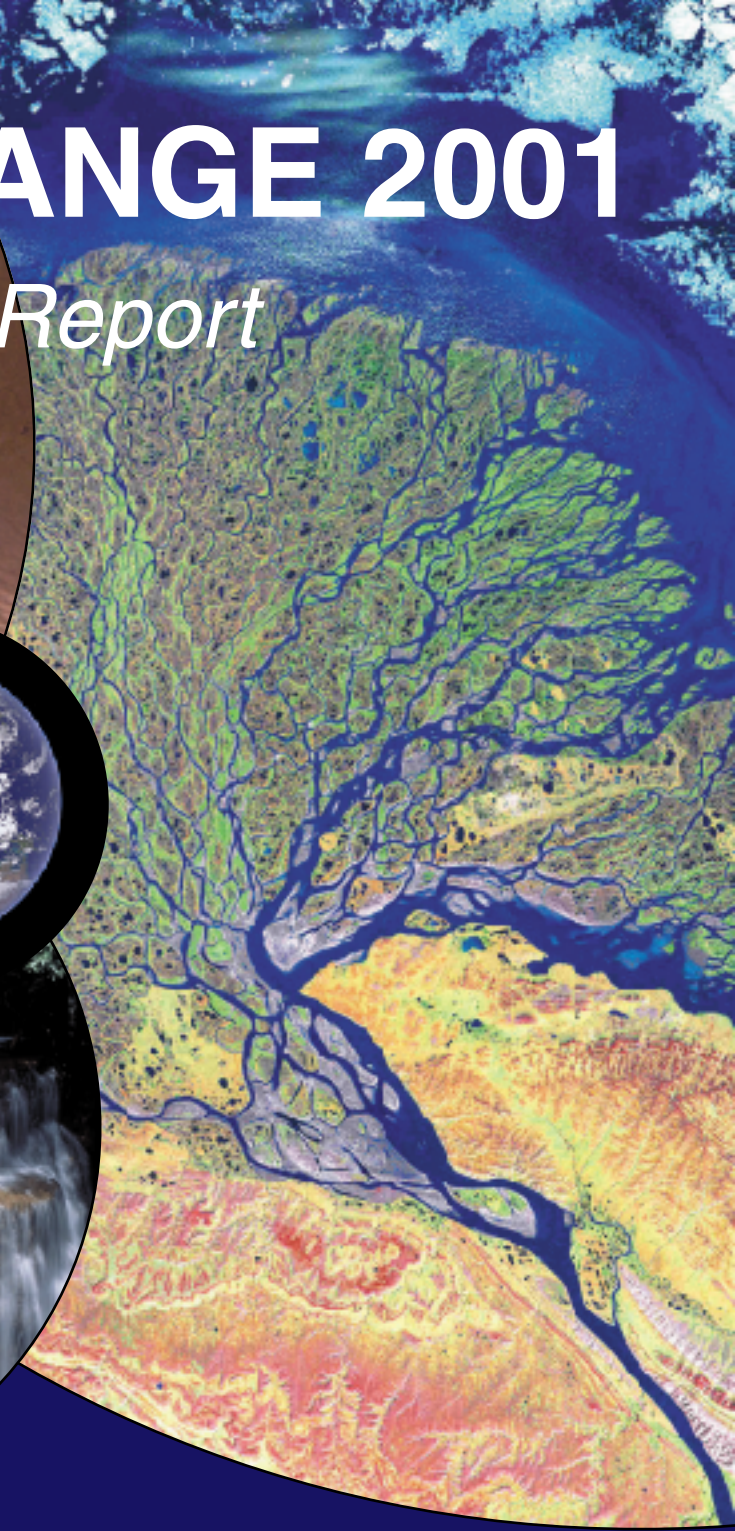


# CLIMATE CHANGE 2001

## *Synthesis Report*



*Subject to Final Copyedit*



A Report of the Intergovernmental Panel on Climate Change



The Summary for Policymakers of this Synthesis Report was approved line by line by the Intergovernmental Panel on Climate Change at its Eighteenth Session (Wembley, United Kingdom, 24-29 September 2001). One hundred and twenty four governments were represented at the session and sixteen international and non-governmental organizations.

The balance of the Synthesis Report was adopted paragraph by paragraph at the same session. The glossary was not submitted to the Panel for action, consistent with normal practice within the IPCC.



### IPCC Assessments Cited in the Synthesis Report

Qx.x	<i>Relevant paragraph in the underlying Synthesis Report</i>	SPM	<i>Summary for Policymakers</i>
WGI TAR	<i>Working Group I contribution to the Third Assessment Report</i>	TS	<i>Technical Summary</i>
WGII TAR	<i>Working Group II contribution to the Third Assessment Report</i>	ES	<i>Executive Summary</i>
WGIII TAR	<i>Working Group III contribution to the Third Assessment Report</i>	GP	<i>Guidance Paper</i>
SRES	<i>Special Report on Emissions Scenarios</i>	TP	<i>Technical Paper</i>
SRLULUCF	<i>Special Report on Land Use, Land-Use Change, and Forestry</i>		
SRTT	<i>Special Report on the Methodological and Technological Issues in Technology Transfer</i>		
SRAGA	<i>Special Report on Aviation and the Global Atmosphere</i>		
DES GP	<i>Guidance Paper on Development, Equity, and Sustainability</i>		
IPCC TP4	<i>Technical Paper on Implications of Proposed CO<sub>2</sub> Emissions Limitations</i>		
IPCC TP3	<i>Technical Paper on Stabilization of Atmospheric Greenhouse Gases: Physical, Biological, and Socio-Economic Implications</i>		
WGII SAR	<i>Working Group II contribution to the Second Assessment Report</i>		

# Climate Change 2001: Synthesis Report

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# Climate Change 2001: Synthesis Report

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# Climate Change 2001: Synthesis Report

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## Summary for Policymakers

### **An Assessment of the Intergovernmental Panel on Climate Change**

*This summary, approved in detail 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.*

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Based on a draft prepared by:

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## Introduction

In accordance with a decision taken at its Thirteenth Session (Maldives, 22 and 25-28 September 1997) and other subsequent decisions, the IPCC decided:

- To include a Synthesis Report as part of its Third Assessment Report
- That the Synthesis Report would provide a policy-relevant, but not policy-prescriptive, synthesis and integration of information contained within the Third Assessment Report and also drawing upon all previously approved and accepted IPCC reports that would address a broad range of key policy-relevant, but not policy-prescriptive, questions
- That the questions would be developed in consultation with the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC).

The following nine questions were based on submissions by governments and were approved by the IPCC at its Fifteenth Session (San Jose, Costa Rica, 15-18 April 1999).

### 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?

**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.**

→ Q1.1

**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—and depends upon mitigative capacity, since the magnitude and the rate of change are both important.** 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.

→ Q1.2

**The Third Assessment Report (TAR) provides an assessment of new scientific information and evidence as an input for policymakers in their determination of what constitutes “dangerous anthropogenic interference with the climate system.”**

→ Q1.3-6

It provides, first, new 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. Second, it provides an assessment of the biophysical and socio-economic impacts of climate change, with regard to risks to unique and threatened systems, risks associated with extreme weather events, the distribution of impacts, aggregate impacts, and risks of large-scale, high-impact events. Third, it provides an assessment of the potential for achieving a broad range of levels of greenhouse gas concentrations in the atmosphere through mitigation and information about how adaptation can reduce vulnerability.

**An integrated view of climate change considers the dynamics of the complete cycle of interlinked causes and effects across all sectors concerned (see Figure SPM-1).**

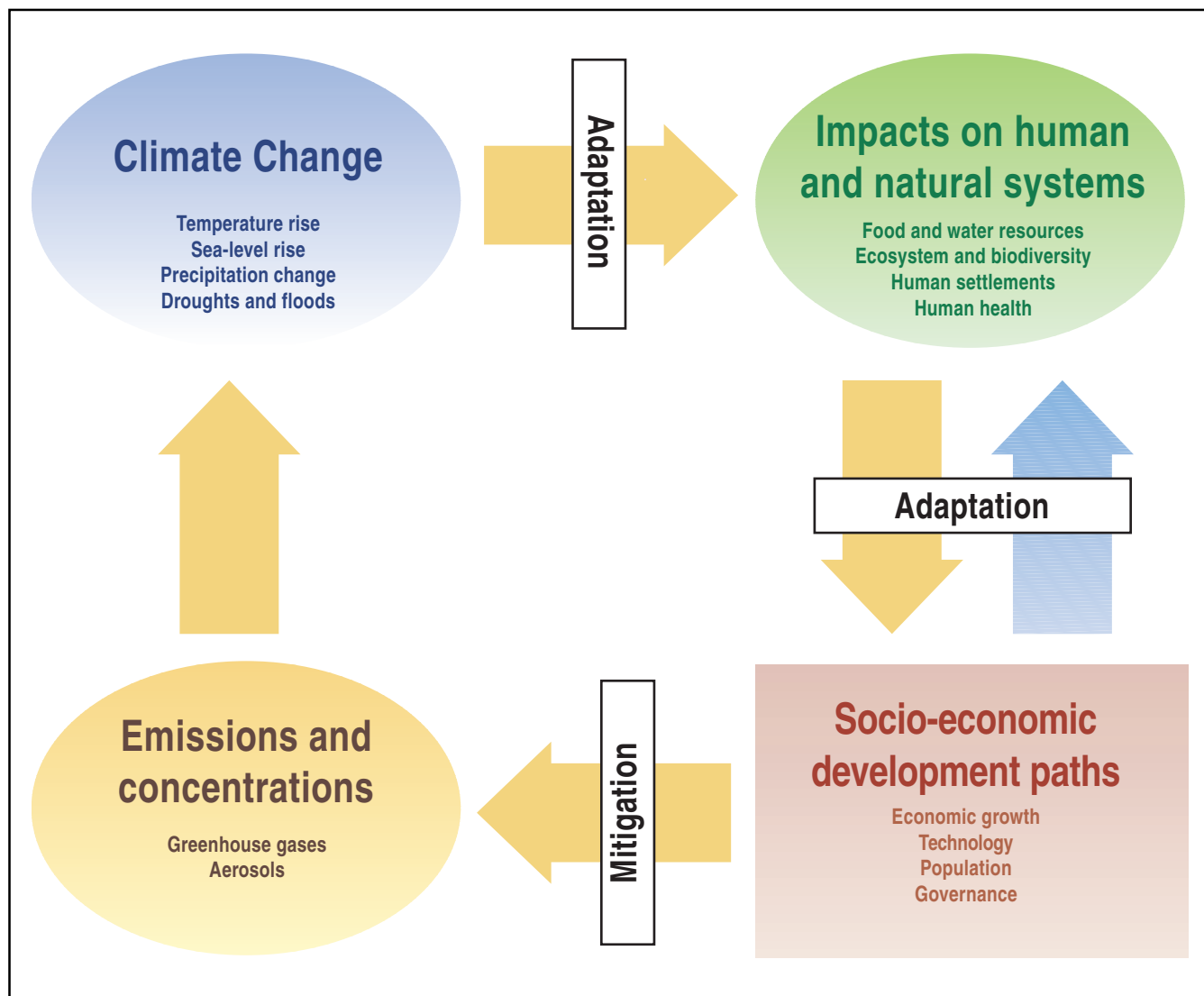
→ Q1.7

The TAR provides new policy-relevant information and evidence with regard to all quadrants of Figure SPM-1. A major new contribution of the *Special Report on Emissions Scenarios* (SRES) was to explore alternative development paths and related greenhouse gas emissions, and the TAR assessed 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.

**Climate change decision making is essentially a sequential process under general uncertainty.**

→ Q1.8

Decision making has to deal with uncertainties including the risk of non-linear and/or irreversible changes and entails balancing the risks 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.



**Figure SPM-1: Climate change – an integrated framework.** Schematic and simplified representation of an integrated assessment framework for considering anthropogenic climate change. The yellow arrows show the 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. See the caption for Figure 1-1 for an expanded description of this framework.

→ Q1 Figure 1-1

**The climate change issue is part of the larger challenge of sustainable development. As a result, climate policies can be more effective when consistently embedded within broader strategies designed to make national and regional development paths more sustainable.** This occurs because the impact of climate variability and change, climate policy responses, and associated socio-economic development will affect the ability of countries to achieve sustainable development goals. Conversely, 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.

→ Q1.9-10

**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, and in cooperation with others, to reduce costs of mitigation and adaptation and to realize benefits associated with achieving sustainable development.

→ Q1.11

## 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?

**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.**

→ Q2.2

**Human activities have increased the atmospheric concentrations of greenhouse gases and aerosols since the pre-industrial era.** The atmospheric concentrations of key anthropogenic greenhouse gases (i.e., carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and tropospheric ozone (O<sub>3</sub>)) reached their highest recorded levels in the 1990s, primarily due to the combustion of fossil fuels, agriculture, and land-use changes (see Table SPM-1). The radiative forcing from anthropogenic greenhouse gases is positive with a small uncertainty range; that from the direct aerosol effects is negative and smaller; whereas the negative forcing from the indirect effects of aerosols on clouds might be large but is not well quantified.

→ Q2.4-5

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

→ Q2.6

**Globally it is very likely that the 1990s was the warmest decade, and 1998 the warmest year, in the instrumental record (1861–2000) (see Box SPM-1).** The increase in surface temperature over the 20th century for the Northern Hemisphere is likely to have been greater than that for any other century in the last thousand years (see Table SPM-1). Insufficient data are available prior to the year 1860 in the Southern Hemisphere to compare the recent warming with changes over the last 1,000 years. Temperature changes have not been uniform globally but have varied over regions and different parts of the lower atmosphere.

→ Q2.7



Table SPM-1 20th century changes in the Earth's atmosphere, climate, and biophysical system. <sup>a</sup>	
Indicator	Observed Changes
<i>Concentration indicators</i>	
Atmospheric concentration of CO <sub>2</sub>	280 ppm for the period 1000-1750 to 368 ppm in year 2000 (31±4% increase).
Terrestrial biospheric CO <sub>2</sub> 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.
Atmospheric concentration of CH <sub>4</sub>	700 ppb for the period 1000-1750 to 1,750 ppb in year 2000 (151±25% increase).
Atmospheric concentration of N <sub>2</sub> O	270 ppb for the period 1000-1750 to 316 ppb in year 2000 (17±5% increase).
Tropospheric concentration of O <sub>3</sub>	Increased by 35±15% from the years 1750 to 2000, varies with region.
Stratospheric concentration of O <sub>3</sub>	Decreased over the years 1970 to 2000, varies with altitude and latitude.
Atmospheric concentrations of HFCs, PFCs, and SF <sub>6</sub>	Increased globally over the last 50 years.
<i>Weather indicators</i>	
Global mean surface temperature	Increased by 0.6±0.2°C over the 20th century; land areas warmed more than the oceans ( <i>very likely</i> ).
Northern Hemisphere surface temperature	Increased over the 20th century greater than during any other century in the last 1,000 years; 1990s warmest decade of the millennium ( <i>likely</i> ).
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 ( <i>likely</i> ).
Hot days / heat index	Increased ( <i>likely</i> ).
Cold / frost days	Decreased for nearly all land areas during the 20th century ( <i>very likely</i> ).
Continental precipitation	Increased by 5-10% over the 20th century in the Northern Hemisphere ( <i>very likely</i> ), although decreased in some regions (e.g., north and west Africa and parts of the Mediterranean).
Heavy precipitation events	Increased at mid- and high northern latitudes ( <i>likely</i> ).
Frequency and severity of drought	Increased summer drying and associated incidence of drought in a few areas ( <i>likely</i> ). In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts have been observed to increase in recent decades.


**Box SPM-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 WGI 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.



Q2 Box 2-1

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

Detection and attribution studies consistently find evidence for an anthropogenic signal in the climate record of the last 35 to 50 years. These studies include uncertainties in forcing due to anthropogenic sulfate aerosols and natural factors (volcanoes and solar irradiance), but do not account for the effects of other types of anthropogenic aerosols and land-use changes. The sulfate and natural forcings are negative over this period and cannot explain the warming; 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



Q2.9-11

Table SPM-1 20th century changes in the Earth's atmosphere, climate, and biophysical system. <sup>a</sup> (continued)	
Indicator	Observed Changes
<i>Biological and physical indicators</i>	
Global mean sea level	Increased at an average annual rate of 1 to 2 mm during the 20th century.
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 ( <i>very likely</i> ).
Arctic sea-ice extent and thickness	Thinned by 40% in recent decades in late summer to early autumn ( <i>likely</i> ) and decreased in extent by 10-15% since the 1950s in spring and summer.
Non-polar glaciers	Widespread retreat during the 20th century.
Snow cover	Decreased in area by 10% since global observations became available from satellites in the 1960s ( <i>very likely</i> ).
Permafrost	Thawed, warmed, and degraded in parts of the polar, sub-polar, and mountainous regions.
El Niño events	Became more frequent, persistent, and intense during the last 20 to 30 years compared to the previous 100 years.
Growing season	Lengthened by about 1 to 4 days per decade during the last 40 years in the Northern Hemisphere, especially at higher latitudes.
Plant and animal ranges	Shifted poleward and up in elevation for plants, insects, birds, and fish.
Breeding, flowering, and migration	Earlier plant flowering, earlier bird arrival, earlier dates of breeding season, and earlier emergence of insects in the Northern Hemisphere.
Coral reef bleaching	Increased frequency, especially during El Niño events.
<i>Economic indicators</i>	
Weather-related economic losses	Global inflation-adjusted losses rose an order of magnitude over the last 40 years (see Q2 Figure 2-7). Part of the observed upward trend is linked to socio-economic factors and part is linked to climatic factors.
<sup>a</sup> 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. An identical table in the Synthesis Report contains cross-references to the WGI and WGII reports.	

are comparable with, or larger than, the observed warming. The best agreement between model simulations and observations over the last 140 years has been found when all the above anthropogenic and natural forcing factors are combined, as shown in Figure SPM-2.

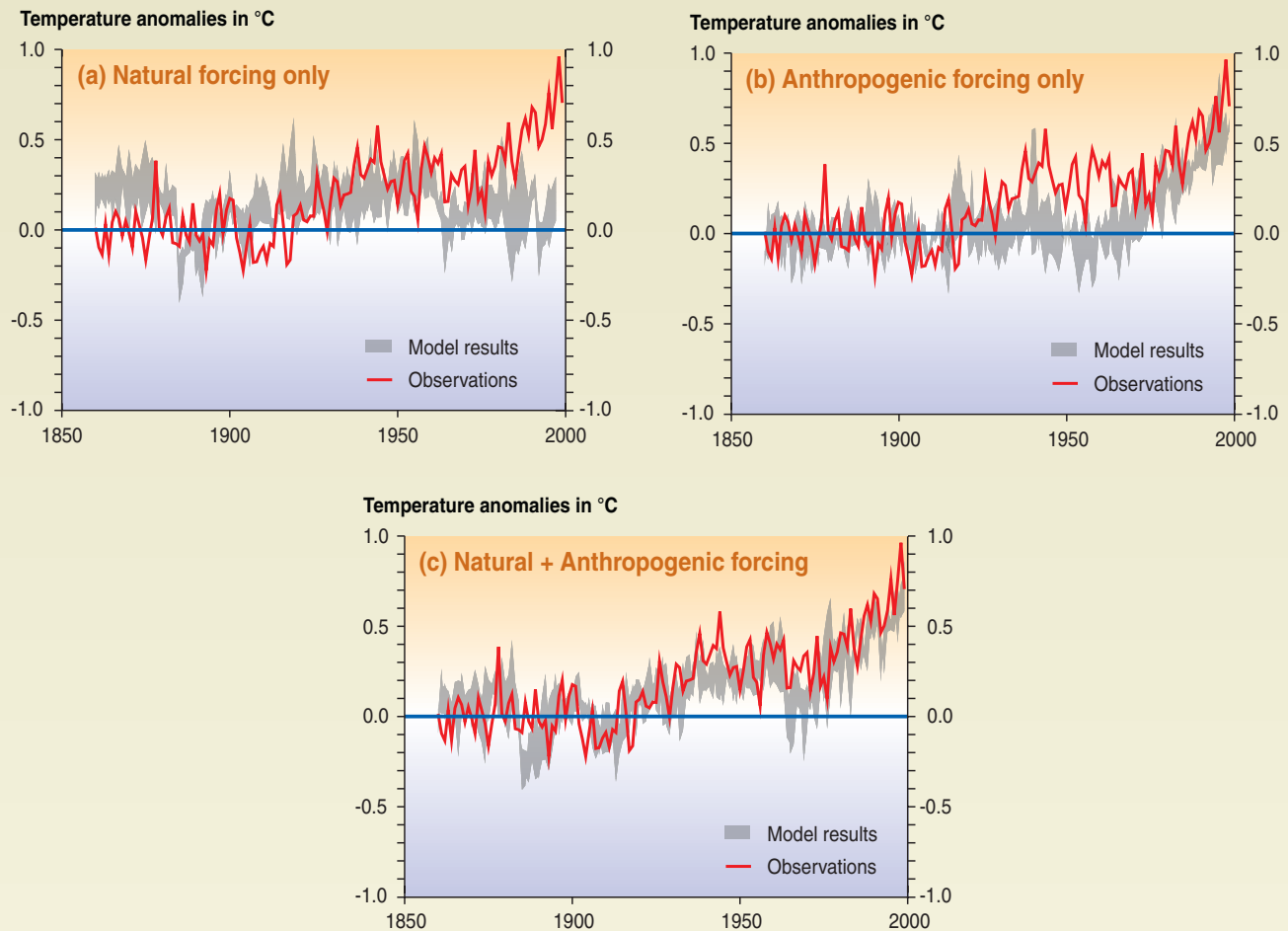
**Changes in sea level, snow cover, ice extent, and precipitation are consistent with a warming climate near the Earth's surface.** Examples of these include a more active hydrological cycle with more heavy precipitation events and shifts in precipitation, widespread retreat of non-polar glaciers, increases in sea level and ocean-heat content, and decreases in snow cover and sea-ice extent and thickness (see Table SPM-1). For instance, it is very likely that the 20th century warming has contributed significantly to the observed sea-level rise, through thermal expansion of seawater and widespread loss of land ice. Within present uncertainties, observations and models are both consistent with a lack of significant acceleration of sea-level rise during the 20th century. There are no demonstrated changes in overall Antarctic sea-ice extent from the years 1978 to 2000. In addition, there are conflicting analyses and insufficient data to assess changes in intensities of tropical and extra-tropical cyclones and severe local storm activity in the mid-latitudes. Some of the observed 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.

→ Q2.12-19

**Observed changes in regional climate have affected many physical and biological systems, and there are preliminary indications that social and economic systems have been affected.**

→ Q2.20 & Q2.25

## Comparison between modeled and observations of temperature rise since the year 1860



**Figure SPM-2: Simulating the Earth's temperature variations (°C) and comparing the results to the measured changes can provide insight to 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. And 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 also have contributed.

→ Q2 Figure 2-4

**Recent regional changes in climate, particularly increases in temperature, have already affected hydrological systems and terrestrial and marine ecosystems in many parts of the world (see Table SPM-1).** The observed changes in these systems<sup>1</sup> are coherent across diverse localities and/or regions 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.

→ Q2.21-24

<sup>1</sup> 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.

**The rising socio-economic costs related to weather damage and to regional variations in climate suggest increasing vulnerability to climate change.** 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. However, because these systems are also affected by changes in socio-economic factors such as demographic shifts and land-use changes, quantifying the relative impact of climate change (either anthropogenic or natural) and socio-economic factors is difficult.

→ Q2.25-26

### 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.

**Carbon dioxide concentrations, globally averaged surface temperature, and sea level are projected to increase under all IPCC emissions scenarios during the 21st century.<sup>2</sup>**

→ Q3.2

**For the six illustrative SRES emissions scenarios, the projected concentration of CO<sub>2</sub> in the year 2100 ranges from 540 to 970 ppm, compared to about 280 ppm in the pre-industrial era and about 368 ppm in the year 2000.** The different socio-economic assumptions (demographic, social, economic, and technological) result in the 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. Therefore, the total range is 490 to 1,260 ppm (75 to 350% above the year 1750 (pre-industrial) concentration). Concentrations of the primary non-CO<sub>2</sub> greenhouse gases by year 2100 are projected to vary considerably across the six illustrative SRES scenarios (see Figure SPM-3).

→ Q3.3-5

**Projections using the SRES emissions scenarios in a range of climate models result in an increase in globally averaged surface temperature of 1.4 to 5.8°C over the period 1990 to 2100. 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.** Temperature increases are projected to be greater than those in the Second Assessment Report (SAR), which were about 1.0 to 3.5°C based on six IS92 scenarios. The higher projected temperatures and the wider range are due primarily to lower projected sulfur dioxide (SO<sub>2</sub>) emissions in the SRES scenarios relative to the IS92 scenarios. 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. By

→ Q3.6-7 & Q3.11

<sup>2</sup> Projections of changes in climate variability, extreme events, and abrupt/non-linear changes are covered in Question 4.

the year 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 SPM-3 shows that the SRES scenarios with the highest emissions result in the largest projected temperature increases. Nearly all land areas will very likely warm more than these global averages, particularly those at northern high latitudes in winter.

**Globally averaged annual precipitation is projected to increase during the 21st century, though at regional scales both increases and decreases are projected of typically 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.

→ Q3.8 & Q3.12

**Glaciers 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, while the Greenland ice sheet is likely to lose mass (see Question 4).

→ Q3.14

**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, but with significant regional variations.** This rise is due primarily to thermal expansion of the oceans and melting of glaciers and ice caps. 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.

→ Q3.9 & Q3.13

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

→ Q3.15

**The severity of the adverse impacts will be larger for greater cumulative emissions of greenhouse gases and associated changes in climate (*medium confidence*).** While beneficial effects can be identified for some regions and sectors for small amounts of climate change, these are expected to diminish as the magnitude of climate change increases. In contrast many identified adverse effects are expected to increase in both extent and severity with the degree of climate change. When considered by region, adverse effects are projected to predominate for much of the world, particularly in the tropics and subtropics.

→ Q3.16

**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 directly (e.g., reduced cold stress in temperate countries but increased heat stress, loss of life in floods and storms) and indirectly through changes in the ranges of disease vectors (e.g., mosquitoes),<sup>3</sup> water-borne pathogens, water quality, air quality, and food availability and quality (*medium to high confidence*). The actual health impacts will be strongly influenced by local environmental conditions and socio-economic circumstances, and by the range of social, institutional, technological, and behavioral adaptations taken to reduce the full range of threats to health.

→ Q3.17

**Ecological productivity and biodiversity will be altered by climate change and sea-level rise, with an increased risk of extinction of some vulnerable species (*high to medium confidence*).** Significant disruptions of ecosystems from disturbances such as fire, drought, pest infestation, invasion of species, storms, and coral bleaching events are expected to

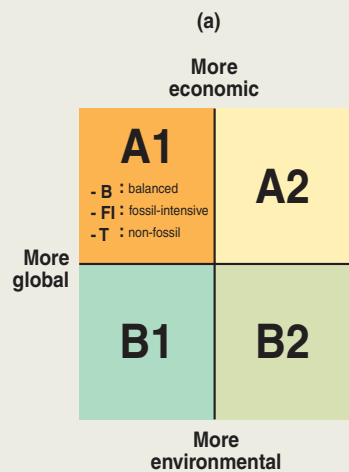
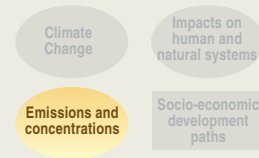
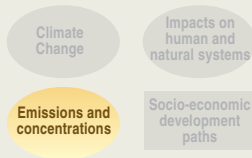
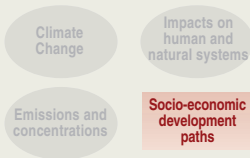
→ Q3.18-20

<sup>3</sup> 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.

**Socio-Economic Scenarios**

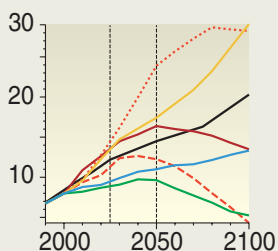
**Emissions**

**Concentrations**

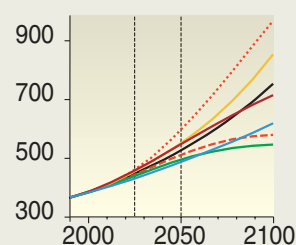


- Scenarios**
- A1B
  - - - A1T
  - ⋯ A1FI
  - A2
  - B1
  - B2
  - IS92a

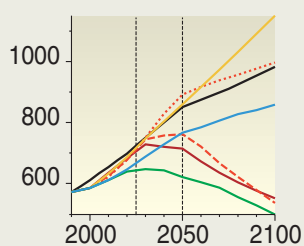
(b) CO<sub>2</sub> emissions (Gt C)



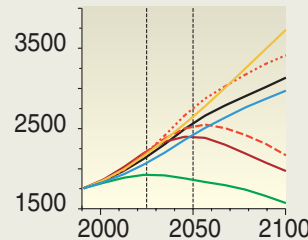
(f) CO<sub>2</sub> concentration (ppm)



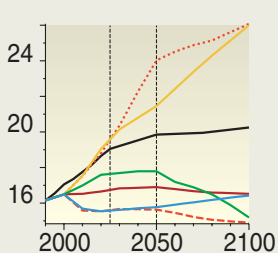
(c) CH<sub>4</sub> emissions (Tg CH<sub>4</sub>)



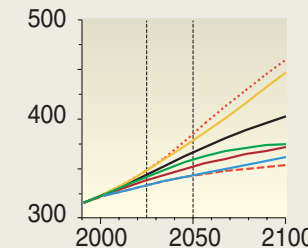
(g) CH<sub>4</sub> concentration (ppb)



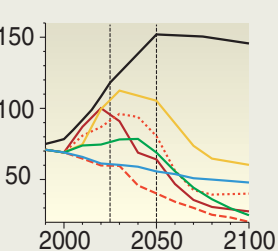
(d) N<sub>2</sub>O emissions (Tg N)



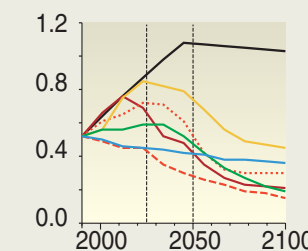
(h) N<sub>2</sub>O concentration (ppb)



(e) SO<sub>2</sub> emissions (Tg S)



(i) Sulfate aerosol (Tg S)



**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

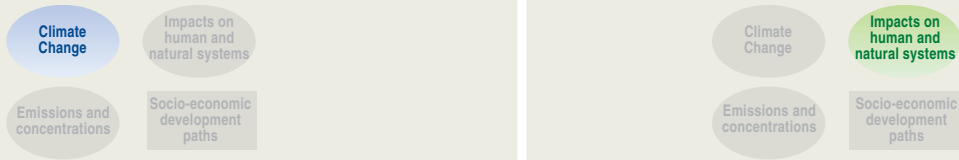
sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).



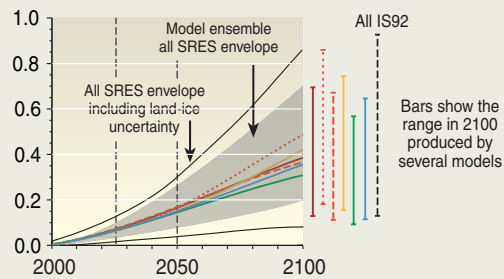
Radiative Forcing

Temperature and Sea-Level Change

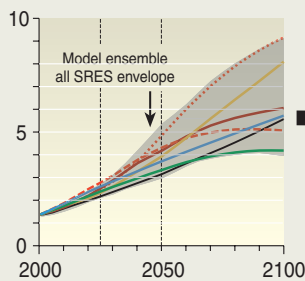
Reasons for Concern



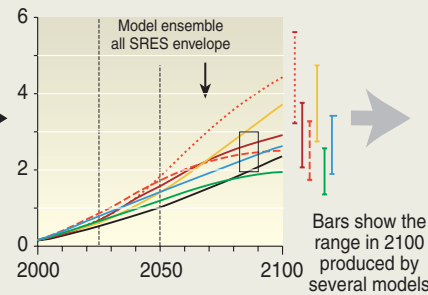
(l) Sea-level rise (m)



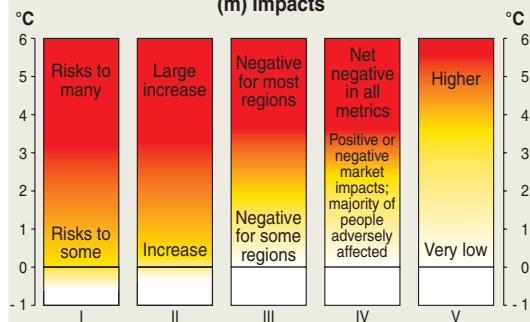
(j) Radiative forcing ( $Wm^{-2}$ )



(k) Temperature change ( $^{\circ}C$ )



Reasons for concern (m) Impacts



- I Risks to unique and threatened systems
- II Risks from extreme climate events
- III Distribution of impacts
- IV Aggregate impacts
- V Risks from future large-scale discontinuities

**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.

**Figure SPM-3: 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 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 SAR (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 SPM-1).

increase. The stresses caused by climate change, when added to other stresses on ecological systems, threaten substantial damage to or complete loss of some unique systems and extinction of some endangered species. The effect of increasing CO<sub>2</sub> concentrations will increase net primary productivity of plants, but climate changes, and the changes in disturbance regimes associated with them, may lead to either increased or decreased net ecosystem productivity (*medium confidence*). Some global models project that the net uptake of carbon by terrestrial ecosystems will increase during the first half of the 21st century but then level off or decline.

**Models of cereal crops indicate that in some temperate areas potential yields increase with 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*).** Where there is also a large decrease in rainfall in subtropical and tropical dryland/rainfed systems, crop yields would be even more adversely affected. These estimates include some adaptive responses by farmers and the beneficial effects of CO<sub>2</sub> fertilization, but not the impact of projected increases in pest infestations and changes in 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.

→ Q3.21

**Climate change will exacerbate water shortages in many water-scarce areas of the world.** 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 substantially reduce available water (as reflected by projected runoff) in many of the water-scarce areas of the world, but to increase it in some other areas (*medium confidence*) (see Figure SPM-4). Freshwater quality generally would be degraded by higher water temperatures (*high confidence*), but this may be offset in some regions by increased flows.

→ Q3.22

**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 degrees (*medium to low confidence*).** 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.

→ Q3.25

**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, in low-lying coastal areas, and on small islands will face risk of displacement. Resources critical to island and coastal populations such as beaches, freshwater, fisheries, coral reefs and atolls, and wildlife habitat would also be at risk.

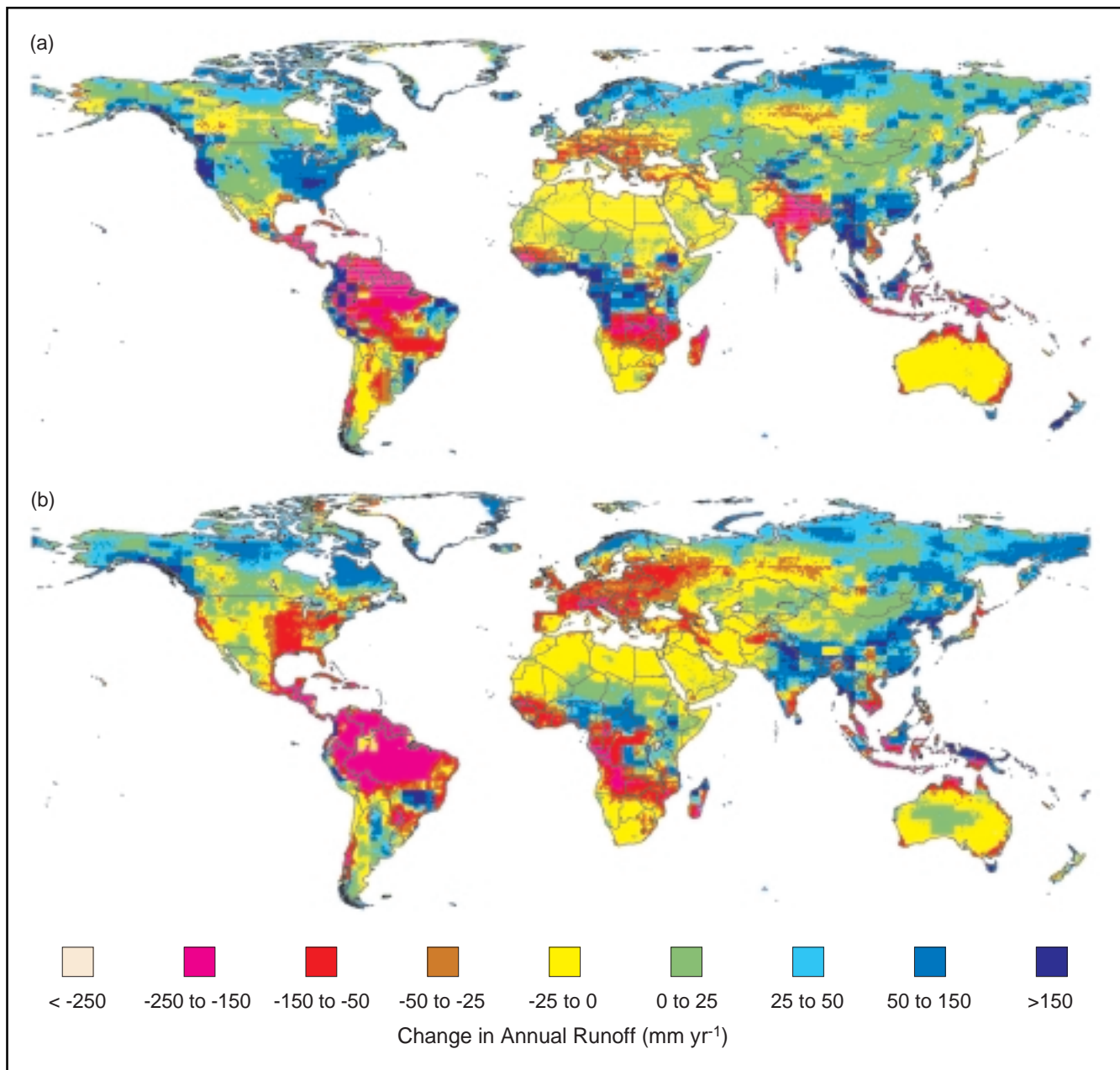
→ Q3.23

**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.** Populations in developing countries are generally exposed to relatively high risks of adverse impacts from climate change. In addition, poverty and other factors create conditions of low adaptive capacity in most developing countries.

→ Q3.33

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

→ Q3.26



**Figure SPM-4: Projected changes in average annual water runoff by the year 2050, relative to average runoff for the years 1961 to 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 atmosphere-ocean general circulation model (AOGCM) for a scenario of 1% per annum increase in effective CO<sub>2</sub> 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.

→ Q3 Figure 3-5

**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.

→ Q3.27

**Greater and more rapid climate change would pose greater challenges for adaptation and greater risks of damages than would lesser and slower change.** 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. However, changes in climate that result in increased frequency of events that fall outside the historic range with which systems have coped increase the risk of severe damages and incomplete recovery or collapse of the system.

→ Q3.28

## 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:

- 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?
- The duration, location, frequency, and intensity of extreme events such as heat waves, droughts, floods, heavy precipitation, avalanches, storms, tornadoes, and tropical cyclones?
- 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?
- The risk of abrupt or non-linear changes in ecological systems?

**An increase in climate variability and some extreme events is projected.**

→ Q4.3-4

**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, decrease of daily variability of surface air temperature in winter, and increased daily variability in summer in the Northern Hemisphere land areas. Many models project more El Niño-like mean conditions in the tropical Pacific. There is no clear agreement concerning changes in frequency or structure of naturally occurring atmosphere-ocean circulation patterns such as that of the North Atlantic Oscillation (NAO).

→ Q4.2

**Models project that increasing atmospheric concentrations of greenhouse gases result in changes in frequency, intensity, and duration of extreme events, such as more hot days, heat waves, heavy precipitation events, and fewer cold days.** Many of these projected changes would lead to increased risks of floods and droughts in many regions, and predominantly adverse impacts on ecological systems, socio-economic sectors, and human health (see Table SPM-2 for details). High resolution modeling studies suggest that peak wind and precipitation intensity of tropical cyclones are likely to increase over some areas. There is insufficient information on how very small-scale extreme weather phenomena (e.g., thunderstorms, tornadoes, hail, hailstorms, and lightning) may change.

→ Q4.2-7

**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.**

→ Q4.9

**Some of the projected abrupt/non-linear changes in physical systems and in the natural sources and sinks of greenhouse gases could be irreversible, but there is an incomplete understanding of some of the underlying processes.** The likelihood of

→ Q4.10-16

<b>Table SPM-2</b> Examples of climate variability and extreme climate events and examples of their impacts (WGII TAR Table SPM-1).	
<b><i>Projected Changes during the 21st Century in Extreme Climate Phenomena and their Likelihood</i></b>	<b><i>Representative Examples of Projected Impacts<sup>a</sup> (all high confidence of occurrence in some areas)</i></b>
Higher maximum temperatures, more hot days and heat waves <sup>b</sup> over nearly all land areas ( <i>very likely</i> )	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 <sup>b</sup> over nearly all land areas ( <i>very likely</i> )	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 ( <i>very likely</i> , 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 ( <i>likely</i> )	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 ( <i>likely</i> , over some areas) <sup>c</sup>	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 ( <i>likely</i> ) (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 ( <i>likely</i> )	Increase in flood and drought magnitude and damages in temperate and tropical Asia.
Increased intensity of mid-latitude storms (little agreement between current models) <sup>b</sup>	Increased risks to human life and health. Increased property and infrastructure losses. Increased damage to coastal ecosystems.
<sup>a</sup> These impacts can be lessened by appropriate response measures. <sup>b</sup> Information from WGI TAR Technical Summary (Section F.5). <sup>c</sup> Changes in regional distribution of tropical cyclones are possible but have not been established.	

the projected changes is expected to increase with the rate, magnitude, and duration of climate change. Examples of these types of changes include:

- Large climate-induced changes in soils and vegetation may be possible and could induce further climate change through increased emissions of greenhouse gases from plants and soil, and changes in surface properties (e.g., albedo).
- Most models project a weakening of the thermohaline circulation of the oceans resulting in a reduction of heat transport into high latitudes of Europe, but none show an abrupt shutdown by the end of the 21st century. However, beyond the year 2100, some models suggest that the thermohaline circulation could completely, and possibly irreversibly, shut down in either hemisphere if the change in radiative forcing is large enough and applied long enough.
- The Antarctic ice sheet is likely to increase in mass during the 21st century, but after sustained warming the ice sheet could lose significant mass and contribute several meters to the projected sea-level rise over the next 1,000 years.
- In contrast to the Antarctic ice sheet, the Greenland ice sheet is likely to lose mass during the 21st century and contribute a few cm to sea-level rise. Ice sheets will continue to react to climate warming and contribute to sea-level rise for thousands of years after climate has been 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 millennia, 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.

- Continued warming would increase melting of permafrost in polar, sub-polar, and mountain regions and would make much of this terrain vulnerable to subsidence and landslides which affect infrastructure, water courses, and wetland ecosystems.

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

→ Q4.17-19

The greater the magnitude and rate of the change, the greater the risk of adverse impacts. For example:

- Changes in disturbance regimes and shifts in the location of suitable climatically defined habitats may lead to abrupt breakdown of terrestrial and marine ecosystems with significant changes in composition and function and increased risk of extinctions.
- 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) and the eventual death of some corals.
- Temperature increase beyond a threshold, which varies by crop and variety, can affect key development stages of some crops (e.g., spikelet sterility in rice, loss of pollen viability in maize, tubers development in potatoes) and thus the crop yields. Yield losses in these crops can be severe if temperatures exceed critical limits for even short periods.

## 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?

**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.**

→ Q5.1-3 & Q5.12-15

### Inertia in Climate Systems

**Stabilization of CO<sub>2</sub> emissions at near-current levels will not lead to stabilization of CO<sub>2</sub> atmospheric concentration, whereas stabilization of emissions of shorter lived greenhouse gases such as CH<sub>4</sub> leads, within decades, to stabilization of their atmospheric concentrations.** Stabilization of CO<sub>2</sub> concentrations at any level requires eventual reduction of global CO<sub>2</sub> net emissions to a small fraction of the current emission level. The lower the chosen level for stabilization, the sooner the decline in global net CO<sub>2</sub> emissions needs to begin (see Figure SPM-5).

→ Q5.2 & Q5.4

**After stabilization of the atmospheric concentration of CO<sub>2</sub> and other greenhouse gases, surface air temperature is projected to continue to rise by a few tenths of a degree per century for a century or more, while sea level is projected to continue to rise for many centuries (see Figure SPM-5).** The slow transport of heat into the oceans and slow response of ice sheets means that long periods are required to reach a new climate system equilibrium.

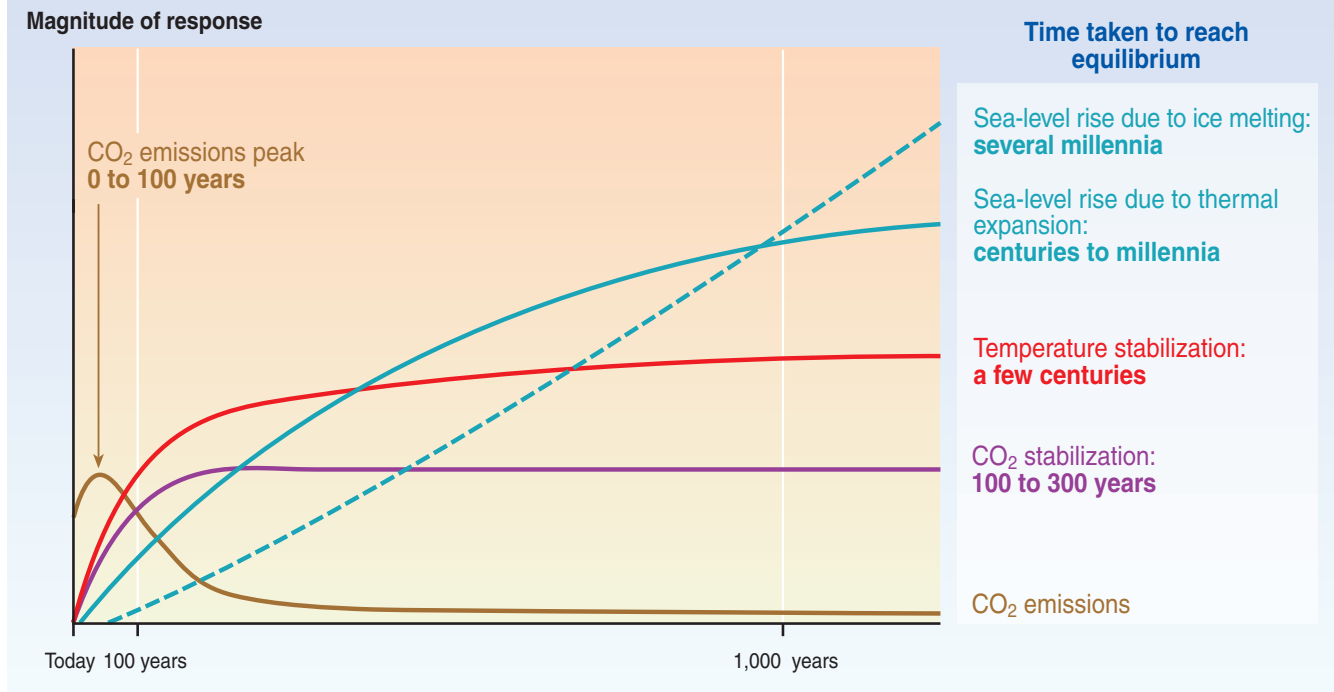
→ Q5.3

**Some changes in the climate system, plausible beyond the 21st century, would be effectively irreversible.** For example, major melting of the ice sheets (see Question 4) and fundamental changes in the ocean circulation pattern (see Question 4) could not be reversed over

→ Q5.3 & Q5.13-16



## CO<sub>2</sub> concentration, temperature, and sea level continue to rise long after emissions are reduced



**Figure SPM-5: After CO<sub>2</sub> emissions are reduced and atmospheric concentrations stabilize, surface air temperature continues to rise slowly for a century or more.** Thermal expansion of the ocean continues long after CO<sub>2</sub> 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<sub>2</sub>.

→ Q5 Figure 5-2

a period of many human generations. The threshold for fundamental changes in the ocean circulation may be reached at a lower degree of warming if the warming is rapid rather than gradual.

### Inertia in Ecological Systems

**Some ecosystems show the effects of climate change quickly, while others do so more slowly.** For example, coral bleaching can occur in a single exceptionally warm season, while long-lived organisms such as trees may be able to persist for decades under a changed climate, but be unable to regenerate. When subjected to climate change, including changes in the frequency of extreme events, ecosystems may be disrupted as a consequence of differences in response times of species.

→ Q5.7 & Q3 Table 3-2

**Some carbon cycle models project the global terrestrial carbon net uptake peaks during the 21st century, then levels off or declines.** The recent global net uptake of CO<sub>2</sub> by terrestrial ecosystems is partly the result of time lags between enhanced plant growth and plant death and decay. Current enhanced plant growth is partly due to fertilization effects of elevated CO<sub>2</sub> and nitrogen deposition, and changes in climate and land-use practices. The uptake will decline as forests reach maturity, fertilization effects saturate, and decomposition catches up with growth. Climate change is likely to further reduce net terrestrial carbon uptake globally. Although warming reduces the uptake of CO<sub>2</sub> by the ocean, the oceanic carbon sink is projected to persist under rising atmospheric CO<sub>2</sub>, 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.

→ Q5.5-6

## Inertia in Socio-Economic Systems

**Unlike the climate and ecological systems, inertia in human systems is not fixed; it can be changed by policies and the choices made by individuals.** The capacity for implementing climate change policies depends on the interaction between social and economic structures and values, institutions, technologies, and established infrastructure. The combined system generally evolves relatively slowly. It can respond quickly under pressure, although sometimes at high cost (e.g., if capital equipment is prematurely retired). If change is slower, there may be lower costs due to technological advancement or because capital equipment value is fully depreciated. 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. Anticipatory action, based on informed judgment, can improve the chance that appropriate technology is available when needed.

→ Q5.9-12

**The development and adoption of new technologies can be accelerated by technology transfer and supportive fiscal and research policies.** Technology replacement can be delayed by “locked-in” systems that have market advantages arising from existing institutions, services, infrastructure, and available resources. Early deployment of rapidly improving technologies allows learning-curve cost reductions.

→ Q5.9 & Q5.21

### Policy Implications of Inertia

**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<sub>2</sub> concentration, temperature, or sea level may be affected by:

→ Q5.17-19 & Q5.22

- 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 the time lags involved in identifying climate change impacts, developing effective adaptation strategies, and implementing adaptive measures.

**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.** 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. These consequences have bearing on the most cost-effective and equitable mix of policy options. Hedging strategies and sequential decision making (iterative action, assessment, and revised action) may be appropriate responses to the combination of inertia and uncertainty. In the presence of inertia, well-founded actions to adapt to or mitigate climate change are more effective, and in some circumstances may be cheaper, if taken earlier rather than later.

→ Q5.19 & Q5.22

**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.

→ Q5.23

## 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.

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

→ Q6.2

**The greater the reductions in emissions and the earlier they are introduced, the smaller and slower the projected warming and the rise in sea levels.** Future climate change is determined by historic, current, and future emissions. Differences in projected temperature changes between scenarios that include greenhouse gas emission reductions and those that do not tend to be small for the first few decades but grow with time if the reductions are sustained.

→ Q6.3

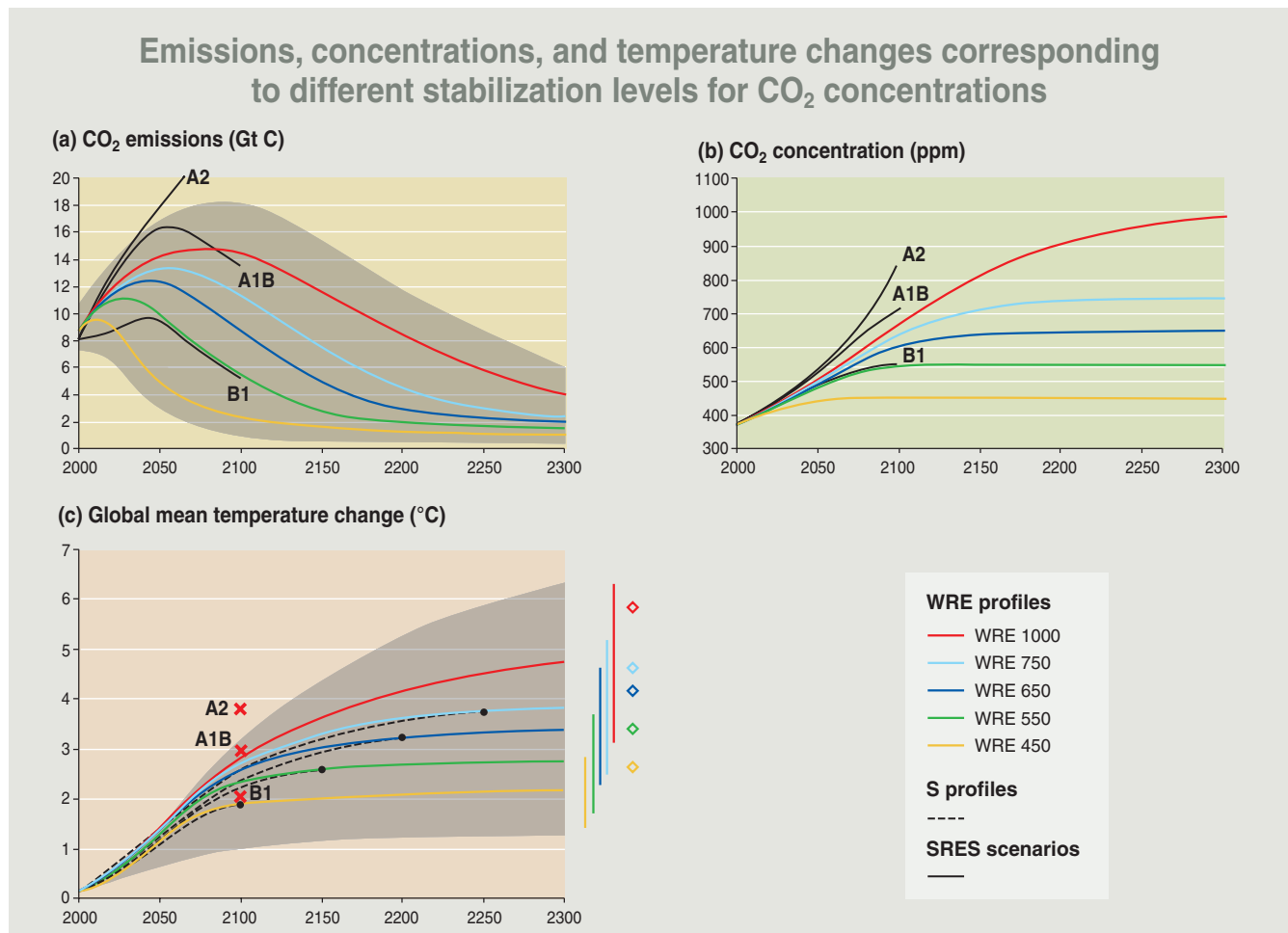
**Reductions in greenhouse gas emissions and the gases that control their concentration would be necessary to stabilize radiative forcing.** For example, for the most important anthropogenic greenhouse gas, carbon cycle models indicate that stabilization of atmospheric CO<sub>2</sub> concentrations at 450, 650, or 1,000 ppm would require global anthropogenic CO<sub>2</sub> emissions to drop below the year 1990 levels, within a few decades, about a century, or about 2 centuries, respectively, and continue to decrease steadily thereafter (see Figure SPM-6). 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. Eventually CO<sub>2</sub> 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.

→ Q6.4

**There is a wide band of uncertainty in the amount of warming that would result from any stabilized greenhouse gas concentration.** This results from the factor of three

→ Q6.5

uncertainty in the sensitivity of climate to increases in greenhouse gases.<sup>4</sup> Figure SPM-7 shows eventual CO<sub>2</sub> stabilization levels and the corresponding range of temperature change estimated to be realized in 2100 and at equilibrium.



**Figure SPM-6: Stabilizing CO<sub>2</sub> concentrations would require substantial reductions of emissions below current levels and would slow the rate of warming.**

[→ Q6 Figure 6-1](#)

- a) *CO<sub>2</sub> emissions*: The time paths of CO<sub>2</sub> emissions that would lead to stabilization of the concentration of CO<sub>2</sub> in the atmosphere at various levels are estimated for the WRE stabilization profiles using carbon cycle models. The shaded area illustrates the range of uncertainty.
- b) *CO<sub>2</sub> concentrations*: The CO<sub>2</sub> concentrations specified for the WRE profiles are shown.
- c) *Global mean temperature changes*: Temperature changes are estimated using a simple climate model for the WRE stabilization profiles. Warming continues after the time at which the CO<sub>2</sub> concentration is stabilized (indicated by black spots), but at a much diminished rate. It is assumed that emissions of gases other than CO<sub>2</sub> 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 SRES scenarios. The dashed lines show the temperature changes projected for the S 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 uncertainty for each stabilization case at the year 2300. The diamonds on the righthand side show the average equilibrium (very long-term) warming for each CO<sub>2</sub> stabilization level. Also shown for comparison are CO<sub>2</sub> emissions, concentrations, and temperature changes for three of the SRES scenarios.

<sup>4</sup>The equilibrium global mean temperature response to doubling atmospheric CO<sub>2</sub> is often used as a measure of climate sensitivity. The temperatures shown in Figures SPM-6 and SPM-7 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.

**Emission reductions that would eventually stabilize the atmospheric concentration of CO<sub>2</sub> at a level below 1,000 ppm, based on profiles shown in Figure SPM-6, and assuming that emissions of gases other than CO<sub>2</sub> 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 eventually stabilize the concentration of CO<sub>2</sub> at levels from 450 to 1,000 ppm. Thus, although all of the CO<sub>2</sub> 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<sub>2</sub> would continue to rise beyond the year 2100. 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 stabilization at 450 ppm, and 3.5 to 8.7°C above the year 1990 levels for stabilization at 1,000 ppm.<sup>5</sup> Furthermore, for a specific temperature stabilization target there is a very wide range of uncertainty associated with the required stabilization level of greenhouse gas concentrations (see Figure SPM-7). The level at which CO<sub>2</sub> concentration is required to be stabilized for a given temperature target also depends on the levels of the non-CO<sub>2</sub> gases.

→ Q6.6

**Sea level and ice sheets would continue to respond to warming for many centuries after greenhouse gas concentrations have been stabilized.** The projected range of sea-level rise due to thermal expansion at equilibrium is 0.5 to 2 m for an increase in CO<sub>2</sub> concentration from the pre-industrial level of 280 to 560 ppm and 1 to 4 m for an increase in CO<sub>2</sub> 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. 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<sub>2</sub>-equivalent.

→ Q6.8

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

→ Q6.9

**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.

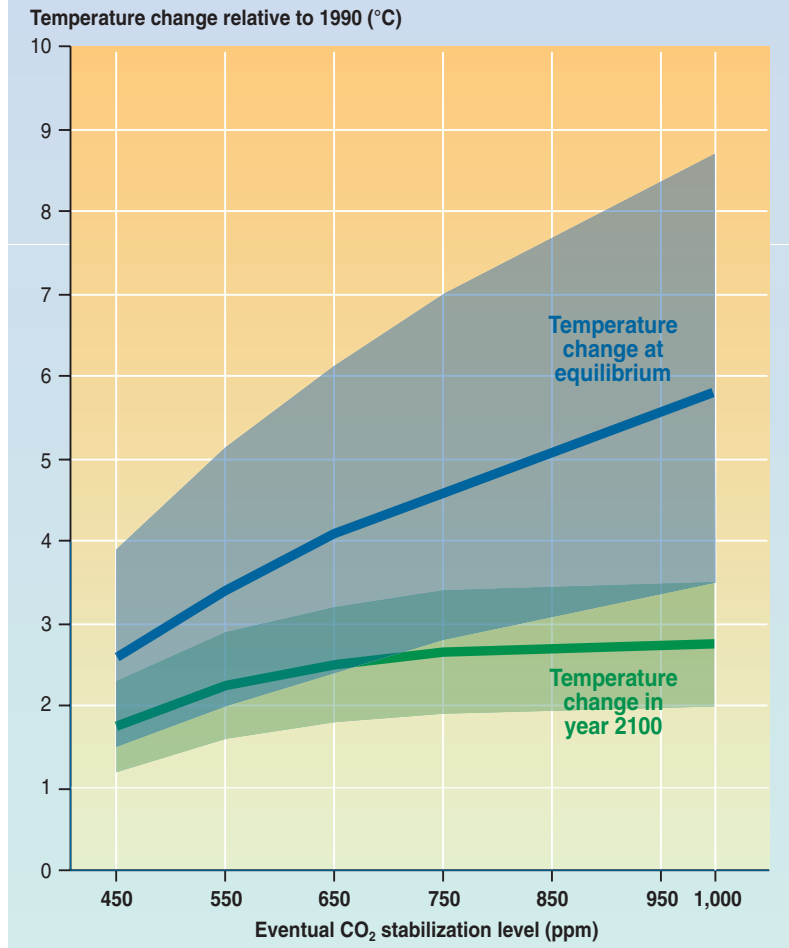
→ Q6.10

**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<sub>2</sub> 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 1.25°C less than is estimated for stabilization at 1,000 ppm (see Figure SPM-7). At equilibrium the difference is about 2 to 5°C. 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.

→ Q6.11

<sup>5</sup> 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<sub>2</sub> concentrations.

**There is a wide band of uncertainty in the amount of warming that would result from any stabilized concentration of greenhouse gases**



**Figure SPM-7: Stabilizing CO<sub>2</sub> concentrations would lessen warming but by an uncertain amount.** Temperature changes compared to year 1990 in (a) year 2100 and (b) at equilibrium are estimated using a simple climate model for the WRE profiles as in Figure SPM-6. 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 lowest and highest estimates.

→ Q6 Figure 6-2

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

Advances have been made in understanding the qualitative character of the impacts of climate change. Because of uncertainty in climate sensitivity, and uncertainty about the geographic and seasonal patterns of projected 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 the 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, are not readily expressed in monetary or other common units. Because of these limitations, the benefits of different greenhouse gas emission 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.

→ Q6.12



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

→ Q6.13

**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. The costs of adaptation can be lessened by mitigation actions that will reduce and slow the climate changes to which systems would otherwise be exposed.

→ Q6.14-15

**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.** Mitigation and adaptation actions can, if appropriately designed, advance sustainable development and equity both within and across countries and between generations. Reducing the projected increase in climate extremes is expected to benefit all countries, particularly developing countries, which are considered to be more vulnerable to climate change than developed countries. Mitigating climate change would also lessen the risks to future generations from the actions of the present generation.

→ Q6.16-18

## 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?

**There are many opportunities including technological options to reduce near-term emissions, but barriers to their deployment exist.**

→ Q7.2-6

**Significant technical progress relevant to the potential for greenhouse gas emission reductions has been made since the SAR in 1995, and has been faster than anticipated.**

→ Q7.3

Net emissions reductions could be achieved through a portfolio of technologies (e.g., more efficient conversion in production and use of energy, shift to low- or no-greenhouse gas-emitting technologies, carbon removal and storage, and improved land use, land-use change, and forestry practices). Advances are taking place in a wide range of technologies at different stages of development, ranging from the market introduction of wind turbines and the rapid elimination of industrial by-product gases, to the advancement of fuel cell technology and the demonstration of underground CO<sub>2</sub> storage.

**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 options.** The potential mitigation opportunities and types of barriers vary by region and sector, and over time. This is caused by the wide variation in mitigative capacity. Most countries could benefit from innovative financing, social learning and innovation, institutional reforms, removing barriers to trade, and poverty eradication. In addition, in 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.

→ Q7.6

**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 may include—according to national circumstances—emissions/carbon/energy taxes, tradable or non-tradable permits, land-use policies, provision and/or removal of subsidies, deposit/refund systems, technology or performance standards, energy mix requirement, product bans, voluntary agreements, government spending and investment, and support for research and development.

→ Q7.7

**Cost estimates by different models and studies vary for many reasons.**

→ Q7.15-19

**For a variety of reasons, significant differences and uncertainties surround specific quantitative estimates of mitigation costs. Cost estimates differ because of the (a) methodology<sup>6</sup> used in the analysis, and (b) underlying factors and assumptions built into the analysis.** The inclusion of some factors will lead to lower estimates and others to higher estimates. Incorporating multiple greenhouse gases, sinks, induced technical change, and emissions trading<sup>7</sup> can lower estimated 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.

→ Q7.14

**Studies examined in the TAR suggest substantial opportunities for lowering mitigation costs.**

→ Q7.20

**Bottom-up studies indicate that substantial low cost mitigation opportunities exist.** According to bottom-up studies, global emissions reductions of 1.9–2.6 Gt C<sub>eq</sub> (gigatonnes of carbon equivalent), and 3.6–5.0 Gt C<sub>eq</sub> per year<sup>8</sup> could be achieved by the years 2010 and 2020, respectively. Half of these potential emissions reductions could be achieved by the year 2020 with direct benefits (energy saved) exceeding direct costs (net capital, operating, and maintenance costs), and the other half at a net direct cost of up to US\$100 per t C<sub>eq</sub> (at 1998 prices). These net direct cost estimates

→ Q7.15

<sup>6</sup>The SAR described two categories of approaches to estimating costs: bottom-up approaches, which build up from assessments of specific technologies and sectors, and top-down modeling studies, which proceed from macro-economic relationships. See Box 7-1 in the underlying report.

<sup>7</sup>A market-based approach to achieving environmental objectives that 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.

<sup>8</sup>The emissions reduction estimates are with reference to a baseline trend that is similar in magnitude to the SRES B2 scenario.

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 2010–2020 at these net direct cost estimates. Realizing these reductions involves additional implementation costs, which in some cases may be substantial, the possible need for supporting policies, increased research and development, 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.

**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.**

→ Q7.4 & Q7.16

Biological mitigation can occur by three strategies: (a) conservation of existing carbon pools, (b) sequestration by increasing the size of carbon pools,<sup>9</sup> and (c) substitution of sustainably produced biological products. The estimated global potential of biological mitigation options is on the order of 100 Gt C (cumulative) by year 2050, equivalent to about 10 to 20% of projected fossil-fuel emissions during that period, although there are substantial uncertainties associated with this estimate. Realization of this potential depends upon land and water availability as well as the rates of adoption of land management practices. The largest biological potential for atmospheric carbon mitigation is in subtropical and tropical regions. Cost estimates 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 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<sub>2</sub> greenhouse gas emissions.

**The cost estimates for Annex B countries to implement the Kyoto Protocol vary between studies and regions, and depend strongly, among others, upon the assumptions regarding the use of the Kyoto mechanisms, and their interactions with domestic measures (see Figure SPM-8 for comparison of regional Annex II mitigation costs).**

→ Q7.17-18

The great majority of global studies reporting and comparing these costs use international energy-economic models. Nine of these studies suggest the following GDP impacts. In the absence of emissions trade between Annex B countries, these studies show reductions in projected GDP<sup>10</sup> of about 0.2 to 2% in the year 2010 for different Annex II regions. With full emissions trading between Annex B countries, the estimated reductions in the year 2010 are between 0.1 and 1.1% of projected GDP. The global modeling studies reported above show national marginal costs to meet the Kyoto targets from about US\$20 up to US\$600 per t C without trading, and a range from about US\$15 up to US\$150 per t C with Annex B trading. For most economies-in-transition countries, GDP effects range from negligible to a several percent increase. However, for some economies-in-transition countries, implementing the Kyoto Protocol will have similar impact on GDP as for Annex II countries. At the time of these studies, most models did not include sinks, non-CO<sub>2</sub> greenhouse gases, the Clean Development Mechanism (CDM), negative cost options,

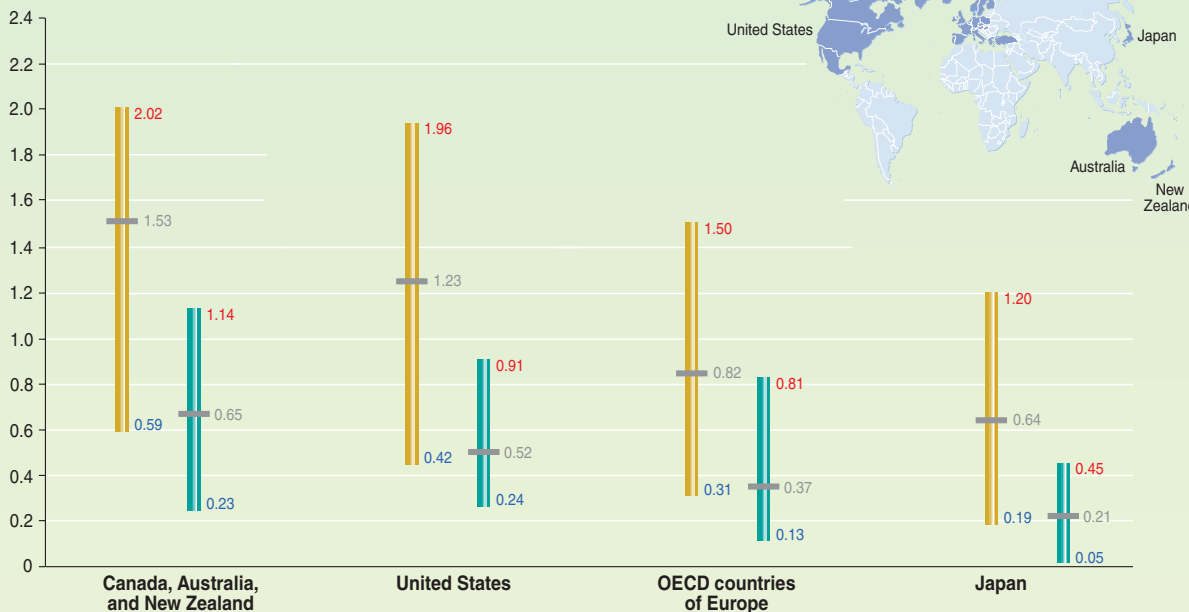
<sup>9</sup> Changing land use could influence atmospheric CO<sub>2</sub> concentration. Hypothetically, if all of the carbon released by historical land-use changes could be restored to the terrestrial biosphere over the course of the century (e.g., by reforestation), CO<sub>2</sub> concentration would be reduced by 40 to 70 ppm.

<sup>10</sup> The calculated GDP reductions are relative to each model's projected GDP baseline. The models evaluated only reductions in CO<sub>2</sub>. In contrast, the estimates cited from the bottom-up analyses above included all greenhouse gases. Many metrics can be used to present costs. For example, if the annual costs to developed countries associated with meeting Kyoto targets with full Annex B trading are in the order of 0.5% of GDP, this represents US\$125 billion (1,000 million) per year, or US\$125 per person per year by 2010 in Annex II (SRES assumptions). This corresponds to an impact on economic growth rates over 10 years of less than 0.1 percentage point.

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

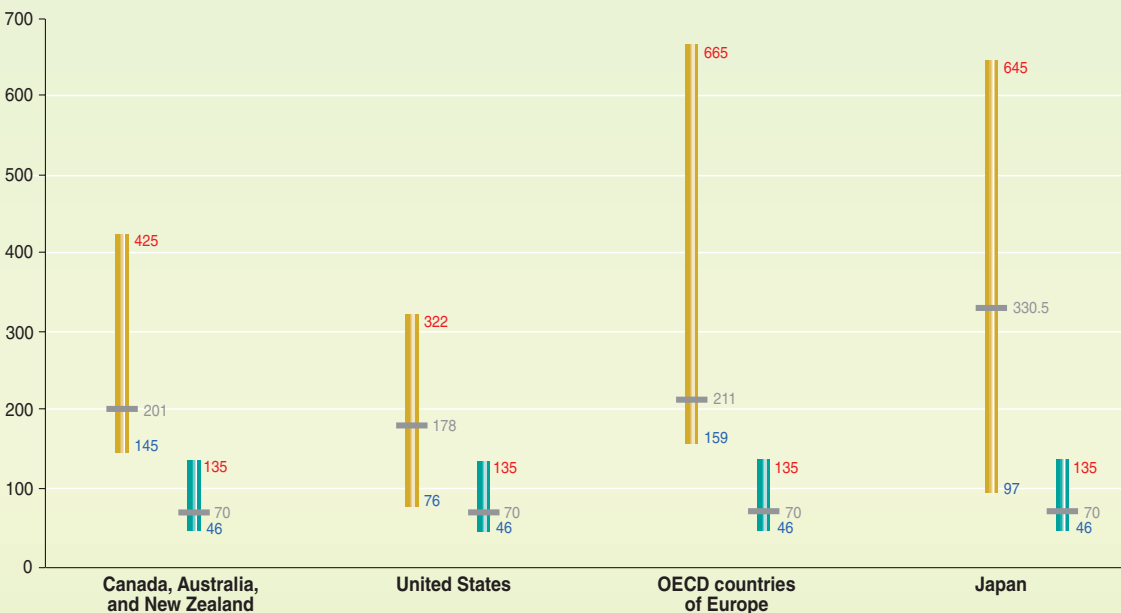
### (a) GDP losses

Percentage of GDP loss in the year 2010



### (b) Marginal cost

1990 US\$ per t C



**Range of outcomes for two scenarios**

**Yellow bar:** Absence in international trade in carbon emissions rights: each region must take the prescribed reduction

**Teal bar:** Full annex B trading of carbon emissions rights permitted

The three numbers on each bar represent the highest, mean, and lowest projections from the set of models.

**Figure SPM-8: Projections of GDP losses and marginal costs in Annex II countries in the year 2010 from global models:**

[Q7.18-19](#)

**(a) GDP losses and (b) marginal costs.** The reductions in projected GDP are for the year 2010 relative to the models' reference case GDP. These estimates are based on results from nine modeling teams that participated in an Energy Modeling Forum study. The projections reported in the figure are for four regions that 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 each case or region, the maximum, minimum, and median values across all models of the estimated marginal costs are shown. For the key factors, assumptions, and uncertainties underlying the studies, see Table 7-3 and Box 7-1 in the underlying report.

ancillary benefits, or targeted revenue recycling, the inclusion of 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 1990 and 2000. The cost reductions from Kyoto mechanisms may depend on the details of implementation, including the compatibility of domestic and international mechanisms, constraints, and transaction costs.

**Emission constraints on Annex I countries have well-established, albeit varied, “spill-over” effects<sup>11</sup> on non-Annex I countries.** Analyses report reductions in both projected GDP and reductions in projected oil revenues for oil-exporting, non-Annex I countries. 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.<sup>12</sup> 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. These studies do not consider policies and measures other than Annex B emissions trading, that could lessen the impacts on non-Annex I, oil-exporting countries. 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 may be adversely affected by reductions in demand for their exports to Organisation for Economic Cooperation and Development (OECD) nations and by the price increase of those carbon-intensive and other products they continue to import. These other non-Annex I 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 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 carbon leakage<sup>13</sup> on the order of 5–20%.

→ Q7.19

**Technology development and diffusion are important components of cost-effective stabilization.**

→ Q7.9-12 & Q7.23

**Development and transfer of environmentally sound technologies could play a critical role in reducing the cost of stabilizing greenhouse gas concentrations.** Transfer of technologies between countries and regions could widen the choice of options at the regional level. Economies of scale and learning will lower the costs of their adoption. Through sound economic policy and regulatory frameworks, transparency, and political stability, governments could create an enabling environment for private- and public-sector technology transfers. Adequate human and organizational capacity is essential at every stage to increase the flow, and improve the quality, of technology transfer. In addition, 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, is essential for most effective technology transfers.

→ Q7.9-12 & Q7.23

**Lower emissions scenarios require different patterns of energy resource development and an increase in energy research and development to assist accelerating the development and deployment of advanced environmentally sound energy technologies.** Emissions of CO<sub>2</sub> due to fossil-fuel burning are virtually certain to be the dominant influence on the trend of atmospheric CO<sub>2</sub> 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. 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

→ Q7.27

<sup>11</sup> These spill-over effects incorporate only economic effects, not environmental effects.

<sup>12</sup> 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.

<sup>13</sup> 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.

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.

### Both the pathway to stabilization and the stabilization level itself are key determinants of mitigation costs.<sup>14</sup>

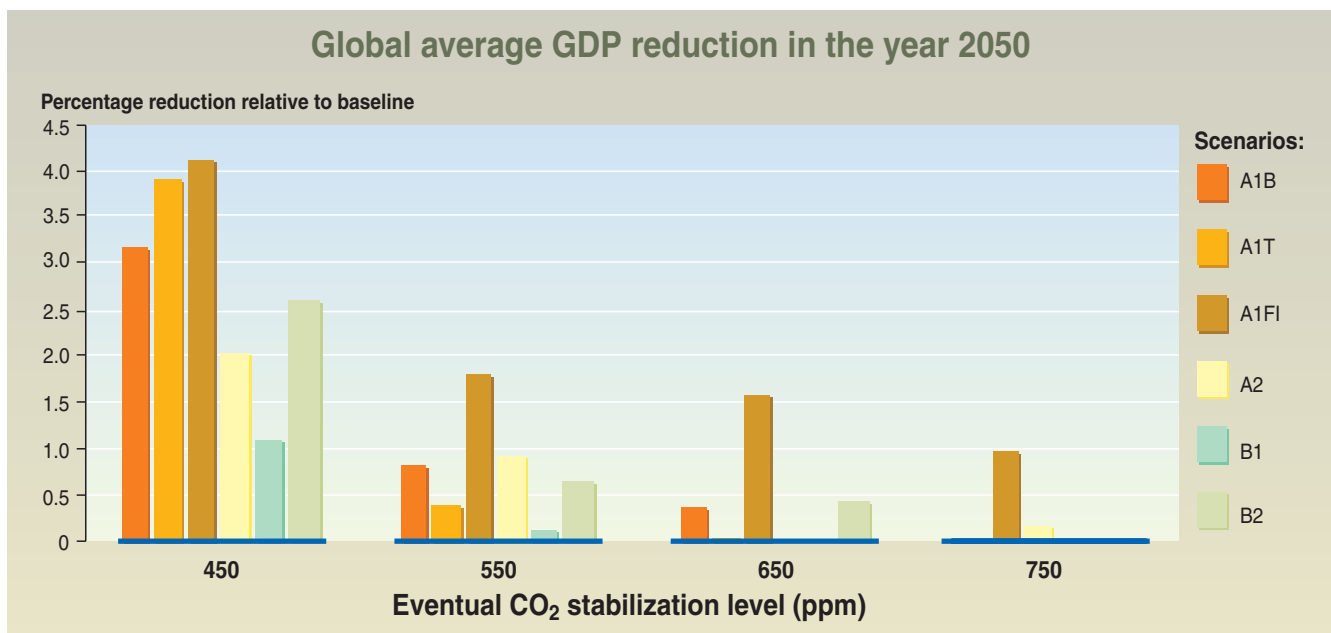
→ Q7.24-25

**The pathway to meeting a particular stabilization target will have an impact on mitigation cost (see Figure SPM-9).** A gradual transition away from the world's present energy system towards a less carbon-emitting economy minimizes costs associated with premature retirement of existing capital stock and provides time for technology development, and avoids premature 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 and the costs associated with projected changes in climate, may stimulate more rapid deployment of existing low-emission technologies, and provide strong near-term incentives to future technological changes.

→ Q7.24

**Studies show that the costs of stabilizing CO<sub>2</sub> concentrations in the atmosphere increase as the concentration stabilization level declines. Different baselines can have a strong influence on absolute costs (see Figure SPM-9).** While there is a moderate increase in the costs when passing from a 750 to a 550 ppm concentration stabilization level, there is a larger increase in costs passing from 550 to 450 ppm unless the emissions in the baseline scenario are very low. 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 studies did not incorporate carbon sequestration and did not examine the possible effect of more ambitious targets on induced technological change. Also, the issue of uncertainty takes on increasing importance as the time frame is expanded.

→ Q7.25



**Figure SPM-9: 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 (for more information, see the caption for Figure 7-4 of the underlying report).

→ Q7.25

<sup>14</sup> See Question 6 for discussion of impacts of climate change.



## 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?

**Local, regional, and global environmental issues are inextricably linked and affect sustainable development. Therefore, there are synergistic opportunities to develop more effective response options to these environmental issues that enhance benefits, reduce costs, and more sustainably meet human needs.**

→ Q8.1-2

**Meeting human needs in many instances is causing environmental degradation, which in turn threatens the ability to meet present and future needs.** For example, increased agricultural production can be achieved through increased use of nitrogenous fertilizers, irrigation, or the conversion of natural grasslands and forests to croplands. However, these changes can affect the Earth's climate through the release of greenhouse gases, lead to land degradation through erosion and salinization of soils, and contribute to the loss of biodiversity and reduction of carbon sequestration through the conversion and fragmentation of natural ecological systems. Agricultural productivity can in turn be adversely affected by changes in climate, especially in the tropics and subtropics, loss of biodiversity and changes at the genetic and species level, and land degradation through loss of soil fertility. Many of these changes adversely affect food security and disproportionately impact the poor.

→ Q8.3 & Q8.15

**The primary factors underlying anthropogenic climate change are similar to those for most environmental and socio-economic issues—that is, economic growth, broad technological changes, life style patterns, demographic shifts (population size, age structure, and migration), and governance structures.** These can give rise to:

→ Q8.4

- 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.

**Climate change affects environmental issues such as loss of biodiversity, desertification, stratospheric ozone depletion, freshwater availability, and air quality, and in turn climate change is affected by many of these issues.** For example, climate change is projected to exacerbate local and regional air pollution and delay the recovery of the stratospheric ozone layer. In addition, climate change could also affect the productivity and composition of terrestrial and aquatic ecological systems, with a potential loss in both genetic and species diversity; could accelerate the rate of land degradation; and could exacerbate problems related to freshwater quantity and quality in many areas. Conversely, local and regional air pollution, stratospheric ozone depletion, changes in ecological systems, and land degradation would affect the Earth's climate by changing the sources and sinks of greenhouse gases, radiative balance of the atmosphere, and surface albedo.

→ Q8.5-20

**The linkages among local, regional, and global environmental issues, and their relationship to meeting human needs, offer opportunities to capture synergies in developing response options and reducing vulnerabilities to climate change, although trade-offs between issues may exist.**

→ Q8.21-25

Multiple environmental and development goals can be achieved by adopting a broad range of technologies, policies, and measures that explicitly recognize the inextricable linkages among environmental problems and human needs. Addressing the need for energy, while reducing local and regional air pollution and global climate change cost-effectively, requires an interdisciplinary assessment of the synergies and trade-offs of meeting energy requirements in the most economically, environmentally, and socially sustainable manner. Greenhouse gas emissions, as well as local and regional pollutants, could be reduced through more efficient 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). Further, the increase of greenhouse gas concentrations in the atmosphere can be reduced also by enhanced uptake of carbon through, for example, afforestation, reforestation, slowing deforestation, and improved forest, rangeland, wetland, and cropland management, which can have favorable effects on biodiversity, food production, land, and water resources. Reducing vulnerability to climate change can often reduce vulnerability to other environmental stresses and *vice versa*. In some cases there will be trade-offs. For example, in some implementations, monoculture plantations could decrease local biodiversity.

**The capacity of countries to adapt and mitigate can be enhanced when climate policies are integrated with national development policies including economic, social, and other environmental dimensions.**

→ Q8.26-27

Climate mitigation and adaptation options can yield ancillary benefits that meet human needs, improve well-being, and bring other environmental benefits. Countries with limited economic resources and low level of technology are often highly vulnerable to climate change and other environmental problems.

**A great deal of interaction exists among the environmental issues that multilateral environmental agreements address, and synergies can be exploited in their implementation.**

→ Q8.11 & Q8.28

Global environmental problems are addressed in a range of individual conventions and agreements, as well as a range of regional agreements. They may contain, *inter alia*, matters of common interest and similar requirements for enacting general objectives—for example, implementation plans, data collection and processing, strengthening human and infrastructural capacity, and reporting obligations. For example, although different, the Vienna Convention for the Protection of the Ozone Layer and the United Nations Framework Convention on Climate Change are scientifically interrelated because many of the compounds that cause depletion of the ozone layer are also important greenhouse gases and because some of the substitutes for the now banned ozone-depleting substances are greenhouse gases.

## 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?

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. **Key uncertainties** in this context are those that, if reduced, may lead to new and

robust findings in relation to the questions of this report. In the examples in Table SPM-3, many of the robust findings relate to 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 timing of the response. After addressing the attribution of climate change, the table deals in order with the issues illustrated in Figure SPM-1. Figure SPM-10 illustrates some of the main robust findings regarding climate change. Table SPM-3 provides examples and is not an exhaustive list.

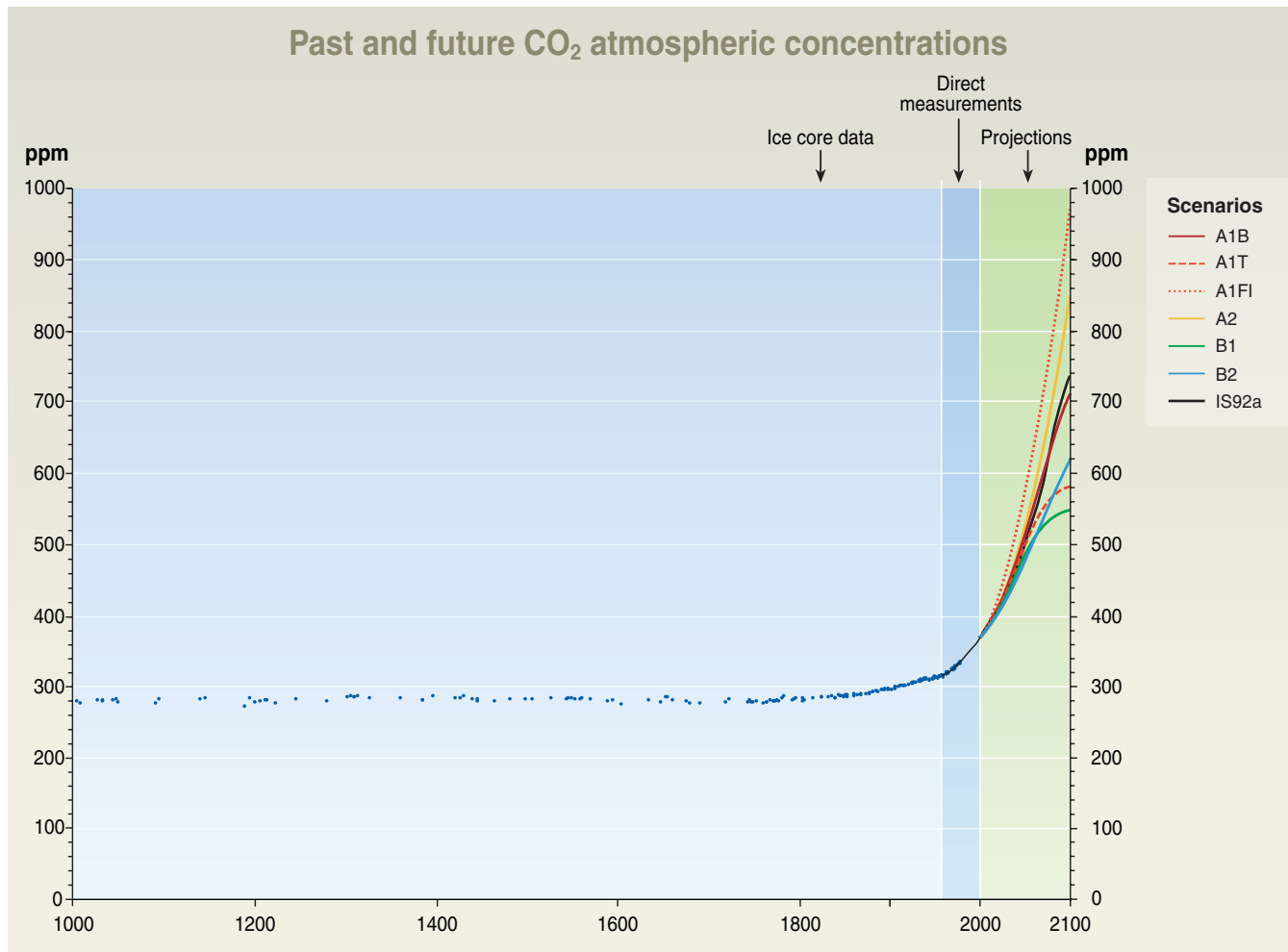
<b>Table SPM-3</b> Robust findings and key uncertainties. <sup>a</sup>		
<i>Robust Findings</i>		<i>Key Uncertainties</i>
<p>Observations show Earth's surface is warming. Globally, 1990s very likely warmest decade in instrumental record (Figure SPM-10b). [Q9.8]</p> <p>Atmospheric concentrations of main anthropogenic greenhouse gases (CO<sub>2</sub> (Figure SPM-10a), CH<sub>4</sub>, N<sub>2</sub>O, and tropospheric O<sub>3</sub>) increased substantially since the year 1750. [Q9.10]</p> <p>Some greenhouse gases have long lifetimes (e.g., CO<sub>2</sub>, N<sub>2</sub>O, and PFCs). [Q9.10]</p> <p>Most of observed warming over last 50 years likely due to increases in greenhouse gas concentrations due to human activities. [Q9.8]</p>	<p><b>Climate change and attribution</b></p>	<p>Magnitude and character of natural climate variability. [Q9.8]</p> <p>Climate forcings due to natural factors and anthropogenic aerosols (particularly indirect effects). [Q9.8]</p> <p>Relating regional trends to anthropogenic climate change. [Q9.8 &amp; Q9.22]</p>
<p>CO<sub>2</sub> concentrations increasing over 21st century virtually certain to be mainly due to fossil-fuel emissions (Figure SPM-10a). [Q9.11]</p> <p>Stabilization of atmospheric CO<sub>2</sub> concentrations at 450, 650, or 1,000 ppm would require global anthropogenic CO<sub>2</sub> 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 to a small fraction of current emissions. Emissions would peak in about 1 to 2 decades (450 ppm) and roughly a century (1,000 ppm) from the present. [Q9.30]</p> <p>For most SRES scenarios, SO<sub>2</sub> emissions (precursor for sulfate aerosols) are lower in the year 2100 compared with year 2000. [Q9.10]</p>	<p><b>Future emissions and concentrations of greenhouse gases and aerosols based on models and projections with the SRES and stabilization scenarios</b></p>	<p>Assumptions underlying the wide range<sup>b</sup> of SRES emissions scenarios relating to economic growth, technological progress, population growth, and governance structures (lead to largest uncertainties in projections). Inadequate emission scenarios for ozone and aerosol precursors. [Q9.10]</p> <p>Factors in modeling of carbon cycle including effects of climate feedbacks.<sup>b</sup> [Q9.10]</p>
<p>Global average surface temperature during 21st century rising at rates very likely without precedent during last 10,000 years (Figure SPM-10b). [Q9.13]</p> <p>Nearly all land areas very likely to warm more than the global average, with more hot days and heat waves and fewer cold days and cold waves. [Q9.13]</p> <p>Rise in sea level during 21st century that will continue for further centuries. [Q9.15]</p> <p>Hydrological cycle more intense. Increase in globally averaged precipitation and more intense precipitation events very likely over many areas. [Q9.14]</p> <p>Increased summer drying and associated risk of drought likely over most mid-latitude continental interiors. [Q9.14]</p>	<p><b>Future changes in global and regional climate based on model projections with SRES scenarios</b></p>	<p>Assumptions associated with a wide range<sup>c</sup> of SRES scenarios, as above. [Q9.10]</p> <p>Factors associated with model projections<sup>c</sup>, in particular climate sensitivity, climate forcing, and feedback processes especially those involving water vapor, clouds, and aerosols (including aerosol indirect effects). [Q9.16]</p> <p>Understanding the probability distribution associated with temperature and sea-level projections. [Q9.16]</p> <p>The mechanisms, quantification, time scales, and likelihoods associated with large-scale abrupt/non-linear changes (e.g., ocean thermohaline circulation). [Q9.16]</p> <p>Capabilities of models on regional scales (especially regarding precipitation) leading to inconsistencies in model projections and difficulties in quantification on local and regional scales. [Q9.16]</p>



Table SPM-3 Robust findings and key uncertainties. <sup>a</sup> (continued)		
Robust Findings		Key Uncertainties
<p>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. [Q9.17]</p> <p>The adverse impacts of climate change are expected to fall disproportionately upon developing countries and the poor persons within countries. [Q9.20]</p> <p>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. [Q9.19]</p> <p>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 °C. [Q9.18]</p> <p>Many physical systems are vulnerable to climate change (e.g., the impact of coastal storm surges will be exacerbated by sea-level rise, and glaciers and permafrost will continue to retreat). [Q9.18]</p>	<p><b>Regional and global impacts of changes in mean climate and extremes</b></p>	<p>Reliability of local or regional detail in projections of climate change, especially climate extremes. [Q9.22]</p> <p>Assessing and predicting response of ecological, 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. [Q9.22]</p> <p>Identification, quantification, and valuation of damages associated with climate change. [Q9.16, Q9.22, &amp; Q9.26]</p>
<p>Greenhouse gas emission reduction (mitigation) actions would lessen the pressures on natural and human systems from climate change. [Q9.28]</p> <p>Mitigation has costs that vary between regions and sectors. Substantial technological and other opportunities exist for lowering these costs. Efficient emissions trading also reduces costs for those participating in the trading. [Q9.31 &amp; Q9.35-36]</p> <p>Emissions constraints on Annex I countries have well-established, albeit varied, “spill-over” effects on non-Annex I countries. [Q9.32]</p> <p>National mitigation responses to climate change can be more effective if deployed as a portfolio of policies to limit or reduce net greenhouse gas emissions. [Q9.35]</p> <p>Adaptation has the potential to reduce adverse effects of climate change and can often produce immediate ancillary benefits, but will not prevent all damages. [Q9.24]</p> <p>Adaptation can complement mitigation in a cost-effective strategy to reduce climate change risks; together they can contribute to sustainable development objectives. [Q9.40]</p> <p>Inertia in the interacting climate, ecological, and socio-economic systems is a major reason why anticipatory adaptation and mitigation actions are beneficial. [Q9.39]</p>	<p><b>Costs and benefits of mitigation and adaptation options</b></p>	<p>Understanding the interactions between climate change and other environmental issues and the related socio-economic implications. [Q9.40]</p> <p>The future price of energy, and the cost and availability of low-emissions technology. [Q9.33-34]</p> <p>Identification of means to remove barriers that impede adoption of low-emission technologies, and estimation of the costs of overcoming such barriers. [Q9.35]</p> <p>Quantification of costs of unplanned and unexpected mitigation actions with sudden short-term effects. [Q9.38]</p> <p>Quantification of mitigation cost estimates generated by different approaches (e.g., bottom-up vs. top-down), including ancillary benefits, technological change, and effects on sectors and regions. [Q9.35]</p> <p>Quantification of adaptation costs. [Q9.25]</p>
<p><sup>a</sup> In this report, a <b>robust finding</b> 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. <b>Key uncertainties</b> in this context are those that, if reduced, may lead to new and robust findings in relation to the questions of this report. This table provides examples and is not an exhaustive list.</p> <p><sup>b</sup> Accounting for these above uncertainties leads to a range of CO<sub>2</sub> concentrations in the year 2100 between about 490 and 1,260 ppm.</p> <p><sup>c</sup> Accounting for these above uncertainties leads to a range for globally averaged surface temperature increase, 1990-2100, of 1.4 to 5.8°C (Figure SPM-10b) and of globally averaged sea-level rise of 0.09 to 0.88 m.</p>		

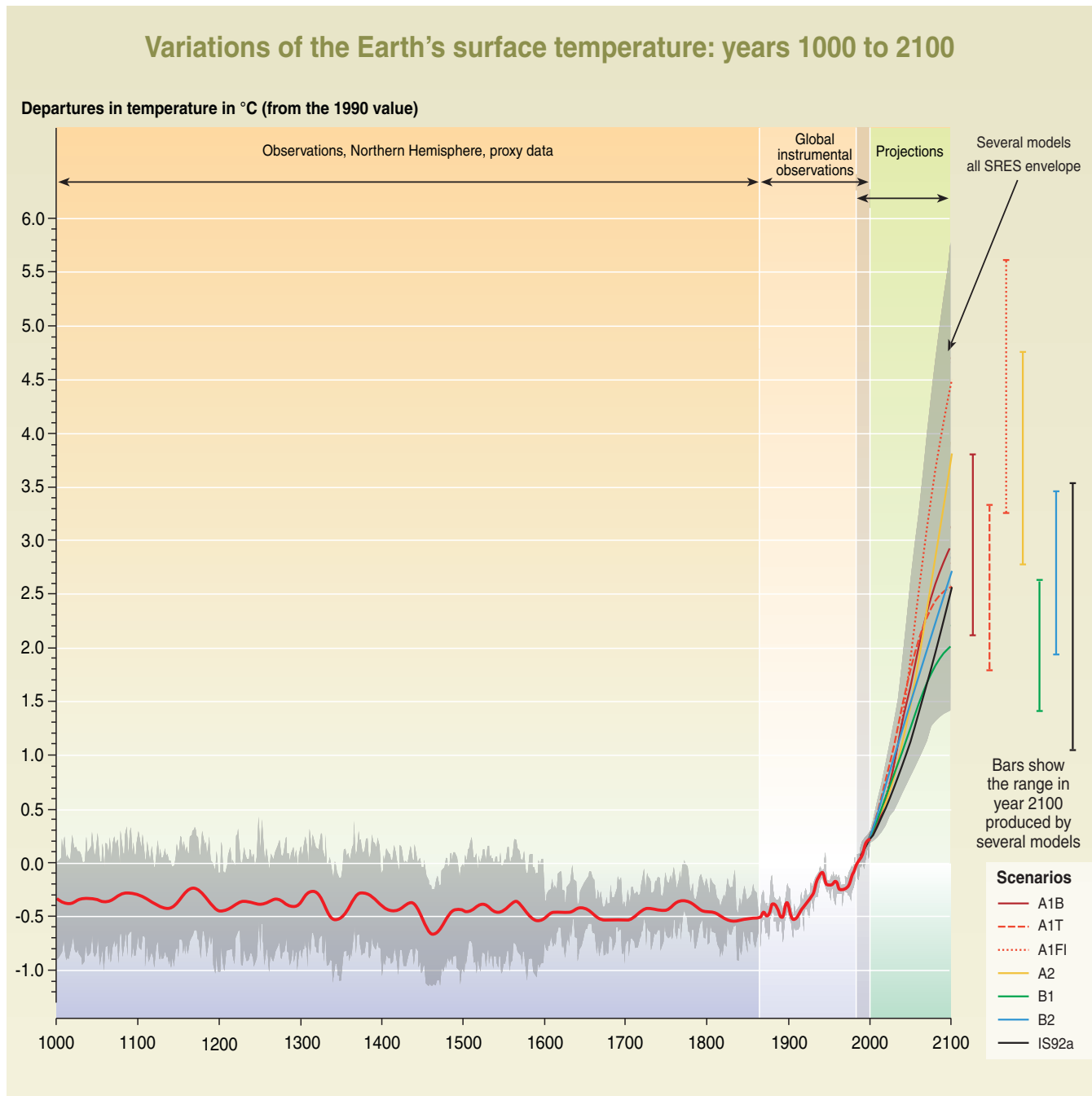
Significant progress has been made in the TAR in many aspects of the knowledge required to understand climate change and the human response to it. However, there remain important areas where further work is required, in particular:

- 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.”



**Figure SPM-10a: Atmospheric CO<sub>2</sub> concentration from year 1000 to year 2000** from ice core data and from direct atmospheric measurements over the past few decades. Projections of CO<sub>2</sub> concentrations for the period 2000 to 2100 are based on the six illustrative SRES scenarios and IS92a (for comparison with the SAR).

[Q9 Figure 9-1a](#)



**Figure SPM-10b: From year 1000 to year 1860 variations in average surface temperature of the Northern Hemisphere** are shown (corresponding data from the Southern Hemisphere not available) reconstructed from proxy data (tree rings, corals, ice cores, and historical records). The line shows the 50-year average, the grey region the 95% confidence limit in the annual data. From years 1860 to 2000 are shown variations in observations of globally and annually averaged surface temperature from the instrumental record; the line shows the decadal average. From years 2000 to 2100 projections of globally averaged surface temperature are shown for the six illustrative SRES scenarios and IS92a using a model with average climate sensitivity. The grey region marked "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. The temperature scale is departure from the 1990 value; the scale is different from that used in Figure SPM-2.

→ Q9 Figure 9-1b