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Spatial and Temporal Variability of Glacier Melt in the McMurdo Dry Valleys, Antarctica

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Abstract

In the McMurdo Dry Valleys, Victoria Land, East Antarctica, melting of glacial ice is the primary source of water to streams, lakes, and associated ecosystems. To better understand meltwater production, three hypotheses are tested: 1) that small changes in the surface energy balance on these glaciers will result in large changes in melt, 2) that subsurface melt does not contribute significantly to runoff, and 3) that melt from 25-m high terminal cliffs is the dominant source of baseflow during cold periods. These hypotheses were investigated using a surface energy balance model applied to the glaciers of Taylor Valley using 14 years of meteorological data and calibrated to ablation measurements. Inclusion of transmission of solar radiation into the ice through a source term in a one-dimensional heat transfer equation was necessary to accurately model summer ablation and ice temperatures. Results showed good correspondence between calculated and measured ablation and ice temperatures over the 14 years using both daily and hourly time steps, but an hourly time step allowed resolution of short duration melt events and melt within the upper 15 cm of the ice. Resolution of short duration melt events was not important for properly resolving seasonal ablation totals. Across the smooth surfaces of the glaciers, ablation was dominated by sublimation and melting was rare. Above freezing air temperatures did not necessarily result in melt, and low wind speed was important for melt initiation. According to the model, subsurface melt between 5 and 15 cm depth was extensive and lasted for up to six weeks in some summers. The model was better able to predict ablation if some subsurface melt was assumed to drain, lowering ice density, consistent with observations of a low density weathering crust that forms over the course of the summer on Dry Valley glaciers. In extreme summers, drainage of subsurface melt may have contributed up to half of the observed surface lowering through reduction of ice density and possibly through collapse of highly weathered ice. When applied spatially, the model successfully predicted proglacial streamflow at seasonal and daily time scales. This was despite omitting a routing scheme, and instead assuming that all melt generated exits the glacier on the same day, suggesting refreezing is not substantial. Including subsurface melt as runoff improved predictions of runoff volume and timing, particularly for the recession of large flood peaks. Because overland flow was rarely observed over much of these glaciers, these model results suggest that runoff may be predominantly transported beneath the surface in a partially melted permeable layer of weathered ice. According to the model, topographic basins, particularly the low albedo basin floors, played a prominent role in runoff production. Smooth glacier surfaces exhibited low melt rates, but were important during high melt conditions due to their large surface area. Estimated runoff contributions from cliffs and cryoconite holes was somewhat smaller than suggested in previous studies. Spatial and temporal variability in albedo due to snow and debris played a dominant role in flow variations between streams and seasons. In general, the model supported the existing assumption that snowmelt is insignificant, but in extreme melt years snowmelt in the accumulation area may contribute significantly to runoff in some locations.

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