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Meteorology and Surface Energy Fluxes In the 2005-2007 Ablation Seasons at Miage Debris-Covered Glacier, Mont Blanc Massif, Italian Alps

Ben Brock (1), Claudia Mihalcea (2), Martin Kirkbride (1), Guglielmina Diolaiuti (2), Mark Cutler (1), and Claudio Smiraglia (2)

(1) University of Dundee, School of Social and Environmental Sciences, Dundee, United Kingdom (b.w.brock@dundee.ac.uk), (2) University of Milan, Department of Earth Sciences "Ardito Desio", Milan, Italy (claudiamihalcea@yahoo.com)

During the 2005 – 2007 June – September ablation seasons, meteorological conditions were recorded on the lower and upper parts of the debris-covered ablation zone of Miage Glacier, Italy. In 2005, debris temperature and sub-debris ice melt were also monitored at 25 points with debris thickness 0.04 - 0.55 m, spread over 5 km2 of the glacier. In this paper we present an analysis of the spatial and temporal patterns of meteorological variables across the glacier and a quantification of the energy balance at the debris surface. The radiative fluxes were directly measured, and near-closure of the surface energy balance is achieved, providing support for the bulk aerodynamic calculation of the turbulent fluxes. Surface-layer meteorology and energy fluxes are dominated by the pattern of incoming solar radiation which heats the debris, driving strong convection. Mean measured sub-debris ice melt rates are 6 - 33 mm d-1 and mean debris thermal conductivity is 0.96 W m-1 K-1 displaying a weak positive relationship with debris thickness. Mean seasonal values of the net shortwave, net longwave and debris heat fluxes show little variation between years, despite contrasting meteorological conditions, while the turbulent latent (evaporative) heat flux was more than twice as large in the wet summer of 2007 compared with 2005. The increase in energy output from the debris surface in response to increasing surface temperature means that sub-debris ice melt rates are fairly insensitive to atmospheric temperature variations, in contrast to debris-free glaciers. Improved knowledge of spatial patterns of debris thickness distribution and 2 m air temperature, and the controls on evaporation of rainwater from the surface, are needed for distributed physically-based melt modeling of debris-covered glaciers.