Response to SC C5878:'Implications regarding uncertainty in future climate projections', Gregory Flato, 12 Aug 2015

In our revised paper we will draw more attention to our conclusion that the (surface of) the Southern Ocean and North Atlantic should cool in coming decades. We have little space for discussing it in the paper, but we discuss it more in the mini-paper that we wrote in response to SC C6361 ('Predictions Implicit in "Ice Melt" Paper and Global Implications' written by James Hansen and Makiko Sato), which is also available at http://www.columbia.edu/~jeh1/mailings/2015/20151012_IceMeltPredictions.pdf.

Thanks for mentioning the way in which we add freshwater to the ocean (as liquid water at temperature -15°C), as that gives me a chance to explain a relevant point. The experiments for this paper were first run about eight years ago at about the time that I (JEH) wrote a 2007 paper titled "Scientific Reticence and Sea Level Rise" and after a paper titled "Slippery Slope: How Much Warming is Dangerous", which had forced me to think about planetary energy balance and the matter of icebergs. In the Slippery Slope paper I discussed the question of how the ice sheet acquires the large amount of energy needed to change the ice sheet (the portion of the ice sheet needed to raise sea level by meters) from ice on land to water in the ocean. The amount of energy needed for a 1-meter sea level rise requires Earth to be out of energy balance by about 9 Watt-years (see Table S1, in the Supporting Online Material of the paper "Earth's Energy Imbalance: Confirmation and Implications, Hansen et al., Science, 308, 1431-1435, 2005). Most of this energy is required for the phase change of ice to water, with some additional energy to raise temperature of the meltwater to the average ocean temperature.

Nine Watt-years over the entire planetary surface for one meter or sea level rise. That's a lot of energy. But that amount and more has been delivered many times, as ice sheets have come and gone. It requires a planetary energy imbalance, more energy coming into the planet than going out. I argued that this energy would not be delivered directly to the ice sheet, but rather to the ocean. So how does the energy get from the ocean to the ice? Mainly by the ice coming to the ocean. The ocean lapping against the ice sheet can melt some ice, but likely it would be more a case of icebergs discharged to the ocean, where the icebergs would melt. One effect of melting icebergs is a cooling of the ocean surface, which would increase the planet's energy imbalance. So in this way the melting process provides for much its own energy need, as melting icebergs cool the ocean, putting the planet out of energy balance – or more out of balance, as the melting presumably was initiated by some imbalance that was causing the planet to warm.

Ice sheet dynamics, describing how an ice sheet disintegrates and dumps its ice into the ocean, was, still is, and probably always will be, a messy problem. However, we could investigate the overall problem without the details of ice sheet breakup by simply putting the ice sheet discharge into the ocean mixed layer in the ocean area around the ice sheet where we expect ice sheet meltwater and icebergs to go. Thus, in the numerical experiments that we did ~8 years ago with the atmosphere-ocean climate model that we had at that time, rather than trying to model the transport and melting of the icebergs, we simply reduced the temperature of the ocean mixed layer in the portion of the ocean (high latitudes of the North Atlantic for Greenland melt and the Southern Ocean for Antarctic melt) that would be affected by the ice sheet discharge.

In those early experiments we examined the sensitivity of the response to the temperature of the ice sheet discharge, i.e., the temperature of the freshwater added to the ocean mixed layer. We found that the regional cooling was not very sensitive to the temperature chosen for the freshwater. Instead the regional cooling was mainly a result of the low density of the freshwater via its effects on ocean overturning.

After Max Kelley made some basic improvements in the ocean model, which are described in our current paper, I decided to run freshwater experiments again with this newer model. These are the experiments reported in our present paper. In all of these model runs we used -15°C as the temperature of the freshwater added to the ocean mixed layer. If a large fraction of the ice sheet discharge is icebergs, the cooling effect would be larger than in our experiments. It would be worthwhile to make additional experiments with models including greater detail, with some portion of the meltwater appearing at the depth of ice shelves, with the model perhaps even transporting icebergs that cool the ocean surface as they melt. A range of assumptions could be made to test the sensitivity to assumptions. We already had as many numerical experiments as we could hope to include in one paper. We are confident that the primary effect of the ice sheet discharge is the reduced density of the oceans upper layers that we have modeled.

As for the magnitude of the assumed freshwater forcing, the paleo data show that the real world has experienced melt rates that fast – in response to forcings weaker than the human-made forcing that is being assumed for this century. Let us hope that we are smart enough not to perform an empirical test using the real world with a forcing of the business-as-usual magnitude.

See also following response to SC C5966 (Dale Berner)