TS.4.3 Magnitudes of impact for varying amounts of climate change

Magnitudes of impact can now be estimated more systematically for a range of possible increases in global average temperature.
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 TS.3 and TS.4. Entries have been selected which are judged to be relevant for people and the environment and for which there is at least medium confidence in the assessment. All entries of impact are drawn from chapters of the Assessment, where more detailed information is available. Depending on circumstances, some of these impacts could be associated with 'key vulnerabilities', based on a number of criteria in the literature (magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts). Assessment of potential key vulnerabilities is intended to provide information on rates and levels of climate change to help decision-makers make appropriate responses to the risks of climate change [19.ES, 19.1].

TS.4.4 The impact of altered extremes

Impacts are very likely to increase due to increased frequencies and intensities of extreme weather events.
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 TS.5.

TS.4.5 Especially affected systems, sectors and regions

Some systems, sectors and regions are likely to be especially affected by climate change.
Regarding systems and sectors, these are as follows.

- Some ecosystems especially
  - terrestrial: tundra, boreal forest, mountain, Mediterranean-type ecosystems;
  - along coasts: mangroves and salt marshes;
  - 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 mid-latitude 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 as follows.

- 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].

TS.4.6 Events with large impacts

Some large-scale climate events have the potential to cause very large impacts, especially after the 21st century.
Very large sea-level rises that would result from widespread deglaciation of Greenland and West Antarctic ice sheets imply major changes in coastlines and ecosystems, and inundation of low-lying areas, with the greatest effects in river deltas. Relocating populations, economic activity and infrastructure would be costly and challenging. There is medium confidence that at least partial deglaciation of the Greenland ice sheet, and possibly the West Antarctic ice sheet, would occur over a period of time ranging from centuries to millennia for a global average temperature increase of 1-4°C (relative to 1990-2000), causing a contribution to sea-level rise of 4-6 m or more. The complete melting of the Greenland ice sheet and the West Antarctic ice sheet would lead to a contribution to sea-level rise of up to 7 m and about 5 m, respectively [WGI AR4 6.4, 10.7; WGII AR4 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, due to global warming. 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 [WGI AR4 10.3, 10.7; WGII AR4 12.6, 19.3].

TS.4.7 Costing the impacts of climate change

Impacts of unmitigated climate change will vary regionally. Aggregated and discounted to the present, they are very likely to impose costs, even though specific estimates are uncertain and should therefore be interpreted very carefully. These costs are very likely to increase over time.

This Assessment (see Tables TS.3 and TS.4) makes it clear that the impacts of future climate change will be mixed across regions. For increases in global mean temperature of less than 1-3°C above 1990 levels, some impacts are projected to produce benefits in some places and some sectors, and produce costs in other places and other sectors. It is, however, projected that some low-latitude and polar regions will experience net costs even for small increases in temperature. It is very likely that all regions will experience either declines in net benefits or increases in net costs for increases in temperature greater than about 2-3°C [9.ES, 9.5, 10.6, T10.9, 15.3, 15.ES]. These observations confirm evidence reported in the Third Assessment that, while developing countries are expected to experience larger percentage losses, global mean losses could be 1-5% of GDP for 4°C of warming [F20.3].

Many estimates of aggregate net economic costs of damages from climate change across the globe (i.e., the social cost of carbon (SCC), expressed in terms of future net benefits and costs that are discounted to the present) are now available. Peer-reviewed estimates of the SCC for 2005 have an average value of US$43 per tonne of carbon (i.e., US$12 per tonne of CO_2) but the range around this mean is large. For example, in a survey of 100 estimates, the values ranged from –US$10 per tonne of carbon (–US$3 per tonne of CO_2) up to US$350 per tonne of carbon (US$95 per tonne of CO_2) [20.6].

The large ranges of SCC are due in large part to differences in assumptions regarding climate sensitivity, response lags, the treatment of risk and equity, economic and non-economic impacts, the inclusion of potentially catastrophic losses, and discount rates. It is very likely that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts. Taken as a whole, the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time [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, net costs will be significantly larger than the global aggregate [20.6, 20.ES, 7.4].

TS.5 Current knowledge about responding to climate change

TS.5.1 Adaptation

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

Societies have a long record of adapting to the impacts of weather and climate through a range of practices that include crop diversification, irrigation, water management, disaster risk management and insurance. But climate change poses novel risks which are often outside the range of experience, such as impacts related to drought, heatwaves, accelerated glacier retreat and hurricane intensity [17.2.1].

There is growing evidence since the TAR that adaptation measures that also consider climate change are being implemented, on a limited basis, in both developed and developing countries. These measures are undertaken by a range of public and private actors through policies, investments in infrastructure and technologies, and behavioural change.

Examples of adaptations to observed changes in climate include:

- partial drainage of the Tsho Rolpa glacial lake (Nepal);
- changes in livelihood strategies in response to permafrost melt by the Inuit in Nunavut (Canada);
- increased use of artificial snow-making by the Alpine ski industry (Europe, Australia and North America);
- coastal defences in the Maldives and the Netherlands;
- water management in Australia;
- government responses to heatwaves in, for example, some European countries.
  [7.6, 8.2, 8.6, 17.ES, 16.5, 1.5]

However, all of the adaptations documented were imposed by the climate risk and involve real cost and reduction of welfare in the first instance [17.2.3]. These examples also confirm the observations of attributable climate signals in the impacts of change.

A limited but growing set of adaptation measures also explicitly considers scenarios of future climate change. Examples include consideration of sea-level rise in the design of infrastructure such as the Confederation Bridge in Canada and a coastal highway in Micronesia, as well as in shoreline management policies and flood risk measures, for example in Maine (USA) and the Thames Barrier (UK) [17.2.2].

Adaptation measures are seldom undertaken in response to climate change alone.

Many actions that facilitate adaptation to climate change are undertaken to deal with current extreme events such as heatwaves and cyclones. Often, planned adaptation initiatives are also not undertaken as stand-alone measures, but embedded within broader sectoral initiatives such as water-resource planning, coastal defence, and risk reduction strategies [17.2.2, 17.3.3]. Examples include consideration of climate change in the National Water Plan of Bangladesh, and the design of flood protection and cyclone-resistant infrastructure in Tonga [17.2.2].

Adaptation will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions.

Past emissions are estimated to involve some unavoidable warming (about a further 0.6°C by the end of the century relative to 1980-1999) even if atmospheric greenhouse gas concentrations remain at 2000 levels (see WGI AR4). There are some impacts for which adaptation is the only available and

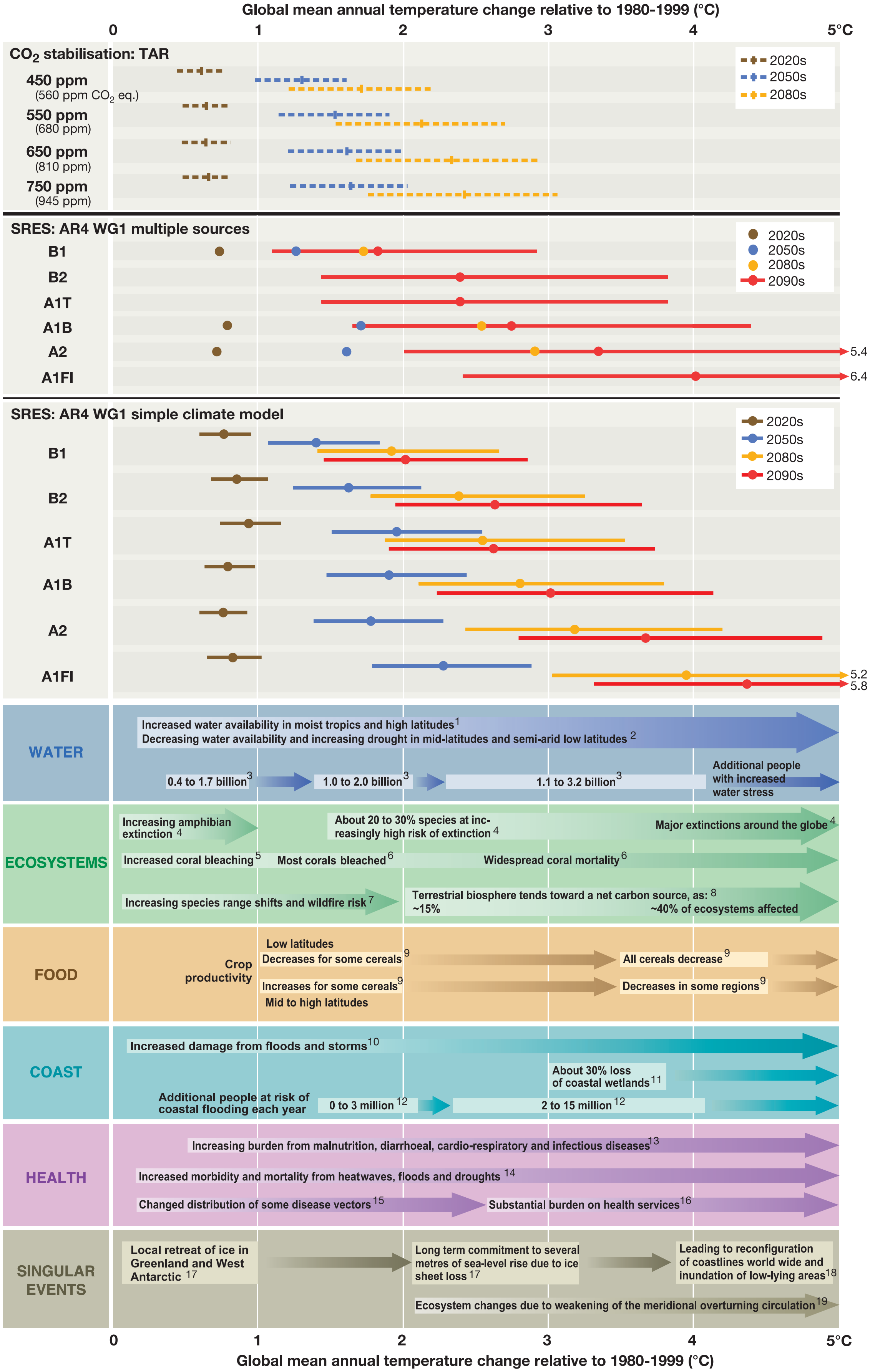

Table TS.3. *Examples of global impacts projected for changes in climate (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century [T20.8]. This is a selection of some estimates currently available. All entries are from published studies in the chapters of the Assessment. (Continues below Table TS.4.)*

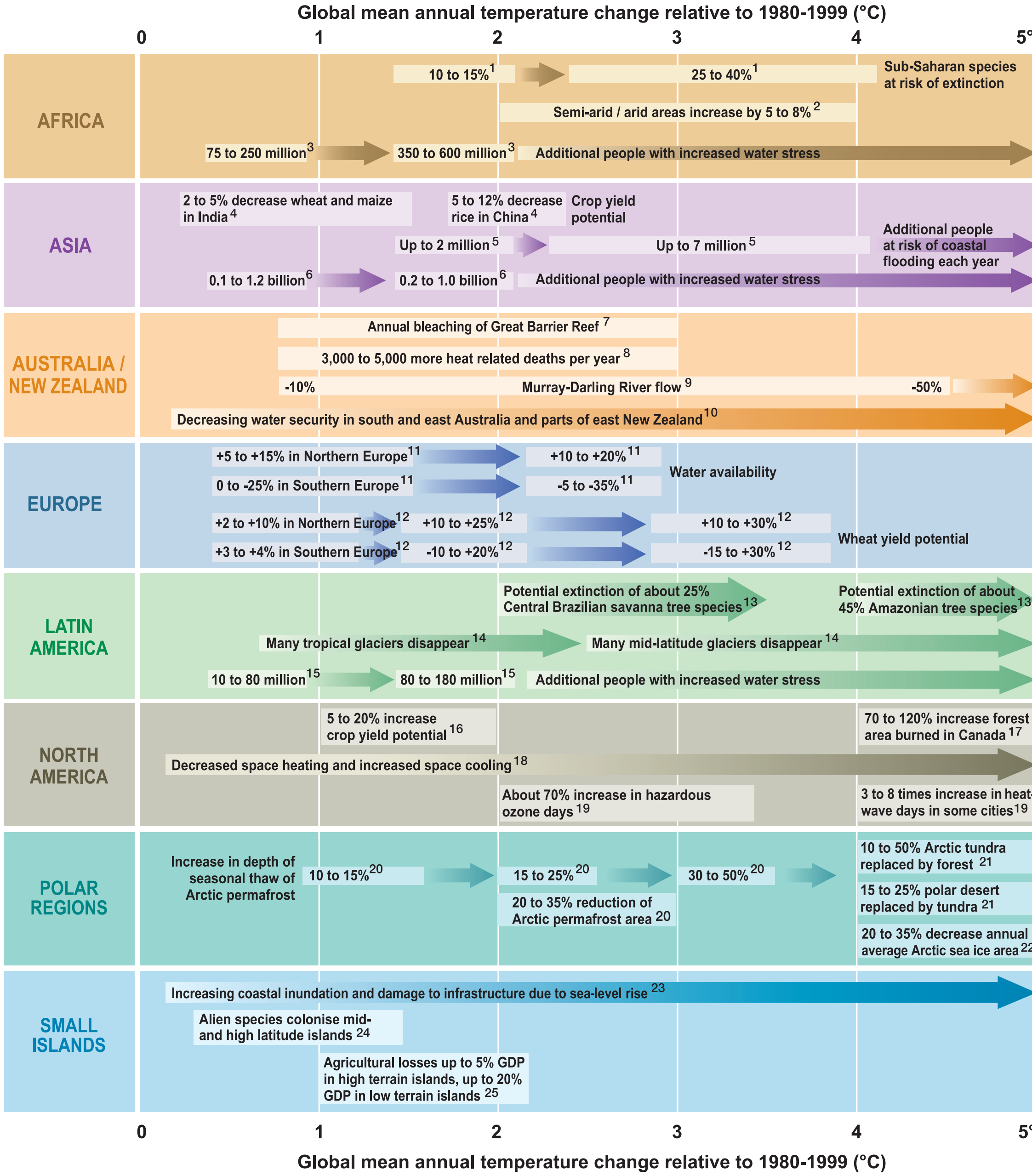

Table TS.4. *Examples of regional impacts [T20.9]. See caption for Table TS.3.*

Table TS.3. (cont.) *Edges of boxes and placing of text indicate the range of temperature change to which the impacts relate. Arrows between boxes indicate increasing levels of impacts between estimations. Other arrows indicate trends in impacts. All entries for water stress and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. For extinctions, 'major' means ~40 to ~70% of assessed species.*

The table also shows global temperature changes for selected time periods, relative to 1980-1999, projected for SRES and stabilisation scenarios. To express the temperature change relative to 1850-1899, add 0.5°C. More detail is provided in Chapter 2 [Box 2.8]. Estimates are for the 2020s, 2050s and 2080s, (the time periods used by the IPCC Data Distribution Centre and therefore in many impact studies) and for the 2090s. SRES-based projections are shown using two different approaches. ***Middle panel:*** *projections from the WGI AR4 SPM based on multiple sources. Best estimates are based on AOGCMs (coloured dots). Uncertainty ranges, available only for the 2090s, are based on models, observational constraints and expert judgement.* ***Lower panel:*** *best estimates and uncertainty ranges based on a simple climate model (SCM), also from WGI AR4 (Chapter 10).* ***Upper panel:*** *best estimates and uncertainty ranges for four CO_2-stabilisation scenarios using an SCM. Results are from the TAR because comparable projections for the 21st century are not available in the AR4. However, estimates of equilibrium warming are reported in the WGI AR4 for CO_2-equivalent stabilisation[18]. Note that equilibrium temperatures would not be reached until decades or centuries after greenhouse gas stabilisation.*

Table TS.3. Sources: 1, 3.4.1; **2,** 3.4.1, 3.4.3; **3,** 3.5.1; **4,** 4.4.11; **5,** 4.4.9, 4.4.11, 6.2.5, 6.4.1; **6,** 4.4.9, 4.4.11, 6.4.1; **7,** 4.2.2, 4.4.1, 4.4.4 to 4.4.6, 4.4.10; **8,** 4.4.1, 4.4.11; **9,** 5.4.2; **10,** 6.3.2, 6.4.1, 6.4.2; **11,** 6.4.1; **12,** 6.4.2; **13,** 8.4, 8.7; **14,** 8.2, 8.4, 8.7; **15,** 8.2, 8.4, 8.7; **16,** 8.6.1; **17,** 19.3.1; **18,** 19.3.1, 19.3.5; **19,** 19.3.5
Table TS.4. Sources: 1, 9.4.5; **2,** 9.4.4; **3,** 9.4.1; **4,** 10.4.1; **5,** 6.4.2; **6,** 10.4.2; **7,** 11.6; **8,** 11.4.12; **9,** 11.4.1, 11.4.12; **10,** 11.4.1, 11.4.12; **11,** 12.4.1; **12,** 12.4.7; **13,** 13.4.1; **14,** 13.2.4; **15,** 13.4.3; **16,** 14.4.4; **17,** 5.4.5, 14.4.4; **18,** 14.4.8; **19,** 14.4.5; **20,** 15.3.4, **21,** 15.4.2; **22,** 15.3.3; **23,** 16.4.7; **24,** 16.4.4; **25,** 16.4.3

[18] Best estimate and likely range of equilibrium warming for seven levels of CO_2-equivalent stabilisation from WGI AR4 are: 350 ppm, 1.0°C [0.6–1.4]; 450 ppm, 2.1°C [1.4–3.1]; 550 ppm, 2.9°C [1.9–4.4]; 650 ppm, 3.6°C [2.4–5.5]; 750 ppm, 4.3°C [2.8–6.4]; 1,000 ppm, 5.5°C [3.7–8.3] and 1,200 ppm, 6.3°C [4.2–9.4].

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems	Water resources	Human health	Industry, settlements and society
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks [5.8.1, 4.4.5]	Effects on water resources relying on snow melt; effects on some water supply [3.4.1, 3.5.1]	Reduced human mortality from decreased cold exposure [8.4.1, T8.3]	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism [7.4.2, 14.4.8, 15.7.1]
Warm spells/ heatwaves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; wildfire danger increase [5.8.1, 5.4.5, 4.4.3, 4.4.4]	Increased water demand; water quality problems, e.g., algal blooms [3.4.2, 3.5.1, 3.4.4]	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated [8.4.2, T8.3, 8.4.1]	Reduction in quality of life for people in warm areas without appropriate housing; impacts on elderly, very young and poor [7.4.2, 8.2.1]
Heavy precipitation events. Frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils [5.4.2]	Adverse effects on quality of surface and groundwater; contamination of water supply; water stress may be relieved [3.4.4]	Increased risk of deaths, injuries, infectious, respiratory and skin diseases [8.2.2, 11.4.11]	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property [T7.4, 7.4.2]
Area affected by drought increases	Likely	Land degradation, lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire [5.8.1, 5.4, 4.4.4]	More widespread water stress [3.5.1]	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases [5.4.7, 8.2.3, 8.2.5]	Water shortages for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration [T7.4, 7.4, 7.1.3]
Intense tropical cyclone activity increases	Likely	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs [5.4.5, 16.4.3]	Power outages cause disruption of public water supply [7.4.2]	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders [8.2.2, 8.4.2, 16.4.5]	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers, potential for population migrations, loss of property [7.4.1, 7.4.2, 7.1.3]
Increased incidence of extreme high sea level (excludes tsunamis)[c]	Likely[d]	Salinisation of irrigation water, estuaries and freshwater systems [3.4.2, 3.4.4, 10.4.2]	Decreased freshwater availability due to salt-water intrusion [3.4.2, 3.4.4]	Increased risk of deaths and injuries by drowning in floods; migration-related health effects [6.4.2, 8.2.2, 8.4.2]	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above [7.4.2]

[a] See WGI AR4 Table 3.7 for further details regarding definitions.
[b] Warming of the most extreme days and nights each year.
[c] Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.
[d] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period [WGI AR4 10.6]. The effect of changes in regional weather systems on sea-level extremes has not been assessed.

Table TS.5. *Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid- to late 21st century. These do not take into account any changes or developments in adaptive capacity. Examples of all entries are to be found in chapters in the full Assessment (see sources). The first two columns of this table (shaded yellow) are taken directly from the Working Group I Fourth Assessment (Table SPM.2). The likelihood estimates in column 2 relate to the phenomena listed in column 1. The direction of trend and likelihood of phenomena are for SRES projections of climate change.*

appropriate response. An indication of these impacts can be seen in Tables TS.3 and TS.4.

Many adaptations can be implemented at low cost, but comprehensive estimates of adaptation costs and benefits are currently lacking.

There are a growing number of adaptation cost and benefit-cost estimates at regional and project level for sea-level rise, agriculture, energy demand for heating and cooling, water-resource management, and infrastructure. These studies identify a number of measures that can be implemented at low cost or with high benefit-cost ratios. However, some common adaptations may have social and environmental externalities. Adaptations to heatwaves, for example, have involved increased demand for energy-intensive air-conditioning [17.2.3].

Limited estimates are also available for global adaptation costs related to sea-level rise, and energy expenditures for space heating and cooling. Estimates of global adaptation benefits for the agricultural sector are also available, although such literature does not explicitly consider the costs of adaptation. Comprehensive multi-sectoral estimates of global costs and benefits of adaptation are currently lacking [17.2.3].

Adaptive capacity is uneven across and within societies.

There are individuals and groups within all societies that have insufficient capacity to adapt to climate change. For example, women in subsistence farming communities are disproportionately burdened with the costs of recovery and coping with drought in southern Africa [17.3.2].

The capacity to adapt is dynamic and influenced by economic and natural resources, social networks, entitlements, institutions and governance, human resources, and technology [17.3.3]. For example, research in the Caribbean on hurricane preparedness shows that appropriate legislation is a necessary prior condition to implementing plans for adaptation to future climate change [17.3].

Multiple stresses related to HIV/AIDS, land degradation, trends in economic globalisation, trade barriers and violent conflict affect exposure to climate risks and the capacity to adapt. For example, farming communities in India are exposed to impacts of import competition and lower prices in addition to climate risks; and marine ecosystems over-exploited by globalised fisheries have been shown to be less resilient to climate variability and change (see Box TS.7) [17.3.3].

High adaptive capacity does not necessarily translate into actions that reduce vulnerability. For example, despite a high capacity to adapt to heat stress through relatively inexpensive adaptations, residents in urban areas in some parts of the world, including in European cities, continue to experience high levels of mortality. One example is the 2003 European heatwave-related deaths. Another example is Hurricane Katrina, which hit the Gulf of Mexico Coast and New Orleans in 2005 and caused the deaths of more than 1,000 people, together with very high economic and social costs [17.4.2].

A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to future climate change. There are barriers, limits and costs, but these are not fully understood.

The array of potential adaptive responses available to human societies is very large (see Table TS.6), ranging from purely technological (e.g., sea defences), through behavioural (e.g., altered food and recreational choices), to managerial (e.g., altered farm practices) and to policy (e.g., planning regulations). While most technologies and strategies are known and developed in some countries, the assessed literature does not indicate how effective various options are at fully reducing risks, particularly at higher levels of warming and related impacts, and for vulnerable groups.

Although many early impacts of climate change can be effectively addressed through adaptation, the options for successful adaptation diminish and the associated costs increase with increasing climate change. 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 and climate risk factors as well as institutional, political and financial constraints [7.6, 17.2, 17.4]. There are significant barriers to implementing adaptation. These include both the inability of natural systems to adapt to the rate and magnitude of climate change, as well as formidable environmental, economic, informational, social, attitudinal and behavioural constraints. There are also significant knowledge gaps for adaptation as well as impediments to flows of knowledge and information relevant for adaptation decisions [17.4.1, 17.4.2]. For developing countries, availability of resources and building adaptive capacity are particularly important [see Sections 5 and 6 in Chapters 3 to 16; also 17.2, 17.4]. Some examples and reasons are given below.

a. The large number and expansion of potentially hazardous glacial lakes due to rising temperatures in the Himalayas. These far exceed the capacity of countries in the region to manage such risks.
b. If climate change is faster than is anticipated, many developing countries simply cannot cope with more frequent/intense occurrence of extreme weather events, as this will drain resources budgeted for other purposes.
c. Climate change will occur in the life cycle of many infrastructure projects (coastal dykes, bridges, sea ports, etc.). Strengthening of these infrastructures based on new design criteria may take decades to implement. In many cases, retrofitting would not be possible.
d. Due to physical constraints, adaptation measures cannot be implemented in many estuaries and delta areas.

New planning processes are attempting to overcome these barriers at local, regional and national levels in both developing and developed countries. For example, Least Developed Countries are developing National Adaptation Plans of Action (NAPA) and some developed countries have established national adaptation policy frameworks [17.4.1].

TS.5.2 Interrelationships between adaptation and mitigation

Both adaptation and mitigation can help to reduce the risks of climate change to nature and society.
However, their effects vary over time and place. Mitigation will have global benefits but, owing to the lag times in the climate and biophysical systems, these will hardly be noticeable until around the middle of the 21st century [WGI AR4 SPM]. The benefits of adaptation are largely local to regional in scale but they can be immediate, especially if they also address vulnerabilities to current climate conditions [18.1.1, 18.5.2]. Given these differences between adaptation and mitigation, climate policy is not about making a choice between adapting to and mitigating climate change. If key vulnerabilities to climate change are to be addressed, adaptation is necessary because even the most stringent mitigation efforts cannot avoid further climate change in the next few decades. Mitigation is necessary because reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation is possible only at very high social, environmental and economic costs [18.4, 18.6].

Many impacts can be avoided, reduced or delayed by mitigation.
A small number of impact assessments have now been completed for scenarios in which future atmospheric concentrations of greenhouse gases are stabilised. Although these studies do not take full account of uncertainties in projected climate under stabilisation – for example, the

	Food, fibre and forestry	Water resources	Human health	Industry, settlement and society
Drying/ Drought	*Crops*: development of new drought-resistant varieties; intercropping; crop residue retention; weed management; irrigation and hydroponic farming; water harvesting *Livestock*: supplementary feeding; change in stocking rate; altered grazing and rotation of pasture *Social*: Improved extension services; debt relief; diversification of income	Leak reduction Water demand management through metering and pricing Soil moisture conservation e.g., through mulching Desalination of sea water Conservation of groundwater through artificial recharge Education for sustainable water use	Grain storage and provision of emergency feeding stations Provision of safe drinking water and sanitation Strengthening of public institutions and health systems Access to international food markets	Improve adaptation capacities, especially for livelihoods Incorporate climate change in development programmes Improved water supply systems and co-ordination between jurisdictions
Increased rainfall/ Flooding	*Crops*: Polders and improved drainage; development and promotion of alternative crops; adjustment of plantation and harvesting schedule; floating agricultural systems *Social*: Improved extension services	Enhanced implementation of protection measures including flood forecasting and warning, regulation through planning legislation and zoning; promotion of insurance; and relocation of vulnerable assets	Structural and non-structural measures. Early-warning systems; disaster preparedness planning; effective post-event emergency relief	Improved flood protection infrastructure "Flood-proof" buildings Change land use in high-risk areas Managed realignment and "Making Space for Water" Flood hazard mapping; flood warnings Empower community institutions
Warming/ Heatwaves	*Crops*: Development of new heat-resistant varieties; altered timing of cropping activities; pest control and surveillance of crops *Livestock*: Housing and shade provision; change to heat-tolerant breeds *Forestry*: Fire management through altered stand layout, landscape planning, dead timber salvaging, clearing undergrowth. Insect control through prescribed burning, non-chemical pest control *Social*: Diversification of income	Water demand management through metering and pricing Education for sustainable water use	International surveillance systems for disease emergence Strengthening of public institutions and health systems National and regional heat warning systems Measures to reduce urban heat island effects through creating green spaces Adjusting clothing and activity levels; increasing fluid intake	Assistance programmes for especially vulnerable groups Improve adaptive capacities Technological change
Wind speed/ Storminess	*Crops*: Development of wind-resistant crops (e.g., vanilla)	Coastal defence design and implementation to protect water supply against contamination	Early-warning systems; disaster preparedness planning; effective post-event emergency relief	Emergency preparedness, including early-warning systems More resilient infrastructure Financial risk management options for both developed and developing regions

Table TS.6. *Examples of current and potential options for adapting to climate change for vulnerable sectors. All entries have been referred to in chapters in the Fourth Assessment. Note that, with respect to ecosystems, generic rather than specific adaptation responses are required. Generic planning strategies would enhance the capacity to adapt naturally. Examples of such strategies are: enhanced wildlife corridors, including wide altitudinal gradients in protected areas. [5.5, 3.5, 6.5, 7.5, T6.5]* 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 TS.3 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 TS.3 and TS.4 provides a picture of the impacts which might be avoided for given ranges of temperature change.

A portfolio of adaptation and mitigation measures can diminish the risks associated with climate change.
Even the most stringent mitigation efforts cannot avoid further impacts of climate change in the next few decades, which makes adaptation essential, particularly in addressing near-term impacts. 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 research (on climate science, impacts, adaptation and mitigation). Such portfolios could combine policies with incentive-based approaches and actions at all levels from the individual citizen through to national governments and international organisations [18.1, 18.5].

These actions include technological, institutional and behavioural options, the introduction of economic and policy instruments to encourage the use of these options, and research and development to reduce uncertainty and to enhance the options' effectiveness and efficiency [18.4.1, 18.4.2]. Many different actors are involved in the implementation of these actions, operating on different spatial and institutional scales. Mitigation primarily involves the energy, transportation, industrial, residential, forestry and agriculture sectors, whereas the actors involved in adaptation represent a large variety of sectoral interests, including agriculture, tourism and recreation, human health, water supply, coastal management, urban planning and nature conservation [18.5, 18.6].

Box TS.7. Adaptive capacity to multiple stressors in India

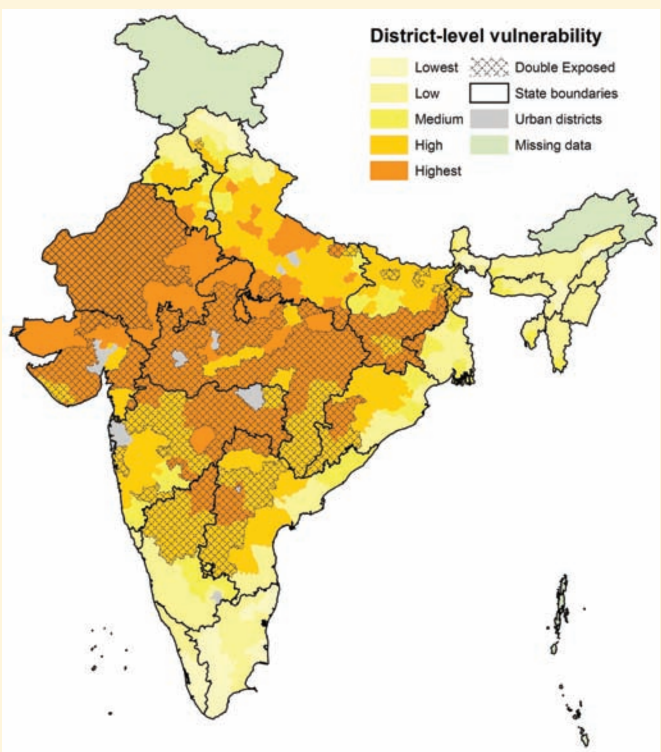

Figure TS.17. *Districts in India that rank highest in terms of (a) vulnerability to climate change and (b) import competition associated with economic globalisation, are considered to be double-exposed (depicted with hatching). [F17.2]*

The capacity to adapt to climate change is not evenly distributed across or within nations. In India, for example, both climate change and trade liberalisation are changing the context for agricultural production. Some farmers are able to adapt to these changing conditions, including discrete events such as drought and rapid changes in commodity prices, but others are not. Identifying the areas where both processes are likely to have negative outcomes provides a first step in identifying options and constraints in adapting to changing conditions [17.3.2].

Figure TS.17 shows regional vulnerability to climate change, measured as a composite of adaptive capacity and climate sensitivity under exposure to climate change. The superimposed hatching indicates those areas which are doubly exposed through high vulnerability to climate change and high vulnerability to trade liberalisation. The results of this mapping show higher degrees of resilience in districts located along the Indo-Gangetic Plains (except in the state of Bihar), the south and east, and lower resilience in the interior parts of the country, particularly in the states of Bihar, Rajasthan, Madhya Pradesh, Maharashtra, Andhra Pradesh and Karnataka [17.3.2].

One way of increasing adaptive capacity is by introducing the consideration of climate change impacts in development planning [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 risk reduction strategies [17.2, 20.8].

Decisions on adaptation and mitigation are taken at a range of different levels.
These levels include individual households and farmers, private firms and national planning agencies. Effective mitigation requires the participation of the bulk of major greenhouse gas emitters globally, whereas most adaptation takes place at local and national levels. The benefits of mitigation are global, whilst its costs and ancillary benefits arise locally. Both the costs and benefits of adaptation mostly accrue locally [18.1.1, 18.4.2]. Consequently, mitigation is primarily driven by international agreements and the ensuing national public policies, whereas most adaptation is driven by private actions of affected entities and public arrangements of impacted communities [18.1.1, 18.6.1].

Interrelationships between adaptation and mitigation can exist at each level of decision-making.
Adaptation actions can have (often unintended) positive or negative mitigation effects, whilst mitigation actions can have (also often unintended) positive or negative adaptation effects [18.4.2, 18.5.2]. An example of an adaptation action with a negative mitigation effect is the use of air-conditioning (if the required energy is provided by fossil fuels). An example of a mitigation action with a positive adaptation effect could be the afforestation of degraded hill slopes, which would not only sequester carbon but also control soil erosion. Other examples of such synergies between adaptation and mitigation include rural electrification based on renewable energy sources, planting trees in cities to reduce the heat-island effect, and the development of agroforestry systems [18.5.2].

Analysis of the interrelationships between adaptation and mitigation may reveal ways to promote the effective implementation of adaptation and mitigation actions.
Creating synergies between adaptation and mitigation can increase the cost-effectiveness of actions and make them more attractive to potential funders and other decision-makers (see Table TS.7). However, synergies provide no guarantee that resources are used in the most efficient manner when seeking to reduce the risks of climate change. Moreover, essential actions without synergetic effects may be overlooked if the creation of synergies becomes a dominant decision criterion [18.6.1]. Opportunities for synergies exist in some sectors (e.g., agriculture, forestry, buildings and urban infrastructure) but they are rather limited in many other climate-relevant sectors [18.5.2]. A lack of both conceptual and empirical information that explicitly considers both adaptation and mitigation makes it difficult to assess the need for, and potential of synergies in, climate policy [18.7].

Decisions on trade-offs between the immediate localised benefits of adaptation and the longer-term global benefits of mitigation would require information on the actions' costs and benefits over time.
For example, a relevant question would be whether or not investment in adaptation would buy time for mitigation. Global integrated assessment models provide approximate estimates of relative costs and benefits at highly aggregated levels. Intricacies of the interrelationships between adaptation and mitigation become apparent at the more detailed analytical and implementation levels [18.4.2]. These intricacies, including the fact that adaptation and mitigation operate on different spatial, temporal and institutional scales and involve different actors who have different interests and different beliefs, value systems and property rights, present a challenge to the practical implementation of trade-offs beyond the local scale. In particular the notion of an "optimal mix" of adaptation and mitigation is problematic, since it usually assumes that there is a zero-sum budget for adaptation and mitigation and that it would be possible to capture the individual interests of all who will be affected by climate change, now and in the future, into a global aggregate measure of well-being [18.4.2, 18.6.1].

Scale	Adaptation Mitigation	Mitigation Adaptation	Parallel decisions affecting adaptation and mitigation	Adaptation and mitigation trade-offs and synergies
Global/policy	Awareness of limits to adaptation motivates mitigation e.g., policy lobbying by ENGOs	CDM trades provide funds for adaptation through surcharges	Allocation of MEA funds or Special Climate Change Fund	Assessment of costs and benefits in adaptation and mitigation in setting targets for stabilisation
Regional/natural strategy/sectoral planning	Watershed planning (e.g., hydroelectricity) and land cover, affect greenhouse gas emissions	Fossil fuel tax increases the cost of adaptation through higher energy prices	National capacity, e.g., self-assessment, supports adaptation and mitigation in policy integration	Testing project sensitivity to mitigation policy, social cost of carbon and climate impacts
Local/biophysical community and individual actions	Increased use of air-conditioning (homes, offices, transport) raises greenhouse gas emissions	Community carbon sequestration affects livelihoods	Local planning authorities implement criteria related to both adaptation and mitigation in land-use planning	Corporate integrated assessment of exposure to mitigation policy and climate impacts

Table TS.7. *Relationships between adaptation and mitigation [F18.3]. ENGO = Environmental Non-Governmental Organisation; CDM = Clean Development Mechanism; MEA = Millennium Ecosystem Assessment.*

People's capacities to adapt and mitigate are driven by similar sets of factors.

These factors represent a generalised response capacity that can be mobilised in the service of either adaptation or mitigation. Response capacity, in turn, is dependent on the societal development pathway. Enhancing society's response capacity through the pursuit of sustainable development pathways is therefore one way of promoting both adaptation and mitigation [18.3]. This would facilitate the effective implementation of both options, as well as their mainstreaming into sectoral planning and development. If climate policy and sustainable development are to be pursued in an integrated way, then it will be important not simply to evaluate specific policy options that might accomplish both goals, but also to explore the determinants of response capacity that underlie those options as they relate to underlying socio-economic and technological development paths [18.3, 18.6.3].

TS.5.3 Key vulnerabilities

Key vulnerabilities are found in many social, economic, biological and geophysical systems.

Vulnerability to climate change is the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change. The term "vulnerability" may therefore refer to the vulnerable system itself (e.g., low-lying islands or coastal cities), the impact to this system (e.g., flooding of coastal cities and agricultural lands or forced migration), or the mechanism causing these impacts (e.g., disintegration of the West Antarctic ice sheet). Based on a number of criteria in the literature (i.e., magnitude, timing, persistence/reversibility, potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts [19.2]), some of these vulnerabilities might be identified as 'key'. Key impacts and resultant key vulnerabilities are found in many social, economic, biological and geophysical systems [19.1.1].

The identification of potential key vulnerabilities is intended to provide guidance to decision-makers for identifying levels and rates of climate change that may be associated with 'dangerous anthropogenic interference' (DAI) with the climate system, in the terminology of the UNFCCC (United Nations Framework Convention on Climate Change) Article 2 [B19.1]. Ultimately, the determination of DAI cannot be based on scientific arguments alone, but involves other judgements informed by the state of scientific knowledge [19.1.1]. Table TS.8 presents an illustrative and selected list of key vulnerabilities.

Key vulnerabilities may be linked to systemic thresholds where non-linear processes cause a system to shift from one major state to another (such as a hypothetical sudden change in the Asian monsoon or disintegration of the West Antarctic ice sheet or positive feedbacks from ecosystems switching from a sink to a source of CO_2). Other key vulnerabilities can be associated with "normative thresholds" defined by stakeholders or decision-makers (e.g., a magnitude of sea-level rise no longer considered acceptable by low-lying coastal dwellers) [19.1.2].

Increasing levels of climate change will result in impacts associated with an increasing number of key vulnerabilities, and some key vulnerabilities have been associated with observed climate change.

Observed climate change to 2006 has been associated with some impacts that can be linked to key vulnerabilities. Among these are increases in human mortality during extreme weather events, and increasing problems associated with permafrost melting, glacier retreat and sea-level rise [19.3.2, 19.3.3, 19.3.4, 19.3.5, 19.3.6].

Global mean temperature changes of up to 2°C above 1990-2000 levels would exacerbate current key vulnerabilities, such as those listed above (high confidence), and cause others, such as reduced food security in many low-latitude nations (medium confidence). At the same time, some systems such as global agricultural productivity at mid- and high-latitudes, could benefit (medium confidence) [19.3.1, 19.3.2, 19.3.3].

Global mean temperature changes of 2 to 4°C above 1990-2000 levels would result in an increasing number of key impacts at all scales (high confidence), such as widespread loss of biodiversity, decreasing global agricultural productivity and commitment to widespread deglaciation of Greenland (high confidence) and West Antarctic (medium confidence) ice sheets [19.3.1, 19.3.4, 19.3.5].

Global mean temperature changes greater than 4°C above 1990-2000 levels would lead to major increases in vulnerability (very high confidence), exceeding the adaptive capacity of many systems (very high confidence) [19.3.1].

Regions already at high risk from observed climate variability and climate change are more likely to be adversely affected in the near future, due to projected changes in climate and increases in the magnitude and/or frequency of already damaging extreme events [19.3.6, 19.4.1].

The "reasons for concern" identified in the Third Assessment remain a viable framework to consider key vulnerabilities. Recent research has updated some of the findings from the Third Assessment.

Unique and threatened systems

There is new and much stronger evidence of the adverse impacts of observed climate change to date on several unique and threatened systems. Confidence has increased that a 1 to 2°C increase in global mean temperature above 1990 levels poses significant risks to many unique and threatened systems, including many biodiversity hotspots [19.3.7].

Extreme events

There is new evidence that observed climate change has likely already increased the risk of certain extreme events such as heatwaves, and it is more likely than not that warming has contributed to intensification of some tropical cyclones, with increasing levels of adverse impacts as temperatures increase [19.3.7].

Key systems or groups at risk	Prime criteria for 'key vulnerability'	Global average temperature change above 1990 0°C 1°C 2°C 3°C 4°C 5°C
Global social systems		
Food supply	Distribution, magnitude	Productivity decreases for some cereals in low latitudes ** Productivity increases for some cereals in mid/high latitudes ** Cereal productivity decreases in some mid/high latitude regions ** Global production potential increases to around 3°C, decreases above this * **a**
Aggregate market impacts and distribution	Magnitude, distribution	Net benefits in many high latitudes; net costs in many low latitudes * **b** Benefits decrease, while costs increase. Net global cost * **b**
Regional system		
Small islands	Irreversibility, magnitude, distribution, low adaptive capacity	Increasing coastal inundation and damage to infrastructure due to sea-level rise **
Indigenous, poor or isolated communities	Irreversibility, distribution, timing, low adaptive capacity	Some communities already affected ** **c** Climate change and sea-level rise adds to other stresses **. Communities in low-lying coastal and arid areas are especially threatened ** **d**
Global biological systems		
Terrestrial ecosystems and biodiversity	Irreversibility, magnitude, low adaptive capacity, persistence, rate of change, confidence	Many ecosystems already affected *** *c*. 20-30% species at increasingly high risk of extinction * Major extinctions around the globe ** Terrestrial biosphere tends toward a net carbon source **
Marine ecosystems and biodiversity	Irreversibility, magnitude, low adaptive capacity, persistence, rate of change, confidence	Increased coral bleaching ** Most corals bleached ** Widespread coral mortality **
Geophysical systems		
Greenland ice sheet	Magnitude, irreversibility, low adaptive capacity, confidence	Localised deglaciation (already observed due to local warming), extent would increase with temperature *** **e** Commitment to widespread ** or near-total * deglaciation, 2-7 m sea-level rise[19] over centuries to millennia * **e** Near-total deglaciation ** **e**
Meridional Overturning Circulation	Magnitude, persistence, distribution, timing, adaptive capacity, confidence	Variations including regional weakening (already observed but no trend identified) **f** Considerable weakening **. Commitment to large-scale and persistent change including possible cooling in northern high-latitude areas near Greenland and north-west Europe •, highly dependent on rate of climate change.
Risks from extreme events		
Tropical cyclone intensity	Magnitude, timing, distribution	Increase in Cat. 4-5 storms */**, with impacts exacerbated by sea-level rise Further increase in tropical cyclone intensity */**
Drought	Magnitude, timing	Drought already increasing * **g** Increasing frequency / intensity drought in mid-latitude continental areas ** **h** Extreme drought increasing from 1% land area to 30% (A2 scenario) * **i** Mid-latitude regions affected by poleward migration of Annular Modes seriously affected ** **j**

Table TS.8. *Table of selected key vulnerabilities. The key vulnerabilities range from those associated with societal systems, for which the adaptation potential is the greatest, to those associated with biophysical systems, which are likely to have the least adaptive capacity. Adaptation potential for key vulnerabilities resulting from extreme events is associated with the affected systems, most of which are socio-economic. Information is presented where available on how impacts may change at larger increases in global mean temperature (GMT). All increases in GMT are relative to circa 1990. Most impacts are the result of changes in climate, weather and/or sea level, not of temperature alone. In many cases climate change impacts are marginal or synergistic on top of other existing and possibly increasing stresses. Criteria for key vulnerabilities are given in Section TS 5.3. For full details refer to the corresponding text in Chapter 19. Confidence symbol legend: *** very high confidence, ** high confidence, * medium confidence, • low confidence.*
Sources for left hand column are T19.1. Sources for right hand column are T19.1, and are also found in Tables TS.3 and TS.4, with the exception of: ***a****: 5.4.2, 5.6;* ***b****: 20.6, 20.7;* ***c****: 1.3, 11.4.8, 14.2.3, 15.4.5;* ***d****: 3.4, 6.4, 11.4;* ***e****: 19.3.5, T19.1;* ***f****: 19.3.5, 12.6;* ***g****: 1.3.2, 1.3.3, T19.1;* ***h****: WGI 10.3.6.1;* ***i****: WGI AR4 10.3.6.1;* ***j****: WGI AR4 10.3.5.6.*

[19] Range combines results from modelling and analysis of palaeo data.

Distribution of impacts

There is still high confidence that the distribution of climate impacts will be uneven, and that low-latitude, less-developed areas are generally at greatest risk. However, recent work has shown that vulnerability to climate change is also highly variable within individual countries. As a consequence, some population groups in developed countries are also highly vulnerable [19.3.7].

Aggregate impacts

There is some evidence that initial net market benefits from climate change will peak at a lower magnitude and sooner than was assumed in the Third Assessment, and that it is likely there will be higher damages for larger magnitudes of global mean temperature increases than estimated in the Third Assessment. Climate change could adversely affect hundreds of millions of people through increased risk of coastal flooding, reduction in water supplies, increased risk of malnutrition, and increased risk of exposure to climate-dependent diseases [19.3.7].

Large-scale singularities

Since the Third Assessment, the literature offers more specific guidance on possible thresholds for partial or near-complete deglaciation of Greenland and West Antarctic ice sheets. There is medium confidence that at least partial deglaciation of the Greenland ice sheet, and possibly the West Antarctic ice sheet, would occur over a period of time ranging from centuries to millennia for a global average temperature increase of 1-4ºC (relative to 1990-2000), causing a contribution to sea-level rise of 4-6 m or more [WGI AR4 6.4, 10.7.4.3, 10.7.4.4; 19.3.5.2].

TS.5.4 Perspectives on climate change and sustainability

Future vulnerability depends not only on climate change but also on development pathway.

An important advance since the Third Assessment has been the completion of impacts studies for a range of different development pathways, taking into account not only projected climate change but also projected social and economic changes. Most have been based on characterisations of population and income levels drawn from the SRES scenarios [2.4].

These studies show that the projected impacts of climate change can vary greatly due to the development pathway assumed. For example, there may 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 TS.18 shows estimates from a recent study of the number of people projected to be at risk of coastal flooding each year under different assumptions of socio-economic development. This indicates that the projected number of people affected is considerably greater under the A2-type scenario of development (characterised by relatively low per capita income and large population growth) than under other SRES futures [T20.6]. This difference is largely explained, not by differences in changes of climate, but by differences in vulnerability [T6.6].

Vulnerability to climate change can be exacerbated by the presence of other stresses.

Non-climate 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 and ocean acidification. Vulnerable regions face multiple stresses that affect their exposure and sensitivity as well as their capacity to adapt. These stresses arise from, for example, current climate hazards, poverty and unequal access to resources, food insecurity, trends in economic globalisation, conflict, and incidence of disease such as HIV/AIDS [7.4, 8.3, 17.3, 20.3].

Climate change itself can produce its own set of multiple stresses in some locations because the physical manifestations of the impacts of climate change are so diverse [9.4.8]. For example, more variable rainfall implies more frequent droughts and more frequent episodes of intense rainfall, whilst sea-level rise may bring coastal flooding to areas already experiencing more frequent wind storm. In such cases, total vulnerability to climate change is greater than the sum of the vulnerabilities to specific impacts considered one at a time in isolation (very high confidence) [20.7.2].

Climate change will very likely impede nations' abilities to achieve sustainable development pathways, as measured, for example, as long-term progress towards the Millennium Development Goals.

Following the lead of the TAR, this Report has adopted the Bruntland Commission definition of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Over the next half-century, it is very likely that climate

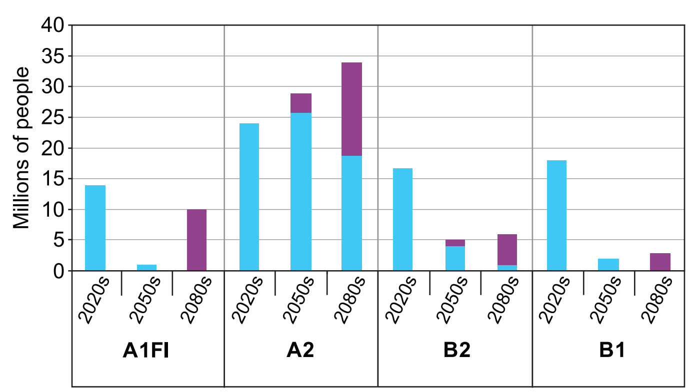

Figure TS.18. *Results from a recent study showing estimated millions of people per annum at risk globally in the 2080s from coastal flooding. Blue bars: numbers at risk without sea-level rise; purple bars: numbers at risk with sea-level rise. [T6.6]* change will make sustainable development more difficult, particularly as measured by their progress toward achieving Millennium Development Goals for the middle of the century. Climate change will erode nations' capacities to achieve the Goals, calibrated in terms of reducing poverty and otherwise improving equity by 2050, particularly in Africa and parts of Asia (very high confidence) [20.7.1].

Even though there are cases where climate-related extreme events have severely interfered with economic development, it is very unlikely that climate change attributed to anthropogenic sources, per se, will be a significant extra impediment to most nations' reaching their 2015 Millennium Development targets. Many other obstacles with more immediate impacts stand in the way [20.7.1].

Sustainable development can reduce vulnerability to climate change by encouraging adaptation, enhancing adaptive capacity and increasing resilience (very high confidence) [20.3.3]. 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 [see Section 7 in Chapters 3 to 8, 20.3, 20.7]. At present, few plans for promoting sustainability have explicitly included either adapting to climate-change impacts, or promoting adaptive capacity [20.3].

Sustainable development can reduce vulnerability to climate change.

Efforts to cope with the impacts of climate change and attempts to promote sustainable development share common goals and determinants including: access to resources (including information and technology), equity in the distribution of resources, stocks of human and social capital, access to risk-sharing mechanisms and abilities of decision-support mechanisms to cope with uncertainty. Nonetheless, some development activities exacerbate climate-related vulnerabilities (very high confidence).

It is very likely that significant synergies can be exploited in bringing climate change to the development community, and critical development issues to the climate-change community [20.3.3, 20.8.2 and 20.8.3]. Effective communication in assessment, appraisal and action are likely to be important tools both in participatory assessment and governance as well as in identifying productive areas for shared learning initiatives [20.3.3, 20.8.2, 20.8.3]. Despite these synergies, few discussions about promoting sustainability have thus far explicitly included adapting to climate impacts, reducing hazard risks and/or promoting adaptive capacity [20.4, 20.5, 20.8.3]. Discussions about promoting development and improving environmental quality have seldom explicitly included adapting to climate impacts and/or promoting adaptive capacity [20.8.3]. Most of the scholars and practitioners of development who recognise that climate change is a significant issue at local, national, regional and/or global levels focus their attention almost exclusively on mitigation [20.4, 20.8.3].

Synergies between adaptation and mitigation measures will be effective through the middle of this century, but even a combination of aggressive mitigation and significant investment in adaptive capacity could be overwhelmed by the end of the century along a likely development scenario.

Tables TS.3 and TS.4 track major worldwide impacts for major sectors against temperature increases measured from the 1980 to 1999 period. With very high confidence, no temperature threshold associated with any subjective judgment of what might constitute "dangerous" climate change can be guaranteed to be avoided by anything but the most stringent of mitigation interventions.

As illustrated in Figure TS.19, it is likely that global mitigation efforts designed to cap effective greenhouse gas concentrations at, for example, 550 ppm would benefit developing countries significantly through the middle of this century, regardless of whether the climate sensitivity turns out to be high or low, and especially when combined with enhanced adaptation. Developed countries would also likely see significant benefits from an adaptation-mitigation intervention portfolio, especially for high climate sensitivities and in sectors and regions that are already showing signs of being vulnerable. By 2100, climate change will likely produce significant vulnerabilities across the globe even if aggressive mitigation were implemented in combination with significantly enhanced adaptive capacity [20.7.3].

TS.6 Advances in knowledge and future research needs

TS 6.1 Advances in knowledge

Since the IPCC Third Assessment, the principal advances in knowledge have been as follows.

- Much improved coverage of the impacts of climate change on developing regions, through studies such as the AIACC project (Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors), although further research is still required, especially in Latin America and Africa [9.ES, 10.ES, 13.ES].
- More studies of adaptation to climate change, with improved understanding of current practice, adaptive capacity, the options, barriers and limits to adaptation [17.ES].
- Much more monitoring of observed effects, and recognition that climate change is having a discernible impact on many natural systems [1.ES, F1.1].
- Some standardisation of the scenarios of future climate change underpinning impact studies, facilitated by centralised data provision through organisations such as the IPCC Data Distribution Centre, thus allowing comparison between sectors and regions [2.2.2].
- Improved understanding of the damages for different levels of global warming, and the link between global warming

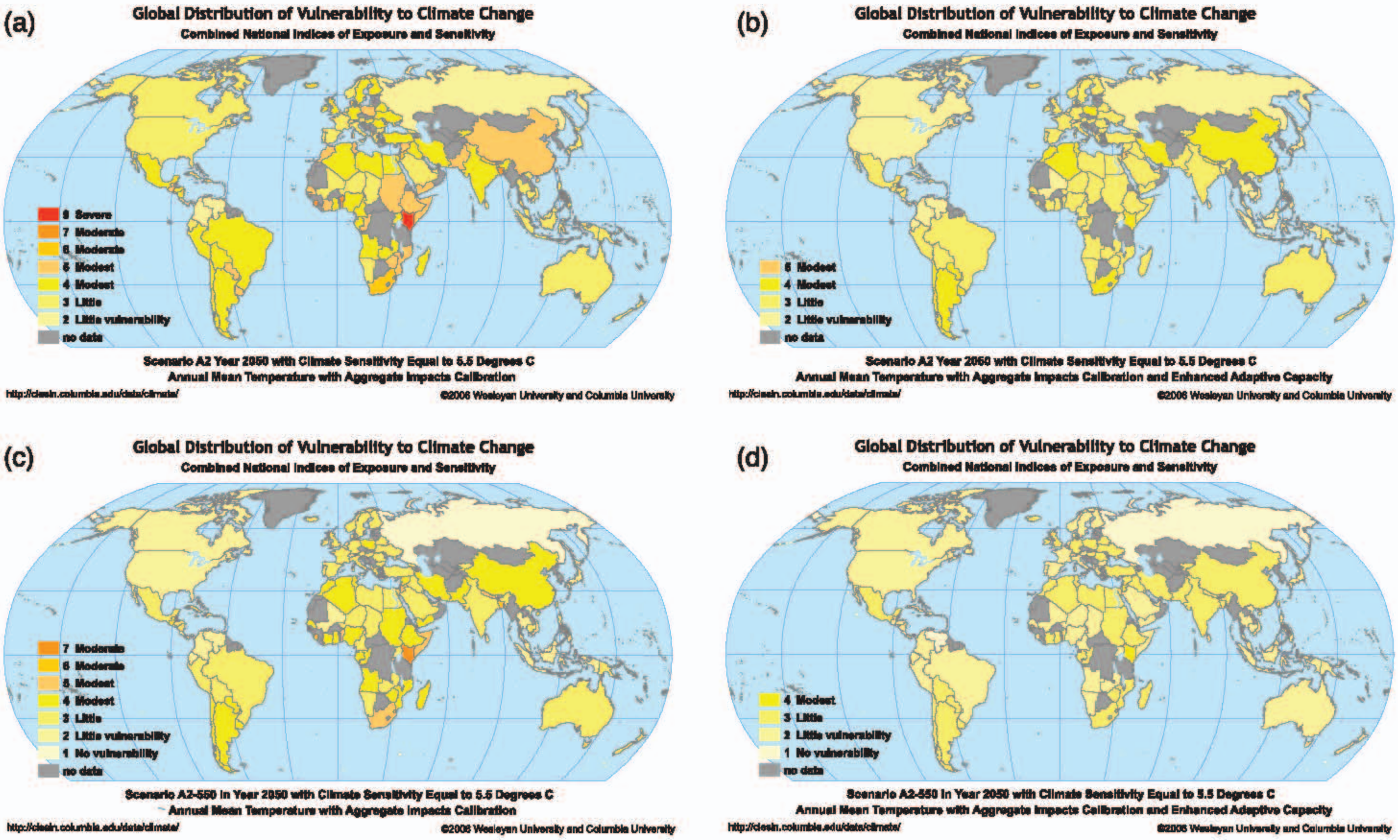

Figure TS.19. *Geographical distribution of vulnerability in 2050 with and without mitigation along an SRES A2 emissions scenario with a climate sensitivity of 5.5°C. Panel (a) portrays vulnerability with a static representation of current adaptive capacity. Panel (b) shows vulnerability with enhanced adaptive capacity worldwide. Panel (c) displays the geographical implications of mitigation designed to cap effective atmospheric concentrations of greenhouse gases at 550 ppm. Panel (d) offers a portrait of the combined complementary effects of mitigation to the same 550 ppmv concentration limit and enhanced adaptive capacity. [F20.6]*

and the probability of stabilising CO_2 at various levels. As a result, we know more about the link between damages and CO_2-stabilisation scenarios [20.7.2, T20.8, T20.9].

However, there has been little advance on:

- impacts under different assumptions about how the world will evolve in future – societies, governance, technology and economic development;
- the costs of climate change, both of the impacts and of response (adaptation and mitigation);
- proximity to thresholds and tipping points;
- impacts resulting from interactions between climate change and other human-induced environmental changes.

TS 6.2 Future research needs

Impacts under different assumptions about future development pathways

Most AR4 studies of future climate change are based on a small number of studies using SRES scenarios, especially the A2 and B2 families [2.3.1]. This has allowed some limited, but incomplete, characterisation of the potential range of futures and their impacts [see Section 4 on key future impacts in all core chapters].

Scenarios are required:

- to describe the future evolution of the world under different and wide-ranging assumptions about how societies, governance, technology, economies will develop in future;
- at the regional and local scales appropriate for impacts analysis;
- which allow adaptation to be incorporated into climate-change impact estimates;
- for abrupt climate change such as the collapse of the North Atlantic Meridional Overturning Circulation, and large sea-level rises due to ice sheet melting [6.8];
- for beyond 2100 (especially for sea-level rise) [6.8, 11.8.1].

Increasingly, climate modellers run model ensembles which allow characterisation of the uncertainty range for each development pathway. Thus, the impacts analyst is faced with very large quantities of data to capture even a small part of the potential range of futures. Tools and techniques to manage these large quantities of data are urgently required [2.3, 2.4].

Damages avoided by different levels of emissions reduction

Very few studies have been carried out to explore the damages avoided, or the impacts postponed, by reducing or stabilising emissions, despite the critical importance of this issue for policy-makers. The few studies which have been performed are reviewed in Chapter 20 of this Report [20.6.2] and show clearly the large reductions in damages which can be achieved by mitigating emissions [T20.4]. Existing research has emphasised the global scale, and studies which are disaggregated to the regional, and even local, scale are urgently required.

Climate-science-related research needs

Two of the most important requirements identified relate to research in climate change science, but have been clearly identified as a hindrance to research in impacts, adaptation and vulnerability.

- The first is that our understanding of the likely future impacts of climate change is hampered by lack of knowledge regarding the nature of future changes, particularly at the regional scale and particularly with respect to precipitation changes and their hydrological consequences on water resources, and changes in extreme events, due in part to the inadequacies of existing climate models at the required spatial scales [T2.5, 3.3.1, 3.4.1, 4.3].
- The second relates to abrupt climate change. Policy-makers require understanding of the impacts of such events as the collapse of the North Atlantic Meridional Overturning Circulation. However, without a better understanding of the likely manifestation of such events at the regional scale, it is not possible to carry out impacts assessments [6.8, 7.6, 8.8, 10.8.3].

Observations, monitoring and attribution

Large-area, long-term field studies are required to evaluate observed impacts of climate change on managed and unmanaged systems and human activities. This will enable improved understanding of where and when impacts become detectable, where the hotspots lie, and why some areas are more vulnerable than others. High-quality observations are essential for full understanding of causes, and for unequivocal attribution of present-day trends to climate change [1.4.3, 4.8].

Timely monitoring of the pace of approaching significant thresholds (such as abrupt climate change thresholds) is required [6.8, 10.8.4].

Multiple stresses, thresholds and vulnerable people and places

It has become clear in the AR4 that the impacts of climate change are most damaging when they occur in the context of multiple stresses arising from the effects, for example, of globalisation, poverty, poor governance and settlement of low-lying coasts. Considerable progress has been made towards understanding which people and which locations may expect to be disproportionately impacted by the negative aspects of climate change. It is important to understand what characteristics enhance vulnerability, what characteristics strengthen the adaptive capacity of some people and places, and what characteristics predispose physical, biological and human systems to irreversible changes as a result of exposure to climate and other stresses [7.1, B7.4, 9.1, 9.ES]. How can systems be managed to minimise the risk of irreversible changes? How close are we to tipping points/thresholds for natural ecosystems such as the Amazon rain forest? What positive feedbacks would emerge if such a tipping point is reached?

Climate change, adaptation and sustainable development

The AR4 recognised that synergies exist between adaptive capacity and sustainable development, and that societies which are pursuing a path of sustainable development are likely to be more resilient to the impacts of climate change. Further research is required to determine the factors which contribute to this synergy, and how policies to enhance adaptive capacity can reinforce sustainable development and vice versa [20.9].

Further understanding of adaptation is likely to require learning-by-doing approaches, where the knowledge base is enhanced through accumulation of practical experience.

The costs of climate change, both the costs of the impacts and of response (adaptation and mitigation)

- Only a small amount of literature on the costs of climate change impacts could be found for assessment [5.6, 6.5.3, 7.5]. Debate still surrounds the topic of how to measure impacts, and which metrics should be used to ensure comparability [2.2.3, 19.3.2.3, 20.9].
- The literature on adaptation costs and benefits is limited and fragmented [17.2.3]. It focuses on sea-level rise and agriculture, with more limited assessments for energy demand, water resources and transport. There is an emphasis on the USA and other OECD countries, with only a few studies for developing countries [17.2.3].

Better understanding of the relative costs of climate change impacts and adaptation allows policy-makers to consider optimal strategies for implementation of adaptation policies, especially the amount and the timing [17.2.3.1].