Controls on the Geometry of Accretion Reflectors

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Basal accretion occurs when meltwater refreezes onto the base of an ice sheet. Thick (600-900 m) regions of accretion ice are identified in radio-echo sounding data as plume-shaped reflectors above the basal reflector and below isochronous layers of meteoric ice. In both Antarctica and Greenland accretion reflectors have been imaged at an elevation of 1/3-1/2 of the ice sheet thickness and extend in the flow direction as far as 100 km. Here we investigate the freezing rates and energy budgets of basal accretion processes using both simple scaling estimates and a two-dimensional thermomechanical higher order numerical flowline model coupled to a basal hydrology model.

Simple scaling estimates for the freezing rate can be derived by linking the observed height of the accretion reflectors, the size of the accreting region, and the known ice velocity or surface accumulation rate. These estimates imply freezing rates on the order of 10-100 cm/yr. Such rates require latent heat fluxes of 1-10 Wm^{-2}, orders of magnitude larger than typical conductive heat fluxes beneath continental ice sheets.

The mismatch between the latent heat flux required to maintain a large freezing rate and the conductive heat flux that can be removed from the ice sheet base implies two end-member possibilities. First is the supercooling possibility, where the freezing rates and latent heat fluxes are of the same order of magnitude as that implied by the simple scaling estimates. In this case the conductive heat flux is supplemented by glaciohydraulic supercooling. In supercooling the heat flux removed is proportional to the water throughput, allowing large heat fluxes to be removed if a large amount of water flux is focused through a small area. Second is the overriding possibility, where a thin layer of accretion ice has overridden a larger zone of deformed meteoric ice. In this possibility the accretion volume and freezing rates are much smaller than what is implied by simple estimates that assume that all the ice underneath the observed reflectors is accretion ice. If the freezing rates are small then conduction can remove the necessary heat flux, but a complex deformation pattern must be found other than normal ice sheet flow. This deformation pattern must be able to cause a thin layer of accretion ice to override meteoric ice to a height of 1/3-1/2 the ice thickness.

We use both simple scaling and our hydrology model to estimate the water flux required to reproduce the observed height of the accretion reflectors through glaciohydraulic supercooling. Under reasonable assumptions about bed and surface gradients, approximately 10^5 m^2a^{-1} of water throughput is required to reproduce the observed height of the accretion reflectors through supercooling. In addition, we use our ice flow model to search for a combination of boundary conditions that can cause a thin layer of accretion ice to override meteoric ice to the required height. We have been unable to find such a pattern so far, even including rapid changes in the basal boundary condition. This suggests, but does not prove, that supercooling is responsible for producing large accretion plumes.