USING REMOTELY-SENSED PRECIPITATION AND GLACIAL VELOCITIES AS CLIMATIC INDICATORS IN THE HIMALAYA

Bodo Bookhagen[1], Dirk Scherler[2]

[1]Geography Department, UC Santa Barbara, USA, bodo@icess.ucsb.edu

[2]Institut für Geowissenschaften, Universität Potsdam, Germany, dirk@geo.uni-potsdam.de

The Himalaya and adjacent Tibetan Plateau are the source of several major Asian rivers supporting a large, diverse ecosystem and a population of more than 1 billion people [Ives and Messerli, 1989; Barnett et al., 2005]. Large rivers such as the Indus, Sutlej, Ganges, Arun, and Brahmaputra/Tsangpo draining the southern Tibetan Plateau and the Himalaya are essential for agriculture and energy generation and are the pathways for sediments leaving the orogen. The southern Himalayan front spans the countries of India, Nepal, and Bhutan, and hosts some of the wettest inhabited placed on Earth. Along its entire length it displays a steep, 10-fold rainfall gradient reaching from the Ganges plains in the south to the very arid parts of the Tibetan Plateau in the north [Bookhagen and Burbank, 2006; in press] (Figure 1A). Precipitation in the upstream and high-elevation parts of Himalayan river basins falls as snow, causing a natural delay in the river discharge. The snowfall nourishes snowfields, and some of the world's largest valley glaciers (Figure 1B). Thus, the hydrologic budget of Himalayan rivers is dominated by monsoonal rainfall as well snow and glacial melt, but their relative contribution is not well established. Current knowledge of rainfall and snow-cover distribution is unreliable because this remote region lacks a dense gauge network. Field observations of glaciers are scarce, and hence satellite and aerial imagery is often used to monitor recent glacier changes [Kääb, 2005; Berthier et al., 2007; Scherler et al., in review], but so far no study has covered large regions from different climatic compartments of the Himalaya to systematically study glacial behavior with respect to their controlling factors. Here, we use calibrated, remote-sensing data for precipitation and snowmelt to constrain the climatic component and combine these with glacial flow-velocity measurements.

Our precipitation and glacial data indicates that despite most of the rain falls during the Indian Monsoon season during the summer months (May – October), snow fields and glaciers strongly depend on winter moisture transport. Our flow-velocity dataset based on image-cross correlation techniques [Scherler et al., 2008; LePrince et al., 2007; Scherler et al., in review] include 196 glaciers across the southern and western edge of the Tibetan Plateau. Key results indicate that (1) glacier-surface velocities are highest near the equilibrium line altitude (ELA), which exhibits a west to east gradient with ~0.5-1 km lower ELAs in the west (Figure 2); (2) glacial-flow characteristic are controlled by topographic slope, moisture budget, local factors including debris cover and topographic shielding.

Snow and glacial contribution to river discharge differ along strike of the Himalaya and outline important areas vulnerable to future climate change. The large western catchments (Indus and Sutlej) derive more than 50% of their annual discharge from snow and glacial melt [Bookhagen and Burbank, in press]. The state of mountain glaciers in global warming scenarios will become more important and understanding their behavior as well as their controlling factor will aid prediction of seasonal meltwater.

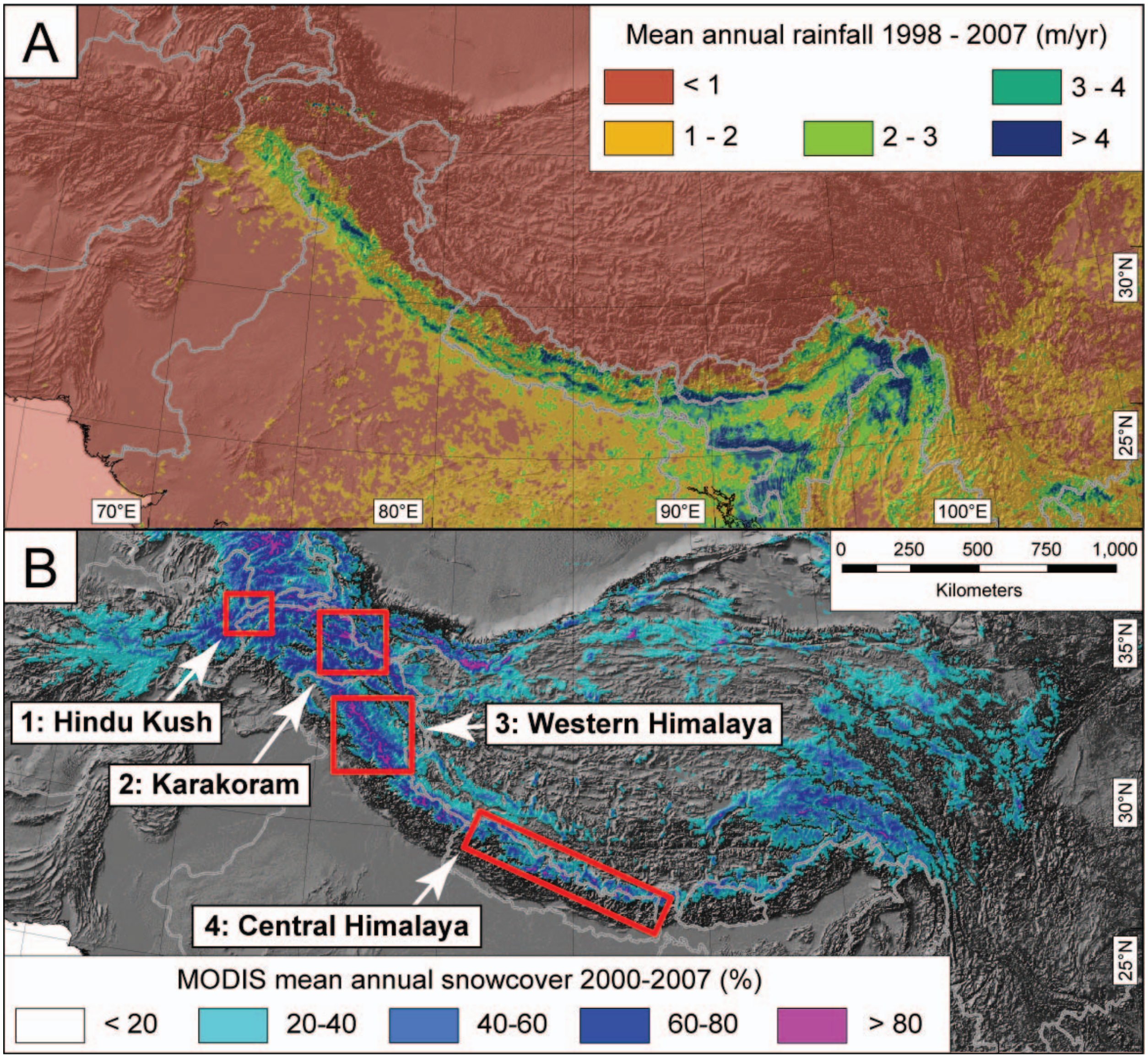

Figure 1: A. Mean annual rainfall based on calibrated TRMM 2B31 data and averaged over 10 years from 1998 to 2007 (see Bookhagen and Burbank (2006; in press) for processing details). Note the formation of an outer and inner rainfall band at the topographic barriers of the Himalaya. B. Mean annual snowcover from 2000 to 2007 derived from the MODIS satellite (Hall et al., 2002). Note that the snow cover is decreasing from West to East on the Tibetan Plateau due to moisture depletion of mid-latitutide westerlies. Red boxes indicate regions for which we have studied glacial velocities shown in Figure 2.

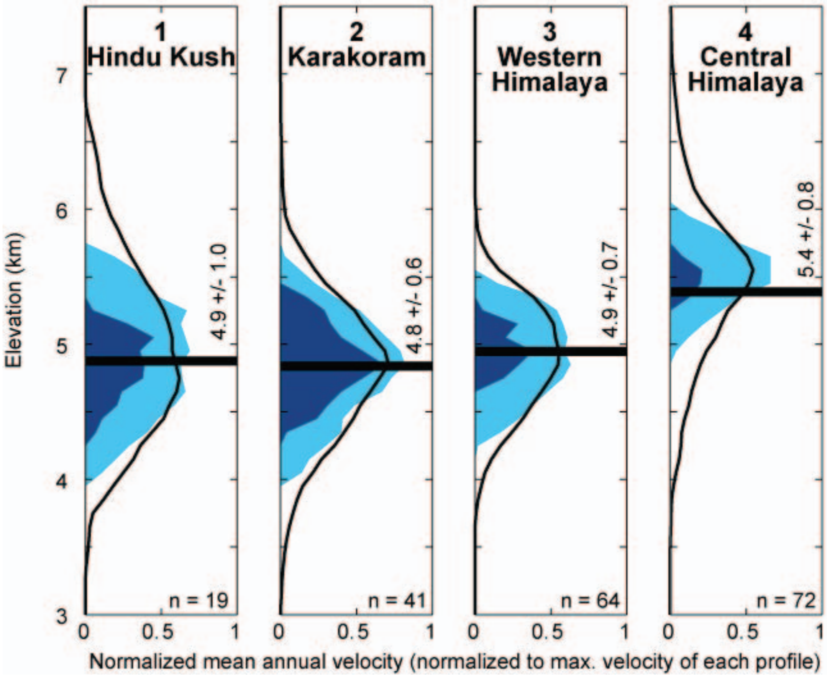

Figure 2: Normalized velocity distribution along elevation for the 4 main regions. The profile densities of 75 and 50% are shaded in dark and light blue, respectively. We have analyzed a total of 196 glaciers and normalized their mean velocity to the maximum velocity for each of the 4 geographic regions [Scherler et al., in review]. The black line indicates the mean elevation of the maximum velocity which generally correlates well with elevation line altitudes taken from optical satellite imagery. Note that the Central Himalayan glaciers are facing south – our limited data from north-facing glaciers in the Central Himalaya indicate a higher elevation of maximum velocities of about 0.5km.

Bibliography

Barnett, T.P., Adam, J.C., Lettenmaier, D.P. (2005): Potential impacts of a warming climate on water availability in snow-dominated regions. Nature, 439, p. 303-309, doi:10.1038/nature04141.

Berthier, E., Arnaud, Y., Kumar, R., Ahmad, S.,Wagnon, P., Chevallier, P. (2007): Remote sensing estimates of glacier mass balances in the Himachal Pradesh (Western Himalaya, India). Remote Sensing of Environment, 108, 327−338.

Bookhagen, B., Burbank, D.W. (2006): Topography, relief, and TRMM-derived rainfall variations along the Himalaya: Geophysical Research Letters, 33, L08405, doi:10.1029/2006GL026037.

Bookhagen, B. and Burbank, D.W. (in press): Towards a complete Himalayan hydrologic budget: The spatiotemporal distribution of snow melt and rainfall and their impact on river discharge, Journal of Geophysical Research-Earth Surface, doi:10.1029/2009jf001426.

Hall, D. K., Riggs, G.A., Salomonson, V.V., DiGirolamo, N.E. and Bayr, K.J. (2002): MODIS snow-cover products, Remote Sensing of Environment, 83, 181-194.

Ives, J. D., and B. Messerli (1989): The Himalayan Dilemma: Reconciling Development and Conservation, John Wiley and Sons, London, U.K.

Kääb, A. (2005): Combination of SRTM3 and repeat ASTER data for deriving alpine glacier flow velocities in the Bhutan Himalaya. Remote Sensing of Environment, 94, 463−474.

Leprince, S., Barbot, S., Ayoub, F., J.-P. Avouac (2007): Automatic and precise orthorectification, coregistration, and subpixel correlation of satellite images, application to ground deformation measurements, IEEE Trans. Geosci. Remote Sensing, 45(6), 1529-1558, doi: 10.1109/TGRS.2006.888937.

Scherler, D., Leprince, S., and M. R. Strecker (2008): Glacier-surface velocities in alpine terrain from optical satellite imagery - accuracy improvement and quality assessment, Remote Sens. Environ., 112, 3806–3819, doi:10.1016/j.rse.2008.05.018.

Scherler, D., Bookhagen, B., Strecker, M.R. (in review): High Asian glaciers: Impact of topography and climatic gradients on debris cover and flow velocity, in review in Journal of Geophysical Research-Earth Surface.