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From Uncertain to Unequivocal

The IPCC Working Group I Report: *Climate Change 2007–The Physical Science Basis*

Reviewed by Diana Liverman

With the publication of the Fourth Assessment report of the Intergovernmental Panel on Climate Change (IPCC), this year marks some important shifts in our understanding of climate change and its impacts. Three working groups produced reports covering physical science (WGI); impacts, adaptation, and vulnerability (WGII); and mitigation (WGIII). The WGI report on physical science involved more than 550 authors and published a summary for policymakers in February, followed by the full report in May after a long process of review by experts and government departments around the world. The reports have been widely discussed in scientific meetings and will become a major reference source, especially since all the reports are freely available on the Internet.[1] The WGI report was published first and attracted considerable media attention because of its apparently definitive conclusions about the rate and causes of climate change.

Perhaps the most emphatic conclusion of the WGI report is that "warming of the climate system is unequivocal" and that much (50 percent) of this warming is very likely (more than 90 percent) due to increases in greenhouse gas concentrations associated with human activity. These statements are much more confident than those in the 2001 IPCC report and may seem unsurprising to those who regularly read the scientific literature. But for many people who are not climate science experts, some of the important incremental shifts in the understanding of climate change are less obvious, especially as the issue has been confused by the sustained media and political attention to climate skeptics.

WGI reports strong evidence that our climate is already changing, including significant increases in global surface temperature of 0.74°C (+/-0.18) over the past century; more frequent heat waves and heavy rainfall events; warming of the ocean to a depth of 3,000 meters (m); increases in atmospheric water content; and declines in mountain glaciers, snow cover, and Arctic sea ice. IPCC also concludes that global average sea level has increased 1.8 millimeters (mm) (+/-0.5) per year since 1961 (and 3.1 mm per year since 1993), there has been an increase in the most intense tropical cyclone activity (but not the number of overall hurricanes) in the North Atlantic, and these changes are more likely than not (at least 50 percent) associated with human causes. The assessment of research on past climates concludes that it is likely that the second half of the twentieth century was warmer than any period in the last 1,300 years. Table 1 on page 29 provides a summary of these and other trends.

The report concludes that anthropogenic greenhouse gas emissions are still growing despite 15 years of international negotiations under the UN Framework Convention on Climate Change. The net effect on the Earth's energy balance (the radiative forcing) is clearly communicated in a graphic showing that although methane, nitrous oxide, and halocarbons have high global warming potentials, and aerosols have a cooling effect, the magnitude and long lifetime of carbon dioxide makes it by far the most significant anthropogenic greenhouse gas (see Figure 1 on page 30). This makes it all the more worrying that overall carbon dioxide emissions from fossil fuels increased from 6.4 gigatons per year (+/-0.4) in the 1990s to more than 7.2 gigatons per year (+/-0.3) since 2000, and concentrations are now 379 parts per million (a 35 percent increase over preindustrial levels and higher than in, at the least, any of the previous 650,000 years).

This trend is toward the higher emission scenarios used in the simulation models of future changes in climate, where, for example, the fossil-intensive economic growth scenario (SRES A1F1) simulations project a best estimate of 4°C global average surface warming by 2090–2099 compared to the 1980–1999 average. The low end (B1) scenario has a best estimate of 1.8°C, and the report reminds us that even if we stabilized emissions at 2000 levels, the world would continue to warm because of the slow response of oceans and ice sheets. This insight, together with the conclusion that warming over the continents between now and 2030 is the same in distribution no matter which scenario is used, highlights the need for adaptation and for strategies to manage the carbon cycle over the much longer term.

The media reported some controversy over the sea-level rise projections, which appear at first glance to be lower than those in the 2001 report. Ranging from 0.18 m to 0.59 m by the 2090–2099 period, depending on the scenario, the range is narrower because the 2001 report projected for the end of the decade in 2100 and because the methodology of the Fourth Assessment gives uncertainties spanning the 5 to 95 percent probability rather than the +/-2 standard deviations used in the Third Assessment in 2001. Additionally, WGI decided not to include some key feedbacks because of uncertainty and a lack of published literature. (For example, it did not include the possibility of rapidly melting Greenland and Antarctic ice sheets, which would bring much higher sea levels.) The WGI report projects a new insight into ocean chemistry of major significance to ecosystems and policy: increased acidification

Table 1. Recent trends, assessment of human influence on the trend, and projections for extreme weather events for which there is an observed late twentieth-century trend

Phenomenon and direction of trend	Likelihood that trend occurred in late twentieth century (typically post 1960)	Likelihood of a human contribution to observed trend	Likelihood of future trends based on projections for twenty-first century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	Very likely[a]	Likely[b]	Virtually certain[b]
Warmer and more frequent hot days and nights over most land areas	Very likely[c]	Likely (nights)[b]	Virtually certain[b]
Warm spells/heat waves. Frequency increases over most land areas	Likely	More likely than not[d]	Very likely
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	Likely	More likely than not[d]	Very likely
Area affected by droughts increases	Likely in many regions since 1970s	More likely than not	Likely
Intense tropical cyclone activity increases	Likely in some regions since 1970	More likely than not[d]	Likely
Increased incidence of extreme high sea level (excludes tsunamis)[e]	Likely	More likely than not[d,f]	Likely[g]

[a] Decreased frequency of cold days and nights (coldest 10 percent).
[b] Warming of the most extreme days and nights each year.
[c] Increased frequency of hot days and nights (hottest 10 percent).
[d] Magnitude of anthropogenic contributions not assessed. Attribution for these phenomena based on expert judgment rather than formal attribution studies.
[e] Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1 percent of hourly values of observed sea level at a station for a given reference period.
[f] Changes in observed extreme high sea level closely follow the changes in average sea level. It is very likely that anthropogenic activity contributed to a rise in average sea level.
[g] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period. The effect of changes in regional weather systems on sea level extremes has not been assessed.

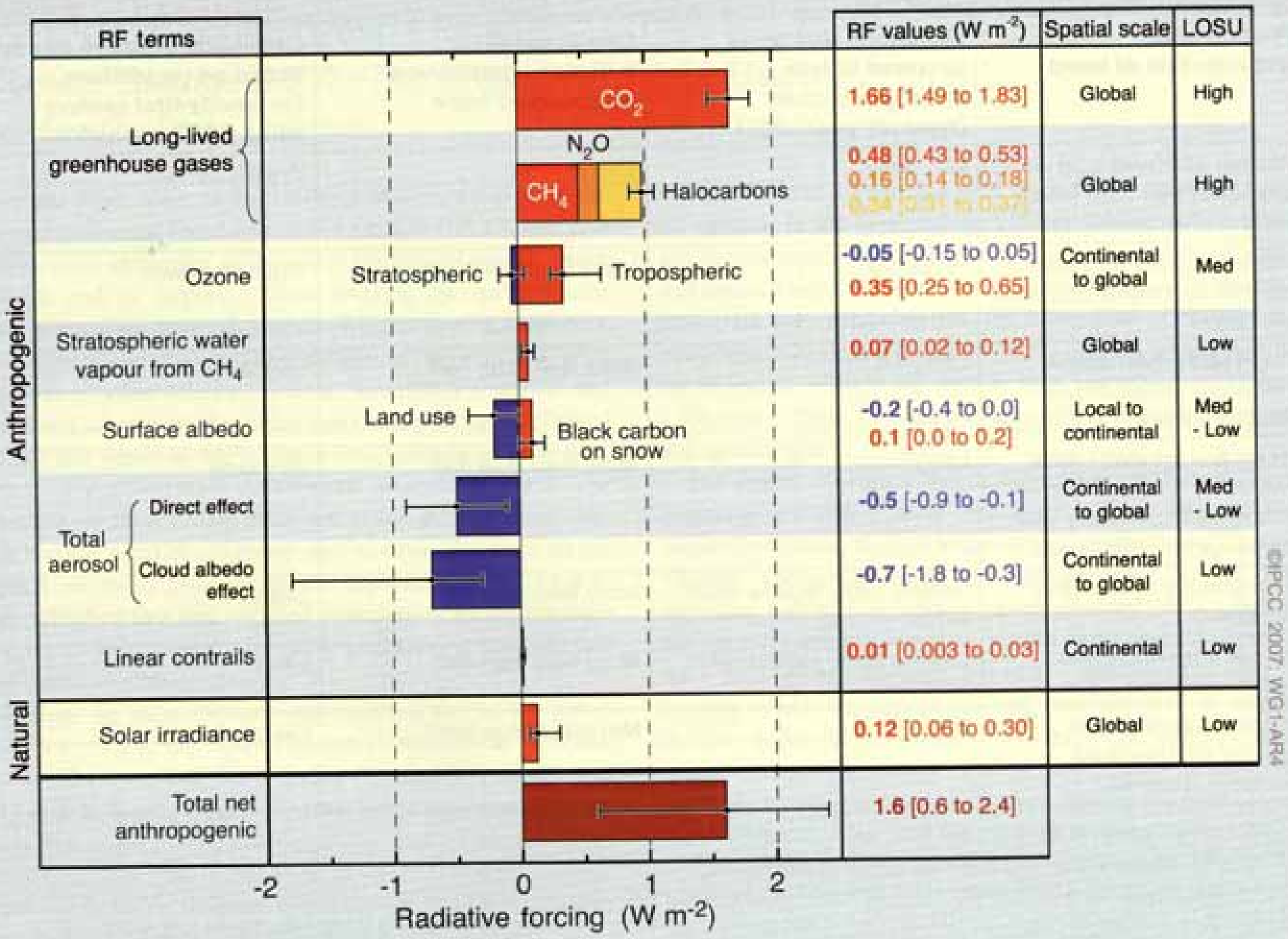
NOTE: SRES refers to the Special Report on Emissions Scenarios (SRES) originally prepared for the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report in 2001.

SOURCE: Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis, Summary for Policymakers* (Geneva: IPCC, 2007), Table SPM.2 at page 8.

of the oceans as a result of high CO_2 concentrations, with reductions in ocean surface pH of between 0.14 and 0.35 units by the end of the twenty-first century. This may have adverse effects on calcifying species, such as corals, and on phytoplankton, and such chemical changes must be accounted for by mitigation technologies.

The Fourth Assessment was able to take advantage of a much larger number of climate models and simulations than previous assessments, including multiple runs (ensembles) that reflect a range of uncertainties about initial conditions, processes, and emissions or other forcings. While policymakers and the public hope that this increased modeling effort will provide more certain projections, it may in actuality increase uncertainty, but with much better understanding and quantification. The climate sensitivity (the equilibrium response to an equivalent doubling of carbon dioxide concentrations over preindustrial levels) is

Figure 1. Radiative forcing components



NOTE: This figure shows global average radiative forcing (RF) estimates and ranges in 2005 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). RF values are measured in watts per square meter (W m^{-2}). The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. The range for linear contrails does not include other possible effects of aviation on cloudiness.

SOURCE: Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007: The Physical Science Basis, Summary for Policymakers* (Geneva: IPCC, 2007), Figure SPM.2 at page 4.

more confidently quantified than in previous assessments, in the range of 2°C to 4.5°C with a most likely value of 3°C, but the report states that values much higher than 4.5°C can not be excluded.

For most of the world's people and ecosystems, the real test of the IPCC is its ability to provide improved projections of how climate will change at the regional level, and here the Fourth Assessment provides less guidance than those concerned with impacts or adaptation might hope for. As noted in previous IPCC reports, the poles are projected to warm more than the equator, and the land more than the oceans. Snow cover and sea ice are projected to decrease and permafrost to thaw. Overall global precipitation is considered very likely to increase at high latitudes, especially in North America and Northern Asia (most models project a 10 percent increase), and likely to decrease in subtropical land regions such as southern Europe and southern Africa. However, over large areas of Latin America, Africa, Asia, and Australia, the climate models could not agree whether precipitation would increase or decrease.

The full report and its technical summary elaborates on the challenges of simulating regional climates, highlighting the difficulties of modeling interannual variability (such as El Niño), extreme weather, and topographical controls. Those interested in assessment for specific regions should turn to Chapter 11 of the full report, which provides a useful region-by-region discussion of key processes, model skill, and projections.

The WGI summary for policymakers is quite cautious in discussing the likelihood of rapid and nonlinear climate change, concluding, for example, that it is unlikely that the Atlantic Ocean circulation will change abruptly or that the Greenland and Antarctic ice sheets will collapse before the end of the twenty-first century. There is also limited mention of other possible instabilities such as rapid shifts in the monsoon, drying of the Amazon, or release of methane from permafrost regions.[2]

The most extensive criticisms and evaluations of the WGI report have so far emerged on Web sites devoted to climate change research and policy and range from unsubstantiated allegations of bias to carefully referenced examinations of key assumptions and results. Some suggest that the report is too cautious, especially in terms of sea-level rise or the likelihood of rapid warming and positive feedbacks such as those associated with the release of methane from thawing permafrost. Others have criticized the process as politicized because of the involvement of governments.[3] A whole host of scientific papers have emerged that already date the report,[4] a handicap of the IPCC that required all research cited in the Fourth Assessment to be published by the end of 2005.

By almost any measure, the IPCC Fourth Assessment WGI report is a tremendous achievement, analyzing hundreds of research papers in crisp, readable language with excellent graphics in the summary as well as the full report. In addition, each chapter of the full report includes a group of frequently asked questions (all brought together in an annex), which are especially useful in highlighting key points and uncertainties.

At one level, the environmental science and policy implications are clear—if we do not manage the concentrations of greenhouse gases in the atmosphere, the planet will continue to warm, bringing significant changes to climates and oceans. But many details are still uncertain, most notably the likely changes in regional climate and the probabilities of climate discontinuities and carbon cycle feedbacks. The report provides little guidance on the climatic effects of different mitigation scenarios and associated emissions trajectories, making no assessment, for example, of the viability of the European Union's 2°C stabilization target.[5]

Thus two key uncertainties that lie at the heart of the international response to climate change—what level of mitigation and emissions are needed to avoid dangerous climate change and what are the likely regional climates to which we need to adapt—are not resolved in this Fourth Assessment report. At the same time, the higher levels of confidence and certainty about the links between emissions and observed changes and the projections of significant changes in temperature, precipitation, and extreme events have been a wake-up call to many governments and communities that are now prepared to act on climate change. In the United States, opinion is shifting toward more action on climate change, especially in states such as California, which has promised to reduce its emissions by 80 percent by 2050. The increasing role of scientists from China and other key developing countries within the IPCC is also contributing to greater acceptance of the physical science by policymakers in those countries. China has committed to a 25 percent reduction in energy intensity; notably, the co-chairs of WGI are Susan Solomon (from the United States) and Dahe Qin (from China).

In the United Kingdom, the government has made commitments to cut greenhouse gases by 60 percent and to invest in adaptation for U.K. regions as well as developing regions receiving foreign assistance.[6] Yet some claim that avoiding dangerous climate change requires a 90 percent cut in emissions, and there are high levels of uncertainty in terms of how precipitation will change in the United Kingdom

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and across much of the tropics. When local authorities or development charities ask how climate will change in their regions, especially whether they should plan for more or less rainfall, it is still very hard to provide an answer. Of course, as WGII argues, one response is to focus on reducing vulnerabilities and increasing resilience to changes in either direction, but it remains an unsatisfactory response to those who believe that the science of climate change is now clear.

At the IPCC WGI report launch in London in March 2007, a government minister and a former energy company CEO were both overheard saying that the debate over the science of climate change was over and that the momentum now needed to move to research and action on mitigation and adaptation. Yet the Fourth Assessment report still has many unanswered questions and uncertainties, and although there is less debate about whether climate change is occurring, the arguments are now moving to when, where, and how the changes are going to occur. Exhausted authors can barely imagine going through the process again in five years, but in fact discussions about the Fifth Assessment have already begun. The IPCC assessment is a Herculean process, and authors deserve a global vote of thanks for the most grueling literature review one can imagine.

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NOTES

1. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, U.K., and New York, NY: Cambridge University Press, 2007), http://ipcc-wg1.ucar.edu/wg1/wg1-report.html.

2. See H. J. Schellnhuber, W. Cramer, N. Nakićenović, T. Wigley, and G. Yohe, eds., *Avoiding Dangerous Climate Change* (Cambridge, U.K., and New York: Cambridge University Press, 2006).

3. See, for example, *Prometheus: The Science Policy Weblog*, http://sciencepolicy.colorado.edu/prometheus; and *RealClimate: Climate Science from Climate Scientists*, http://www.realclimate.org.

4. Some examples include S. Rahmstorf, "A Semi-Empirical Approach to Projecting Future Sea-Level Rise," *Science* 315, no. 5810 (19 January 2007): 368–70 (higher sea-level rise); F. J. Wentz, L. Ricciardulli, K. Hilburn, and C. Mears, "How Much More Rain Will Global Warming Bring?" *Science* 317, no. 5835 (13 July 2007): 233–35 (revised precipitation change estimates); C. Le Quéré et al., "Saturation of the Southern Ocean CO_2 Sink Due to Recent Climate Change," *Science* 316, no. 5832 (22 June 2007): 1735 (revised ocean carbon uptake); and E. Pennisi, J. Smith, and R. Stone, "Momentous Changes at the Poles," *Science* 315, no. 5818 (16 March 2007): 1513 (accelerated polar ice sheet melting).

5. A brief section at the end of Chapter 10 of *The Physical Basis of Climate Change* (IPCC, note 1 above, page 827) discusses an idealized stabilization scenario for 2150 and summarizes a small number of studies, including work that estimates the risk of overshooting 2°C as 68–99 percent for 500 parts per million stabilization (M. Meinshausen, "What Does a 2°C Target Mean for Greenhouse Gas Concentrations? A Brief Analysis Based on Multi-Gas Emission Pathways and Several Climate Sensitivity Uncertainty Estimates," in Schellnhuber, Cramer, Nakićenović, Wigley, and Yohe, note 2 above, pages 265–79).

6. For the U.K. commitment to cut greenhouse gases by 60 percent, see U.K. Government, Draft Climate Change Bill, http://www.official-documents.gov.uk/document/cm70/7040/7040.asp. For a description of actions on adaptation, see the U.K. Department for Environment, Food and Rural Affairs (Defra), *Action in the UK—Adapting to Climate Change*, http://www.defra.gov.uk/environment/climatechange/uk/adapt/index.htm.