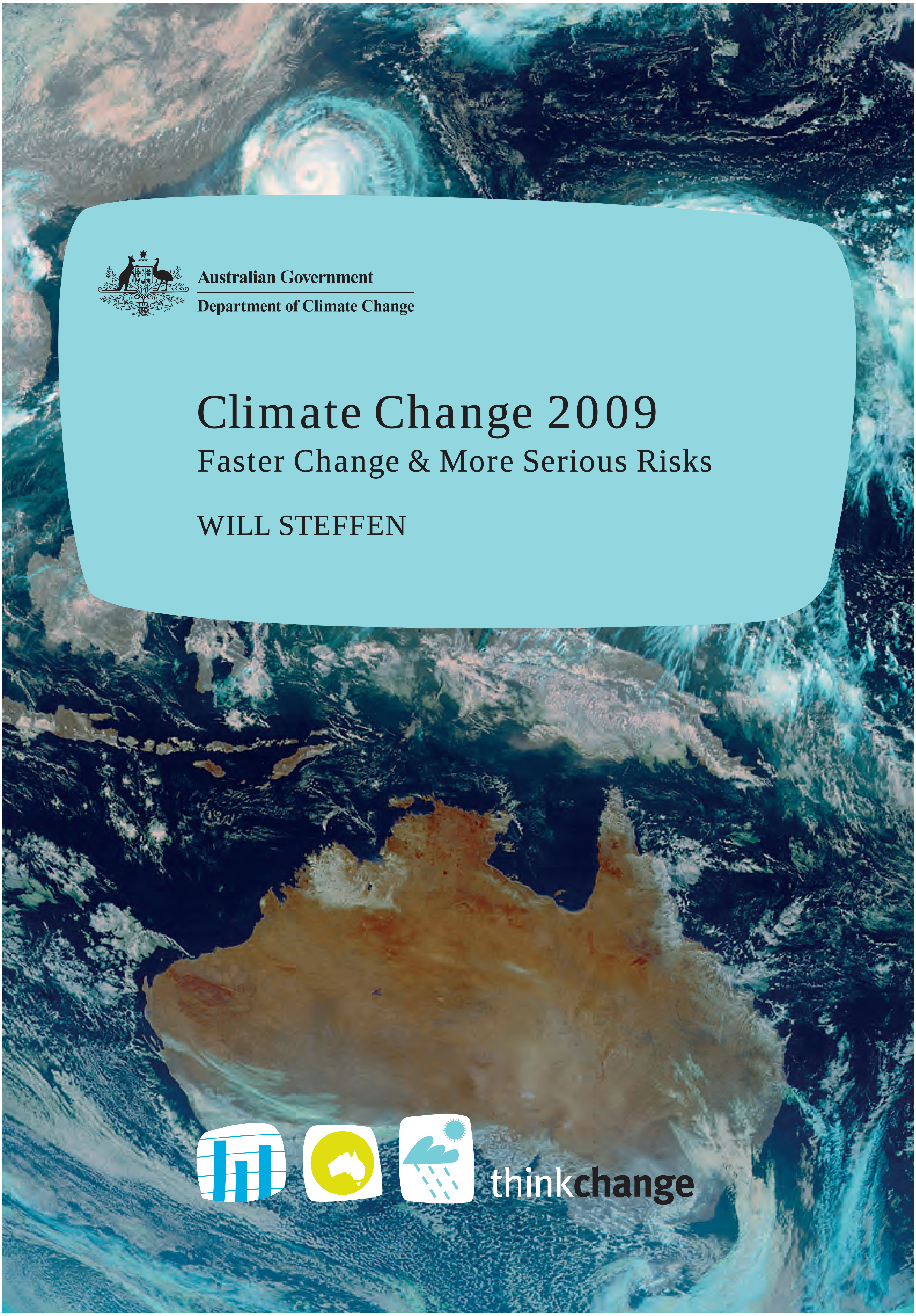

Australian Government

Department of Climate Change

Climate Change 2009

Faster Change & More Serious Risks

WILL STEFFEN

thinkchange

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Faster change and more serious risks

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Preface

Over the past few years climate change has risen to become the pre-eminent social, economic and environmental issue facing contemporary society. The reports of the Intergovernmental Panel on Climate Change (IPCC) provide an excellent scientific underpinning to inform the discussions and debates about how to deal with the climate change challenge. Climate change science, however, is a rapidly evolving field of interdisciplinary research, and much relevant research has been published since the IPCC's Fourth Assessment Report (AR4) was released in 2007.

This document reviews and synthesises the science of climate change since the publication of the IPCC's AR4, with an emphasis on rapidly changing areas of science of direct policy relevance. In that regard, the report is selective; it highlights a small number of critical issues rather than attempting to be comprehensive across the full range of climate science. Also, the report is focused more strongly on issues of importance to Australia, although it places these in a global context.

The synthesis is based primarily on scientific papers published since the IPCC's AR4, along with selected earlier papers required to provide context to the synthesis. In any report of this type, there is always room for a range of judgments regarding the published literature. I am grateful to many colleagues in the Australian climate research community for their helpful comments on drafts of this document. I have tried to accommodate their comments as far as possible; however, I assume the final responsibility for the emphases made and inferences drawn based on the published literature.

The views expressed in this document are my own, and do not necessarily represent the views of the Australian Government Department of Climate Change.

Will Steffen
Canberra
May 2009

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Executive summary: state of the science 2009

The IPCC's Fourth Assessment Report (AR4) is an outstanding source of information on our current scientific understanding of the climate system and how it is responding to the changes in the atmospheric concentration of greenhouse gases caused by human activities. In particular, the AR4 provides an excellent overview on issues where there is strong agreement, and points towards those issues where further research is required. But climate science is a rapidly moving field as researchers respond to the challenges laid out by the IPCC and the needs of governments and other groups for even better knowledge about climate change. Over the past three to four years, many new developments have occurred and many significant new insights have been gained. The most important of these are:

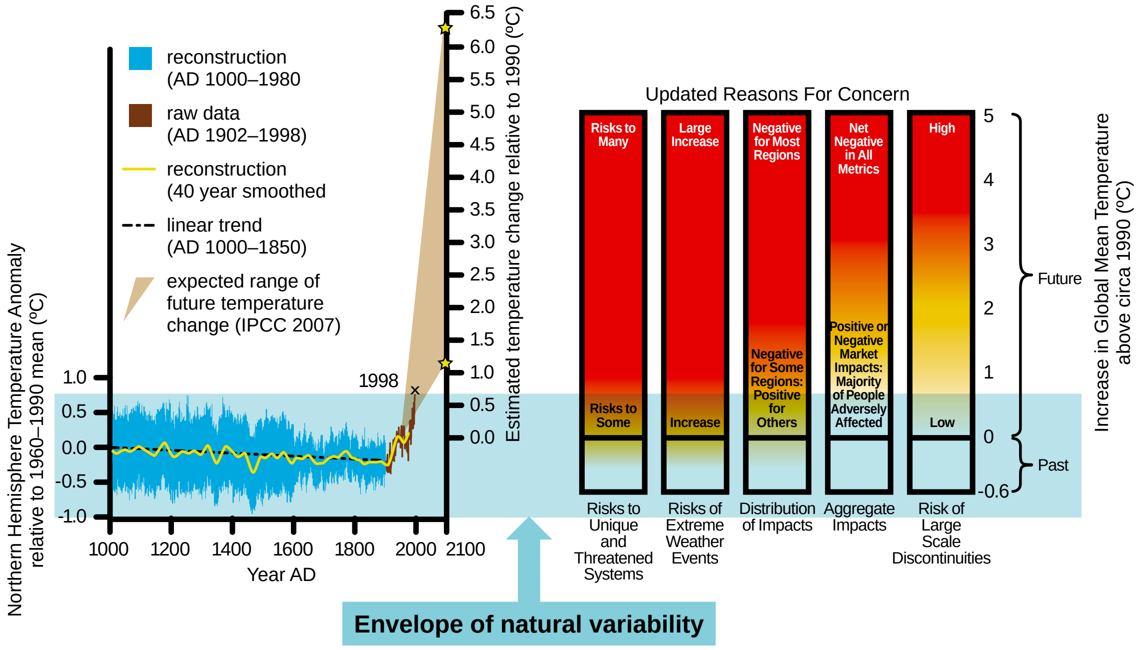
- The climate system appears to be changing faster than earlier thought likely. Key manifestations of this include the rate of accumulation of carbon dioxide in the atmosphere, trends in global ocean temperature and sea level, and loss of Arctic sea ice.
- Uncertainties still surround some important aspects of climate science, especially the rates and magnitudes of the major processes that drive serious impacts for human societies and the natural world. However, the majority of these uncertainties operate in one direction – towards more rapid and severe climate change and thus towards more costly and dangerous impacts.
- The risk of continuing rapid climate change is focusing attention on the need to adapt, and the possible limits to adaptation. Critical issues in the Australian context include the implications of possible sea-level rise at the upper end of the IPCC projections of about 0.8 m by 2100; the threat of recurring severe droughts and the drying trends in major parts of the country; the likely increase in extreme climatic events like heatwaves, floods and bushfires; and the impacts of an increasingly acidic ocean and higher ocean temperatures on marine resources and iconic ecosystems such as the Great Barrier Reef.
- Climate change is not proceeding only as smooth curves in mean values of parameters such as temperature and precipitation. Climatic features such as extreme events, abrupt changes, and the nonlinear behaviour of climate system processes will increasingly drive impacts on people and ecosystems. Despite these complexities, effective societal adaptation strategies can be developed by enhancing resilience or, where appropriate, building the capacity to cope with new climate conditions. The need for effective reduction in greenhouse gas emissions is also urgent, to avoid the risk of crossing dangerous thresholds in the climate system.
- Long-term feedbacks in the climate system may be starting to develop now; the most important of these include dynamical processes in the large polar ice sheets, and the behaviour of natural carbon sinks and potential new natural sources of carbon, such as the carbon stored in the permafrost of the northern high latitudes. Once thresholds in ice sheet and carbon cycle dynamics are crossed, such processes cannot be stopped or reversed by human intervention, and will lead to more severe and ultimately irreversible climate change from the perspective of human timeframes.

The executive summary figure places the climate change dilemma in a broad perspective. The nearly 1,000-year northern hemisphere temperature record gives an indication of the envelope of natural variability within which contemporary civilisation has developed. The IPCC projections, shown on the same timescale as the palaeo-record, depict not only the magnitude but especially the rate of the climatic changes that may lie ahead. The right-hand side of the figure illustrates why societies should be concerned about these projections.

…climate science is a rapidly moving field as researchers respond to the challenges laid out by the IPCC and the needs of governments and other groups

The executive summary figure illustrates why Lord Nicholas Stern (2009) has referred to climate change (in economic terms) as "…an externality like none other", and further commented that "…risks, scales and uncertainties (associated with climate change) are enormous. There is a large probability of a devastating outcome". Ross Garnaut (2008) has called climate change "a diabolical policy problem". Policy and economics are obviously central to responding to the climate change challenge, but the biophysical sciences will continue to play an essential, central role in characterising the climate change threat and in shaping effective solutions.

Executive summary figure
The envelope of natural variability and IPCC projections for 2100.



1 Chapter one

Climate change science: the IPCC Fourth Assessment Report and beyond

Scientific understanding of climate change has improved remarkably over the past decade. The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change recently summarised the state of climate science up to 2005–06, noting both the areas in which there is a strong scientific consensus and those issues on which much more research is required. The primary conclusions of the IPCC's Working Group I included (IPCC 2007):

- Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.
- At continental, regional and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heatwaves and the intensity of tropical cyclones.
- Palaeoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1,300 years. The last time polar regions were significantly warmer than at present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 m of sea-level rise.
- Most of the observed increase in global average temperatures since the mid 20th century is *very likely*[1] due to the observed increase in anthropogenic greenhouse gas concentrations. … Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns.
- Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century.

The strong consensus on these core aspects of climate change science provides a powerful base on which to build policy responses to the climate change challenge. However, climate science is changing rapidly. Over the past two to three years much progress has been made on further reducing uncertainties in critical aspects of the core science (e.g. Pittock 2009), but at the same time studies of important components of the climate system are revealing new uncertainties that demand further research. For example, observed recent changes in the behaviour of the large polar ice sheets and the natural carbon sinks are consistent with accelerating climate change (Rignot and Kanagaratnam 2006; Rignot et al. 2008; Cazenave 2006; Le Quéré et al. 2007), but much more needs to be understood about these phenomena to assess the degree of risk they pose. Over-the-horizon research on nonlinear aspects of climate change – tipping elements and abrupt changes – points to the serious consequences that can result from incremental changes in temperature if thresholds are crossed (Lenton et al. 2008), but much uncertainty surrounds the location of such tipping points and the probability that they will be crossed.

The objective of this document is to review the science of climate change since the publication of the IPCC's AR4, with an emphasis on areas of science that are changing rapidly and have significant consequences for our understanding and analysis of critical issues for policy and management. The report particularly focuses on our evolving understanding of the risks associated with a rapidly changing climate system.

1 *Very likely* is defined by the IPCC to mean >90% probability of the occurrence or outcome.

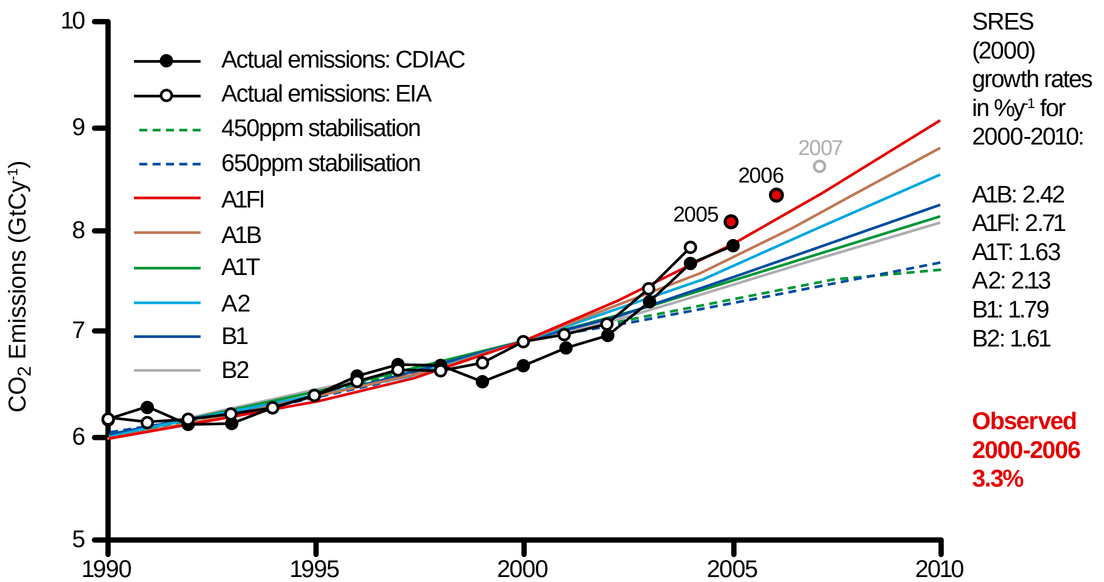
…the risks associated with the upper range of the IPCC projections of climate change for this century need to be considered seriously.

Several observations of the behaviour of the climate system over the past few decades to the present, which highlight the rate at which the system is currently changing, provide a backdrop for this review of the most recent science. Figure 1a shows that anthropogenic emissions of carbon dioxide (CO_2), the most important of the anthropogenic greenhouse gases, have been rising at or near the upper limit of the envelope of the IPCC projections since they were first published in 1990 (for updates see Sheehan et al. 2008). Furthermore, the rate of emissions has increased since 2000, due to a combination of growth in the global economy, an increase in the carbon intensity of the economy, and a decline in the efficiency of natural carbon sinks in absorbing anthropogenic emissions of CO_2 (Canadell et al. 2007). The impact of the global financial crisis on greenhouse gas emissions will probably be discernible at the global scale. Whether a likely fall in emissions is a short-term phenomenon with a return to the post-2000 emissions rates, or whether the financial crisis marks the beginning of a longer-term return to lower emissions rates, remains to be seen.

Consistent with the observed trajectory of CO_2 emissions to date, the trajectories of global average temperature (Easterling and Wehner 2009) and sea-level rise are tracking within the IPCC envelope of projections, with sea level rising near the upper limit of the IPCC range (figures 1b,c; Rahmstorf et al. 2007; Domingues 2008). The precipitous decline in the area of Arctic sea ice in summer over the past two years (Figure 2a,b; Johannessen 2008) is evidence that some components of the climate system are responding rapidly and nonlinearly to the current rate and magnitude of warming due to anthropogenic emissions of greenhouse gases.

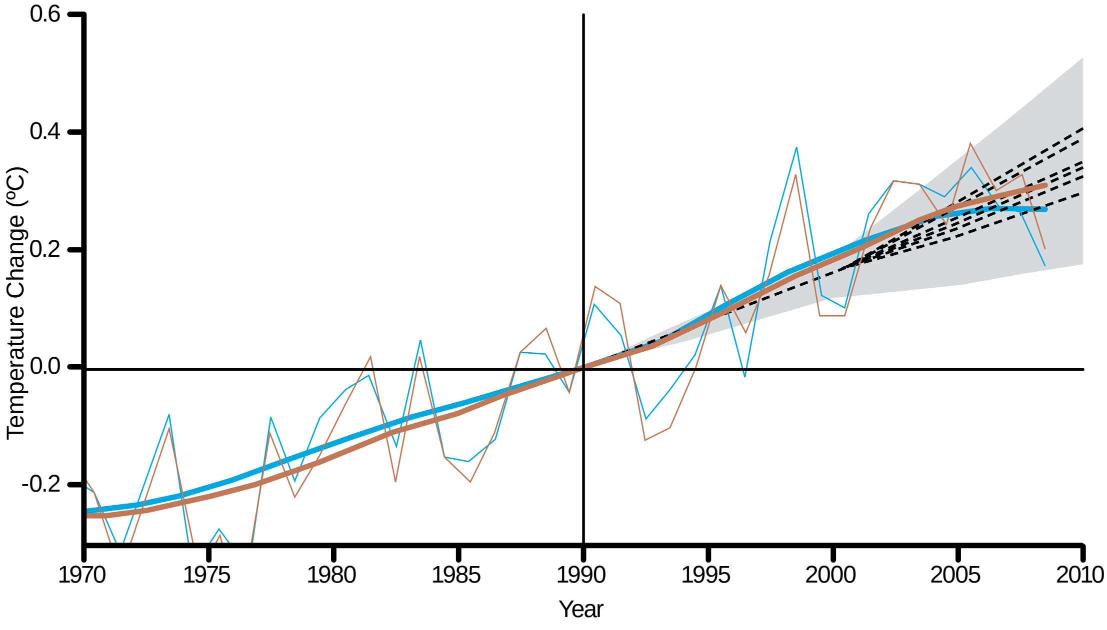
In summary, these observations and post-AR4 research are leading to a perception amongst many scientists that the risks associated with the upper range of the IPCC projections of climate change for this century need to be considered seriously.

Figure 1a. Observations of anthropogenic CO_2 emissions from 1990 to 2007.



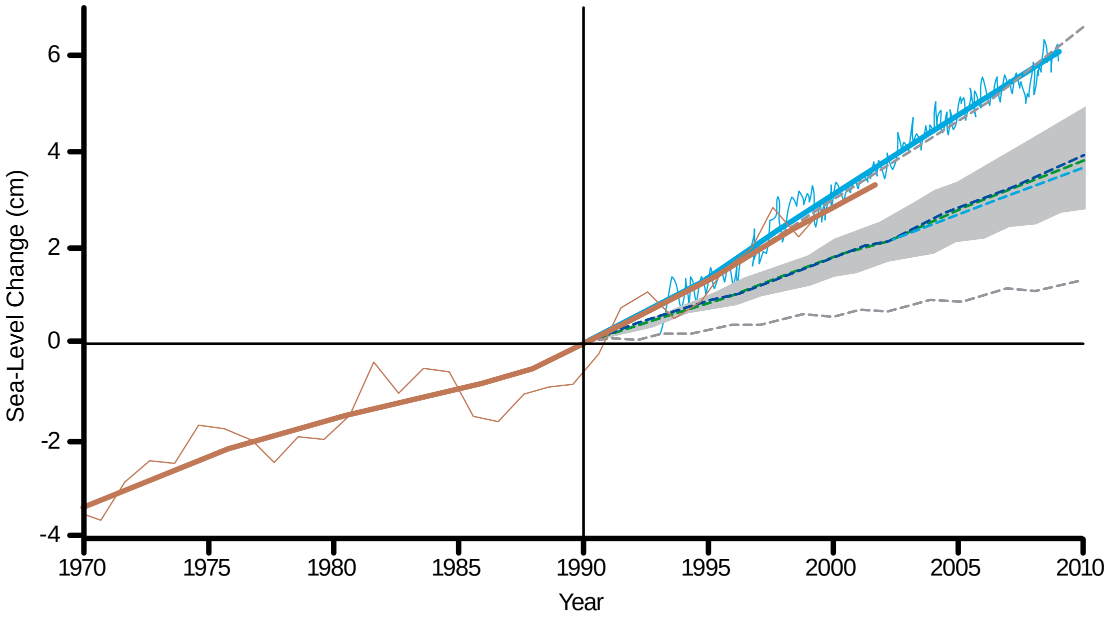
The envelope of IPCC projections are shown for comparison. (Source: Raupach et al. 2007 with additional data points from Canadell et al. 2007 and Global Carbon Project annual carbon budgets)

Figure 1b. Global average surface air temperature (smoothed over 11 years).



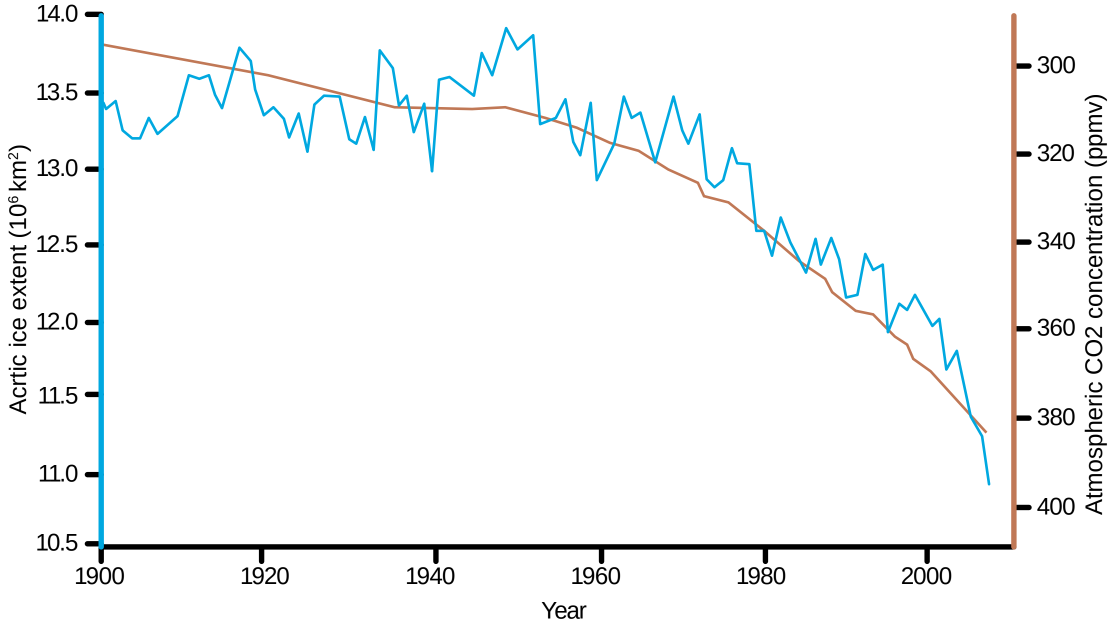
The blue line represents data from Hadley Center; the brown line is GISS data. (Source: Rahmstorf et al. 2007 with data for 2007 and 2008 from S. Rahmstorf)

Figure 1c. Sea-level change from 1970 to 2008.



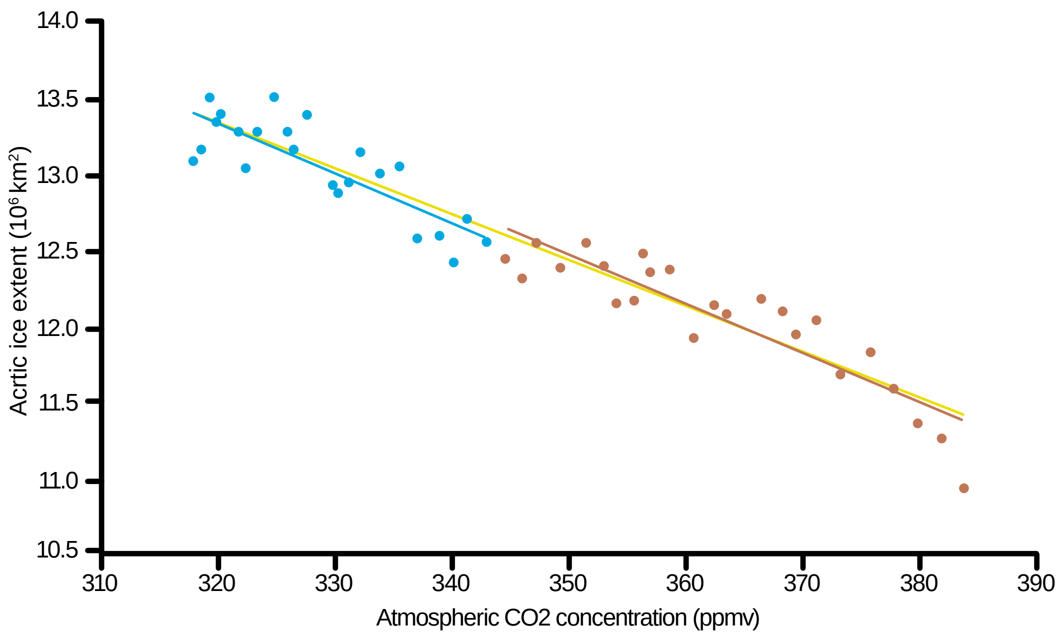
The envelope of IPCC projections are shown for comparison. (Source: After Rahmstorf et al. 2007, based on data from Cazenave and Narem (2004); Cazenave (2006) and A. Cazenave for 2006–2008 data)

Figure 2a. Arctic sea-ice extent and CO_2.



Time series of annual Arctic sea-ice extent and atmospheric concentrations of CO_2 for the period 1900–2007. Note that the CO_2 scale is inverted. (Source: Johannessen 2008, including further details on data)

Figure 2b. Correlation of CO_2 and sea-ice extent.



Scatterplot and regression lines indicate the correlation of CO_2 and sea-ice extent for the periods 1961–1985 (blue) and 1986–2007 (brown). (Source: Johannessen 2008, including further details on data)