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# Surface radiation, energy, and mass balance on a valley glacier, Southeast Tibet: Observation and analysis

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The first glacio-meteorological experiment in Southeast Tibet was implemented on the ablation zone of Parlung No. 4 Glacier during the summer of 2009. Hydro-meteorological observations included turbulent fluxes, four radiation components, ambient air temperature and humidity, three-layers ice temperatures as well as melting depth. We investigated the radiation, energy, and mass balance and major findings are as follows.

The observed average melting rate is 42 mm w.e. d-1 and surface net radiation is 147 Wm-2. Both of them are among the highest values as reported in previous studies worldwide. During the mature stage of South Asian monsoon, the net radiation and the melting rate were further enhanced by both low albedo of the bare ice ($\sim$ 0.21) and more incoming longwave radiation.

After strict data quality-control, we evaluated three parameterizations of the scalar roughness lengths (z0T for temperature and z0q for humidity), viz. key factors to accurate estimations of sensible heat and latent heat fluxes using the bulk aerodynamic method. An approach, which was developed for (semi-)arid regions but has never received applications over an ice/snow surface, produces fairly low errors in energy flux estimates both in individual melt phases and over the whole ablation season; it thus emerges as a practically useful choice to parameterize z0T, q in glaciated areas. Moreover, we find all the three candidate parameterizations unable to predict diurnal variations in the excess resistances to humidity transfer, thus encouraging more efforts for improvement.

An energy balance model indicates the contribution of net radiation to the total melt energy is dominant, sensible heat and latent heat play a secondary role, and subsurface flux is negligible. The combined role of cloud and surface albedo controls the surface energy balance during the onset period of the Indian monsoon. A survey was made to compare the contribution of net radiation to the melting between highland glaciers (>4000 m) and lowland glaciers (<3000 m) worldwide. It is demonstrated that the ratio of the net radiation to the melt energy is higher than 90% for highland glaciers while it varies over 30%$\sim$80% for lowland glaciers. The differential ratios are associated with highland climate conditions that generally lead to more net radiation while less sensible and latent heat fluxes on glacier surfaces.

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