



MEMORANDUM

From: Mark Briscoe
Date: 7 March 2004
Subject: Climate Change Beyond 2100

Introduction

The implications of climate change beyond the year 2100 depend heavily on what occurs during the coming century. Because of the uncertainties involved, climate scientists are reluctant to predict how much CO₂ and other greenhouse gases people will emit over the 21st century. For example, one commonly cited unknown involves the inability of scientists to predict how technological innovations might reduce or sequester greenhouse gas emissions. Equally uncertain are the rates of population growth and economic growth during the coming century, both of which will influence the amount of greenhouse gases people create.

Rather than making predictions, climate scientists make projections based on possible greenhouse gas emissions and atmospheric accumulations. In other words, they project what would happen to the climate under a scenario of, say, rapid economic growth and high technological innovation and under another scenario of, say, slow economic growth and moderate innovation. However, most climate researchers are reluctant to predict which of these scenarios is more likely to actually occur. This uncertainty is why climate models yield a fairly broad range of future temperature increases (such as an increase of 1.4° C to 5.8° C by 2100 as reported in the IPCC's TAR). There is an on-going debate in the scientific community about whether scientists should assign probabilities to the various warming scenarios as a means of at least partially resolving the uncertainty issue. Of course, we believe they should, and this is a strongly held view of Dr. Stephen Schneider, among others.

Beyond 2100, the uncertainties are increasingly huge and therefore our understanding of how climate is likely to change is increasingly small. Currently, most researchers feel that with aggressive international actions to limit CO₂ emissions, it may be possible to stabilize the atmospheric CO₂ concentration at about double pre-industrial levels. Under a so-called "business-as-usual" scenario in which CO₂ emissions continue to increase at the current rate of about 1% per year, the atmospheric CO₂ level would nearly triple by 2100 and continue rising steeply thereafter. The consensus is that actual emissions and stabilization levels will likely fall somewhere between these two extremes.

Scientists assume that governments will eventually have no choice but to take action to radically reduce CO₂ emissions to levels (20% to 40% of current emissions—or less) that will stabilize CO₂ concentrations. Most climate models run based on

assumptions about when and at what level CO₂ will stabilize. Projections of the stabilization level range from a doubling of pre-industrial CO₂ levels to a quadrupling.

Selected Studies and Papers

IPCC

The IPCC reports generally use the year 2100 as a cutoff when assessing the impacts of climate change. However, the Third Assessment Report does provide some insight into climate change beyond 2100. Some of the key statements in the report include:

- “Carbon cycle models indicate that stabilization of atmospheric CO₂ concentrations at 450, 650 or 1,000 ppm would require global anthropogenic CO₂ emissions to drop below 1990 levels, within a few decades, about a century, or about two centuries, respectively, and continue to decrease steadily thereafter. Eventually CO₂ emissions would need to decline to a very small fraction of current emissions.”¹
- “After greenhouse gas concentrations have stabilised, global average surface temperatures would rise at a rate of only a few tenths of a degree per century rather than several degrees per century as projected for the 21st century without stabilisation. The lower the levels at which concentrations are stabilised, the smaller the total temperature change.”²
- “Global mean surface temperature increases and rising sea level from thermal expansion of the ocean are projected to continue for hundreds of years after stabilisation of greenhouse gas concentrations (even at present levels), owing to the long timescales on which the deep ocean adjusts to climate change.”³
- “Projected climate changes during the 21st century have the potential to lead to large-scale and possibly irreversible changes in Earth systems resulting in impacts at continental and global scales. These possibilities are very climate scenario-dependant and a full range of plausible scenarios has not yet been evaluated. Examples include significant slowing of the ocean circulation that transports warm water to the North Atlantic, large reductions in the Greenland and West Antarctic Ice Sheets, accelerated global warming due to carbon cycle feedbacks in the terrestrial biosphere, and releases of terrestrial carbon from permafrost regions and methane from hydrates in coastal sediments. The likelihood of many of these changes in Earth systems is not well-known, but is probably very low; however, their likelihood is expected to increase with the rate, magnitude, and duration of climate change.

“If these changes in Earth systems were to occur, their impacts would be widespread and sustained. For example, significant slowing of the oceanic thermohaline circulation would impact deep-water oxygen

¹ Summary for Policymakers, Working Group I, p. 12.

² Ibid., 17.

³ Ibid.

levels and carbon uptake by oceans and marine ecosystems, and would reduce warming over parts of Europe. Disintegration of the West Antarctic Ice Sheet or melting of the Greenland Ice Sheet would raise global sea level up to 3 m each over the next 1,000 years, submerge many islands, and inundate extensive coastal areas. Depending on the rate of ice loss, the rate and magnitude of sea-level rise could greatly exceed the capacity of human and natural systems to adapt without substantial impacts. Releases of terrestrial carbon from permafrost regions and methane from hydrates in coastal sediments, induced by warming, would further increase greenhouse gas concentrations in the atmosphere and amplify climate change.”⁴

Princeton

Syukuro Manabe and Ronald J. Stouffer of NOAA’s Geophysical Fluid Dynamics Laboratory at Princeton University published early studies evaluating the potential long-term consequences of climate change. They ran their climate model using scenarios resulting in an eventual doubling in atmospheric CO₂ and in a quadrupling. The first scenario produced a surface air temperature increase of about 3.5° C and a sea-level rise due to thermal expansion of about 1 m over 500 years. The second scenario yielded a temperature increase of about 7° C and a sea-level rise of about 2 m.⁵

Potsdam Institute

Stefan Rahmstorf and Andrey Ganopolski of the Potsdam Institute for Climate Research investigated a scenario in which CO₂ atmospheric concentrations increase rapidly through 2100 and peak in 2150 at a quadrupling of pre-industrial levels. Their scenario also assumes the end of the fossil-fuel age and a decrease of CO₂ emissions to near zero by 2200. The model results in a temperature increase of 4.3° C in 2100. The peak CO₂ concentration occurs in 2150 and the average surface temperature peaks at just over 5° C several decades thereafter. However, the elevated average temperature is slow to decline. “[T]he subsequent decline in global temperature is much slower than the CO₂ concentration decline. While the prescribed CO₂ anomaly is back to half its peak value in the year 2330, the temperature anomaly takes to around the year 2600 to go back to half its peak level.”

The model also looks at a scenario under which the thermohaline circulation of the ocean collapses due to global warming. This produces an average air temperature rise of 3° C for the North Atlantic until 2100, but then a rapid decline in the average temperature of 3° C within four decades. According to the model, the cooling continues

⁴ Summary for Policymakers, Working Group II, p. 6.

⁵ Syukuro Manabe and Ronald J. Stouffer, “Century-Scale Effects of Increased Atmospheric CO₂ on the Ocean-Atmosphere System,” *Nature* 364 (15 July 1993): 215. Note: the sea-levels rise projection only account for thermal-expansion of the oceans; the authors state that melting ice sheets and glaciers will result in a significant additional sea-level rise.

and by the year 3000, the North Atlantic's average air temperature is 6° C cooler than in pre-industrial times, bringing serious consequences for northwest Europe.⁶

Hadley Centre

Models run by the Hadley Center of the United Kingdom's Meteorological Office project climate change for scenarios in which CO₂ emissions stabilize at 750 ppm (nearly three times pre-industrial levels) early in the 23rd century and 550 ppm (double pre-industrial levels) during the mid 22nd century. Under the first scenario, the global average temperature would rise by just over 4° C by the 2230s. Under the second, temperatures would rise just over 3° C.⁷

Klaus Hasselmann, et al.

A group of European researchers compared two "business as usual" (BAU) scenarios and scenarios that reduce CO₂ emissions based on "optimized cost/benefit trajectories." The first BAU scenario assumes that the world uses up all conventional fossil fuel resources. This scenario results in a peak CO₂ concentration of quadruple the pre-industrial level in about 2200 and a peak temperature increase of about 4° C in early 23rd century, with the temperature slowly declining to slightly more than 3° C over the pre-industrial level by the year 3000. Sea-levels would rise by nearly 4 m by 3000.

The second BAU scenario assumes that the world uses up all conventional and exotic fossil fuel resources. This scenario is even bleaker. It results in a peak CO₂ concentration in the 26th century at 15 times the pre-industrial level and a global temperature that reaches 9° C over the pre-industrial average late in this millennium. The sea level would reach nearly 8 m above the pre-industrial level by 3000 and would continue to rise.⁸

Once again, however, the uncertainties play a large role. The researchers warn that for both of the BAU scenarios: "Predictions of this magnitude are beyond the calibration ranges of climate models and must therefore be treated with caution."

The scenarios under which governments, businesses, and individuals implement long-term, cost-benefit-based CO₂ reduction plans result in peak CO₂ concentrations of less than double pre-industrial levels. The peak temperature increase under these scenarios (occurring around the 24th century) would range from 1.4° to 1.7° C over the pre-industrial average. The sea level change in the year 3000 would be around 1 m or slightly less.⁹

⁶ Stefan Rahmstorf and Andrey Ganopolski, "Long-Term Global Warming Scenarios Computed With an Efficient Coupled Climate Model," *Climatic Change* 43 (1999): 353-367.

⁷ The Meteorological Office (UK), "Climate Change and Its Impacts: Stabilisation of CO₂ in the Atmosphere," October 1999.

⁸ This study only considers CO₂ emissions and concentrations. "Inclusion of other greenhouse gases could increase the peak values by ~10 to 20%."

⁹ K. Hasselmann, et al., "The Challenge of Long-Term Climate Change," *Science* 302 (12 Dec. 2003): 1923-1925.

Jerry Mahlman

Mahlman, senior research fellow at the National Center for Atmospheric Research, has written a very good paper explaining why global warming, rising sea-levels, and other consequences of climate change will continue for centuries after the stabilization of CO₂ in the atmosphere. The paper, “The Long Time Scales of Human-Caused Climate Warming: Further Challenges for the Global Policy Process,” also discusses problems faced by policymakers when developing responses to climate change. The paper is online at:

http://www.atmos.colostate.edu/dept/40th/talks/timing_mahlman.pdf.

Conclusion

Although climate projections beyond 2100 are complicated by high levels of uncertainty, some modelers have begun to address this important issue. This memo represents a collection of work that will prove vital when we move forward with legal actions designed to force federal agencies to include implications of long-term climate change in their future policy decisions and environmental impact assessments.

Finally, the issue of climate change beyond 2100 goes hand-in-hand with our development of an “uncertainty” policy paper and our efforts to clarify uncertainty in global warming science for policymakers. Developing a greater understanding of what is meant by “uncertainty” in climate change science will enhance our efforts to compel policymakers and the courts to take long-term warming seriously.

Selected Scientists Who Have Made Long-Term Climate Projections

United States

Syukuro Manabe, NOAA-Princeton (retired)

Ronald J. Stouffer, NOAA-Princeton

Jerry D. Mahlman, National Center for Atmospheric Research

Berrien Moore

International

Stefan Rahmstorf, Potsdam Institute for Climate Research

Andrey Ganopolski, Potsdam Institute for Climate Research

Klaus Hasselmann, European Climate Forum and Max Planck Institute

The Hadley Centre for Climate Prediction and Research, the Met. Office, London