Sea Level Rise, Green Greenland & Fantabulous Inference

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Sea Level Rise:

I confess to collaborating with Michael Le Page in making an abbreviated version of "Scientific reticence and sea level rise" http://pubs.giss.nasa.gov/abstracts/2007/Hansen.html The abbreviated, popularized version, titled "Climate catastrophe" and published in the 28 July issue of New Scientist, is at http://pubs.giss.nasa.gov/abstracts/2007/Hansen_2.html

The abbreviation aims to make a broader audience aware of the threat to ice sheet stability posed by "business-as-usual" growth of greenhouse gas emissions. Inevitably the abbreviation contains less substantiation and thus may appear more arbitrary. It misses reference to scholarly discussions of cultural resistance to changes of scientific understanding (see references in the longer paper's Introduction), as well as reference to Eipper's discussion on 'The Scientist's Role' mentioned in the final section of the longer paper.

Heightened concern about ice sheet stability and sea level rise derives from:

(1) increasingly clear paleoclimate evidence showing how sensitive climate and sea level are to even weak climate forcings, summarized in our paper in Phil. Trans. Royal Soc. http://pubs.giss.nasa.gov/abstracts/2007/Hansen_etal_2.html

(2) precise data on changes occurring in the past few years on Antarctica and Greenland. Mass loss from West Antarctica, albeit at a modest rate so far, is of special concern. The likelihood of meter-scale sea level rise within the century is higher for West Antarctica than for Greenland, because West Antarctic ice sits on bedrock below sea level and is thus vulnerable to melt from a warming ocean as well as from increased surface melt.

Green Greenland:

A useful recent study (Willerslev et al., Ancient biomolecules from deep ice cores reveal a forested Southern Greenland, *Science,* **317**, 111-114, 2007) found organic material at the base of the ice sheet at Dye 3 in Southern Greenland, where the ice is now more than 2 km thick. The organic material shows that a boreal forest existed there during an interglacial period sometime during the past several hundred thousand years.

A good candidate for when this forest existed is the unusually warm interglacial that occurred about 425,000 YBP (see Figure 1 below), but the authors do not rule out the possibility that the organic material is from the penultimate interglacial period, the Eemian, about 125,000 YBP (years before present).

Regardless of which interglacial period it is from, the forest is an example of the strong feedbacks that can occur as ice-covered land or permafrost is converted to dark vegetation. As discussed in our Phil. Trans. Royal Society paper (see above), this is one of the positive feedbacks that accounts for the remarkably high climate sensitivity to even small climate forcings on paleoclimate time scales.

This positive feedback as forests move poleward is not included in most IPCC climate simulations. Yet forest migration is already observed. And a recent comparison of vegetation models with observations (Soja et al., Climate induced boreal forest change: predictions versus current observations, *Global Planet. Change*, **56**, 274-296, 2007) shows that forests are moving faster than modeled, leading Soja et al. to suggest the possibility of "…a potential non-linear rapid response to changes in climate, as opposed to the predicted slow linear response…".

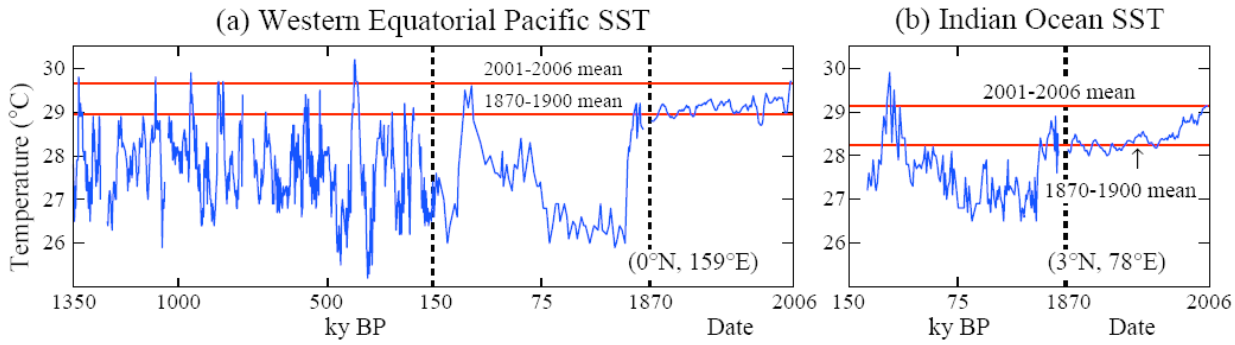

Figure 1. Sea surface temperature in the Pacific Warm Pool (a) and the Indian Ocean (b). Temperatures prior to 1870 are inferred from the composition of shells of microscopic animals that lived near the ocean surface and are preserved in ocean sediment cores. Note that the temperature scale changes twice in (a) and once in (b). There is an uncertainty in matching the proxy temperatures (those prior to 1870) with the modern (1870-2006) *in situ* data. However, the 1870 temperature must fall within the range of Holocene values, so the error in matching up the proxy and *in situ* temperatures should not exceed several tenths of a degree. The temporal resolution is higher in the modern data, which may reveal peak temperatures better than the coarser resolution proxy data. However, there is no expectation that the mean 21st century temperatures will be less than current values, so it is not misleading to compare the coarser resolution proxy data and finer resolution modern data, as we have here.

An important question is: how much warmer was the world during the interglacials at ~125,000 and ~425,000 YBP, compared to today? [Sea level is believed to have been at least 4 m higher than today during both of these interglacials, although Hearty (PAGES News, 15, No. 1, April 2007) presents evidence that sea level was even much higher 425,000 YBP.]

Data do not exist for accurate comparison of global mean temperature during the various interglacial periods. However, the next best thing is to compare tropical ocean temperatures. As we showed in Supplementary data (http://www.pnas.org/cgi/data/0606291103/DC1/3) to our paper in PNAS in 2006 (http://www.pnas.org/cgi/reprint/103/39/14288), Indian Ocean temperatures provide the highest correlation with global mean temperature in the modern period with accurate global data. The Western Pacific Warm Pool temperature is also highly correlated with global temperature, and the Warm Pool temperature is of global importance as a source of energy and moisture transported to much of the world via both atmosphere and ocean.

Figure 1 shows that temperatures of both the Indian Ocean and the Warm Pool are within less than a degree of the warmest interglacial periods in the past million years. This implies that global mean temperature is now within ~1°C of the maximum of the warmest interglacials. [Glacial to interglacial temperature changes are typically 3-4°C in the tropics, of the order of 10°C at the poles, and about 5°C on global average.]

"Business-as-usual" greenhouse gas emissions would cause **global mean** temperature to rise by at least 2-3°C this century, even without full accounting of "slow" feedbacks such as forest movement. Thus Figure 1 shows that continued "business-as-usual" greenhouse gas emissions would yield global temperature this century far above that in any interglacial period in the past million years.

Fantabulous Inference:

Willerslev et al. (2007) showed that during one of these interglacial periods, which was globally warmer than at present by at most ~1°C, local/regional climate feedbacks were strong enough for boreal forest to exist in Southern Greenland, comparable to forests today in Sweden or Canada. The temperature in this part of Greenland during that forested period was much

warmer than when the region was covered with ice, consistent with the large positive (amplifying) feedback that occurs when an ice-covered or permafrost region is replaced by forest, as discussed in our Phil. Trans. paper.

It is uncertain whether the forested area existed during the Eemian interglacial (~125,000 YBP) or an earlier interglacial. Willerslev et al. (2007) believe that the organic material beneath the ice is probably from an earlier interglacial period, perhaps the one 425,000 years ago. Let's assume that they are right, that the organic material is older than 125,000 years. This implies that some ice must have survived in Southern Greenland through this last interglacial to preserve the older material.

Now here is the fantabulous inference from these facts, as reported in the Boston Globe, Eurekalert, and other media, and as has been relayed to me by various people. It is concluded that existence or forests on Greenland implies that ice sheets are more stable than has been thought and that they can survive warming of several degrees Celsius. What a relief!

Unfortunately, the logic is perverse. Consider:

(1) global warming during these interglacials was only a fraction of the warming that will occur if we stay on "business-as-usual" greenhouse gas emissions,

(2) sea level did go up several meters during these interglacials, even with the more modest global warmings.

Apparently Wilerslev et al. wanted to make the point that a specific ice model that suggested that Southern Greenland ice disappeared entirely during the last interglacial is wrong (I was not aware that we had ice sheet models that were claimed to be reliable for results such as expected existence or nonexistence of ice at the Dye 3 location). Somehow this comment of Willerslev et al. became twisted in media reports so as to lead people to believe that our concerns about sea level rise are unfounded. On the contrary, the Wilerslev et al. paper should add to those concerns!