?

Box 5-1 Time scale and inertia.

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 taken 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.

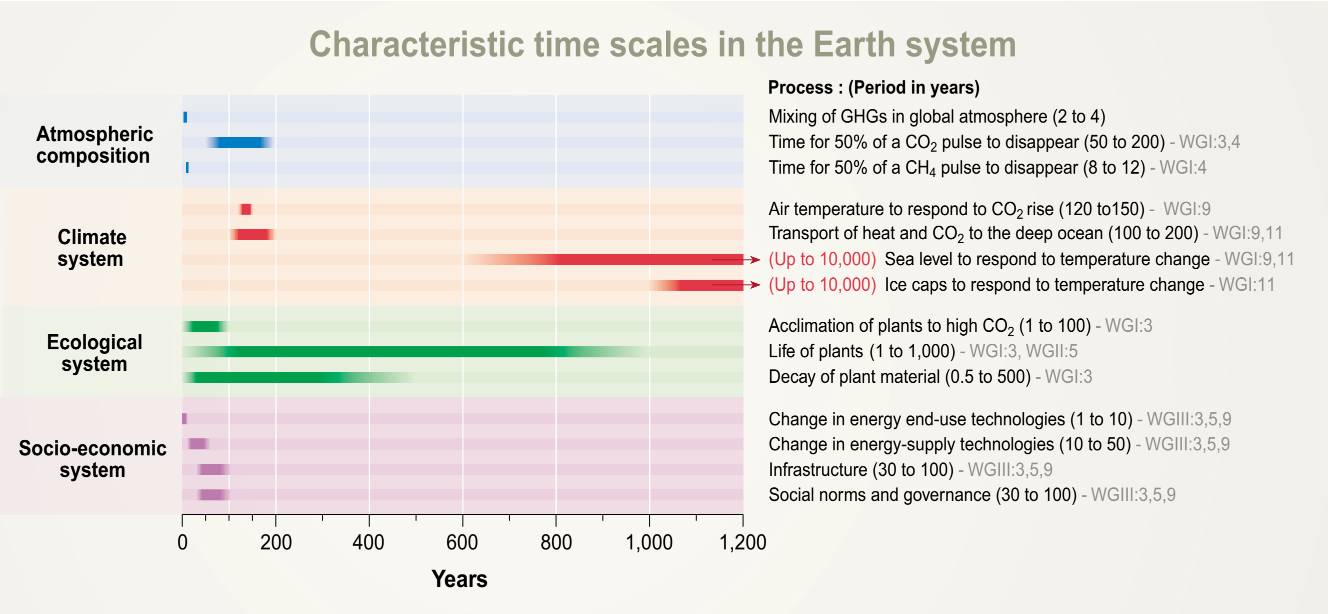


Figure 5-1: The characteristic time scales of some key processes in the Earth system: atmospheric composition (blue), climate system (red), ecological system (green), and socio-economic system (purple). "Time scale" is defined here as the time needed for at least half of the consequences of a change in a driver of the process to have been expressed. Problems of adaptation arise when response process (such as the longevity of some plants) are much slower than driving process (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.

WGI TAR Chapters 3, 4, 7, & 11, WGII TAR Chapter 5, & WGIII TAR Chapters 5, 6, & 10

5.1 This response dicusses, and gives examples of, inertia and varying time scales associated with important processes in the interacting climate, ecological, and socio-economic systems. It then discusses potentially irreversible changes—that is, situations where parts of the climate, ecological, or socio-economic systems may fail to return to their former state within time scales of multiple human generations after the driving forces leading to change are reduced or removed. Finally, it explores how the effects of inertia may influence decisions regarding the mitigation of, or adaptation to, climate change.

5.2 **Inertia is a widespread inherent characteristic of the interacting climate, ecological, and socio-economic systems. Thus some impacts of anthropogenic climate change may be slow to become apparent, and some could be irreversible if climate change is not limited in both rate and magnitude before associated thresholds, whose positions may be poorly known, are crossed.**

5.3 **The combined effect of the interacting inertias of the various component processes is such that stabilization of the climate and climate-impacted**

WGI TAR Sections 3.2, 3.7, & 4.2, & WGI TAR Figure 9.16

systems will only be achieved long after anthropogenic emissions of greenhouse gases have been reduced. The perturbation of the atmosphere and oceans, resulting from CO_2 already emitted due to human activities since 1750, will persist for centuries because of the slow redistribution of carbon between large ocean and terrestrial reservoirs with slow turnover (see Figures 5-2 and 5-4). The future atmospheric concentration of CO_2 is projected to remain for centuries near the highest level reached, since natural processes can only return the concentration to pre-industrial levels over geological time scales. By contrast, stabilization of emissions of shorter lived greenhouse gases such as CH_4 leads, within decades, to stabilization of atmospheric concentrations. Inertia also implies that avoidance of emissions of long-lived greenhouse gases has long-lasting benefits.

WGI TAR Sections 7.3, 7.5, & 11.5.4, & WGI TAR Figures 9.1, 9.24, & 11.16

5.4 **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 1,000 years.** Due to the great mass, thickness, and thermal capacity of the oceans and cryosphere, and the slowness of the heat transport process, 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 from the atmosphere into the upper "mixed layer" of the ocean occurs within decades, but transport of heat into the deep ocean requires centuries. 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.

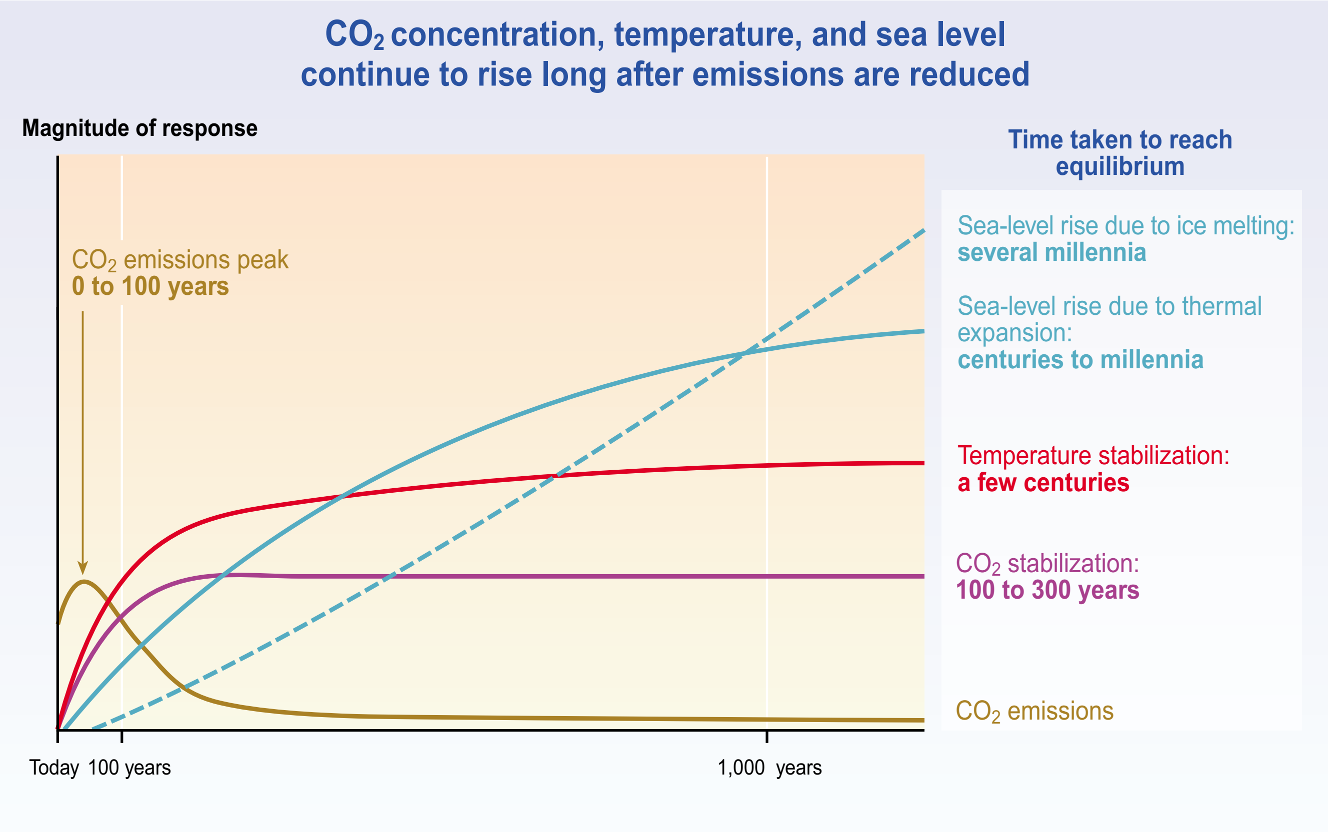


Figure 5-2: After CO_2 emissions are reduced and atmospheric concentrations stabilize, surface air temperature continues to rise by a few tenths of a degree per century for a century or more. Thermal expansion of the ocean continues long after CO_2 emissions have been reduced, and melting of ice sheets continues to contribute to sea-level rise for many centuries. This figure is a generic illustration for stabilization at any level between 450 and 1,000 ppm, and therefore has no units on the response axis. Responses to stabilization trajectories in this range show broadly similar time courses, but the impacts become progressively larger at higher concentrations of CO_2.

WGI TAR Sections 3.7, 9.3, & 11.5, & WGI TAR Figures 3.13, 9.16, 9.19, 11.15, & 11.16

5.5 **The lower the stabilization target for atmospheric CO_2, the sooner emissions of CO_2 would need to decrease to meet it.** If emissions were held at present levels, carbon cycle models indicate that the atmospheric concentration of CO_2 would continue to rise (see Figure 5-3).

WGI TAR Sections 3.2.3.2, 3.7.3, & 9.3.3.1

- Stabilization of CO_2 concentrations at any level requires ultimate reduction of global net emissions to a small fraction of the current emission level.
- Stabilization of atmospheric CO_2 concentrations at 450, 650, or 1,000 ppm would require global anthropogenic CO_2 emissions to drop below the year 1990 level, within a few decades, about a century, or about 2 centuries, respectively, and continue to decrease steadily thereafter (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 carbon 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. Chemical reaction involving ocean sediments has the potential to remove up to a further 15% over a period of 5,000 years.

5.6 **A delay between biospheric carbon uptake and carbon release is manifest as a temporary net carbon uptake.** The main flows in the global carbon cycle have widely differing characteristic time scales (see Figures 5-1 and 5-4). The net terrestrial carbon uptake that has developed over the past few decades is partly a result of the time lag between photosynthetic carbon uptake and carbon release when plants eventually die and decay. For example, the uptake 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 elevated CO_2 or nitrogen deposition 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. Some models project that the recent global net terrestrial carbon uptake will peak, then level off or decrease. The peak could be passed within the 21st century according to several model projections. Projections of the global net terrestrial carbon exchange with the atmosphere beyond a few decades remain uncertain (see Figure 5-5).

WGI TAR Sections 3.2.2-3 & 3.7.1-2, & WGI TAR Figure 3.10

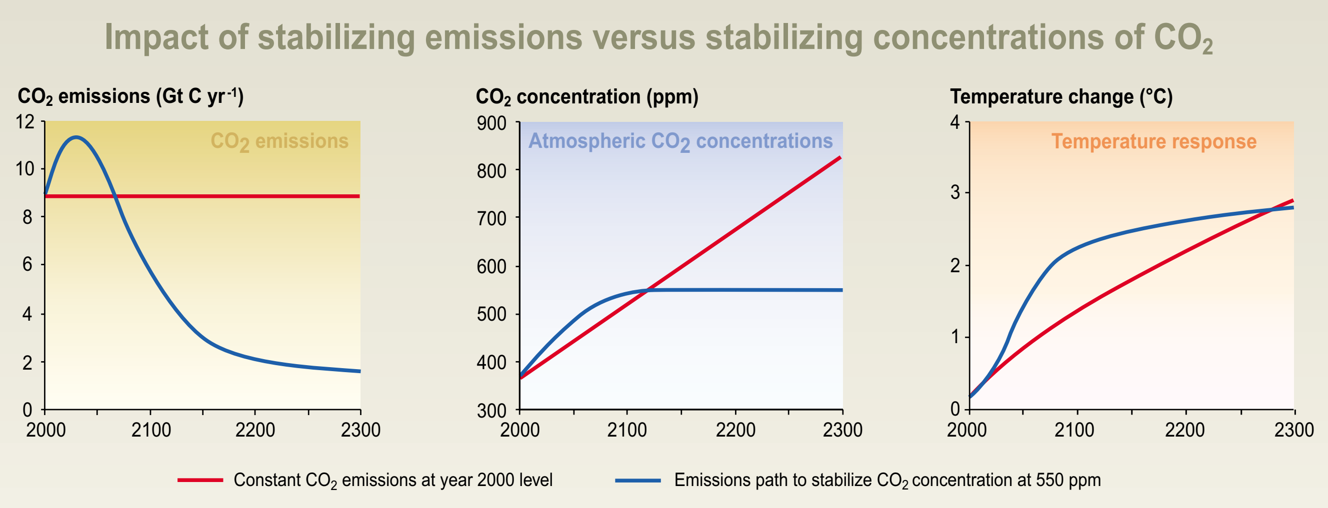


Figure 5-3: Stabilizing CO_2 *emissions* at current levels will result in a continously rising atmospheric CO_2 *concentration* and temperature. Stabilization of atmospheric CO_2 and temperature change will eventually require the emissions to drop well below current levels. In all three panels the red curves illustrate the result of emissions held constant at the level prescribed by the WRE 550 profile for the year 2000 (which is slightly higher than the actual emissions for the year 2000), while the blue curves are the result of emissions following the WRE 550 stabilization profile. Both cases are illustrative only: Constant global emissions are unrealistic in the short term, and no preference is expressed for the WRE 550 profile over others. Other stabilization profiles are illustrated in Figure 6-1. Figure 5-3 was constructed using the models described in WGI TAR Chapters 3 & 9.

WGI TAR Sections 3.7 & 9.3

5.7 Although warming reduces the uptake of CO_2 by the ocean, the oceanic net carbon uptake is projected to persist under rising atmospheric CO_2, at least for the 21st century. Movement of carbon from the surface to the deep ocean takes centuries, and its equilibration there with ocean sediments takes millennia.

WGI TAR Sections 3.2.3 & 3.7.2, & WGI TAR Figures 3.10c,d

5.8 **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 resulting loss of capacity by the ecosystem to supply services such as food, timber, and biodiversity maintenance on a sustainable basis may not be immediately apparent. 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

5.9 **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

WGII TAR SPM 2.7, WGII TAR Sections 4.6.4, 18.2-4, & 18.8, & WGIII TAR Section 10.4.2

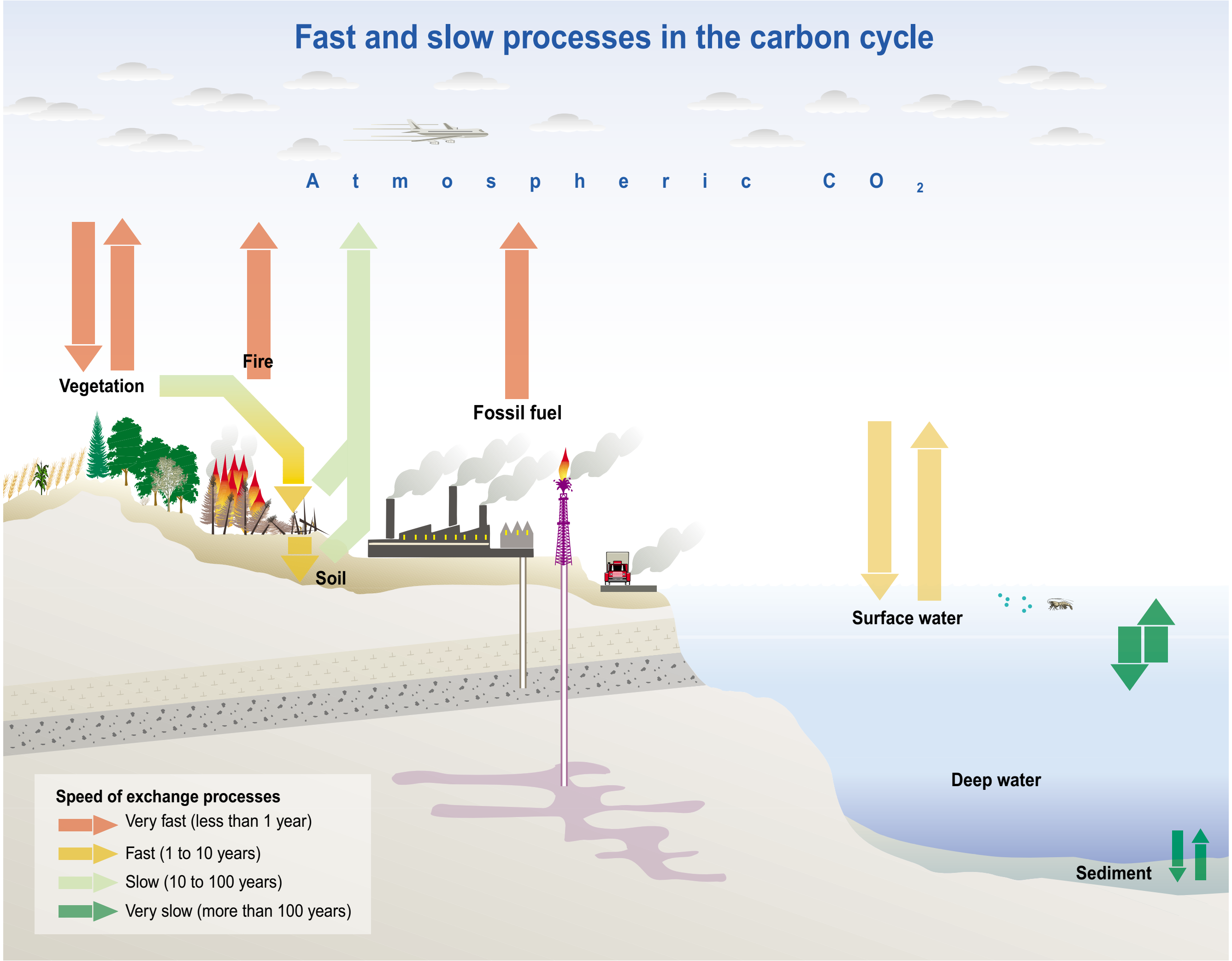
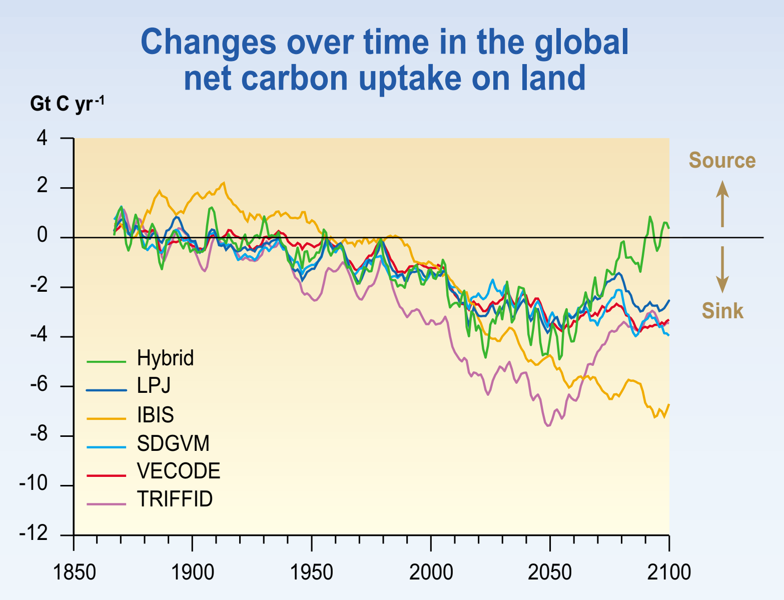


Figure 5-4: The range of time scales of major processes within the global carbon cycle leads to a range of response times for perturbations of CO_2 in the atmosphere, and contributes to the development of transient sinks, as when the atmospheric CO_2 concentration rose above its pre-1750 equilibrium level.



WGI TAR Figure 3.10b

Figure 5-5: The recent net uptake of carbon on the land is partly due to 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 processes contribute to the enhanced plant growth: changes in land use and management, fertilizing effects of elevated CO_2 and nitrogen, and some climate changes (such as a longer growing season at high latitudes). A range of models (identified by their acronyms in the figure) project a continued increase in the strength of the net carbon uptake on land for several decades, then a leveling off or decline late in the 21st century for reasons explained in the text. The model results illustrated here arise from the IS92a scenario, but similar conclusions are reached using other scenarios.

any experienced by human societies over at least the past 5 millennia. 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 decision making in the area of adaptation and mitigation, and in implementing those decisions, on 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.

5.10 **There is typically a delay of years to decades between perceiving a need to respond to a major challenge, planning, researching and developing a solution, and implementing it.** This delay 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 perceived 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 Sections 3.2, 5.3.1, & 10.4

5.11 **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 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 many

WGIII TAR Sections 3.2, 3.8.6, 5.2-3, & 10.3, SRTT SPM, & SRTT Chapter 4 ES

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 decades. Energy use and greenhouse gas mitigation 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.

5.12 **Social and economic time scales are not fixed: They are sensitive to social and economic forces, and could be changed by policies and the choices made by individuals.** 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 5-6). 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 both 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.

WGIII TAR Chapter 2, WGIII TAR Sections 3.2 & 10.1.4.3, & WGII SAR Section 20.1

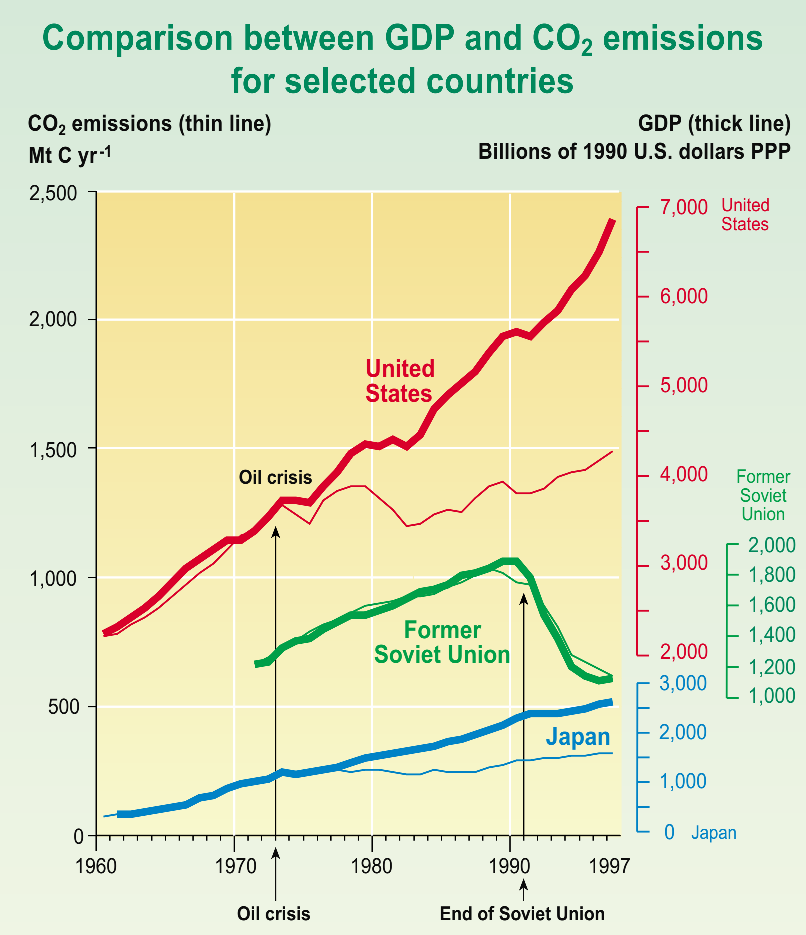
5.13 **Stabilization of atmospheric CO_2 concentration at levels below about 600 ppm is only possible with reductions in carbon intensity and/or energy intensity greater than have been achieved historically.** This implies shifts toward alternative development pathways with new social, institutional, 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 to 1992. The historically recorded annual rates of improvement of global energy intensity (1 to 1.5% per year) 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 5-7). Carbon intensity (carbon per unit energy produced) reduction rates would eventually have to change by even more (e.g., up to 1.5% per year (the historical baseline is 0.3 to 0.4% per year)). In reality, both energy intensity and carbon intensity are likely to continue to improve, but greenhouse gas stabilization at levels below 600 ppm 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 would need to occur.

WGI TAR Section 3.7.3.4, WGIII TAR Section 2.5, & SRES Section 3.3.4

5.14 Some climate, ecological, and socio-economic system changes are effectively irreversible over many human lifetimes, and others are intrinsically irreversible.

5.15 **There are two types of apparent irreversibility.** "Effective irreversibility" derives from processes that have the potential to return to their pre-disturbance state, but take centuries to millennia to do so. An example 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. "Intrinsic irreversibility" results from crossing a threshold beyond which the system no longer spontaneously returns to the previous state. 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, & WGII TAR Sections 16.2.1 & 17.2.5



WGIII TAR Table 3.1 & WGII SAR Figure 20-1

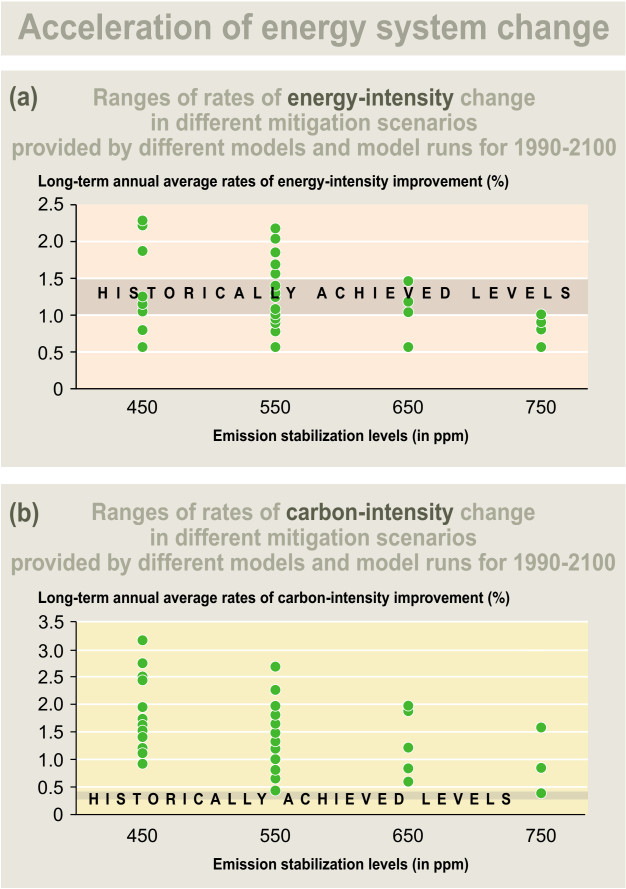
Figure 5-6: The response of the energy system, as indicated by the emission of CO_2 (expressed as carbon), to economic changes, indicated by GDP (expressed in Purchasing Power Parity (PPP) terms). The response can be almost without inertia if the shock is large. The "oil crisis"—during which energy prices rose substantially over a short period of time—led to an almost immediate and sustained divergence of the formerly closely linked emissions and GDP in most developed countries: Japan and United States are shown as examples. At the breakup of the Former Soviet Union, the two indicators remained closely linked, leading the emission to drop rapidly in tandem with declining GDP.

5.16 **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 if the world warms rapidly. While such a transition is very 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, THC 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 THC. When a system approaches a threshold, as is the case for a weakening THC under global warming, resilience to perturbations decreases.

WGI TAR Sections 2.4.3, 7.3.7, & 9.3.4.3, & WGII TAR Section 1.4.3.5

5.17 **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 per year. 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

WGII TAR Sections 1.2.1.2, 4.7.3, & 5.2, WGIII TAR TS 2.3, SRES Box 4.2, & WGII SAR A.4.1



WGIII TAR Figures 2.8 & 2.18

Figure 5-7: (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 (carbon 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 7-3).

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.

5.18 Inertia in the climate, ecological, and socio-economic systems makes adaptation inevitable and already necessary in some cases, and inertia affects the optimal mix of adaptation and mitigation strategies.

5.19 **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 climate in the year 2100 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.

WGIII TAR Section 8.4.2

5.20 **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). Earlier mitigation action may reduce the risk of incurring severe lasting or irreversible impacts, while reducing the need for more rapid mitigation later. Accelerated action may help to drive down the costs of mitigation and

WGII TAR Sections 1.3.4 & 2.7.1, WGIII TAR Chapter 2, WGIII TAR Sections 10.1 & 10.4.2-3, & WGIII TAR Table 10.7

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 uncertainty, resulting in a sequential decision-making 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.

5.21 **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 the year 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 1995 (5 to 12 cm) would be substantially less than if the same emission reduction occurred in the year 2020 (14 to 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 Sections 2.7.1 & 17.2.1

5.22 **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 mobile 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.

WGII TAR Chapter 2, WGIII TAR Section 10.3.3, SRES Section 3.3.4.8, & SRTT SPM

5.23 **Inertia and uncertainty in the climate, ecological, and socio-economic systems imply that safety margins should be considered in setting strategies, targets, and time tables for avoiding dangerous levels of interference in the climate system.** Stabilization target levels of, for instance, atmospheric CO_2 concentration, temperature, or sea level may be affected by:

- The inertia of the climate system, which will cause climate change to continue for a period after mitigation actions are implemented
- Uncertainty regarding the location of possible thresholds of irreversible change and the behavior of the system in their vicinity
- The time lags between adoption of mitigation goals and their achievement.

Similarly, adaptation is affected by time lags involved in identifying climate change impacts, developing effective adaptation strategies, and implementing adaptive measures. Hedging strategies and sequential decision making (iterative action, assessment, and revised action) may be appropriate responses to the combination of inertia and uncertainty. Inertia has different consequences for adaptation than for mitigation, with adaptation being primarily oriented to address localized impacts of climate change, while mitigation aims to address the impacts on the climate system. 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 10.1.4.1-3

5.24 **The pervasiveness of inertia and the possibility of irreversibility in the interacting climate, ecological, and socio-economic systems are major reasons why anticipatory adaptation and mitigation actions are beneficial.** A number of opportunities to exercise adaptation and mitigation options may be lost if action is delayed.

Question 6

Q6

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.

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 the 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 projected rate and magnitude of warming and sea-level rise can be lessened by reducing greenhouse gas emissions.

6.3 **The greater the reductions in emissions and the earlier they are introduced, the smaller and slower the projected warming and rise in sea levels.** Future climate change is determined by historic, current, and future emissions. 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.[6] 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 the year 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 the year 2100, the projected CO_2 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 the year 2100 than the same emissions reductions implemented at a later time.

IPCC TP4

6.4 **Reductions in greenhouse gas emissions and the gases that control their concentration would be necessary to stabilize radiative forcing.** For example, for the most important anthropogenic greenhouse gas, carbon cycle models indicate that stabilization of atmospheric CO_2 concentrations at 450, 650, or 1,000 ppm would require global anthropogenic CO_2 emissions to drop below year 1990 levels within a few decades, about a century, or about 2 centuries, respectively, and continue to decrease steadily thereafter (see Figure 6-1). These models illustrate that emissions would peak in about 1 to 2 decades (450 ppm) and roughly a century (1,000 ppm) from the present (see Table 6-1). Eventually CO_2 emissions would need to decline to a very small fraction of current emissions. The benefits of different stabilization levels are discussed later in Question 6 and the costs of these stabilization levels are discussed in Question 7.

WGI TAR Section 3.7.3

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 thereafter, are presented in Figure 6-1c. The uncertainty about climate sensitivity yields a wide range of estimates of temperature change that would result

WGI TAR Section 9.3.3

[6] In these analyses, emissions by developed countries of CH_4, N_2O, and SO_2 are kept constant at their year 1990 values, and halocarbons follow a scenario consistent with the Copenhagen version of the Montreal Protocol. 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. The IS92 scenarios are described in the IPCC *Special Report on Radiative Forcing of Climate Change*.

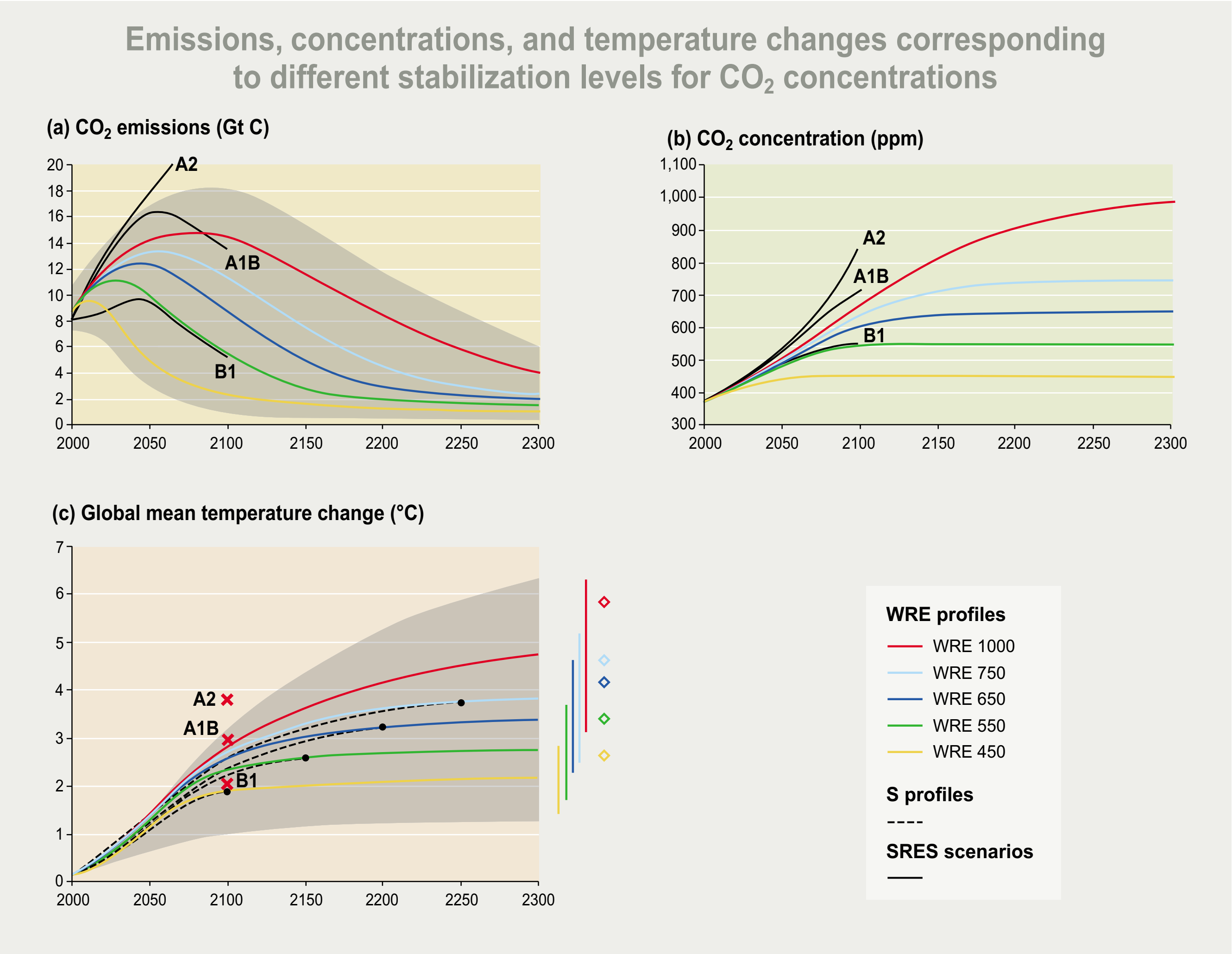


Figure 6-1: Stabilizing CO_2 concentrations would require substantial reductions of emissions below current levels and would slow the rate of warming.

WGI TAR Sections 3.7.3 & 9.3.3, & IPCC TP3

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 1,000 ppm are estimated for the WRE stabilization profiles using carbon cycle models. Lower CO_2 concentration levels would require an earlier reversal of emissions growth and earlier decreases to levels below current emissions. The shaded area illustrates the range of uncertainty in estimating CO_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 profiles gradually approach stabilized levels that range from 450 to 1,000 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:*** Global mean temperature changes are estimated for the WRE stabilization profiles using a simple climate model tuned in turn to each of several more complex models. Estimated warming slows as growth in the atmospheric concentration of CO_2 slows and warming continues after the time at which the CO_2 concentration is stabilized (indicated by black spots) but at a much diminished rate. It is assumed that emissions of gases other than CO_2 follow the SRES A1B projection until the year 2100 and are constant thereafter. This scenario was chosen as it is in the middle of the range of the SRES scenarios. The dashed lines show the temperature changes projected for the S profiles, an alternate set of CO_2 stabilization profiles (not shown in panels (a) or (b)). The shaded area illustrates the effect of a range of climate sensitivity across the five stabilization cases. The colored bars on the righthand side show, for each WRE profile, the range at the year 2300 due to the different climate model tunings and the diamonds on the righthand side show the equilibrium (very long-term) warming for each stabilization level using average climate model results. Also shown for comparison are temperature increases in the year 2100 estimated for the SRES emission scenarios (indicated by red crosses).

Table 6-1 Projected CO_2 concentrations for the SRES emissions scenarios and deduced emissions for the WRE profiles leading to stabilization of atmospheric CO_2.[a]

	CO_2 Emissions ($Gt\ C\ yr^{-1}$)		*Accumulated CO_2 Emissions*	*Year in which Emissions*		*Atmospheric Concentration (ppm)*		*Year of Concentration Stabilization*
	2050	*2100*	*2001 to 2100 (Gt C)*	*Peak*	*Fall below 1990 Levels*[b]	*2050*	*2100*	
SRES Emissions Scenarios								
A1B	16.4	13.5	1,415			490–600	615–920	
A1T	12.3	4.3	985			465–560	505–735	
A1FI	23.9	28.2	2,105			520–640	825–1,250	
A2	17.4	29.1	1,780			490–600	735–1,080	
B1	11.3	4.2	900			455–545	485–680	
B2	11.0	13.3	1,080			445–530	545–770	
WRE Stabilization Profiles								
450	3.0–6.9	1.0–3.7	365–735	2005–2015	<2000–2045	445	450	2090
550	6.4–12.6	2.7–7.7	590–1,135	2020–2030	2030–2100	485	540	2150
650	8.1–15.3	4.8–11.7	735–1,370	2030–2045	2055–2145	500	605	2200
750	8.9–16.4	6.6–14.6	820–1,500	2040–2060	2080–2180	505	640	2250
1,000	9.5–17.2	9.1–18.4	905–1,620	2065–2090	2135–2270	510	675	2375

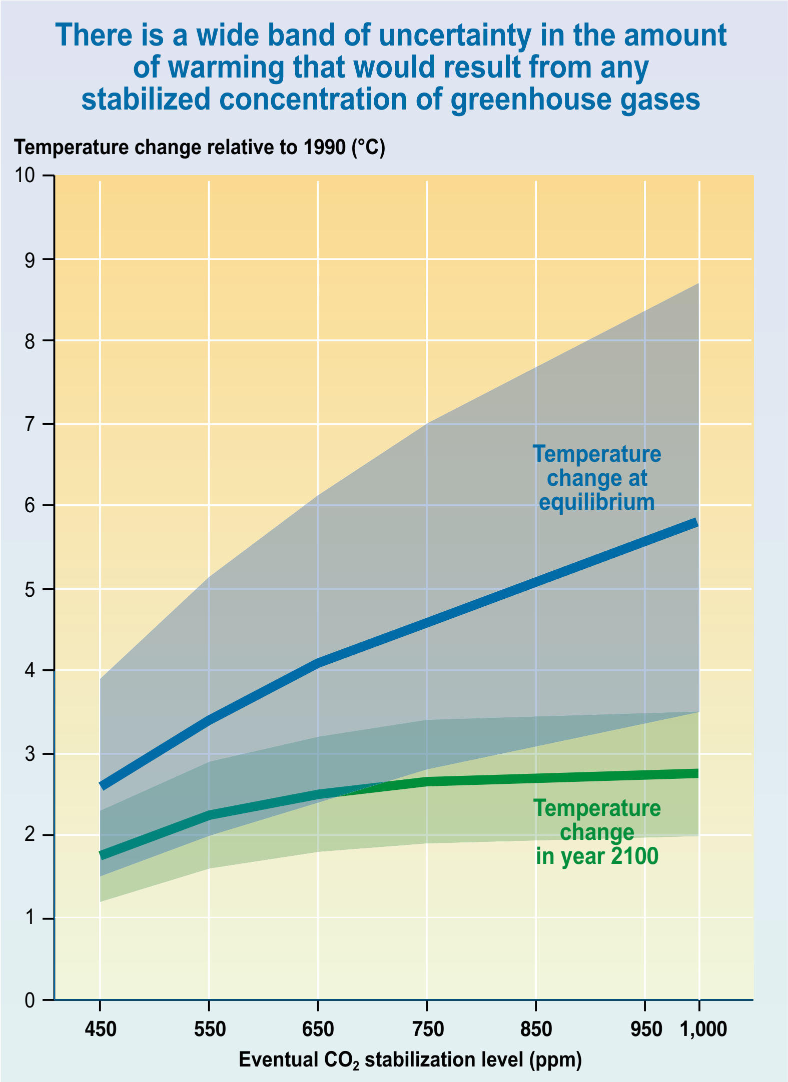
[a] blue text = prescribed and black text = model results; both fossil-fuel and land-use change emissions are considered. Ranges from two simple carbon cycle models: ISAM model range is based on complex model results, while BERN-CC model range is based on uncertainties in system responses and feedbacks. The SRES results can be found in Appendix II.1.1 of the WGI TAR. The exact timing of the WRE emissions depends on the pathway to stabilization.
[b] 1990 emissions are taken to be 7.8 Gt C; this value is uncertain primarily due to the uncertainty in the size of the land-use change emissions, assumed here to be 1.7 Gt C, the annual average value through the 1980s.

from emissions corresponding to a selected concentration level.[7] This is shown more clearly in Figure 6-2, which shows eventual CO_2 concentration stabilization levels and the corresponding range of temperature change that is estimated to be realized in the year 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 the year 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.

6.6 **Emission reductions that would eventually stabilize the atmospheric concentration of CO_2 at a level below 1,000 ppm, based on profiles shown in Figure 6-1, and assuming that emissions of gases other than CO_2 follow the SRES A1B projection until the year 2100 and are constant thereafter, are estimated to limit global mean temperature increase to 3.5°C or less through the year 2100.** Global average surface temperature is estimated to increase 1.2 to 3.5°C by the year 2100 for profiles that would limit CO_2 emissions so as to eventually stabilize the concentration of CO_2 at a level from 450 to 1,000 ppm. Thus, although all of the CO_2 concentration stabilization profiles analyzed would prevent, during the 21st century, much of the upper end of the SRES projections of warming (1.4 to 5.8°C by the year 2100), it should be noted that for most of the profiles the concentration of CO_2 would continue to rise beyond the year 2100. Owing to the large inertia of the ocean (see Question 5), temperatures are projected to continue to rise even after stabilization of CO_2 and other 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 equilibrium temperature rise would take many centuries to reach, and ranges from 1.5 to 3.9°C above the year 1990 levels for

WGI TAR Section 9.3.3 & WGI TAR Table 9.3

[7] The equilibrium global mean temperature response to doubling atmospheric CO_2 is often used as a measure of climate sensitivity. The temperatures shown in Figures 6-1 and 6-2 are derived from a simple model calibrated to give the same response as a number of complex models that have climate sensitivities ranging from 1.7 to 4.2°C. This range is comparable to the commonly accepted range of 1.5 to 4.5°C.



WGI TAR Section 9.3.3

Figure 6-2: Temperature changes relative to 1990 in (a) year 2100 and (b) at equilibrium are estimated using a simple climate model for the WRE profiles as in Figure 6-1. The lowest and highest estimates for each stabilization level assume a climate sensitivity of 1.7 and 4.2°C, respectively. The center line is an average of the low and high estimates.

stabilization at 450 ppm and 3.5 to 8.7°C above the year 1990 levels for stabilization at 1,000 ppm.[8] Furthermore, for a specific temperature stabilization target, there is a very wide range of uncertainty associated with the required stabilization level of greenhouse gas concentration (see Figure 6-2). The level at which CO_2 concentration is required to be stabilized for a given temperature target also depends on the levels of the non-CO_2 gases. 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 the year 1990.[9]

WGI TAR Section 9.3.3.1

6.7 **Different time paths of emissions that lead to a common level for stabilization of the atmospheric concentration of greenhouse gases yield different time paths of temperature change.** For CO_2 stabilization levels of 450, 550, 650, and 750 ppm, two sets of emission time paths have been analyzed in previous IPCC reports and are

[8] For all these scenarios, the contribution to the equilibrium warming from other greenhouse gases and aerosols is 0.6°C for a low climate sensitivity and 1.4°C for a high climate sensitivity. The accompanying increase in radiative forcing is equivalent to that occurring with an additional 28% in the final CO_2 concentrations.

[9] This rate of emission growth closely approximates the IS92a emission scenario.

referred to as the S and WRE profiles.[10] The WRE profiles allow higher emissions in early decades than do the S profiles, but then must require lower emissions in later decades to achieve a specified stabilization level. This deferment of emission reductions in the WRE profiles 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 the year 2050, when the difference is most pronounced. Beyond the year 2100, the temperature changes of the WRE and S profiles converge. The temperature projections for the S and WRE profiles are compared in Figure 6-1c.

6.8 **Sea level and ice sheets would continue to respond to warming for many centuries after greenhouse gas concentrations have been stabilized (see Question 5).** The projected range of sea-level rise due to thermal expansion at equilibrium is 0.5 to 2 m for an increase in CO_2 concentration from the pre-industrial level of 280 to 560 ppm and 1 to 4 m for an increase in CO_2 concentration from 280 to 1,120 ppm. The observed rise over the 20th century was 0.1 to 0.2 m. The projected rise would be larger if the effect of increases in other greenhouse gas concentrations were to be taken into account. There are other contributions to sea-level rise over time scales of centuries to millennia (see Question 5). Models assessed in the TAR project sea-level rise of several meters from polar ice sheets (see Question 4) and land ice even for stabilization levels of 550 ppm CO_2-equivalent.

WGI TAR SPM & WGI TAR Section 11.5.4

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

6.10 **Greenhouse gas emission reduction (mitigation) actions would lessen the pressures on natural and human systems from climate change.** Slower rates of increase in global mean temperature and sea level would allow more time for adaptation. Consequently, mitigation actions are expected to delay and reduce damages caused by climate change and thereby generate environmental and socio-economic benefits. Mitigation actions and their associated costs are assessed in the response to Question 7.

WGII TAR Sections 1.4.3, 18.8, & 19.5

6.11 **Mitigation actions to stabilize atmospheric concentrations of greenhouse gases at lower levels would generate greater benefits in terms of less damage.** Stabilization at lower levels reduces the risk of exceeding temperature thresholds in biophysical systems where these exist. Stabilization of CO_2 at, for example, 450 ppm is estimated to yield an increase in global mean temperature in the year 2100 that is about 0.75 to 1.25ºC less than is estimated for stabilization at 1,000 ppm (see Figure 6-2). At equilibrium the difference is about 2 to 5ºC. The geographical extent of the damage to or loss of natural systems, and the number of systems affected, which increase with the magnitude and rate of climate change, would be lower for a lower stabilization level. Similarly, for a lower stabilization level the severity of impacts from climate extremes is expected to be less, fewer regions would suffer adverse net market sector impacts, global aggregate impacts would be smaller, and risks of large-scale high-impact events would be reduced. Figure 6-3 presents a summary of climate change risks or reasons for concern (see Box 3-2) juxtaposed against the ranges of global mean temperature change in the year 2100 that have been estimated for different scenarios.[11]

WGI TAR Section 9.3.3 & WGII TAR Sections 1.4.3.5, 5.2, 5.4, & 19.3-6

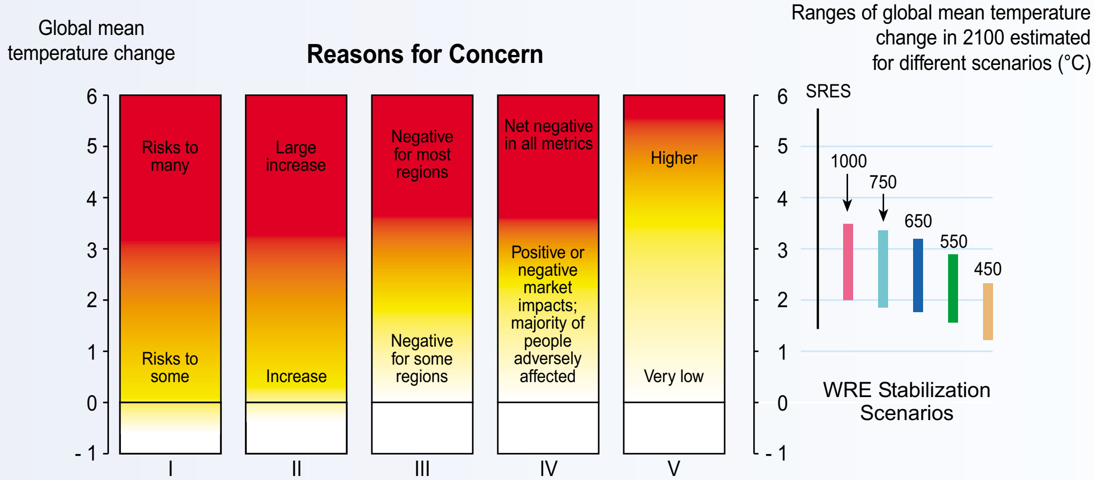
6.12 **Comprehensive, quantitative estimates of the benefits of stabilization at various levels of atmospheric concentrations of greenhouse gases do not yet exist.**

WGII TAR Sections 19.4-5

[10] The S and WRE profiles are discussed in the WGI SAR and are described in more detail in IPCC Technical Paper 3.

[11] 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.

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 time scale).

WGI TAR Section 9.3.3 & WGII TAR Section 19.8.2

Figure 6-3: Risks of climate change damages would be reduced by stabilizing CO_2 concentration. 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 by the year 2100 relative to the year 1990 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. Many risks associated with warming above 3.5°C by the year 2100 would be avoided by stabilizing CO_2 concentration at or below 1,000 ppm. Stabilization at a lower level would reduce risks further. 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.

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 climate change cannot be uniquely determined for individual emission scenarios. There are also uncertainties about key processes and sensitivities and adaptive capacities of systems to changes in climate. In addition, impacts such as changes in the composition and function of ecological systems, species extinction, and changes in human health, and disparity in the distribution of impacts across different populations and regions, are not readily expressed in monetary or other common units. Because of these limitations, the benefits of different greenhouse gas reduction actions, including actions to stabilize greenhouse gas concentrations at selected levels, are incompletely characterized and cannot be compared directly to mitigation costs for the purpose of estimating the net economic effects of mitigation.

6.13 Adaptation is a necessary strategy at all scales to complement climate change mitigation efforts. Together they can contribute to sustainable development objectives.

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 at a low level, will neither altogether prevent climate change or sea-level rise nor altogether prevent their impacts. Many reactive adaptations will occur in response to the changing climate and rising seas and some have already occurred. 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 implemented 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 Sections 18.2.2, 18.3, & 18.8

6.16 **Mitigation and adaptation actions can, if appropriately designed, advance 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 improve the prospects for sustainable development.[12]

WGII TAR Section 18.6.1, & WGIII TAR Sections 2.2.3 & 10.3.2

[12] The relationships 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.

6.17 **The impact of climate change is projected to have different effects within and between countries. The challenge of addressing climate change raises an important issue of equity.** Climate change pressures can exacerbate inequities between developing and developed countries; lessening these pressures through mitigation and enhancement of adaptive capacity 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 benefit all countries, particularly developing countries.

WGII TAR Sections 18.5.3 & 19.4

6.18 **Reducing and slowing climate change can also promote inter-generational 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, & WGIII TAR Section 10.4.3

Question 7

Q7

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?

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, which 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 macro-economic 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.

Potential, Barriers, Opportunities, Policies, and Costs of Reducing Greenhouse Gas Emissions in the Near Term

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

7.3 **Significant technical progress relevant to greenhouse gas emissions reduction has been made since the SAR, 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 emissions 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 some at the global level, providing estimates of potential greenhouse gas emissions reductions to the 2010 and 2020 time frame.

WGIII TAR Sections 3.3-8, & WGIII TAR Chapter 3 Appendix

7.4 **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 (see 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,[13] 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 the year 2050, equivalent to about 10 to 20% of projected fossil-fuel emissions during that period, although there are substantial uncertainties associated with

WGIII TAR Sections 3.6.4 & 4.2-4, & SRLULUCF

[13] Changing land use could influence atmospheric CO_2 concentration. Hypothetically, if 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 40 to 70 ppm.

Table 7-1 Estimates of potential global greenhouse gas emission reductions in 2010 and in 2020 (WGIII SPM Table SPM-1).

Sector	***Historic Emissions in 1990 [Mt C_{eq} yr^{-1}]***	***Historic C_{eq} Annual Growth Rate over 1990-1995 [%]***	***Potential Emission Reductions in 2010 [Mt C_{eq} yr^{-1}]***	***Potential Emission Reductions in 2020 [Mt C_{eq} yr^{-1}]***	***Net Direct Costs per Tonne of Carbon Avoided***
Buildings[a] CO_2 only	1,650	1.0	700–750	1,000–1,100	Most reductions are available at negative net direct costs.
Transport CO_2 only	1,080	2.4	100–300	300–700	Most studies indicate net direct costs less than US$25 per t C but two suggest net direct costs will exceed US$50 per t C.
Industry CO_2 only – Energy efficiency – Material efficiency	2,300	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 US$0–10 per t C_{eq}.
Agriculture[b] CO_2 only Non-CO_2 gases	210 1,250–2,800	n/a	150–300	350–750	Most reductions will cost between US$0–100 per t C_{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 CH_4 recovery from landfills at net negative direct cost; 25% at a cost of US$20 per t C_{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 US$200 per t C_{eq}.
Energy supply and conversion[c] CO_2 only	(1,620)	1.5	50–150	350–700	Limited net negative direct cost options exist; many options are available for less than US$100 per t C_{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 WGIII TAR Chapter 3 for all six gases. It excludes non-energy related sources of CO_2 (cement production, 160 Mt C; gas flaring, 60 Mt C; and land-use change, 600–1,400 Mt C) and energy used for conversion of fuels in the end-use sector totals (630 Mt C). If petroleum refining and coke oven gas were added, global year 1990 CO_2 emissions of 7,100 Mt C 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 Mt C_{eq} for the year 2010 and of 12,000–16,000 Mt C_{eq} for the year 2020. The emissions reduction estimates are most compatible with baseline emissions trends in the SRES B2 scenario. The potential reductions take into account regular turnover of capital stock. They are not limited to cost-effective options, but exclude options with costs above US$100 t C_{eq} (except for Montreal Protocol gases) or options that will not be adopted through the use of generally accepted policies.

this estimate. Realization of this potential depends upon land and water availability as well as the rates of adoption of land management practices. The largest biological potential for atmospheric carbon mitigation is in subtropical and tropical regions.

7.5 Adoption of opportunities including greenhouse gas-reducing technologies and measures may require overcoming barriers through the implementation of policy measures.

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

Categories of Mitigation Options	*Potential Emission Reductions in 2010 [Mt C yr^{-1}]*	*Potential Emission Reductions [Mt C]*	
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]		1,788	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	1,202–1,589	1,788	

[a] Source: SRLULUCF 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 for the period 2008–2012 (Mt C yr^{-1}).
[b] Source: SRLULUCF 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).
[c] Source: SRLULUCF Table SPM-4. Potential refers to the estimated net change in carbon stocks in the year 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.

7.6 **The successful implementation of greenhouse gas mitigation options would need to overcome 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 (see Figure 7-1).** The potential mitigation opportunities and types of barriers vary by region and sector, and over time. Most countries could benefit from innovative financing, social learning and innovation, and institutional reforms, removing barriers to trade, and poverty eradication. 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 industrialized 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 Sections 1.5 & 5.3-5

7.7 **National responses to climate change can be more effective if deployed as a portfolio of policy instruments to limit or reduce net 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, land-use policies, deposit/refund systems, technology or performance standards, energy mix 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.

WGIII TAR Sections 1.5.3, 5.3-4, & 6.2

7.8 **Coordinated actions among countries and sectors may help to reduce mitigation cost by addressing 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

WGIII TAR Sections 6.3-4 & 10.2

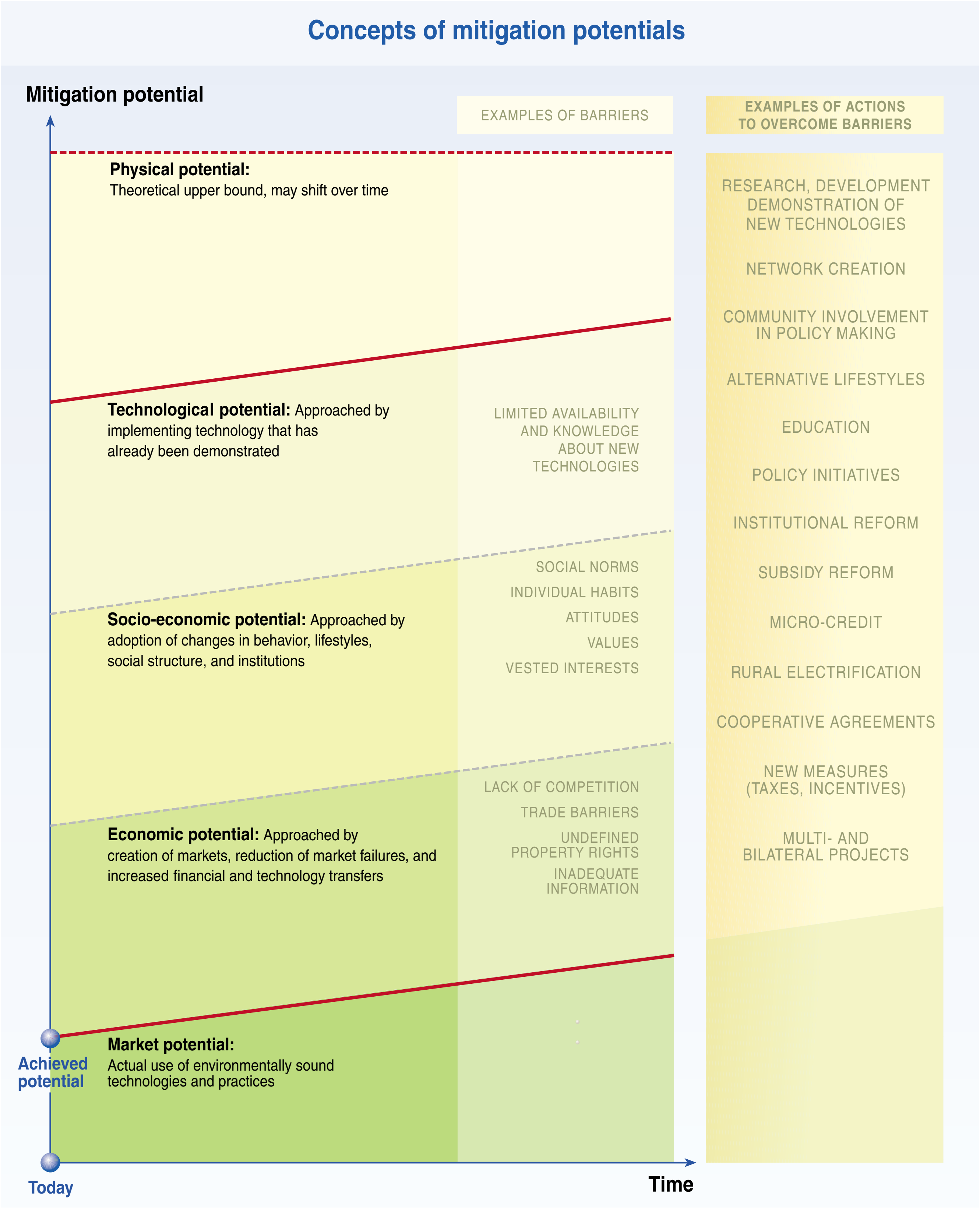


Figure 7-1: Penetration of environmentally sound technologies (including practices): a conceptual framework. Various barriers prevent the different potentials from being realized. Opportunities exist to overcome barriers through innovative projects, programs, and financing arrangements. An action can 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.

WGIII TAR Section 5.2

(JI), and the Clean Development Mechanism (CDM). Other international instruments also assessed in the WGIII TAR 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.

7.9 **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.**

7.10 **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 2.4.5 & 10.3.3, & SRTT SPM

7.11 **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 macro-economic 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.

WGIII TAR Section 10.3.3 & SRTT SPM

7.12 **Networking among private and public stakeholders, and focusing on products and techniques with multiple ancillary benefits that meet or adapt to local development 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.

WGIII TAR Section 10.3.3 & SRTT SPM

7.13 **For participating countries, an increasing scale of international cooperation, such as emissions trading[14] and technology transfer, will lower mitigation costs.**

7.14 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

[14] This market-based approach to achieve environmental objectives allows those reducing greenhouse gas emissions below what is required to use or trade the excess reductions to offset emissions at another source inside or outside the country. Here the term is broadly used to include trade in emission allowances and project-based collaboration.

Box 7-1	Bottom-up and top-down approaches to cost estimates: critical factors and the importance of uncertainties.

For a variety of reasons, significant differences and uncertainties surround specific quantitative estimates of mitigation costs. Cost estimates differ because of the (a) methodology used in the analysis, and (b) underlying factors and assumptions built into the analysis. 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, delay, or make more costly the adoption of these 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.

The inclusion of some factors will lead to lower cost estimates and others to higher estimates. Incorporating multiple greenhouse gases, sinks, induced technical change, and emissions trading can lower costs. Further, studies suggest that 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 such as correcting market imperfections, inclusion of ancillary benefits, and efficient tax revenue recycling. International cooperation that facilitates cost-effective emissions reductions can lower mitigation costs. On the other hand, accounting for potential short-term macro shocks to the economy, constraints on the use of domestic and international market mechanisms, high transaction costs, inclusion of ancillary costs, and ineffective tax recycling measures can increase estimated costs. Since no analysis incorporates all relevant factors affecting mitigation costs, estimated costs may not reflect the actual costs of implementing mitigation actions.

WGIII TAR Sections 3.3-8, 7.6.3, 8.2-3, & 9.4, & WGIII TAR Box SPM-2

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.

7.15 **Bottom-up studies indicate that substantial low-cost mitigation opportunities exist.** According to bottom-up assessments (see Box 7-1) of specific technologies and sectors, half of the potential emissions reductions noted in Table 7-1 may be achieved by the year 2020 with direct benefits exceeding direct costs, and the other half at a net direct cost of up to US$100 per 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. Depending on the emissions scenario, this could allow global emissions to be reduced below year 2000 levels in the period 2010–2020 at these net direct costs. Realizing these reductions involves additional implementation costs, which in some cases may be substantial, the possible need for supporting policies, increased R&D, effective technology transfer, and overcoming other barriers. The various global, regional, national, sector, and project studies assessed in the WGIII TAR have different scopes and assumptions. Studies do not exist for every sector and region.

WGIII TAR Sections 1.5, 3.3-8, 5.3-4, & 6.2

7.16 **Cost estimates using bottom-up analyses reported to date for biological mitigation vary significantly and do not consistently account for all significant components of cost.** Cost estimates using bottom-up analyses reported to date for biological mitigation vary significantly from US$0.1 to about US$20 per t C in several tropical countries and from US$20 to US$100 per t C in non-tropical countries. Methods of financial analyses and carbon accounting have not been comparable. Moreover, 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

WGIII TAR Sections 4.3-4

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. Biological mitigation options may reduce or increase non-CO_2 greenhouse gas emissions.

7.17 **Projections of abatement cost of near-term policy options implemented without Annex B emissions trade for meeting a given near-term CO_2 emissions target as reported by several models[15] of the global economy (top-down models) vary within regions (as shown by the brown lines in Figure 7-2a for Annex II regions and in Table 7-3a).** Reasons for the differentiation among models within regions is due to varying assumptions about future GDP growth rates and changes in carbon 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 Sections 8.2-3

7.18 **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 brown and blue lines in Figure 7-2b and Table 7-3b show that the national marginal costs to meet the Kyoto targets range from about US$20 up to US$600 per t C without Annex B trading, and range from about US$15 up to US$150 per t C with Annex B trading, respectively. At the time of these studies, most models did not include sinks, non-CO_2 greenhouse gases, CDM, negative cost options, ancillary benefits, or targeted revenue recycling, which will reduce estimated costs. On the other hand, these models make assumptions which underestimate costs because they assume full use of emissions trading without transaction costs, both within and among Annex B countries, and that mitigation responses would be perfectly efficient and that economies begin to adjust to the need to meet Kyoto targets between the years 1990 and 2000. 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 reported for Annex B countries:

- *For Annex II countries, the above modeling studies show reductions in GDP, compared to projected levels in the year 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 from 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 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.

WGIII TAR Sections TS 8.3, 7.3, 8.3, 9.2, & 10.2

[15] The above-referenced models report results for Energy Modeling Forum scenarios examining the benefits of emissions trading. For the analyses reported here, these models exclude sinks, multiple gases, ancillary benefits, macro-economic shocks, and induced technical change, but include lump sum tax revenue recycling. In the model baseline, additional no-regrets options, which are not listed above, are included.

Projections of GDP losses and marginal cost in Annex II countries in the year 2010 from global models

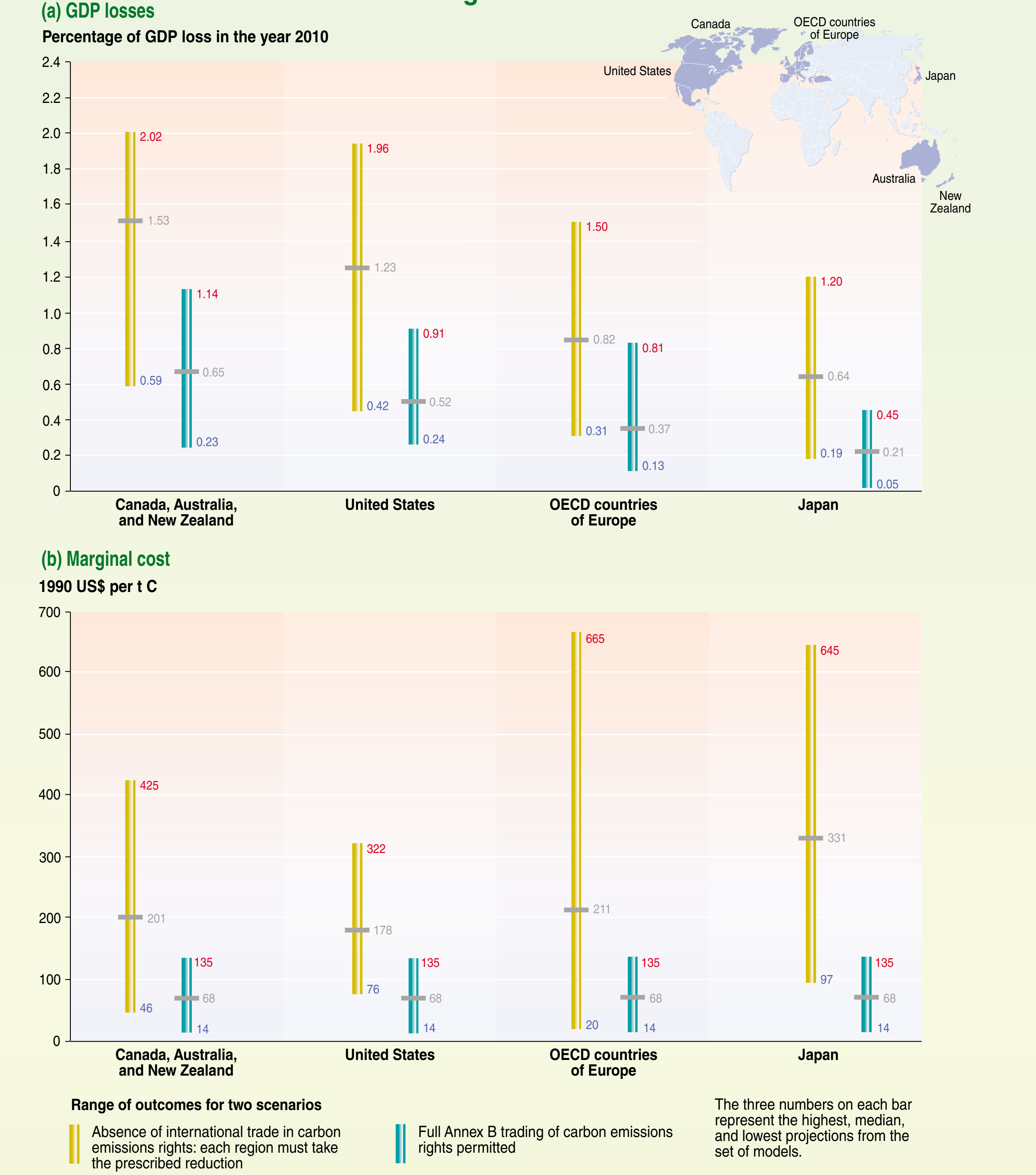


Figure 7-2: Projections of GDP losses and marginal costs in Annex II countries in the year 2010 from global models: (a) GDP losses and (b) marginal costs. The reductions in projected GDP are for the year 2010 relative to the model reference case GDP. These estimates are based on results of an Energy Modeling Forum study. The projections reported in the figures are for four regions, which constitute Annex II. The models examined two scenarios. In the first, each region makes the prescribed reduction with only domestic trading in carbon emissions. In the second, Annex B trading is permitted and thereby marginal costs are equal across regions. For the key factors, assumptions, and uncertainties underlying the studies, see Box 7-1.

WGIII TAR Sections 8.3.1 & 10.4.4

Table 7-3 Results of model comparison from the Energy Modeling Forum.[a]

(a) Calculated losses (as % of total GDP) for various postulated trading regimes associated with meeting the Kyoto targets in Annex B countries.

	No Trading				*Annex I Trading*			
Model	***CANZ***	***USA***	***OECD Europe***	***Japan***	***CANZ***	***USA***	***OECD Europe***	***Japan***
ABARE-GTEM	1.96	1.96	0.94	0.72	0.23	0.47	0.13	0.05
AIM	0.59	0.45	0.31	0.25	0.36	0.31	0.17	0.13
CETA		1.93				0.67		
G-Cubed	1.83	0.42	1.50	0.57	0.72	0.24	0.61	0.45
GRAPE			0.81	0.19			0.81	0.10
MERGE3	2.02	1.06	0.99	0.80	1.14	0.51	0.47	0.19
MS-MRT	1.83	1.88	0.63	1.20	0.88	0.91	0.13	0.22
RICE	0.96	0.94	0.55	0.78	0.54	0.56	0.28	0.30

(b) Marginal abatement costs (in 1990 US$ per t C; 2010 Kyoto target).

Model	***CANZ***	***USA***	***OECD Europe***	***Japan***	***Annex I Trading***
ABARE-GTEM	425	322	665	645	106
AIM	147	153	198	234	65
CETA		168			46
Fund					14
G-Cubed	157	76	227	97	53
GRAPE			204	304	70
MERGE3	250	264	218	500	135
MIT_EPPA	247	193	276	501	76
MS-MRT	213	236	179	402	77
RICE	145	132	159	251	62
SGM	201	188	407	357	84
WorldScan	46	85	20	122	20

(c) Costs of Kyoto Protocol implementation for oil-exporting countries according to various models.[b]

Model[c]	***Without Trading***[d]	***With Annex I Trading***	***With "Global Trading"***
G-Cubed	–25% oil revenue	–13% oil revenue	–7% oil revenue
GREEN	–3% real income	"substantially reduced loss"	n/a
GTEM	0.2% GDP loss	<0.05% GDP loss	n/a
MS-MRT	1.39% welfare loss	1.15% welfare loss	0.36% welfare loss
OPEC	–17% OPEC revenue	–10% OPEC revenue	–8% OPEC revenue
CLIMOX	n/a	–10% some oil exporters' revenues	n/a

[a] Table 7-3a derived from WGIII TAR Table TS-5, Table 7-3b from WGIII TAR Table TS-4, and Table 7-3c from WGIII TAR Table TS-6.
[b] The definition of oil-exporting country varies. For G-Cubed and the OPEC models, it is the OPEC countries; for GREEN, a group of oil-exporting countries; for GTEM, Mexico and Indonesia; for MS-MRT, OPEC countries plus Mexico; and for CLIMOX, west Asian and north African oil exporters.
[c] The models report impact on the global economy in the year 2010 with mitigation according to the Kyoto Protocol targets (usually in the models applied to CO_2 mitigation by the year 2010 rather than greenhouse gas emissions to the period 2008–2012) achieved by imposing a carbon tax or auctioned emission permits with revenues recycled through lump-sum payments to consumers. No ancillary benefits, such as reductions in local air pollution damages, are taken into account in the results.
[d] "Trading" denotes trading in emission permits between countries.
n/a = not available.

7.19 **Emission constraints on Annex I countries have well-established, albeit varied, "spill-over" effects[16] on non-Annex I countries.**

WGIII TAR Sections 8.3.2 & 9.3.1-2

- *Oil-exporting, non-Annex I countries: Analyses report costs differently, including,* inter alia, *reductions in projected GDP and reductions in projected oil revenues.* 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 the year 2010.[17]

[16] Spill-over effects incorporate only economic, not environmental, effects.
[17] 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 per year; with Annex B emissions trading, growth rate is reduced by less than 0.005 percentage points per year.

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 the year 2010 (see Table 7-3c). These studies do not consider policies and measures[18] 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 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%.*[19] 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.

7.20 **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").**

WGIII TAR Sections 5.3-5, 7.3.3, 8.2.2, 8.2.4, 9.2.1-2, 9.2.4, 9.2.8, & 10.4

- *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.

[18] 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.

[19] 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.

Potential, Barriers, Opportunities, Policies, and Costs of Stabilizing Atmospheric Greenhouse Gas Concentrations in the Long Term

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

7.22 **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[20] 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 year 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, 3.5, & 8.4, & WGIII TAR Chapter 3 Appendix

7.23 **The development and diffusion of new economically competitive and 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 stabilization levels. 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 and depends upon the magnitude and timing of emissions mitigation, the assumed reference scenario, and the economic competitiveness of the technology.

WGIII TAR Section 10.3.3

7.24 **The pathway to stabilization can be as important as the stabilization level 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 increase flexibility in moving towards stabilization, decrease environmental and human risks associated with rapid climatic changes, while minimizing potential implications of inertia in climate and ecological systems (see Question 5). It may 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 Sections 2.3.2, 5.3.1, 8.4, & 10.4.2-3

7.25 **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 to a 550 ppmv concentration stabilization level, there is a larger

WGIII TAR Sections 2.5.2, 8.4.1, 8.4.3, & 10.4.6

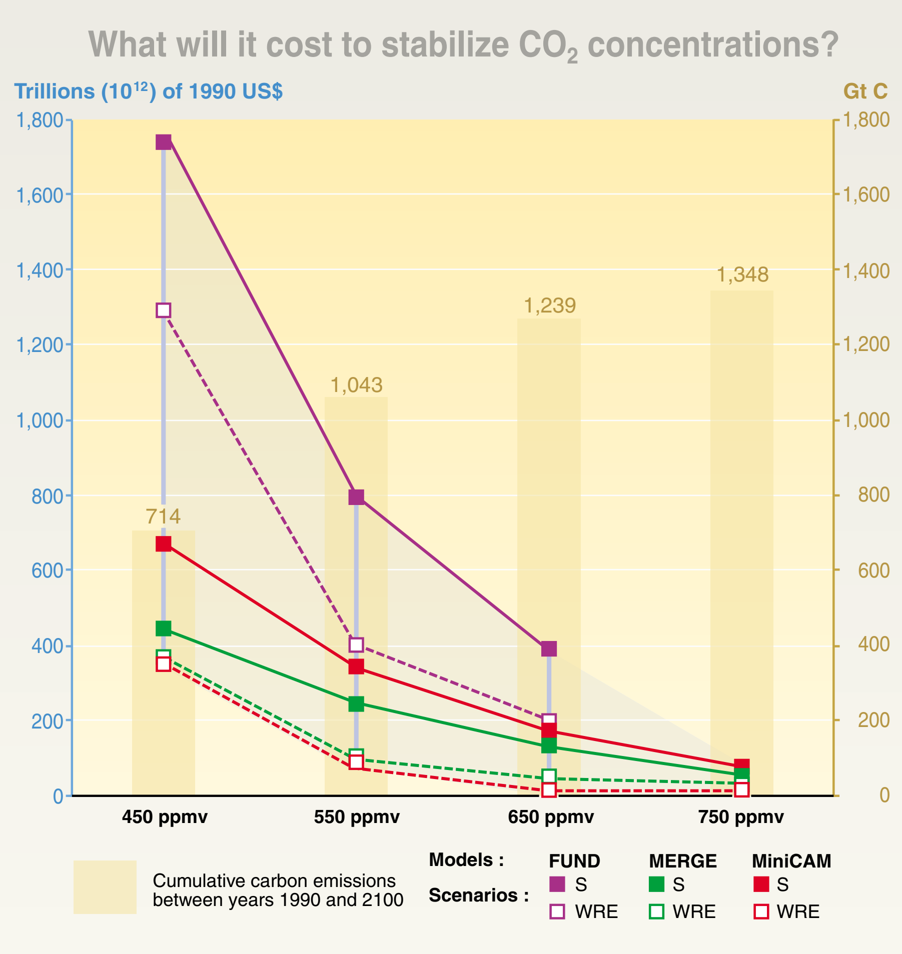
[20] "Known technological options" refer to technologies that exist in operation or pilot plant stage today, as referenced in the mitigation scenarios discussed in this report. It does not include any new technologies that will require drastic technological breakthroughs. In this way it can be considered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

increase in costs passing from 550 to 450 ppmv (see Figure 7-3) unless the emissions in the baseline scenario are very low (see Figure 7-4). Although model projections indicate long-term global growth paths of GDP are not significantly affected by mitigation actions towards stabilization, these do not show the larger variations that occur over some shorter time periods, sectors, or regions. These results, however, do not incorporate carbon sequestration, 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. Also, the issue of uncertainty takes on increasing importance as the time frame is expanded.

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

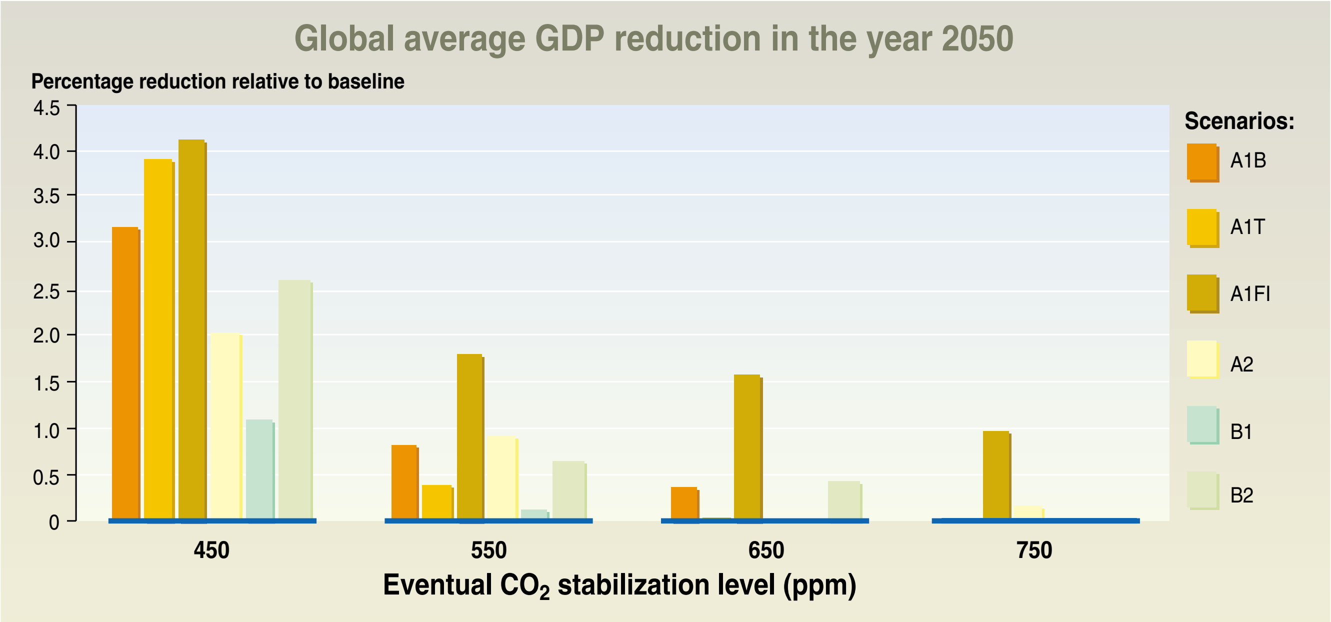
WGIII TAR Sections 2.5.1-2, 3.8.4, & 8.4.5

7.27 **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.** Emissions of CO_2 due to fossil-fuel burning are virtually certain to be the dominant influence on the atmospheric CO_2 concentration trend during the 21st century. Resource data assessed in the TAR may imply a change in the energy mix and the introduction of new sources of energy during the 21st century. Fossil-fuel resources will not limit carbon



WGIII TAR Sections 2.5.2, 8.4.1, 8.4.3, & 10.4.6

Figure 7-3: The mitigation costs (1990 US$, present value discounted at 5% per year for the period 1990 to 2100) of stabilizing CO_2 concentrations at 450 to 750 ppmv are calculated using three global models, based on different model-dependent baselines. Avoided impacts of climate change are not included. In each instance, costs were calculated based on two emission pathways for achieving the prescribed target: S (referred as WGI emissions pathways in WGIII TAR) and WRE as described in response to Question 6. The bars show cumulative carbon emissions between the years 1990 and 2100. Cumulative future emissions until carbon budget ceiling is reached are reported above the bars in Gt C.



WGIII TAR Figure 8-18

Figure 7-4: Indicative relationship in the year 2050 between the relative GDP reduction caused by mitigation activities, the SRES scenarios, 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. These projected mitigation costs do not take into account potential benefits of avoided climate change.

emissions during the 21st century (see Figure 7-5). The carbon in proven conventional oil and gas reserves is much less than the cumulative carbon emissions associated with stabilization of CO_2 at levels of 450 ppmv or higher.[21] These resource data may imply a change in the energy mix and the introduction of new sources of energy during the 21st century. 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.

7.28 **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.

WGIII TAR Section 10.3.3 & SRTT Section 2.3

7.29 **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.

WGIII TAR Sections 1.4.3, 5.3.7, 10.3.2, & 10.3.4

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

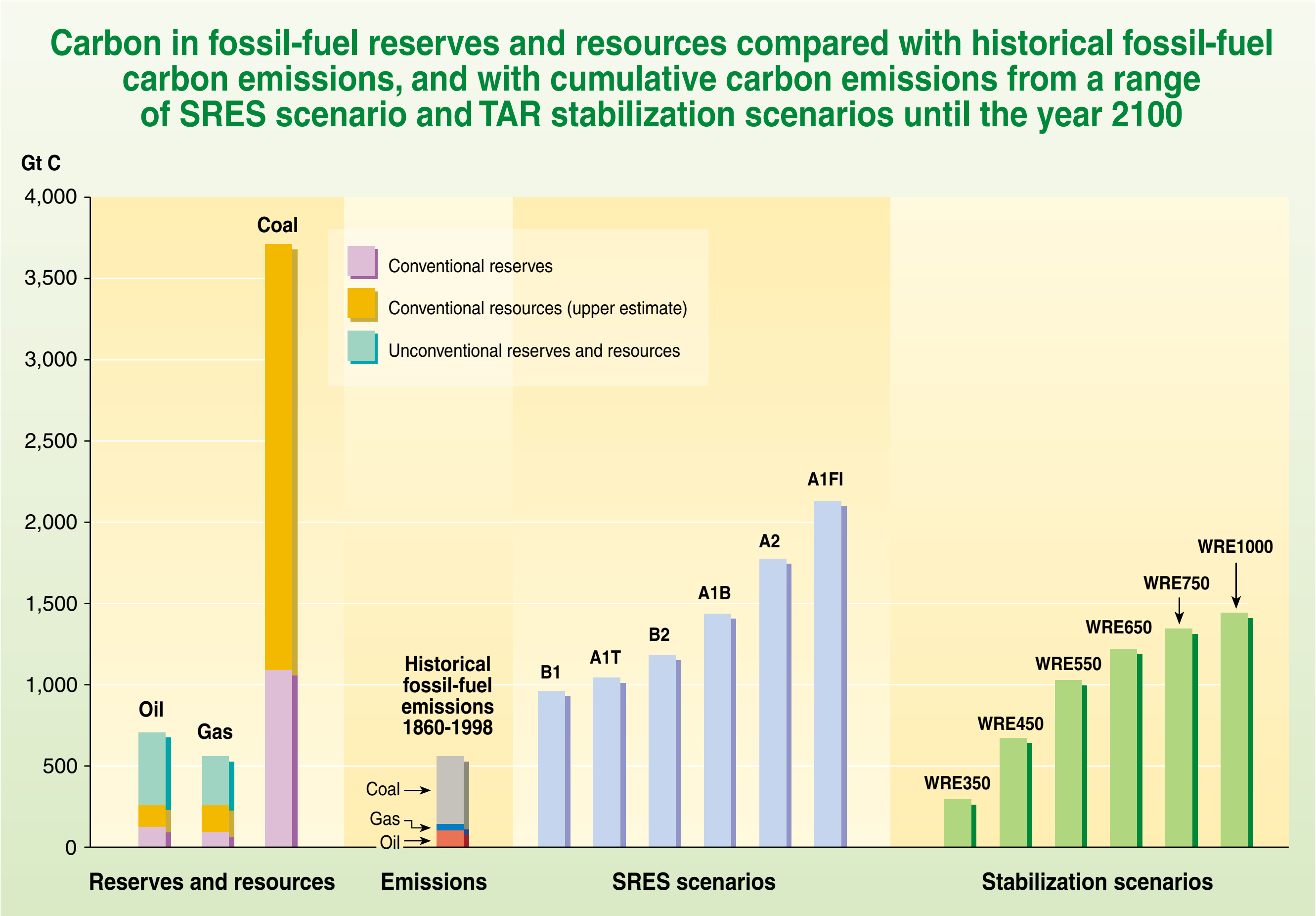
In the longer term, such innovations in combination with technological change may further enhance socio-economic potential, particularly if preferences and cultural norms shift towards lower emitting and sustainable behaviors. These innovations frequently meet with resistance, which may be addressed by encouraging greater public participation in the decision-making process. This can help contribute to new approaches to sustainability and equity.

Integrating Near- and Long-Term Considerations

7.30 **Climate change decision making is a sequential process under uncertainty. Decision making at any point in time entails balancing the risks of either insufficient or excessive action.**

7.31 **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

WGIII TAR Section 10.4.3



WGIII TAR Section 3.8.1

Figure 7-5: Carbon in oil, gas, and coal reserves and resources is compared with historic fossil-fuel carbon emissions over the period 1860–1998, and with cumulative carbon emissions from a range of SRES scenarios and TAR stabilization scenarios until the year 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 aquifers, 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 the year 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.

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."

7.32 **Stabilizing atmospheric concentrations would depend upon emissions reductions beyond those agreed to in the Kyoto Protocol.** Most post-SRES scenario analyses suggest that achievement of stabilization at 450 ppmv may require emission reductions during the period 2008 to 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 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 Sections 2.5.2 & 8.4

7.33 Climate change mitigation raises both inter-regional and inter-temporal equity considerations.

7.34 **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.[22] 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:

WGIII TAR Sections 1.3, 2.5.2, 8.2.2, 10.2, & 10.4.5

- *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 limit and reduce their greenhouse gas emissions first.*[23] 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).
- *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.*[24] Inter-generational 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).

[22] 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.

[23] 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. 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.

[24] See above for other aspects of timing of greenhouse gas emissions reductions.

Question 8

Q8

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?

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 air pollution, scarcity of freshwater, deforestation, desertification, acid deposition, loss of biological diversity and changes at the genetic and species level, 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. 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 & 5.1-2, & WGIII TAR Sections 3.6 & 4.2

8.4 **Just as different environmental problems are often caused by the same underlying driving forces (economic growth, broad technological changes, life-style patterns, demographic shifts (population size, age structure, and migration), and governance structures), common barriers inhibit solutions to a variety of environmental and socio-economic issues.** Approaches to the amelioration of environmental issues can be 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 sound technologies; the lack of recognition of the true value of natural resources; failure to appropriate for the global values of natural resources at the local level; and failure to internalize the costs of environmental degradation into the market price of a resource
- Limited availability and transfer of technology, inefficient use of technologies, and inadequate investment in research and development for the technologies of the future
- Failure to manage adequately the use of natural resources and energy.

WGIII TAR Chapter 5, SRES Chapter 3, & SRTT TS 1.5

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 how climate change is interlinked with several other environmental issues.

Surface Ozone Air Pollution and Climate Change

8.7 **Surface ozone air pollution and the emissions that drive it are important contributors to global climate change.** The same pollutants that generate surface

WGI TAR Sections 4.2.3-4

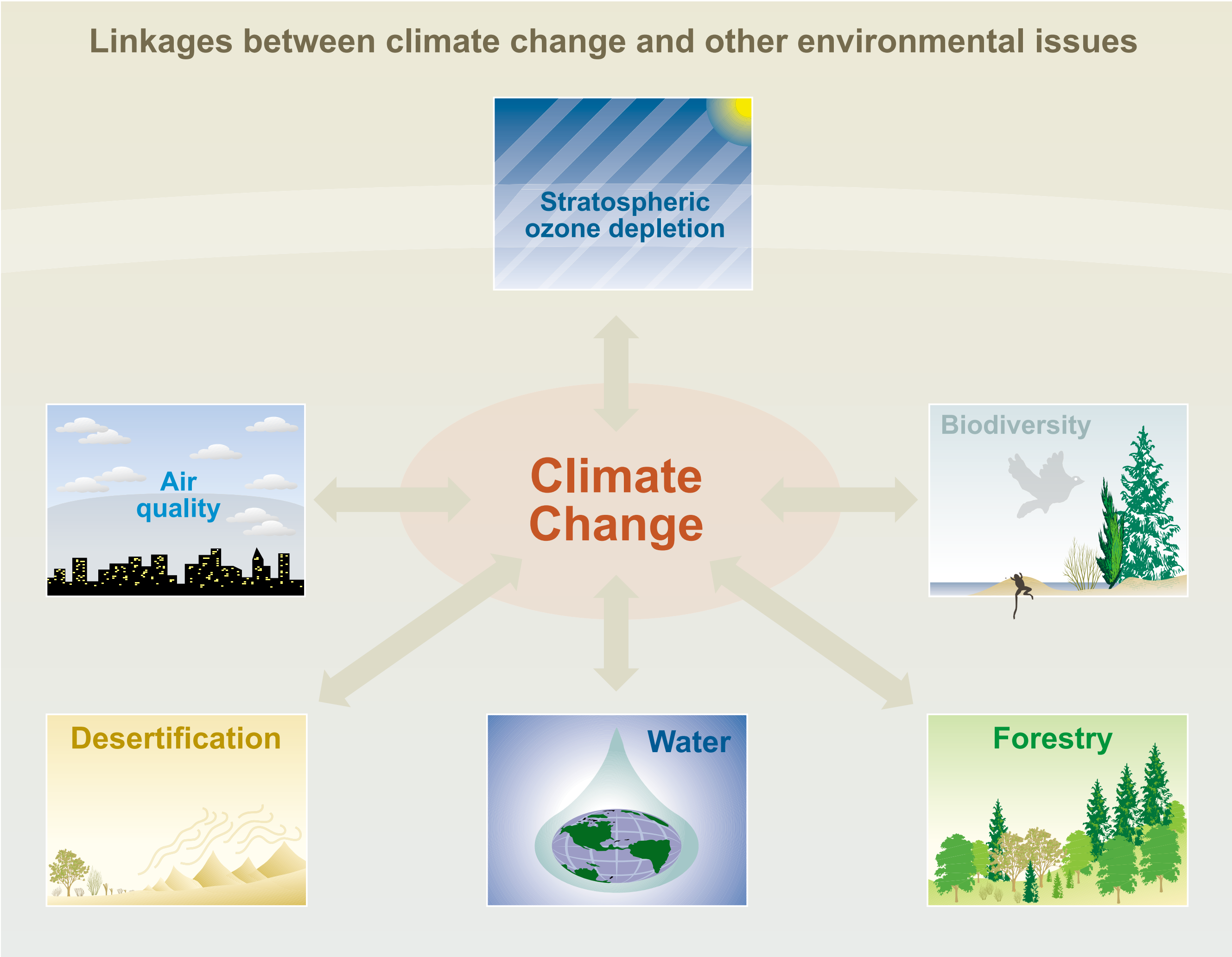


Figure 8-1: Climate is controlled by geochemical processes and cycles resulting from the interplay among the environment's components involved, as affected by human action. The scheme shows some of these issues. For simplicity, the single double-ended arrows between issues represent some of the linkages 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, such as 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, nitrogen, and water. 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.

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 CO_2 and CH_4 (see Figure 2-2). In some regions emissions of ozone precursor substances are controlled by regional environmental treaties (see Table 8-3) and other regulations.

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

WGI TAR Sections 4.4.4 & 4.5-6, & WGII TAR Sections 7.2.2.3 & 9.6

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.

Acid Deposition and Climate Change

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 has adverse impacts on both terrestrial and aquatic ecosystems and causes damage to human health and many materials. Some of these impacts could be exacerbated by climate change (e.g., through increase in humidity and temperature). 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 offset the greenhouse gas-induced warming.

WGI TAR Sections 5.2.2.6, 5.5.3, 6.7, & 6.15, WGII TAR Sections 5.6, 5.7.3, & 15.2.4.2, & SRES Section 3.6.4

Stratospheric Ozone Depletion and Climate Change

8.10 **Depletion of the stratospheric ozone layer leads to an increased penetration of UV-B radiation and to a cooling of the climate system.** Ozone depletion has allowed for increased penetration of UV-B radiation, with harmful effects on human and animal health, plants, etc. 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. 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 CH_4 thereby reducing its radiative forcing. These effects lead also to a cooling of the climate system.

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, 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 chlorofluorocarbons is hydrofluorocarbons, which are among the greenhouse gases listed under the Kyoto Protocol. This overlap can give rise to a potential conflict beween the goals of the two Protocols.

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 Sections 4.5, 6.4, & 7.2.4.2

Biodiversity, Agriculture and Forestry, and Climate Change

8.13 **Changes in terrestrial and marine ecosystems are closely linked to changes in climate and *vice versa*.** Changes in climate and in atmospheric concentrations of CO_2 cause changes in the biodiversity and function of some ecosystems. In turn, ecosystem changes influence the land-atmosphere exchange of greenhouse gases (e.g., CO_2, CH_4, and N_2O) 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 impacts 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 affect 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, increased CO_2 concentrations, and changes in storm frequency and intensity. Table 8-1 gives main implications of climate change for natural ecosystems at the regional scale.

WGII TAR Chapters 5 & 6

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 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 Chapters 5 & 6, & WGIII TAR Sections 4.1-2

8.16 **Climate change can influence the distribution and migration of species in unmanaged 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 their current habitat unsuitable. Vegetation distribution models since the SAR suggest that a mass ecosystem or biome movement is most unlikely to occur because differerent species have different climate tolerance and different migration abilities, and are affected differently by the arrival of new species. Lastly, in a related sense, climate change can enhance the spreading of pests and diseases, thereby affecting both natural ecosystems, crops, and livestock (e.g., changes in temperature and humidity thresholds allow pests and diseases to move to new areas).

WGII TAR Chapter 5

8.17 **Carbon storage capacities of managed and unmanaged ecosystems, particularly forests, influence impacts and feedbacks with climate change.** For example, forests, agricultural lands, and other terrestrial ecosystems offer a significant carbon mitigation potential. Although not necessarily permanent, conservation and sequestration may allow time for other options to be further developed and implemented. Terrestrial ecosystem degradation may be exacerbated by climate change, affecting the storage of carbon, and adding to the stresses resulting from the current deforestation practices. It should be noted that, if appropriate management practices are not carried out, CO_2 emissions in the future could be higher. For example, abandoning fire management in forests or reverting from direct seeding to intensive tillage in agriculture may result in rapid loss of part, at least, of the accumulated carbon.

WGIII TAR Section 4.3 & SRLULUCF SPM

Land Degradation and Desertification and Climate Change

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, and one quarter of the world soil resources, most of them in the developing countries. The annual recorded losses of millions of hectares significantly undermine economies and create some irreversible situations. 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

WGI TAR Sections 2.7.3.3, 9.3, & 10.3, WGII TAR Section 5.5, & WGII TAR Table SPM-1

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	Decreases in agricultural productivity and aquaculture due to thermal and water stress, sea-level rise, floods and droughts, and tropical cyclones would diminish food security 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 5.2.1-2 & Sections 11.2.1-2
Australia and 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, 12.4.4-5, & 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 (*medium confidence*).	TS 5.4.2-3 & Sections 13.2.1.4, 13.2.2.1, 13.2.2.3-5, & 13.2.3.1
Latin America	It is well-established that Latin America accounts for one of the Earth's largest concentrations 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, & Sections 14.2.1-2
North America	There is 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 5.6.4-5 & Sections 15.2.2-3
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 16.2.7-8
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 increased 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 island endemics, while 23% of bird species are threatened. Coral reefs, mangroves, and seagrass beds that often rely on stable environmental conditions will be adversely affected by rising air and sea temperatures and sea-level rise (*medium confidence*). Declines in coastal ecosystems would negatively impact reef fish and threaten reef fisheries (*medium confidence*).	TS 5.8 & Sections 17.2.4-5 & 17.2.8.2

likely would be impacted include those with scarce water resources, rangelands, and land subsidence (see Table 8-2).

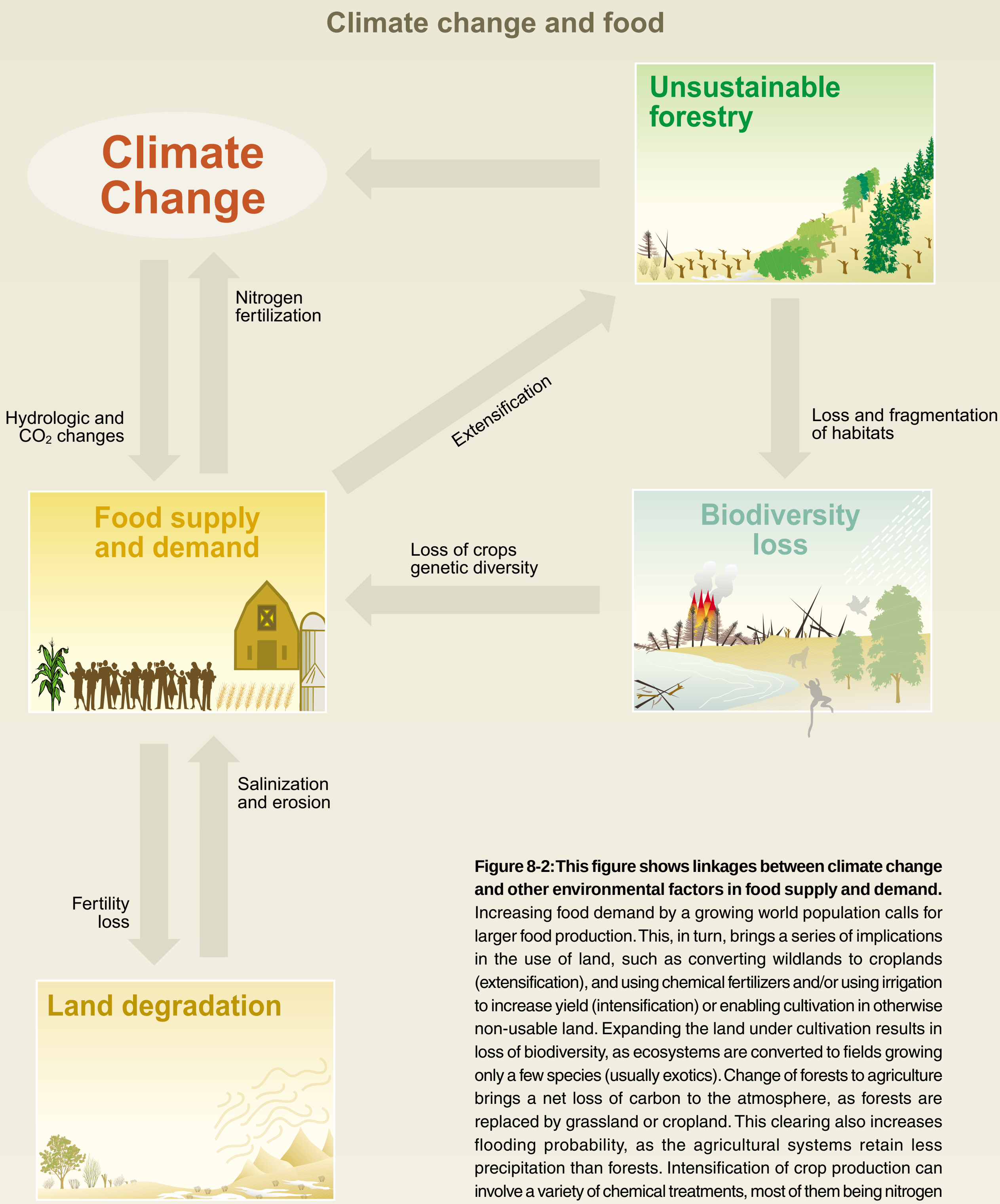


Figure 8-2: This figure shows linkages between climate change and other environmental factors in food supply and demand. Increasing food demand by a growing world population calls for larger food production. This, in turn, brings a series of implications in the use of land, such as converting wildlands to croplands (extensification), and using chemical fertilizers and/or using irrigation to increase yield (intensification) 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 forests are replaced by grassland or cropland. 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. Meeting the needs for increased agricultural production has the potential to increase global rates of biodiversity loss, climate change, and desertification. There are interrelations, particularly to water, that underly all these issues, but for simplicity are not shown in the figure.

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, Chapter 10 ES, Sections 10.2.1 & 10.2.6, & Table SPM-2
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 & 11.2.3
Australia and 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 (*high confidence*) 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 & Sections 12.1.5.3 & 12.3
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 (*high confidence*). Flood hazards will increase across much of Europe (*medium to 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, & Section 13.2.1
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, & Section 14.2.4
North America	Snowmelt-dominated watersheds in western North America will experience earlier spring peak flows (*high confidence*) and reduction in summer flow (*medium confidence*); adaptive responses may offset some, but not all, of the impacts on water resources and aquatic ecosystems (*medium confidence*).	TS 5.6.2, Section 15.2.1, & Table SPM-2
Small Islands	Islands with very limited water supplies are highly vulnerable to the impacts of climate change on the water balance (*high confidence*).	TS 5.8.4, Section 17.2.6, & Table SPM-2

Freshwater and Climate Change

WGII TAR Sections 4.1, 4.4.3, 4.5.2, & 4.6.2

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 1,700 m^3 yr^{-1} of water per capita. In the year 1990, approximately one-third of the world's population lived in countries using more than 20% of their water resources, and by the year 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.

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 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 interlinking 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, greenhouse gas emissions as well as local and regional pollutants could be reduced through more efficient and environmentally sound use of energy and increasing the share of lower carbon emitting fossil fuels, advanced fossil-fuel technologies (e.g., highly efficient combined cycle gas turbines, fuel cells, and combined heat and power), and renewable energy technologies (e.g., increased use of environmentally sound biofuels, hydropower, solar, wind- and wave-power). 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 availability. For example, in some implementations, monoculture plantations could decrease local biodiversity.

WGIII TAR Sections 3.6.4, 4.4, 8.2.4, & 9.2.2-5

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

WGIII TAR Sections 2.4, 9.2.8, & 10.3.2, & SRES 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.

8.24 **Adopting environmentally sound technologies and practices offer particular opportunities for economically, environmentally, and socially 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 balanced 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 migration of rural population into urban centers, reduce needs for transportation, and allow the use of environmentally sound 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

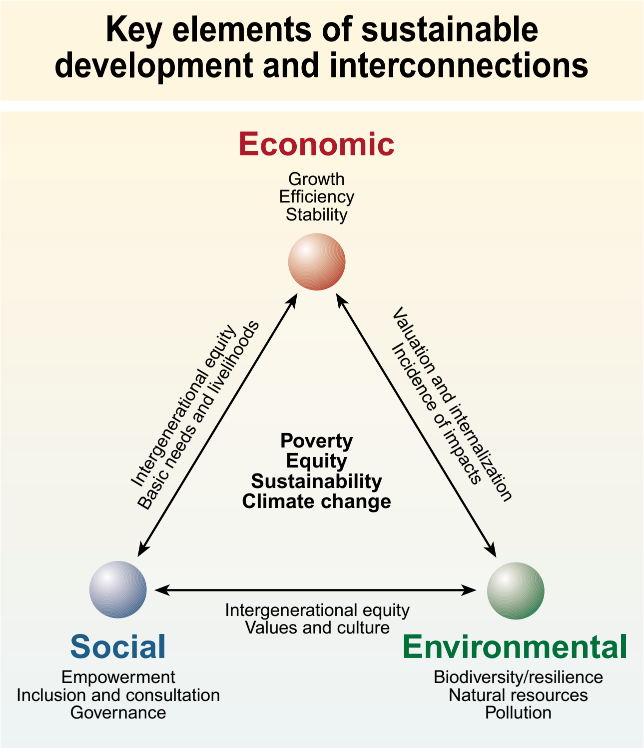
8.25 **Reducing vulnerability to climate change can often reduce vulnerability to other environmental stresses and *vice versa*.** Examples include, *inter alia*:

- *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 4.1-2 & 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 those 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.

WGIII TAR Sections 1.3.4, 2.2.3, & 10.3.2, & DES GP



DES GP

Figure 8-3: 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.

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 limited 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 Sections 1.5.1, 2.4.4, 5.3, 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 agreements—the Vienna Convention and its Montreal Protocol, the United Nations Framework Convention on Climate Change, the United Nations Convention on Biological Diversity, the United Nations Convention to Combat Desertification, and the United Nations Forum on Forests—as well as a range of regional agreements, such as the Convention on Long-Range Transboundary Air Pollution. Table 8-3 provides a list of selected examples of such conventions and instruments. They may contain, *inter alia*, similar requirements concerning common shared or coordinated governmental and civil institutions to enact the general objectives—for example, 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. Also they provide a framework within which synergies in scientific assessment can be utilized (see Box 8-1).

WGIII TAR Section 10.3.2

Table 8-3 Selected international environmental treaties.

Convention and Agreement	*Place and Date of Adoption*
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	Paris, 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 the 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 Nations 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 Nations Framework Convention on Climate Change – Kyoto Protocol to the United Nations 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.

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 hydrofluorocarbons) 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, & 7.2.4, WGIII TAR Chapter 3 Appendix, & SRAGA Section 4.2

Question 9

Q9

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?

Introduction

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.

9.2 **In this report, 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 unaffected by uncertainties.** A robust finding can be expected to fall into the categories of *well-established* (high level of agreement and high amount of evidence) and *established but incomplete* (high level of agreement, but incomplete evidence) 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 robust findings in relation to the questions of this report.** These findings may, in turn, lead to better or more of the information that underpins policy making. 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 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 1-1 shows how adaptation and mitigation can be integrated into the assessment. The human and natural systems will have to adapt to climate change, and development will be affected. The adaptation will be both autonomous and via government initiatives, and adaptation actions will reduce (but cannot entirely avoid) some of the impacts of climate change on these systems and on development. Adaptation actions provide benefits but also entail costs. Mitigation is unlike adaptation in that it reduces emissions at the start of the cycle, it reduces concentrations (compared to what would otherwise occur), and it reduces climate change and the risks and uncertainties associated with climate change. It further reduces the need for adaptation, the impacts of climate change, and effects on socio-economic development. It is also different in that mitigation aims to address the impacts on the climate system, whereas adaptation is primarily oriented to address localized impacts of climate change. The primary benefit of mitigation is avoided climate change, but it also has costs. In addition, mitigation gives rise to ancillary benefits (e.g., reduced air pollution leading to improvements in human health). A fully integrated approach to climate change assessment would consider the whole cycle shown in Figure 1-1 dynamically with all the feedbacks but this could not be accomplished in the TAR.

9.6 Many of the ***robust findings*** as listed in Table SPM-3 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.

Attribution of Climate Change

9.7 **There is now stronger evidence for a human influence on 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 the year 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 1,000 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 and the magnitude of climate forcings due to natural factors and anthropogenic aerosols (particularly indirect effects) and the relating of regional trends to anthropogenic climate change.

Q2.7 & Q2.10-11

Future Emissions and Concentrations of Greenhouse Gases and Aerosols

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

9.10 **Since the year 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 (Figure 9-1a).** Other greenhouse gases have also increased in concentrations since the year 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 (see Box 3-1), CO_2 concentrations continue to grow to the year 2100. Most SRES scenarios show reductions in SO_2 emissions (precursor for sulfate aerosols) by the year 2100 compared with the year 2000. Some greenhouse gases (e.g., CO_2, N_2O, perfluorocarbons) have long lifetimes (a century or more) for their residence in the atmosphere, while the lifetime of aerosols is measured in days. ***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 lower atmosphere ozone and aerosol precursors. Smaller uncertainties arise from lack of understanding of all the factors inherent in modeling the carbon cycle and including the effects of climate feedbacks. Accounting for all these uncertainties leads

Q2.4, Q3.3, Q3.5, & Q5.3

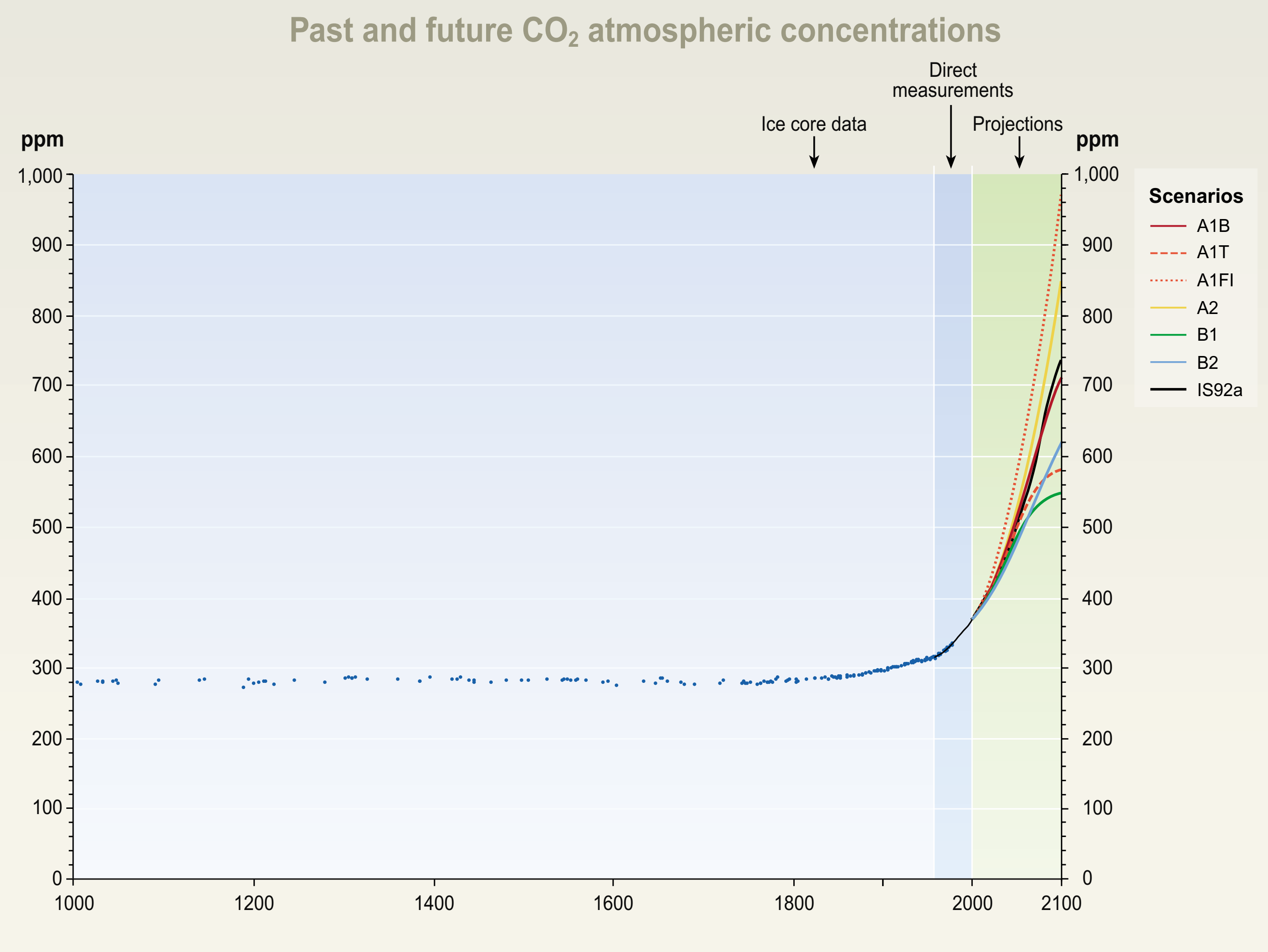


Figure 9-1a: Observations of atmospheric CO_2 concentration over the years 1000 to 2000 from ice core data supplemented with data from direct atmospheric measurements over the past few decades. Over the period 2000 to 2100, projections are shown of CO_2 concentrations based on the six illustrative SRES scenarios and IS92a (for comparison with the SAR).

WGI TAR SPM Figures 2a & 5b

to a range of CO_2 concentrations in the year 2100 between about 490 and 1,260 ppm (compared to the pre-industrial concentration of about 280 ppm and of about 368 ppm in the year 2000).

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 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.

Q4.11 & Q7.4

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 (Figure 9-1b).** It is very 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 cold days, cold waves, and frost days; and a reduced diurnal temperature range.

Q3.7, Q3.11, & Q4.5

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, an increase in temperatures globally 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.

Q2.24, Q3.8, Q3.12, Q4.2, & Q4.6

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.

Q3.9, Q3.14, Q4.15, & Q5.4

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, water vapor, and aerosols (including their indirect forcing). Allowing for these uncertainties leads to a range of projections of surface temperature increase for the period 1990 to 2100 of 1.4 to 5.8ºC (see Figure 9-1b) and of sea-level rise from 0.09 to 0.88 m. Another uncertainty concerns the understanding of the probability distribution associated with temperature and sea-level projections for the range of SRES scenarios. ***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. A further key uncertainty concerns the mechanisms, quantification, time scales, and likelihoods associated with large-scale abrupt/non-linear changes (e.g., ocean thermohaline circulation).

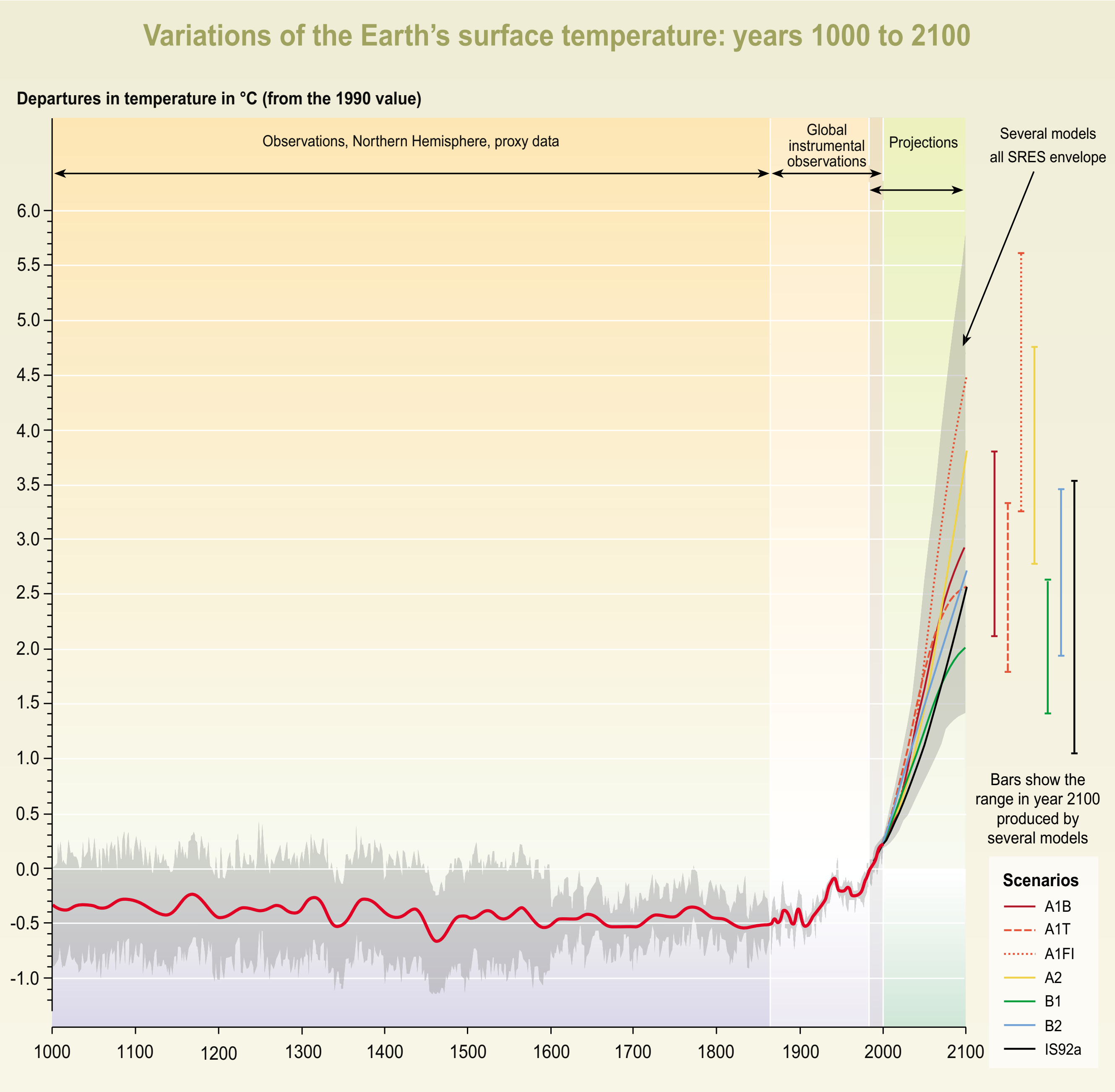
Q3.6, Q3.9, & Q4.9-19

Regional and Global Impacts of Climate Change

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

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

Q3.14 & Q3.18-21



WGI TAR SPM Figures 1b & 5d

Figure 9-1b: Variations of the Earth's surface temperature: years 1000 to 2100. Over the period 1000 to 1860, observations are shown of variations in average surface temperature of the Northern Hemisphere (corresponding data from the Southern Hemisphere not available) constructed from proxy data (tree rings, corals, ice cores, and historical records). The line shows the 50-year average, and the grey region the 95% confidence limit in the annual data. From the years 1860 to 2000, observations are shown of variations of global and annual averaged surface temperature from the instrumental record. The line shows the decadal average. Over the period 2000 to 2100, projections are shown 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.

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. Many physical systems are vulnerable to climate change: For example, the impact of coastal storm surges will be exacerbated by sea-level rise, and glaciers and permafrost will continue to retreat. In some mid- to high latitudes, plant productivity (trees and some agricultural crops) would increase with small increases in temperature. Plant productivity would decrease in most regions of the world for warming beyond a few ºC. In most tropical and subtropical regions, yields are projected to decrease for almost any increase in temperature.

9.19 **Ecosystems and species are vulnerable to climate change and other stresses (as illustrated by observed impacts of recent regional temperature changes) and some will be irreversibly damaged or lost.** Natural systems at risk include 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.

Q3.18

9.20 **The adverse impacts of climate change are expected to fall disproportionately upon developing countries and the poor persons within countries.** 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. While overall precipitation is projected to increase, there are likely to be much larger changes in intensity and frequency, which will increase the likelihood of extremes of drying and precipitation, and thus droughts and floods during the 21st century. These increases combined with increased water stress (occurring already because of increasing demand) will affect 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.

Q3.17, Q3.21-22, & Q3.33

9.21 **Populations that inhabit small islands and low-lying coastal areas are at particular risk of severe social and economic effects from sea-level rise and storm surges.** Tens of millions of people living in deltas, low-lying coastal areas, and on small islands will face risk of displacement. 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.

Q3.23-24

9.22 ***Key uncertainties*** in the identification and quantification of impacts arise from the lack of reliable local or regional detail in climate change, 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 social (e.g., impact of vector- and water-borne diseases), and economic systems to the combined effect of climate change and other stresses such as land-use change, local pollution, etc.

Q3.13, Q4.10, & Q4.18-19

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 adverse impacts of climate change, to enhance beneficial impacts, and to produce many immediate ancillary benefits, but will not prevent all damages.**

Q3.26-28 & Q3.33

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 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.** Q3.31 & Q3.36-37

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. Q3.27

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

9.28 **Greenhouse gas emission reduction (mitigation) action would lessen the pressures on natural and human systems from climate change.** Comprehensive, quantitative estimates of global primary benefits of mitigating climate change do not exist. For mean temperature increases over a few ºC relative to the year 1990, impacts are predominantly adverse, 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 a few ºC. These averages conceal wide regional variations. Q6.10

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 1,000 ppm would require global anthropogenic CO_2 emissions to drop below year 1990 levels within a few decades, about a century, or about 2 centuries, respectively, and continue to decrease steadily thereafter. Emissions would peak in about 1 to 2 decades (450 ppm) and roughly a century (1,000 ppm) from the present. 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 development pathways and how these affect the timing of emissions reductions. 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 industries dependent on energy produced from these fossil fuels—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, services, and new industries whose development is stimulated by demand for low-emission fuels and production techniques. 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. Q7.14, Q7.17, & Q7.34

9.32 **Emission constraints in Annex I countries have well established, albeit varied, "spill-over" effects on non-Annex I countries.** Analyses of the effects of emissions constraints on Annex I countries report reductions below what would otherwise occur in both projected GDP and in projected oil revenues for oil-exporting non-Annex I countries.

Q7.19

9.33 **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.** Emissions of CO_2 due to fossil-fuel burning are virtually certain to be to the dominant influence on the trend on the atmospheric CO_2 concentration during the 21st century. Resource data assessed in the TAR may imply a change in the energy mix and the introduction of new sources of energy during the 21st century. Fossil-fuel resources will not limit carbon emissions during the 21st century. The carbon in proven conventional oil and gas reserves is much less, however, than the cumulative carbon emissions associated with stabilization of CO_2 at levels of 450 ppm or higher.[25] These resource data may imply a change in the energy mix and the introduction of new sources of energy during the 21st century. 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. ***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.

Q7.27

9.34 **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, 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 R&D expenditures on these technologies.

Q7.3

9.35 **Studies examined in the TAR suggest substantial technological and other opportunities for lowering mitigation costs. National mitigation responses to climate change can be more effective if deployed as a portfolio of policy instruments to limit or reduce net greenhouse gas emissions.** 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 substantially reduced or even turned into net benefits with a portfolio of policy instruments (including those that help to overcome barriers) 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 to 2.6 Gt C_{eq} yr^{-1} by year 2010 and 3.6 to 5.0 Gt C_{eq} yr^{-1} by year 2020. Half of these reductions may be realized with one component of their economic cost (net capital, operating, and maintenance costs) with direct benefits exceeding direct costs, and the other half with that component of their economic cost ranging from US$0 to US$100 per t C_{eq}.[26] Depending on the emissions scenario, global emissions could be reduced below year 2000 levels over the 2010 to 2020 time frame. ***Key uncertainties*** are the identification,

Q7.6-7, Q7.14-15, Q7.20, & Q7.23, & Q7 Box 7-1

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

[26] These cost estimates in 1998 prices 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.

extent, and nature of any barriers that impede adoption of promising low-emission technologies, and the estimation of 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:* 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. ***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.

9.36 **Modeling studies show that emissions trading reduces costs of mitigation for those participating in the trading.** 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[27] group of countries. *Annex I OECD[28] 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:

Q7.18-19

- Allowance for exemptions in the emission-permit trading in concert with other policies and measures
- Consideration of various market imperfections
- 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., CH_4 from agriculture)
- Offsets from sinks.

9.37 **Although model projections indicate that long-term global growth paths of GDP are not significantly affected by mitigation actions towards stabilization, these do not show the larger variations that occur over some shorter time periods, sectors, or regions.**

Q7.25

9.38 **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

Q7.24 & Q7.31

[27] *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.

[28] *Annex I countries:* Group of countries included in Annex I to the United Nations Framework Convention on Climate Change, including all developed countries in the the Organisation for Economic Cooperation and Development and those with economies in transition.

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, shifts towards low-emission technologies, and/or changes towards more sustainable lifestyles.

9.39 **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. Inertia in the interacting climate, ecological, and socio-economic systems is a major reason why anticipatory adaptation and mitigation actions are beneficial.

Q5.19 & Q5.24

9.40 **Adaptation can complement mitigation in a cost-effective strategy to reduce climate change risks; together they can contribute to sustainable development objectives.** 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 policy-making processes.

Q1.9 & Q8.21-28

9.41 **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 the climate are being made now in both developed and developing countries. Information is available to help decision makers 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.

Q5.22, Q7.25, & Q8.26

Further Work

9.42 **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 important areas where further work is required, in particular:

- The detection and attribution of climate change
- The understanding and prediction of regional changes in climate and climate extremes
- The quantification of climate change impacts at the global, regional, and local levels
- The analysis of adaptation and mitigation activities
- The integration of all aspects of the climate change issue into strategies for sustainable development
- Comprehensive and integrated investigations to support the judgment as to what constitutes “dangerous anthropogenic interference with the climate system.”

WGI TAR SPM, WGII TAR SPM, & WGIII TAR SPM