Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report

Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability

Summary for Policymakers

Confidential Draft in preparation for Final Government Review

Note: The content of this draft should not be cited or quoted, and is embargoed from news coverage

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A. Introduction

This Summary sets out the key policy-relevant findings of the Fourth Assessment Report of Working Group II of the Intergovernmental Panel on Climate Change (IPCC).

The Assessment is of current scientific understanding of impacts of climate change on natural, managed and human systems, their capacity to adapt and their vulnerability[1]. It builds upon past assessments and incorporates new knowledge gained since the Third Assessment.

Statements in this Summary are based on chapters in the Assessment and sources are given at the end of each paragraph[2].

B. Current knowledge about observed impacts in natural and managed systems

The number of studies of observed trends in the physical and biological environment and their relationship to regional climate changes has increased greatly in the past five years, as has the quality of the data sets. This allows a broader and more confident assessment of the relationship between observed warming and impacts than was made in the IPCC Third Assessment, which concluded that "there is high confidence[3] that recent regional changes in temperature have had discernible impacts on many physical and biological systems". From the current Assessment we conclude the following.

Many natural systems, on all continents and in some oceans, are being affected by regional climate changes, particularly temperature increases [very high confidence].

With regard to changes in **physical systems**, there is high confidence that changes in the cryosphere are affecting natural systems, such as:

- enlargement and increased numbers of glacial lakes, with increased risk of outburst floods [1.3];
- increasing ground instability in mountain and other permafrost regions, and ice and rock avalanches in mountain regions [1.3.];
- changes in some Arctic and Antarctic flora and fauna, including sea-ice biomes and predators high in the food chain [1.3, 4.4, 15.4].

There is high confidence that hydrological systems are also being affected, for example:

- enhanced run-off and earlier spring peak discharge in many glacier- and snow-fed rivers [1.3];
- lakes and rivers in many regions are warming, with effects on thermal structure and water quality [1.3, 15.2].

With regard to changes in **biological systems**, there is very high confidence that observed changes in some terrestrial species are linked to higher temperatures, including such changes as:

- earlier timing of spring events, such as leaf-unfolding, bird migration and egg-laying [1.3.];
- poleward and upward shifts in ranges in plant and animal species [1.3, 8.2, 15.4].

Based on satellite observations since the early 1980s, there is high confidence that there has been a trend in many regions towards earlier 'greening'[4] of vegetation in the spring and increased net primary production linked to longer growing seasons and increasing atmospheric CO_2 concentrations. [1.3, 14.2]

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[1] See Endbox 1.
[2] The example source [3.3] refers to Chapter 3, Section 3. In the sourcing, F = Figure, T = Table, B = Box and ES = Executive Summary.
[3] See Endbox 2.
[4] Measured by the Normalised Difference Vegetation Index, which is a relative measure of vegetation greenness in satellite images.

There is high confidence that extensive changes observed in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels, and circulation [1.3]. These include:

- poleward shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans [1.3];
- increases in algal and zooplankton abundance in high-latitude and high-altitude lakes [1.3];
- earlier fish migrations and range changes in rivers [1.3].

Observed effects of recent ocean acidification on the marine biosphere are as yet undocumented. [1.3]

At the global scale the anthropogenic component of warming over the last three decades has had a discernible influence on many physical and biological systems [high confidence].

Much more evidence has accumulated over the past five years to indicate that the effects described above are linked to the anthropogenic component of warming[5]. There are three sets of evidence which, taken together, support this conclusion [Box SPM-1]:

1. There have been several studies that have linked responses in some physical and biological systems to the anthropogenic component of warming by comparing observed trends with modelled trends in which the natural and anthropogenic forcings are explicitly separated. [1.4]
2. Observed changes in many physical and biological systems are consistent with a warming world. The majority (>85% of the >29,000 datasets whose locations are displayed in Figure SPM-1) of changes in these systems has been in the direction expected as a response to warming. [1.4]
3. A global synthesis of studies in this Assessment strongly demonstrates that the spatial agreement between regions of significant regional warming across the globe and the locations of significant observed changes in many systems consistent with warming is very unlikely[6] to be due solely to natural variability of temperatures or natural variability of the systems. [1.4]

Limitations and barriers remain in the evidence chain that would permit full causal linkage of the observed system responses to anthropogenic warming. First, the few analyses that have been performed are limited in the number of systems and locations considered. Second, natural temperature variability is larger at the regional than the global scale, thus affecting identification of changes due to external forcing. Finally, at the regional scale other factors (such as land-use change, pollution, and invasive species) complicate the issue. [1.4]

Nevertheless, the consistency between observed and modelled changes in several studies and the spatial agreement between significant regional warming and consistent impacts at the global scale is sufficient to conclude with high confidence that the anthropogenic component of warming over the last three decades has had a discernible influence on many physical and biological systems. [1.4]

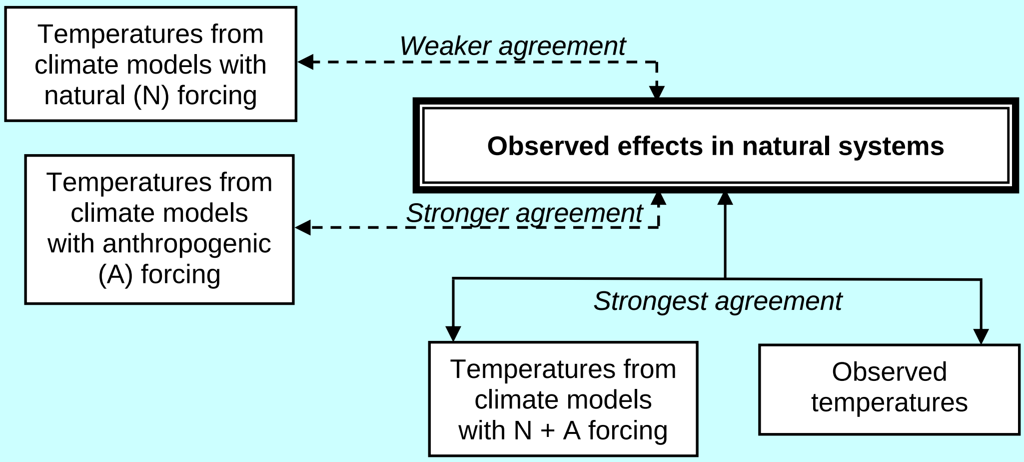
Effects of regional temperature increases on some managed and human systems are emerging, although these are more difficult to discern than those in natural systems due to adaptation and non-climatic drivers [medium confidence].

Those managed and human systems where there is some evidence of effects from regional increases in temperature include the following:

- some coastal zones affected by erosion due to sea-level rise [1.3];
- effects on agricultural and forestry management at northern higher latitudes, such as earlier spring planting [1.3];
- some aspects of human health, such as heat-related mortality in Europe and Asia, infectious disease vectors in some areas, and allergenic pollen in northern mid-latitudes [1.3, 8.2, 8.ES];
- some human activities in the Arctic (such as aspects of indigenous livelihoods and shorter vehicle travel seasons) and in lower-elevation alpine areas (such as mountain sports). [1.3]

[5] Warming over the past 50 years at the continental scale has been attributed to anthropogenic effects [IPCC WGI SPM].
[6] See Endbox 2.

Box SPM-1. Linking the causes of climate change to observed effects in natural systems



1. Using Climate Models

The study of causal connection by separation of natural and anthropogenic forcing factors (set of evidence 1 on page 3) compares observed effects in systems with modelled temperatures, where the models are forced using only changes in natural external factors (solar irradiance and volcanic aerosols, N in diagram above), using only anthropogenic changes (greenhouse gases and aerosols, A), and using both (N+A). With combined N+A forcing, the agreement between temperatures and system effects is strongest.

Thus, observed changes in physical and biological systems are likely responding to both natural and anthropogenic climate forcings, thus linking causes of climate change to observed effects. [1.4]

2. Using Spatial Pattern Analysis

The study of causal connection by spatial analysis (set of evidence 3 on page 3) follows these stages:
(i) It identifies 5º by 5º cells across the globe that exhibit significant warming (1.0 to 3.5ºC), warming (0.2 to 1.0ºC) , cooling (-0.2 to -1.0ºC) and significant cooling (-1.0 to -2.0ºC), and
(ii) it identifies 5º by 5º cells that contain significant observed changes in natural systems that are consistent with warming and that are not consistent with warming, and
(iii) it statistically determines the degree of spatial agreement between the two sets of cells.

In this assessment, the conclusion is that the agreement across the globe is significant at more than the 1% level, and that the location of observed changes is very unlikely to be solely due to natural variability of climate.

Taken together with evidence of significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica [WGI SPM], this shows a discernible human influence on changes in many natural systems. [1.4]

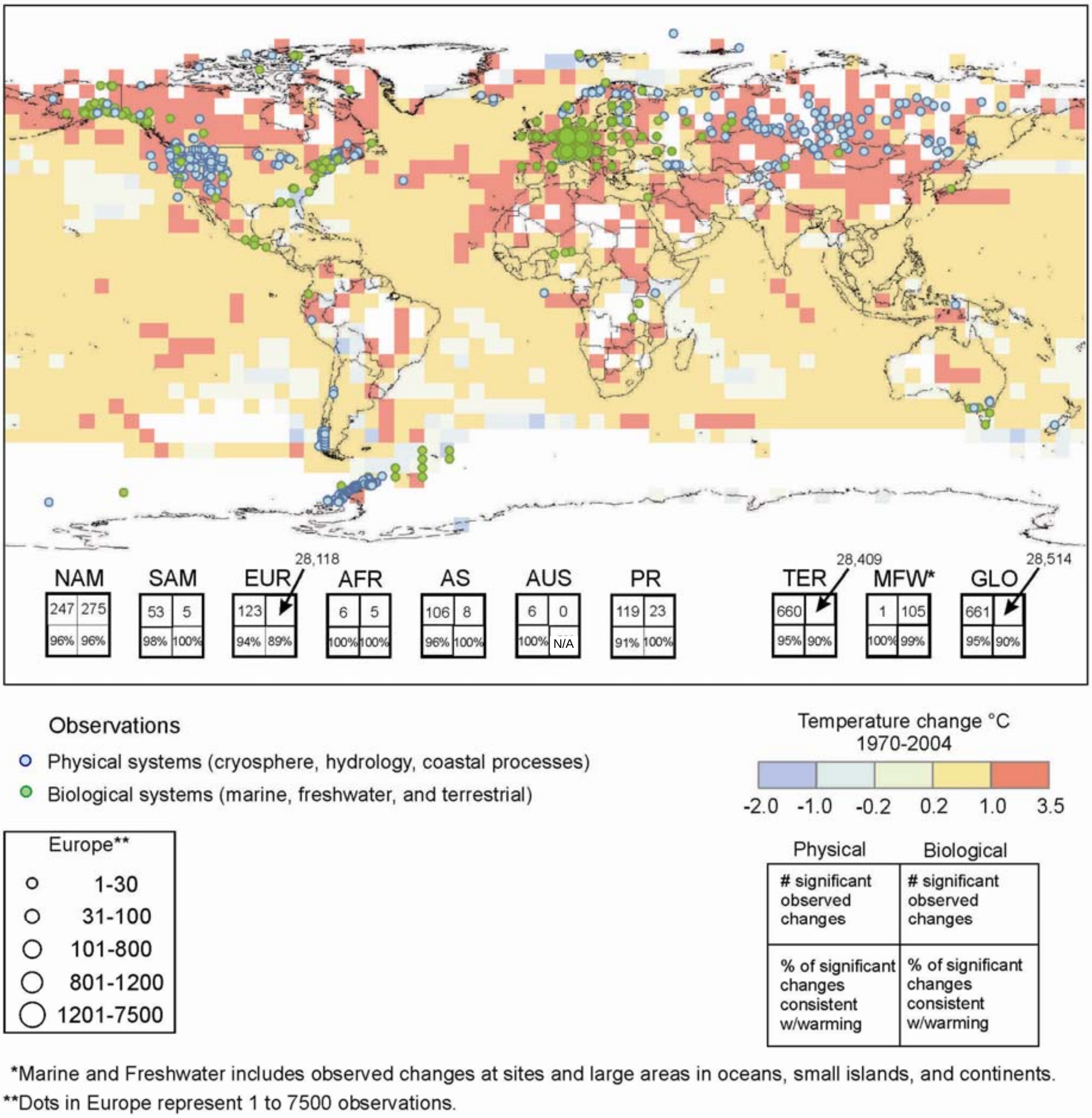


Figure SPM-1. Locations of observed changes in physical systems (cryosphere, hydrology, and coastal processes) and biological systems (terrestrial, marine, and freshwater biological systems), for studies ending in 1990 or later with at least 20 years of data, shown together with surface temperature changes for 1970-2004. Data for the system changes are taken from ~75 studies (of which ~70 are new since the TAR) containing >29,000 data series. White regions do not contain sufficient observational climate data to estimate a trend. Boxes are for (i) continental regions: North America (NAM), South America (SAM), Europe (EUR), Africa (AFR), Asia (AS), Australia (AUS), and Polar Regions (PR) and (ii) global-scale: Terrestrial (TER), Marine and Freshwater (MFW), Global (GLO) changes in physical and biological systems. Top row of boxes shows number of observed time series with a significant trend and bottom row shows percentage of these in which trend is consistent with warming. [F1.8, F1.9]

C. Current knowledge about future impacts

The following is a summary of the main projected impacts in each system and sector and region over this century[7], judged in terms of relevance for people and the environment. It assumes that climate change is not mitigated, and that adaptive capacity has not been enhanced by climate policy. All global temperature changes are expressed relative to 1990, unless otherwise stated[8]. The impacts stem from changes in climate and sea-level changes associated with global temperature change, and frequently reflect projected changes in precipitation and other climate variables in addition to temperature.

SYSTEMS AND SECTORS

Water

Runoff and water availability are very likely to increase at higher latitudes and in some wet tropics, including populous areas in E and SE Asia, and decrease over much of the mid-latitudes and dry tropics, which are presently water-stressed areas. ** D[9] [F3.4]

Drought-affected areas will likely increase and extreme precipitation events, which are likely to increase in frequency and intensity, will augment flood risk. Increase of frequency and severity of floods and droughts will have implications on sustainable development. ** N [3.4]

Water volumes stored in glaciers and snow cover are very likely to decline, reducing summer and autumn flows in regions where more than one sixth of the world population currently live. ** N [3.4]

Ecosystems

The resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g., wildfire, insects), and other global change drivers. ** N [4.1 to 4.6]

In the second half of this century terrestrial ecosystems are likely to become a net source of carbon, especially from previously under-estimated C stocks, thus amplifying climate change. ** N [F4.2]

Roughly 20-30% of species are likely to be at high risk of irreversible extinction if global average temperature exceeds 1.5-2.5°C. * N [4.4]

For increases in global average temperature exceeding 1.5-2.5°C and in concomitant atmospheric CO_2 concentrations, there are very likely to be major changes in ecosystem structure and function, species' ecological interactions, and species' geographic ranges, with predominantly negative consequences for goods and services. ** N [4.4]

Food

Crop yield potential is likely to increase at higher latitudes for global average temperature increases of up to 1-3°C depending on the crop, and then decrease beyond that (allowing for effects of CO_2 fertilisation). * D [5.4]

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[7] Unless otherwise stated.
[8] To express the temperature change relative to pre-industrial (about 1750) levels, add 0.6°C.
[9] In the Section C text, the following conventions are used

<u>*Relationship to the TAR:*</u>		<u>*Confidence in a statement:*</u>	
D	*Development*	***	*Very high confidence*
N	*New*	**	*High confidence*
		*	*Medium confidence*

At lower latitudes, especially the seasonally dry tropics, crop yield potential is likely to decrease for even small global temperature increases, which would increase risk of hunger. * D [5.4]

Global agricultural production potential is likely to increase with increases in global average temperature up to about 3°C, but above this it is very likely to decrease. * D [5.6]

Increased frequency of droughts and floods would affect local production negatively, especially in subsistence sectors at low latitudes. ** D [5.4, 5.ES]

Coastal systems and low-lying areas

Coasts are very likely to be exposed to increasing risks due to climate change and sea-level rise and the effect will be exacerbated by increasing human-induced pressures on coastal areas. *** D [6.3, 6.4]

It is likely that corals will experience a major decline due to increased bleaching and mortality due to rising seawater temperatures. Salt marshes and mangroves will be negatively affected by sea-level rise. *** D [6.4]

Hundreds of millions of people are vulnerable to flooding due to sea-level rise, especially in densely-populated and low-lying settlements where adaptive capacity is relatively low and which already face other challenges such as tropical storms or local coastal subsidence. The numbers affected will be largest in the mega-deltas of Asia but small islands face the highest relative increase in risk. *** D [6.4, 16.3]

Industry, settlement and society

Benefits and costs of climate change for industry, settlement, and society will vary widely by location and scale. Some of the effects in temperate and polar regions will be positive and others elsewhere will be negative. In the aggregate, however, net effects are more likely to be strongly negative under larger or more rapid warming. ** N [7.4, 7.6, 15.3, 15.5]

The most vulnerable industries, settlements and societies are those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources, and those in areas prone to extreme weather events, especially where rapid urbanization is occurring. ** D [7.1, 7.5]

Poor communities can be especially vulnerable because they tend to be concentrated in relatively high-risk areas, have more limited coping capacities, and can be more dependent on climate-sensitive resources such as local water and food supplies. ** N [7.2, 7.4]

Where extreme weather events become more intense, the economic costs of those events will increase, and these increases are likely to be substantial in the areas most directly affected. ** N [7.5]

Health

Projected climate change is likely to affect millions of people, particularly those with low adaptive capacity, through increases in malnutrition and consequent disorders, with implications for child growth and development; increased deaths, disease and injury due to heat waves, floods, storms, fires and droughts; the altered burden of water-related diseases; the increased frequency of cardio-respiratory diseases due to higher concentrations of ground level ozone; and the altered spatial distribution of some infectious disease vectors. ** D [8.4, 8.ES, 8.2]

Climate change is likely to have some mixed effects, such as the expansion and contraction of the range of malaria. ** D [8.4]

In some places, climate change is likely to bring some benefits to health such as fewer deaths from cold exposure. ** D [8.4]

REGIONS

Africa

Some regions will likely experience increased water shortages which, coupled with complex water governance and increased demand, are likely to affect livelihood and lead to large increases in numbers of people at risk of water scarcity. ** D [9.4]

Reductions in the area suitable for agriculture, and in length of growing seasons and yield potential, are likely to lead to increased risk of hunger. ** D [9.4]

Projected sea-level rise threatens large cities. ** D [9.4]

Mangroves and coral reefs will likely be further degraded, with additional consequences for local fisheries and tourism. ** D [9.4]

Decreased fish catches from large lakes, due to rising water temperatures and over-fishing, will have important impacts on local food supplies. * N [9.4, 5.4]

Asia

Glacier melt in the Himalayas is virtually certain to increase related flooding, rock avalanches from destabilized slopes, and disruption of water resources. ** N [10.2, 10.4]

Coastal areas, especially heavily-populated mega-delta regions in South, East and Southeast Asia, are likely to be at greatest risk of increased flooding from rivers and the sea. ** D [10.4]

In southern and eastern Asia, the interaction of climate change impacts with rapid economic and population growth, and migration from rural to urban areas, is likely to affect development. ** N [10.4]

Projected increases in temperature and changes in precipitation will likely lead to declines in crop productivity that will increase the risk of hunger in Asia especially in developing countries. ** D [10.4]

Australia and New Zealand

Ongoing water security problems are very likely to increase in southern and eastern Australia, and parts of eastern New Zealand. ** D [11.4]

Further loss of biodiversity is likely in ecologically-rich sites including the Great Barrier Reef, Kakadu wetlands, the Queensland Wet Tropics, sub-Antarctic islands and the Alpine national parks of both countries. Many of these are World Heritage Sites. *** D [11.4]

Coastal communities with ongoing development and population growth, such as the Cairns region, Southeast Queensland and Northland to Bay of Plenty, are very likely to have increased risk from sea-level rise, increases in the severity and frequency of storms and coastal flooding. *** D [11.4, 11.6]

Up to about 1-2°C global average temperature increase, benefits are likely in some areas, especially New Zealand and parts of southern Australia, and include longer growing seasons, less frost risk, reduced winter energy demand, and increased hydroelectric potential and irrigation water. Greater warming is likely to lead to net negative effects. ** N [11.4]

Europe

In Southern Europe, climate change is very likely to have negative impacts by increasing risk to health due to more frequent heat waves, reducing water availability and hydropower, endangering crop production, and increasing the frequency of wildfires. ** D [12.4, 12.7]

In Northern Europe, climate change is likely to bring benefits in the form of reduced exposure to cold periods, increased crop yields, increased forest and Atlantic waters productivity, and augmented hydropower potential. ** D [12.4]

By the 2020s, there is likely to be increased risk of flash floods throughout Europe, of winter floods in northern Europe, and of snowmelt floods in central and eastern Europe. ** D [12.4]

Coastal flooding is likely to threaten up to an additional 2.5 million people each year by 2080. ** D [12.4]

Latin America

Increases in temperature and decreases in soil water would lead to replacement of tropical forest by savanna in eastern Amazonia. In northeast Brazil and northern Mexico semi-arid vegetation is likely to be replaced by arid-land vegetation. In tropical forests, species extinctions are likely. ** D [13.4]

In drier areas, climate change is likely to lead to salinisation and desertification of agricultural land. Yields of some important crops are projected to decrease and livestock productivity is very likely to decline, with adverse consequences for food security. In temperate zones soybean yields are likely to increase. ** N [13.4, 13.7]

Sea-level rise is very likely to cause increased risk of flooding in low-lying areas (e.g., in El Salvador, Guyana and the Rio de la Plata estuary). ** N [13.4, 13.7]

Increases in sea surface temperature are likely to have adverse effects on Mesoamerican coral reefs, and shifts in the location of south-east Pacific fish stocks. ** N [13.4]

North America

Projected warming in western mountains is very likely to cause decreased snowpack, more winter flooding, and reduced summer flows, exacerbating competition for over-allocated water resources. *** D [14.4.1, B14.2]

Disturbances from pests, diseases, and fire are likely to have increasing impacts on forests, with an extended period of high fire risk and large increases in area burned. *** N [14.4., B14.1]

Cities with a history of heat waves are likely to experience many more, with potential for adverse health impacts. The growing population over age 65 is most at risk. *** D [14.4]

Population growth and development in coastal areas are very likely to increase risks and economic losses from sea-level rise, severe weather, and storm surge. Current adaptation is uneven and readiness for increased exposure is low. ** N [14.4, 14.4]

Polar Regions

The main projected biophysical effects are likely to be reductions in thickness and extent of glaciers and ice sheets, changes in the extent of sea ice and permafrost, an increase in the depth of permafrost seasonal thawing, and changes in natural ecosystems with detrimental effects on migratory birds, mammals and higher predators. ** D [15.3, 15.4, 15.2]

For Arctic human communities it is virtually certain that there will be both negative and positive impacts, particularly through changing cryospheric components, on infrastructure and transport. ** D [15.4]

In both polar regions, specific ecosystems and niche habitats are highly likely to be vulnerable as climatic barriers to species invasions are lowered. ** D [15.6, 15.4]

Small Islands

Sea-level rise is likely to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure that supports the socio-economic well-being of island communities. *** D [16.4]

There is strong evidence that under most climate change scenarios, water resources in small islands are likely to be seriously compromised. *** D [16.4]

With higher temperatures, increased invasion by non-native species is likely to occur, particularly on middle and high-latitude islands. ** N [16.4]

Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching, is likely to reduce the attractiveness of these destinations for tourism. ** D [16.4]

Magnitudes of impact can now be estimated more systematically for a range of possible increases in global average temperature [high confidence].

Since the IPCC Third Assessment, many additional studies, particularly in regions that previously had been little researched, have enabled a more systematic understanding of how the timing and magnitude of impacts is likely to be affected by changes in climate and sea level associated with differing amounts and rates of change in global average temperature.

Examples of this new information are presented in Tables SPM-1 and SPM-2. Entries have been selected which are judged to be important for human welfare and for which there is some confidence in the assessment. All entries of impact are drawn from chapters of the Assessment, where more detailed information is available[10]. Some of these impacts might be identified as 'key vulnerabilities'. Assessment of potential key vulnerabilities is intended to provide guidance to decision-makers, for example, for identifying levels and rates of climate change that, in the terminology of the UNFCCC Article 2, could result from 'dangerous anthropogenic interference' (DAI) with the climate system. Ultimately, the definition of DAI cannot be based on scientific arguments alone, but involves other judgements informed by the state of scientific knowledge. [19.1, 19.2]

[10] Criteria of choice: Likelihood, magnitude, timing, persistence/reversibility, distribution of impacts, the potential for adaptation to them, and for which there is some confidence in the assessment (which relates to the numbers of studies and their reliability).

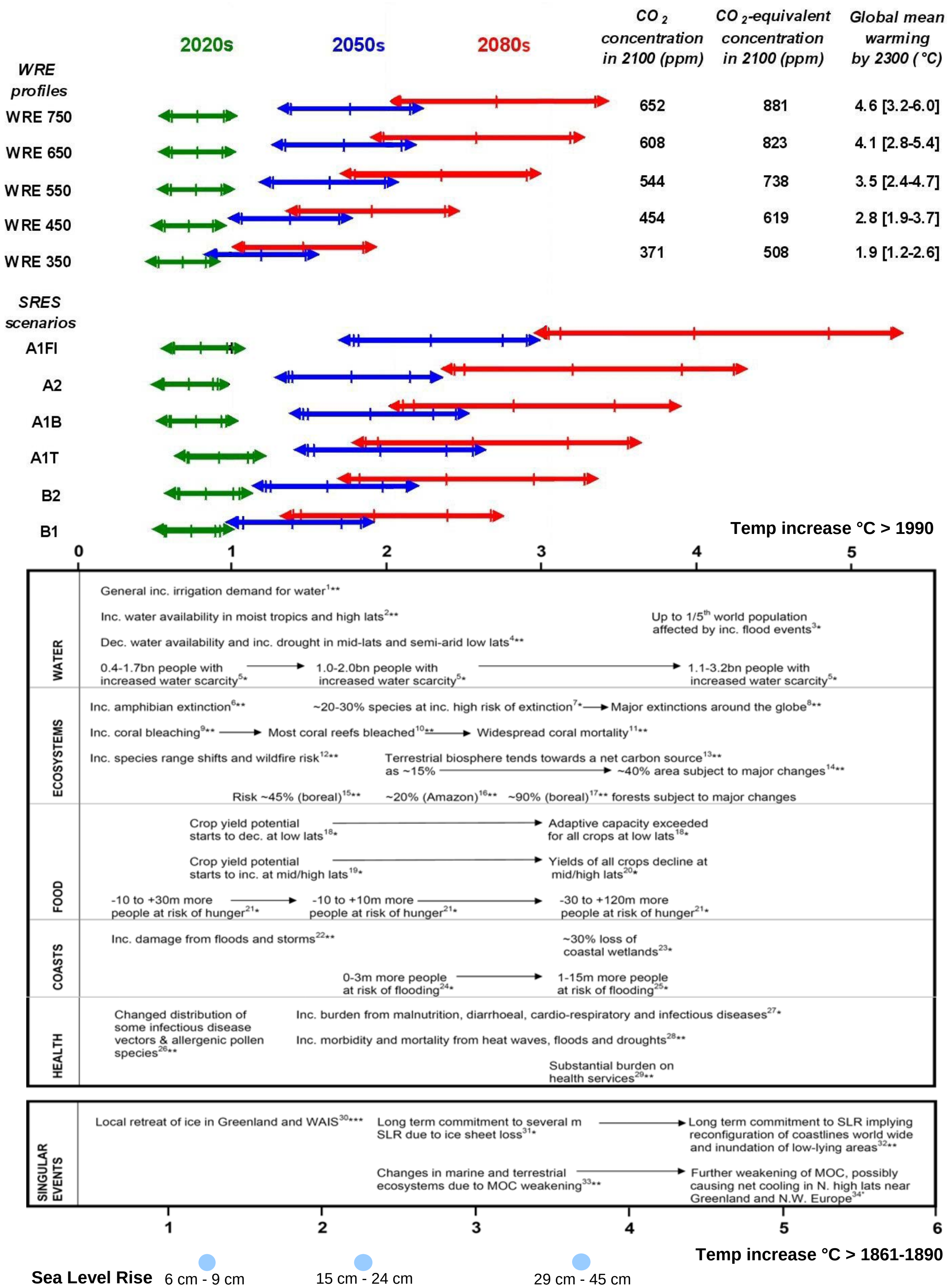

Table SPM-1. Examples of global impacts projected for varying changes in global average surface temperature. All entries are recorded in the full Assessment (see sources, below) [T20.7].

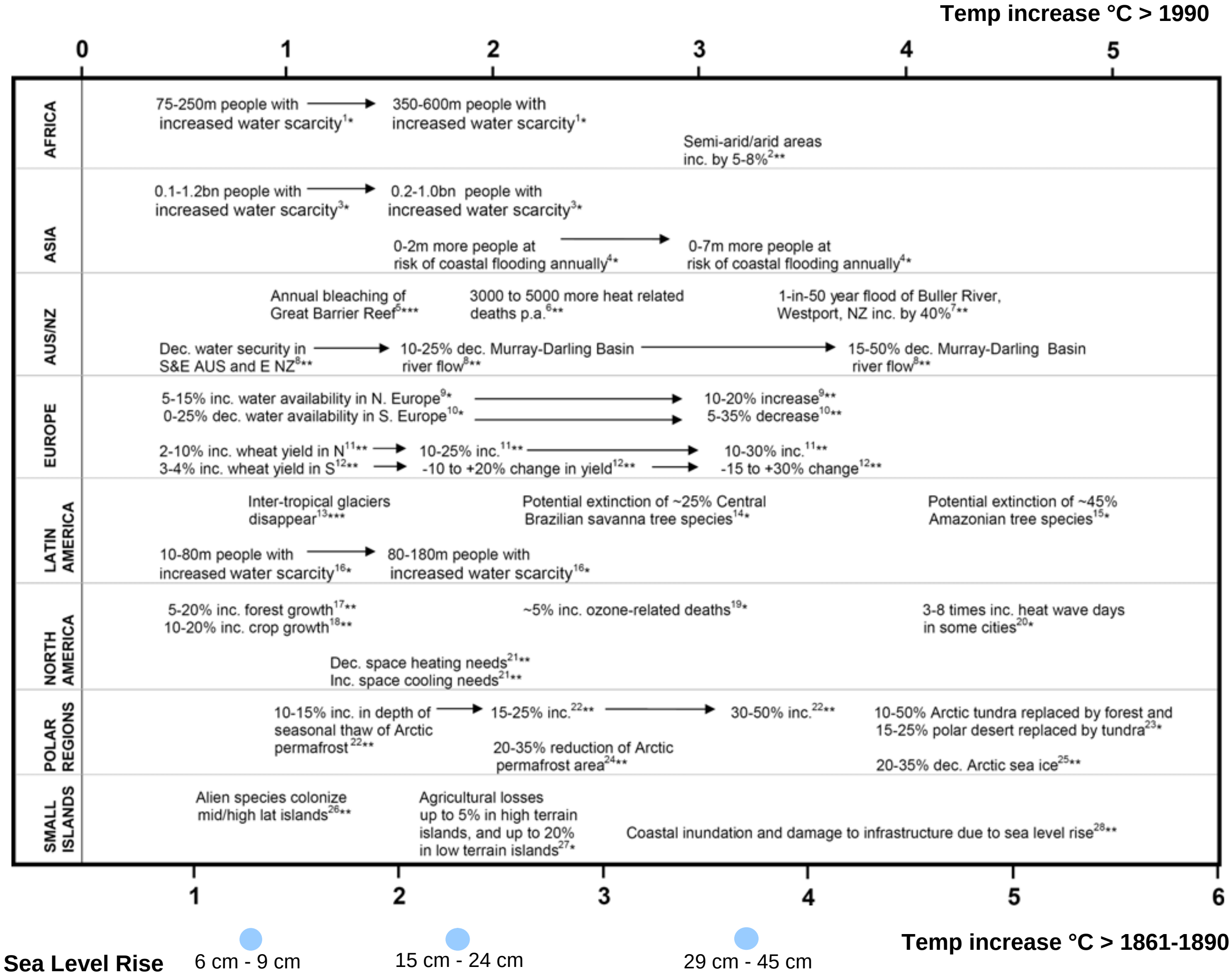

Table SPM-2. Examples of regional impacts projected for varying changes in global average surface temperature. All entries are recorded in the full Assessment (see sources, below) [T20.8].

Table SPM-1 (cont.)

Higher part of Table:

Bars indicate the projected range of global mean annual temperature change by 2020s, 2050s and 2080s relative to 1990 and 1861-1890 for the six illustrative SRES scenarios and for five CO_2-stabilisation profiles (WRE) [2.4, B2.8, 2.1]. 1990 is based on calculations for 1980-2000. Time periods are based on calculations for 2025, 2055 and 2085. (Subject to revision)

Estimates are based on a simple climate model tuned to nineteen AOGCMs. The central three tick marks represent the mean and ±1 standard deviation for the nineteen model tunings and medium carbon cycle settings. Note that the simple model means show about 10% greater warming over the 21st century than the means of the corresponding AOGCMs. The outer tick marks (SRES scenarios only) depict the change in the uncertainty range if carbon cycle feedbacks are assumed to be higher or lower than in the medium setting. Arrows indicate that the bars show only part of the full uncertainty range. WRE stabilisation profiles are described in the IPCC Third Assessment Synthesis Report. These approach CO_2 stabilisation at different times in the future (CO_2 and CO_2-equivalent concentrations are shown for 2100). Warming continues for many decades after CO_2-stabilisation (see mean and ±1 standard deviation range for 2300). [2.4, B2.8, F2.1] (Subject to revision)

Lower part of Table:

Coding for confidence levels: *** very high confidence; ** high confidence; * medium confidence. Entries are placed so that the left-hand side of text indicates approximate onset of a given impact. Arrows indicate increasing levels of impact between two or more entries.

Outlying impacts could occur either side of the entries. Most impacts have been estimated from modelling analyses based on scenarios of altered climate (temperature, precipitation, etc.).

These assume unmitigated climate change and adaptation not enhanced by climate policy. Most socio-economic impacts are time dependent (i.e., they assume certain levels of population, income and technology, and these vary with time). Entries for these impacts in the Table are for global average temperature levels projected under the SRES A2 scenario. Estimates for numbers of people with increased water scarcity, hunger and coastal flooding cover the range of SRES scenarios A1FI, A2, B1 and B2 (see Endbox 3). Note that these are estimated climate-induced changes to the estimated number for a future without climate change. Estimates for hunger assume CO_2 fertilisation effects. For extinctions 'major' means ~40-~70% of assessed species. For boreal and Amazon forests and the terrestrial biosphere 'major changes' means biome changes, including changes to novel biomes. Indicative sea-level rise (SLR) scenarios are estimated from the 5% and 95% estimates reported for 2100 in WGI, scaled using the earlier TAR WGI SLR scenarios [WGI Ch5].

Sources Table SPM-1:
1, 3.5; **2**, 3.4; **3**, 3.4; **4**, 3.4, 3.7; **5**, 3.5; **6**, 4.4, F4.4, T4.1; **7**, 4.4; **8**, F4.4, T4.1, 4.4; **9**, 4.4, B4.4, F4.4, T4.1, 6.4, B6.1; **10**, 4.4, B4.4, F4.4, T4.1, 6.4, B6.1; **11**, 4.4, B4.4, F4.4, T4.1, 6.4, B6.1; **12**, 4.4, T4.1, 4.2; **13**, F4.2, 4.4, F4.3, F4.4, T4.1; **14**, 4.4, F4.3; **15**, 4.4, F4.3; **16**, 4.4, F4.3, F4.4, T4.1; **17**, 4.4, F4.3; **18**, 5.4; **19**, 5.4, 5.5; **20**, 5.4; **21**, 5.3; **22**, 6.3, B6.2; **23**, 6.4; **24**, 6.4; **25**, 6.4; **26**, 8.2; **27**, 8.2, 8.4; **28**, 8.2, 8.4, 8.7; **29**, 8.3, 8.6, 8.8; **30**, 19.3; **31**, 19.3; **32**, 19.3; **33**, 19.3; **34**, 19.3, 12.6

Sources Table SPM-2:
1, 9.4; **2**, 9.4; **3**, 10.4; **4**, 6.4; **5**, 11.6; **6**, 11.4; **7**, 11.4; **8**, 11.4; **9**, 12.4; **10**, 12.4; **11**, 12.4; **12**, 12.4; **13**, 13.2; **14**, 13.4; **15**, 13.4; **16**, 13.4; **17**, 14.4; **18**, 14.4; **19**, 14.4; **20**, 14.4; **21**, 14.4; **22**, 15.3; **23**, 15.4; **24**, 15.3; **25**, 15.3; **26**, 16.4; **27**, 16.4; **28**, 16.4.

Impacts are very likely to increase due to increased frequencies and intensities of extreme weather events [high confidence].

Since the IPCC Third Assessment, confidence has increased that some weather events and extremes will become more frequent, more widespread or more intense during the 21st century; and more is known about the potential effects of such changes. These are summarised in Table SPM-3.

Phenomena and direction of trend [WGI SPM]	**Likelihood of trend in 21st C** [WGI SPM]	**Major impacts by sector**			
		Agriculture, forestry	**Water resources**	**Human health/ mortality**	**Industry/settlement/ society**
Warmer/fewer cold days/nights; warmer/more hot days/nights over most land areas.	Virtually certain	Increased yields in colder environments; decreased yields in warmer environments	Effects on water resources relying on snow melt	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced effects of snow, ice etc.
Warm spells/heat waves: frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; fire danger increase	Increased water demand; water quality problems, e.g., algal blooms	Increased risk of heat-related mortality	Reduction in quality of life for people in warm areas without air conditioning; impacts on elderly and very young; reduced thermoelectric power production efficiency
Heavy precipitation events: frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land, water logging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply	Deaths, injuries, infectious diseases, allergies and dermatitis from floods and landslides	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures
Area affected by drought: increases	Likely	Land degradation, lower yields/crop damage and failure; livestock deaths	More widespread water stress	Increased risk of food and water shortage and wild fires; increased risk of water- and food-borne diseases	Water shortages for settlements, industry and societies; reduced hydropower generation potentials; potentials for population migration
Number of intense tropical cyclones: increases	Likely	Damage to crops; windthrow of trees	Power outages cause disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers
Incidence of extreme high sea-level: increases	Likely	Salinisation of irrigation and well water	Decreased freshwater availability due to saltwater intrusion	Increase in deaths by drowning in floods; increase in stress-related disease	Costs of coastal protection *versus* costs of land-use relocation; also see tropical cyclones above

Table SPM-3. Possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid to late 21st century. Examples of all entries will be found in the full Assessment.

Some systems, sectors and regions are likely to be especially affected by climate change [high confidence].

Regarding systems and sectors, these are:

- Ecosystems especially: tundra, boreal forest, mountain, mediterranean-type ecosystems; along coasts, mangroves and salt marshes; and in oceans, coral reefs and the sea ice biomes [4.ES, 4.4, 6.4].
- Low-lying coasts due to the threat of sea-level rise [6.ES].
- Water resources in middle and dry low-latitude regions due to decreases in rainfall and higher rates of evapotranspiration [3.4].
- Agriculture in low-latitude regions due to reduced water availability [5.4, 5.3].
- Human health, especially in areas with low adaptive capacity [8.3].

Regarding regions, these are:

- The Arctic, because of high rates of projected warming on natural systems [15.3].
- Africa, especially the sub-Saharan region, because of current low adaptive capacity as well as climate change [9.ES, 9.5].
- Small islands, due to high exposure of population and infrastructure to risk of sea-level rise and increased storm surge [16.1, 16.2].
- Asian megadeltas, such as the Ganges-Brahmaputra and the Zhujiang, due to large populations and high exposure to sea-level rise, storm surge and river flooding [T10.9, 10.6].

Within other areas, even those with high incomes, some people can be particularly at risk (such as the poor, young children and the elderly) and also some areas and some activities. [7.1, 7.2, 7.4]

Some events have the potential to cause very large impacts, especially after the 21st century [medium confidence].

Very large sea-level rises that would result from widespread deglaciation of Greenland and West Antarctic ice sheets imply major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas. Relocating populations, economic activity, and infrastructure would be costly and challenging. There is medium confidence that both ice sheets would be committed to partial deglaciation for a global average temperature increase greater than 1-2°C, causing sea-level rise of 4-6 m over centuries to millennia. [WGI 6.4, 10.7, WGII 19.3]

Based on climate model results, it is very unlikely that the Meridional Overturning Circulation (MOC) in the North Atlantic will undergo a large abrupt transition during the 21st century. Slowing of the MOC this century is very likely, but temperatures over the Atlantic and Europe are projected to increase nevertheless. Impacts of large-scale and persistent changes in the MOC are likely to include changes to marine ecosystem productivity, fisheries, ocean CO_2 uptake, oceanic oxygen concentrations and terrestrial vegetation, and perhaps net cooling in some locations, such as northern high latitude areas near Greenland and north-west Europe, especially after the 21st century. [WGI 10.3, 10.7, WGII 12.6, 19.3]

D. Current knowledge about responding to climate change

Some adaptation is occurring now, to observed and projected future climate change, but on a very limited basis [high confidence].

There is growing evidence since the IPCC Third Assessment that adaptation is occurring in response to observed and anticipated climate change. For example, climate change forms part of the design consideration in infrastructure projects such as coastal defence in the Maldives and prevention of glacial lake outburst flooding in Nepal, and management projects such as water management in Australia and government response to heat waves in some European countries. [7.6, 8.2, 8.6, 17.ES, 17.2, 16.5, 11.5].

Adaptation will be necessary to address impacts resulting from warming to which there is already a commitment [high confidence].

Past emissions are estimated to involve a current commitment to a 0.6°C rise in global average surface temperature by 2100 [WGI T10.5]. There are, therefore, some impacts to which there is already a commitment, and adaptation is the only available and appropriate response option for these. An indication of the impacts to which there is a commitment can be seen in Tables SPM-1 and SPM-2.

More extensive adaptation is required to reduce vulnerability, but there are barriers, limits and costs [high confidence].

Impacts are expected to increase broadly in line with increases in global average temperature, as indicated in Tables SPM-1 and SPM-2. Adaptation has the capacity to cope with many of these effects, but its ability to do this diminishes and the associated costs increase with temperature increase. At present we do not have a clear picture of the limits to adaptation, or the cost, partly because effective adaptation measures are highly dependent on specific, geographical, climate risk factors as well as the policy environment. [7.6, 17.2, 17.4]

The array of potential adaptive responses available to human societies is very large, ranging from purely technological (e.g., sea defences), through behavioural (e.g., altered food and recreational choices) to managerial (e.g., altered farm practices), to policy (e.g., planning regulations). Yet there remain formidable environmental, economic, informational, social, attitudinal and behavioural barriers to implementation of adaptation. For some developing countries, availability of resources is particularly important. [See sections x.5 and x.6 in the core chapters, 7.4, 7.6, 17.2, 17.4].

However, adaptation alone is not expected to cope with all the projected effects of climate change, and especially not over the long run as most impacts increase in magnitude [Tables SPM-1 and SPM-2].

Vulnerability to climate change can be exacerbated by the presence of other stresses [very high confidence].

Multiple stresses can increase vulnerability to climate change by reducing resilience and can also reduce adaptive capacity because of resource deployment to competing needs. For example, current stresses on some coral reefs include marine pollution and chemical runoff from agriculture as well as increases in water temperature. Vulnerable regions face multiple stresses that affect their exposure and sensitivity as well as their capacity to adapt, for example from current climate hazards, poverty and unequal access to resources, food insecurity, trends in economic globalization, conflict, and incidence of disease such as HIV/AIDS. [7.4, 8.3, 17.3, 20.3]

Furthermore, because it can lead to a wide range of different impacts, climate change itself can be a source of multiple stresses. In these cases, overall vulnerability will be greater than the sum of vulnerabilities taken in isolation. [7.6, 20.3, 20.7]

Future vulnerability depends not only on climate change but also on development pathway [very high confidence].

An important advance since the IPCC Third Assessment has been the completion of impacts studies for a range of different development pathways. Most have been based on characterisations of population and income level drawn from the IPCC Special Report on Emission Scenarios (SRES) (Endbox 3). [2.4]

These studies show that the impacts of climate change can vary greatly due to the development pathway assumed. There can be large differences in regional population, income and technological development under alternative scenarios, which are often a strong determinant of the level of vulnerability to climate change. [2.4]

To illustrate, Figure SPM-2 shows estimates from a recent study of the number of people projected to be at risk under different assumptions of socio-economic development. This indicates that the flood impacts are projected to be highest in the A2-type scenario of development, which is characterized, *inter alia*, as having a larger and poorer population than other scenarios. The difference between impact is largely explained, not by differences in emissions, but by differences in the size of low-income population which is generally more vulnerable to flooding. [T6.6]

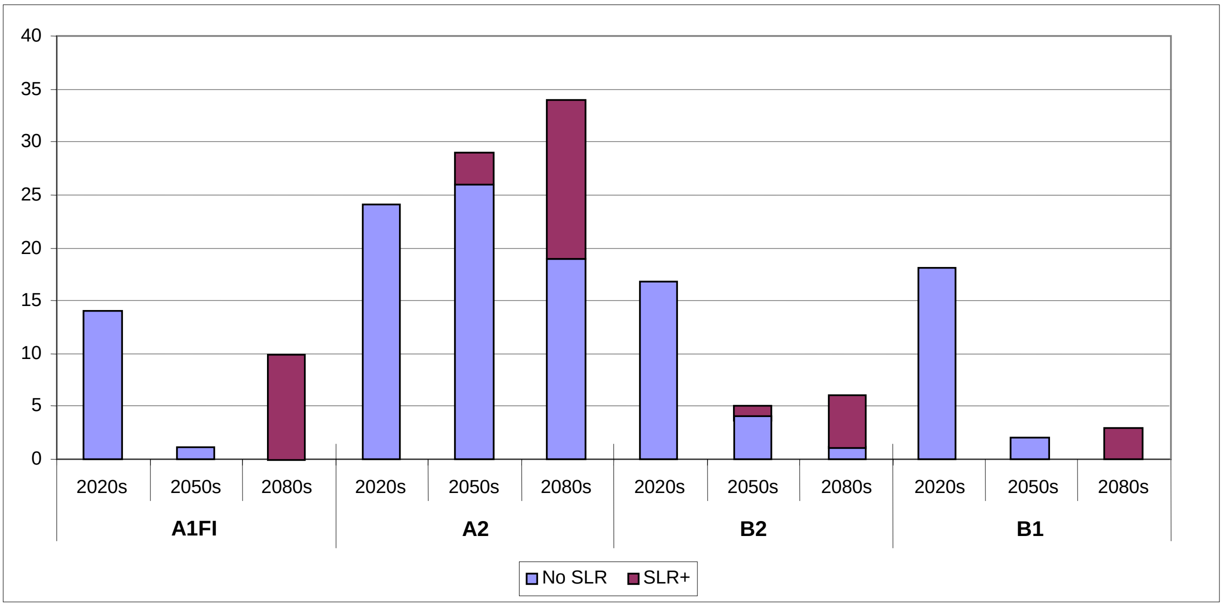

Figure SPM-2. Results from a recent study showing estimated millions of people per annum at risk from coastal flooding, with (purple and blue bars) and without (blue bars) sea-level rise (SLR). The figure shows: i) differences in total numbers at risk due to differences in socio-economic development; and ii) increases over time in the proportion of the total at risk due to sea-level rise. [T6.6]

Sustainable development can reduce vulnerability to climate change [very high confidence].[11]

Sustainable development can reduce vulnerability to climate change by enhancing adaptive capacity and increasing resilience. At present, however, few plans for promoting sustainability have explicitly included either adapting to climate impacts, or promoting adaptive capacity. [20.3]

On the other hand, it is very likely that climate change can slow the pace of progress toward sustainable development either directly through increased exposure to adverse impact or indirectly through erosion of the capacity to adapt. This point is clearly demonstrated in the sections of the sectoral and regional chapters of this report that discuss implications for sustainable development. [8.7, 9.6, 12.6, 13.6, 16.6, 20.3, 20.7]

The Millennium Development Goals (MDGs) are one measure of progress towards sustainable development. Over the next half-century, it is very likely that climate change will impede achievement of the MDGs. [20.7]

Many impacts can be reduced or delayed by mitigation [high confidence].

A small number of impact assessments have now been completed for scenarios in which future atmospheric concentrations of greenhouse gases are stabilized. Although these studies do not take full account of uncertainties in projected climate under stabilization, for example, the sensitivity of climate models to forcing, they nevertheless provide indications of damages avoided or vulnerabilities and risks reduced for different amounts of emissions reduction. [2.4, T20.6]

In addition, more quantitative information is now available concerning when, over a range of temperature increases, given amounts of impact may occur. This allows inference of the amounts of global temperature increase that are associated with given impacts. Table SPM-1 illustrates the change in global average temperature projected for three periods (2020s, 2050s, 2080s) for several alternative stabilisation pathways and for emissions trends assumed under different SRES scenarios. Reference to Tables SPM-1 and SPM-2 provides a picture of the impacts which might be avoided for given ranges of temperature changes.

A portfolio of adaptation and mitigation measures can further diminish the risks associated with climate change [high confidence].

Adaptation and mitigation are complementary strategies to reduce impacts. On the one hand, the effects of reduced emissions in avoiding impacts by slowing the rate of temperature increase will not emerge until after several decades, due to the inertia of the climate system. Adaptation, therefore, will be important in coping with early impacts. Specifically, adaptation will be necessary to meet the challenge of impacts to which we are already committed. On the other hand, unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt. [20.7]

This suggests the value of a portfolio or mix of strategies that includes mitigation, adaptation, technological development (to enhance both adaptation and mitigation) and scientific research (on climate science, impacts, adaptation and mitigation). Such portfolios might combine regulations with incentive-based approaches, and actions at all levels from the individual citizen through to national governments and international organizations. [18.1, 18.5]

Adaptive capacity can be increased by introducing adaptation measures into development planning (sometimes termed ‘mainstreaming’) [18.7], for example, by:

- including adaptation measures in land-use planning and infrastructure design [17.2];
- including measures to reduce vulnerability in existing disaster preparedness programmes e.g. by introducing drought warning systems [17.2, 20.8];

[11] The Brundtland Commission definition of sustainable development is used in this Assessment: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. The same definition was used by the IPCC Working Group II Third Assessment and Synthesis Reports.

- improving connectivity among ecosystems and widening the range of climates covered by reserves [4.6, 10.5, 11.5, 12.5, 13.5, 16.5].

Impacts of unmitigated climate change will vary regionally but, aggregated and discounted to the present, they are very likely to impose costs [high confidence], and these costs would increase over time [very high confidence].

Tables SPM-1 and SPM-2 make it clear that the impacts of climate change are mixed across regions. It is likely that some impacts will produce benefits while others will produce costs for increases in global mean temperature less than about 2°C from 1990 levels. It is, though, very likely that some low latitude regions will experience costs even for modest increases in temperature. Tables SPM-1 and SPM-2 also show that it is very likely that all regions will experience either declines in benefits or increases in costs for increases in temperature greater than about 2°C. [9.ES, 9.5, 10.6, T10.9, 15.3]

Many estimates of global aggregate damages, expressed in terms of future net benefits and costs that are discounted to the present, are now available. Two surveys of published estimates put the range between US$-3 and more than US$400 per tonne of CO_2. A study of peer-reviewed estimates found a mean value of US$12 per tonne of CO_2 with a standard deviation of US$23 per tonne of CO_2. Uncertainties and deliberate choices regarding climate sensitivity, response lags, discount rates, valuing non-market impacts (including ecosystem impacts), the treatment of inter-regional equity, and the treatment of catastrophic losses explain much of this variation. Most studies do not consider damages associated with increases in temperature greater than about 4°C; nor do they account for all of the damage associated with even more moderate temperature increases below about 2°C because they cannot include many non-quantifiable impacts. No single cost estimate from the published literature is very likely to be correct. Taken as a whole, however, the range of published estimates shows with high confidence that net costs are positive [T20.3, 20.6, F20.4].

It is virtually certain that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries, and populations. In some locations and amongst some groups of people with high exposure, high sensitivity, and/or low adaptive capacity, it is virtually certain that net costs will be larger than the global aggregate. [20.6, 20.ES, 7.4]

E. Systematic observing and research needs

This fourth Working Group II Assessment of the IPCC has benefited from the significant increase in research studies over the past few years inspired in part by the needs identified in the Third Assessment Report. However, many of these needs are still valid and require continued scientific, technical and operational efforts in order to provide policy-makers with the information needed for climate change risk-management. Among these needs are:

- enhancement of networks of systematic observations of key elements of physical, biological, managed and human systems affected by climate change particularly in regions where such networks have been identified as insufficient;
- continued research on the attribution of observed impacts of climate change to natural and anthropogenic forcings;
- research into understanding and managing physical, biological and human systems where there is a risk of irreversible change due to climate and other stresses;
- an increased understanding of the potential costs of impacts due to various amounts of climate change, of damages avoided by different levels of emissions reduction, and of options for adapting to these impacts and managing the risks;
- studies to explore how adapting to climate change and pursuing sustainable development can be complementary;
- further understanding of adaptation is likely to require learning-by-doing approaches, where the base of knowledge is enhanced through accumulation of practical experience.

Endbox 1. Definitions of key terms

Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where *climate change* refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

This box of key definitions is exactly as used in the TAR and has been subject to prior line-by-line approval by the Panel

Endbox 2. Likelihood and confidence language

In this Summary for Policymakers, the following terms have been used to indicate: the assessed likelihood of an outcome or a result:
Virtually certain > 99% probability of occurrence, *Extremely likely* > 95%, *Very likely* > 90%, *Likely* > 66%, *More likely than not* > 50%, *Very unlikely* < 10%, *Extremely unlikely* < 5%.

The following terms have been used to express confidence in a statement:
Very high confidence At least a 9 out of 10 chance of being correct, *High confidence* About an 8 out of 10 chance, *Medium confidence* About a 5 out of 10 chance, *Low confidence* About a 2 out of 10 chance, *Very low confidence* Less than a 1 out of 10 chance.

Endbox 3. The Emission Scenarios of the IPCC Special Report on Emission Scenarios (SRES)*

A1. 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).

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.

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound.

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

*This box summarizing the SRES scenarios is exactly as used in the TAR and has been subject to prior line by line approval by the Panel.