ACSYS/CLIC meeting, Kiel, 23-27 October 2000

14 (xxi): Ice sheet issues in the IPCC assessment of sea-level change

Philippe Huybrechts

Report contribution

A short overview was given of issues related to the Greenland and Antarctic ice sheets arising in Chapter 11: Changes in Sea Level, of Working Group I of the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC). The discussion on the Antarctic and Greenland ice sheets in this chapter was divided in three main parts. The first part largely consisted of an overview of recent literature on the crucial question of the ice sheet's current evolution, on which methods are being used to answer this question and on what we know about the ice sheet's basic response mechanisms and their sensitivity to climate change. A second part dealt with numerical predictions of sea-level change during the 21st century and on a discussion of longer-term changes of the Greenland and Antarctic ice sheets during the third millenium. In the closing section, ways were discussed to reduce uncertainties in the current and future estimates of sea-level change, and recommendations were formulated on ways forward. Compared to the Second Assessment Report (SAR) of 1995, notable progress concerned the use of new methods to investigate the current evolution of the ice sheets, in particular from satellite observations and numerical models, the intensive use of GCM results to drive model predictions of the future ice sheet response, and a much more profound discussion of the possible longer-term changes of the Greenland and West Antarctic ice sheets under conditions of sustained climatic warming.

From the discussion on the current evolution of the Greenland and Antarctic ice sheets, it became clear that the classical budget method, in which mass gain on the ice sheets is compared with mass loss at their margins, is prone to substantial error bars that will be difficult to overcome. The problem is not so much with the accumulation estimate, for which errors seem to fall below 10%, but with the mass loss terms. That is because runoff, mainly on the Greenland ice sheet, cannot be measured directly and has to be estimated from rather crude methods, and because the flux across the grounding line is only known very approximately. The latter arises because of the difficulties of determining the velocity and thickness distribution along the grounded ice sheet's perimeter and the need to make assumptions about the vertical velocity distribution. Inferring the mass loss from the calving flux or iceberg production rate is hampered by the basically unknown melting rate below the ice shelves, giving rise to large uncertainties. Satellite or aircraft altimetry offers the most promising prospect of resolving the imbalance issue, provided that density variations and isostatic adjustments can be determined, but available records are currently too short to confidently distinguish between a short-term mass-balance variation and the longer-term ice-sheet dynamic imbalance. At present, the combination of ice-sheet modeling results with geological sea-level data probably offers the most accurate estimate of the longer-term ice dynamic contribution to sea-level rise. We estimate this range to be between 0 and 0.5 mm/yr, significantly narrower than the range put forward in the SAR. This is additional to the effect of 20th century and future climate change. Our central estimate of the ice-sheet contribution to the 20th century global sea level rise is now 2 cm, or about 15% of the totally observed estimate of 15 cm.

To make projections of Greenland and Antarctic ice sheet mass changes during the 21st century, thermomechanical ice-sheet models were integrated using boundary conditions of temperature and precipitation derived by perturbing present-day climatology according to the geographically and seasonally dependent patterns changes predicted by the T106 ECHAM4 model for a doubling of CO_2. To generate time-dependent boundary conditions, these patterns were scaled with the area-average changes over the ice-sheets as a function of time for 12 available AOGCM"s. The resulting predictions were generally smaller than those of the SAR because of the larger precipitation increases and smaller temperature rise in the ablation zone (as compared to the ice-sheet average) projected by the T106 ECHAM4 time slice results. These results were then scaled with results taking into account the range given by the recent set of SRES emission scenarios. The combined contribution to sea-level change from the Greenland and Antarctic ice sheets during the 21st century, spanning the full range of emission scenarios, and including the ongoing response to past climatic change and additional ice-dynamic and mass-balance parameterisation uncertainties, is found to be between +9 cm and –13 cm. In all simulations, the 21st century mass-balance only sea-level response was positive for the Greenland ice sheet and negative for the Antarctic ice sheet, reflecting the dominant role played by increased runoff and increased snowfall for the respective ice sheets.

The section on longer-term changes during the third millenium made the point that the ice sheets will continue to react to climate change even if the climate is stabilised. The Greenland ice sheet was found to be most vulnerable to a warming because ablation will increase as the temperature rises. For an annual-average warming of larger than 3°C, ablation is predicted to be larger than accumulation causing the Greenland ice sheet to eventually disappear, except for residual glaciers at high altitudes. Model results indicate that loss of mass would occur at a rate giving a sea-level rise of between 1 mm/yr for a temperature perturbation of 3°C to as much as 7 mm/yr for a sustained warming of 12°C, the latter being an extreme scenario in which the ice sheet would be eliminated within 1000 years.

The chapter also dealt in substantial detail with the contentious issue of the possible collapse of the West Antarctic ice sheet (WAIS). In the discussion, a clear distinction was made between the 21st century and the period beyond. Based on a careful literature study and supported by a risk analysis exercise that involved the main international experts, it was concluded that major loss of grounded ice, and accelerated sea-level rise due to changes of WAIS, is very unlikely during the 21st century. The chance that WAIS will contribute more than a few tens of centimeters to sea-level rise was put at a few percent at most, with an equally large chance that the WAIS contribution will be negative by a similar amount by the year 2100. On a longer time scale, the chance that WAIS will shrink and contribute significantly to sea-level rise is larger, with a 50% chance that the sea-level rise due to WAIS will be larger than 20 cm per century after 1000 years. Results of numerical models were quoted that put an upper bound of 3 mm/year of sea-level equivalent on WAIS shrinking. Thresholds for disintegration of the East Antarctic ice sheet by surface melting, on the other hand, involve warmings above 20°C, a situation that has not occurred for at least the last 15 million years, and which is far more than thought possible under any scenario of climatic change currently under consideration.

In the final section, recommendations were made to reduce the uncertainties on the current and future evolution of the polar ice sheets. The case was made to maximally exploit current and upcoming satellite products (altimetry, radar interferometry, gravimetry, etc..) and to continue such measurements on a continuous basis for at least 15 years. Also improved estimates of surface mass balance (including its spatial and temporal variability) are needed, from both in-situ accumulation observations and atmospheric moisture budget studies, as well as improved estimates of the rate of iceberg calving and the meltwater flux. Finally, improved modelling of the ice sheets should involve developing and coupling more realistic models of both atmospheric circulation and ice dynamics. Major uncertainties are associated with estimating future snowfall and runoff on the major ice sheets. Glaciological models of the dynamics of ice sheets, ice streams, and ice shelves also need to be improved. In particular, fast-flowing features such as outlet glaciers and ice streams need to be incorporated in a more realistic way.