SNOW AND ICE FEEDBACK AND CLIMATE SENSITIVITY

(Abstract)

by

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A new parameterization of snow and ice area and albedo is presented, based on recent satellite observations of snow and ice extent (Robock 1980, 1983). This parameterization is incorporated into a seasonal energy-balance climate model. Experiments are conducted with the model to determine the effects of this parameterization on the latitudinal and seasonal distribution of model sensitivity to external forcings of climate change (solar constant variations and volcanic dust) and to internally forced climate change.

The snow/ice area and snow/ice meltwater feedbacks are found to determine the sensitivity pattern to external forcing, producing enhanced sensitivity in the polar regions in the winter and decreased sensitivity in the polar regions in the summer. This result holds for both equilibrium experiments, where a step function forcing is applied at the beginning of the simulation and the model is run to equilibrium (Robock 1983), and for transient experiments where the forcing is time-dependent (Robock 1981). This pattern is produced by the sea-ice thermal inertial feedback. Snow and ice albedo feedbacks are relatively weak.

This response pattern is the same as that found by Manabe and Stouffer (1980) with a general circulation model. The enhanced sensitivity in the summer found by Ramanathan and others (1979) is shown to be due to a surface albedo feedback parameterization which does not allow the thermal inertia to change.

The sensitivity to internal forcing is amplified by the snow/ice feedback, producing a higher variance of the resulting temperature time series. The spectra of the series are shifted to more variance in the lower frequencies. The latitudinal and seasonal pattern of variance shows higher variance at higher latitudes due to the lower mean thermal inertia, but the pattern is relatively unaffected by the presence or absence of snow/ice feedbacks because the mean thermal inertia does not change.

ACKNOWLEDGEMENT

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MODELING THE LATE-QUATERNARY GLACIAL VARIATIONS WITH MULTI-COMPONENT CLIMATIC SYSTEMS

(Abstract)

by

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Because of the small net rates of energy flow involved in very long-term changes in ice volume (10^{-1} W m^{-2}) it will be impossible to proceed in a purely deductive manner to develop a theory for these changes. An inductive approach will be necessary entailing the formulation of multi-component stochastic-dynamical systems of equations governing the variables and feedbacks thought to be relevant from qualitative physical reasoning (e.g. "conceptual models"). The output of such models should be required to conform as closely as possible to all lines of observational evidence on climatic change and, in addition, should have a predictive quality in the search for new observational evidence. Moreover, the models themselves should be required to satisfy the general conservation laws and all the results of physical measurement of the fast response (high energy flow) processes in the system that generally lead to diagnostic relation-

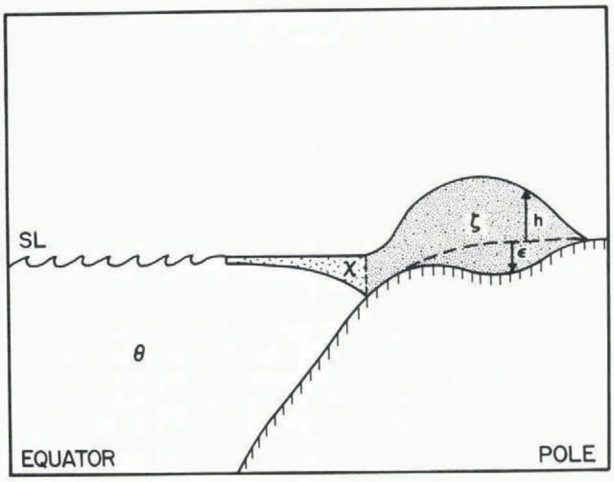

Fig.1. Schematic meridional cross-section of the climatic system showing the three main prognostic variables treated in this study: ζ (total continental ice mass extending to the grounding line), χ (total marine ice mass; ice shelves, icebergs and pack ice beyond the grounding line), and Θ (mean ocean temperature). Other prognostic variables not considered in this study are isostatic depression ε and ice thickness above sea-level h.

ships. General discussions of these questions are given by Saltzman (1983 and in press) and Saltzman and Sutera (in preparation‡).

A prototype of such an inductive model, recently developed by Saltzman and Sutera (in preparation‡), is described. The model is formulated by considering the feedbacks that are likely to dominate, in the form of a nonlinear dynamical system governing three prognostic components; continental ice mass ζ, marine ice mass χ, and mean ocean temperature Θ (see Fig.1). The dynamical climatic system is the following:

$$\frac{d\zeta'}{dt} = (a_1 - a_2\chi')\chi' - a_3\Theta' + F_\zeta + R_\zeta \tag{1}$$

$$\begin{aligned}\frac{d\chi'}{dt} = {} & b_0\zeta' + (b_1 - b_2\chi' - b_3\chi'^2 - b_4\chi'^2)\chi' - \\ & - b_5\Theta' + F_\chi + R_\chi\end{aligned} \tag{2}$$

$$\frac{d\Theta'}{dt} = c_0\zeta' + c_1\chi' - c_2\Theta' + F_\Theta + R_\Theta \tag{3}$$

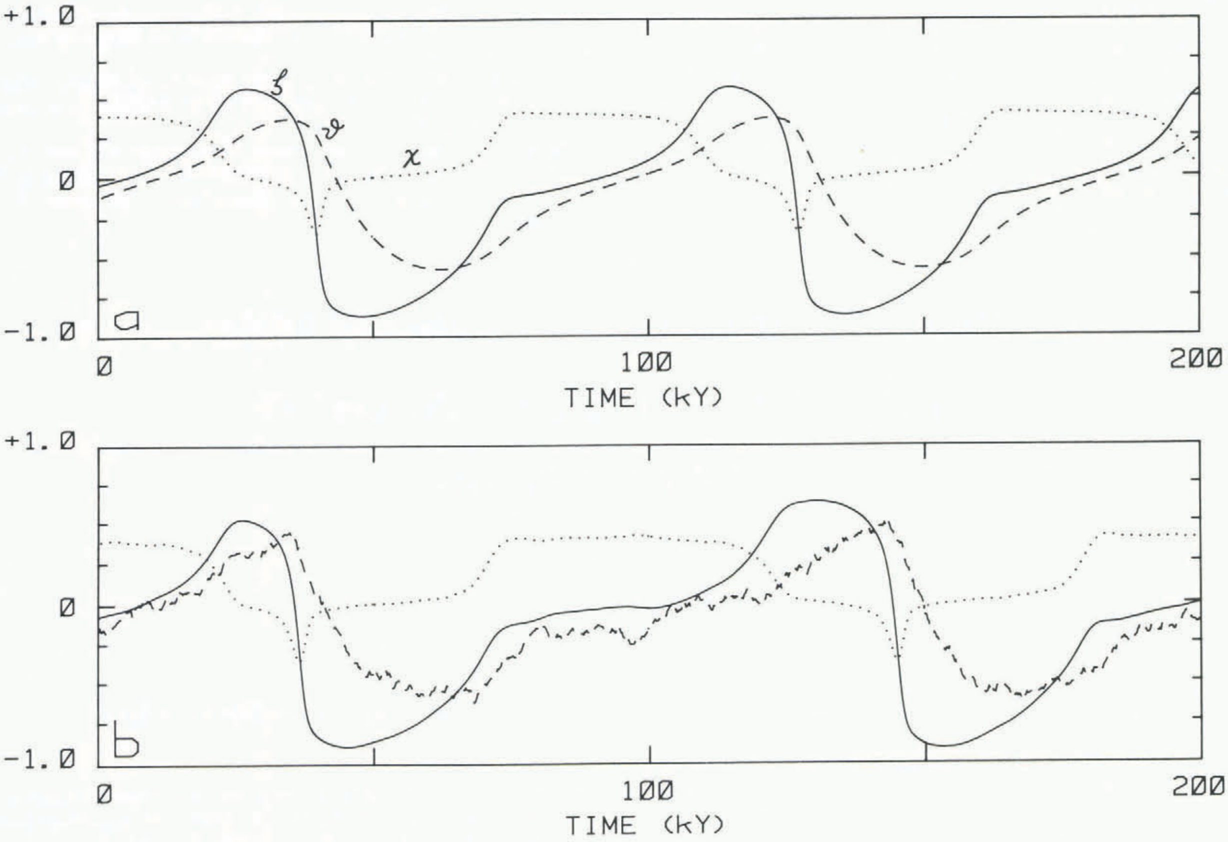

Fig.2. Solution obtained for the (ζ′, χ′, Θ′) system of Equations (1) (2) and (3): (a) with no deterministic or stochastic forcing and (b) with stochastic forcing included in Equation (3). The curves shown are for the non-dimensional values $\zeta^* = 1.45Z^{-1}\zeta'$, $\chi^* = 0.75X^{-1}\chi'$, and $\Theta^* = 0.96\Theta^{-1}\Theta'$, which can be inverted to give ζ′, χ′, and Θ′ for any choice of characteristic ranges of fluctuations of ζ, χ, and Θ denoted by Z, X and Θ, respectively.

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‡ Submitted for publication:
Saltzman B, Sutera A A model of the internal feedback system involved in the late Quaternary climatic variations.

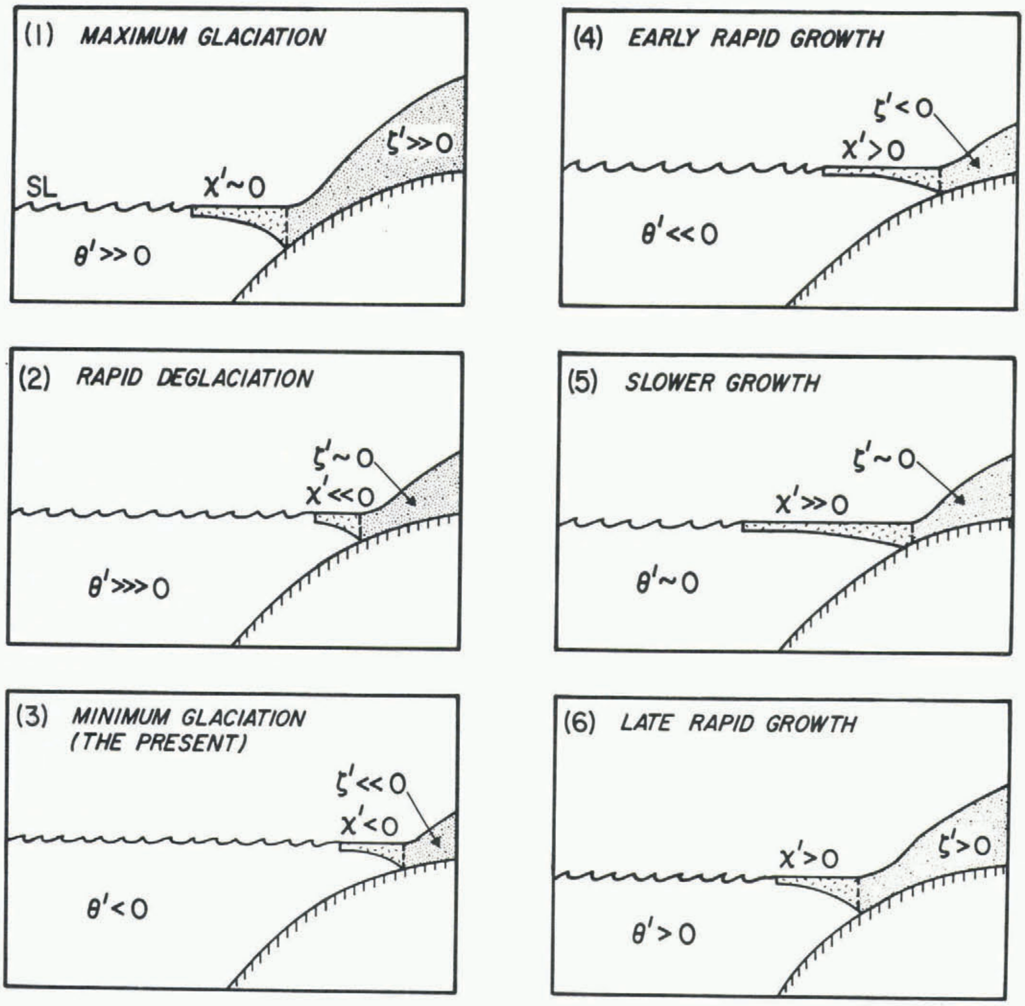

Fig.3. Schematic snapshot representations of the solution shown in Figure 2(a), at selected consecutive points in time starting with maximum continental glaciation. The first three points (1,2,3) represent the rapid deglaciation phase and the next three points (4,5,6) represent the slower glacial buildup.

where the primes denote departures from an equilibrium, F denotes external deterministic forcing, R denotes stochastic forcing, and the coefficients are positive constants (e.g. c_2^{-1}, the only linear damping time constant in the system, is taken to be 10 ka).

The free, unforced, solution is shown in Figures 2(a) and (b) without and with stochastic perturbation, respectively. It can be seen to have several features in common with the $^{18}/^{16}$O-derived records of ζ, e.g. a period of nearly 100 ka with rapid deglaciations, and the solution also predicts concomitant variability in χ and Θ. The distributions of ζ', χ' and Θ' corresponding to six consecutive points of interest in this solution cycle are shown in Figure 3.

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