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Quantifying the individual contributions of melt from snow and glaciers in High Mountain Asia river basins: Syr Darya, Amu Darya, Indus, Ganges, and Brahmaputra

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In High Mountain Asia, snow and glacier ice contribute to streamflow, but the respective contributions are not fully understood. We use daily maps of snow and glacier ice from MODIS at 500 m spatial resolution as input to an energy balance melt model to estimate daily snow and glacier ice contributions to streamflow. Daily maps of 1) snow over ice (SOI), 2) exposed glacier ice (EGI), and 3) snow over land (SOL) are generated using fractional snow cover, snow grain size, and annual minimum ice and snow from MODIS-derived MODSCAG and MODICE products. These maps are calibrated using semi-automated class maps from Landsat 8 at 30 m spatial resolution. We estimate snow and ice melt contributions using an uncalibrated energy balance model (ParBal) forced with CERES meteorological data. We summarize rainfall from APHRODITE for available years in the MODIS record to complete the balance of atmospheric sources of water. The ParBal model is superior for estimating snow and ice melt volumes relative to a temperature index model because it does not rely on calibration and can easily be transferred from basin to basin. It is also less sensitive to temperature biases frequently observed in reanalysis data because solar and longwave radiation contribute significant energy to melt. In cloudy regions, using CERES data is more accurate than widely-used LDAS forcing data. We compare total melt volumes from ParBal summed with rainfall from APHRODITE to streamflow in the Naryn sub-basin of the Syr Darya River basin, the Vakhsh sub-basin of the Amu Darya River basin, the Narayani, Sapta Kosi, and Karnali sub-basins of the Ganges River basin and multiple nested sub-basins of the Indus River basin.

The expansive modeled geographic area captures a wide range of snow and ice conditions including: highly glacierized regions, less glacierized and more arid regions, and lower elevation regions with only seasonal snow cover and large contributions from rainfall. For example, melt from the ParBal model in the highly glacierized Shigar, Hunza, and Shyok sub-basins of the Upper Indus River Basin (UIB) show that surface water comprises 20% to 31% SOI melt, 15% to 24% EGI melt, 44% to 49% SOL melt, and 1% to 17% rainfall. In contrast, in the less glaciated, more arid, Kharmong and Astore sub-basins of the UIB, ParBal show surface water comprises 2% to 6% SOI melt, 2% to 5% EGI melt, 77% to 89% SOL melt, and 1% to 19% rainfall. In the lower-elevation Tarbela sub-basin, nearly half of the surface water is SOL melt while the other half is rainfall. On a larger regional scale, moving from east to west across High Mountain Asia, rainfall contributions decrease and the contribution from glaciers and snow increases. We summarize contributions from melting snow and ice compared to rainfall in the Syr Darya, Amu Darya, Indus, Ganges, and Brahmaputra River basins. The method allows a systematic analysis of the annual cycle of snow and glacier ice extents over High Mountain Asia.