A NUMERICAL ICE-STREAM MODEL: APPLICATION TO HOLOCENE RETREAT IN THE ROSS SEA, WEST ANTARCTICA

(Abstract)*

by

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A numerical model of ice-stream retreat during the Holocene period of rising sea-level has been constructed, and applied to one of the ice streams draining the Ross Sea sector of the West Antarctic ice sheet. The purpose of the experiment is to assess the relative significance of eustatic sea-level rise, the response of the solid Earth to the changing ice load, and the formation of the Ross Ice Shelf on retreat of the ice-stream grounding line to its present position in the Ross embayment. An underlying hypothesis is that marine ice sheets (such as that in West Antarctica), the ocean, and the solid Earth form a coupled dynamic system in which changes, once initiated by an external event such as rising sea-level, can proceed independently of climatic change. Ice stream E (see maps by Rose 1979) was used as a test case during development of the model.

The thinning rate at the grounding line was computed by evaluating an equation of continuity during the model-time intervals required for each increment of grounding-line retreat. The accumulation rate, the rate of advection of thicker ice from up-glacier, and the vertical strain-rate caused by the tendency of the ice shelf to spread were taken into account. The rate of grounding-line retreat was then found by invoking a requirement that the ice remain in hydrostatic equilibrium (Thomas and Bentley 1978). The change in the ice-stream thickness profile was computed by solving an equation of continuity along the flow band, during the time intervals required for each increment of grounding-line retreat.

The ice stream was assumed to move by basal sliding, and sliding was assumed to be governed by a relationship of the kind determined experimentally by Budd and others (1979). The bed-roughness factor in this sliding relation was replaced, however, by an empirical sliding function with values determined by relating the base stress, thickness, and balance-velocity profiles along the flow band. The basal sliding relation was thus scaled to the ice stream, using an assumption that it is, at present, in a state of mass balance.

Elastic uplift of the Earth caused by Holocene thinning of the flow band was found by using the elastic Green's functions computed by Farrell (1972). The viscous component of uplift was found by using Green's functions computed for an Earth model consisting of a three-dimensional viscous half-space (upper mantle) overlain by an elastic plate (lithosphere)(Cathles 1975: 267-272). Time-dependent isostatic uplift at all points along the central flow line was found by convolving a load function equal to the change in the thickness profile with the elastic and viscous Green's functions, periodically during grounding-line retreat.

The following initial conditions and assumptions were used. (1). The ice stream was initially grounded to the edge of the continental shelf in the Ross Sea, as reconstructed by Hughes and others (1981), and in dynamic equilibrium such that the retreat rate was zero. (2). The Earth was initially depressed, and in isostatic equilibrium. (3). An ice shelf formed seaward of the retreating grounding line. (4). The shear stress between the ice shelf and its sides was 0.65 bar. (5). The Ross Ice Shelf calving front retreated so that the ice-shelf front attained its present position by 3 ka BP. (6). Eustatic sea level rose by 130 m during the Holocene, according to a curve similar to that of Milliman and Emery (1968).

Elastic and viscous uplift of the Earth, caused by thinning of the flow band, was found to delay grounding-line retreat relative to computed retreat when the ice stream was assumed to be resting on a rigid bed. Grounding-line retreat was found to begin very slowly, at 15 ka BP, because of rising eustatic sea-level. Retreat accelerated after about 30 km, at 13 ka BP, because of increasing water depth and a sea-bed sloping down toward the ice-sheet interior. After 8 k model years, i.e. by 8 ka BP, the feedback effects of isostatic uplift caused grounding-line retreat to be delayed by about 1 ka, relative to computed retreat on a rigid Earth. The elastic and viscous Earth response exerted a moderating influence on the computed retreat rate, because uplift at the grounding line partially counteracted the effect of increasing water depth.

Grounding-line retreat slowed, and gradually stopped, near the present position of the grounding-line of ice stream E. Isostatic uplift caused the total retreat distance to be reduced by 80 km, relative to retreat computed on a rigid Earth model. A re-advance of 20 km of the model grounding line occurred between 3 ka BP and the present, because continuing viscous uplift caused sea depth to decrease.

Resistance from the Ross Ice Shelf was found to be of primary importance in bringing grounding-line retreat to a stop in the Ross embayment, as determined earlier by Thomas and Bentley (1978). In addition, the timing of retreat of the ice-shelf calving front was found to exert a major influence on the timing of grounding-line retreat. Reliable methods for predicting the rate at which an ice-shelf calving front should retreat or advance due to iceberg calving do not exist, so the ice-shelf retreat history is a

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large source of uncertainty in the computed timing of grounding-line retreat. Alternative retreat histories for the ice-shelf calving front were investigated, subject to control provided by a date from the basal portion of the Holocene sediment layer on the bottom of the Ross Sea (Kellogg and others 1979). Within the context of a given ice-shelf retreat history, the feedback effects of isostatic uplift caused a reduction of the grounding-line retreat rate, a reduction of the total computed retreat distance, and a re-advance of the grounding line after the eustatic sea-level stopped rising.

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TIDES, TIDALLY DRIVEN BAROTROPIC CIRCULATION AND THE FORMATION OF TIDAL FRONTS BELOW THE ROSS ICE SHELF, ANTARCTICA

(Abstract)

by

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ABSTRACT

Ocean circulation and heat transport below the Ross Ice Shelf are difficult to observe because of the thick ice cover. Numerical modeling thus provides a practical method for testing ideas about sub-ice-shelf circulation and basal melting. In this study, tidal rectification (Zimmerman 1981), tidal front formation (Fearnhead 1975), and their impact on the sub-ice-shelf environment are determined from a numerical tidal model.

The model indicates that periodic tidal currents drive steady circulations having magnitude less than 0.02 m s^{-1} along the sides of several topographic bumps and ridges below the ice shelf. Ventilation of the sub-ice-shelf cavity is indicated by the Lagrangian trajectories shown in Figure 1. The cross-ice-front heat transport resulting from this flow is estimated to induce approximately 0.5 ± 0.25 m a^{-1} basal melting over 10% of the ice-shelf area closest to the eastern and western ends of the ice front.

The observed rate of water mass renewal within the entire sub-ice-shelf region cannot be attributed to tidally driven barotropic circulation alone. Another circulation mechanism related to tidally induced vertical mixing may, however, operate in the deeper reaches of the sub-ice-shelf cavity. Away from the ice front, the warmest water resides at the sea bed because of its high salinity. Basal melting is thus suppressed unless turbulence generated by tidal currents is sufficiently strong to completely mix the water column against buoyancy input. From analysis of the tidal-energy budget produced by the numerical simulation, complete vertical mixing is anticipated in the shaded regions of Figure 2. These mixed zones are primarily along the Siple Coast where the water-column thickness is less than 100 m.

Basal melting in the well-mixed region is estimated to be between 0.05 and 0.5 m a^{-1}, and will drive a thermohaline circulation having the following characteristics: warm high-salinity water formed in the open Ross Sea during winter flows along the sea bed towards the tidal-mixing fronts, vertical mixing behind the fronts promotes heat transfer between the water and ice, catalyzing basal melting, and meltwater produced behind the fronts flows out of the sub-ice-shelf cavity between the inflowing warm water and the ice-shelf base.

Given present conditions, basal melting along the

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