Geophysical Research Abstracts
Vol. 19, EGU2017-7103, 2017
EGU General Assembly 2017

The surface energy balance and turbulence characteristics of a mid-latitude glacier

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In the vast majority of glacier surface energy balance (SEB) studies, parameterisation rather than direct measurement is used to estimate one or more of the individual heat fluxes, with others, such as the rain and ground heat fluxes, deemed negligible. Turbulent fluxes of sensible and latent heat (QH and QL) are commonly parameterised using the bulk aerodynamic technique. This method was developed for horizontal, uniform landscapes rather than sloped, inhomogeneous glacier terrain, and contains significant uncertainty regarding the selection of appropriate roughness length (z0) values and atmospheric stability schemes. Customised weather stations were installed on glaciers in the Purcell Mountains of British Columbia, Canada, over the 2014 - 2016 melt seasons, to directly measure all relevant heat fluxes. This included the use of eddy covariance sensors to observe QH and QL, and to calculate z0 values. The melt rate and surface conditions of the glacier were also simultaneously recorded. The obtained dataset was used to design a SEB model, and evaluate the most common forms of the bulk method. Melt estimates from the model showed very good agreement with observed rates at seasonal, daily, and sub-daily timescales, giving a high level of confidence in the observation method and that effective closure of the SEB had been achieved. Significant differences were noted between observed z0 values and those commonly used in the literature, particularly in the case of the water vapour roughness lengths. The three stability schemes tested with the bulk method (Log Profile, Bulk Richardson, and Monin – Obukhov) resulted in either over or under-suppression of the calculated turbulent fluxes during stable atmospheric conditions on the glacier. The Monin – Obukhov method returned mean values closest to those observed, but displayed poor performance on sub-daily timescales, and insufficient suppression of the fluxes during katabatic conditions. Overall, the designed observation system and model provide an effective method of capturing glacier SEB, but questions remain regarding turbulence generation, and its relationship with stability and slope angle on a glacier.