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Distinguishing snow and glacier ice melt in High Asia using MODIS

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In High Mountain Asia, snow and glacier ice contribute to streamflow, but the contribution of each of these hydrologic components is not fully understood. We generate daily maps of snow cover and exposed glacier ice derived from MODIS at 500 m resolution as inputs to melt models to estimate daily snow and glacier ice contributions to streamflow. The daily maps of 1) exposed glacier ice (EGI), 2) snow over ice (SOI) and 3) snow over land (SOL) between 2000 and 2014 are generated using fractional snow cover, snow grain size, and annual minimum ice and snow from the MODIS-derived MODSCAG and MODICE products. The method allows a systematic analysis of the annual cycle of snow and glacier ice extents over High Mountain Asia. We compare the time series of these three types of surfaces for nine sub-basins of the Upper Indus Basin (UIB) and characterize the variability over the MODIS record. Results show that the Dras Nala, Astore, and Zanskar sub-basins located in the eastern part of the UIB have the highest annual fraction of SOL driven by mid-winter westerly storms. Sub-basins in the northwestern extent of the UIB with relatively high mean elevations, the Hunza, Shigar, and Shyok show the highest annual fraction of both SOI and EGI (i.e. accumulation and ablation zones of the glacier). The largest sub-basin, Kharmong has the smallest annual fraction of SOL, SOI, and EGI, and a smaller SOI and EGI than the mouth of the river (Tarbela).

Using these maps, snow and ice melt contributions are then estimated for the nine Upper Indus sub-basins using two melt models: a calibrated temperature-index (TI) model and an uncalibrated energy balance (EB) model. Near-surface air temperatures for the TI model are downscaled from ERA-Interim upper air temperatures, bias corrected using observed temperatures, and aggregated to 100 m elevation bands. We calibrate the seasonally variable degree-day factors for ice and snow by comparing streamflow to the sum of melt (SOL+SOI+EGI) and rainfall for a subset of years. Our uncalibrated spatially-distributed energy-balance model requires solar and longwave radiation, temperature, and wind data, that we downscale to 500 m from GLDAS NOAH surface simulations. In the Hunza sub-basin, the TI model produces more EGI melt than the EB model at all elevations, resulting in an annual EGI melt contributions of 19-34% and 9-20% respectively. Melt from SOI is similar from both models below 4500 m; however, above 4500 m (perhaps near the 0-degree-Celsius) the physically based EB model produces more melt. Annually, SOI contributes 8-14% and 20-25% when estimated by the EB and TI models. Melt from SOL is similar from both models in dry to average years but in wet years the EB model produces more melt at higher elevations. Annually, SOL contributes 36-44% and 34-44% of annual streamflow from the EB and TI models respectively. We compare melt volume results from both models to streamflow where available.