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BACKGROUND NOTE

THE RISKS OF CLIMATE CHANGE: A SYNTHESIS OF NEW SCIENTIFIC KNOWLEDGE SINCE THE FINALIZATION OF THE IPCC FOUTH ASSESMENT REPORT (AR4)

by

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The risks of climate change: A synthesis of new scientific knowledge since the finalization of the IPCC Fourth Assessment Report (AR4)

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Background note to the World Development Report 2010

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1 Science of climate change

Scientific understanding of past and future climate change has made substantial progress since finalization of the IPCC WG1 AR4. New knowledge includes improved analysis of prehistoric climate shifts, updated observations of recent climate change, better attribution of the causes of observed climate change to anthropogenic and natural factors, improved understanding of carbon cycle feedbacks, and new projections of future changes in extreme weather events. As a result, many risks are now assessed to be larger than in the AR4, in particular the risk of large sea-level rise already in the current century and the risks from increases in extreme weather events.

1.1 Observed climate change

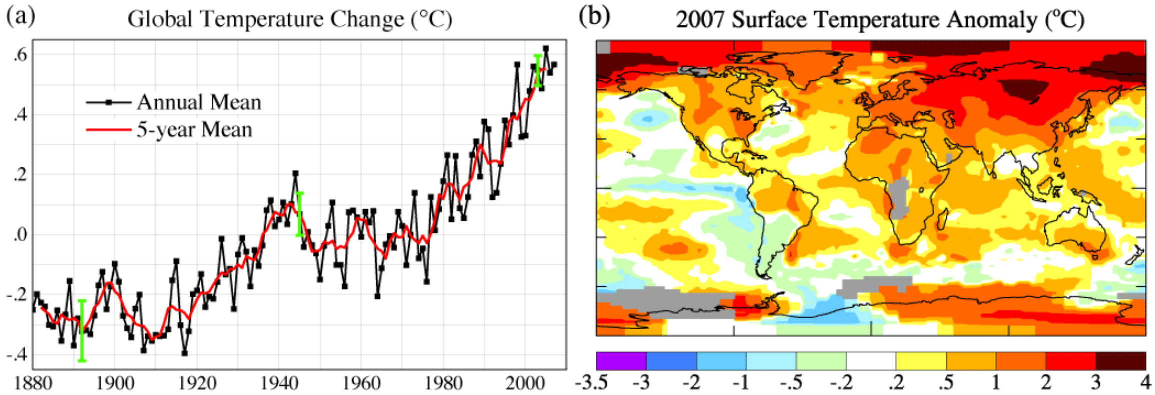

Figure: Observed change in global mean temperature (left) and 2007 surface temperature anomaly. Source: NASA GISS, 2008

The IPCC AR4 published in 2007 stated that 11 out of the 12 warmest years on record (i.e., since 1850) had occurred during the last 12 years. According to the NASA Goddard Institute for Space Studies (GISS), 2007 was another exceptionally warm year that tied with 1998 for Earth's second warmest year on record. The eight warmest years have all occurred since 1998. [GISS, 2008]

Comparison of the most recent observed climate trends for carbon dioxide concentration, global-mean surface temperature and sea level with the projections in the IPCC Third Assessment Report (TAR) shows that previous projections have not exaggerated, but in some respects underestimated, the change in global climate. The observed increase in global mean surface temperature since 1990 is 0.33 °C; this is in the upper part of the range set by the IPCC. Sea level data from tide gauges and satellite data show a linear trend of 3.3 mm/yr, which is faster than the best-estimate projections in the TAR of 2 mm/yr. [Rahmstorf et al., 2007]

A new analysis of satellite observations suggests that precipitation and total atmospheric water have increased at about the same rate over the past two decades, while climate models suggest that precipitation would increase much more slowly. If this observed trend continues, climate change will result in substantially more rain than currently predicted by climate models. [Wentz et al., 2007]

Sea surface temperatures in the North Sea and the Baltic Sea show an unprecedented warming trend since the mid-1980s in all seasons. Temperatures in summer since 1985 have increased at nearly triple the global warming rate and summer temperatures have risen two to five times faster than those in other seasons. Therefore, globally averaged warming is likely to underestimate the magnitude of climate change in the North and Baltic Sea and the resulting impacts. [Mackenzie & Schiedek, 2007]

A team of British and US scientists was able solve one of the remaining gaps in understanding 20^{th} century climate change. These scientists reanalyzed the weak cooling trend observed in global surface temperatures between 1940 and 1970. They explain an abrupt temperature drop of 0.3 degrees C in summer 1945 as the apparent result of uncorrected instrumental biases in the sea surface temperature record. Therefore, the largest climate shift in the 20^{th} century that climate models were unable to explain is actually a mirage. The results do not alter estimates of the century-long trend in global- mean temperatures. [Thompson et al., 2008]

A new analysis of radiosonde data for the first time shows a warming trend in the upper troposphere, which agrees well with predictions from global climate models. The consistency between model simulations and inferred data increases confidence in model-based climate projections. [Allen & Sherwood, 2008]

1.2 Detection and attribution of recent climate change

Improved data and analyses techniques have improved understanding of observed climate change. These findings add to the already extensive evidence of the anthropogenic signal on all aspects of current climate.

Scientists from the UK Met Office found that anthropogenic greenhouse gas emissions have led to a rapidly increasing risk of extremely hot summers in the Northern hemisphere, such as those experienced in large parts of Europe in 2003 and 2006 . Hot summers which were infrequent 20-40 years ago are now much more common and the current sharp rise in incidence of hot summers is likely to continue. [Jones et al., 2008] Another study was able to detect and separate the effect of greenhouse gases from that of sulfate aerosols on the observed warming trend since 1950 in nine world regions. [Zhang et al., 2006]

The human influence on climate has for the first time been detected in precipitation at global and regional scales. A recent study finds that anthropogenic forcing contributed significantly to observed increases in precipitation in the Northern Hemisphere mid-latitudes, drying in the Northern Hemisphere subtropics and tropics, and moistening in the Southern Hemisphere subtropics and deep tropics. These changes cannot be explained by internal climate variability or natural forcing. [Zhang et al., 2007] New analyses combining climate model simulations with satellite data and surface measurements have also shown that the atmospheric moisture content over land and over oceans has increased substantially in recent decades, and that the increase is primarily due to anthropogenic greenhouse gas emissions. [Santer et al., 2007, Willett et al., 2007]

1.3 Changes in ice sheets, glaciers and sea level

Many new studies have investigated prehistorical and recent changes in glaciers, large ice sheets and sea level in order to improve projections of future sea-level rise. UNEP and the World Glacier Monitoring Service have compiled a database on glacier fluctuations from 1803 glaciers as far back as the 19th century. They find that 2006 established a new record annual mass loss of the reference glaciers under long-term observation. The average annual melting rate of mountain glaciers has doubled after 2000, in comparison with the already accelerated melting rates observed in the two decades before. [UNEP/WGMS, 2008]

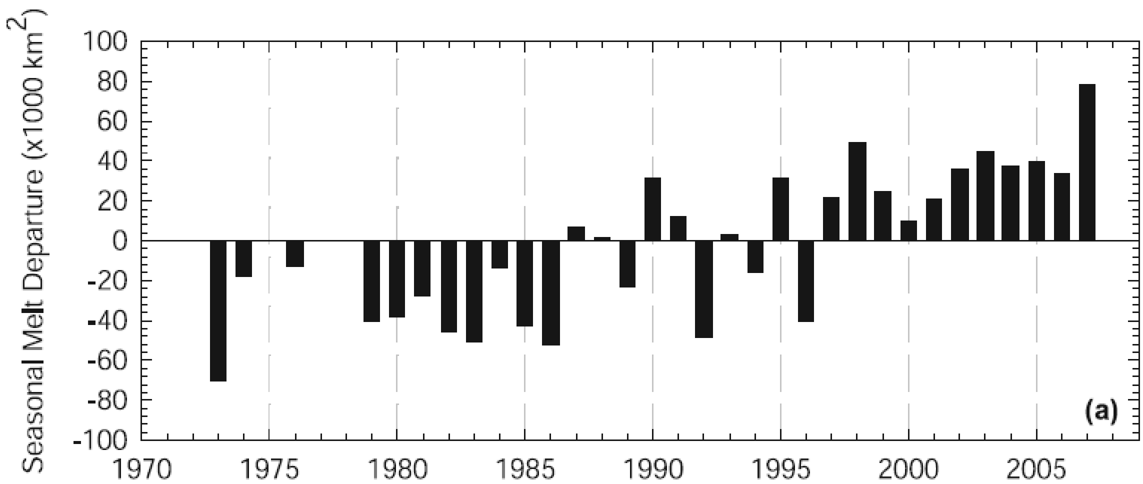

*Figure: Change in melting area of the Greenland ice sheet. Source: [*Mote, 2007*]*

Melting of the Greenland ice sheet in summer 2007 established a new record, which was 60% above the previous high in 1998. The most recent 11 summers have all experienced melting greater than the average of the available time series (1973 to 2007). [Mote, 2007]

The current and future contribution to sea level rise from Antarctica has been subject to large uncertainties. A recent study used extensive satellite observations to estimate the total Antarctic ice flux into the ocean from 1992 to 2006. The Antarctic ice sheet as a whole was found to be losing mass, mostly in West Antarctica, and the mass loss increased by 75% in 10 years. [Rignot et al., 2008] Other studies have also found that changes in the Greenland and the West Antarctic ice sheets are accelerating. [Shepherd & Wingham, 2007, Velicogna & Wahr, 2006]

A team of US and Canadian scientists found that between 9000 and 8500 years ago, melting of the Laurentide ice sheet on Greenland contributed around 6.6 m of sea level rise at about 1.3 m per century. Other scientists have found that the average rate of sea-level rise during the last interglacial period, around 120,000 years ago, was about 1.6 m per century. The two groups suggest that climatic conditions (in terms of the increase in summer surface air temperatures and global mean temperature, respectively) in these periods were comparable to those projected for the 21st century under business-as-usual emission scenarios. [Carlson et al., 2008, Rohling et al., 2008]

A team of US scientists has combined climate modelling and paleoclimatic data to assess the potential for large increases in sea level by the end of the 21st century. Their maximum and best estimates of total sea-level rise by 2100 are 2 m and 0.8 m, respectively. [Pfeffer et al., 2008] Independently, a scientist from PIK has developed a semi-empirical model of sea-level rise, which simulates sea-level rise for the period 1880-2001 much better than current GCMs. This model calculates a best estimate of sea-level rise of 55 to 125 cm by 2100 for the TAR climate scenarios and of 54 to 89 cm for the AR4 climate scenarios (which exclude the highest emission scenario, SRES A1FI). [Rahmstorf, 2007, Horton et al., 2008] All these figures are substantially higher than the model-based estimates in the IPCC AR4, which did not include ice-sheet dynamics. Thus, the risk of large sea-level rise in the 21st century is now estimated to be much greater than in the AR4.

1.4 Changes in sea ice

According to data from the United States National Snow and Ice Data Center, Arctic sea ice area reached a new all-time minimum on 14 September 2007 at 3.6 Mio km^2, which is 27%

lower than the previous record low reached in 2005. The decline in ice cover has accelerated substantially, from 3% per decade in 1979-1996 to -11% per decade in the last 10 years. [Comiso et al., 2008] The observed sea ice decline is about three times faster than the model mean, which suggests that melting of Arctic sea ice is likely to happen much faster than projected by current climate models. [Stroeve et al., 2007, Arzel et al., 2006]

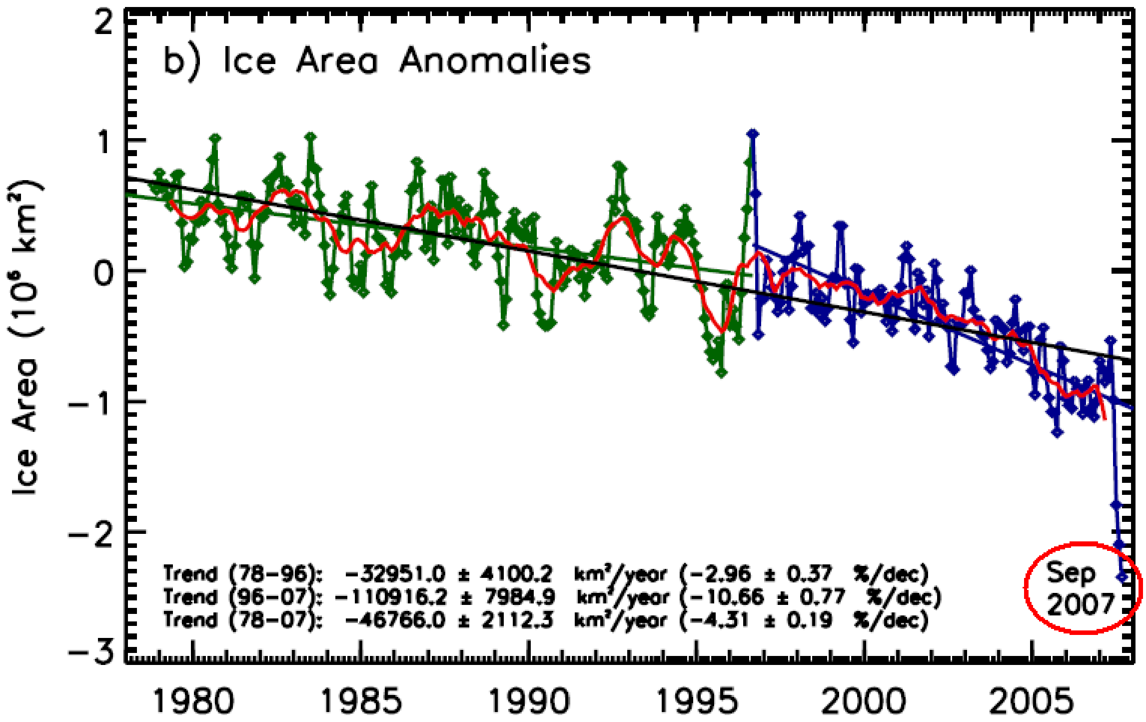

*Figure: Area of Arctic sea ice. Source: [*Comiso et al., 2008*]*

1.5 Carbon cycle feedbacks

Most climate simulations in the IPCC AR4 did not include physical or biological carbon-cycle feedbacks. Recent research has provided new knowledge on carbon cycle feedbacks and their implications for future climate change. One study finds that the warming signal from a rapid loss of Arctic sea ice would penetrate up to 1500 km inland, where it would cause rapid degradation of permafrost, which in turn may lead to additional methane emissions. [Lawrence et al., 2008] New measurements of methane emissions from Siberian thaw lakes revealed that these emissions are already five times greater than previous estimates. Hence, future methane releases from decaying Arctic permafrost may create a new significant positive climate feedback that has not been considered by climate modellers. [Walter et al., 2006]

Inclusion of geological and ecosystem feedbacks in warming projections could increase global warming over the next century due to human emissions of greenhouse gases by an additional 15-78%. [Scheffer et al., 2006, Torn & Harte, 2006] For a given emissions scenario that would stabilize CO2 concentrations at 550 ppm in the absence of carbon-cycle feedbacks, consideration of carbon-cycle feedbacks increased the probability of exceeding 2°C warming by 2100 from 10 to 23% and the probability of exceeding 2°C warming by 2200 from 23 to 41%. [Matthews & Keith, 2007] Thus, anthropogenic emissions result in higher final greenhouse gas concentrations, and therefore more warming, than would be predicted in the absence of this feedback. These findings imply that emissions need to be lower than previously estimated to reach a given target for temperature stabilization.

1.6 Changes in tropical cyclones

Current global climate models are rather poor in simulating tropical cyclones (i.e, hurricanes and typhoons), due in part to the coarse spatial resolution of these models. In addition, there is still debate on the quality of observational cyclone datasets for the 20th century. [Landsea et al., 2006] Several recent studies find that the frequency of strong tropical cyclones has increased in recent decades in all world regions. This observed increase is attributed primarily to increases in sea-surface temperature caused by anthropogenic warming. Most studies suggest that strong cyclones will further increase in the future. [Elsner et al., 2008, Hoyos et al., 2006, Santer et al., 2006, Saunders & Lea, 2008]

1.7 Changes in extreme events

Knowledge on recent and future changes in extreme events has improved significantly, due to better models and improved analysis techniques. New research reveals that since 1950 extremely warm temperatures have increased by between 1 and 3°C, which is much larger than the change in average temperature. [Brown et al., 2008] A group of Dutch scientists estimates that for the SRES A1B emissions scenario, 100-year return temperature values exceed a dangerously high level of 50°C in densely populated areas of India, the Middle East, North Africa, the Sahel, Australia, and equatorial and subtropical South America by 2100. [Sterl et al., 2008] A recent study by German scientists projects that indices of extreme precipitation will also increase significantly in most regions, especially those that are presently experiencing significant precipitation. Conversely those regions which are presently dry are projected to become drier because of longer dry spells. In conclusion, the difference between humid and arid regions in terms of extreme events is projected to become even greater under a changing climate. [Sillmann & Roeckner, 2008]

1.8 Abrupt climate change and tipping elements

The Younger Dryas cooling about 12,700 years ago is one of the most abrupt climate changes observed in Northern Hemisphere palaeoclimate records. A recent study indicates an abrupt increase in storminess occurring from one year to the next at 12,679 yr BP, which is broadly coincident with other climatic changes in this region. These findings imply that the substantial cooling in Europe associated with the younger Dryas event occurred very abruptly, largely within a single year. [Brauer et al., 2008]

Human activities have the potential to push the Earth's system beyond critical thresholds (tipping points) so that it will no longer function in the way we have come to know and expect. Recent research has identified that the two most sensitive tipping elements are Arctic summer ice, with an estimated threshold temperature of 1-2.5°C above preindustrial levels, and the Greenland ice sheet, with an estimated threshold temperature of 1.5-2.5°C above preindustrial. Tipping of these elements can no longer be prevented with certainty, but stringent mitigation can substantially reduce the risk of large-scale changes. Global warming of 3.5°C above preindustrial could trigger additional tipping elements, including the West Antarctic ice sheet, the Atlantic thermohaline circulation, the El Nino–Southern Oscillation, the West African monsoon, the Amazon rainforest, and the boreal forest. [Lenton et al., 2008] Eight ancient abrupt climate shifts were all preceded by a characteristic slowing down of the fluctuations starting well before the actual shift. Such slowing down can be mathematically shown to be a hallmark of tipping points. These findings provide support to the concept of tipping points, but they might be used as a universal early warning signal for upcoming catastrophic change. [Dakos et al., 2008]

1.9 Paleoclimate

Global warming sceptics frequently seize on disagreement amongst geologists over whether high atmospheric CO2 concentrations were always associated with global warming in the distant geological past. A new study supports the view that atmospheric CO2 concentrations and Earth surface temperatures have always been closely coupled. The results are consistent with the view that increased CO2 concentrations drive or amplify increased global temperatures. [Came et al., 2007]

1.10 Long-term effects of current emissions

A group of US scientists have applied a coupled carbon cycle-climate model to investigate the impacts of delaying emissions reductions on the ability to reach different targets for stabilizing atmospheric CO2 concentrations. Assuming that global emissions can decline at 1% per year, beginning emissions reductions today would achieve stabilization at about 475 ppm. When mitigation is postponed, options disappear at a rate of 9 ppm year. This value is much larger than the recent annual increase in atmospheric CO2 concentrations of around 2 ppm per year because it considers the inertia in the energy and climate system. These results suggest that delaying mitigation further impedes reaching a given stabilization level much faster than generally assumed. [Mignone et al., 2008]

Other studies have investigated the long-term effects of current emission. A recent review study involving all leading global climate models finds that 20-60% of the CO2 from fossil fuel emissions remains in the atmosphere for more than thousand years. As a result, current emissions have a substantial impact on the earth's climate for many millennia to come, much longer than generally expected. [Archer & Brovkin, 2008]

2 Impacts of climate change and adaptation

Projections of climate impacts and understanding of adaptation have improved significantly since finalization of the IPCC WG2 AR4 in 2007. Many recent studies conclude that the consideration of current climate variability and its potential changes in climate impact assessments increases the estimated adverse impacts of climate change on agriculture, natural ecosystems, coastal regions, and human health. Furthermore, evidence increases that ocean acidification presents a very substantial risk from anthropogenic greenhouse gas emissions for marine ecosystems, which is independent of climatic changes.

2.1 Synthesis of climate impacts

Climate change impacts for different emissions scenarios were not displayed explicitly in the IPCC AR4 SPMs due to a lack of consensus in the IPCC plenary. Leading scientists from the outgoing IPCC Bureau have compiled information from the IPCC AR4 on climate impacts for different mitigation levels. They show major global impacts even for a 50% reduction of global emissions by 2050 compared to 1990. These results confirm that both adaptation and mitigation are essential, the latter because the longer we delay mitigation, the more likely it is that global change will exceed our capacity to adapt. [Parry et al., 2008]

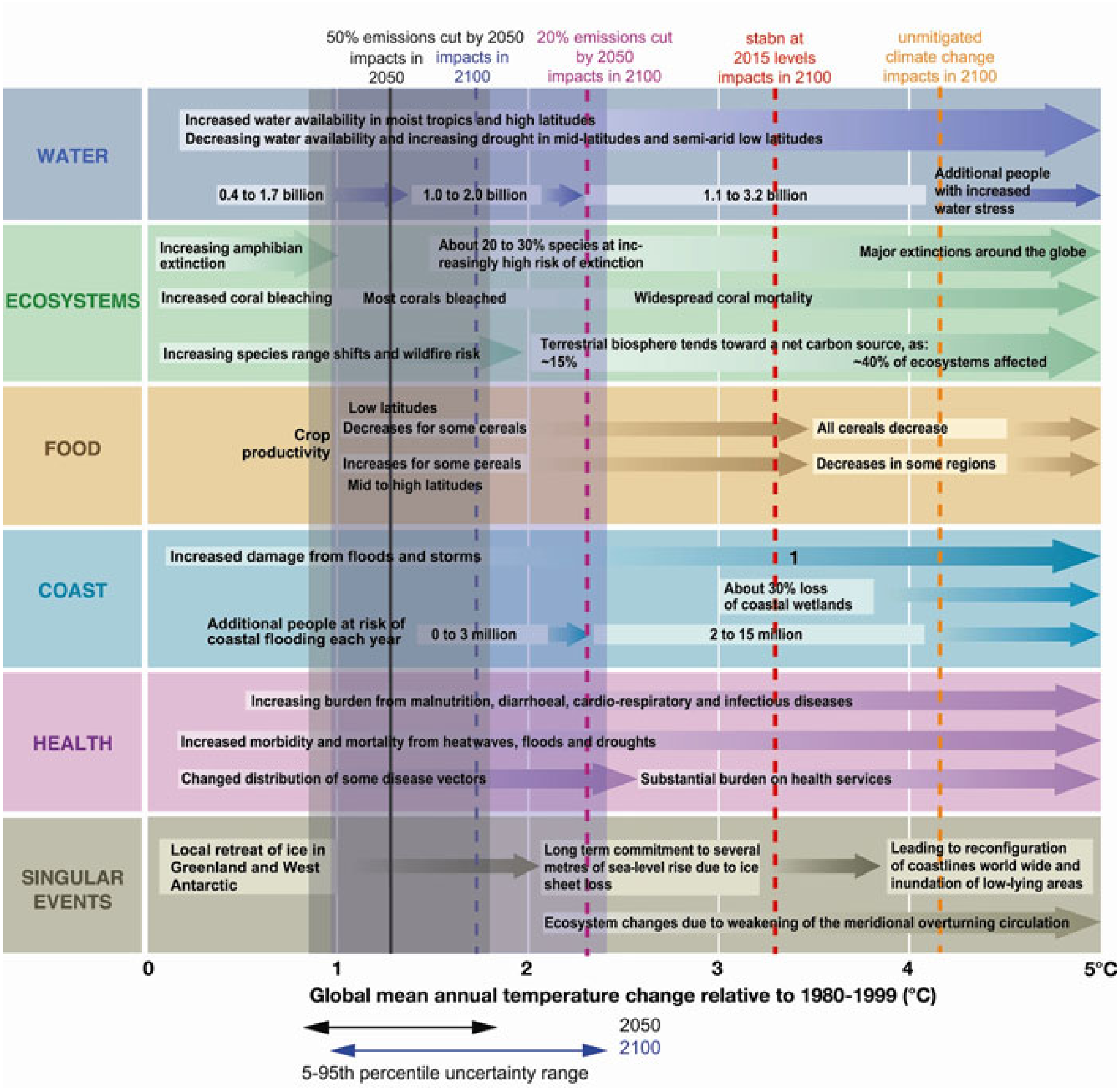

*Figure: Selected global impacts from warming associated with various reductions in global greenhouse gas emissions. Vertical lines indicate likely impacts of the median warming expected to result from indicated emissions scenarios (percentage cuts are from 1990 levels); shaded columns show 5 to 95% uncertainty ranges for impacts of a 50% cut. Source: [*Parry et al., 2008*], adapted from the IPCC WG2 AR4 Technical Summary*

2.2 Climate impacts on food production

Negative impacts on crops associated with recent warming between 1980 and 2002 have very likely offset some of the yield gains associated with rising CO2 and technological advances. The negative impact was most pronounced for wheat, maize and barley. This finding suggests that some caution should be used in accepting model assessments showing global crop benefits for warming up to about 2°C. [Lobell & Field, 2007]

Simulations with agricultural crop models have suggested that increased temperature and decreased soil moisture will act to reduce global crop yields by 2050, but that the direct fertilization effect of rising CO2 concentration will offset these losses. A new study based on results of recent experiments with free-air concentration enrichment technology shows that elevated CO2 enhanced yield of major grain crops by 50% less than in earlier studies based on enclosure experiments. This finding casts serious doubt on projections that rising CO2 will fully offset global crop yield losses due to climate change. [Long et al., 2006]

2.3 Climate impacts on ecosystems

Coral reefs are among the most important biodiversity hotspots, and they provide important services to society, including for coastal protection and coastal tourism. A recent review study shows the crucial role of ocean acidification in the destruction of coral reefs during previous mass extinction events. The study finds carbon cycle changes in general and ocean chemistry in particular as the primary causes of the five known mass extinction events, each of which has left the Earth without living reefs for at least four million years. The author suggests that ocean acidification has the potential to trigger a sixth mass extinction event and to do so independently of anthropogenic extinctions that are currently taking place. [Veron, 2008] Another study finds that atmospheric carbon dioxide concentration in exceedance of 500 ppm and a global temperature rise of more than 2°C significantly exceeds conditions of at least the past 420,000 years during which most extant marine organisms evolved. [Hoegh-Guldberg et al., 2007] Many corals rely on their symbiotic algae for survival. The hypothesis that corals may survive climate change by exchanging algal types has been shown to be potentially applicable only to a minority of corals. Out of 442 coral species assessed in a recent study, the vast majority (77%) do not change their symbiontic algae over time, even when a coral colony is transplanted to different environments or subjected to increased temperatures. Thus, without stringent mitigation measures coral reefs will undergo a substantial reduction in biodiversity during the 21st century because most coral species are unable to adapt. [Goulet, 2006]

Recent research has underlined the large risks to the Amazon rainforest from climate change. One study projects a 70% reduction in the extent of the Amazon rain forest by the end of the 21st century for a high emissions scenario. Rain forest vegetation disappears entirely from Bolivia, Paraguay and Argentina and most of Brazil and Peru. While these dramatic results are dependent on the global climate model applied, they add to the existing evidence that the continued existence of most of the Amazon rainforest may be at risk from climate change. [Cook & Vizy, 2008] Another study found that aerosol forcing has delayed greenhouse gas-induced reductions in Amazonian rainfall but is unlikely to do so for much longer. Model simulations suggest a substantial increase in droughts in western Amazonia, such as the one that occurred in 2005, under conditions of increased greenhouse gas concentrations and reduced aerosol loading in the Northern Hemisphere. A '2005-like' year is an approximately 1-in-20-yr event currently but is projected to become a 1-in-2-yr event by 2025 (at about 450 ppm CO_2) and a 9-in-10-yr event by 2060 (at around 610 ppm CO_2). [Cox et al., 2008]

The impact of anthropogenic climate change on terrestrial organisms is often predicted to increase with latitude, in parallel with the rate of warming. Recent research shows that warming in the tropics, although relatively small in magnitude, is likely to have the most deleterious consequences because most tropical animals are relatively sensitive to temperature change and are currently living very close to their optimal temperature. In the absence of ameliorating factors such as migration and adaptation, the greatest extinction risks from global warming may be in the tropics, where biological diversity is also greatest. [Deutsch et al., 2008]

A detailed analysis of all 400 large wildfires in the western USA over a 34 year period has found that large wildfire activity increased suddenly and markedly in the mid-1980s, with higher large-wildfire frequency, longer wildfire durations, and longer wildfire seasons. Earlier snowmelt and higher summer temperatures are critical factors in this increase; years with early snowmelt had five times as many wildfires as years with late snowmelt. The marked increase in wildfire activity happened in spite of increased expenditure in fire suppression, pointing to the limited success in adaptation. Projected temperature increases until the 2050s alone are projected to increase wildfire activity further threefold. [Westerling et al., 2006]

In a comprehensive study of climate-induced changes in key ecosystem processes across the globe during the 21st century forced, a global vegetation model was forced with multiple scenarios from 16 climate models. Ecosystems in much larger areas were affected by global warming of >3°C compared with <2°C, and some impacts occur only at higher warming levels. With >3°C of warming, the estimated land sink of carbon also converts to a source in about half of the model runs, suggesting a positive climate feedback. [Scholze et al., 2006]

2.4 Climate impacts on coastal regions

Sea-level rise is expected to effect coastal properties in two-ways: inundation of low-lying property and episodic flooding of properties at an elevation. A recent detailed study estimated the cost from episodic storm events to be much greater (up to 250 times) than the costs from inundation alone. While the specific numbers represent the particular circumstances of the study area, the results strongly suggest the total cost of sea-level rise could be underestimated if the costs of episodic flooding are not accounted for. [Michael, 2007]

2.5 Climate impacts on human health

Recent research has shown that the death toll of the unprecedented 2003 European summer heat wave was much larger than previously estimated. Based on an analysis of daily mortality numbers at the regional level from 16 European countries this study finds that more than 70,000 additional deaths occurred in Europe during the record heat wave in summer 2003. Furthermore, mortality levels after the heat wave were not lower than during the reference period, which is in contrast to wide-held beliefs that most of the deceased were at the brink of dying anyway. [Robine et al., 2008] The new results reemphasize that even wealthy countries can be quite vulnerable to climate change, in particular when it involves extreme climatic conditions never experienced before in a region.

2.6 Adaptation to climate change

Climate change is a multi-dimensional issue and in terms of adaptation numerous state and non-state actors are involved from global to national and local scales. Several recent studies have highlighted failures of past adaptation actions and obstacles for future adaptation.

One study has investigated the reasons for a largely unsuccessful adaptive effort which was intended to reduce flood risk in Mozambique. Among other measures, a resettlement programme was implemented, with entire villages being built to accommodate farmers in hills overlooking the floodplain. Just a few months later, farmers returned to the floodplain and re-built homes there. One reason for the failure of this resettlement programme was disagreement between farmers and policy makers about the seriousness of climate risks, and the potential negative consequences of proposed adaptive measures. A project to provide more information about climate change to farmers did not change their beliefs. The results imply that adaptation to climate change might be more difficult than currently assumed, even if risks are clearly identified and economic resources are available. [Patt & Schröter, 2008] Another study has analyzed the dynamics between the key institutions involved in climate change in South Africa. Climate change is recognised to be a cross-cutting issue to which all government departments must sign up, but institutional networks appear weak, and information transfer between different government departments and between them and non-governmental adaptation actors is inadequate. Thus, adaptation to climate change will be particularly difficult in countries where institutional networks between governments departments and relevant non-governmental adaptation actors are weak. [Koch et al., 2007]

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