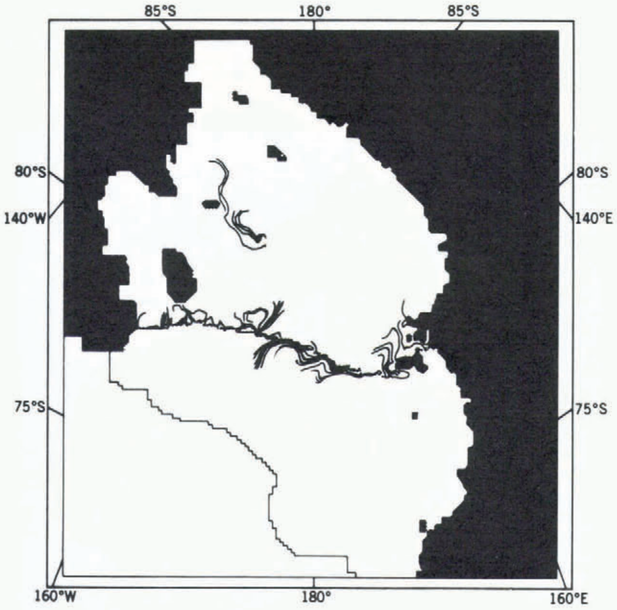
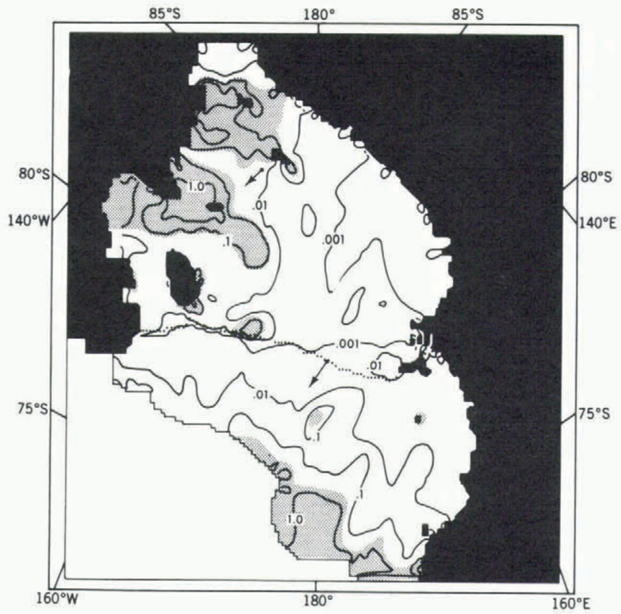


MIXING INTO THE SUB-ICE SHELF REGION: 3 YEARS

Fig.1. Tracer streak-lines emitted from the ice front and select sub-ice-shelf locations display how tidal rectification ventilates the sub-ice-shelf cavity.



THE MELT RATE NEEDED TO MAINTAIN STRATIFICATION (m/yr)

Fig.2. Shaded regions indicate where tidal-energy dissipation is predicted to cause vertically well-mixed waters and thereby to induce strong basal meltin[g]

well-mixed Siple Coast is not expected to be sensitive to climatic change because the inflowing water mass is constrained to have the sea-surface freezing temperature. For this buffering to be upset by climatic change, the production of high-salinity water on the continental shelves of Antarctica must be eliminated.

REFERENCES

Fearnhead P G 1975 On the formation of fronts by tidal mixing around the British Isles. *Deep-Sea Research* 22(5): 311-321

Zimmerman J T F 1981 Dynamics, diffusion and geomorphological significance of tidal residual eddies. *Nature* 290(5807): 549-555

A TIME-DEPENDENT SIMULATION OF THE ROSS ICE SHELF FLOW

(Abstract)

by

Douglas R. MacAyeal*

(Geophysical Fluid Dynamics Program, Box 308, Princeton University, Princeton, New Jersey 08540, U.S.A.)

and Robert H. Thomas

(Jet Propulsion Laboratory, c/o Code EE-8, NASA Headquarters, Washington, D.C. 20546, U.S.A.)

ABSTRACT

The finite-element model discussed by MacAyeal and Thomas (1982) has been improved to include solution of the heat equation within each element, and to accelerate convergence to solution of the momentum-balance equations in terms of ice-shelf spreading rates. The model is now sufficiently rapid to permit both snapshot and time-marching simulations of a large ice shelf at high spatial and temporal resolution (grid size 10 km; time step 0.1 a). Here, we describe three model simulations of Ross Ice Shelf behavior.

First, a snapshot solution was obtained for ice velocities, strain-rates, stresses and temperatures, using measured values of ice thickness and inflow velocities of tributary glaciers and ice streams. Ice rheology and its temperature dependence were prescribed to be compatible with laboratory and ice-shelf measurements, and ice temperatures were calculated using observed surface temperatures and

*Now at: Department of Geophysical Science, University of Chicago, 5734 South Ellis Avenue, Chicago, Illinois 60637, USA.

https://doi.org/10.3189/S0260305500003888 Published online by Cambridge University Press

snow-accumulation rates, and basal melt rates that are consistent with available data (MacAyeal 1984). The model results show close agreement with measured velocities, except in regions where ice movement is locally constrained by nearby ice rises or ice-shelf margins. In these areas, the model velocities are too low (generally by less than 30%), and we believe this is because ice in the marginal shear bands is softened by strain heating, ice-crystal fabric, and crevassing. We intend to incorporate these sub-grid-scale effects in future development of the model.

The other simulations project future ice-shelf behavior (temperatures, strain-rates, stresses, velocities, ice thickness, etc.) in response to contrasting climates, i.e. present-day conditions and a warmer climate induced by doubling atmospheric CO_2. Climate parameters for the CO_2 scenario are from the Goddard Institute for Space Studies (GISS) climate model (Hansen personal communication): a 6.5°C increase in surface temperatures and a 30% increase in snow accumulation. Basal melting rates are assumed also to increase (to 1.8 m a^{-1} along the Siple Coast and to double present-day values near the seaward ice front) in response to greater influx of warm Circumpolar Deep Water beneath the ice shelf (MacAyeal 1984).

Time-marching the ice shelf with present-day climate indicates only minor changes in ice-shelf configuration over the next 400 a, apart from progressive grounding in the mouth of ice stream B, and diversion of downstream flowlines in the ice shelf. For CO_2 warming, however, major changes occur. In one simulation, we increased only the basal melting rates. This resulted in ice-shelf thinning by as much as 400 m upstream of Crary Ice Rise and Roosevelt Island, and a slowing of the ice-front velocity by 200 m a^{-1}. Slowing is due mainly to a reduction in mean ice-shelf temperatures associated with increased basal melting. In a second simulation, we increased basal melting rates, snow accumulation and surface temperatures. Ice-shelf thinning was more pronounced than for basal melting only, and ice velocities finally increased above present-day values. In this case, the effects of surface warming and increased snowfall counterbalanced those of basal melting, and average ice-shelf temperatures increased. The thickness and velocity differences between the present and the "full CO_2" simulation after 400 a are displayed in Figures 1 and 2.

Our simulations indicated that changes in ice-shelf temperature have a major influence on future behavior. To emphasize this, we compared the influences on ice-shelf thickness of basal melting and freezing. We used the analytic expression for isotropic spreading (Weertman 1957) to project thickness responses of two icebergs, each initially 1 000 m thick. The temperature-depth profiles of the icebergs were simulated using a one-dimensional and time-dependent model of the heat equation. On one, we imposed basal melting of 3.0 m a^{-1} for 50 a, and on the other we imposed basal freezing of 3.0 m a^{-1} for 50 a. Each iceberg has a surface temperature of -30°C and zero snow accumulation. Initially, the melting iceberg rapidly thins by both melting and creep, but, as the average ice temperature decreases in response to the melting, creep thinning also decreases. After basal melting ceases, thinning rates are very low. The freezing iceberg also thins, initially very slowly because creep thinning is almost balanced by freezing. But, as the depth-averaged temperature increases, creep rates increase and, once freezing ceases, thinning rates are considerably larger than for the melting iceberg. Indeed, after 100 a it actually becomes thinner than the melting iceberg. This is an extreme example, but it does highlight the importance of changes in ice-shelf temperature. Clearly, these can be induced by factors other than basal melting; changes in either surface temperature or snow-accumulation rates will have a similar effect.

Our Ross Ice Shelf simulations indicate the potential for major changes in ice-shelf configuration as a consequence of CO_2-induced warming. However, we

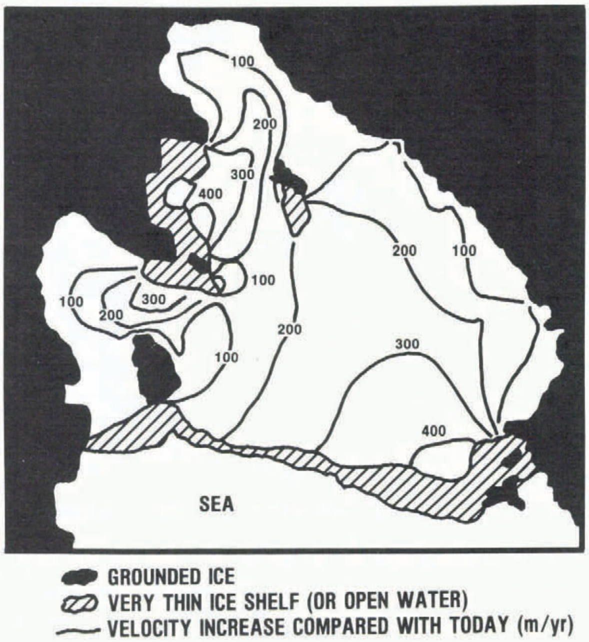


Fig.1. Changes in Ross Ice Shelf thickness associated with CO_2-induced climatic warming. Note that drainage rates of tributary glaciers were not allowed to change for this simulation. In reality, their drainage rates would increase, and ice-shelf thinning would be less pronounced than shown here.

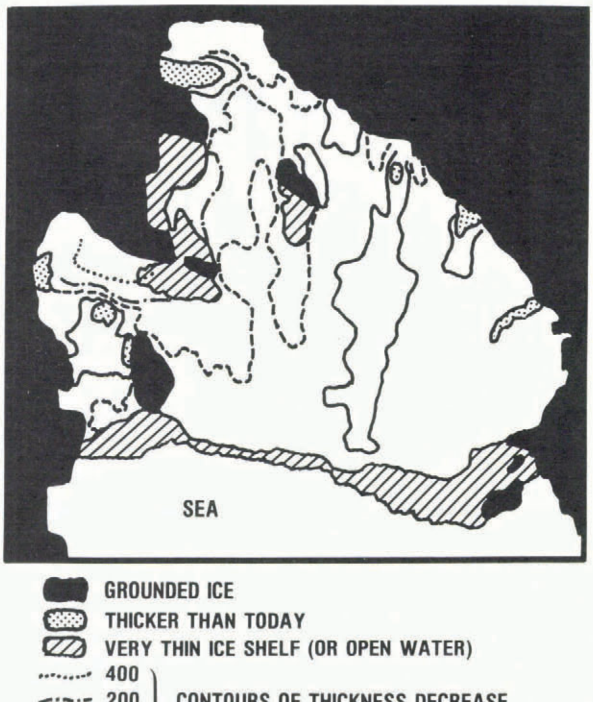


Fig.2. Changes in Ross Ice Shelf velocities caused by CO_2-induced climatic warming. These estimates represent the effect of ice softening only; actual velocity increases would probably be greater due to acceleration of glacier drainage rates.

stress that our study was confined to ice-shelf responses; discharge from ice streams into the ice shelf was held constant throughout. Currently, we are incorporating this response by including a simple analytic treatment of ice streams that will provide first-order estimate of ice-stream discharge. In brief, we believe the effects of ice-stream feedback are to reduce ice-shelf thinning rates and to increase ice velocities.

REFERENCES

MacAyeal D R 1984 Tides, tidally-driven barotropic circulation and the formation of tidal fronts below the Ross Ice Shelf, Antarctica. *Annals of Glaciology* 5: 216-217

MacAyeal D R, Thomas R H 1982 Numerical modeling of ice-shelf motion. *Annals of Glaciology* 3: 189-194

Weertman J 1957 Deformation of floating ice shelves. *Journal of Glaciology* 3(21): 38-42

COMPUTER SIMULATION OF THE ICE SHEET IN THE SHIRASE BASIN, ANTARCTICA

(Abstract)

by

M. Nagao, M. Nakawo and A. Higashi

(Department of Applied Physics, Faculty of Engineering, Hokkaido University, Sapporo 060, Japan)

A three-dimensional numerical model is developed to simulate the variation with time of the form of the ice sheet in the Shirase basin, Antarctica (Fig.1). The model is composed of two-dimensional grids on which the mass flux of ice is computed so as to satisfy the equation of continuity. Local conditions of the flow of ice, particularly the effect of the depth profile of temperature, are considered. Adopting a simple method for calculating the mass flux developed by the same authors (Nagao and others 1982) procedures of numerical calculations are simplified. Areal grids of 50 km distances covering the basin are used, paying special attention to the boundary conditions at its margin and glacier tongue.

Results of the calculations show that a nearly stable form of the ice sheet could be obtained after approximately 10 ka when started from 1 000 m ice thickness all over the basin. The obtained stable surface topography shows its sensitive dependence on the bedrock topography. There was a tendency for the bottom temperature of the glacier downstream to be higher than the melting point, which may confirm the suggested instability of the ice sheet near the central stream line of Shirase Glacier (Mae 1979).

REFERENCES

Mae S 1979 The basal sliding of a thinning ice sheet, Mizuko Plateau, East Antarctica. *Journal of Glaciology* 24(90): 53-61

Nagao M, Nakawo M, Higashi A 1982 A simple method for calculating mass flux in an ice sheet, with a consideration of its temperature profile. *Memoirs of National Institute of Polar Research*. Special Issue 24: 192-200

https://doi.org/10.3189/S0260305500003888 Published online by Cambridge University Press