An Open Letter from Scientists in the United States on the Intergovernmental Panel on Climate Change and Errors Contained in the Fourth Assessment Report: *Climate Change 2007*

{Annotated version with documentation through Figures and Tables}

Many in the popular press and other media, as well as some in the halls of Congress, are seizing on a few errors that have been found in the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) in an attempt to discredit the entire report. None of the handful of mis-statements (out of hundreds and hundreds of unchallenged statements) remotely undermines the conclusion that "warming of the climate system is unequivocal" {see Figure 1} and that most of the observed increase in global average temperatures since the mid-twentieth century is very likely due to observed increase in anthropogenic greenhouse gas concentrations {see Figure 2}. Despite its excellent performance for accurately reporting the state-of-the-science, we certainly acknowledge that the IPCC should become more forthcoming in openly acknowledging errors in a timely fashion, and continuing to improve its assessment procedures to further lower the already very low rate of error.

It is our intention in offering this open letter to bring the focus back to credible science, rather than invented hyperbole, so that it can bear on the policy debate in the United States and throughout the world. We first discuss some of the key messages from climate science and then elaborate on IPCC procedures, with particular attention to the quality-control mechanisms of the IPCC. Finally we offer some suggestions about what might be done next to improve IPCC practices and restore full trust in climate science.

The Climate Challenge

Our understanding of human contributions to climate change and the associated urgency for humans to respond has improved dramatically over the past two decades. Many of the major components of the climate system are now well understood, though there are still sources of significant uncertainty (like the processes that produce the observed rapid ice-sheet melting and/or collapse in the polar regions). It is now well established, for example, that atmospheric concentrations of greenhouse gases from human sources have increased rapidly since the Industrial Revolution {see Figure 3}. Increasing concentrations of greenhouse gases in the atmosphere reduce the heat going out of the climate system, i.e., the radiation balance of the Earth – and so first principles of physics tell us to expect, with a very high likelihood, that higher temperatures should have been observed.

Indeed, measurements of global average temperatures show an increase of about 0.6 degrees C over the twentieth century and about 0.8 degrees C warming since mid-19th century. The pattern of increase has not been smooth or monotonic. There have been several 10- to 15-

year periods of stable or declining temperatures over the past 150 years, but 14 of the warmest 15 years on record have been experienced between 1995 and 2009 {see Figure 4 and right panel of Figure 5}. Since 1970, observational evidence from all continents and most oceans shows that many natural systems are already being affected by these temperature increases {see Figure 6}.

Because the long-term warming trends are highly significant relative to our estimates of the magnitude of natural variability, the current decadal period of stable global mean temperature does nothing to alter a fundamental conclusion from the AR4: warming has unequivocally been observed and documented. Moreover, well-understood lags in the responsiveness of the climate system to disturbances like greenhouse gas increases mean that the current temperature plateau will very likely not persist much longer. Global climate model projections show that present-day greenhouse gas concentrations have already committed the planet to about 0.5 degree C in warming over this century {see the right panel of Figure 5}.

Increasing emissions of carbon dioxide from the consumption of coal, oil and natural gas as well as deforestation have been the major drivers of this observed warming. While we cannot predict the details of our climate future with a high degree of certainty, the majority of studies from a large number of research groups in the US and elsewhere project that unabated emissions could produce between 1 and 6 degrees C more warming through the year 2100 {see Figures 5 and 7 and Table 1}.

Other research has identified multiple reasons to be concerned about climate change; these apply to the United States as well as globally. They include (1) risks to unique and threatened systems (including human communities), (2) risks from extreme events (like coastal storms, floods, droughts, heat waves, and wildfires), (3) economic damages (driven by, for example, pest infestations or inequities in the capacity to adapt), (4) risks from large-scale abrupt climate change (e.g., ice-sheet collapse, ocean circulation slowing, sharply increased methane emissions from permafrost) or abrupt impacts of more predictable climate change (generated by thresholds in the coping capacities of natural and human systems to climate variability), and (5) risks to national security (driven largely by extreme events across the world interacting with already-stressed situations) {see Figure 8}.

These sources of risk and the potential for triggering temperature-driven impacts at lower thresholds, as well as the explicit recognition in the AR4 that risk is the product of likelihood and consequence, led the nations of the world to take note of the Copenhagen Accord last December. The Accord highlights 2 degrees C in warming as a target that might reduce the chance of "dangerous anthropogenic interference with the climate system" to more manageable levels. Research has shown that increasing the likelihood of achieving this goal over the next century is economically and technically feasible with emission reduction measures and changes in consumption patterns; but it will not be easy without major national and international actions to deviate substantially from the status quo {see Tables 2 and 3 and Figure 9}.

The IPCC and the Fourth Assessment Report

The World Meteorological Organization (WMO) and the United Nations Environment

Programme (UNEP) established the IPCC in 1988 to provide policy makers regularly with balanced assessments of the state of knowledge on climate change. In so doing, they created an open intergovernmental organization in which scientists, policy analysts, engineers, and resource managers from all over the world were asked to collaborate. At present, more than 150 countries including the United States participate in the IPCC. IPCC publishes an assessment report approximately every six years. The most recent Fourth Assessment, approved by member countries and released in 2007, contained three volumes: *The Physical Science Basis* (Working Group I); *Impacts, Adaptation and Vulnerability* (Working Group II) and *Mitigation of Climate Change* (Working Group III) and a Synthesis Report. More than 44 writing teams and 450 lead authors contributed to the Fourth Assessment – authors who have been selected on the basis of their expertise in consultation with all member countries and who were assisted by another 800 scientists and analysts who served as contributing authors on specific topics. Authors donated their time gratis, and the entire process was supported by four Technical Support Units (TSUs) that employ 5 to 10 people each.

Errors in the Fourth Assessment Report

It was hard not to notice the extraordinary commotion that erupted around errors that were eventually found in the AR4. The wrong year for the projected disappearance of the Himalayan glaciers and the wrong percentage of 'land below sea level' in the Netherlands are examples of errors that need to be acknowledged frankly and rectified promptly. In a few other cases, like the discussion of the correlations between crop yields, climate change, and climate variability in North Africa, caveats that were carefully crafted within the chapters were not included when language was shortened for the Synthesis Report {compare page 13 of the AR4-WGII-SPM with the Africa row in Table SPM.3 of the AR4-Synthesis Report SPM}. While striving to simplify technical details and summarize major points, some important qualifications were left behind. These errors of omission in the summary process should also be recognized and corrected. Other claims, like the one reported at the end of February suggesting that the AR4 did not mention the millions of more people who will see increases in water availability that were reported in the cited literature along with the millions of more people who will be at risk of water shortage, are simply not true {see page 194 in Chapter 3 of the AR4-WGII Report}. In any case, it is essential to emphasize that none of these interventions alter the key finding from the AR4 that human beings are very likely changing the climate, with far-reaching impacts in the long run.

The heated debates that have emerged around these instances have even led some to question the quality and integrity of the IPCC. Recent events have made it clear that the quality control procedures of the IPCC are not watertight, but claims of widespread and deliberate manipulation of scientific data and fundamental conclusions in the AR4 are not supported by the facts. We also strongly contest the impression that the main conclusions of the report are based on dubious sources. The reference list of the AR4 contains about 18,000 citations, the vast majority of which were published in peer-reviewed scientific journals. The IPCC also has transparent procedures for using published but not peer-reviewed sources in their reports. These procedures were not properly followed in the isolated Himalaya case, but that statement was never elevated into the Summary for Policymakers of either Working Group II or the Synthesis

Report – documents that were approved unanimously and word for word by all member nations.

Nonetheless, failsafe compliance with these procedures requires extra attention in the writing of the next round of assessments. We propose implementing a topic-based cross-chapter review process by which experts in an impact area of climate change, such as changes in water resources, scrutinize the assessment of related vulnerability, risk analyses, and adaptation strategies that work downstream from such changes. Here we mean, to continue the example, assessments of possible increases in flooding damage in river basins and the potential for wetlands to provide buffers in the sectoral and regional chapters. This would be most productively implemented just before the first-order draft, so that chapter authors can be alerted to potential problems before the major review step.

Quality Control within the IPCC and US Review

The impression that the IPCC does not have a proper quality-control procedure is deeply mistaken. The procedure for compiling reports and assuring its quality control is governed by well-documented principles that are reviewed regularly and amended as appropriate. Even now, every step in the preparation of every chapter can be traced on a website: *First Order Drafts* (with comments by many scientists as well as author responses to those comments), *Second Order Drafts* in which those comments are incorporated (and comments by experts and country representatives on revised versions as well as another round of author responses), and so on, up through the final, plenary-approved versions.

To be clear, 2,500 reviewers together provided about 90,000 comments on the 44 chapters for the AR4. Each comment is documented on a website that also describes how and why the comment was or was not incorporated in the next revision. Review editors for each chapter worked with the authors to guarantee that each comment was treated properly and honestly in the revision; in fact, no chapter can ever move forward for publication without the approval of its set of two or three review editors.

The US Government opened its reviews of the draft IPCC report to any US expert who wanted to review it. In order to protect against having this preliminary pre-reviewed draft leaked before its ultimate approval by the IPCC Plenary, the US Government asked all potential reviewers to agree not to disclose the contents of the draft. For each report, the US Government assembled its own independent panel of government experts to vet the comments before submission to the IPCC. Anything with scientific merit was forwarded. There were multiple rounds for each of the Working Group reports and the Synthesis Report, and opportunities for US experts to review the drafts were posted as Federal Register notices.

IPCC principles also govern how authors treat published but non-peer reviewed sources. These procedures acknowledge that peer-reviewed scientific journals contain little information about on-the-ground implementation of adaptation or mitigation – matters such as the emission reduction potential in a given industrial sector or country, for example, or catalogues of the specific vulnerabilities and adaptation strategies of sectors and regions with regard to climate change. This information is frequently only available in reports from research institutes, reports of workshops and conferences, or in publications from industries or other non-governmental organizations. This is the so-called *gray* literature. The IPCC procedure prescribes that authors are obliged to assess critically any *gray* source that they wish to include. The quality and validity of a finding from a non-peer reviewed source needs to be verified before its finding may be included in a chapter text. Each source needs to be completely traceable; and in cases where gray sources are used, a copy must be deposited at the IPCC Secretariat to guarantee that it is available upon request for third parties.

We conclude that the IPCC procedures are transparent and thorough, even though they are not infallible. Nonetheless, we are confident that no single scholar or small group of scholars can manipulate the process to include or to exclude a specific line of research; authors of that research can (and are fully encouraged to) participate in the review process. Moreover, the work of every scientist, regardless of whether it supports or rejects the premise of human-induced climate change, is subject to inclusion in the reports. The work is included or rejected for consideration based on its scientific merit.

It is important to note that we are not addressing here the criteria and procedures by which the IPCC selects chairs and authors. These are handled exclusively by the IPCC and its members according to terms of reference that were initially defined in the authorizing language of 1988. That is to say, governments or their appointees frame and implement these policies; and they create, approve and staff Technical Support Units for each working group. We do not make suggestions on these topics since they lie beyond our purview.

What comes next?

We expect that the robust findings of the AR4 will continue to be supported by new information gleaned from literature published since 2006, and that IPCC findings will be confirmed – i.e., that the climate change issue is serious and real. Given these findings, we believe that the climate change issue deserves the urgent and non-partisan consideration of the country’s legislative and administrative leaders. We feel strongly that exaggerated focus on a few errors from 2007 cannot be allowed to detract from open and honest deliberations about how to respond to climate risk by reducing emissions and promoting adaptation at home and abroad.

As the process of producing the IPCC Fifth Assessment Report (AR5) begins, the IPCC should become more responsive in acknowledging errors rapidly and openly as they become known. To this end, we urge the IPCC to put an erratum on its website that rectifies all errors that have been discovered in the text after publication. In doing so, a clear distinction needs to be made between errors and progressing knowledge. IPCC assessments are detailed snapshots of the state of scientific knowledge at a given time, while knowledge evolves continuously through ongoing research and experience; it is the errors in the assessments that need immediate attention. In contrast, progressing knowledge is published in new scientific journal articles and reports; this information should be used as a basis for the AR5, but it cannot be listed as errata for the AR4 because it was not available when that assessment was conducted. The website should, as well, respond rapidly and openly when reports of errors in past assessments are themselves in error. We cannot let misperceptions fester anymore than errors go uncorrected.

Climate research and the IPCC reports on the state of knowledge provide a scientific foundation for climate policy making, whose agenda is defined by the governments of the IPCC and not the lead authors per se. The quality of and the balance in the knowledge delivered by any assessment is certainly essential, as is clear and explicit communication of associated uncertainties. Given the recent political and media commotion surrounding a few clear errors, it is now equally essential that we find ways to restore full trust in the integrity of the overwhelming majority of the climate change research and policy communities. To that end, we are pleased that an independent critical evaluation of IPCC procedures will be conducted; we hope that the process will solicit participation by the National Academies of the member nations.

The significance of IPCC errors has been greatly exaggerated by many sensationalist accounts, but that is no reason to avoid implementing procedures to make the assessment process even better. The public has a right to know the risks of climate change as scientists currently understand them. We are dedicated to working with our colleagues and government in furthering that task.

March 12, 2010

Signed:

Gary W. Yohe — Wesleyan University and Yale University School of Forestry and Environmental Studies
gyohe@wesleyan.edu

Stephen H. Schneider — Stanford University
shs@stanford.edu

Cynthia Rosenzweig — NASA Goddard Institute for Space Studies and Columbia University
crosenzweig@giss.nasa.gov

William E. Easterling — Pennsylvania State University
billeasterling@psu.edu

Figure 1: Evidence that "warming of the climate system is unequivocal"; source: IPCC (2007):

Changes in temperature, sea level and Northern Hemisphere snow cover

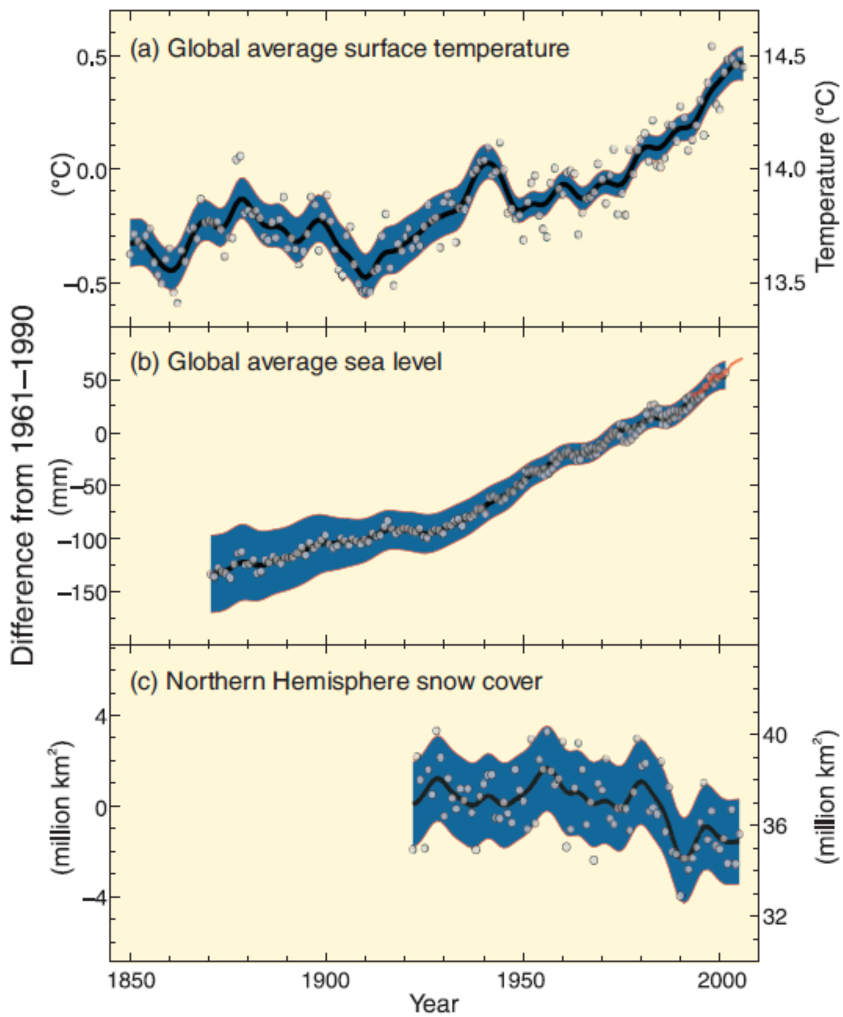

Figure SPM.1. *Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {Figure 1.1}*

Figure 2: Evidence that anthropogenic forcing is required to explain changes in global scale surface temperatures; source: IPCC (2007):

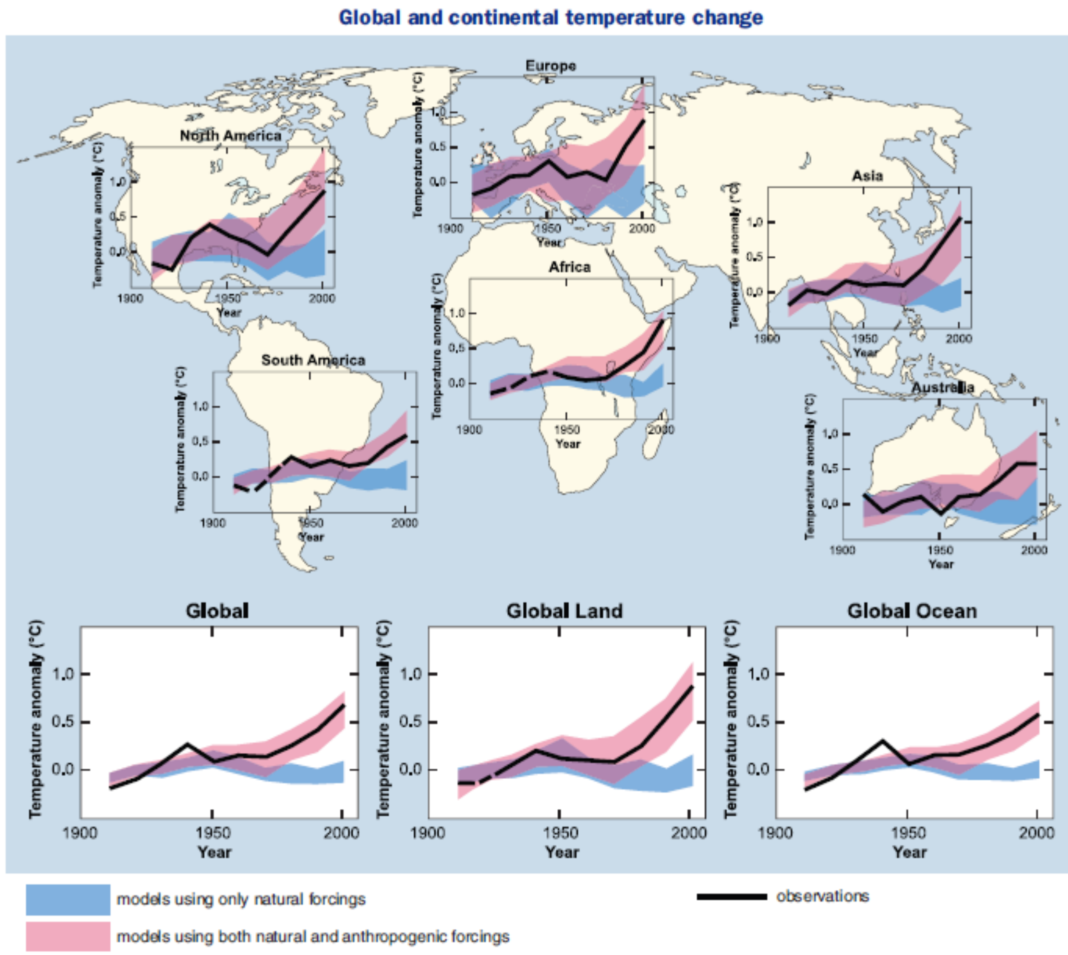

Figure SPM.4. *Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the period 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. {Figure 2.5}*

Figure 3: Atmospheric concentrations of carbon dioxide – the Keeling record; source: McCarthy (2010):

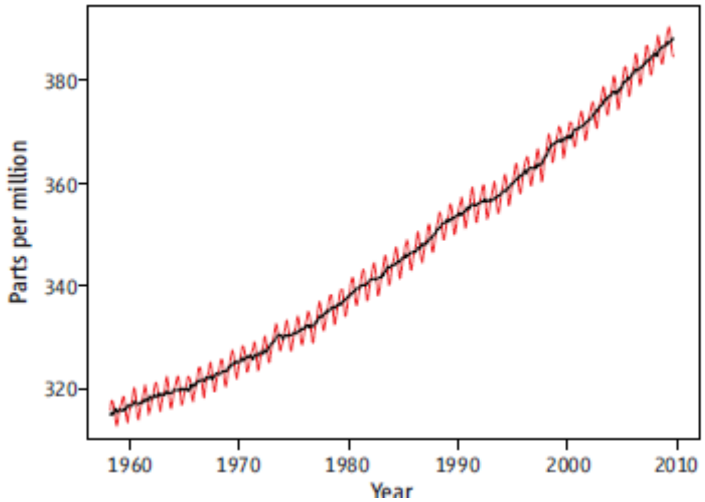

Figure 4: Global surface temperatures over time – long-term temperature trends can be inferred from the color code; source: McCarthy (2010):

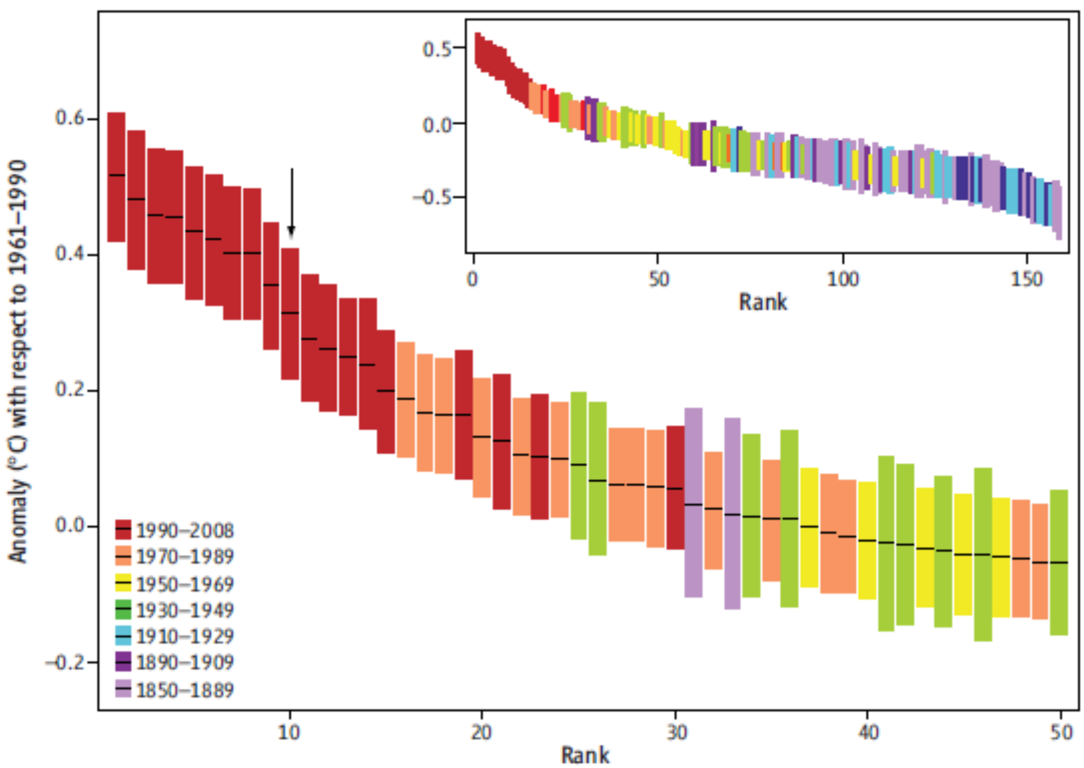

Fig. 6. Global surface temperature. Global ranked surface temperatures for the warmest 50 years. The inset shows global ranked surface temperatures from 1850. The size of the bars indicates the 95% confidence limits associated with each year. The source data are blended land-surface air temperature and sea surface temperature from the HadCRUT3 series. Values are simple area-weighted averages for the whole year (*28*).

Figure5: Projections of greenhouse gas emissions, global surface warming, and warming ranges for the 2080's for SRES alternative scenarios; source: IPCC (2007):.

Scenarios for GHG emissions from 2000 to 2100 (in the absence of additional climate policies) and projections of surface temperatures

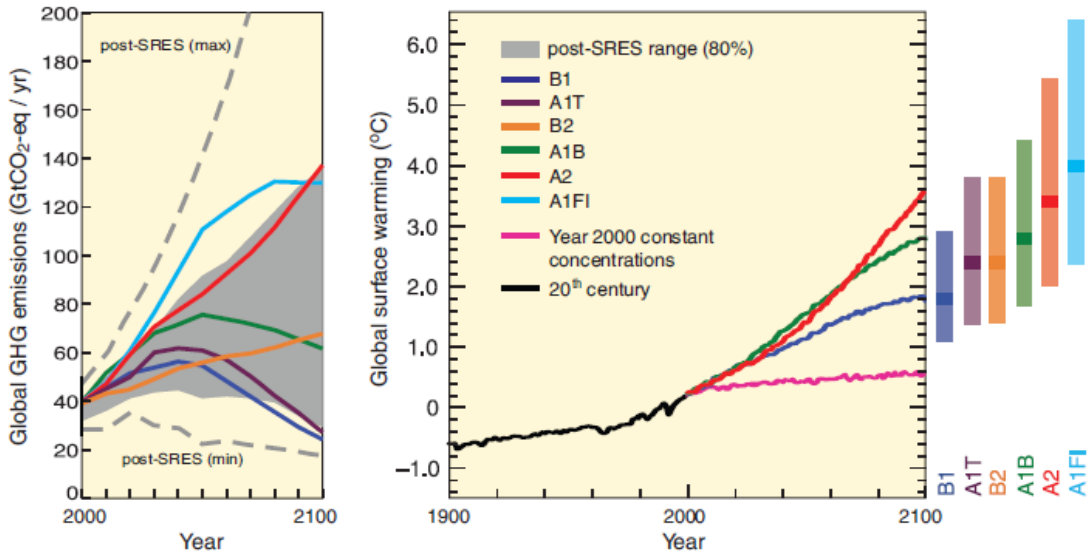

Figure SPM.5. ***Left Panel:*** *Global GHG emissions (in GtCO$_2$-eq) in the absence of climate policies: six illustrative SRES marker scenarios (coloured lines) and the 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO_2, CH_4, N_2O and F-gases.* ***Right Panel:*** *Solid lines are multi-model global averages of surface warming for scenarios A2, A1B and B1, shown as continuations of the 20th-century simulations. These projections also take into account emissions of short-lived GHGs and aerosols. The pink line is not a scenario, but is for Atmosphere-Ocean General Circulation Model (AOGCM) simulations where atmospheric concentrations are held constant at year 2000 values. The bars at the right of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090-2099. All temperatures are relative to the period 1980-1999. {Figures 3.1 and 3.2}*

Figure 6: Observed changes in physical and biological systems; source: IPCC (2007):

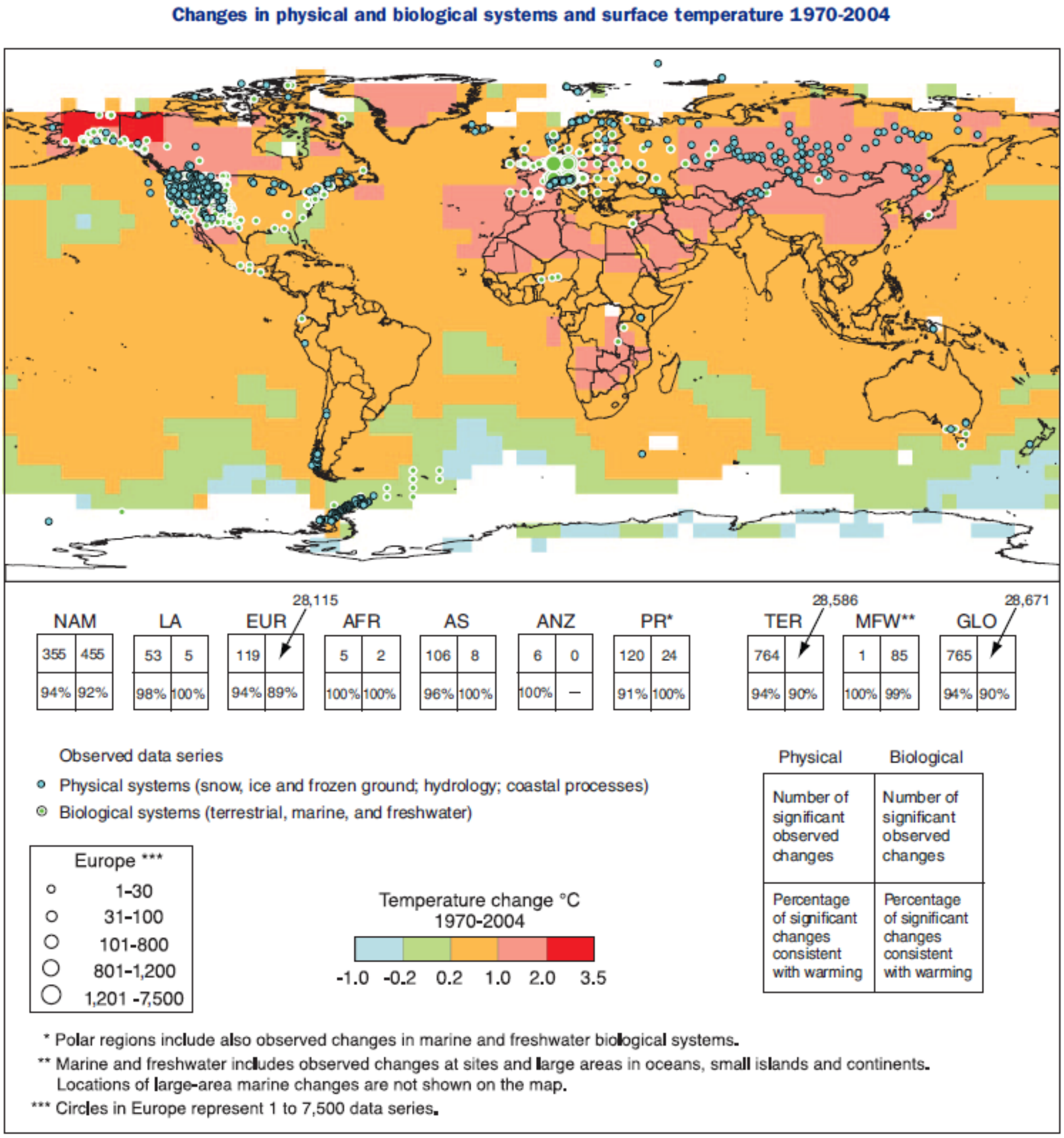

Figure SPM.2. *Locations of significant changes in data series of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine and freshwater biological systems), are shown together with surface air temperature changes over the period 1970-2004. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies. These data series are from about 75 studies (of which about 70 are new since the TAR) and contain about 29,000 data series, of which about 28,000 are from European studies. White areas do not contain sufficient observational climate data to estimate a temperature trend. The 2 × 2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row) for (i) continental regions: North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR) and (ii) global-scale: Terrestrial (TER), Marine and Freshwater (MFW), and Global (GLO). The numbers of studies from the seven regional boxes (NAM, EUR, AFR, AS, ANZ, PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFW) systems. Locations of large-area marine changes are not shown on the map. {Figure 1.2}*

Figure 7: Sources of recent global annual greenhouse gas emissions; source: IPCC (2007):

Global anthropogenic GHG emissions

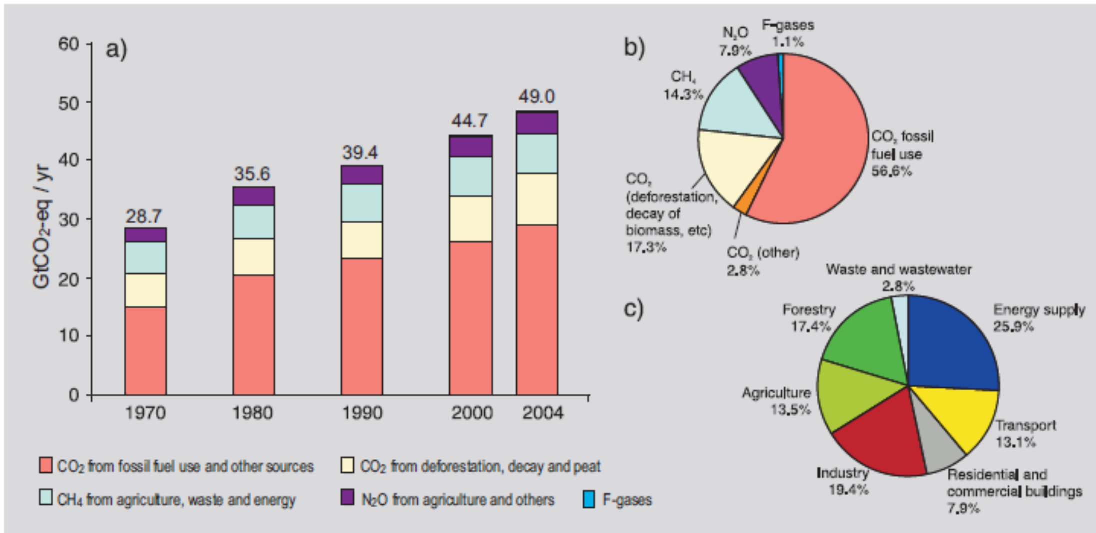

Figure SPM.3. *(a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.[5] (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of carbon dioxide equivalents (CO_2-eq). (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq. (Forestry includes deforestation.) {Figure 2.1}*

Figure 8: Reasons for Concern since 2001; sources IPCC (2001) text from IPCC (2007) and more recent literature as reported in Smith, et al. (2009) and Yohe (2010):

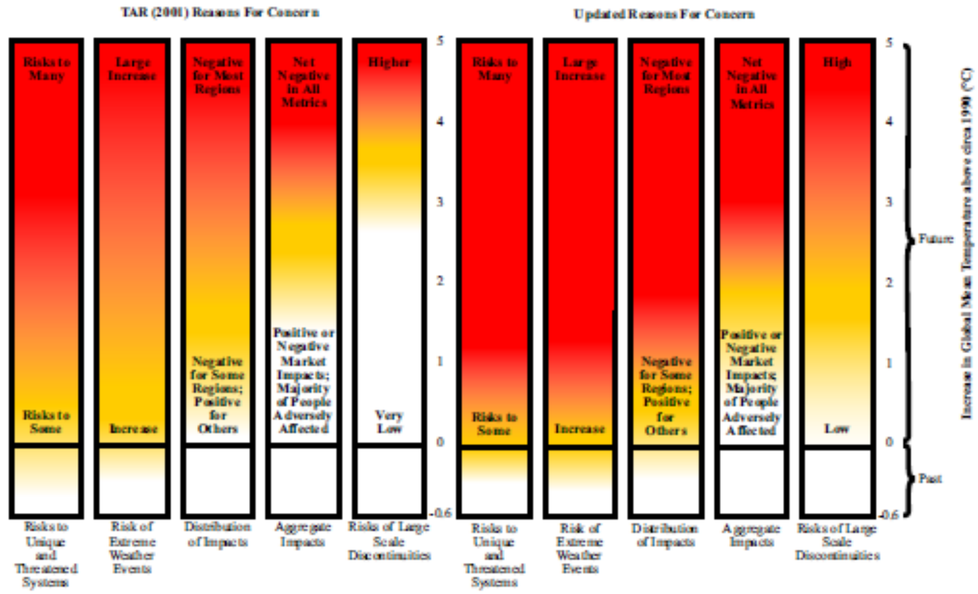

Fig. 1. Risks from climate change, by reason for concern—2001 compared with updated data. Climate change consequences are plotted against increases in global mean temperature (°C) after 1990. Each column corresponds to a specific RFC and represents additional outcomes associated with increasing global mean temperature. The color scheme represents progressively increasing levels of risk and should not be interpreted as representing "dangerous anthropogenic interference," which is a value judgment. The historical period 1900 to 2000 warmed by ~0.6 °C and led to some impacts. It should be noted that this figure addresses only how risks change as global mean temperature increases, not how risks might change at different rates of warming. Furthermore, it does not address when impacts might be realized, nor does it account for the effects of different development pathways on vulnerability. (*A*) RFCs from the IPCC TAR as described in section 1. (*B*) Updated RFCs derived from IPCC AR4 as supported by the discussion in section 2. (Reproduced with permission from Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Figure SPM-2. Cambridge University Press.)

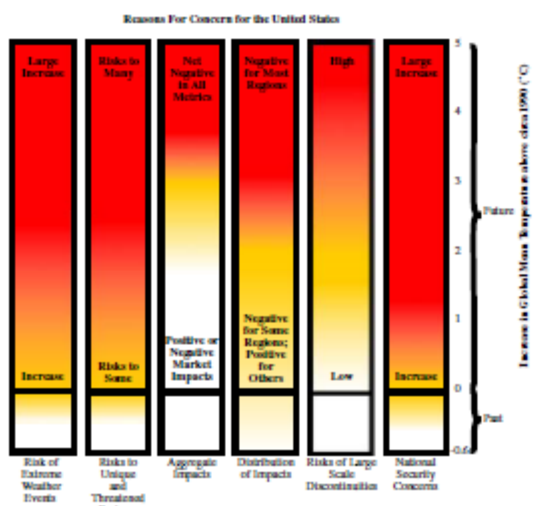

Fig. 1 Risks from Climate Change by Reason for Concern for the United States. Climate change consequences for the United States are plotted against increases in global mean temperature (°C) after 1990. Each column represents country-specific outcomes associated with increasing global mean temperature for each of the now six RFC's. The color scheme is the same as IPCC (2001a, b) and Smith et al. (2009): white indicates neutral or small negative or positive impacts or risks, yellow indicates negative impacts for some systems or low risks, and red means negative impacts or risks that are more widespread and/or greater in magnitude. The historical period 1900 to 2000 warmed by 0.6°C and led to some impacts. It should be noted that this figure addresses only how risks change as global mean temperature increases. The sensitivities of risks to rates of warming are not reflected. Nor do the RFC's explicitly address when impacts might be realized, and they do not account for the effects of different development pathways on vulnerability

Figure 9: Emissions profiles and warming ranges for alternative concentration stabilization targets; source: IPCC (2007):

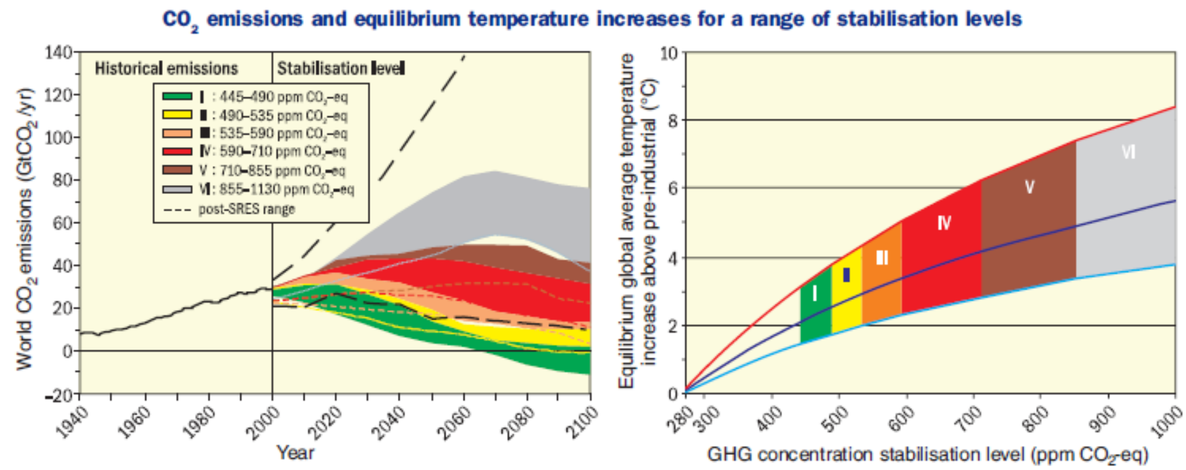

Figure SPM.11. *Global CO_2 emissions for 1940 to 2000 and emissions ranges for categories of stabilisation scenarios from 2000 to 2100 (left-hand panel); and the corresponding relationship between the stabilisation target and the* likely *equilibrium global average temperature increase above pre-industrial (right-hand panel). Approaching equilibrium can take several centuries, especially for scenarios with higher levels of stabilisation. Coloured shadings show stabilisation scenarios grouped according to different targets (stabilisation category I to VI). The right-hand panel shows ranges of global average temperature change above pre-industrial, using (i) 'best estimate' climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of* likely *range of climate sensitivity of 4.5°C (red line at top of shaded area) (iii) lower bound of* likely *range of climate sensitivity of 2°C (blue line at bottom of shaded area). Black dashed lines in the left panel give the emissions range of recent baseline scenarios published since the SRES (2000). Emissions ranges of the stabilisation scenarios comprise CO_2-only and multigas scenarios and correspond to the 10th to 90th percentile of the full scenario distribution. Note: CO_2 emissions in most models do not include emissions from decay of above ground biomass that remains after logging and deforestation, and from peat fires and drained peat soils. {Figure 5.1}*

Table 1: Ranges of projected warning for 2000 concentrations and SRES scenarios in the 2090's; source: IPCC (2007):

Table SPM.1. *Projected global averaged surface warming and sea level rise at the end of the 21st century. {Table 3.1}*

Case	Temperature change (°C at 2090-2099 relative to 1980-1999) [a, d]		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations[b]	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:

a) Temperatures are assessed best estimates and *likely* uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints.

b) Year 2000 constant composition is derived from Atmosphere-Ocean General Circulation Models (AOGCMs) only.

c) All scenarios above are six SRES marker scenarios. Approximate CO_2-eq concentrations corresponding to the computed radiative forcing due to anthropogenic GHGs and aerosols in 2100 (see p. 823 of the Working Group I TAR) for the SRES B1, AIT, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550ppm, respectively.

d) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C.

Table 2: Ranges of projected pathways and consequences of alternative concentration stabilization targets; source: IPCC (2007):

Table SPM.6. *Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only.[a] {Table 5.1}*

Category	CO_2 concentration at stabilisation (2005 = 379 ppm)[b]	CO_2-equivalent concentration at stabilisation including GHGs and aerosols (2005 = 375 ppm)[b]	Peaking year for CO_2 emissions[a,c]	Change in global CO_2 emissions in 2050 (percent of 2000 emissions)[a,c]	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity[d, e]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only[f]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Notes:

a) The emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed here might be underestimated due to missing carbon cycle feedbacks (see also Topic 2.3).

b) Atmospheric CO_2 concentrations were 379ppm in 2005. The best estimate of total CO_2-eq concentration in 2005 for all long-lived GHGs is about 455ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375ppm CO_2-eq.

c) Ranges correspond to the 15[th] to 85[th] percentile of the post-TAR scenario distribution. CO_2 emissions are shown so multi-gas scenarios can be compared with CO_2-only scenarios (see Figure SPM.3).

d) The best estimate of climate sensitivity is 3°C.

e) Note that global average temperature at equilibrium is different from expected global average temperature at the time of stabilisation of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150 (see also Footnote 21).

f) Equilibrium sea level rise is for the contribution from ocean thermal expansion only and does not reach equilibrium for at least many centuries. These values have been estimated using relatively simple climate models (one low-resolution AOGCM and several EMICs based on the best estimate of 3°C climate sensitivity) and do not include contributions from melting ice sheets, glaciers and ice caps. Long-term thermal expansion is projected to result in 0.2 to 0.6m per degree Celsius of global average warming above pre-industrial. (AOGCM refers to Atmosphere-Ocean General Circulation Model and EMICs to Earth System Models of Intermediate Complexity.)

Table 3: Ranges of projected mitigation costs for alternative concentration stabilization targets; source: IPCC (2007):

Table SPM.7. *Estimated global macro-economic costs in 2030 and 2050. Costs are relative to the baseline for least-cost trajectories towards different long-term stabilisation levels. {Table 5.2}*

Stabilisation levels (ppm CO_2-eq)	Median GDP reduction[a] (%)		Range of GDP reduction[b] (%)		Reduction of average annual GDP growth rates (percentage points)[c,e]	
	2030	2050	2030	2050	2030	2050
445 – 535[d]	Not available		< 3	< 5.5	< 0.12	< 0.12
535 – 590	0.6	1.3	0.2 to 2.5	slightly negative to 4	< 0.1	< 0.1
590 – 710	0.2	0.5	-0.6 to 1.2	-1 to 2	< 0.06	< 0.05

Notes:
Values given in this table correspond to the full literature across all baselines and mitigation scenarios that provide GDP numbers.
a) Global GDP based on market exchange rates.
b) The 10th and 90th percentile range of the analysed data are given where applicable. Negative values indicate GDP gain. The first row (445-535ppm CO_2-eq) gives the upper bound estimate of the literature only.
c) The calculation of the reduction of the annual growth rate is based on the average reduction during the assessed period that would result in the indicated GDP decrease by 2030 and 2050 respectively.
d) The number of studies is relatively small and they generally use low baselines. High emissions baselines generally lead to higher costs.
e) The values correspond to the highest estimate for GDP reduction shown in column three.

References

IPCC (2001), *Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Watson, R.T. and the Core Writing Team (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 398 pp.

IPCC (2007), *Climate Change 2007: Synthesis Report. A Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds)], IPCC, Geneva, Switzerland, 104 pp.

McCarthy, James, 2010, "Reflections on: Our Planet and Its Life, Origins and Futures", *Science* **306**: 1646-1653.

Smith, J.B., Schneider, S. H., Oppenheimer, M., Yohe, G., Hare, W., Mastrandrea,, M.D., Patwardhan, A., Burton, I., Corfee-Morlot, J., Magadza, C.H.D., Füssel, H-M, Pittock, A.B., Rahman, A., Suarez, A., and van Ypersele, J-P, (2009) "Dangerous Climate Change: An Update of the IPCC Reasons for Concern", *Proceedings of the National Academy of Science* **106**: 4133-4137, March 17, 2009 {available at www.pnas.org_cgi_doi_10.1073_pnas.0812355106}.

Yohe, G., (2010) "Reasons for Concern" (about Climate Change) in the United States", *Climatic Change* **99:** 295-302 {http://www.springerlink.com/content/98403021086522r4}.