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ASTER image based assessment of glacier mass balance of Nanga Parbat massif, Pakistan

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Starting with the analytical approach given in detail by Nuth and Kääb (2011; henceforth NK2011), we have further developed an approach toward analysis of repeat stereo ASTER-derived DEMs to extract specific and net annual mass balance of glaciers of Nanga Parbat, Pakistan. We used the approach of NK2011 to coregister DEMs obtained from ASTER stereo images acquired in September 2004 and October 2010, and the glacier outlines produced by Haritashya et al. (2014 in prep) as a mask to isolate glacier from stable (nonglacier) areas. We then devised a protocol to remove DEM data deemed to be the pits, cones, and bulges that are common artifacts with ASTER DEM data. We developed an approach similar to that given by NK2011 to make corrections for cross- and along-track errors of elevation differences and to zero out the mean elevation difference bias for stable (non-glacier points). The largest sources of correctable error were cross-track and along-track slope-dependent artifacts, which we corrected using an approach modified from that of NK2011. Several small systematic errors, such as that related to elevation, became even smaller when cross- and along-track errors were corrected. We then proceeded to analyze the statistics for the cumulative ice area and for individual glaciers. Also using the DEM-change spread function for stable areas, we deconvolved the random error from the actual change signal present in the glacier areas. Ten glaciers of Nanga Parbat thinned by an average of 6 m, i.e. 1 m/year over the 6-year period. Ice in the highest elevations remained fairly stable or even thickened by a few meters, whereas that in lower elevations thinned. Bazhin Glacier apparently was undergoing a surge-like phenomenon of rapid mass transfer from higher elevations (where thinning occurred) to lower elevations (where it thickened), though the terminus advanced by only $\sim$182 m (Haritashya et al. 2014). Hence, our results indicate fluctuations of glaciers in Nanga Parbat, consistent with a widespread occurrence of surge-type glaciers in the nearby Karakoram Range, but an overall negative mass balance in this part of the western Himalaya. The magnitude of the thinning rate is similar to that elsewhere in the Himalaya.