Ice Sheets and Sea Level

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LETTERS

edited by Etta Kavanagh

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IN THE TANDEM PAPERS ON THE STABILITY OF the Antarctic and Greenland Ice Sheets by J. T. Overpeck, B. L. Otto-Bliesner, and co-workers ("Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise," J. T. Overpeck *et al.*, Reports, 24 Mar., p. 1747; "Simulating Arctic climate warmth and icefield retreat in the last interglaciation," B. L. Otto-Bliesner *et al.*, Reports, 24 Mar., p. 1751), firm statements are made about the possible contributions of these ice sheets to future sea-level change. Several doubtful assumptions are made, and the quality of model results seems to be overvalued.

The estimate of the contribution of the Greenland Ice Sheet (GIS) to the higher sea-level stand in the Eemian interglacial (between 2.2 and 3.4 m) is based on the assumption that there was no ice at the location of the Dye-3 ice core in southern Greenland. However, Eemian ice has been found at the base of this ice core (*1*). The presence of Eemian ice in south and coastal Greenland implies that the GIS was essentially intact in a much warmer climate and could not have contributed more than 1 to 2 m to sea-level rise.

For the Arctic Climate Impact Assessment (ACIA), we have used the output from five different state-of-the-art climate models to calculate possible changes in the volume of Arctic ice masses for the next 100 years (*2*). Among these models is the one used by Otto-Bliesner, Overpeck, and co-workers (the NCAR Community Climate System Model). For the same greenhouse gas scenario (IPPC-B2), the differences in model output are striking, especially concerning precipitation in the Arctic. Some models predict a significant increase in snowfall over the GIS; others do not. Given the additional problems in calculating ablation (because the climate model does not resolve the melt zone of the GIS), we think that the uncertainty in the predicted Eemian mass balance, and consequently the response of the ice-sheet model, is very large.

There is no justification for extrapolating observed changes on a short time scale (a decade or less) to longer term trends. Natural variability is large on virtually all scales and generated by nonlinear processes in the system. During recent years, the weather over Greenland has been warmer, and the effect on run-off and the dynamics of outlet glaciers is now clearly seen. We should follow this closely, but not conclude at this moment that "sea-level rise could be faster than widely thought," as stated by Overpeck *et al.*

The statement by Overpeck *et al.* that "our inference that the Antarctic Ice Sheet likely contributed to sea-level rise during the [last interglaciation period] indicates that it could do the same if the Earth's climate warms sufficiently in the future" requires a comment. This possibility was mentioned decades ago by J. H. Mercer and T. Hughes [see (*3*)]. However, this statement implies that it would not happen without warming. Actually, it is possible that the West Antarctic Ice Sheet will continue to shrink (as it has probably been doing during the entire Holocene) even without warming. Several physical processes give ice sheets a very long memory (e.g., low temperatures of the older, deeper ice layers affecting ice viscosity, slow response of Earth's crust to a changing ice load, ice-age dust layers coming to the surface and affecting melt rates, etc.). In spite of admirable efforts in ice-sheet modeling, measuring from space, and laborious in situ observations, we are uncertain about what the ice sheets

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would do without any change in climate.

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References

1. W. Dansgaard, H. B. Clausen, N. Gundestrup, S. Johnsen, C. Rygner, in *Greenland Ice Core: Geophysics, Geochemistry, and the Environment*, C. C. J. Langway, H. Oeschger, W. Dansgaard, Eds. (American Geophysical Union, Washington, DC, 1985), pp. 71–76.
2. J. Oerlemans *et al.*, *Ann. Glaciol.*, in press.
3. M. Oppenheimer, *Nature* **393**, 325 (1998).

Response

WE THANK OERLEMANS *ET AL.* FOR THEIR INTEREST and insights. However, none of the points raised affect our result that future "sea-level rise could be faster than widely thought."

Recent observations indicate shrinkage of both the Greenland Ice Sheet (GIS) [e.g., (*1*)] and the Antarctic Ice Sheet (AIS) [e.g., (*2*)]. Although long-term trends may be contributing, especially for the AIS, much work shows that recent warming has contributed to the mass loss [e.g., (*1*, *3*–*5*)]. Furthermore, some of the "fast" processes by which warming contributes to ice-sheet mass loss are not fully represented in the comprehensive ice-flow models that informed, e.g., the IPCC Third Assessment Report (*6*, *7*).

To these results, we added historical perspective: Whatever the details, the last time the Arctic was significantly warmer than today, global sea level was at least 4 to 6 m above present level, and most of this sea-level rise had to be the result of polar ice sheet melting. With warming projected for the future, and despite the important remaining uncertainties, we believe that this evidence shows that accelerated sea-level rise from the polar ice sheets could occur.

Oerlemans *et al.* do raise issues that warrant clarification. They suggest that there was a larger Eemian (last interglaciation) GIS than we inferred, based on the presence of isotopically enriched, possibly Eemian ice at the base of the Dye 3 ice core. However, this enriched ice does not prove that the GIS southern dome survived the peak interglacial warmth in the period 130,000 to 125,000 years ago. In contrast, the lack of ice from the previous glaciation argues for ice-sheet removal from the site at some point in the Eemian. The enriched ice at Dye 3 can be interpreted as (i) late-Eemian "growth ice," when the ice sheet reestablished itself in southern Greenland (*8*), or (ii) ice that flowed into the region from central Greenland or from a surviving but isolated southern dome (*9*). An improved understanding of the response of the GIS to the last interglacial warmth will come from an ice core that penetrates the full Eemian [e.g., (*10*)]. If Eemian mass loss from the GIS was smaller than our calculations, a correspondingly larger mass loss from the AIS is necessary to explain the reconstructed Eemian sea-level high-stand of +4 to +6 m.

We share Oerlemans *et al.*'s interest in the long-term trend in ice-sheet behavior [e.g., (*11*)] and their respect for the pioneering work of Mercer, Hughes, and others. We agree that Earth-system models exhibit important differences in regional reconstructions, including those in the Arctic. However, the success of the model we used (CCSM2, an improved version of the NCAR model used in ACIA) in simulating peak-Eemian conditions matching available paleoclimatic data increases our confidence in our results.

We look forward to working with Oerlemans *et al.* and other members of the community to narrow the uncertainties on this critical topic.

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References

1. R. Thomas *et al.*, *Geophys. Res. Lett.* **33**, L10503 10.1029/2006GL026075 (2006).
2. I. Velicogna, J. Wahr, *Science* **311**, 1754 (2006).
3. J. Box *et al.*, *J. Clim.*, in press.
4. A. Shepherd, D. Wingham, T. Payne, P. Skvarca, *Science* **302**, 856 (2003).
5. T. A. Scambos, J. A. Bohlander, C. A. Shuman, P. Skvarca, *Geophys. Res. Lett.* **31**, L18402 10.1029/2004GL020670 (2004).
6. IPCC, *The Science of Climate Change* (Cambridge Univ. Press, Cambridge, 2001).
7. R. B. Alley, P. U. Clark, P. Huybrechts, I. Joughin, *Science* **310**, 456 (2005).
8. R. M. Koerner, D. A. Fisher, *Ann. Glaciol.* **35**, 19 (2002).
9. N. Lhomme, G. K. C. Clarke, S. J. Marshall, *Quat. Sci. Rev.* **24**, 173 (2005).
10. D. J. Dahl-Jensen *et al.*, "The last interglacial and beyond: A northwest Greenland deep ice core drilling project," International Partnerships in Ice Core Sciences, http://www.pages.unibe.ch/science/initiatives/ipics/data/ipics_neem.pdf (2005).
11. R. B. Alley, I. M. Whillans, *J. Geophys. Res.* **89C**, 6487 (1984).