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Trends in annual minimum exposed snow and ice cover in High Mountain Asia from MODIS

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Though a relatively short record on climatological scales, data from the Moderate Resolution Imaging Spectroradiometer (MODIS) from 2000-2014 can be used to evaluate changes in the cryosphere and provide a robust baseline for future observations from space. We use the MODIS Snow Covered Area and Grain size (MODSCAG) algorithm, based on spectral mixture analysis, to estimate daily fractional snow and ice cover and the MODICE Persistent Ice (MODICE) algorithm to estimate the annual minimum snow and ice fraction (fSCA) for each year from 2000 to 2014 in High Mountain Asia. We have found that MODSCAG performs better than other algorithms, such as the Normalized Difference Index (NDSI), at detecting snow. We use MODICE because it minimizes false positives (compared to maximum extents), for example, when bright soils or clouds are incorrectly classified as snow, a common problem with optical satellite snow mapping.

We analyze changes in area using the annual MODICE maps of minimum snow and ice cover for over 15,000 individual glaciers as defined by the Randolph Glacier Inventory (RGI) Version 5, focusing on the Amu Darya, Syr Darya, Upper Indus, Ganges, and Brahmaputra River basins. For each glacier with an area of at least 1 km2 as defined by RGI, we sum the total minimum snow and ice covered area for each year from 2000 to 2014 and estimate the trends in area loss or gain. We find the largest loss in annual minimum snow and ice extent for 2000-2014 in the Brahmaputra and Ganges with 57% and 40%, respectively, of analyzed glaciers with significant losses (p-value<0.05). In the Upper Indus River basin, we see both gains and losses in minimum snow and ice extent, but more glaciers with losses than gains. Our analysis shows that a smaller proportion of glaciers in the Amu Darya and Syr Darya are experiencing significant changes in minimum snow and ice extent (3.5% and 12.2%), possibly because more of the glaciers in this region are smaller than 1 km2 than in the Indus, Ganges, and Brahmaputra making analysis from MODIS (pixel area ∼0.25 km2) difficult. Overall, we see 23% of the glaciers in the 5 river basins with significant trends (in either direction). We relate these changes in area to topography and climate to understand the driving processes related to these changes.

In addition to annual minimum snow and ice cover, the MODICE algorithm also provides the date of minimum fSCA for each pixel. To determine whether the surface was snow or ice we use the date of minimum fSCA from MODICE to index daily maps of snow on ice (SOI), or exposed glacier ice (EGI) and systematically derive an equilibrium line altitude (ELA) for each year from 2000-2014. We test this new algorithm in the Upper Indus basin and produce annual estimates of ELA. For the Upper Indus basin we are deriving annual ELAs that range from 5350 m to 5450 m which is slightly higher than published values of 5200 m for this region.