ISOTOPIC DIFFUSION IN POLAR FIRN

Abstract

by

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Hammer and others (1978) have shown how seasonal cycles in stable isotopic ratio, the delta-value, of ice can be used to date ice cores. The formation and preservation of these cycles is associated with seasonal deposition of snow and subsequent isotopic exchange in the firn. Alteration in the firn may be accomplished by meltwater movement (downward or upward) and by vapor diffusion with or without the effects of temperature gradients. Here we address vapor diffusion in porous firn with no liquid phase.

Examples of the importance of vapor diffusion are given by Hammer and others. They describe cases in which the seasonal cycle is lost due to diffusion and also the interesting case of the 1973 core from Milcent, Greenland, where seasonal isotopic cycles can be counted from the bottom of the core at 1177 AD to 1971 AD, but not with confidence for the youngest two years (other techniques are used in the upper layers). It seems that, at this site, sub-surface diffusion acts to form a clear seasonal cycle in delta-value that was not present in the snow as deposited.

Isotopic exchange may be important even where seasonal cycles are not preserved, as for example, in central East Antarctica. There depth variations on the 0.1 m scale are due to irregular accumulation events and the record of these variations smooths with time. If the smoothing process can be understood, perhaps deep-core records can be interpreted with respect to accumulation-event variability in times past.

Theory is therefore needed to predict isotopic smoothing in terms of such parameters as accumulation rate. Johnsen (1977) addressed this question for solid ice and in a rather difficult fashion for firn.

The theory proposed and tested here is for water-vapor diffusion. Water molecules in the air in the firn exchange and tend to homogenize isotopically via the interconnecting pores between the ice grains. The molecules of water vapor also exchange with the neighboring ice matrix so that all of the molecules are affected by vapor exchange. In this way, isotopic variations in firn formed at the surface become, with time, less pronounced.

Consideration is taken of the restrictions to vapor exchange because of reduced permeability at higher densities, because of the mass of ice to be exchanged, and because of temperature effects, especially that affecting the denisty of water molecules in the air.

The theory is successful in describing observed isotopic smoothing at two extreme sites, at the crest of the ice sheet in southern Greenland (site 3008) (accumulation rate, 0.411 Mg m^{-2} a^{-1}; mean temperature $-21\,^{\circ}$C), and at Dome C, in central East Antarctica (accumulation rate 0.035 Mg m^{-2} a^{-1}; mean temperature $-52\,^{\circ}$C). The main difficulty in comparing the numerical results with observation is that there is no known independent way in which to separate smoothing effects and original-depositional variations in the observed profiles.

Isotopic variations can also be developed in firn after burial due to isotopic diffusivity gradients. Simple numerical experiments were conducted to determine the isotopic effects of density contrasts (such as with "wind" crusts) and of seasonal temperature gradients. Maybe, by the time of the conference, we will be able to explain the development of the seasonal cycle at Milcent.

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