INSOLATION REGIME OF THE WARM TO COLD TRANSITIONS

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Abstract

Warm to cold global climate transitions of the past 130 thousand years took place while insolation was rapidly increasing in low latitudes in February, March and April, and decreasing in the high and middle latitudes of both hemispheres in August, September and October. Among the elements potentially affected by the changes in insolation were the heating of the tropical oceans, seasonal changes of atmospheric water vapor greenhouse forcing, surface albedo in the high latitudes, including sea ice melt in the Southern Hemisphere, and deep water formation and circulation in the North Atlantic. Drawing parallels with the contemporary seasonal cycle, we propose that as a result of the increased meridional insolation gradient, the transport of warm water from the low latitudes to the northern middle latitudes and the transfer of water vapor from the middle to the high northern latitudes increased enough to support the build-up of glaciers. Our conceptual model of glacial onset requires no lag in the climate response to insolation changes and both hemispheres operate in phase.

Introduction

It has been demonstrated beyond reasonable doubt that perturbations of the Earth's orbit (the Milankovitch mechanism) and past climate variations have common frequencies. The coincident timing has been best shown over the interval of the last 130 thousand years in the raised coral reefs of Barbados and New Guinea (Broecker, 1966; Mesolella et al., 1969; Chappell et al., 1974) and over the last 450,000 years in deep sea sediments (Hays et al., 1976). Many other records confirm parallels between the periodicity of the Earth's orbital parameters as computed from astronomic laws (Berger, 1978), and geologic evidence of past climates which have been independently dated by radiometric methods and by interpolation of sediment thickness (Lorius et al., 1990; Hays et al., 1976). The unresolved issue is the mechanism which links the variation of the earth's orbit with climate. Many theories have
been proposed (cf. overview by Imbrie and Imbrie, 1979) but none thus far has been supported by rigorous physical and mathematical evidence. Most models consider the summer insolation to the high northern latitudes (commonly represented by June at 65°N) to be the driver of global climate.

Three arguments are frequently cited to dispute the role of orbital perturbations in climate change. First, the annual total of the insolation which reaches the top of the atmosphere (TOA) over the globe is almost constant through time, only the seasonal and latitudinal distribution varies. Second, the largest insolation changes, those due to the precessional cycle, are out of phase in the two hemispheres by 12 thousand years. Except for the Arctic and Antarctic, most of the variation of insolation is practically compensated for within a single year. However, the changes in past climate which clearly reflect the precessional cycle in the geologic record, appear to be globally synchronous. Third, June insolation at 65°N today is approximately the same as it was at the peak of the last glaciation. This implies a millenia long lag in the response of the climate system to insolation forcing which is plausible during deglaciation, but improbable during a glacial onset.

It is possible that the mechanism connecting orbital perturbations with terrestrial climate operates only in one hemisphere, or that each hemisphere responds to a separate mechanism, during different seasons. In order to identify probable mechanisms, Rind et al. (1989) tested the impact of changing insolation on climate in a general circulation model driven by insolation forcing at 116 and 106 ka B.P., typical of initial glacial conditions. The experiment failed to start glacial cooling or the growth of the ice sheets. Additional snow accumulated in autumn due to lower incoming radiation but melted totally in spring due to increased insolation. In the face of paleoclimatic evidence to the contrary, it was concluded that the model is still inadequate in its treatment of the climate system and probably does not properly represent processes which would render insolation in one season more sensitive than in another. This may be due to an excessively simplified representation of the hydrological system, cryosphere and oceanic circulation in the current general circulation climate models (Cess et al., 1989; Schlesinger and Mitchell, 1985).

Short et al. (1991) studied the effect of extreme orbital configurations on the simulated climate of a linear two dimensional seasonal energy balance model. They found a large seasonal temperature response to insolation changes over mid latitude lands and a complicated temperature response in the equatorial zone. However, the model did not address the mechanism which could initiate a glaciation.