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Physical Geography

Reconciling high altitude precipitation in the upper Indus basin with glacier mass balances and runoff (EGU2016-9812)

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Mountain ranges in Asia are important water suppliers, especially if downstream climates are arid, water demands are high and glaciers are abundant. In such basins, the hydrological cycle depends heavily on high altitude precipitation. Yet direct observations of high altitude precipitation are lacking and satellite derived products are of insufficient resolution and quality to capture spatial variation and magnitude of mountain precipitation. Here we use glacier mass balances to inversely infer the high altitude precipitation in the upper Indus basin (UIB) and show that the amount of precipitation required to sustain the observed mass balances of large glacier systems is far beyond what is observed at valley stations or estimated by gridded precipitation products.

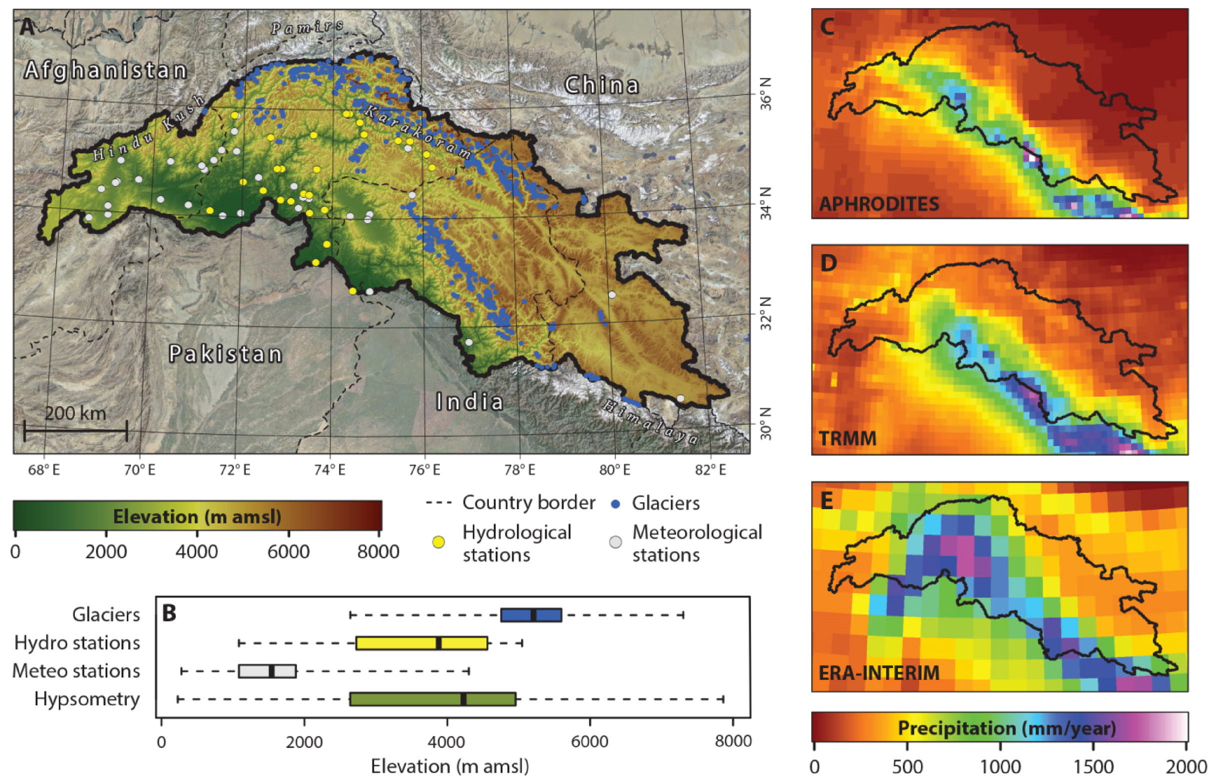

Figure: Overview of the UIB, basin hypsometry and three gridded precipitation products.

The problem

- High altitude meteorological stations are almost non-existent, but UIB is an important water resources.
- Commonly used gridded products show extremely dry upper part of the upper Indus or of coarse resolution to be used in impact modelling.
- Yet the largest glacier system beyond the polar regions are found in the UIB.

Approach

- Glacier mass balance model was used for all glaciers with an area 5 km² to estimate vertical precipitation gradient (PG) required to sustain glacier mass balance derived from ICESat .
- Rigorous 10,000 member Monte Carlo uncertainty analysis for key parameters.
- Uncertainty analysis of the spatial correlation within a mountain range of the key parameters (fully correlated, uncorrelated and intermediate case).
- APHRODITES precipitation field were corrected using interpolated PGs for all 10,000 members.
- Runoff estimates were derived for sub-basins using the corrected precipitation, ensemble of actual evapotranspiration estimates and the ICESat mass balance estimate.

Results

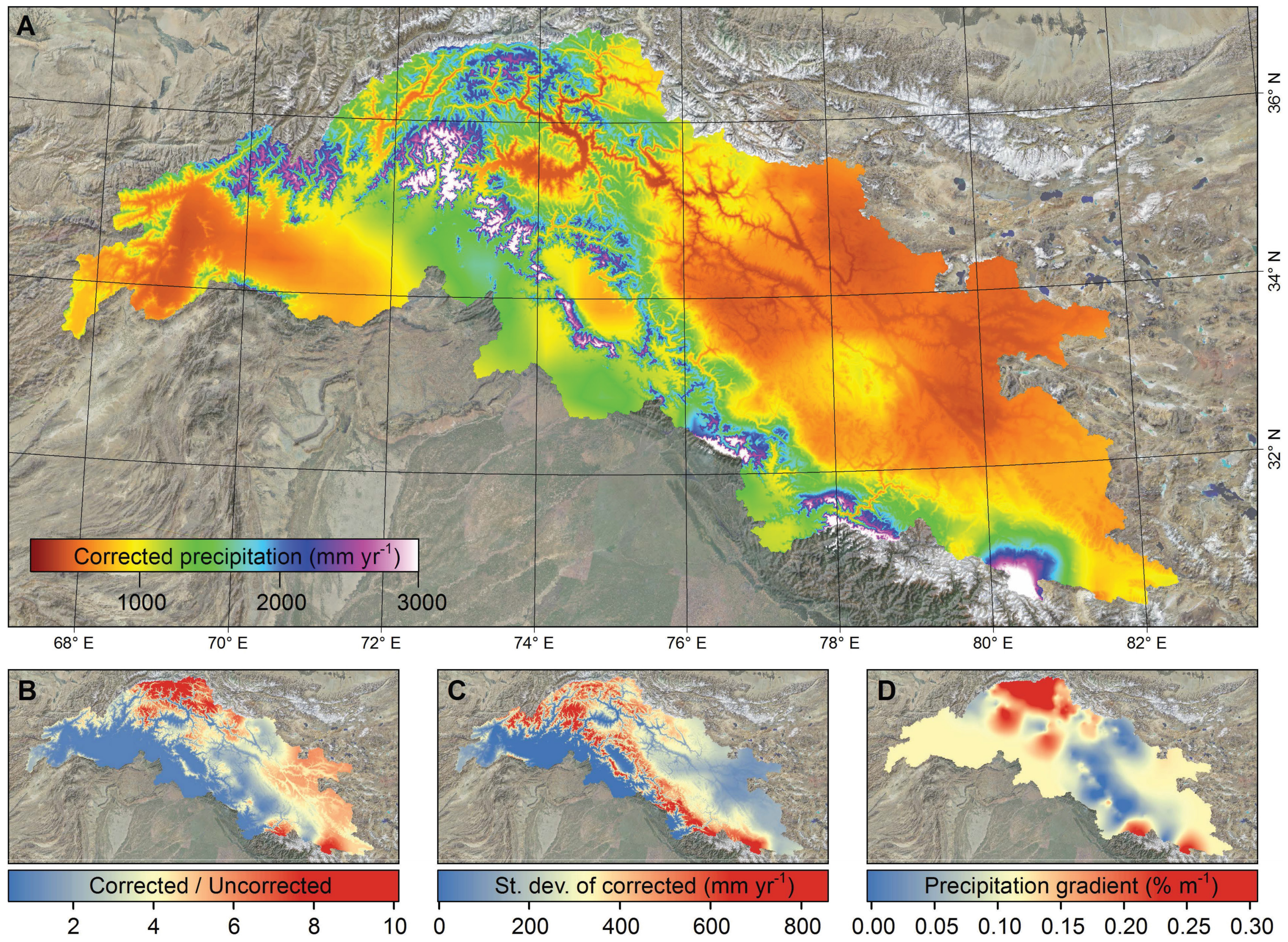

Figure: Corrected precipitation and estimated uncertainty for the UIB for the case with intermediate spatial correlation between model parameters. Panel A shows the average modelled precipitation field based on 10,000 simulations for the period 2003-2007, Panel B shows the ratio of corrected precipitation to the uncorrected APHRODITE precipitation for the same period, Panel C shows the standard deviation of the 10,000 simulations and panel D shows the average precipitation gradient.

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Validation

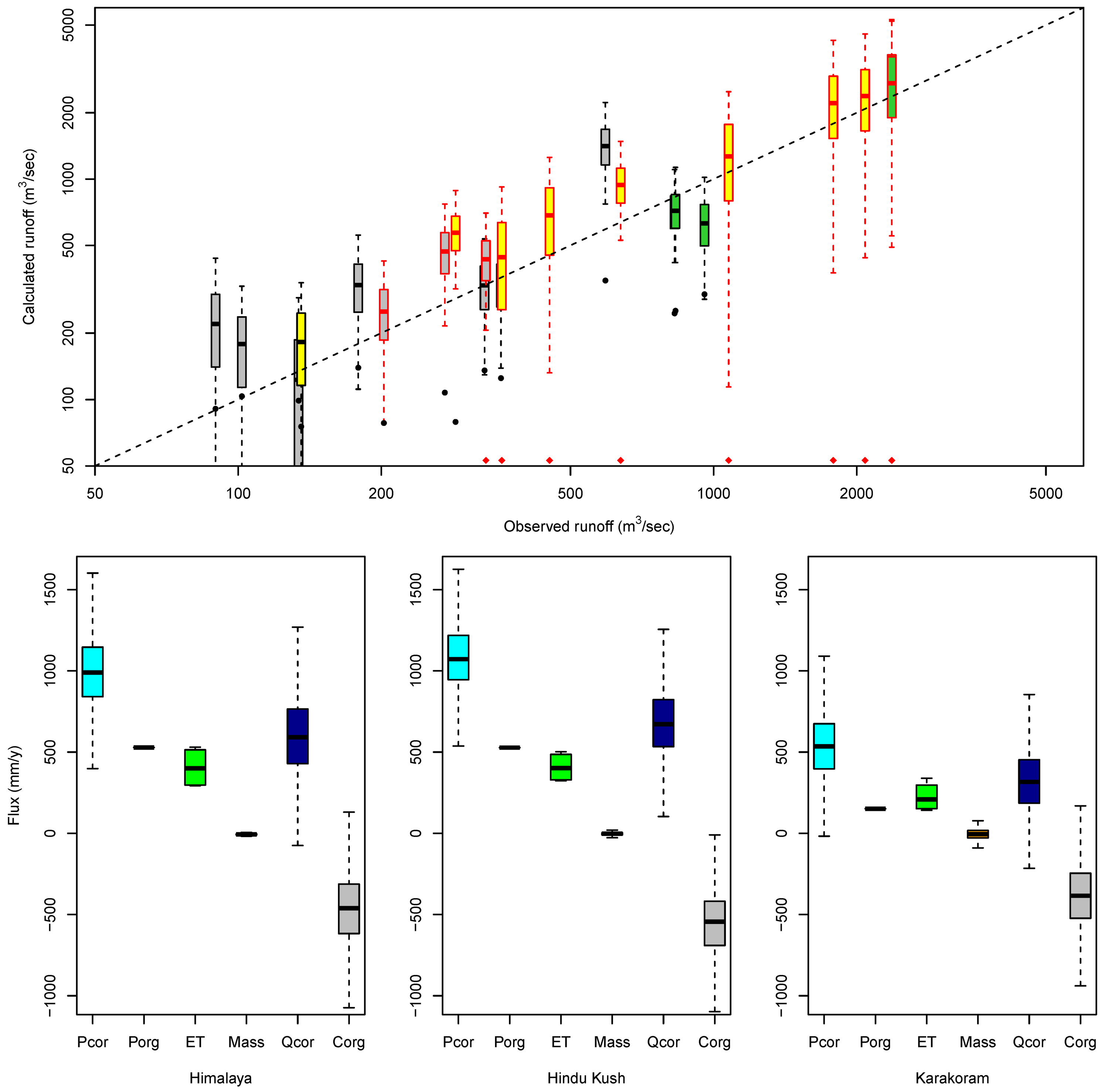

Figure: Validation of the precipitation correction using observed discharge. Top panel: The box plots are based on the runoff estimate based on 10,000 corrected precipitation fields (grey: stations for which the observed record does not coincide with the 2003-2007 period, yellow: stations for which the 2003 – 2007 period is part of the observational record, green: stations for which the observations are based precisely on the 2003 – 2007 period). The black dots and red diamonds (estimated runoff below 50 m3s-1) show the estimated runoff based on the uncorrected precipitation. The box plots with a red outline have an average elevation higher than 4000 m. and the box plots with a black outline have an elevation lower than 4000 m. Bottom panels: Water balance components of each zone (Pcor = corrected precipitation, Porg = uncorrected APHRODITES precipitation, ET = actual evapotranspiration, Mass = glacier mass balance, Qcor = estimated runoff, Corg = water balance gap in case the Porg is used).

Conclusions

- The estimated average UIB precipitation is 913 ± 323 mm y^{-1}, which more than twice as high than the uncorrected APHRODITES product (437 mm y^{-1}).
- In the most extreme case, precipitation is underestimated by a factor 5 to 10 in the region where the Pamir, Karakorum and Hindu-Kush ranges intersect.
- Our inverse modelling shows that the large glacier systems in the region can only be sustained if snowfall in their accumulation areas totals around 2000 mm y^{-1}.
- Median precipitation gradients in the Hindu-Kush and Karakoram ranges (0.260 % m^{-1} and 0.119 % m^{-1} respectively) are larger than those observed in the Himalayan range, e.g 0.044 % m^{-1}.