

SEA CHANGE

IMPLICATIONS OF THE 4TH IPCC REPORT FOR 21ST CENTURY CLIMATE CHANGE AND SEA LEVEL PROJECTIONS

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Observed temperature rises through the 21st century have been decoupled from the temperature effects of solar insolation about the mid-1970 (Fig. 1) and are tracking at the top of the ICPP-2007 predictions (Fig. 2). Climate trends since the mid-1970s are distinguished from Quaternary atmospheric patterns by (1) the rise of CO₂ levels by ~36% relative to maximum levels of ~280 ppm since the mid-Miocene (3 Myr) to ~380 ppm in 2006; (2) Late 19th century to early 21st century rates of greenhouse gas (GHG) and temperature rise are one to two orders of magnitude higher relative to glacial terminations (Table 1). In the wake of the 4th IPCC Report, representing refereed publications and official reports of major science organizations (NASA, CSIRO, Hadley, Potsdam, universities), the emerging trends involve two end-scenarios:

Scenario (1): Major cuts in carbon emissions on the scale of >50% of present levels by mid-21st century and CO₂ stabilization at or below ~450 ppm. Due to the high CO₂ levels already present in the atmosphere (>400 ppm CO₂ equivalent, including CH₄, nitric oxide, CFC, H₂O in tropical and subtropical latitudes), and the inertia of the atmosphere–ocean–land system, global temperature will continue to rise by ~1 to 3°C through the 21st century.

Scenario (2): Continuation of ‘business as usual’ (IPCC-2007 Scenarios A1B, A2, A1FI), leading to mean global temperature rises in the order of ~2 to 5.5°C through the 21st century.

The IPCC-2007 report takes little account of greenhouse gas (GHG) feedback effects, where amplified radiative forcing may cross runaway global-warming thresholds (also referred to as “gates”) due to further release of CO₂ from oceans and drying vegetation. Release of methane from melting permafrost, warming bogs and sedimentary methane hydrates, are difficult to quantify but add to the effects. Nor does the report take full account of albedo-reduced effects due to melting of the Arctic sea, Greenland and West Antarctic ice sheets. Some of these processes are already in evidence.

In the 2nd scenario ('business as usual'), melting rates and collapse dynamics of Greenland and West Antarctic ice sheets may lead to sea-level rises of up to 14 metres (Greenland — 6.5 metres; Antarctic — 7.3 metres), with rising warming sea levels further destabilizing ice shelves in East Antarctic. By contrast, a decrease in temperatures over parts of East Antarctic suggests relative stability due to a greater wind-chill factor associated with pole-ward retreat and accelerated spin of the Antarctic wind vortex.

The time scales of these processes are indicated by Hansen *et al.* (2007) in the following terms: *"Paleoclimate data show that the Earth's climate is remarkably sensitive to global forcings. Positive feedbacks predominate. This allows the entire planet to be whipsawed between climate states. One feedback, the 'albedo flip' property of water, provides a powerful trigger mechanism. A climate forcing that 'flips' the albedo of a sufficient portion of an ice sheet can spark a cataclysm. Ice sheet and ocean inertia provides only moderate delay to ice sheet disintegration and a burst of added global warming. Recent greenhouse gas (GHG) emissions place the Earth perilously close to dramatic climate change that could run out of our control, with great dangers for humans and other creatures" ... "An ice sheet response time of centuries seems likely, and we cannot rule out large changes on decadal time scales once wide scale surface melt is underway." ... "The imminent peril is initiation of dynamical and thermo-dynamical processes on the West Antarctic and Greenland ice sheets that produce a situation out of humanity's control, such that devastating sea level rise will inevitably occur. Climate forcing this century under a "Business As Usual" scenario would dwarf natural forcings of the past million years, indeed it would probably exceed climate forcing of the Middle Pliocene, when the planet was 2-3 °C warmer and sea level 25±10 m higher" (Zachos *et al.*, 2001; Wing *et al.*, 2005).*

The IPCC-2007 documents a near-doubling of sea-level rise from 0.18±0.05 cm/year in 1961–2003 to 0.31±0.07 cm/year in 1993–2003, and combined melting of Greenland and Antarctic ice sheets melt from 0.019 cm/year to 0.041 cm/year. The IPCC-2007 states *"The remainder of the ice loss from Greenland has occurred because losses due to melting have exceeded accumulation due to snowfall"*. Satellite gravity and microwave measurements indicate a doubling of Greenland ice melt areas per decade (NASA 2006). Rates of ice loss of the Greenland ice sheet have increased, involving an increase in melt area of 16% from 1979 to 2002.

Satellite scanning of the Antarctic ice sheet during the period April 2002–August 2005 found that the mass of the ice sheet decreased at a rate of 152±80 cubic kilometers per year. Most of this mass loss came from the West Antarctic Ice Sheet. GRACE-based estimates identify ice loss of 77±14 km³/year in West Antarctic and gain of +80±16 km³/year in Enderby Land of East Antarctic. Due to sparse distribution of measurement stations in Antarctic, the balance between ice melt and snow fall is not clear.

The IPCC-2007 estimates a sea-level rise of 18–59 cm by 2100, and further refers to millennia-scale melting of the Greenland ice sheet and the unknown nature of ice melting dynamics. This estimate does not take into account potential factors such a sharp decrease in ice-sheet albedo, collapse of the Gulf Stream and changes in the thermohaline circulation (Hansen *et al.*, 2007; Pittock, 2007). Advanced melting of Arctic sea ice documented between 1950 and 2005 reduced the extent of September sea ice from ~8.5 to ~5.0 million km², with effects on the Earth's albedo.

Rahmstorf (2006) used linear extrapolation of relations between decadal sea level rise and global warming, suggesting a proportionally constant value of 0.34 cm/year for each 1°C temperature rise, and projecting sea-level rises in 2100 of +0.5–1.4 metres above the 1990 levels. According to Hansen *et al.* (2007), nonlinear doubling of combined Greenland and Antarctic 1993–2003 melt rates of +0.41 mm/year could lead to exponential sea-level rise reaching ~0.5–0.6 metres by mid-century and ~5 metres toward the end of the 21st century. These estimates are consistent with the Rahmstorf (2007) time-averaged temperature-sea level plot, which suggests a range from minimum values of ~4 metre/ °C to a maximum value of ~18 metre/ °C (Rahmstorf *et al.*, 2007) (Fig. 3). If current GHG rise rates, which exceed the last glacial termination rate by one to two orders of magnitude (Table 1), are an indication, the millennia-long sea-level lag of the last glacial termination about 11.5 kyr ago may be shortened, not least in view of observed rapid ice sheet collapse in Greenland and West Antarctica (Bamber *et al.*, 2007).

Reviewing these projections, Pittock (2007)—a pioneer of climate change research in Australia—states: *“Uncertainties in projections of climate change have long been recognized by climate change scientists. Scientists have tended to focus on central estimates within the range of uncertainty, while the so-called sceptics focus on the low end, and environmentalists emphasize the high end of the range of possibilities. The balance of evidence from recent observational studies across different fields and disciplines has by and large pointed to developments occurring at the upper end of the range of possibilities. This suggests that we should be taking the more extreme possibilities more seriously, as is done in normal policy-relevant risk assessments, where risk is understood to be a combination of probability of an outcome and its magnitude. Prudent planning (including insurance and defence policies), seeks to avoid or prepare for the more serious outcomes, not for the most likely. In giving policy-relevant advice, scientists should be alerting decision makers to plausible worst cases that should be guarded against by policy actions.”*

It is likely that only drastic cuts to carbon emissions, possibly combined with ‘geo-engineering’ measures aimed at ‘buying time’, may be able to slow down the current runaway global warming process and its deleterious consequences. Interest has been growing, in particular in the US, in potential geo-engineering measures, including injection of stratospheric aerosols (sulphur dioxide or aluminum particles) intended to enhance the albedo and cool the Earth for limited periods, simulating the effects of natural volcanic eruptions (Crutzen, 2006).

Finally, it is possible that the temperature rise of ~0.3–0.4°C associated with rising solar irradiance during 1870-1940 may revert at some unspecified time in the 21st century or later, offering a transient respite from greenhouse gas-induced global warming. Such cooling, yielding temporary relief, would be a factor about 5 to 10 times smaller compared to IPCC-2007 temperature-rise projections.

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References

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Table 1. variations in CO₂ and temperature growth rates per year between Termination II (130-128 kyr), Termination I (17-11.5 kyr), 1850-1970 and 1970-2003

Period	CO ₂ ppm/year	°C/year
130-128 kyr		0.003
17-11.5 kyr	0.014	14-11.5 kyr: 0.0018
1850-1970	0.42	0.0016
1970-2003	2.2	0.018

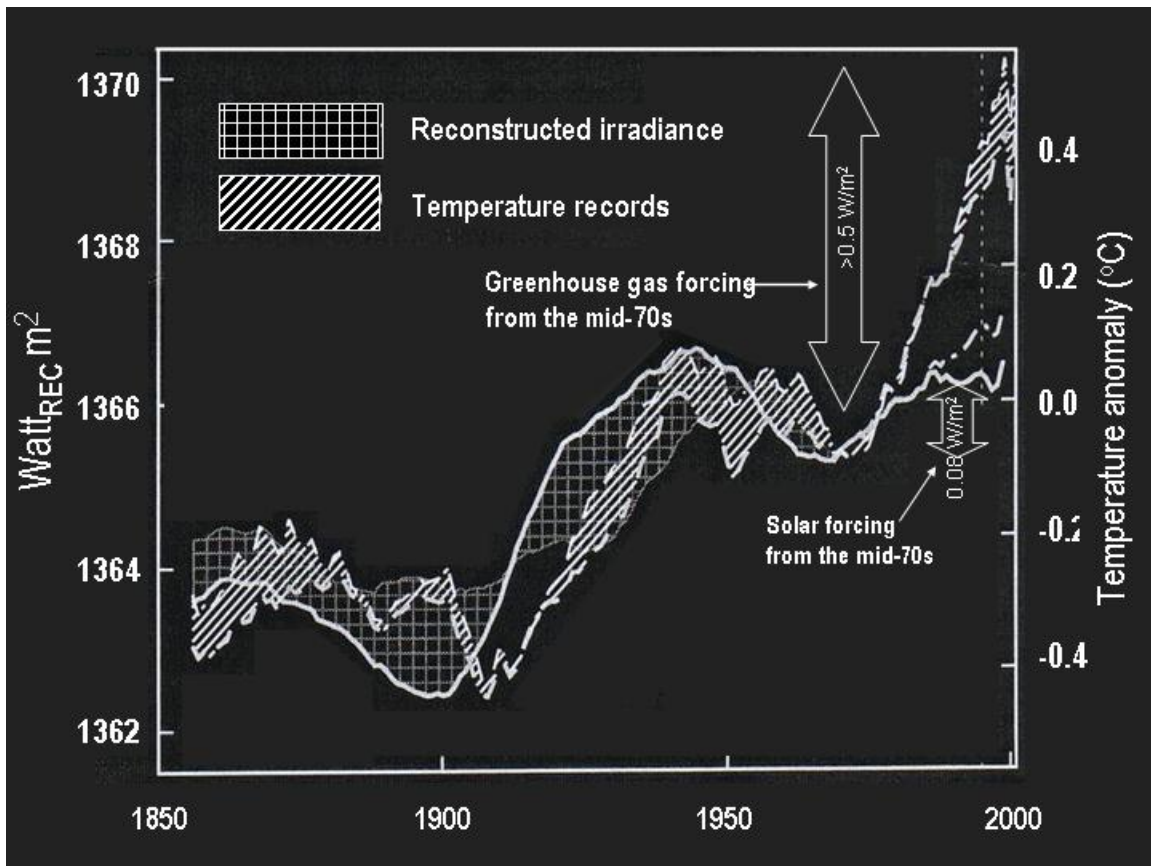


Figure 1. Variations in solar irradiance and temperature records during 1850–2000 (Solanki, 2002). Note (1) the broad co-variations of temperature with solar irradiance during 1850 and the mid-1970s; (2) the rise in mean global temperatures of about 0.4°C during the first half of the 20th century, and (3) the sharp decoupling of mean temperature and irradiance fields and the rise of temperature by about 0.5°C from the mid-1970s as compared to solar irradiance rise of 0.08 Watt/m². Solar irradiance has decreased since 2002.

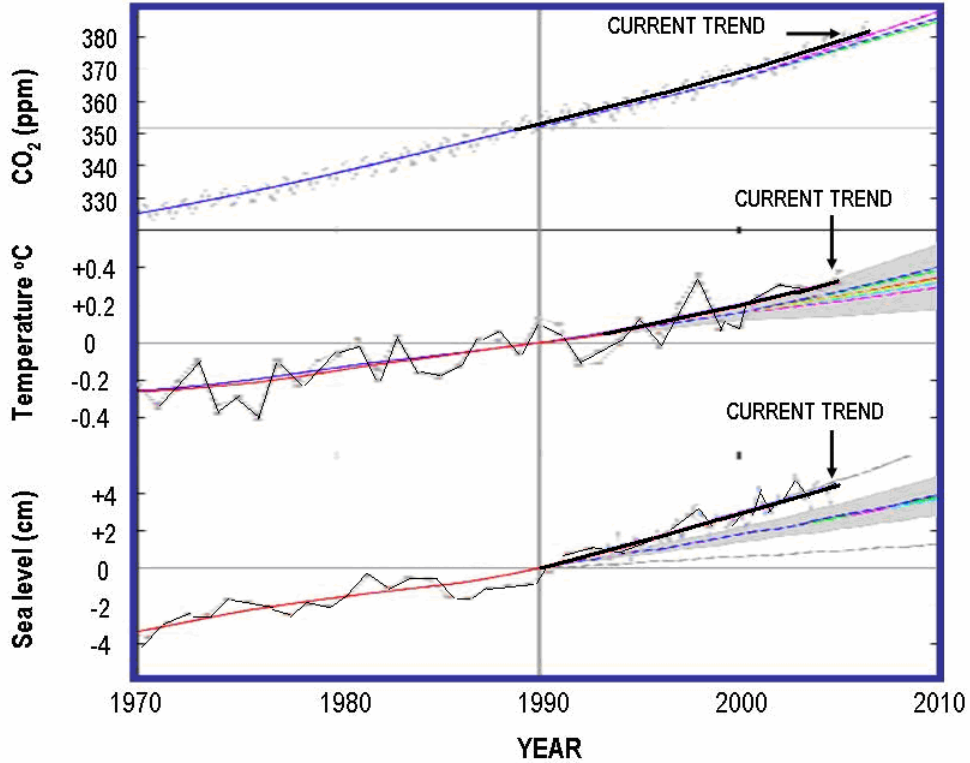


Figure 2. Changes in key global climate parameters since 1973, compared to the scenarios of the IPCC [shown as dashed lines and gray ranges in all panels]. (a) Monthly carbon dioxide concentration and its trend line at Mauna Loa, Hawaii up to January 2007, from Scripps in collaboration with NOAA. (b) Annual global-mean land and ocean combined surface temperature from GISS and the Hadley Centre up to 2006, with their trends. (c) Sea-level data based primarily on tide gauges (annual) and from satellite altimeter (3-month data spacing up to mid-2006) and their trends. Note the solid line, representing currently observed trends, exceeds the IPCC projections. (After Rahmstorf, 2007)

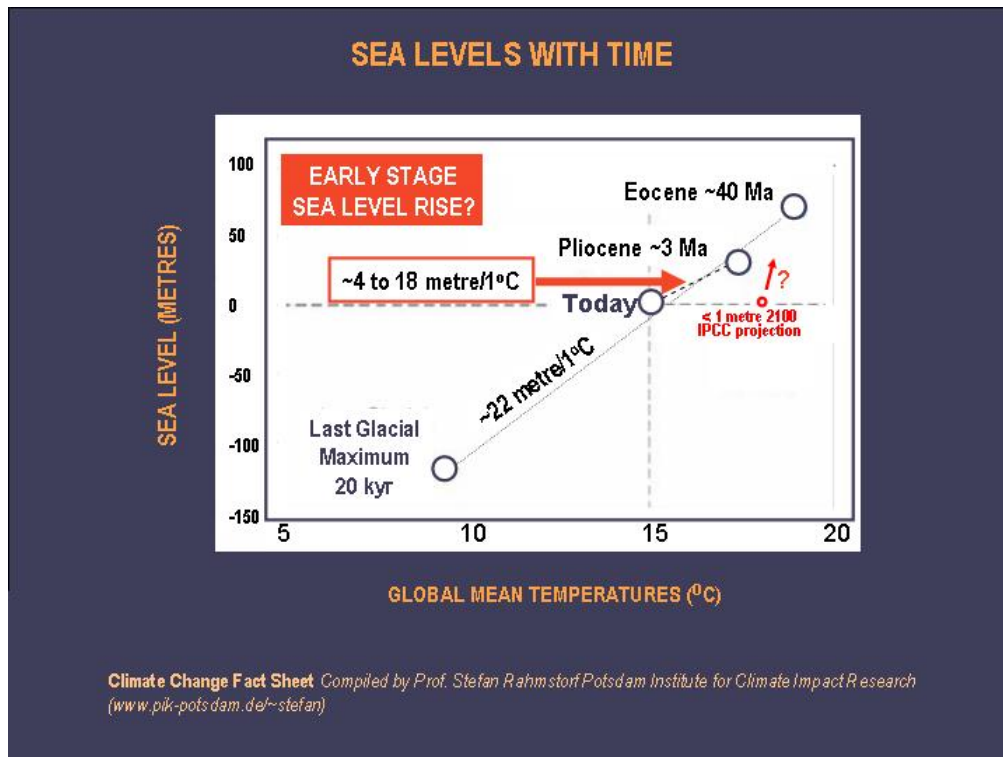


Figure 3.. Time averaged sea level-temperature relationships in the Eocene (~40 Ma), mid-Pliocene (3 Ma), last glacial maximum (~20 kyr) and at present, including projections to 2100. The slope between the mid-Pliocene and the present ranges from a minimum of 4 metres/1°C to a maximum of 18 metres/1°C, defining the medium to long term sea level rises as a function of temperature rise during the 21st century. (from Rahmstorf, 2007. Climate Change Fact Sheet).