ICE AND CLIMATE MODELING: AN EDITORIAL ESSAY

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Abstract. The growth and decay of ice sheets are driven by forces affecting the seasonal cycles of snowfall and snowmelt. The external forces are likely to be variations in the earth's orbit which cause differences in the solar radiation received. Radiational control of snowmelt is modulated by the seasonal cycles of snow albedo and cloud cover. The effects of orbital changes can be magnified by feedbacks involving atmospheric CO₂ content, ocean temperatures and desert areas. Climate modeling of the causes of the Pleistocene ice ages involves modeling the interactions of all components of the climate system; snow, sea ice, glacier ice, the ocean, the atmosphere, and the solid earth. Such modeling is also necessary for interpreting oxygen isotope records from ice and ocean as paleoclimatic evidence.

The study of causes of the ice ages is now seeing vigorous activity for two reasons: First are the advances in quantitative mathematical modeling of atmosphere, ice, ocean, and solid earth that are now allowing the possibility of setting up models in which all of these components interact. Second is the growth in new sources of paleoclimatic evidence concerning the ice ages, especially from ice cores and ocean sediment cores. These cores have come up with great surprises, such as the intriguing variations of atmospheric CO₂ content and dust fallout rates that suggest formerly unsuspected feedbacks in the climate system. During the next year there will be at least two conferences on causes of the ice ages: “Milankovitch and Climate, Understanding the Response to Orbital Forcing” in December 1982 at Lamont-Doherty Geological Observatory, and “Ice and Climate Modelling” in June 1983 at Northwestern University.

The causes of the Pleistocene ice ages have been a popular subject for speculation, for example in the classic work of Brooks (1927), as well as by Flohn (1974), Kellogg (1975), and Hughes (1982), among others. Now, however, many of the theories can be quantified by writing down equations that approximate them into a computer model. Models designed to look at changes in climate over thousand-year time scales must include processes that are held fixed in weather prediction models or seasonal forecast models, such as ice sheet sizes, crustal depression and rebound, and deep ocean temperatures. Because of the long times involved, they cannot take the 10-min time steps of a general circulation model to follow the atmospheric circulation in detail, and must ‘parameterize’ the effects of processes that act on time or space scales shorter than the smallest time step (or spatial grid) of the model. Climate models attempting to calculate the course of the ice ages vary greatly in their choices of parameterization. These models are reviewed to some extent in this issue of Climatic Change by Budd (1982) and Oerlemans (1982a). Most of these modeling efforts now try to include the known effects of variations in the earth’s orbit on solar radiation, which were shown by Hays et al. (1976) to correlate with the paleoclimatic record of ice volume. These models have mostly used either a simple ice
flow model and a more detailed atmospheric model (e.g. Pollard, 1978) or a detailed ice flow model with atmospheric effects entering only as parameterized accumulation and ablation rates. For example, the model of Budd and Smith (1981) uses two adjustable parameters which control the strength of the radiational forcing and which are chosen for "best fit for matching the historical growth and retreat of the ice sheets". It thus implicitly assumes that the ice ages were forced by orbital variations and is not well designed for actually testing that hypothesis. (For example, suppose the orbital variations merely correlate in time with the ice volume changes but are of insufficient magnitude to cause them. The model might not be able to make this discovery.) Others of these models, such as that of Oerlemans (1982a), exhibit 'free oscillations', meaning that the model climate can oscillate with no change in external conditions. This oscillatory behavior is usually found only for certain values of model parameters whose realistic range has not yet been pinned down, so it is not yet clear whether the real climate can exhibit free oscillations. For example, Harvey and Schneider (1982) showed that the oscillations in the model of Kallen et al. (1979) disappeared when a more realistic description of oceanic thermal inertia was used, allowing the ocean surface temperature to change more rapidly than the deep ocean temperature.

Climate models are usually broken into a number of components (atmosphere, ocean, land ice, sea ice) each of which can be modeled separately by specifying the interactions with the other components. I will discuss some of the current problems in modeling each of the components separately, as well as some of the interactions (feedbacks) which should appear when they are put together in a 'coupled' model.

Snowmelt

It is worth mentioning some of the details of initiation and growth of ice sheets which so far have been hidden in the parameterizations of coupled models. The problem of ice sheet initiation is well-illustrated by Figure 1 of Adams and Rogerson (1968), showing the snow depth at Knob Lake. This location is close to the site of final disappearance of the Labrador-Ungava ice dome about 6000 yr BP, shown in the maps of Denton and Hughes (1981). The snow depth builds up steadily from September to April, then melts rapidly in a 6-week period, leaving the ground snow-free for nearly four months. Now what would be required to melt the snow so much more slowly that some would still remain at the end of the summer? Williams (1979) has studied this question and found glacial inception in Northern Canada rather difficult, requiring a summer temperature decrease of 10–12 K (or its radiation equivalent). This same difficulty was encountered in the models of Budd and Smith (1981) and Birchfield et al. (1982) which thus emphasized the need for a region of high elevation to act as a 'seed' for the ice sheet. Koerner (1980) has however pointed out that "the extension (in time) of the annual period of snow cover generally is more important to the feedback process (by increasing albedo) than the specific lowering of the equilibrium line", suggesting that "a decreased variability of summer climate, and hence the disappearance of 'anomalously' warm summers, may be an integral part of the glacierization process".