



Decrease, Increase or Stability? Glacier Response to Climate Change in the Trans-Himalayas of Ladakh, Northern India

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The eastern and central parts of the Greater Himalayas display a general picture of rapidly melting glaciers, whereas the glaciers in the western Himalayas, Hindu Kush and Karakorum show a more differentiated response to climate change. It includes individual advancing glaciers and relatively stable snout positions. The Trans-Himalayan region of Ladakh is possibly located at the interface between shrinking and advancing or stable glaciers. The region is characterized by cold and arid conditions (mean annual air temperature amounts 5.6 °C and precipitation 93 mm in Leh, 3545 m a.s.l.), while the influence of the monsoon is rather limited. Due to low summer precipitation and the variability of winter snow fall, glaciers largely determine the potentials and limitations of irrigated crop cultivation, forming the primary basis of subsistence agriculture and regional food security. The glaciers of Ladakh are located above 5200 m a.s.l. and according to their small size (generally less than 2 km²), their response to climate change is expected to be direct and predictable. To detect and to quantify glacier changes in different aspects of the NNW-SSE oriented Kang Yatze Massif (6401 m a.s.l.), which is sandwiched between the Zanskar and Stok Ranges, multi-temporal and multi-scale remote sensing data were used. In order to map the changes of glacier covered areas two panchromatic Corona images from 1969 were compared to a high resolution panchromatic Worldview image from 2009. The data gap of the 40 years period was filled with Spot images (1991, 2006), and several Landsat and Aster data. To identify and quantify the glacierized areas a semi-automatic thresholding approach was applied for the co-registered multi-spectral datasets. Additionally, the delineation of glaciers was manually digitized on the panchromatic images. First results for the time period between 1969 and 2009 reveal a minor decrease of almost all investigated glaciers in the Kang Yatze Massif. In order to embed the results into the regional scale of the upper Indus catchment three other study areas of the Stok and Ladakh Ranges in the northern vicinity were integrated. The relative stability of seasonal glacier runoff patterns can further be validated by regional land use and land cover development. Selected multi-temporal studies of cultivated areas in the tributaries between 1969 and 2006 reveal a high grade of persistence. The remote sensing results were validated by three field campaigns which were carried out between 2007 and 2009.