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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming is highly dangerous" *by* J. Hansen et al.

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This is another Hansen masterwork of scholarly synthesis, modeling virtuosity, and insight, with profound implications. The main thrust of the paper, the part getting all the press, arises from the confluence of several recent developments in glaciology. First is the identification of a runaway condition in outflow glaciers of the West Antarctic ice sheet that makes the IPCC prediction for year-2100 sea level rise clearly obsolete. The other is the recognition that warming ocean temperatures at the grounding line for the

glaciers is driving a really strong flow and thus melting response. Temperatures at this depth tend to have a paradoxical inverse relationship with surface temperatures, which can cool due to fresh meltwater input, trapping heat in the subsurface. This idea may also explain the mystery of why Heinrich events, collapses of the Laurentide ice sheet, always came at cold times in the D-O cycles.

Analysis of sea level changes during Eemian time, the last interglacial, show changes of several meters in time scales of a century. If our ice sheets are going to change our sea level that much, from its current rate of melt, the melt rate would have to increase exponentially in the future. The way that could happen is if there is a positive feedback, such that melting begets faster melting, as opposed to a linear response where the melting rate is driven simply by temperature. The climate modeling results in this paper identify such a feedback. Release of freshwater around the margins of the ice sheets causes freshening at the ocean surface, stratification, and warming of subsurface waters. The melting water has a significant cooling impact on the planet, which I hadn't expected, but I guess the difference here is the huge rate of freshwater addition; the authors argue that the responsiveness of the model is not much different from other climate models. The melting water actually results in an increase in heat uptake by the planet, with the increase going directly into the ocean, exacerbating the feedback. Antarctic cooling and increase in sea ice causes a warming-induced increase in precipitation in the Antarctic region to fall over the ocean rather than to Antarctica, another amplification of the freshwater forcing mechanism. This seems like a plausible interplay of mechanisms to me, given that it's observed happening today, and that something like this is required to explain evidence from the past such as Heinrich events. The conclusions of this paper confirm what I had gloomily expected people would figure out, and they provide a mechanism by which the implications of the past can be explained and cast into a forecast for the future.

The paper describes a link between southern ocean stratification and atmospheric CO2 which I think overstates our understanding. Actually, the paper seems clear enough

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that we don't have all the pieces of the puzzle in some sentences, like on page 20100, line 15, "Much remains to be learned about glacial-interglacial carbon cycle mechanisms". But the discussion of the biological and solubility pumps on that same page doesn't say that these pumps won't do the whole job. No detailed models of ocean chemistry are able to pull atmospheric CO2 down to glacial levels, and the conceptual model invoked here of storing a bunch of organic carbon in a box during glacial times doesn't work either, in that the box would be anoxic, yet there are no real traces of an anoxic glacial deep ocean. The solubility pump drawdown due to temperature alluded to would be counteracted by a decrease in CO2 solubility due to increased salinity. I agree that the evidence is very strong that the Southern Ocean really calls the shots with atmospheric CO2, I just don't believe that the explanation we have for that today holds water. There is a lot of attention paid in this paper to the fidelity with which climate models can reproduce the ice melting feedback, but no mention of the fact that models have near-zero fidelity to reproduce atmospheric CO2 glacial cycles, with the wide swings down to 180 ppm, and their incredibly tight correlation with ice volume. The question of how this works would be important to this paper if we were looking to project the Southern Ocean CO2 effect into our future. However, the paper doesn't do that, it decides (sensibly) that the ice sheet freshwater input / grounding line water temperature / stratification feedback is more likely to be important in our future. Which raises for me the question of whether the paleo SO / CO2 cycle discussion is really necessary in this paper. It is very illuminating, I'm glad to have read it, but on the other hand the paper is very long and its main point (the ice melting feedback) would be more accessible if it were streamlined. We plan to discuss this paper in our graduate student reading group, but we expect that due to the length of the paper most of the students won't read it in advance.

The storminess of a deglaciating world is another, related but strictly speaking unnecessary, thread to the paper. Perhaps a more usual strategy, from a researcher who is less of a creative and intellectual volcano than Hansen, would be to publish the storminess part separately. This paper is breathtakingly rich and panoramic, I'm not being

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critical about streamlining, nor would I push for it as a condition for publication. It's just an observation, that the paper is very long.

The topic on which I wanted more was an explanation of why and how the authors expect Greenland not to be subject to the same nonlinearity as Antarctica. On page 20094 it's stated that the most of Greenland's glacial valleys are prograde, as opposed to in West Antarctica where they deepen toward the center. The same oceanographic stratification / subsurface warming amplification mechanism acts in both places. I suppose that in Greenland, the ice can melt back to the beach line, at which point the ocean no longer matters? Probably a few sentences would do. At least, when the topic comes up again on page 20120, it would be useful to remind the reader of the prograde / retrograde idea.

The paper is very clearly written on a sentence to section level, and can be followed by paying attention to the headings. However, the organization of the sections into a whole seemed a bit chaotic, going between geological observations, to model descriptions, back to observations, etc. In part this is due to the wide-ranging scope of the paper. Due to its important conclusions, primarily about the ice sheet melting climate feedback, I expect this paper will be widely read, but it will make its readers work for it.

Interactive comment on Atmos. Chem. Phys. Discuss., 15, 20059, 2015.