Quantifying climate change — Too rosy a picture?

Stephen E. Schwartz, Robert J. Charlson and Henning Rodhe

Submitted to: *Nature Reports – Climate Change*

May 2, 2007

The challenge of climate change research is to develop confident predictive capability. Given prospective future emissions of greenhouse gases and other climate influencing substances such as aerosols, what changes in global mean surface temperature and other climate attributes can be expected, and what confidence can be placed in these projected changes? The single most important concept here is the relationship between climate forcing and the response of the system. Forcing (measured in watts per square metre) is the global mean change in energy balance imposed over time by changes in atmospheric composition (for example CO_2, CH_4 and aerosols) and other influences such as land use. It is the key diagnostic of human climate perturbation.

In its latest report on the physical science basis of climate change[1], the Intergovernmental Panel on Climate Change (IPCC) moves increasingly beyond detecting global change and attributing it to human activity, into quantitative assessment of the ability to forecast the prospective change in climate that would result from future emissions scenarios. This new direction requires careful analysis of the uncertainties associated with assessing future climate change, and the new report is explicit in its definitions. In a departure from previous reports, the latest assessment gives a best estimate of climate sensitivity — the increase in global mean surface temperature that would be expected to result from a doubling of atmospheric CO_2 levels. The present best estimate of 3 °C is the same as that given by a US National Research Council panel in 1979, but it now comes with a well-defined confidence interval. Specifically, the report states that the sensitivity "is likely to be in the range 2 °C to 4.5 °C," where "likely" is defined to mean a greater than 66% probability that the actual quantity is within the stated range.

In a further important departure from earlier IPCC reports, the fourth assessment report estimates the total climate forcing from human activity (and its uncertainty), calculated as the sum of individual components such as land use, ozone levels and direct greenhouse-gas emissions (and their respective uncertainties) (See Fig. 1). The estimated forcing for the several components combined — 1.6 W m^{-2} over the industrial period — is nearly the same as that from CO_2 emissions alone because some of the warming effects of greenhouse gases are being cancelled out by the cooling effects of anthropogenic aerosols. Cooling, or negative forcing, occurs primarily through direct effects such as scattering of light in cloud-free air and indirect effects such as enhanced reflection of light by clouds. These aerosol forcings are much less certain than the greenhouse-gas forcings, and hence the total forcing is likewise quite uncertain. The new report estimates total anthropogenic forcing to be 0.6 to 2.4 W m^{-2} (5–95% confidence range). This factor of four range greatly limits the ability to evaluate the skill of climate models in reproducing past temperature changes and to infer climate sensitivity from observed change because a given temperature increase might result from a large forcing and low climate sensitivity or alternatively from a small forcing and high climate sensitivity.

An accurate estimate of climate forcing from prior anthropogenic emissions is essential for assessing the performance of global climate model calculations by comparison with observations. Carrying out such calculations for a range of forcings consistent with the uncertainty estimates would allow the resulting uncertainty in modelled temperature change to be determined. The temperature changes over the twentieth century summarized in the IPCC report (see Fig. 2) represent results from an ensemble of 58 runs with 14 climate models. Comparing the model results to observations, the report asserts that "the models produce good simulations of the warming that has occurred over the past century," as the figure indeed indicates. The range of modelled global temperature changes from such an ensemble of runs would be expected to be larger than that arising from the uncertainty in the forcing as it would also reflect uncertainties arising from the differences in the multiple climate models used. Contrary to such an expectation, the range in modelled global mean temperature change, given by the width of the rose-colored band in Fig. 2 — about a factor of two and stated as representing the 5–95% confidence level of the temperature change obtained with this ensemble of simulations — is much smaller than that associated with the forcings, which is a factor of four.

How can this be? Evidently a variety of forcings and different representations of these forcings were used in simulations with the different models. As the use of such an ensemble of opportunity led to a narrowing of uncertainty rather than to the expected increase, it would seem that the forcings used in the models did not span the full range of the uncertainty shown in Fig. 1. Another possibility is that the forcings used in the model runs were anticorrelated with the sensitivities of the models; that is, models with high sensitivities used low forcings and vice versa. Either way, the uncertainty in modelled temperature increase that should have resulted from such an exercise must be substantially greater than is indicated by the range of modelled temperature trends over the twentieth century shown in Fig. 2.

Does resolving this inconsistency matter? Yes, even if only to give a more accurate picture of the range of sensitivities of current models. As it stands, the narrow range of modelled temperatures gives a false sense of the certainty that has been achieved. A much more realistic assessment of present understanding would be gained by testing the models over the full range of forcings given in Fig. 1. Additionally, the predictive ability of the models could be confidently assessed by subjecting them to the same forcing profile over the twentieth century and comparing the modelled temperature changes. A much more difficult task would be to carry out the research necessary to constrain the forcing sufficiently well to rule out models that do not accurately represent temperature changes over the twentieth century.

The century-long lifetime of atmospheric CO_2 and the anticipated future decline in atmospheric aerosols mean that greenhouse gases will inevitably emerge as the dominant forcing of climate change, and in the absence of a draconian reduction in emissions, this forcing will be large. Such dominance can be seen, for example, in estimates from the third IPCC report of projected total forcing in 2100 for various emissions scenarios[2] as shown at the bottom of Fig. 1. Depending on which future emissions scenario prevails, the projected forcing is 4 to 9 W m^{-2}. This is comparable to forcings estimated for major climatic shifts, such as that for the end of the last ice age[3]. Developing effective strategies, both to limit emissions of CO_2 and to adapt to the inevitable changes in global climate will depend on climate sensitivity. The magnitude of forcing anticipated in 2100 thus highlights the urgency of reducing uncertainty in Earth's climate sensitivity.

Stephen E. Schwartz is in the Atmospheric Sciences Division, Brookhaven National Laboratory, Upton, New York 11973, USA. Robert J. Charlson is in the Department of Atmospheric Sciences, University of Washington, Seattle, Washington 98195, USA. Henning Rodhe is in the Department of Meteorology, Stockholm University, 10691 Stockholm, Sweden.

References

1. *Working Group I Report: The Physical Basis of Climate Change* (Intergovernmental Panel on Climate Change, 2001); http://ipcc-wg1.ucar.edu/wg1/wg1-report.html

2. Intergovernmental Panel on Climate Change, 2001. C*limate Change 2001: The Scientific Basis*. (eds Houghton, J. T. *et al.*) (Cambridge Univ. Press, Cambridge, 2001).

3. Hoffert, M. I. & Covey C. *Nature* **360,** 573– 576 (1992).

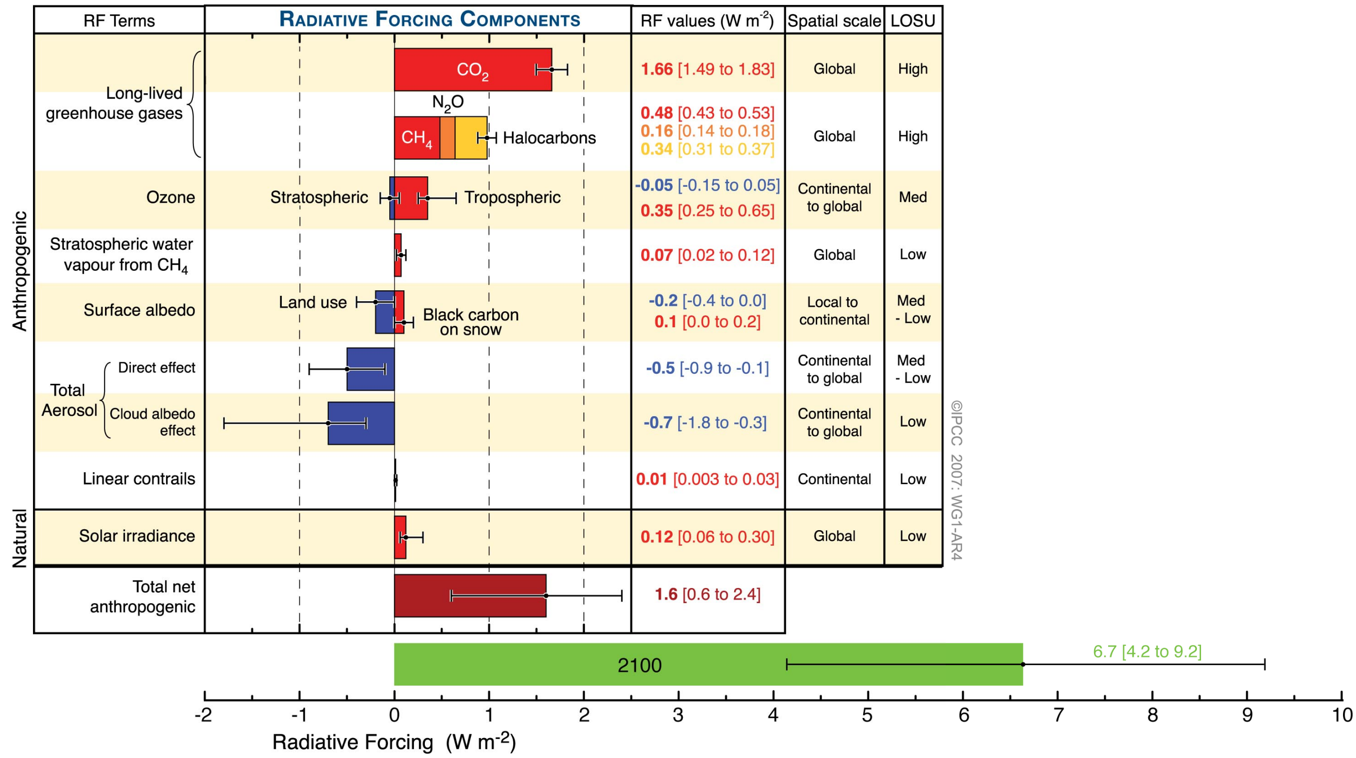

Figure 1 Global average radiative forcing (RF) estimates and uncertainty ranges in 2005, relative to the preindustrial climate, for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The total anthropogenic radiative forcing and its associated uncertainty (5–95% confidence interval) are also shown[1]. Added to the figure (green bar at bottom and associated uncertainty range) is the estimate from the 2001 IPCC report[2] of the total forcing projected for 2100, where the uncertainty denotes the range of estimates for different emission scenarios.

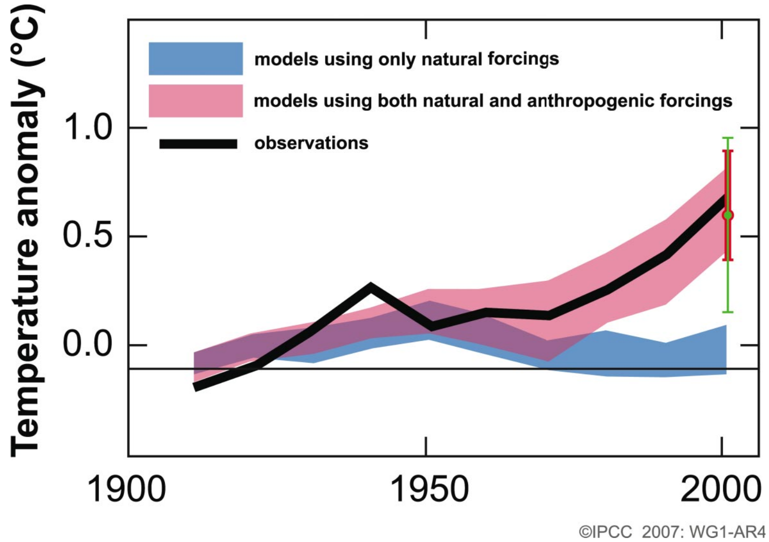

Figure 2 Comparison of observed changes in global mean surface temperature with results simulated by climate models using natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906–2005 (black) plotted against the centre of the decade and relative to the corresponding average for 1901–1950. The blue band shows the 5–95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. The rose-colored band shows the 5–95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings[1]. Added to the figure are I-beams denoting uncertainties. The range of the modelled increase in global mean surface temperature over the twentieth century (red) — ~0.5 to 1.0 °C, or a factor of 2 — is smaller than that of the IPCC estimate for the global mean forcing (green), given in Fig. 1, which is a factor of 4.