FORUM

Are Scientists Underestimating Climate Change?

The consensus view of climate scientists, as represented by the 2001 Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report, is that the enhanced greenhouse effect likely will lead to global average surface warming by 2100 of between 1.4° and 5.8°C, and global sea level rise of between 9 and 88 centimeters. This assumes the climate sensitivity is in the range 1.5°–4.5°C for an equilibrium doubling of preindustrial carbon dioxide concentrations, and the Special Report on Emissions Scenarios (SRES) range of emissions scenarios [*IPCC*, 2000]. However, recent developments suggest that this dated IPCC view might underestimate the upper end of the range of possibilities and shift the probabilities toward an increasing risk of greater warmings and sea level rises by 2100.

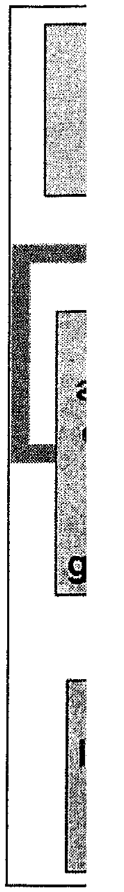
Recent estimates of the climate sensitivity, based on modeling, in some cases constrained by recent or paleoclimatic data, suggest a higher range, around 2°–6°C [*Annan and Hargreaves*, 2006; *Forster and Gregory*, 2006; *Hegerl et al.*, 2006; *Murphy et al.*, 2004, *Piani et al.*, 2005; *Stainforth et al.*, 2005; *Torn and Harte*, 2006]. These estimates throw doubt on the low end of the *IPCC* [2001] range and suggest a much higher probability of warmings by 2100 exceeding the midlevel estimate of 3.0°C.

At least eight recent developments, largely based on observed changes, point to a higher probability of more serious impacts. These include the following:

1. Global dimming is large but decreasing. Reductions by aerosols of sunlight at the Earth's surface are diminishing as particulate emissions are brought more under control [*Pinker et al.*, 2005; *Bellouin et al.*, 2005; *Wild et al.*, 2005], thus decreasing the cooling effect of aerosols. Greenhouse gas emissions, especially of carbon dioxide (CO_2), have a cumulative effect, and thus continue to increase warming, whereas the cooling effect of aerosols is highly responsive to reductions in sulphur emissions, since aerosols have a short lifetime in the atmosphere [*Andreae et al.*, 2005]. Global dimming has delayed warming of the oceans [*Delworth et al.*, 2005] and been greatest in the northern hemisphere, so reductions in global dimming are likely to have asymmetric effects, leading to changes in cross-equatorial flows such as the Australian monsoon [*Rotstayn et al.*, 2006] and the circulation in the Atlantic Ocean [*Cai et al.*, in press].

2. Permafrost melting is widespread. Observations show rapid melting of permafrost [*Arctic Climate Impact Assessment*, 2004; *Nelson*, 2003], which is expected to increase [*Lawrence and Slater*, 2005]. This changes the albedo of the surface [*Chapin et al.*, 2005; *Foley*, 2005] and leads to emissions of CO_2 and methane. These are positive feedback effects that may have been underestimated. Changes wrought by global warming in the Arctic are complex and pervasive [*Hinzman et al.*, 2005].

3. Biomass feedbacks are kicking in. Observations of soil and vegetation acting as sources rather than sinks of greenhouse gases [*Bellamy et al.*, 2005; *Raupach et al.*, 2006] suggest an earlier than expected [*Friedlingstein et al.*, 2001; *Matthews et al.*, 2005] positive feedback in the terrestrial carbon cycle [*Gruber et al.*, 2004; *Scheffer et al.*, 2006]. *Angert et al.* [2005] attribute an observed decreased summer uptake of carbon dioxide in middle and high latitudes to hotter and drier conditions, which cancel out increased uptake in warmer springs. This has been observed at ground level in some regions, under extreme warm conditions [*Ciais et al.*, 2005], which are expected to occur more frequently [*Stott et al.*, 2004]. Other factors that may lead to a more rapid global warming include reduced sequestration of root-derived soil carbon [*Heath et al.*, 2005], overestimates of responses to ambient CO_2 increases [*Kilronomos et al.*,



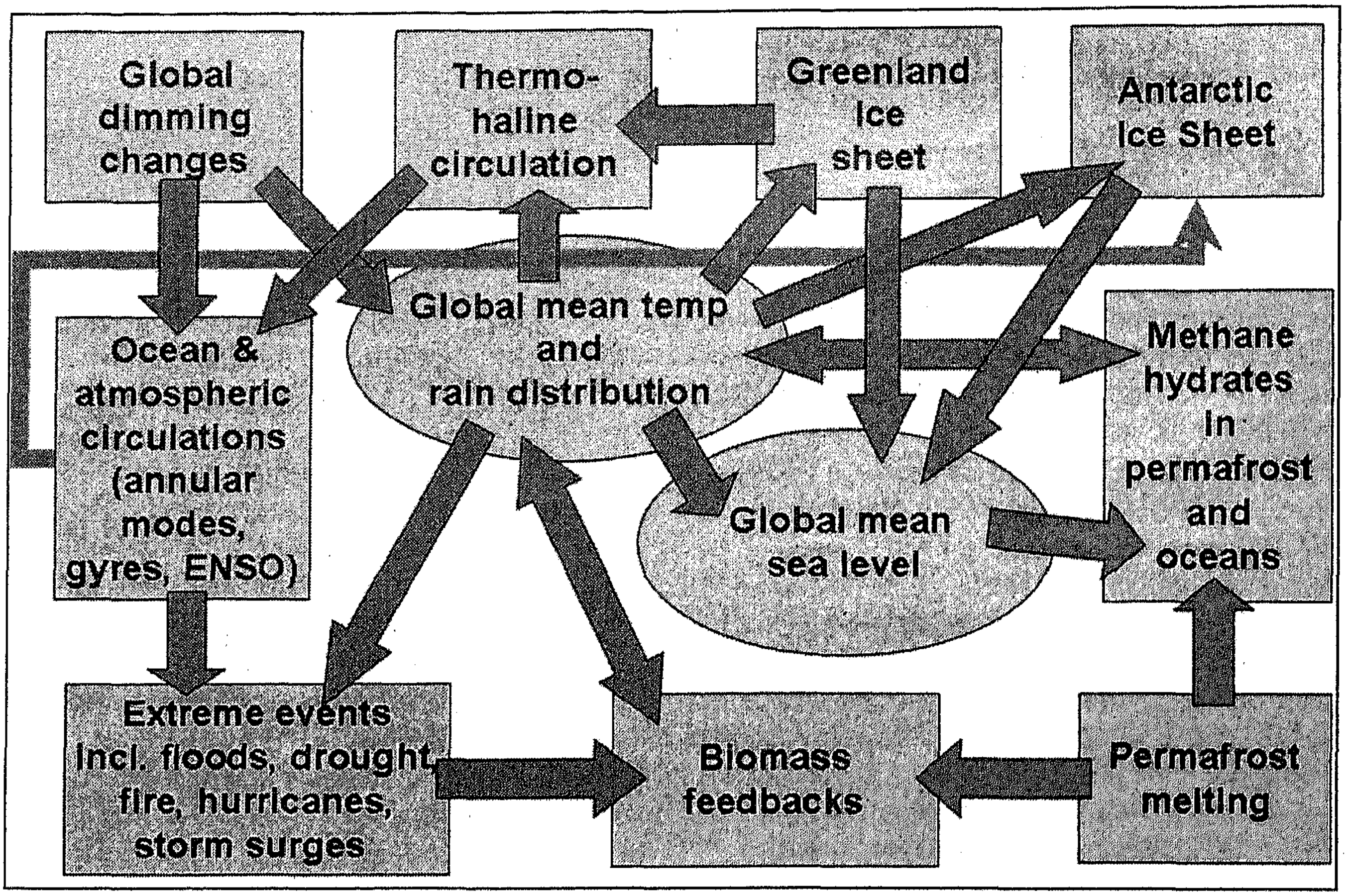


Fig 1. Links between parts of the climate system include feedbacks that may accelerate climate change and its impacts.

2005], and forest and peat fires [*Page et al.*, 2002; *Aldhous*, 2004] exacerbated by land clearing and draining of swamps. The recent high growth rates in atmospheric CO_2 concentrations reported by *Francey* [2005] appear to be persisting through 2004–2005 (David Etheridge, CSIRO, personal communication, 2006) and may be linked to the regional surface observations [*Langenfelds et al.*, 2002].

4. Arctic sea ice is retreating rapidly. Rapid recession of Arctic sea ice has been observed, again leading to an early positive feedback as reduced albedo adds to global warming [*Gregory et al.*, 2002; *Comiso and Parkinson*, 2004; *Lindsay and Zhang, 2005*; *NASA*, 2005; *Stroeve et al.*, 2005; *NSIDC*, 2006].

5. Circulation changes in mid to high latitudes. The northern and southern annular modes have become more positive, with increasing sea level pressures in midlatitudes, poleward movement of the midlatitude westerlies, and a strengthening of the major ocean gyres [*Gillett et al.*, 2003; *Marshall*, 2003; *Cai*, 2006; *Cai et al.*, 2005]. This is due to a combination of the enhanced greenhouse effect and reductions in stratospheric ozone, has significant effects on surface climatology [*Carril et al.*, 2005; *Fyfe*, 2003; *Fyfe and Saenko*, 2006], and may be under-

South Atlantic hurricane may be linked to global warming.

8. Changes are occurring in the North Atlantic Ocean. *Bryden et al.* [2005] report a significant slowing of the Atlantic meridional overturning circulation, supporting other observations [*Quadfasel*, 2005; *Schiermeier*, 2006]. This has long been projected in climate models, but most models suggest that significant slowing and collapse of this heat transport system are not likely until well into the twenty-first or twenty-second century [*Kerr*, 2005b], if at all. This could be related to significant freshening of the surface waters [*Curry et al.*, 2003] due to increased precipitation [*Josey and Marsh*, 2005], increased river inflow [*Labat et al.*, 2004; *Peterson et al.*, 2002], and increased ice melt [*Swingedouw et al.*, 2006].

The above lines of evidence, while not definitive and in some cases controversial, suggest that the balance of evidence may be swinging toward a more extreme outcome. While some of the observations may be due merely to natural fluctuations, their conjunction and in some cases (items 2, 3, 4, and 6) positive feedbacks are causes for concern. They suggest that critical levels of global warming may occur at even lower trol [*Pinker et al.*, 2005; *Bellouin et al.*, 2005; *Wild et al.*, 2005], thus decreasing the cooling effect of aerosols. Greenhouse gas emissions, especially of carbon dioxide (CO_2), have a cumulative effect, and thus continue to increase warming, whereas the cooling effect of aerosols is highly responsive to

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International Continental Drilling Project/ESF-Magellan Joint Workshop Announcement

Deep Drilling Project at Campi Flegrei Caldera (Italy)
13th-15th November 2006
Naples, Italy

Caldera-forming eruptions are the most devastating natural catastrophes on the Earth, posing a serious threat to mankind. On the other side, large geothermal systems formed by volcanic activity at calderas represent a potential huge source of energy. Campi Flegrei caldera, located within the metropolitan area of Naples (Italy) represents an ideal natural laboratory for the observation and understanding of the explosive volcanism, and its impact on a densely populated area. The location of Campi Flegrei caldera, extending partly onland and offshore, presents a unique opportunity for a joint IODP and ICDP scientific exploration project. A Workshop, sponsored by ICDP and ESF-Magellan, will be held in Naples, on 13-15 November 2006, to prepare a scientific deep drilling project at Campi Flegrei caldera.

The main scientific topics of the workshop are:

1. Reconstruction of the tectonic setting of the Campania continental margin and its relations to volcanism during the Quaternary.
2. Reconstruction of the deep caldera structure, thermal state, stress and rheol ogy (location of magma reservoirs and brittle-ductile transition in the crust)
3. Modeling of the geothermal system and its possible interactions with magma reservoirs, both during eruptive and pre-eruptive phases.
4. Precise reconstruction of the volcanic history, from detailed analysis of pre- and post-caldera deposits.
5. Reconstruction of a tephrostratigraphic framework and sediment dispersal pathways from the offshore sectors.
6. Determination of optimal strategies for geothermal energy exploitation and use
7. Improvement of shallow and deep monitoring technologies and risk mitigation

About 50 participants will attend the Workshop from all over the World and having competencies in a variety of disciplines (volcanology, geothermy, marine geophysics and geology, physics and new technologies, etc.). Limited funding is available for travel and participation. Scientists interested to contribute/participate to the Workshop are invited to submit, within the dead-line of October 1st, an application indicating their name, institution, contact details, research interests and expertise to one of the following people:

Giuseppe De Natale (denatale@ov.ingv.it), Claudia Troise (troise@ov.ingv.it)
Marco Sacchi (marco.sacchi@iamc.cnr.it), Aldo Zollo (aldo.zollo@na.infn.it
See also the website www.lab-ov.it

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tude westerlies, and a strengthening of the major ocean gyres [*Gillett et al.*, 2003; *Marshall*, 2003; *Cai*, 2006; *Cai et al.*, 2005]. This is due to a combination of the enhanced greenhouse effect and reductions in stratospheric ozone, has significant effects on surface climatology [*Carril et al.*, 2005; *Fyfe*, 2003; *Fyfe and Saenko*, 2006], and may be underpredicted in climate models [*Gillett*, 2005].

6. Rapid changes in Antarctica and Greenland. Rapid disintegration of ice shelves around the Antarctic Peninsula, surface melting of the Greenland Ice Sheet, and acceleration of outlet glaciers point to the role of ice shelves in retarding glacier outflow, and of surface meltwater in accelerated glacier flow rates and ice shelf disintegration [*Scambos et al.*, 2000; *Rignot et al.*, 2004; *Thomas et al.*, 2004, 2006; *Alley et al.*, 2005; *Cook et al.*, 2005; *Fountain et al.*, 2005; *Hansen*, 2005; *Dowdeswell*, 2006; *Dupont and Alley*, 2006; *Kerr*, 2006; *NASA*, 2006; *Rignot and Kannagaratnam*, 2006]. Recent modeling of the effect of global warming on the West Antarctic and Greenland ice sheets does not appear to incorporate these mechanisms [*Greve*, 2000; *Gray et al.*, 2005; *Ridley et al.*, 2005]. Strengthening and warming of the Antarctic circumpolar current (point 5) may add to Antarctic ice sheet disintegration by enhancing local warming, preventing sea ice formation, and undercutting ice shelves [*Goosse and Renssen*, 2001; *van den Broeke et al.*, 2004; *Carril et al.*, 2005]. Some indirect observations suggest that Antarctic sea ice extent is already in decline [*Curran et al.*, 2004], while radar observations [*Zwally et al.*, 2005] and satellite gravity surveys show Antarctica to be losing mass [*Velicogna and Waher*, 2006].

7. Tropical cyclones may be more intense. Some observational analyses point to a rapid intensification of tropical cyclones [*Emanuel*, 2005 a, b; *Webster et al.*, 2005; *Hoyos et al.*, 2006]. However, modeling of tropical cyclone behavior under enhanced global warming conditions [*Knutson and Tuleya*, 2004; *Walsh et al.*, 2004] suggests more modest increases in intensity, more in line with the analysis by *Trenberth* [2005]. The record hurricane season of 2005 in the Caribbean region has prompted debate on whether the modeling or more extreme observations are more likely correct [*Kerr*, 2005a; *Pielke et al.*, 2005; *Anthes et al.*, 2006; *Klotzbach*, 2006; *Witze*, 2006]. While the observations have their limitations [*Pielke*, 2005; *Landsea*, 2005], it is also clear that the modeling to date has not been at sufficient horizontal resolution to capture the details of tropical cyclone behavior [*Schrope*, 2005], nor perhaps the effects of subsurface warming of the ocean. According to *Pezza and Simmonds* [2005], the first recorded

suggest that the balance of evidence may be swinging toward a more extreme outcome. While some of the observations may be due merely to natural fluctuations, their conjunction and in some cases (items 2, 3, 4, and 6) positive feedbacks are causes for concern. They suggest that critical levels of global warming may occur at even lower greenhouse gas concentrations and/or anthropogenic emissions than was considered justified in the *IPCC* [2001] report. Point 6 suggests that a more rapid rise in sea level may be imminent (for which there is some evidence [*Church et al.*, 2005]), while several of the points suggest rapidly occurring regional impacts. Taken together, they increase the urgency of further improving climate models, and of action to reduce emissions if we are to avoid the risk of unacceptable levels of climate change (see also *NRC* [2002], *Schellnhuber et al.* [2006], *Steffen* [2006], and *Time Magazine* [2006]).

Uncertainties in climate change science are inevitably large, due both to inadequate scientific understanding and to uncertainties in human agency or behavior [*Jones*, 2004]. Policies therefore must be based on risk management [*Kerr*, 2005b; *Pittock*, 2005], that is, on consideration of the probability times the magnitude of any deleterious outcomes for different scenarios of human behavior.

A responsible risk management approach demands that scientists describe and warn about seemingly extreme or alarming possibilities, for any given scenario of human behavior (such as greenhouse gas emissions), if they have even a small probability of occurring. This is recognized in military planning and is commonplace in insurance. The object of policy-relevant advice must be to avoid unacceptable outcomes, not to determine the most likely outcome.

The above recent developments simply might mean that the science is progressing, but it also may suggest that up until now many scientists may have consciously or unconsciously downplayed the more extreme possibilities at the high end of the uncertainty range, in an attempt to appear moderate and 'responsible' (that is, to avoid scaring people). However, true responsibility is to provide evidence of what must be avoided: to define, quantify, and warn against possible dangerous or unacceptable outcomes.

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Because of space limitations, references for this article are given in the Eos *online supplement found at http://www.agu.org/eos_elec/climatechange_refs.html*