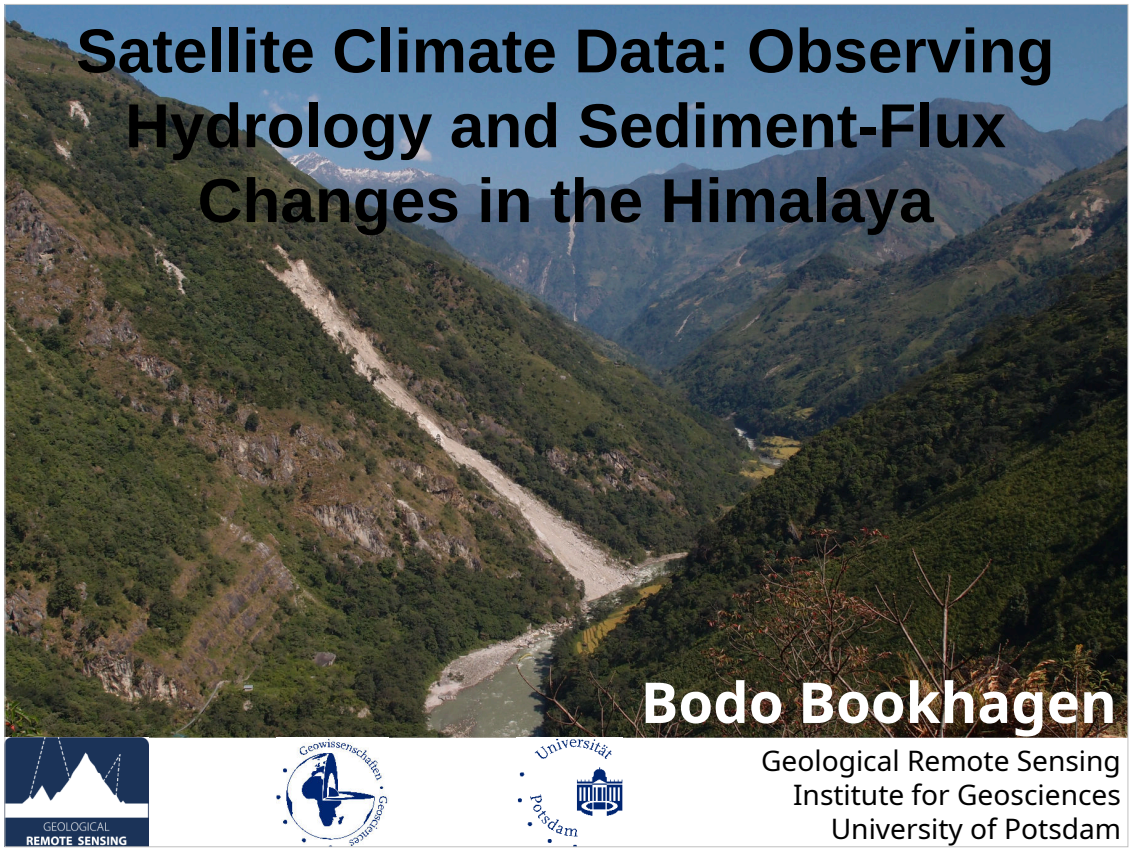


Satellite Climate Data: Observing Hydrology and Sediment-Flux Changes in the Himalaya

Bodo Bookhagen

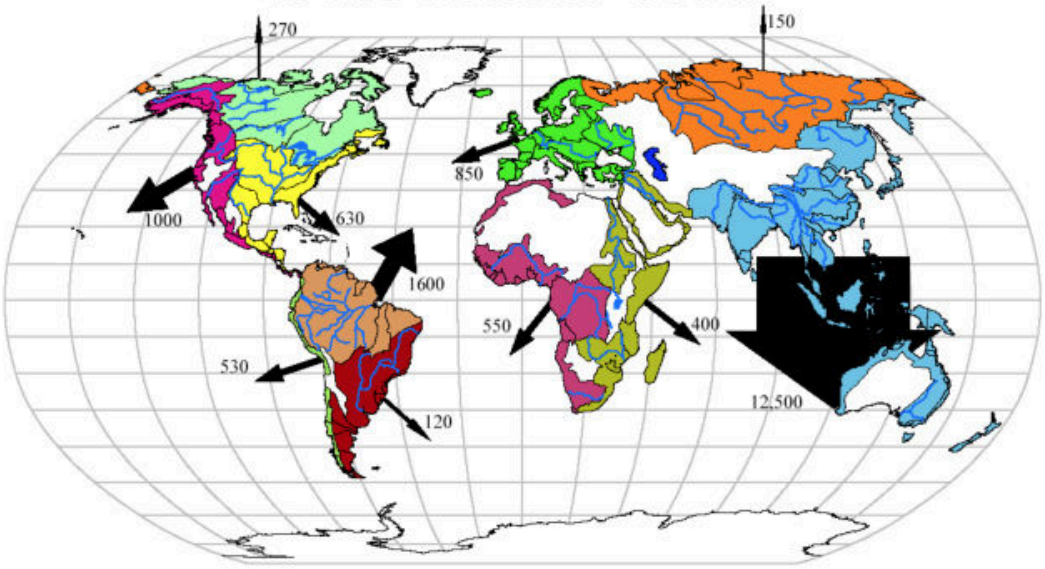
Geological Remote Sensing
Institute for Geosciences
University of Potsdam

The importance of sediment transport

I. **Sediment transport from mountains through rivers to the ocean is an important component of the natural cycle of mass and nutrient transport. These processes are key to form and maintain fertile floodplains.**

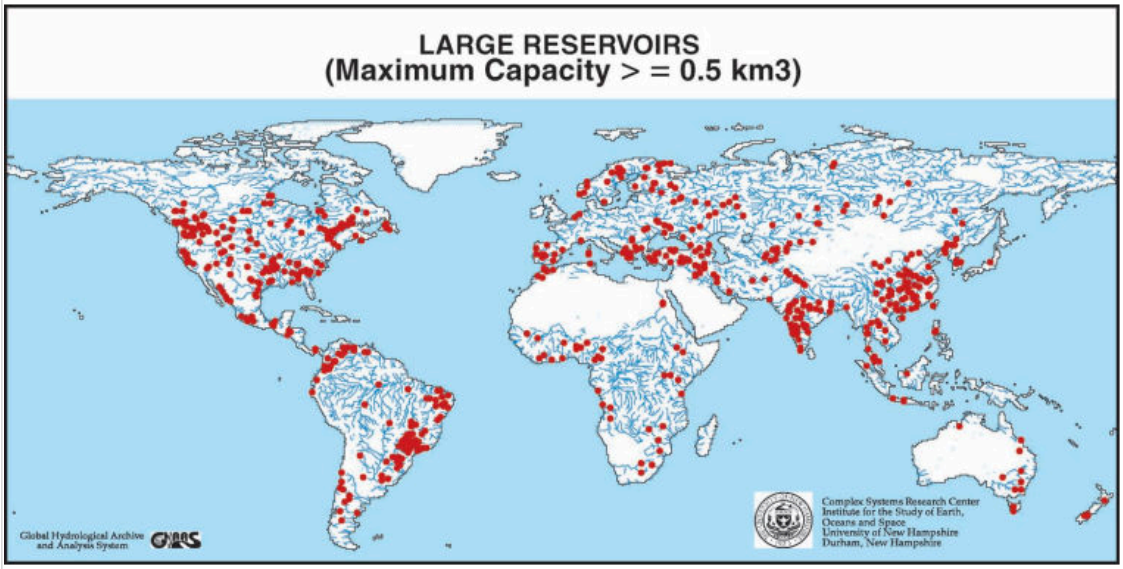
II. **Sediment transport from mountain ranges and their changes through time are not well understood and have significant implications for downstream populations, ecology, and water-resource management.**

Fluvial Discharge of Suspended Sediment to the Coastal Ocean



Total = 19,000 * 10^6 t/yr (Milliman and Farnsworth, 2011)

Spatial distribution of large anthropogenic reservoirs



Large reservoirs are subject to sediment infilling; rapid infilling will decrease a reservoir's life time.

Vörösmarty et al., 2003

Key problems

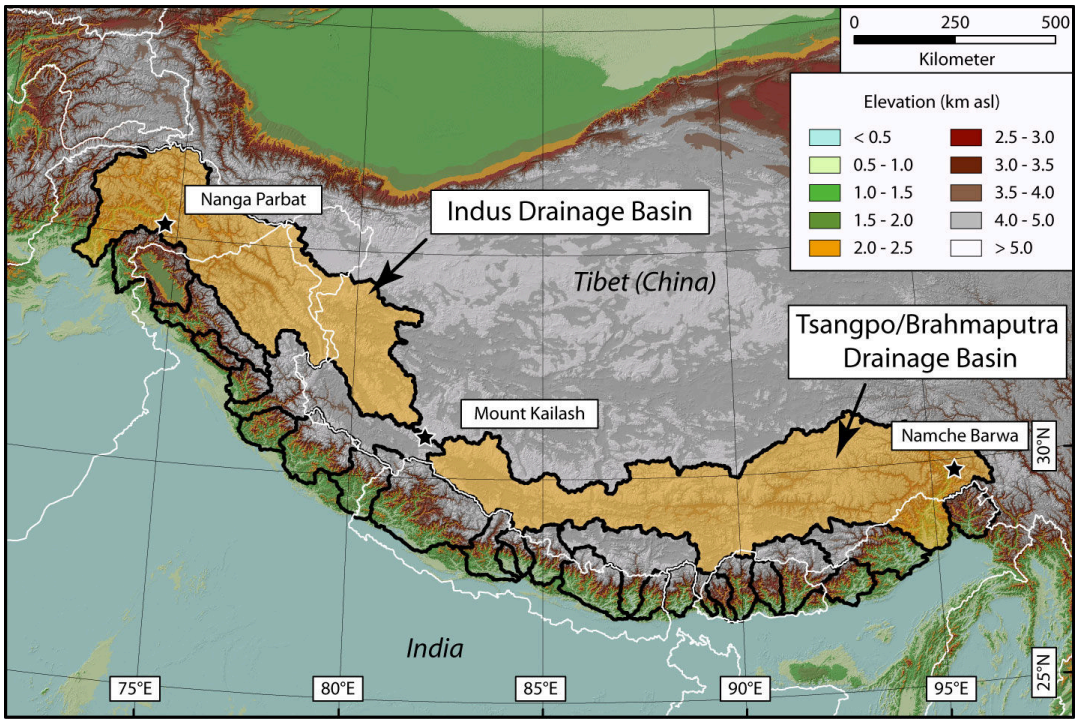
I. Sediment transport is a stochastic, event-based process. Most time series are not long enough to capture the extreme (or relevant) events and underestimate long-term transport.

Key problems

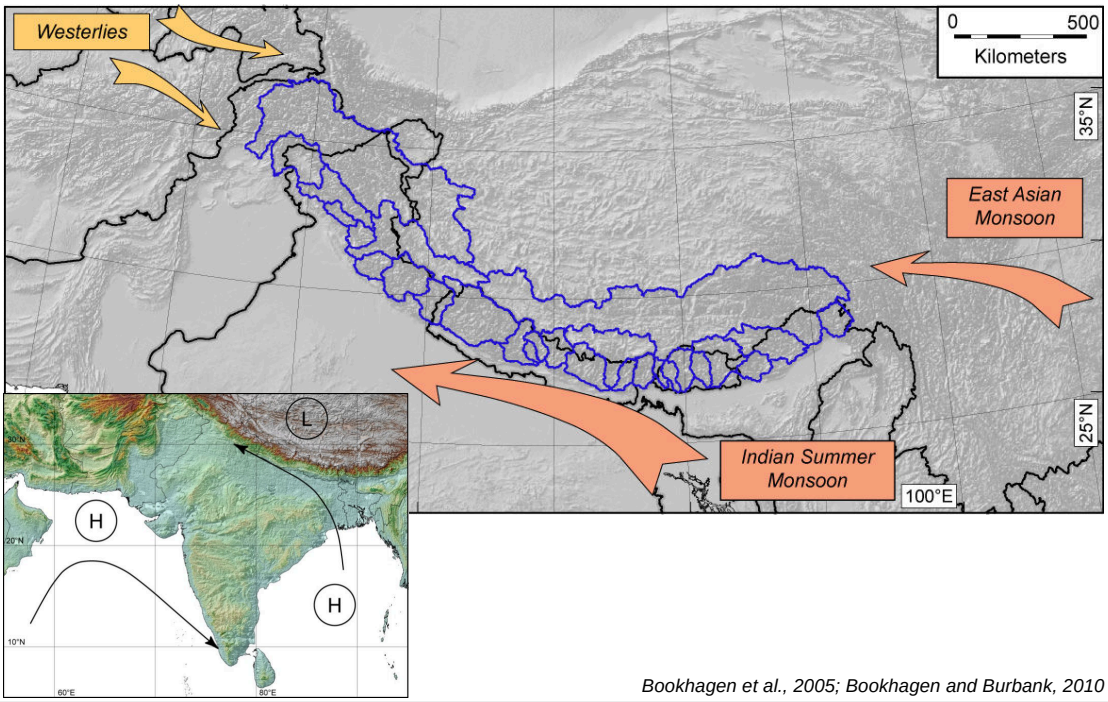
I. Sediment transport is a stochastic, event-based process. Most time series are not long enough to capture the extreme (or relevant) events and underestimate long-term transport.

II. Most sediment-transport measurements in steep mountain terrain are unreliable or have large uncertainties because of the inherent difficulty to measure flux in highly dynamic systems.

High Asian Topography and River Catchments

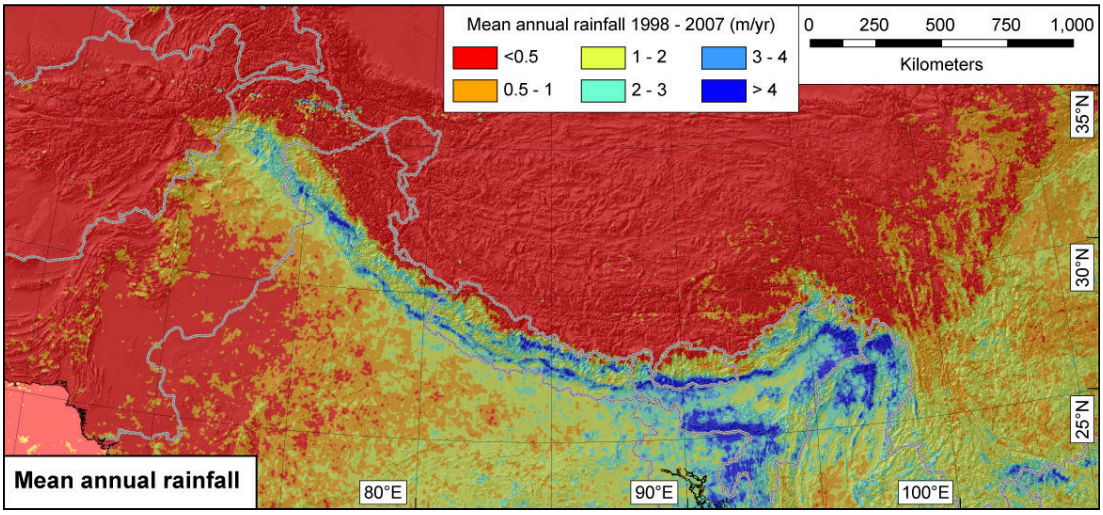


General Atmospheric Circulation Patterns



Bookhagen et al., 2005; Bookhagen and Burbank, 2010

TRMM Rainfall - High Spatial Resolution (5x5 km²) Data



Bookhagen and Burbank, 2006 and 2010; data calibrated with 1741 rain-gauge stations from this area

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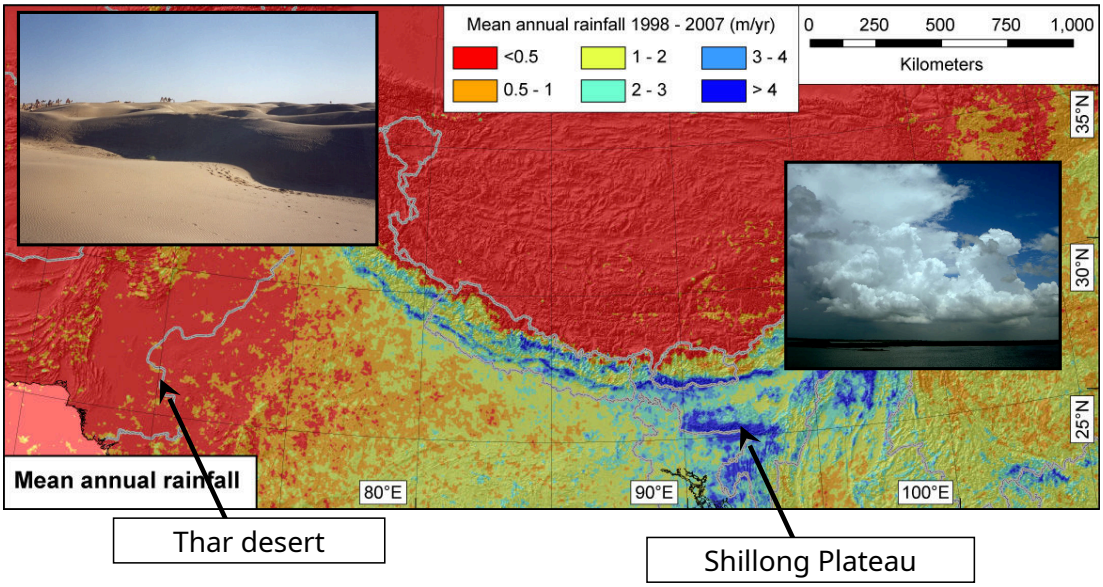

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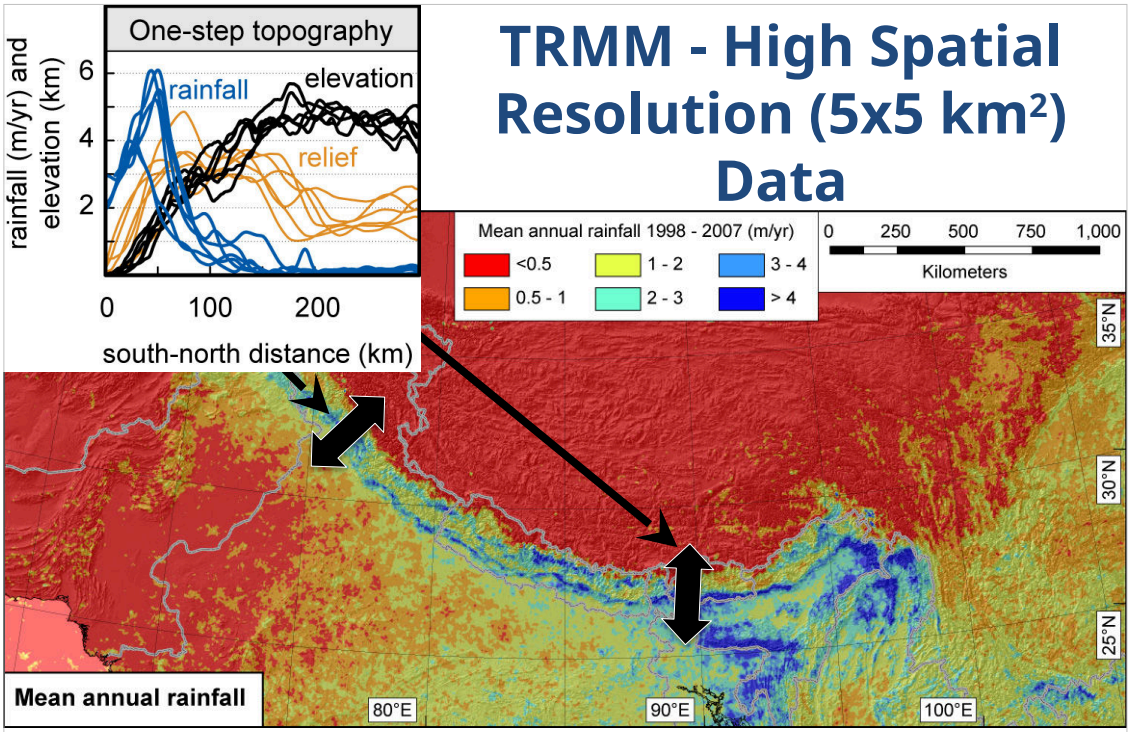

Bookhagen and Burbank, 2006; Bookhagen and Burbank, 2010

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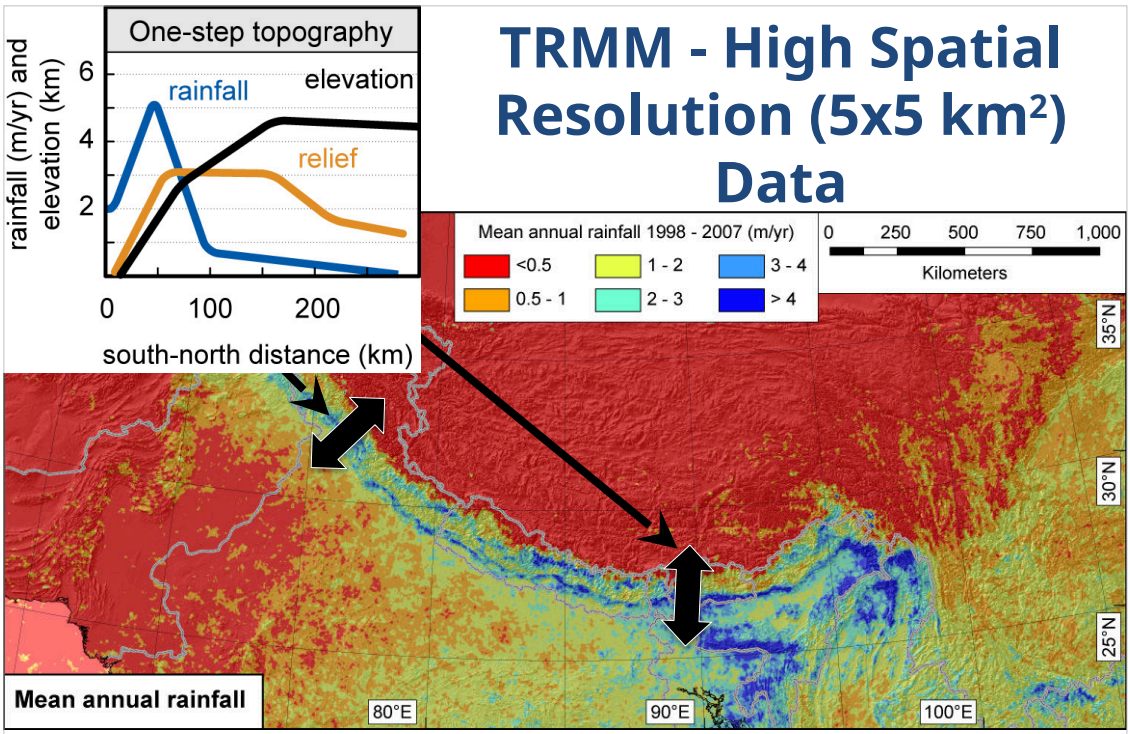

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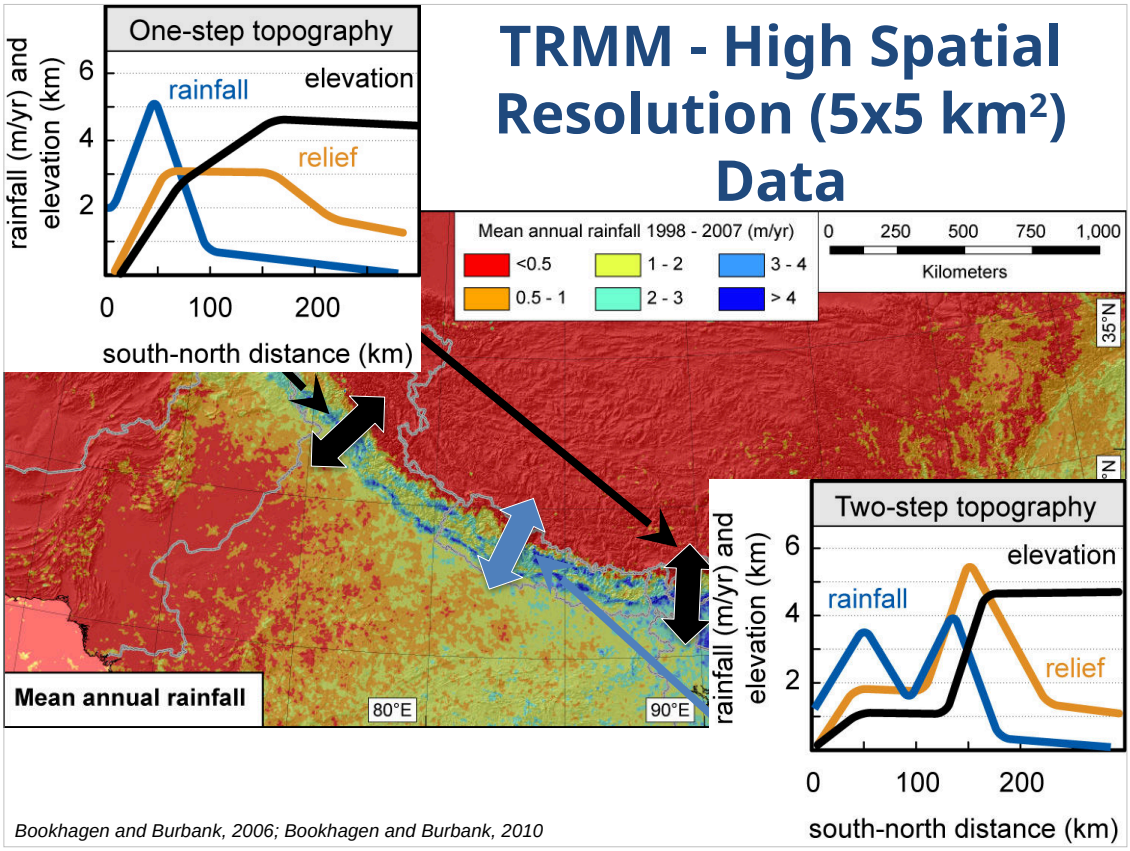

Bookhagen and Burbank, 2006; Bookhagen and Burbank, 2010

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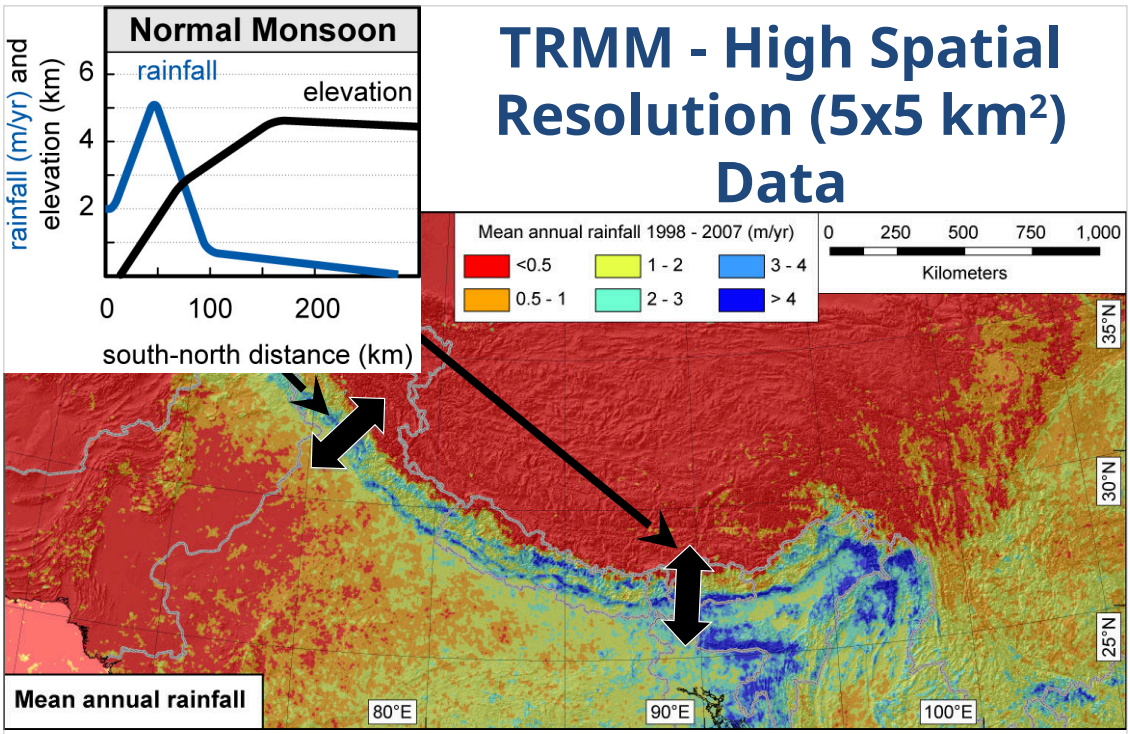

Bookhagen and Burbank, 2006;2010

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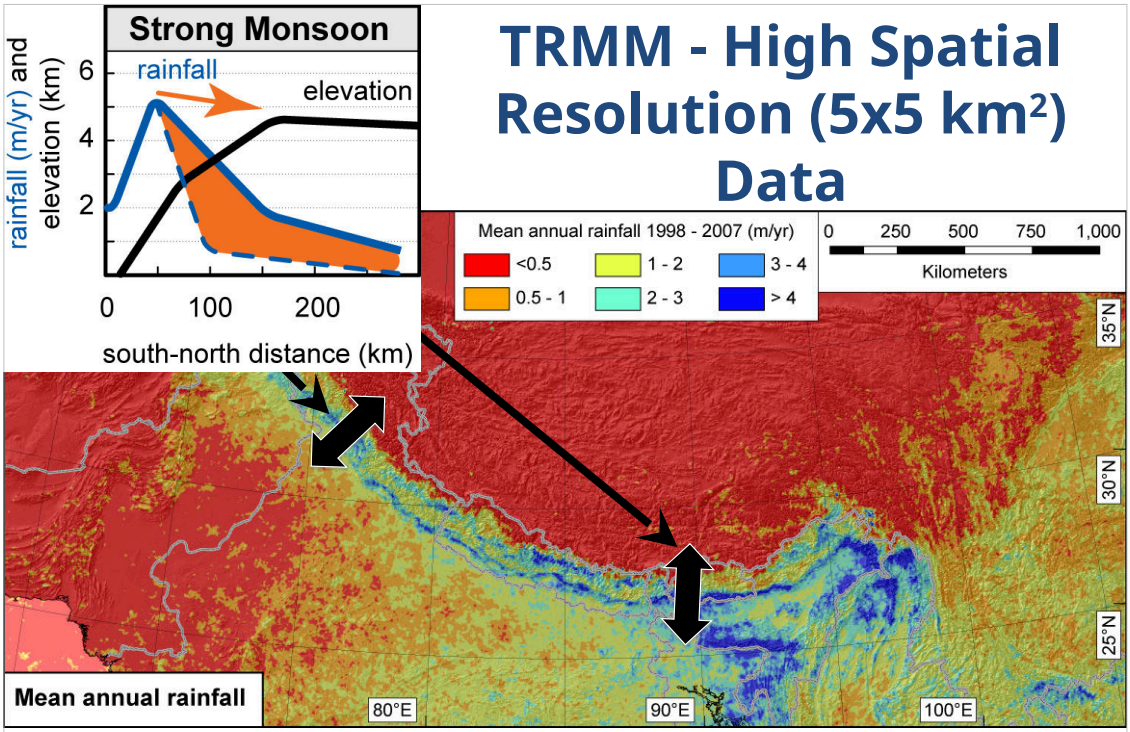
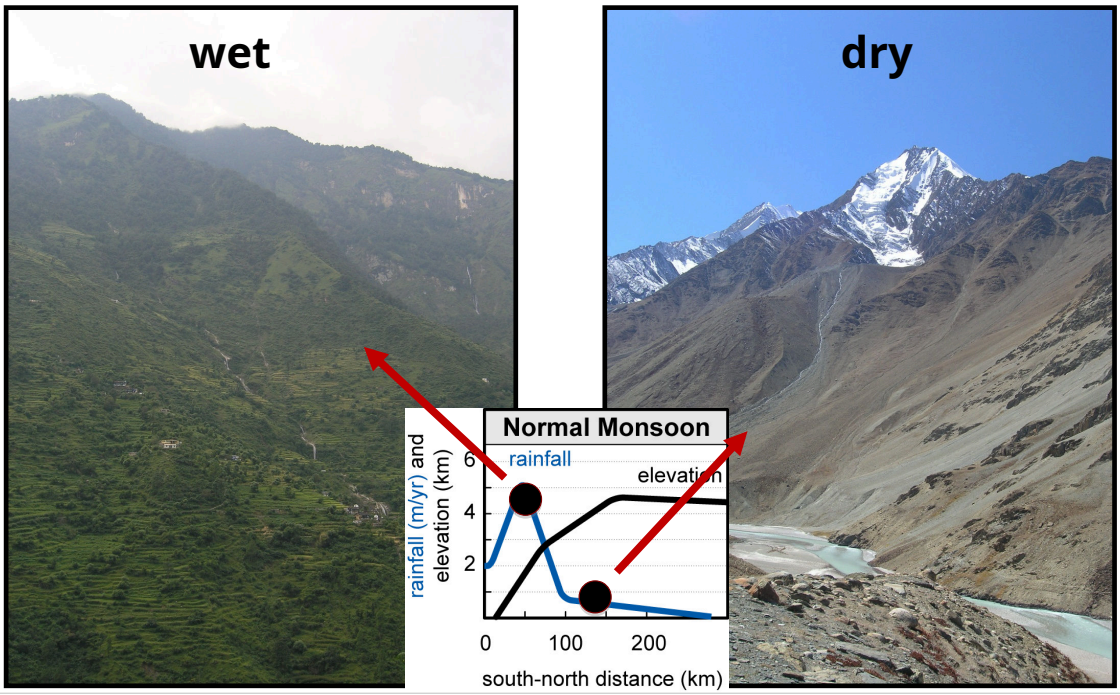
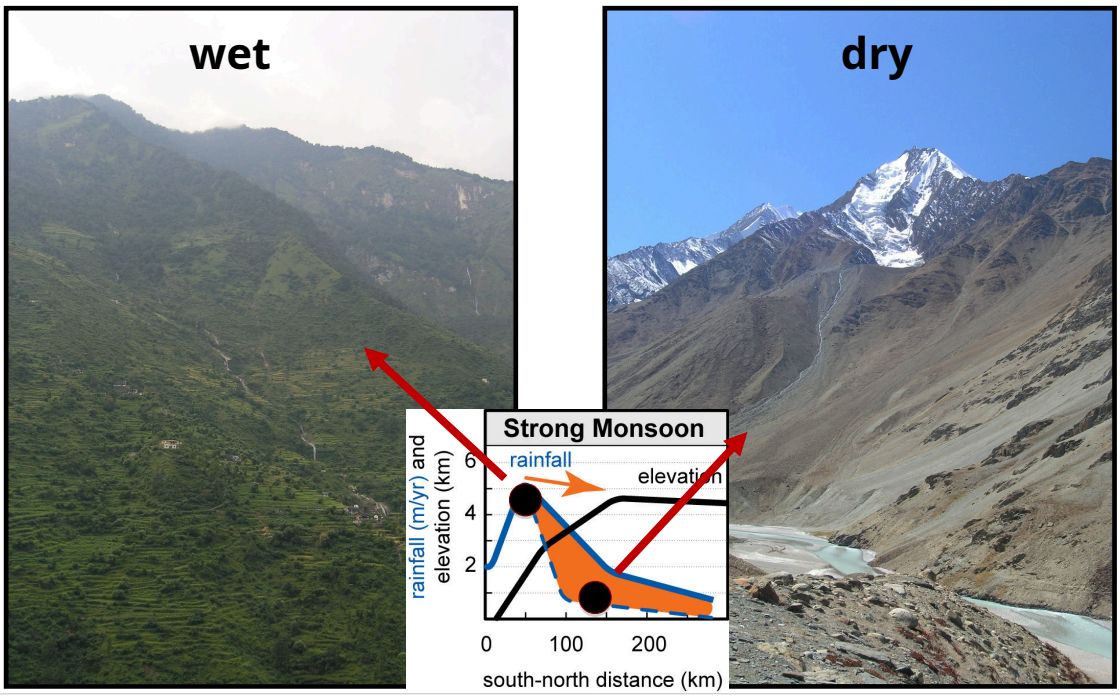


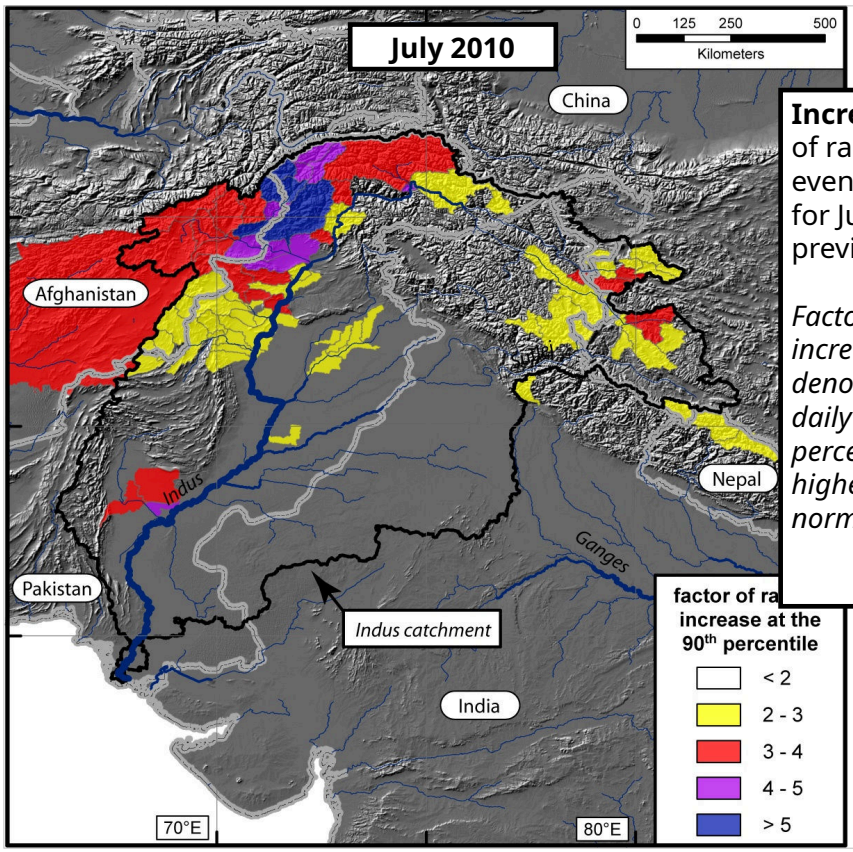
Bookhagen and Burbank, 2006;2010

Contrasting Climate and Hillslope regimes



Contrasting Climate and Hillslope regimes



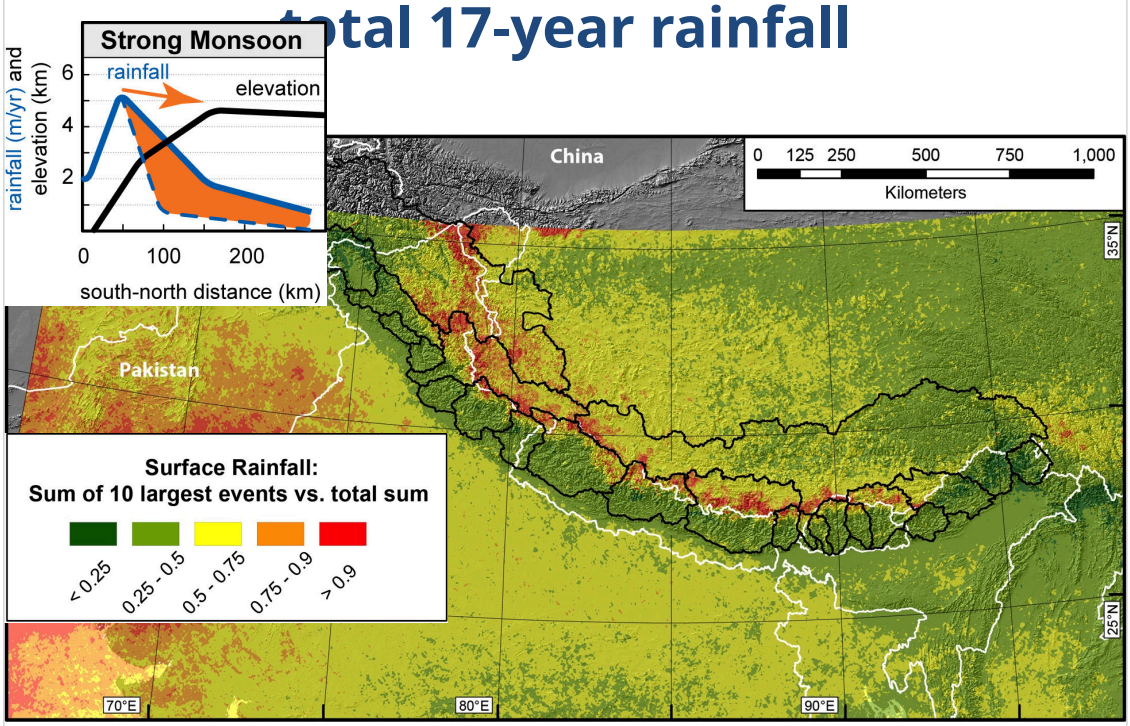


Increase in magnitude of rainfall-extreme events (90th percentile) for July 2010 vs. the previous 12 years.

Factor indicates rainfall increase, i.e. red colors denote regions where the daily rainfall at the 90th percentile is 3-4 times higher than during normal years.

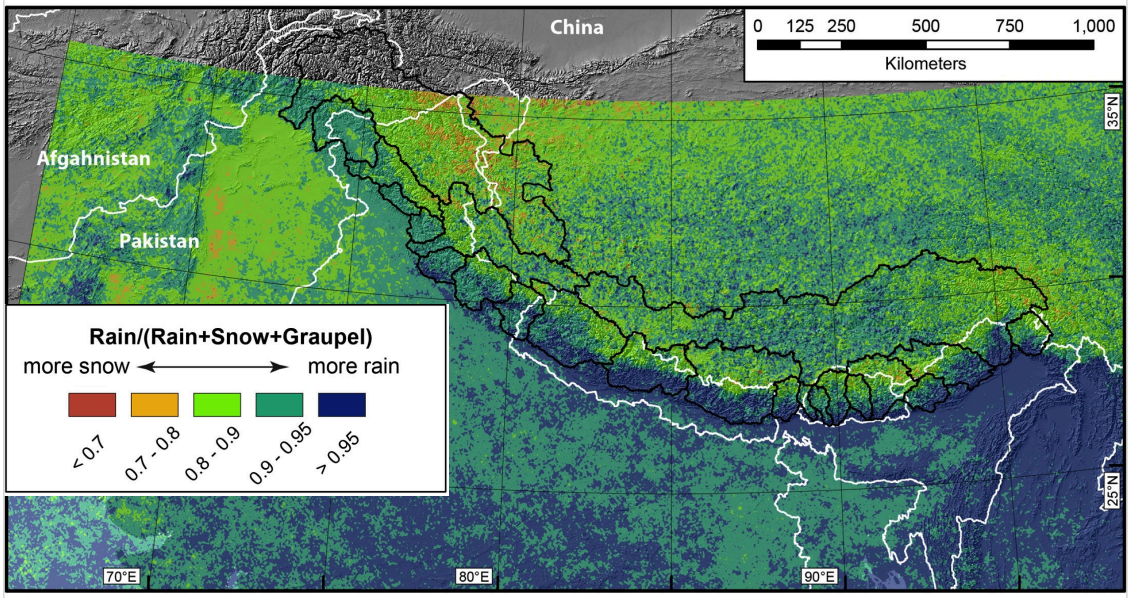
Bookhagen, 2013

Sum of 10-largest rainfall events vs. total 17-year rainfall



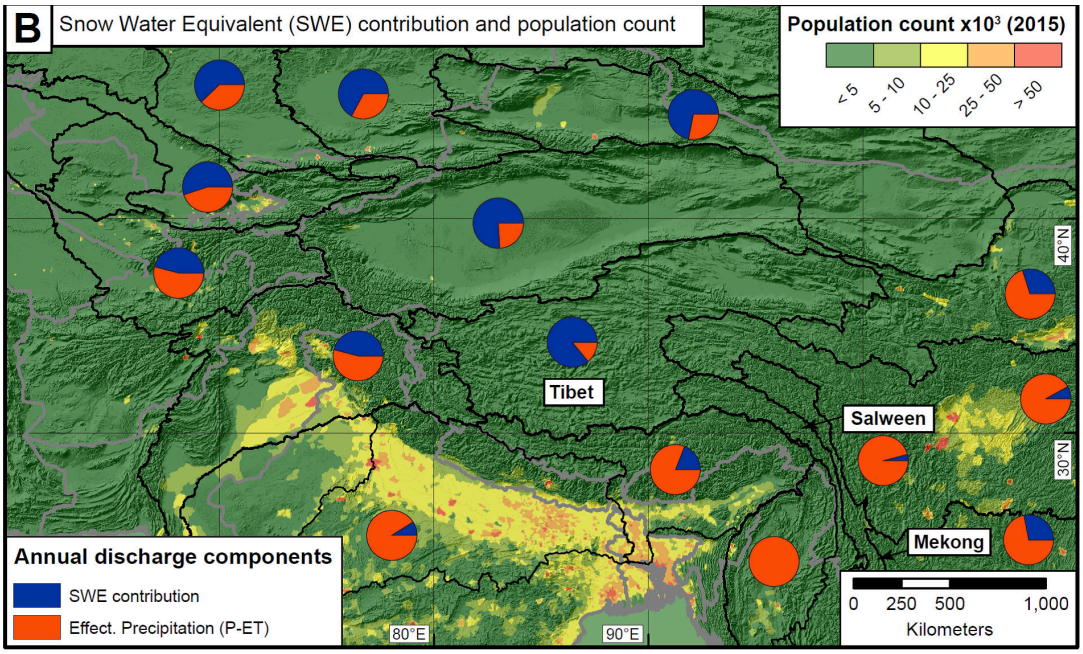
Bookhagen, in preparation

Rain vs. Snow Ratio

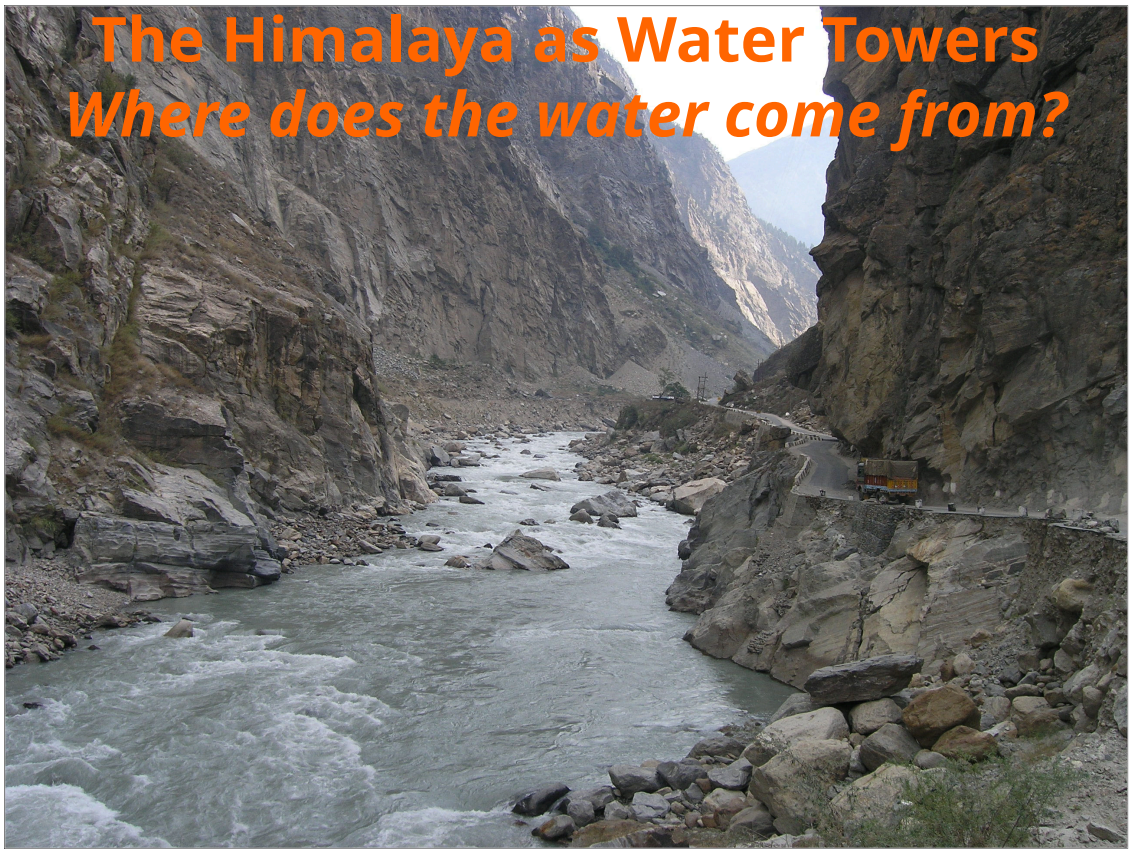


Bookhagen, in preparation

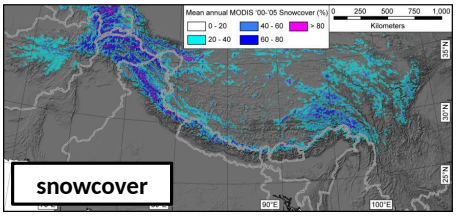
Snow-Water Equivalent (SWE) in Asia

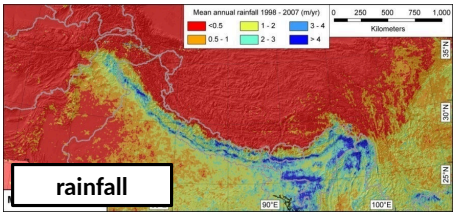


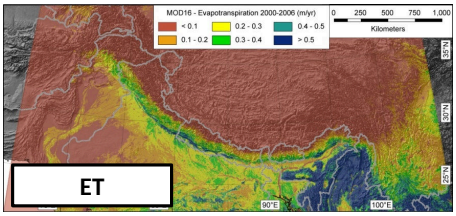
Huss et al., 2017: **Toward mountains without permanent snow and ice**



Parameterization of the hydrological budget







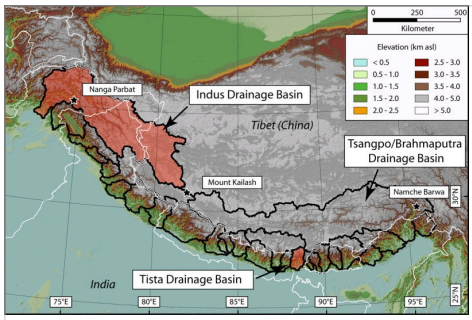
Discharge *= snowmelt + rainfall – evapotranspiration*

Snowmelt based on:
- snowcover data (MOD10)
- surface temperature (MOD11)
- solar radiation

Rainfall based on:
- calibrated 5x5 km^2 TRMM

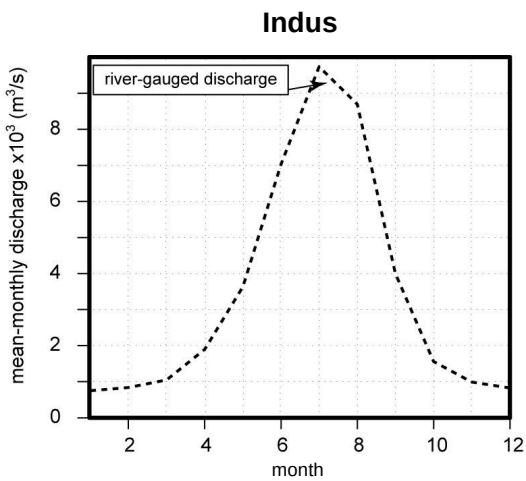
Evapotranspiration (ET) based on:
- Penman-Monteith method (MOD16)

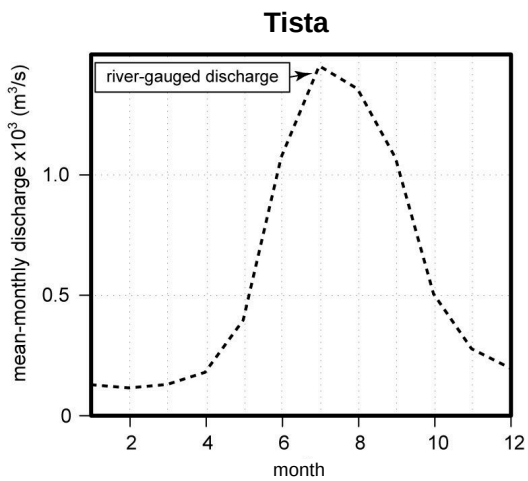
Bookhagen and Burbank,

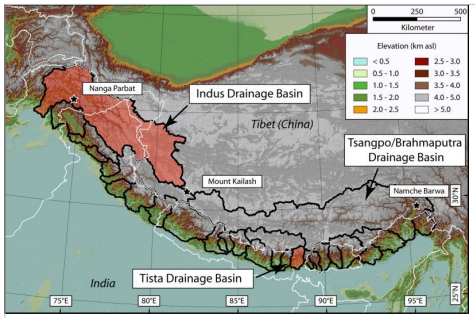


Discharge Estimation

Measured mean-monthly discharge for a 10-year period (*note the discharge-scale differences*)



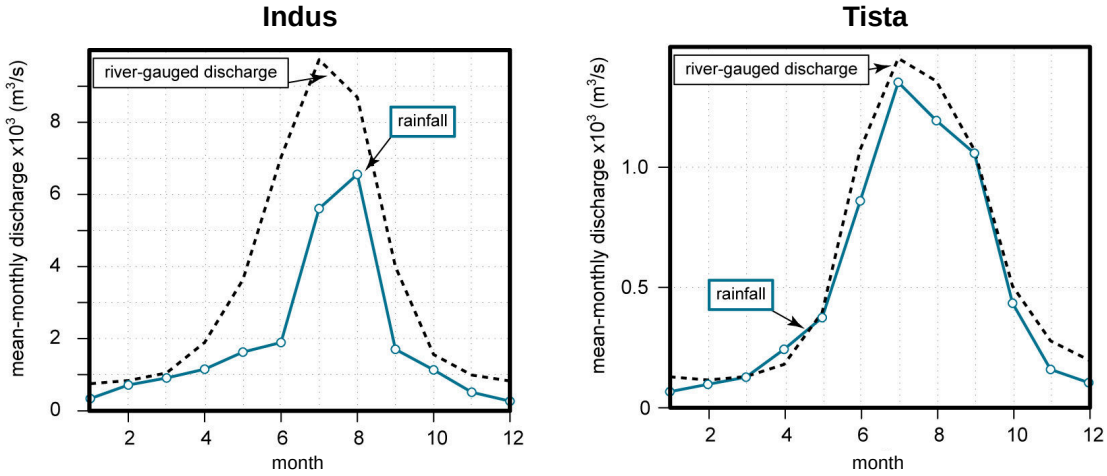


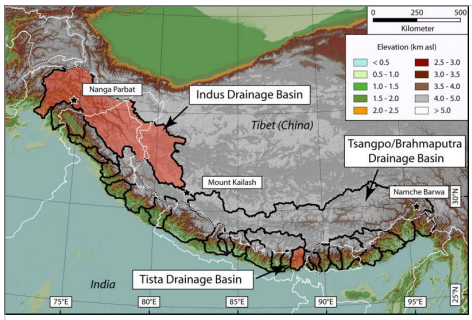


Discharge Estimation

Measured mean-monthly discharge for a 10-year period (*note the discharge-scale differences*)

Rainfall-derived discharge





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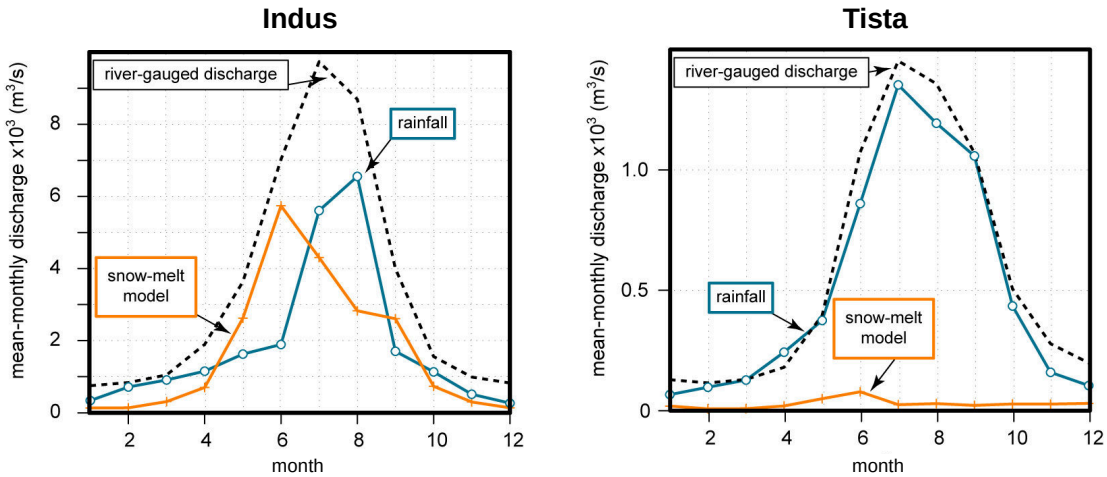
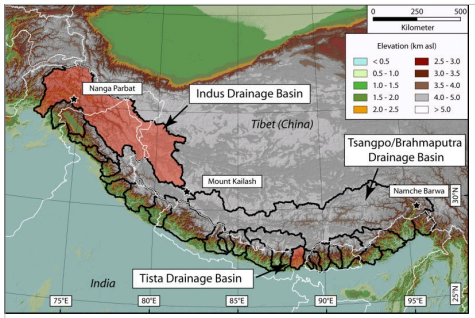
Snowmelt-model derived discharge





Discharge Estimation

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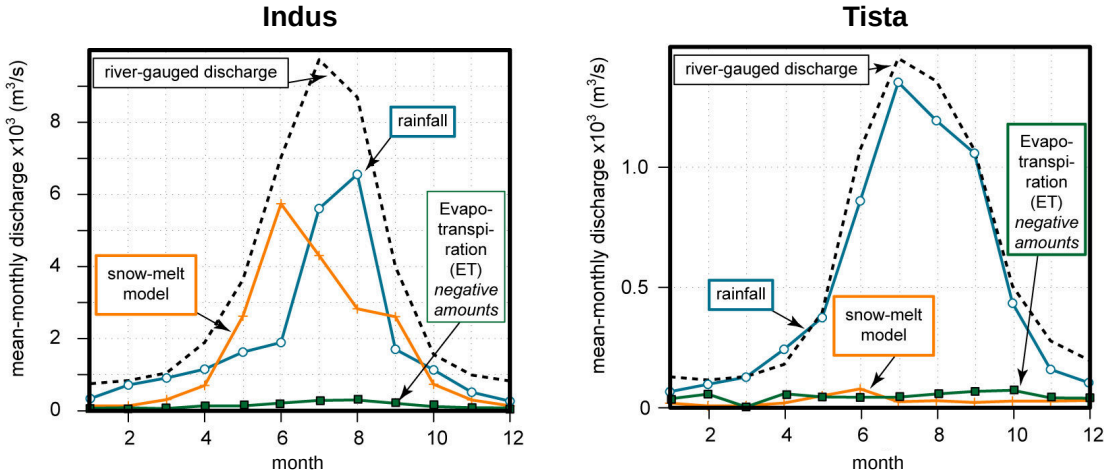
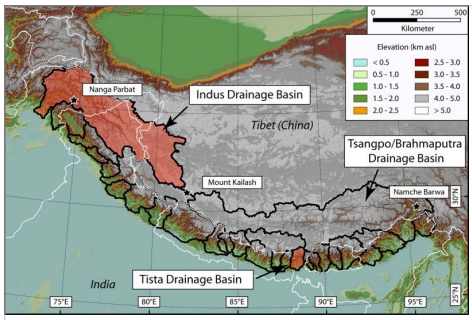
Rainfall-derived discharge

Snowmelt-model derived discharge

Evapotranspiration-derived component





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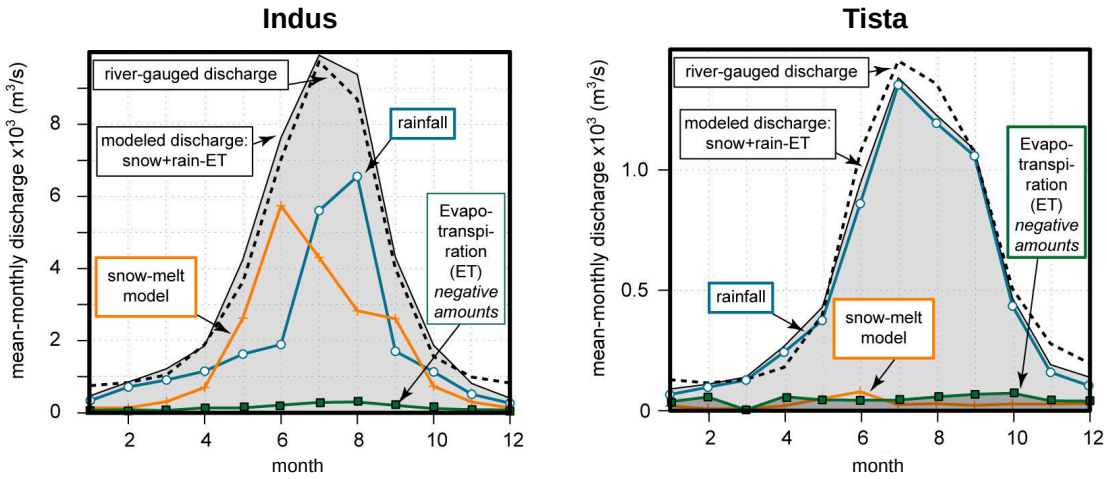
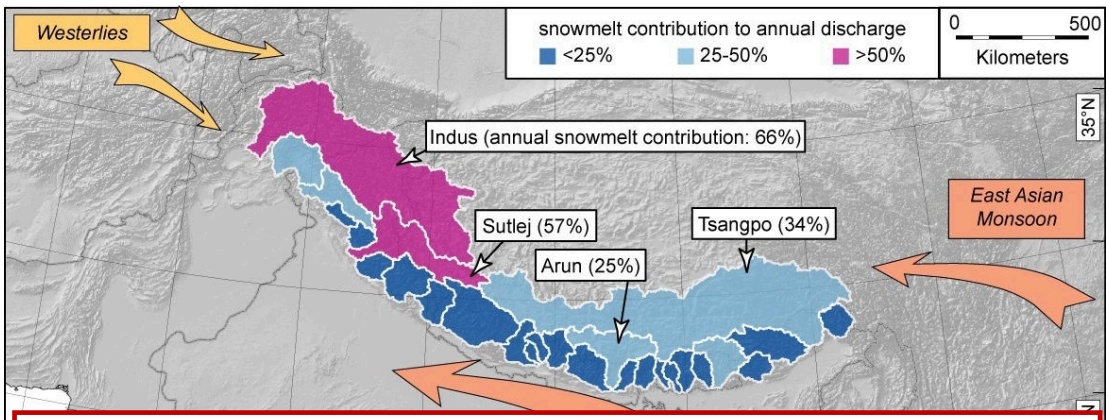


Predicting River Discharge in the Himalaya – Rainfall and Snowmelt Contribution



Discharge in the pre-monsoon season (March-May) for all Himalayan catchments significantly depends on transiently stored moisture (snow- and glacial melting, permafrost and soil moisture)!

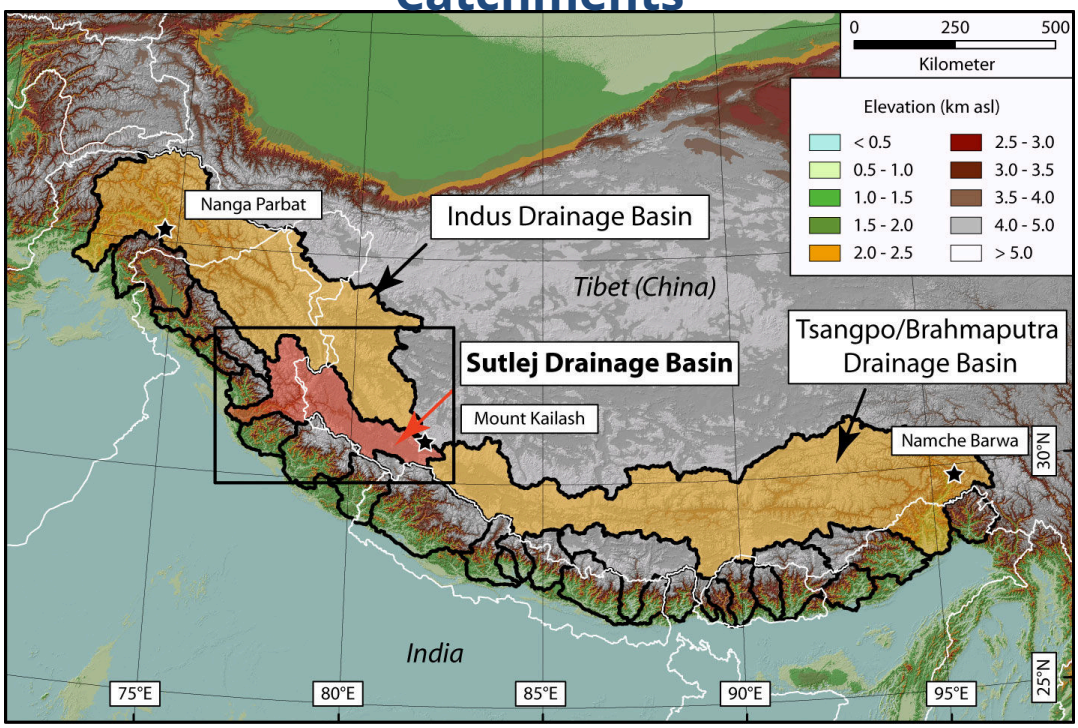
- *Discharge is calculated by accounting for rainfall, snowmelt, and evapotranspiration*
- *Validated with 13 daily river-gauge stations throughout the Himalaya (Nash-Sutcliffe coefficients between 0.7 and 0.9)*

Bookhagen and Burbank, 2010

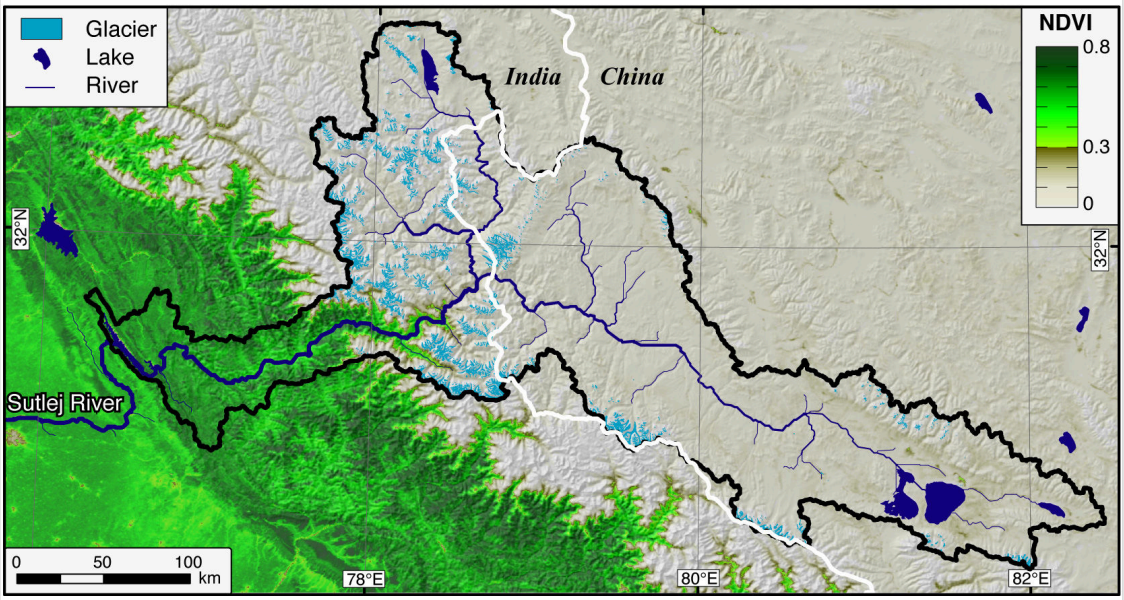
Sediment Flux Variations in the Himalaya

1. **Magnitudes of sediment transport during rainfall extreme events (>90th percentile)**
2. **Impact of rare floods (landslide-lake outburst floods) on sediment transport rates**
3. **Changes of erosion rates through time**

Himalayan Topography and River Catchments



Sutlej River: Normalized Difference Vegetation Index (NDVI)



Wulf, Bookhagen, and Scherler (2012)

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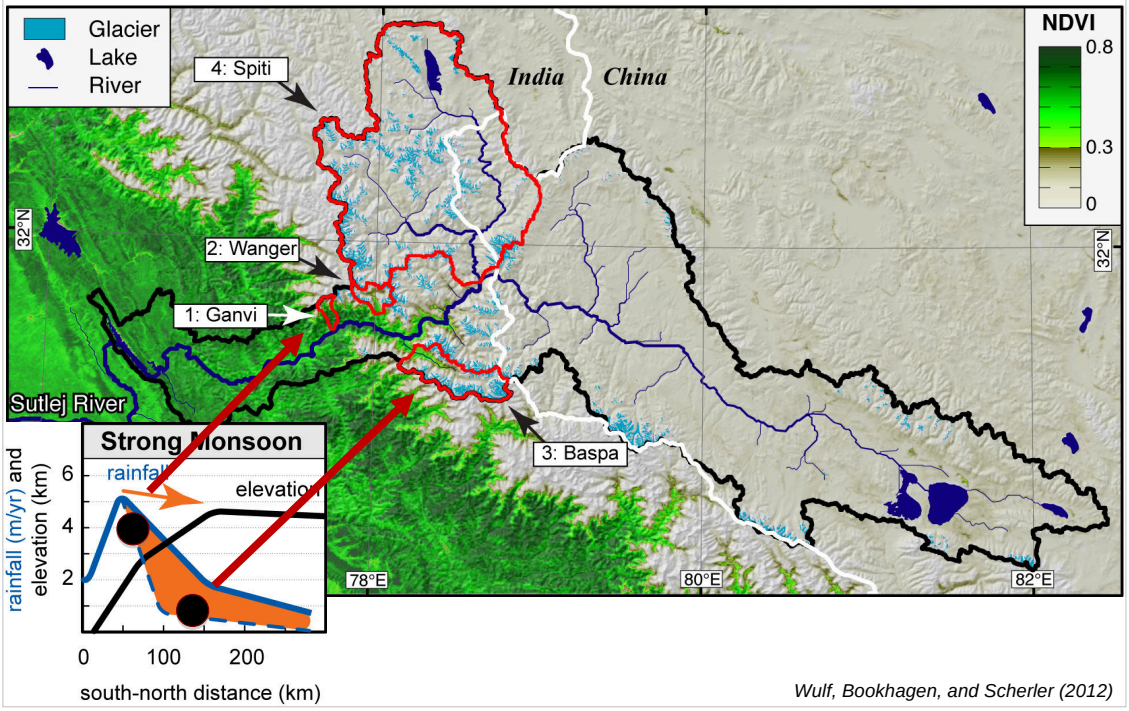
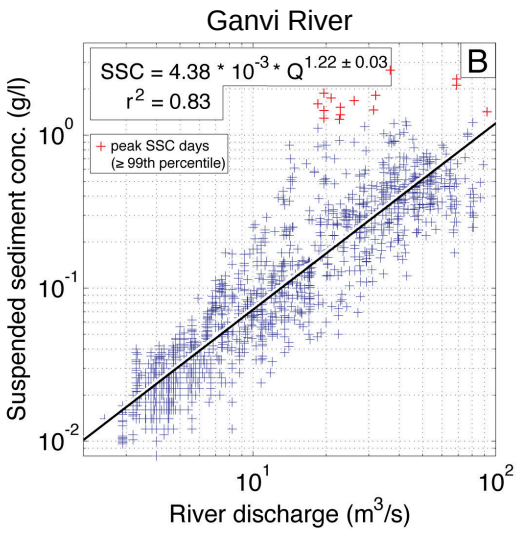
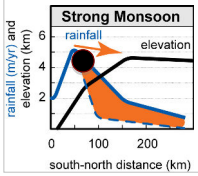


Wulf, Bookhagen, and Scherler (2012)

Hydrometeoric Low-Frequency, High-Magnitude Sediment Transport Events





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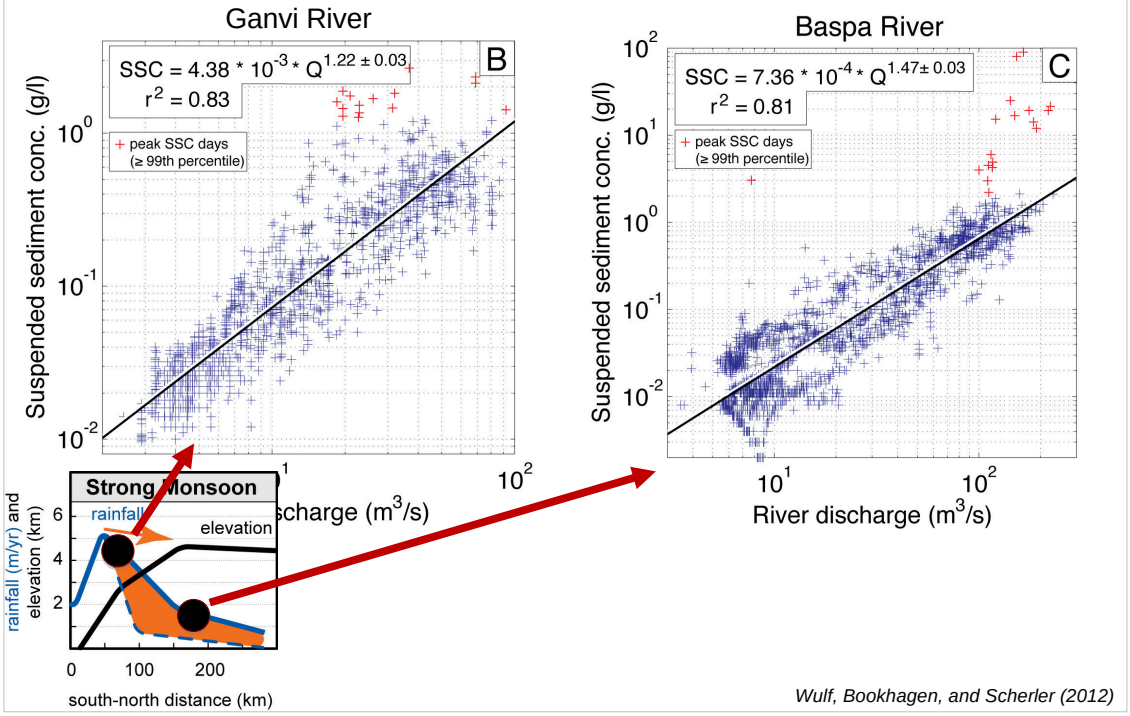
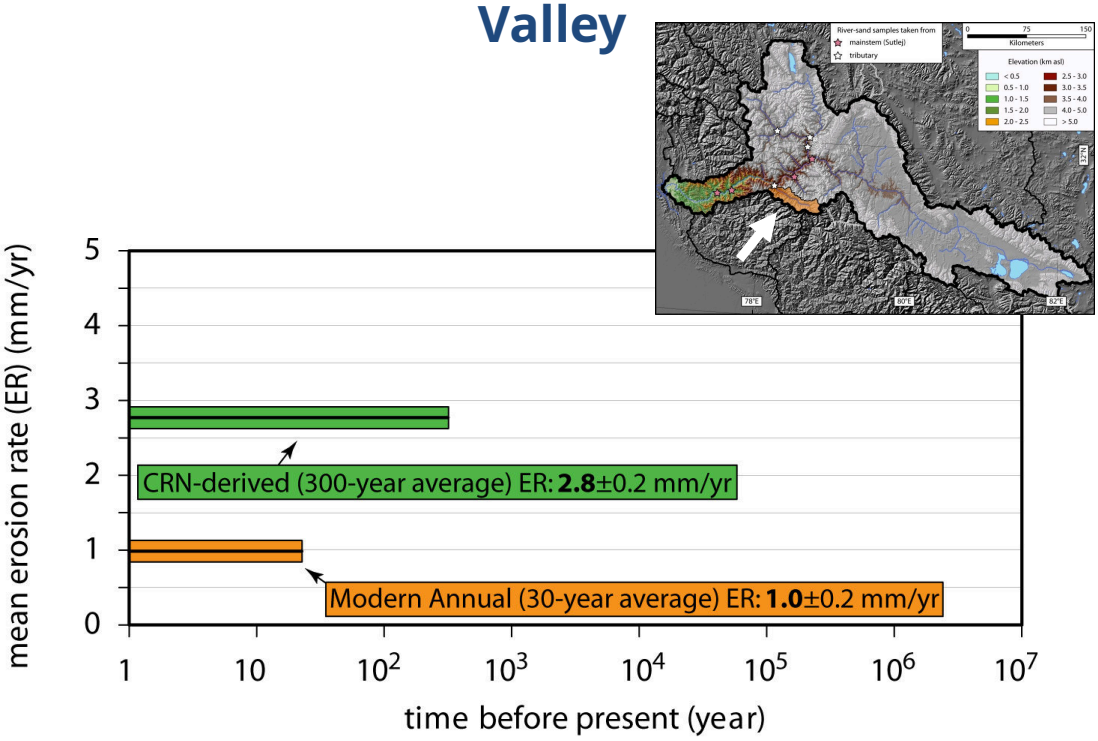


Wulf, Bookhagen, and Scherler (2012)

Changes in Erosion Rates (ER) for the Baspa Valley



Data from: Bookhagen et al., 2005a; Bookhagen et al., 2005b; Wulf et al., 2010, Bookhagen et al., 2019

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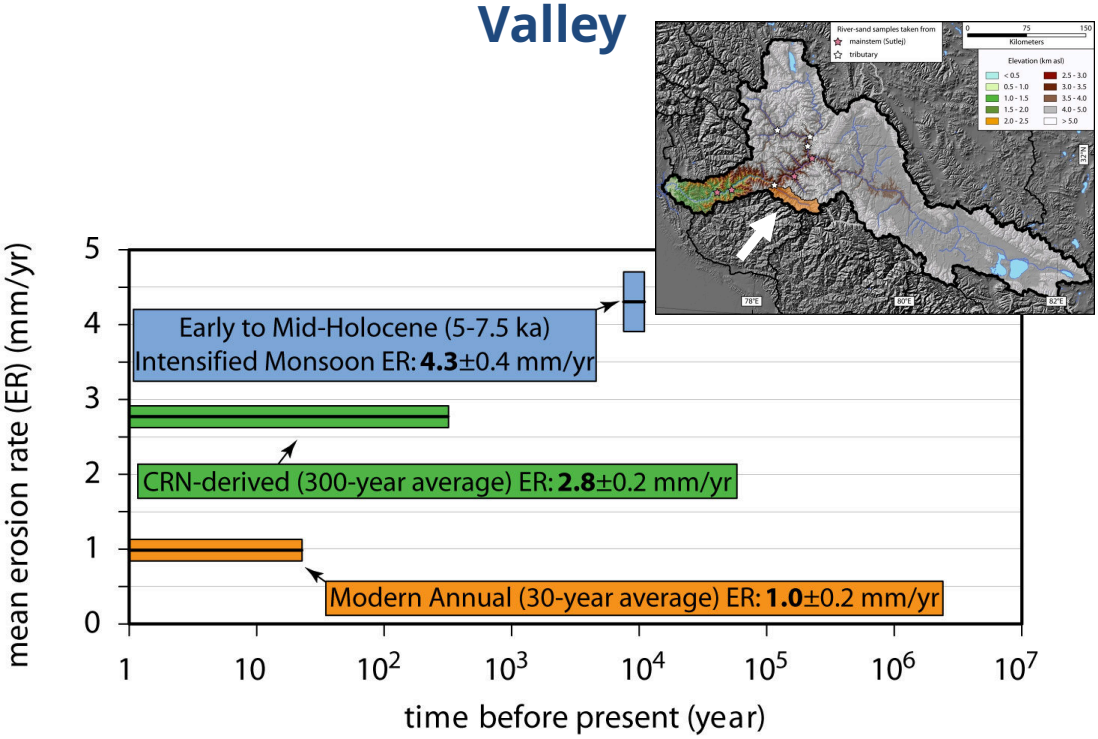

Data from: Bookhagen et al., 2005a; Bookhagen et al., 2005b; Wulf et al., 2010, Bookhagen et al., 2019