Reports

Topography, Albedo-Temperature Feedback, and Climate Sensitivity

Abstract. *Numerical experiments with an energy balance model of the earth's climate suggest an enhancement of albedo-temperature feedback caused by the presence of a high middle-latitude plateau in the zonally averaged Northern Hemisphere topography. The increased climate sensitivity arises from the increased rate of change of snow cover produced by the advance or retreat of the winter snow line over the north slope of this topographic feature.*

If the hemispheric solar radiation at the top of the atmosphere is reduced, the drop in surface temperature may cause the hemispheric snow cover to extend farther equatorward, persist longer in the spring, or arrive earlier in the fall. The higher reflectivity of an ice-snow surface relative to bare land or ocean results in less absorption of insolation, which tends to cool the surface. With expanded hemispheric snow cover the mean temperature may be lowered, which may cause a further expansion of snow cover. Such feedback has long been considered important in the earth's climate (*1, 2*).

The Himalayan-Alpine Belt, the Tibetan Plateau, and the Colorado Plateau appear in the zonally averaged elevation of the continents as a single plateau at an altitude of more than 1600 m centered between 30°N and 40°N. This report presents the results of numerical experiments which point to an enhancement of the albedo-temperature feedback caused by the presence of this middle-latitude plateau in the zonally averaged topography.

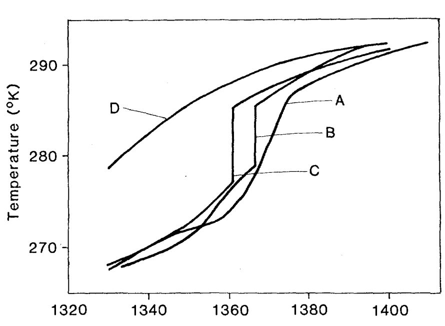

Fig. 1. Mean annual Northern Hemisphere surface air temperature plotted as a function of solar constant for three diffusivity coefficients (in square meters per second): curve A, 3.25×10^6; curve B, 3.4×10^6; and curve C, 3.55×10^6. Curve D is the same curve B, except that the topography has been eliminated.

The snow line, taken to be a cross section of the surface in the atmosphere which intersects the surface of the earth at the seasonally varying boundary of snow and bare land, corresponds roughly to the 273 K isotherm; its elevation generally increases with decreasing latitude and its slope is $\sim 10^{-3}$. With a small southward displacement of the snow line, the amount of land brought under snow cover for an earth with no topography will be greater, the greater the amount of land relative to ocean at that latitude and the lower the latitude. If the earth's surface slopes upward in the same sense as the snow line, there will be an increased amount of snow cover produced by the displacement, compared to the case for a displacement over a horizontal surface; the closer the slope of the terrain to the snow line slope, the greater the increase in area for the same horizontal displacement. The reverse effect should occur for a downward sloping terrain.

For the present climate the zonally averaged January snow line lies close to the north side of the middle-latitude average plateau (*3, 4*), while in July the snow line is in polar latitudes. Thus topographically produced enhancement of the albedo feedback should be more closely dependent on the position of the snow line in the winter half year than in the summer half.

To investigate the effects of the extensive belt of high elevation in middle latitudes on albedo feedback, we carried out numerical experiments with a global zonally averaged seasonal energy balance model in which surface topography has been incorporated. The model, based on one of Suarez and Held (*5*), has two atmospheric layers with detailed radiation calculations incorporated implicitly, a 120-m mixed layer, and a sea ice and snow budget; energy calculations are done for the atmosphere, the mixed layer, and the land surface; latitudinal heat flux is accomplished by linear diffusion in the atmosphere.

The equilibrium seasonal climate is calculated for a sequence of values of the solar constant, *S*; the Northern Hemisphere mean annual surface air temperature is plotted against *S*. Experiments have been conducted for different values of latitudinal heat diffusivity and for different values of the surface albedo.

The results, based on the use of surface albedo values of 0.85 for fresh snow, 0.60 for old or melting snow, 0.14 for bare land, and 0.07 for open ocean, are shown in Fig. 1. If *S* is lowered from a relatively high value, the mean annual temperature drops smoothly until near 286 K, at which point, for higher heat diffusivities, there is a discontinuous drop in temperature.

For an equilibrium state just above this drop, there is no perennial land ice, although there is perennial sea ice in the Arctic Ocean; Fig. 2 shows that for this case the winter extremum snow line is near the north slope of the zonally averaged plateau, the summer snow line being over the Arctic Ocean. For temperatures below the jump, the winter extremum snow line has crossed the top of the

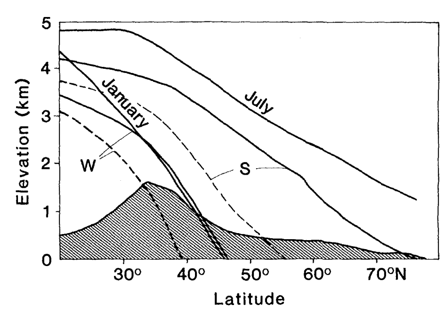

Fig. 2. Cross section through the atmosphere. Elevation is plotted versus latitude, showing the zonally averaged topography (curve with hatching) (*9*). The solid lines labeled *W* and *S* correspond, respectively, to the winter and summer model snow lines for a value of *S* at the top of the jump of curve B in Fig. 1; the dashed lines similarly labeled are for a point at the bottom of the jump. The solid curves labeled *January* and *July* on the temperature profiles are for the present climate calculated from (*10*).

plateau; perennial ice has appeared on the continent, extending well down into middle latitudes.

If the latitudinal heat diffusivity is reduced, with a lowering of S, there is no sharp drop in temperature when the winter snow line approaches the north side of the middle-latitude plateau (curve A in Fig. 1). There is, instead, a sharp increase in the rate of cooling with lowering S; the appearance of perennial ice on the continent is roughly coincident, but the explosive southward advance is replaced by a more retarded expansion. The rapid expansion of continental ice with large diffusivity occurs as a result of the reduced latitudinal temperature gradients; for a given reduction of mean temperature, a much greater surface area can be affected than when a larger temperature gradient is present.

The surface albedo values for snow-ice used in these experiments are very high and are more appropriate for polar latitudes (*2, 6*). Additional experiments were carried out with the use of a fresh snow value of 0.75 and an old snow value of 0.55; the response was similar to curve A in Fig. 1, displaced toward somewhat lower values of S. A more comprehensive test of the topographic enhancement shoud allow for albedo dependence on the terrain type, which is not easily incorporated into the model used here.

The transition to increased sensitivity with the lowering of S, at 286 K, is about 2 K below the present temperature of the Northern Hemisphere (*3*). This model estimate may be low because of an underprediction of summer temperatures, as seen in Fig. 2.

The model's zonal symmetry may result in excessive sensitivity; different distributions of topography with longitude, each with the same zonal average, can produce different rates of increased snow cover with a displacement of the snow line. The absence of the Asian monsoon in the model rules out consideration of the large seasonal fluctuation of the snow line over Asia, and in winter the large deviation from the zonal mean (*7*). Another missed feature is the large area of permanent snow over the Himalayas. Topographic enhancement of feedback may also be exaggerated in the model, because of the use of snowfall rate independent of longitude, the snowfall and hence the mean albedos over the Asian landmass being overestimated.

Although these numerical experiments are only suggestive of topographic enhancement of albedo feedback, the establishment of such a link between climate and topography would provide a potential mechanism for climate change on the geologic time scale. It is likely, for example, that most of the features making up the middle-latitude feature achieved roughly their present elevations in the early Pleistocene, about 2 million years ago (*8*), that is, at the beginning of Northern Hemisphere glaciations.

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7. A. Robock, *ibid.*, p. 267.
8. See, for example, C. M. Powell and P. J. Conaghan, *Earth Planet. Sci. Lett.* **51**, (1973).
9. The zonally averaged topography was computed from (*4*). Because the model cannot treat both bare land and land ice simultaneously at a given latitude, the permanent ice cover of Greenland was not included in the zonally averaged topography; this permanent ice cover will not directly affect the rate of change of snow-covered area as discussed here.
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3 February 1982; revised 20 September 1982

Removal of Uranium(VI) from Solution by Fungal Biomass and Fungal Wall–Related Biopolymers

Abstract. Penicillium digitatum *mycelium can accumulate uranium from aqueous solutions of uranyl chloride. Azide present during the uptake tests does not inhibit the process. Killing the fungal biomass in boiling water or by treatment with alcohols, dimethyl sulfoxide, or potassium hydroxide increases the uptake capability to about 10,000 parts per million (dry weight). Formaldehyde killing does not enhance the uranium uptake. The inference that wall-binding sites were involved led to the testing of uranium uptake by chitin, cellulose, and cellulose derivatives in microcolumns. All were active, especially chitin.*

Although bioaccumulation of the heavy elements has been well known and well documented for more that 30 years (*1*), our recent discovery of the capability of *Penicillium digitatum* isolates to absorb uranyl chloride (UO_2Cl_2) (*2*) is one of the few examples in which fungi exhibit the behavior (*3, 4*).

This capability is all the more significant in light of the additional demonstrations that (i) the absorbed uranium can be quantitatively recovered if one strips the metal-loaded mycelium with aqueous solutions of alkali carbonates and (ii) the biosorbent property does not require living hyphae (*5*). Our study of the fungal absorption system indicates that uranium uptake by *P. digitatum* preparations can be greatly enhanced by boiling and other treatments and that the basis for uranium binding resides mainly in wall macromolecules.

General methods for the preculture and handling of fungal biomass have been detailed in (*2, 5*), as has the procedure for uranium analysis, "delayed neutron release" (*6*). In principle, neutrons released by fission products formed after sample irradiation with thermal neutrons are counted. The sensitivity is ~ 0.1 μg at natural isotopic composition with an accuracy of ± 5 percent. For the delayed neutron procedure, 100 parts per million (ppm) of $UO_2Cl_2 \cdot 2H_2O$ standards correspond to 61.7 ppm of uranium; hence the correction factor 0.617 has been applied to all data presented here. The results are based on at least duplicate determinations.

Two specific test procedures were used in the experiments reported here. For the study of uptake enhancement, control mycelial charges of 3 g fresh weight (0.125 g dry weight) were incubated with 20 ml of 100 ppm UO_2Cl_2 solution (61.7 ppm uranium) for 4 hours at 23° to 24°C. Additional charges of mycelial biomass comparable in size were