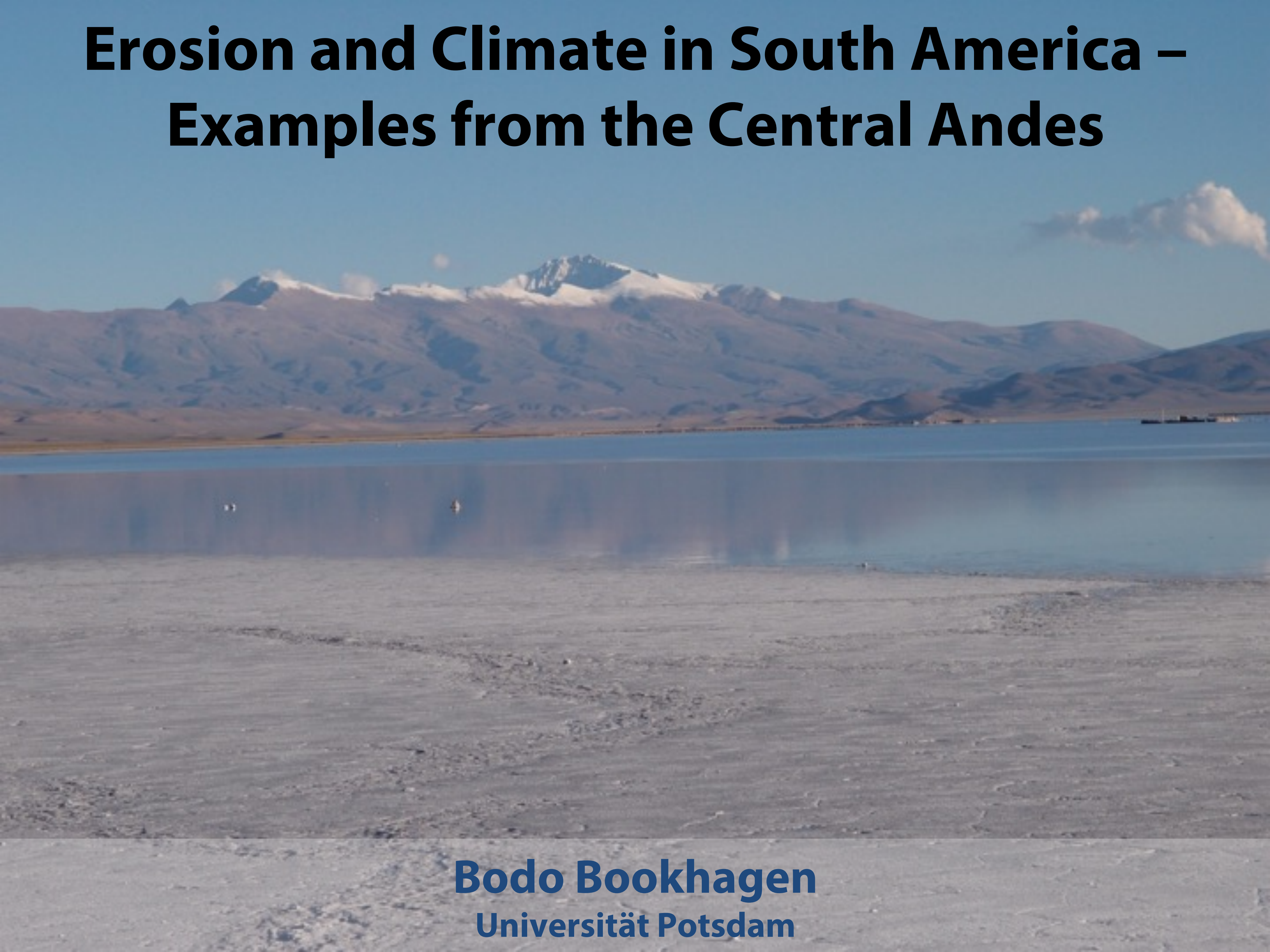
Erosion and Climate in South America – Examples from the Central Andes

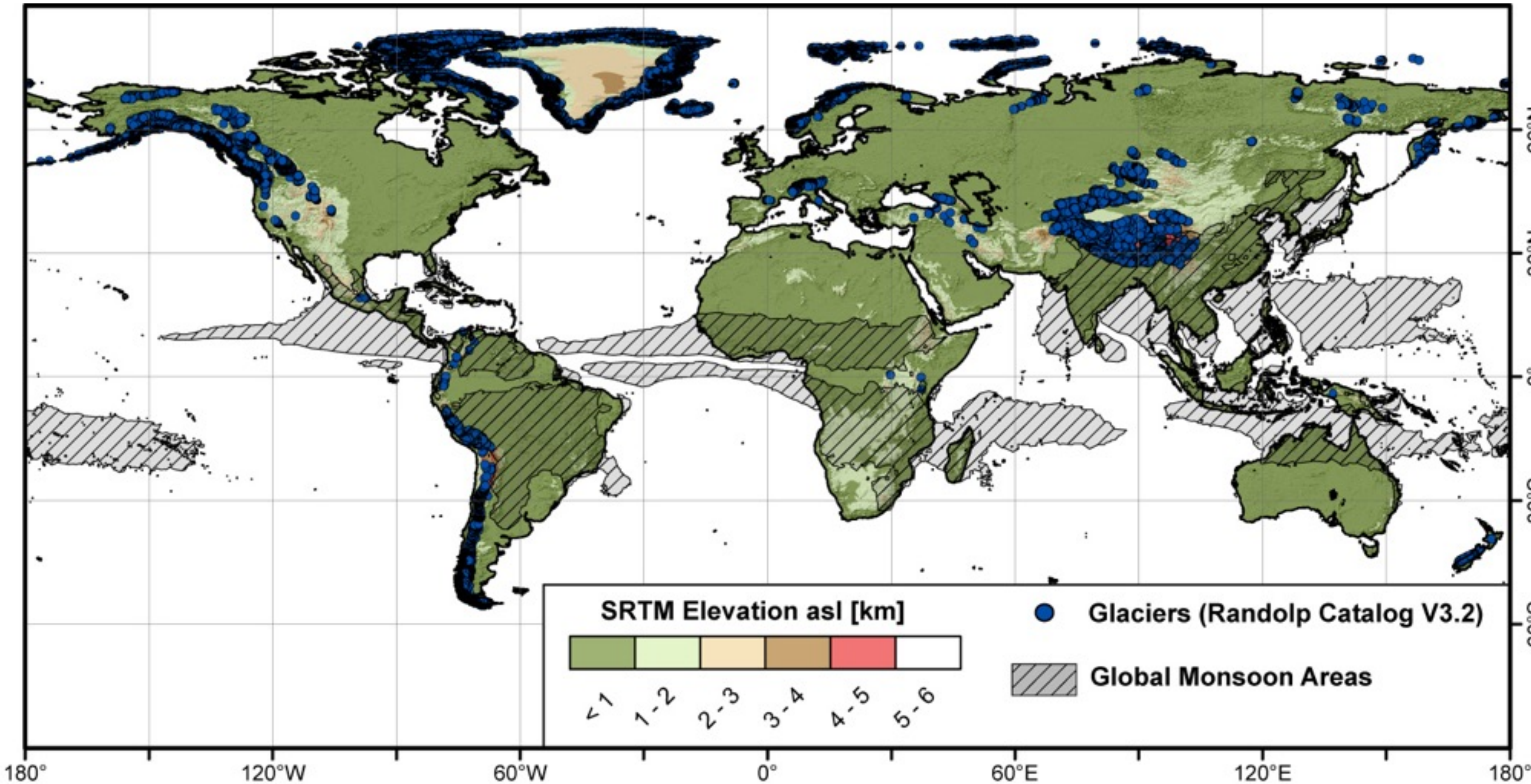


Bodo Bookhagen
Universität Potsdam

Rainfall Extreme Events and their dynamics in South America

1. **Climate of South America and the South American Monsoon System**
2. **Impact of Climate on the Environment**
   - Glacial retreat
   - Amazon discharge
3. **Weather and Climate of the NW Argentine Andes**
4. **Linkages between Climate and Erosion**

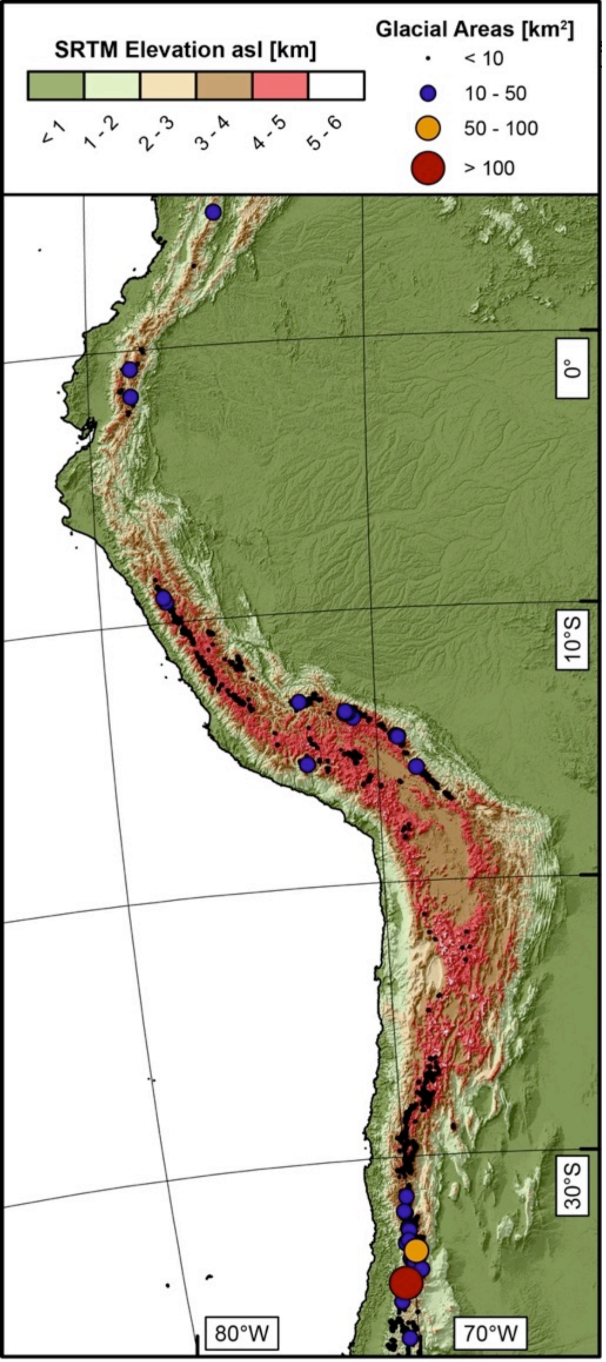
Global Monsoon Areas



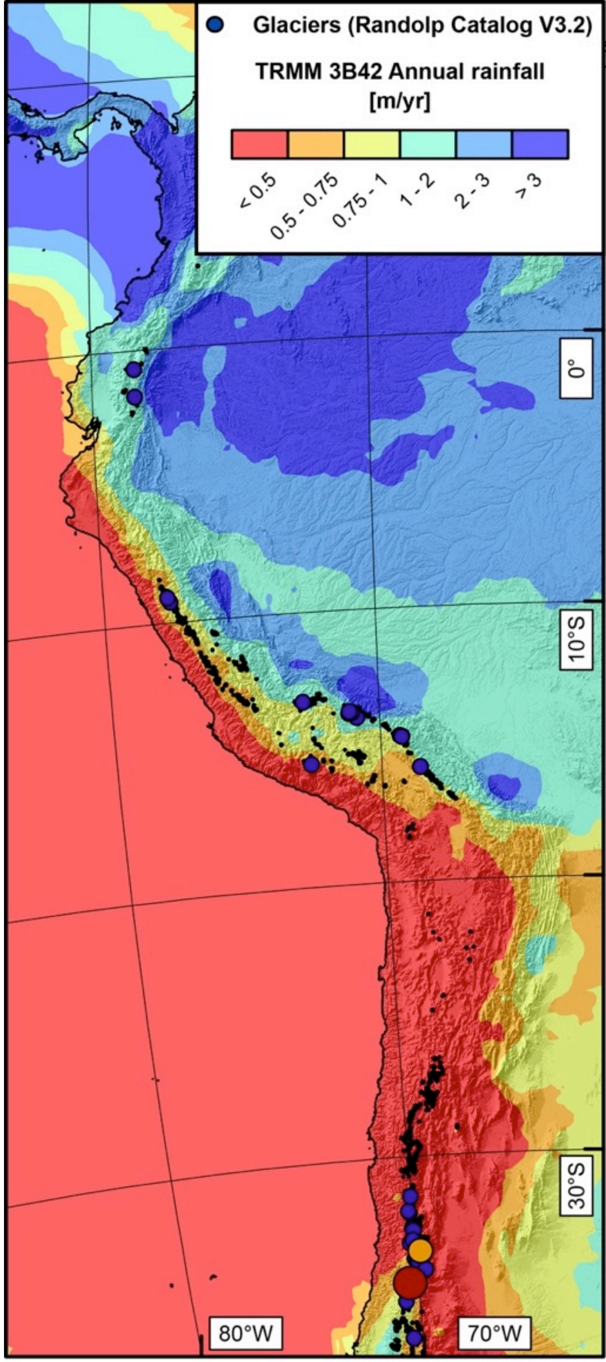
Global monsoon domains are approximated by the following approach: where the grid-cell summer-minus-winter precipitation rate exceeds 2.5 mm/day and the local summer precipitation exceeds 55 % of the annual total.

Bookhagen, 2015, *Glaciers and Monsoon Systems* in **The Monsoons and Climate Change**, Springer

Glaciers in South America



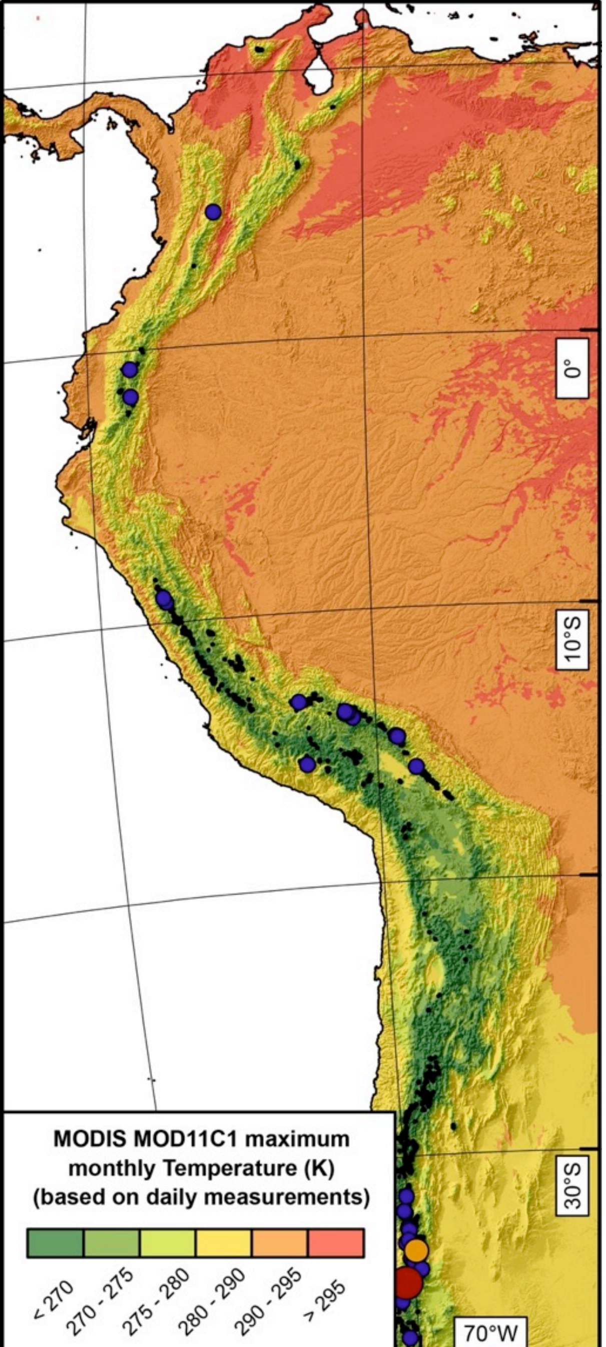
Topography and glacier locations (RGI V4).



TRMM 3B42 V7 mean annual rainfall.

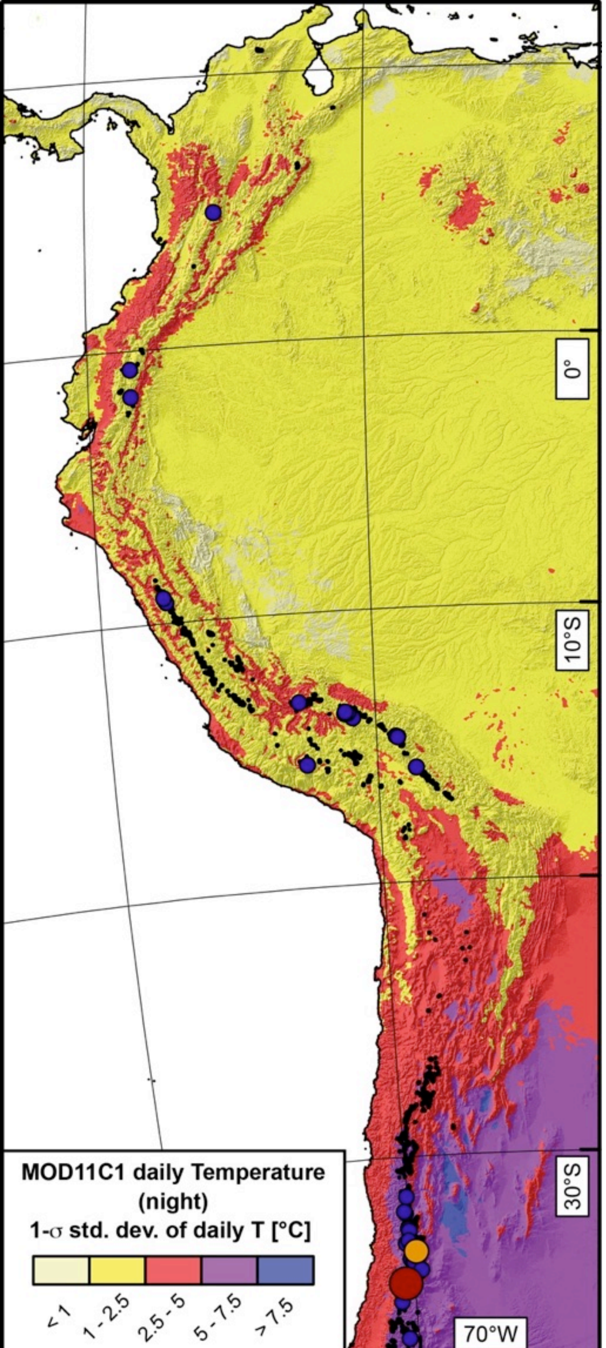
Bookhagen, 2015, *Glaciers and Monsoon Systems* in **The Monsoons and Climate Change**, Springer

Glaciers in South America



Maximum Temperature (273 K = 0°C)

Bookhagen, 2015, *Glaciers and Monsoon Systems* in **The Monsoons and Climate Change**, Springer

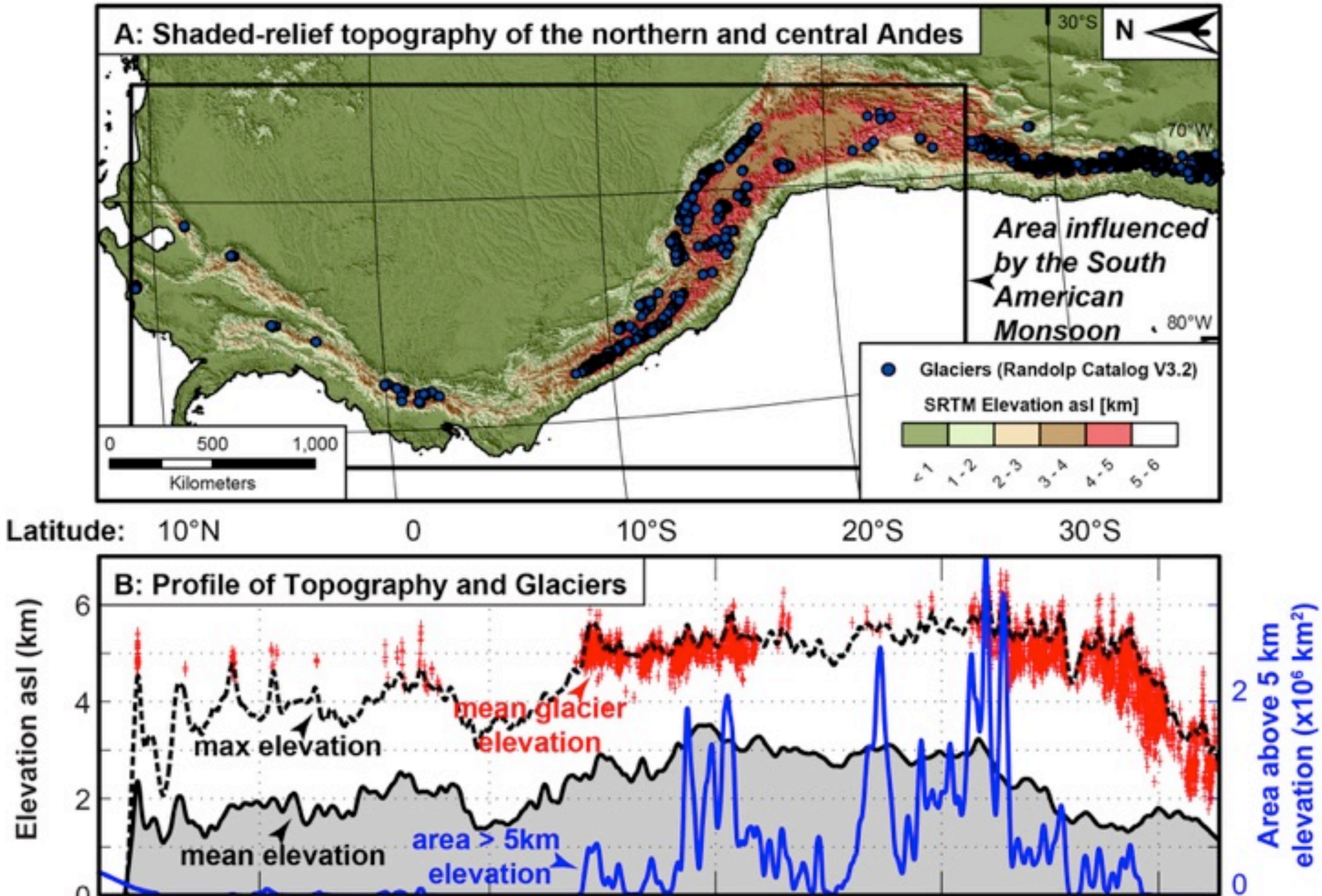


Land Surface Temperature in South America

Temperature Variability along the Andes orogen.

Bookhagen, 2015, *Glaciers and Monsoon Systems* in **The Monsoons and Climate Change**, Springer

Climate and Glaciers in South America



Topographic variability and glacier locations along the Andes orogen.

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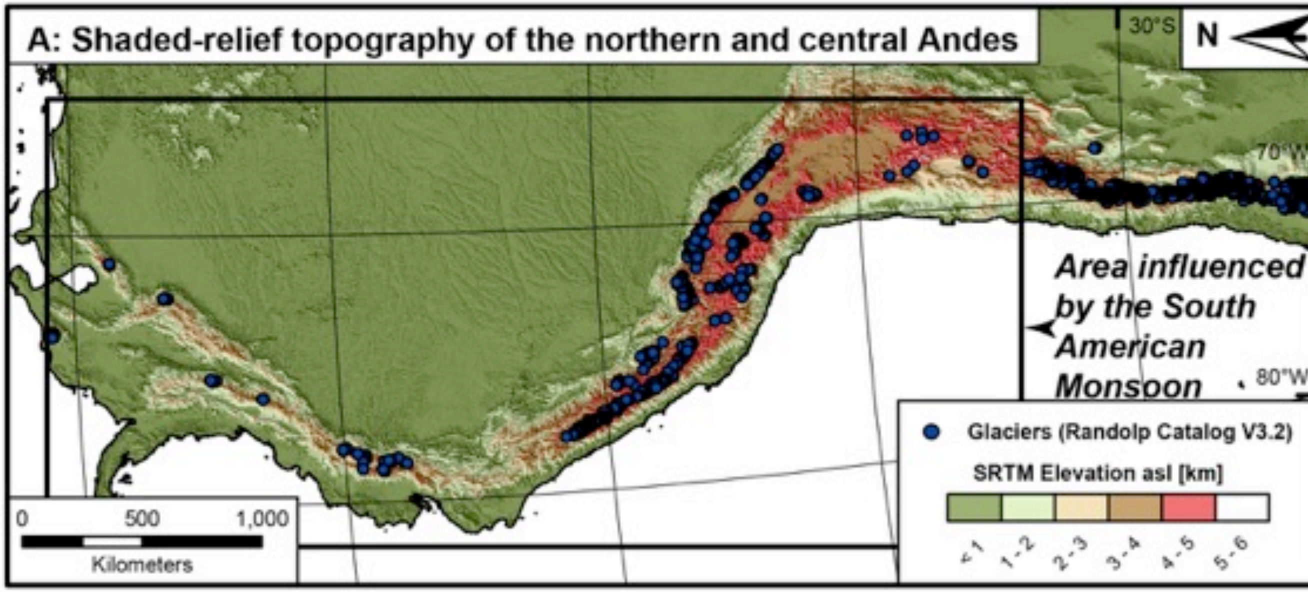
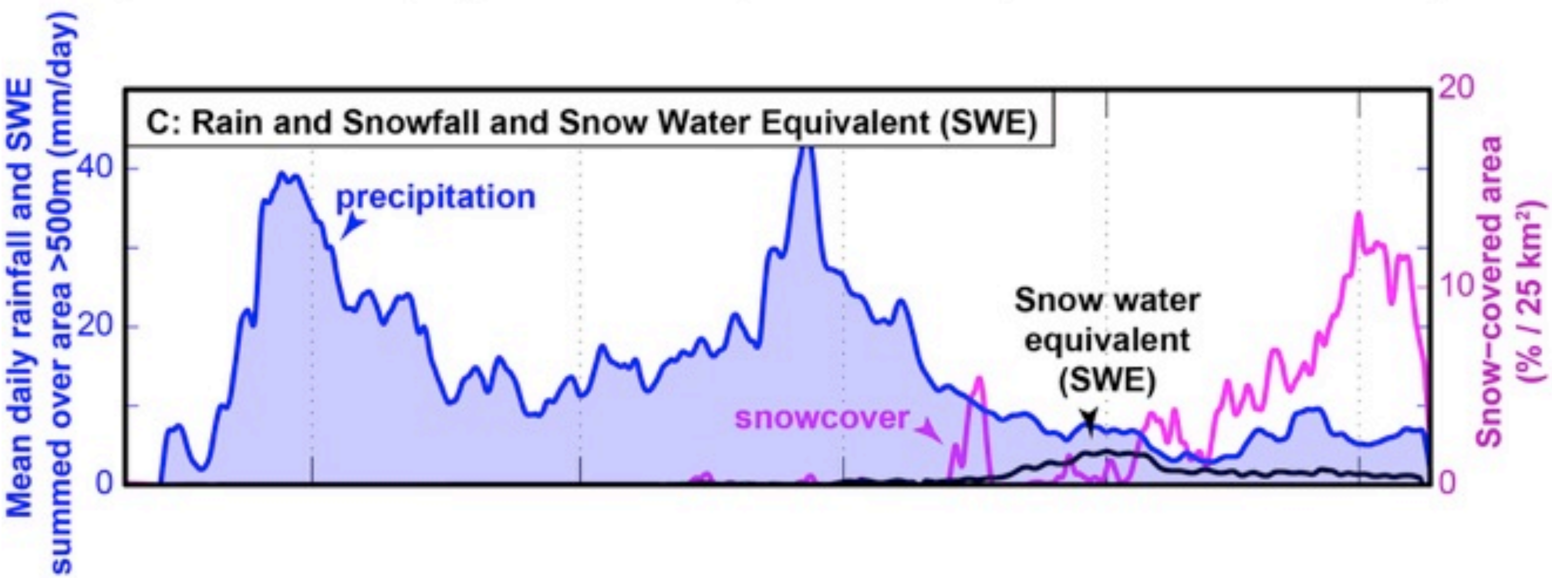
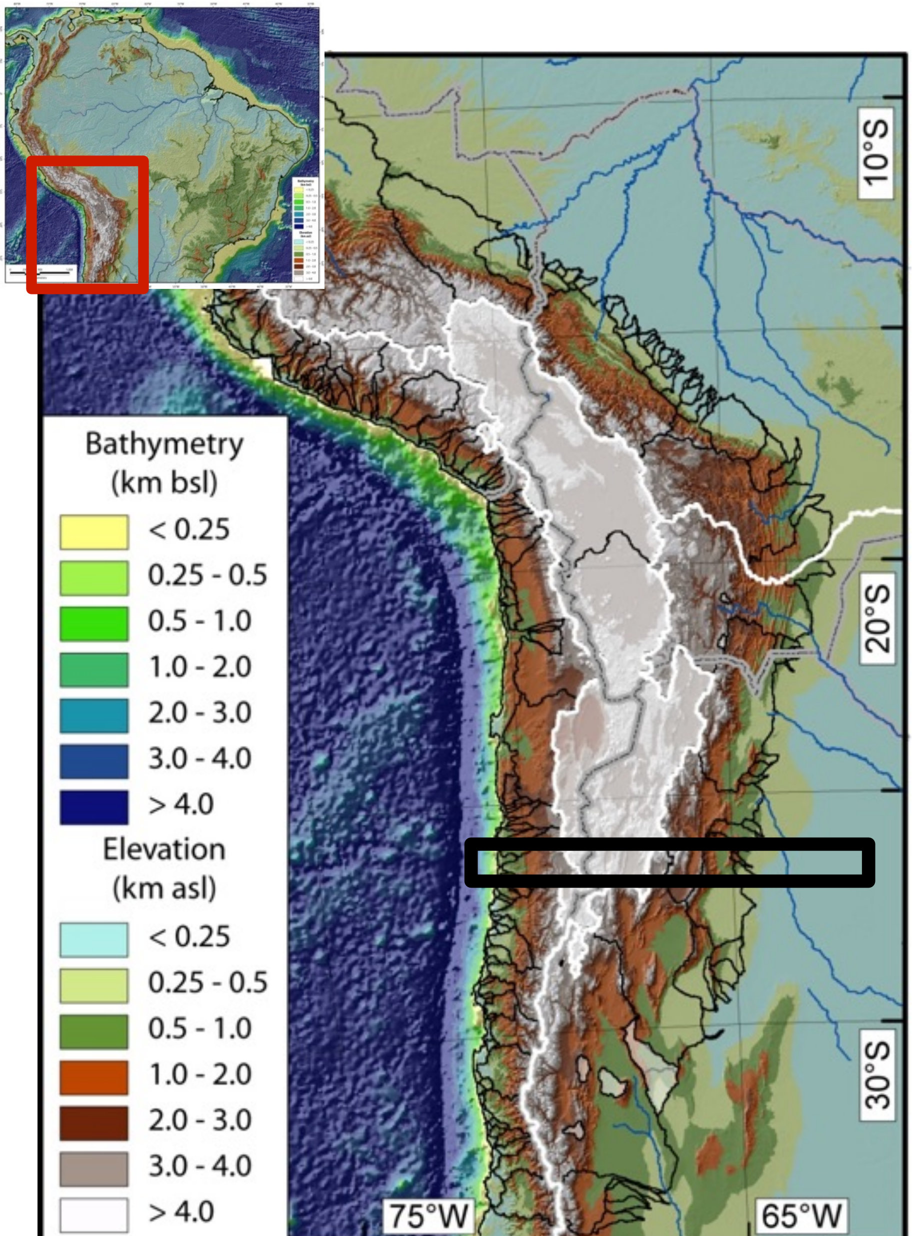
Climate and Glaciers in South America

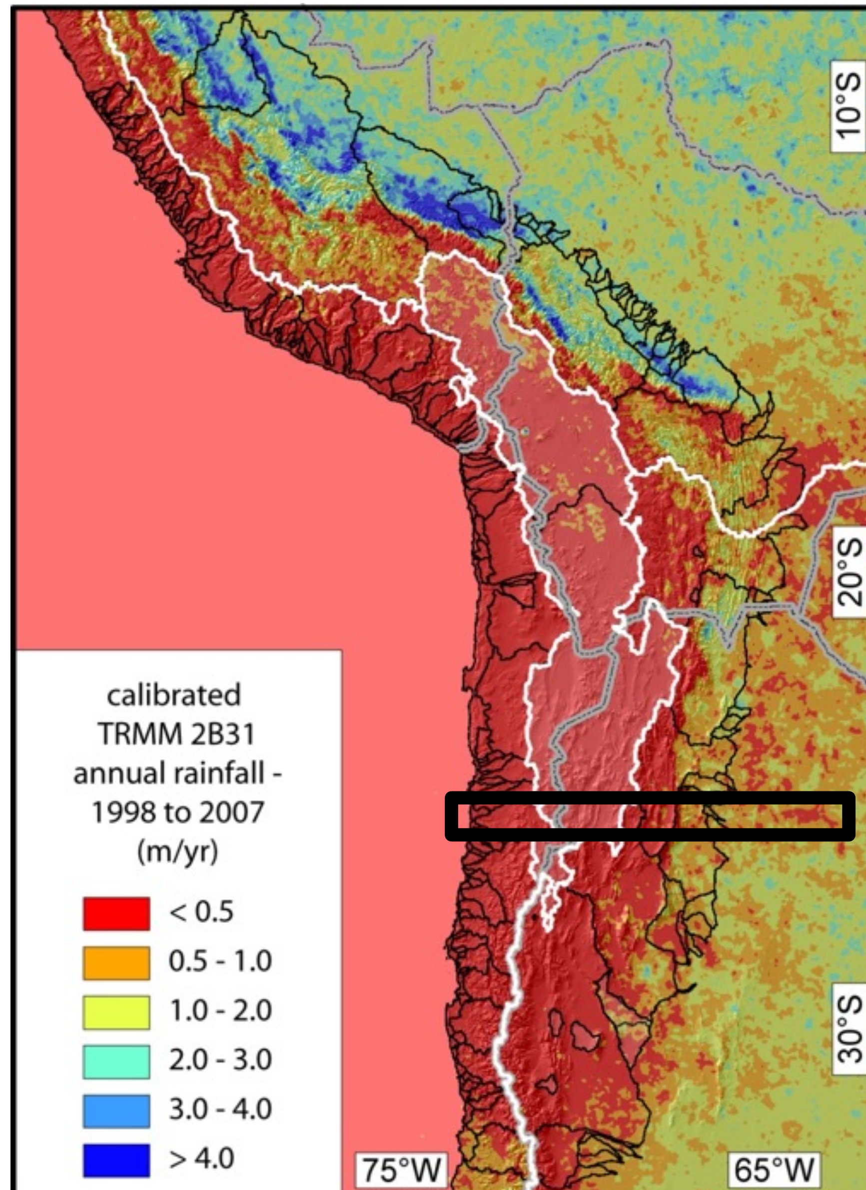




Bookhagen, 2015, *Glaciers and Monsoon Systems* in **The Monsoons and Climate Change**, Springer

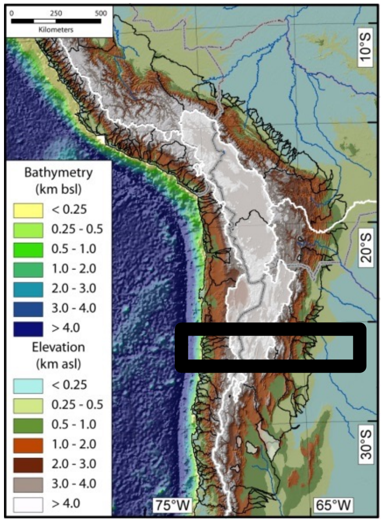
Climatic Gradients in the Central Andes

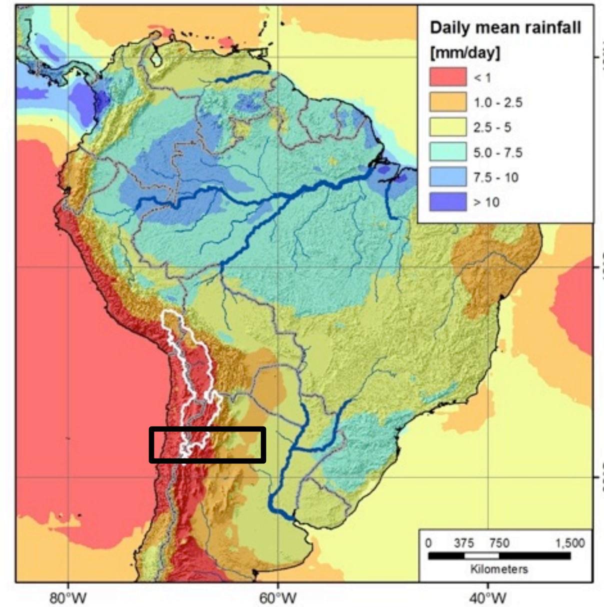


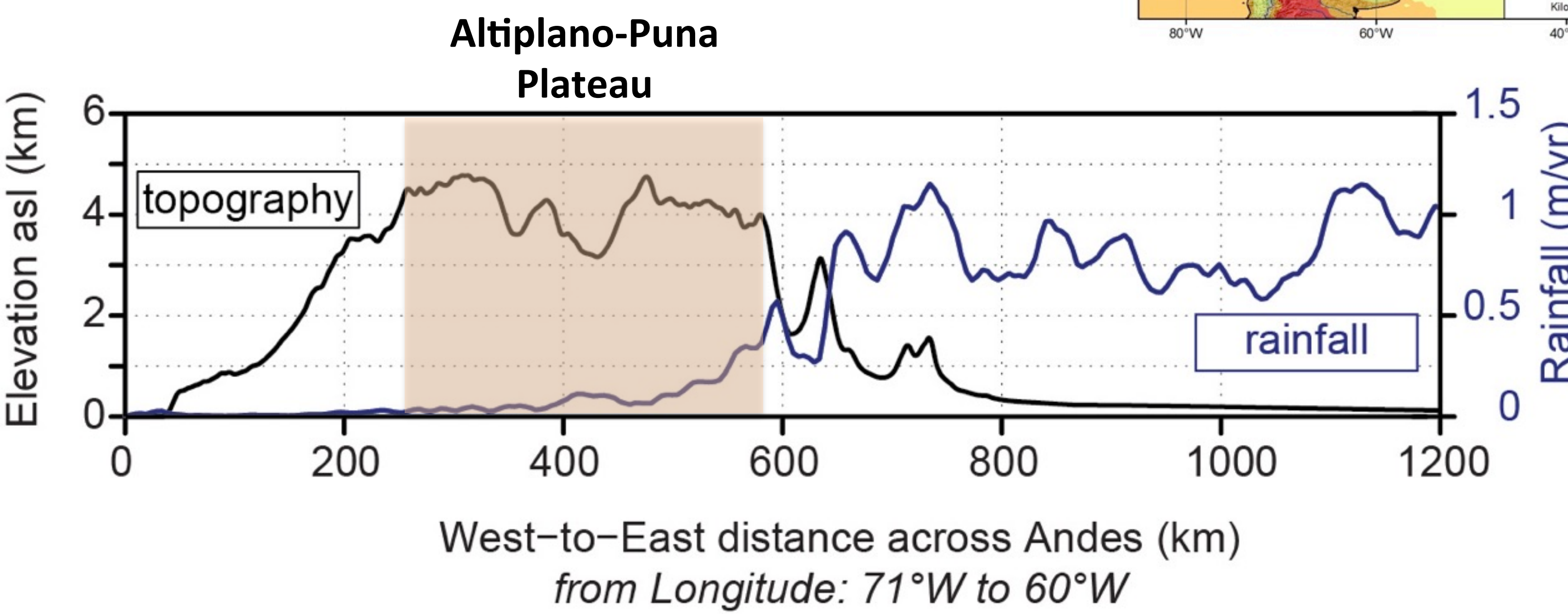


Bookhagen and Strecker, 2008 , 2012

Climatic Gradients in the Southern Central Andes

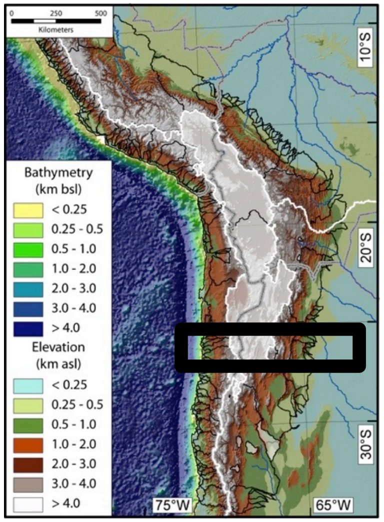


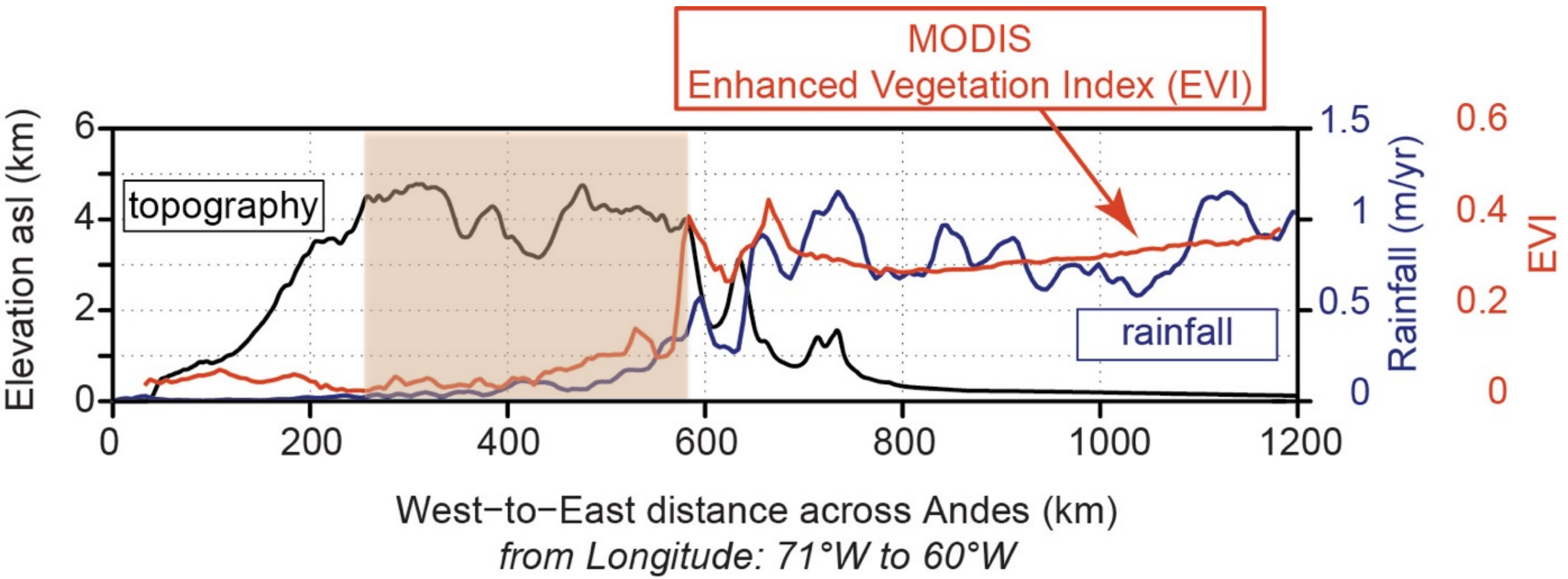




Bookhagen and Strecker, in preparation

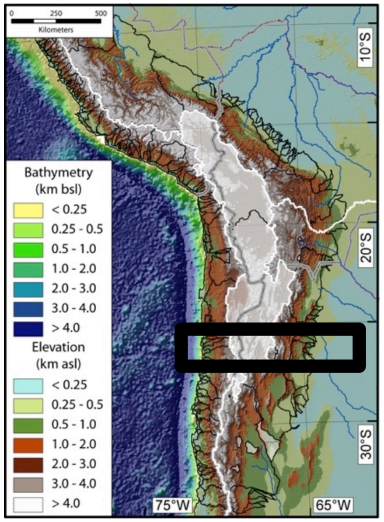
Climatic and Vegetation Gradients in the S. Central Andes

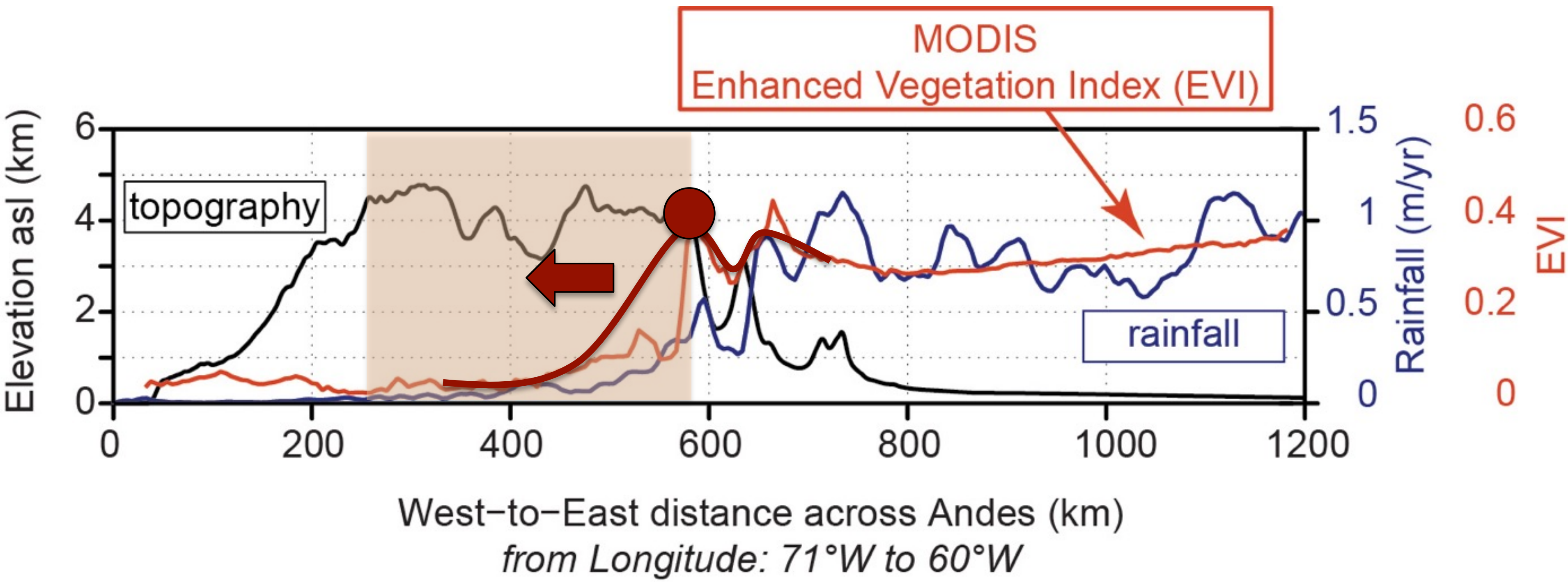




Bookhagen and Strecker, in preparation

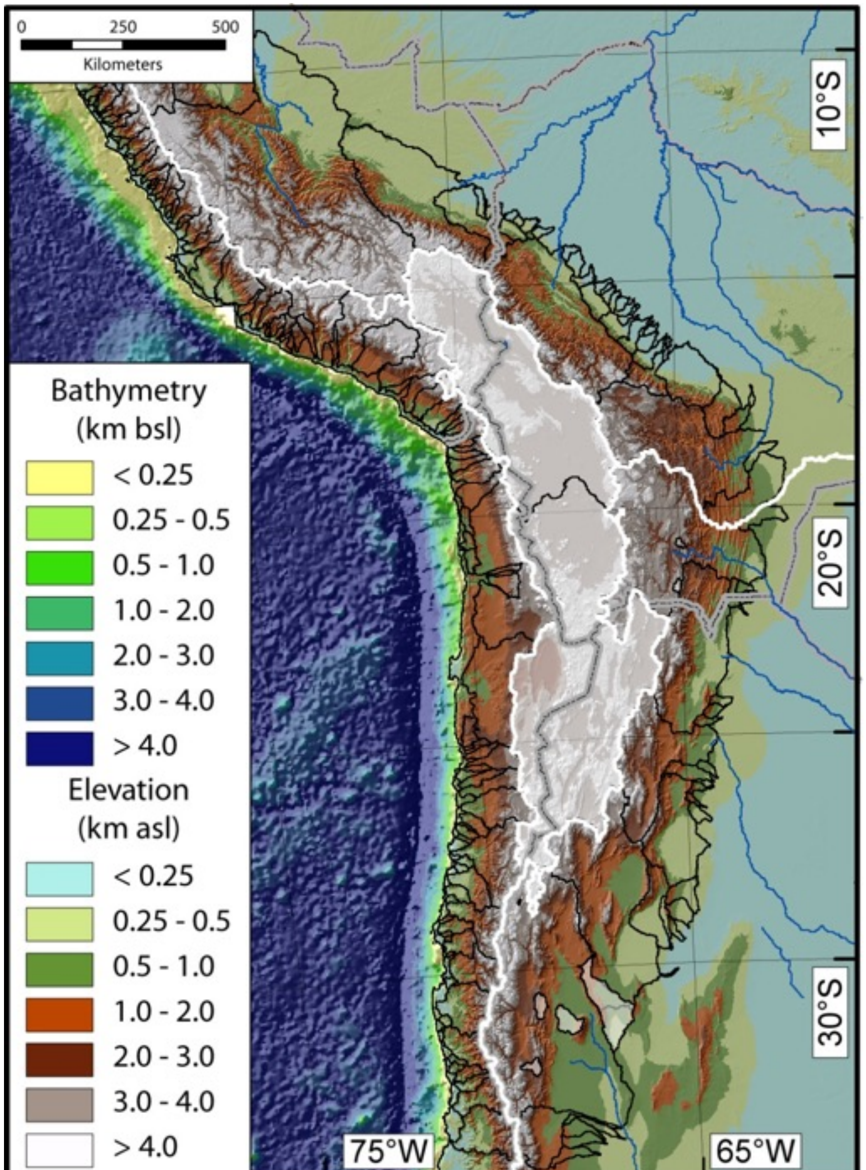
Climatic and Vegetation Gradients in the S. Central Andes

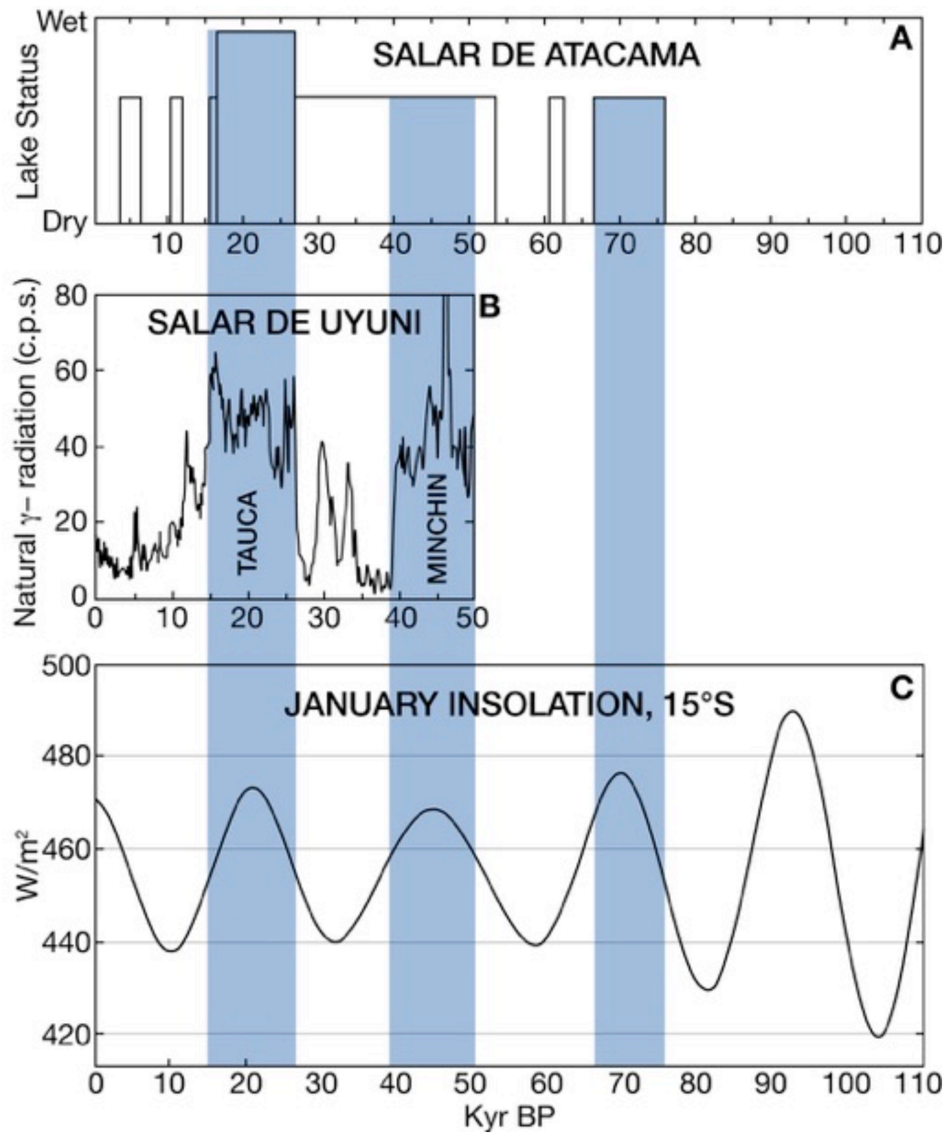




Bookhagen and Strecker, in preparation

Pleistocene-Holocene lake-level highstands in the Central Andes: paleoclimatic proxy record





Bobst et al., 2001

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Earth Surface Processes and Geomorphology

Geomorphology is the study of landforms and processes that shapes them.

Geomorphologists study forces that move or transport mass on the Earth's surface. For example, **rivers** (fluvial forces), **wind** (aeolian forces), **glaciers** and **permafrost**, **biological** and **biophysical** processes, and various gravitational-driven **mass movements** (landslides, debris flows, creep).

Earth Surface Processes and Geomorphology

Geomorphology is the study of how landscape grows and decays (or erodes).

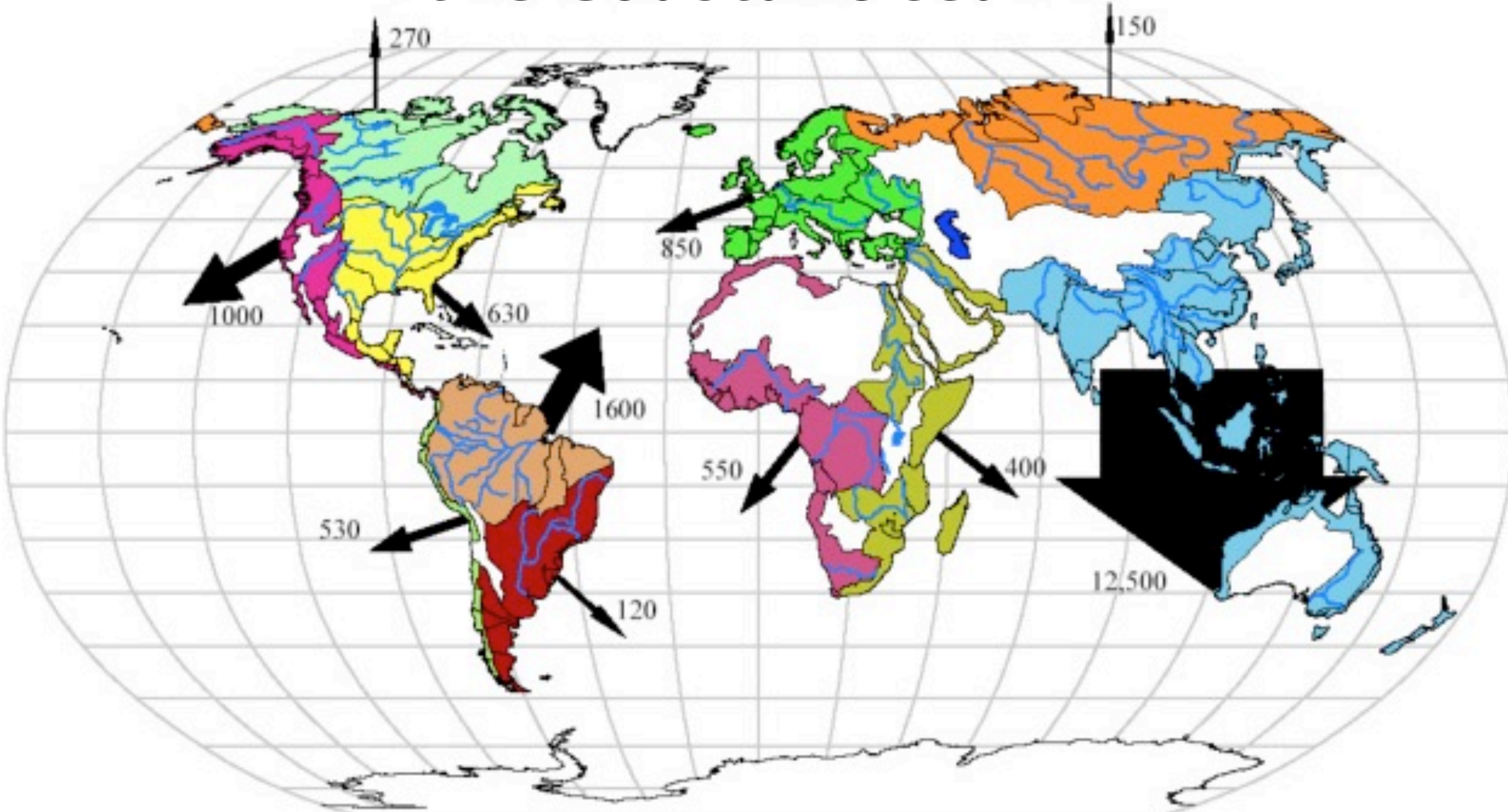
- *What are the magnitudes and timescales of transport processes?*
- *How does climate, vegetation, and civilization impact Earth Surface Processes and how do they interact?*

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 x 10^6 t/yr

Milliman and Farnsworth, 2011

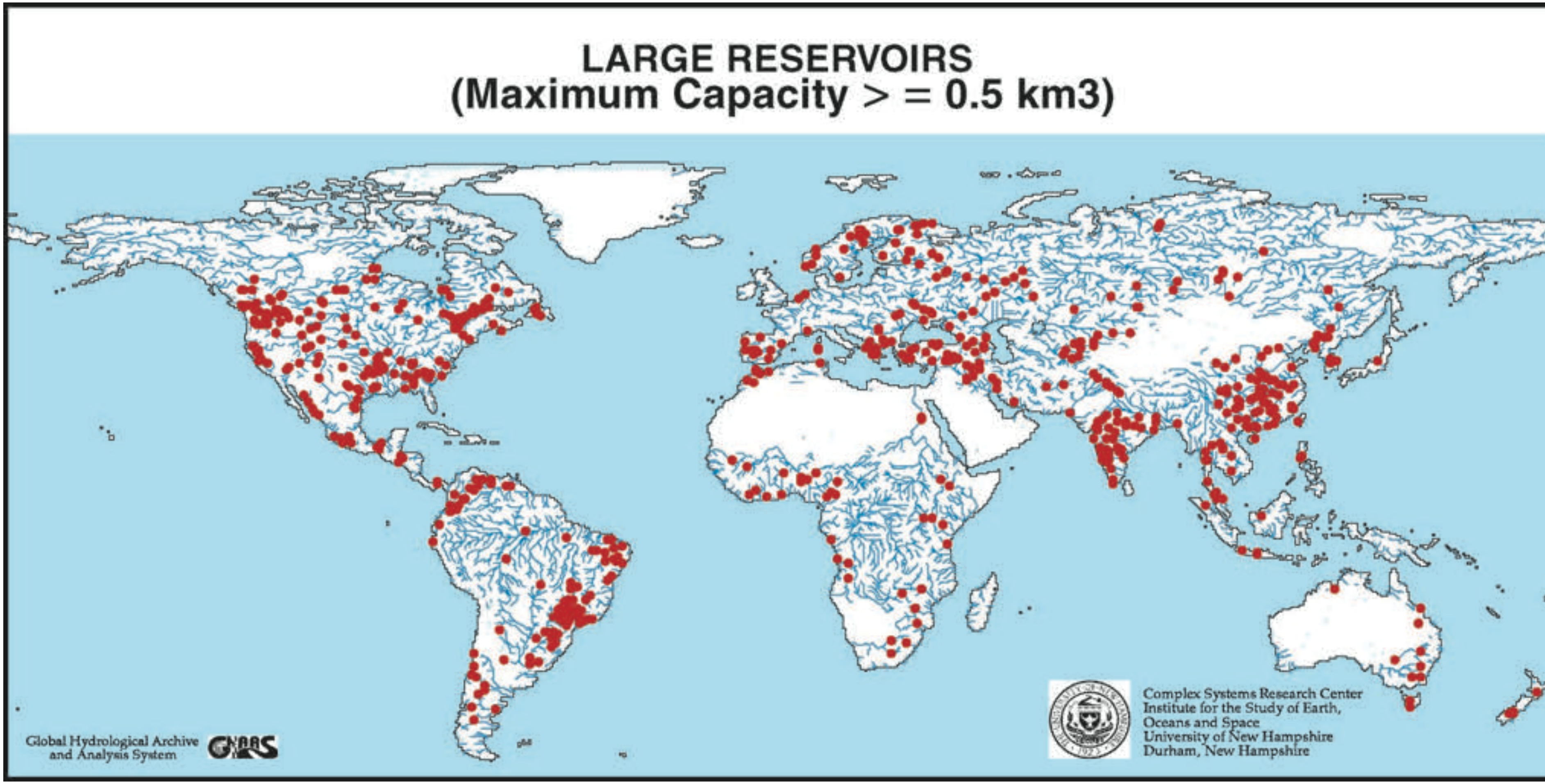
Key problems

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. Lack of process-based transport models that allow prediction based on boundary conditions.

III. 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.

Spatial distribution of large anthropogenic reservoirs



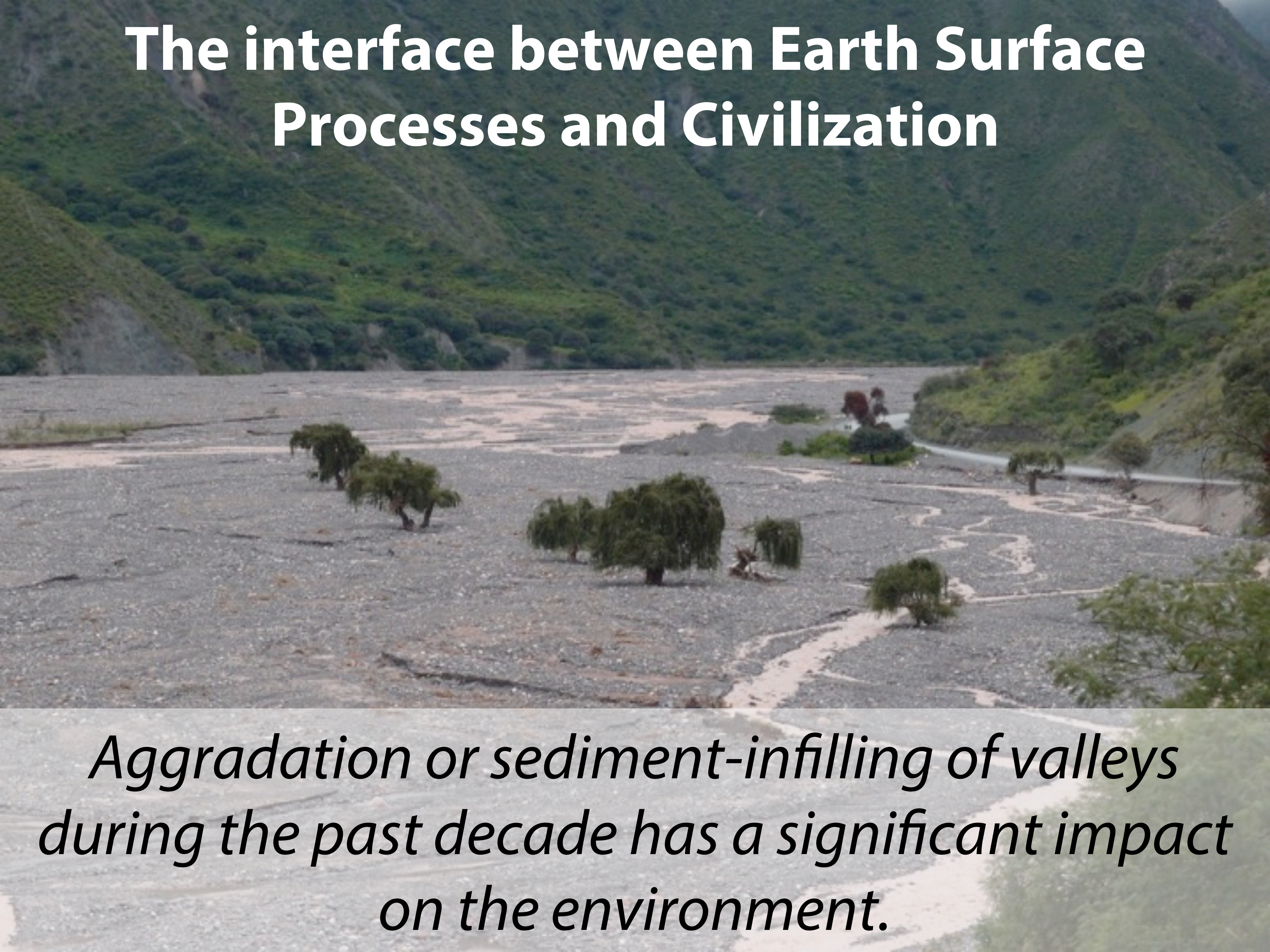
Large reservoirs are subject to sediment infilling; rapid infilling will decrease a reservoir's life time.

Vörösmarty et al., 2003

The interface between Earth Surface Processes and Civilization

Why do we care about mass-transport processes?

The interface between Earth Surface Processes and Civilization



Aggradation or sediment-infilling of valleys during the past decade has a significant impact on the environment.

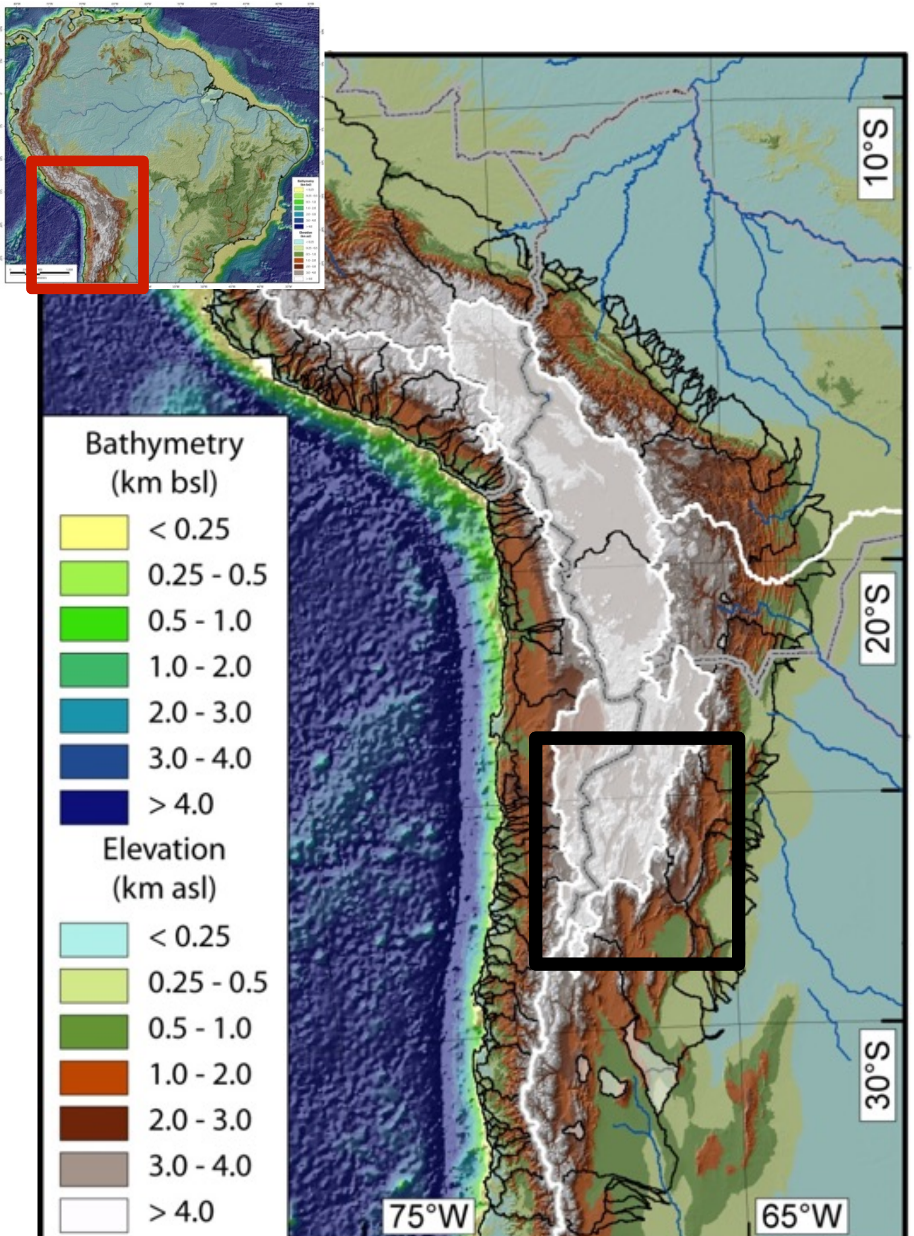
The interface between Earth Surface Processes and Civilization

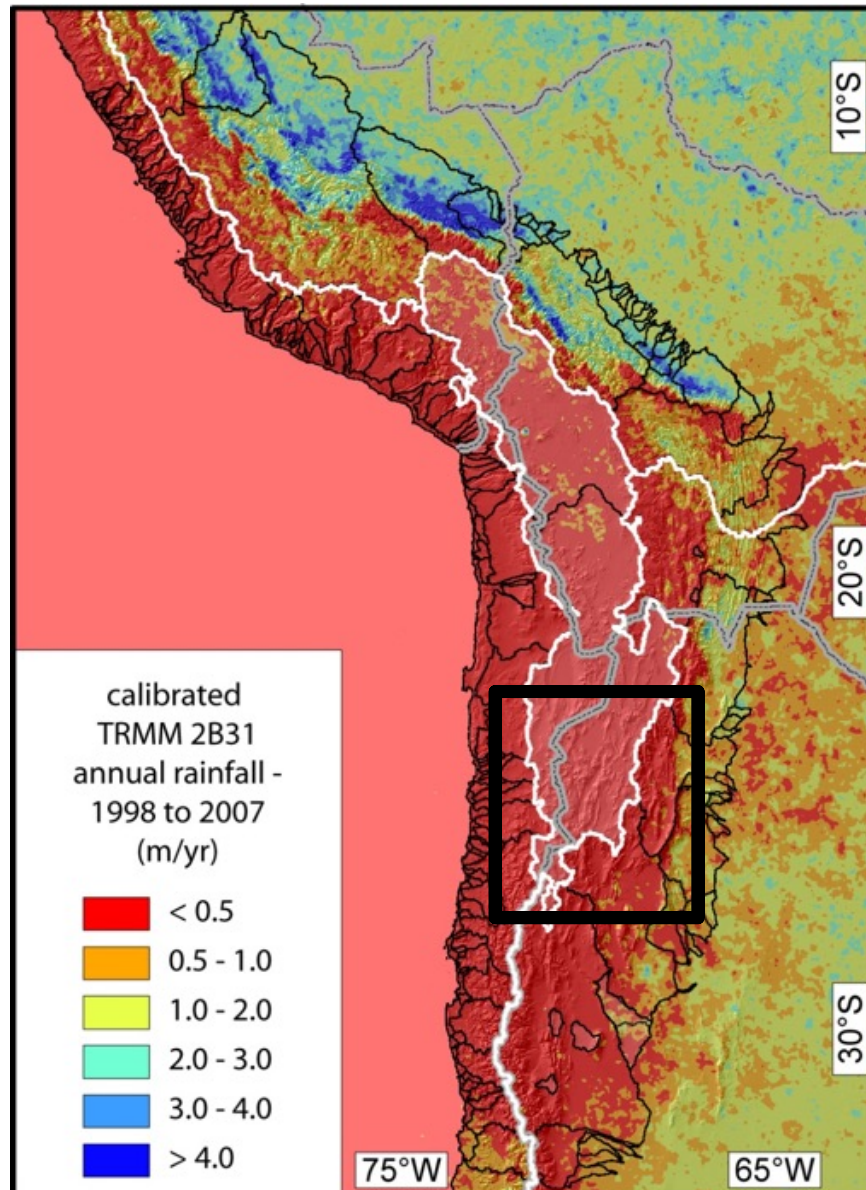
Aggradation or sediment-infilling of valleys during the past decade has a significant impact on the environment.

The interface between Earth Surface Processes and Civilization

Potential source of sediments: increased 'rilling' (or 'arroyo' formation) and transport of material from upstream usually arid areas.

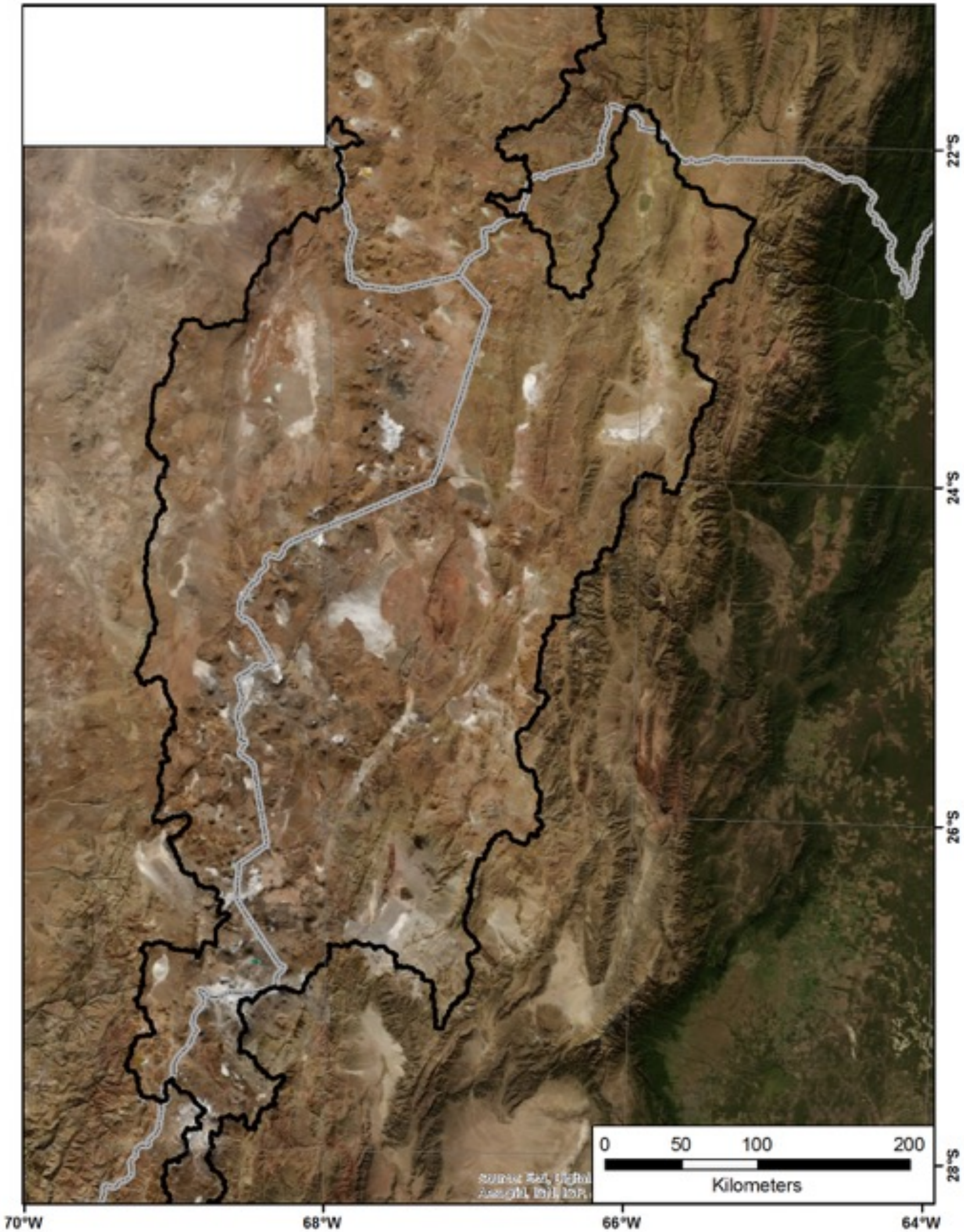
Climatic Gradients in the Central Andes



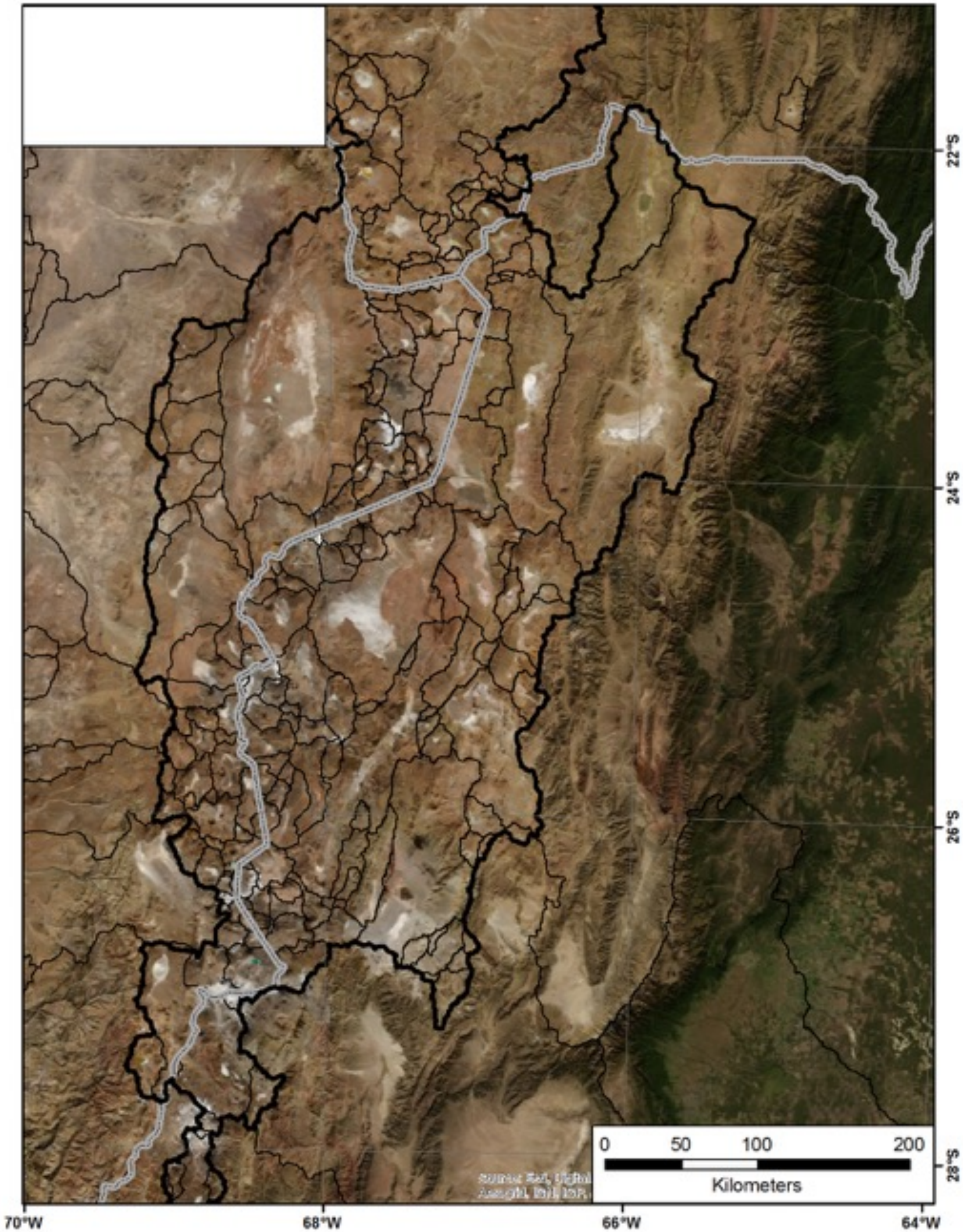


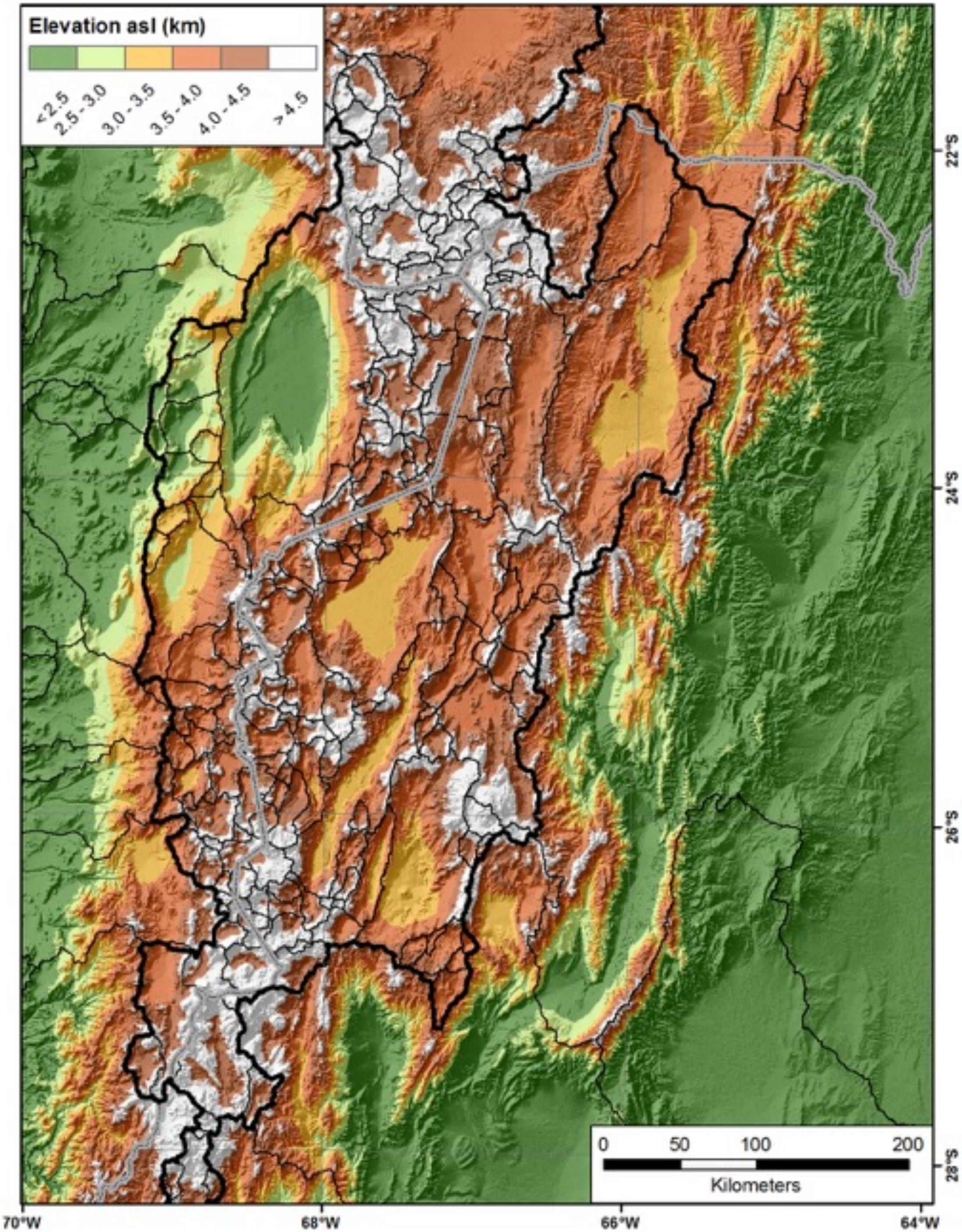
Bookhagen and Strecker, 2008 , 2012

Southern Central Andes –



Southern Central Andes – Hydrologic Catchments of the Puna de Atacama



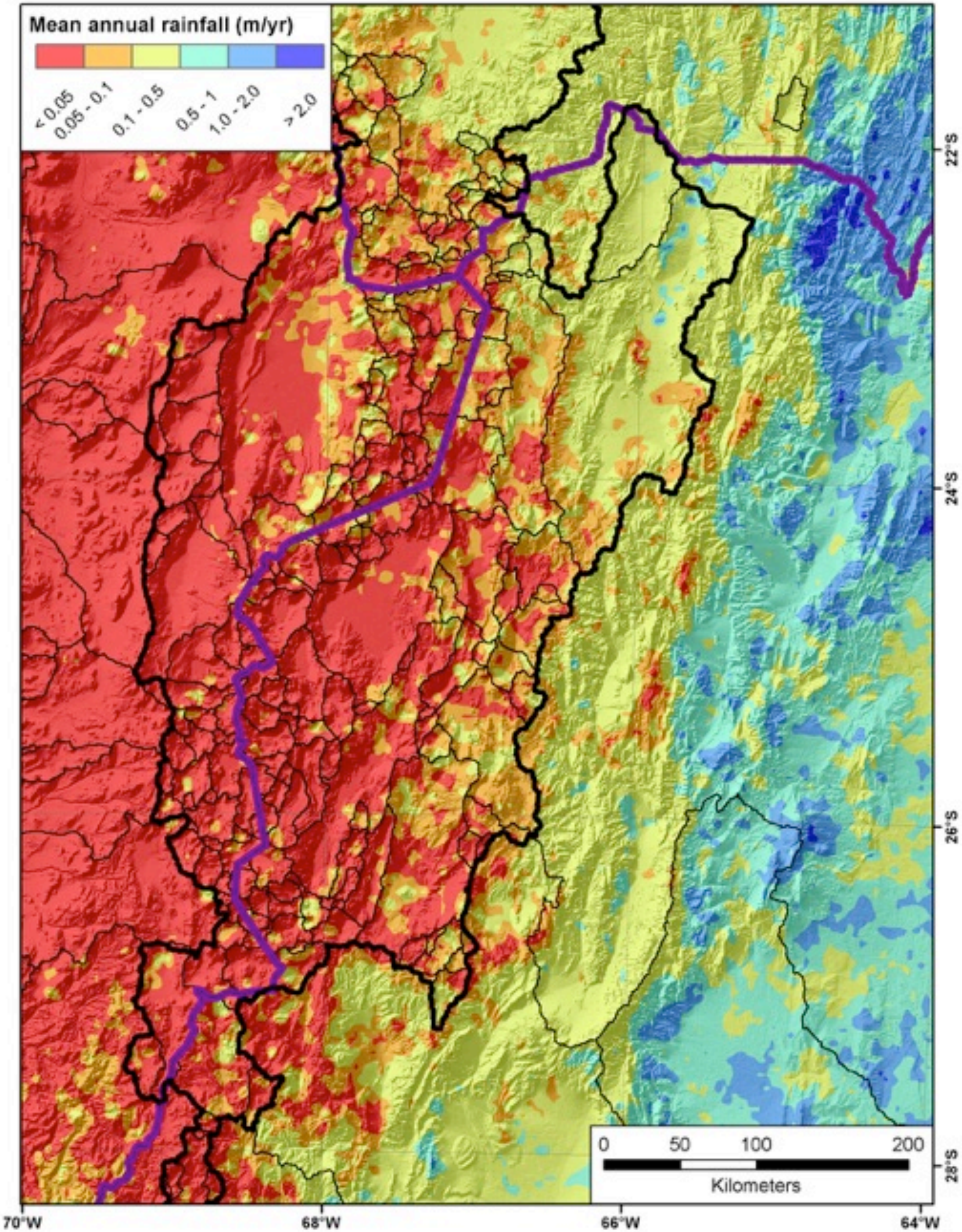


Southern Central Andes – Hydrologic Catchments of the Puna de Atacama

The Puna is separated into hydrologically disconnected catchments with variable sizes.

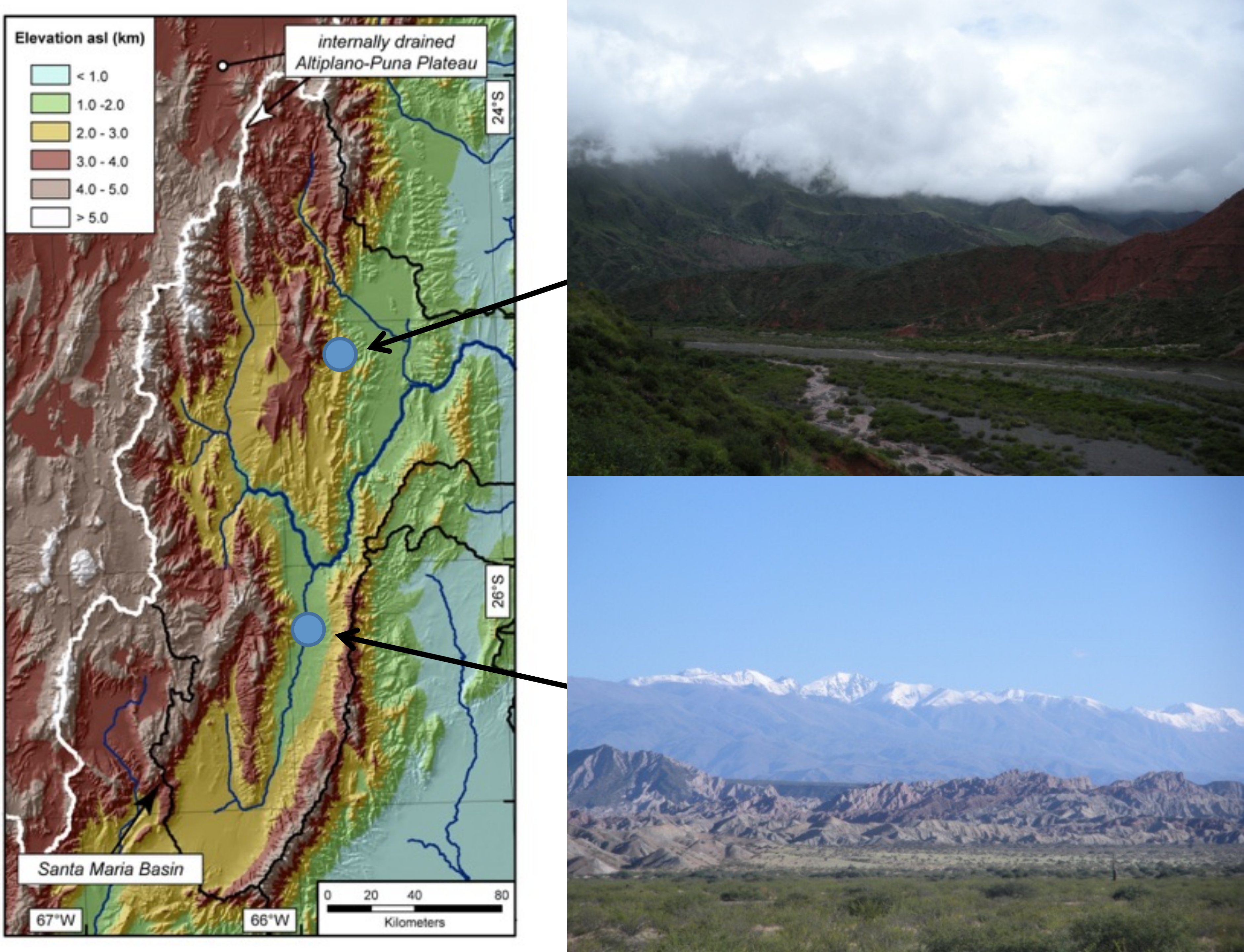
Bookhagen and Strecker, in preparation

Southern Central Andes – Mean Annual rainfall (1998-2013)

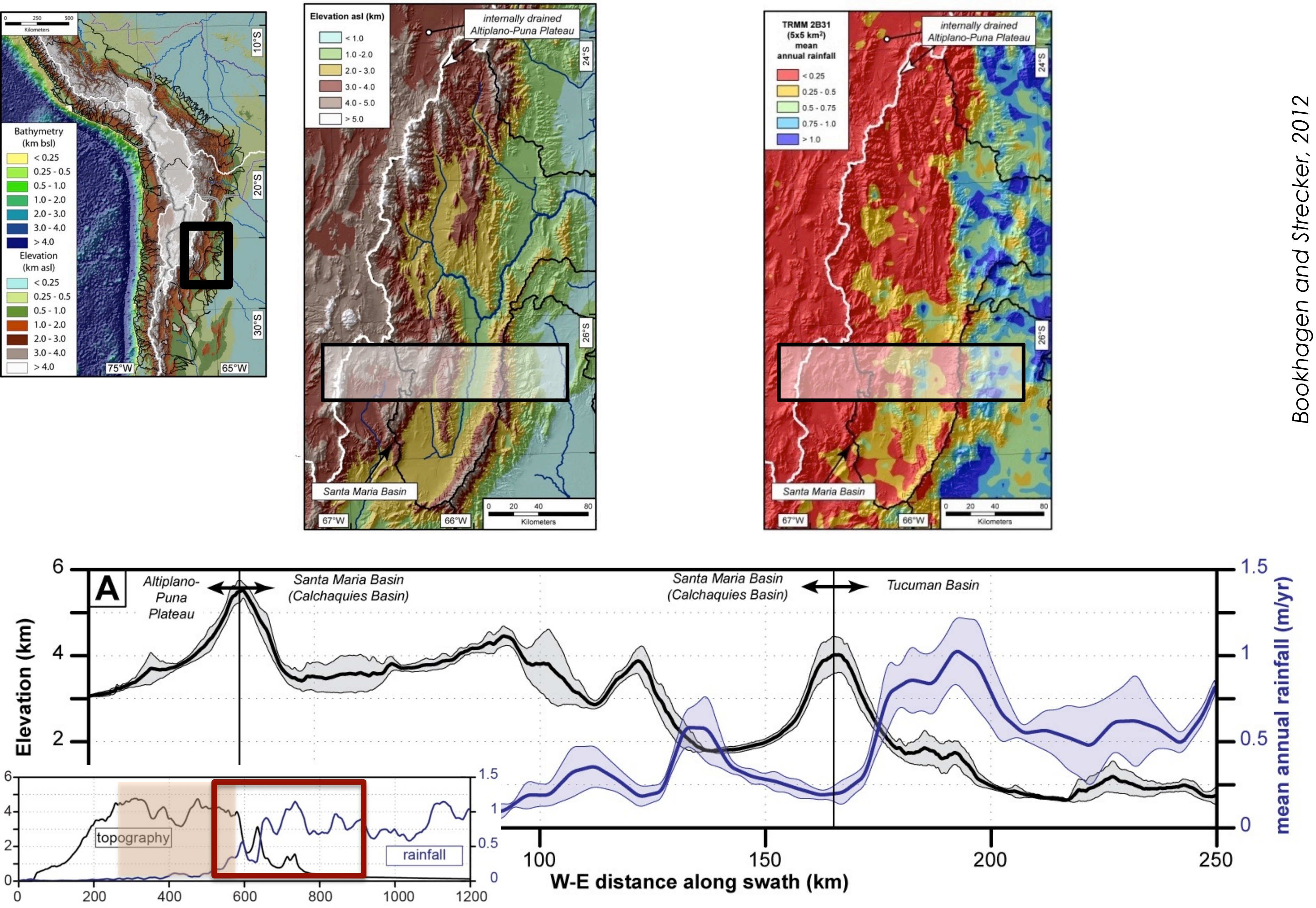


Mean annual rainfall from TRMM2B31 and 2A25 show a ~10-fold rainfall gradient from the eastern foreland to the Altiplano.

Bookhagen and Strecker, 2008; Bookhagen and Strecker, in preparation


Elevation asl (km)
< 1.0
1.0 -2.0
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
> 5.0
internally drained
Altiplano-Puna Plateau
24°S
26°S
Santa Maria Basin
67°W
66°W
0 20 40 80
Kilometers

Rainfall and Topographic Swath Profile I

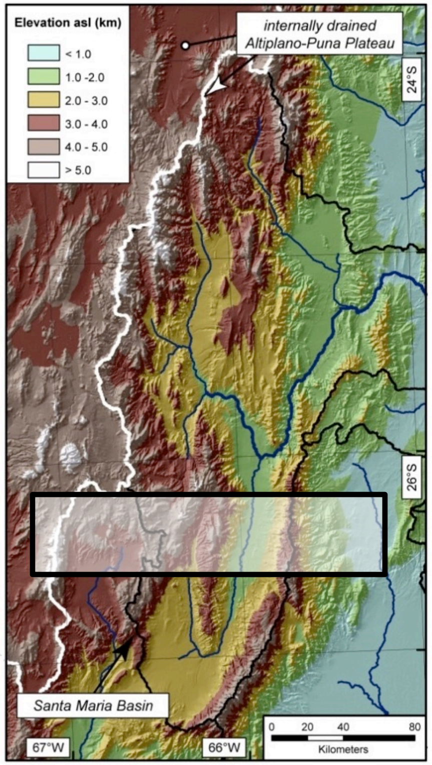


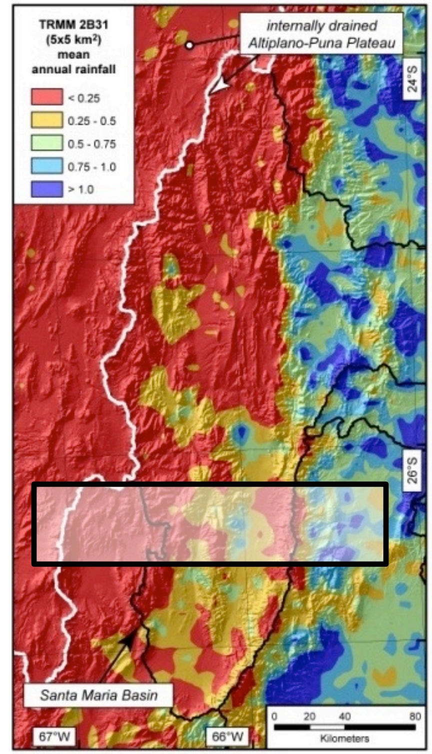
Bookhagen and Strecker, 2012

Rainfall and Topographic Swath Profile II

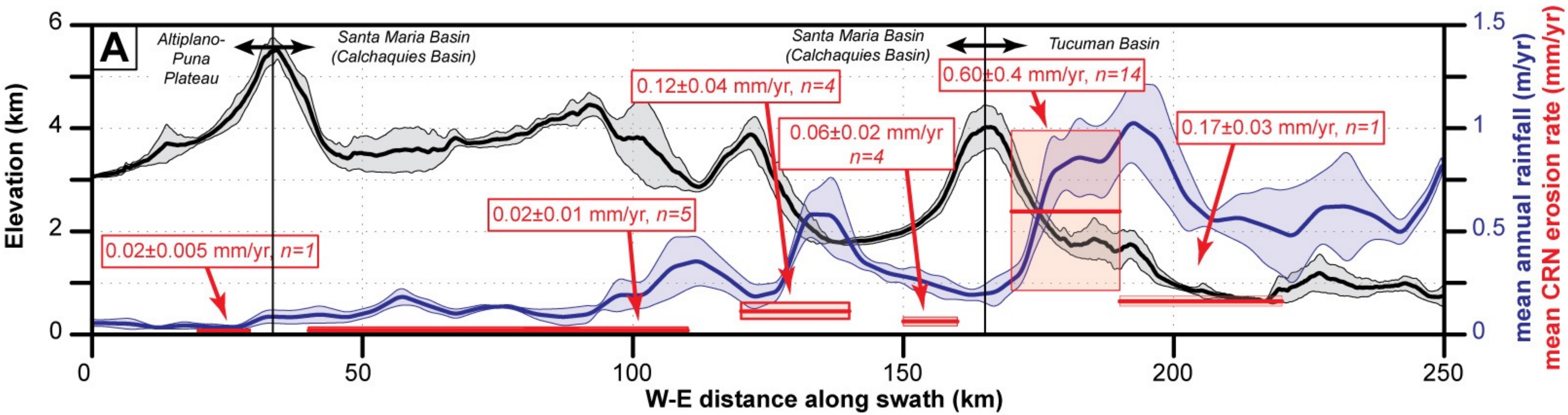
40 Cosmogenic-nuclide erosion rates across a climatic gradient

Deciphering spatial erosion-rate distribution





Bookhagen and Strecker, 2012



Modern and Paleo-erosion rates during pluvial periods

Sediment budget quantified from a landslide-dammed lake in the Santa Maria Basin

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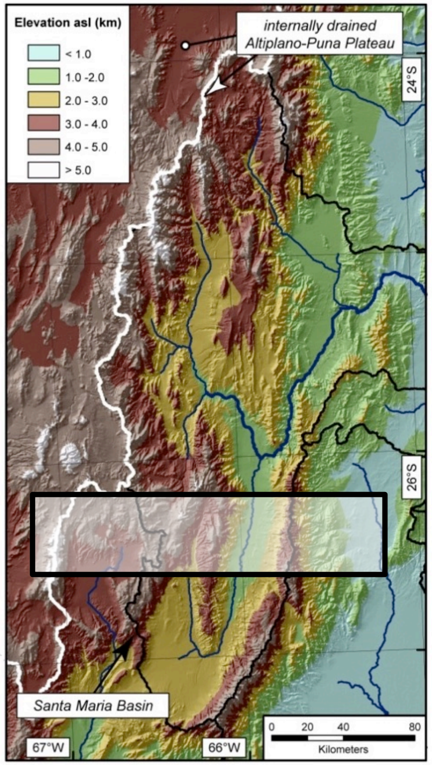
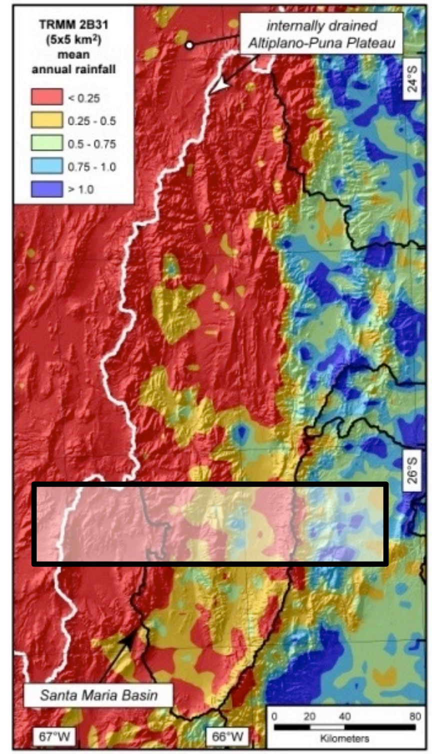
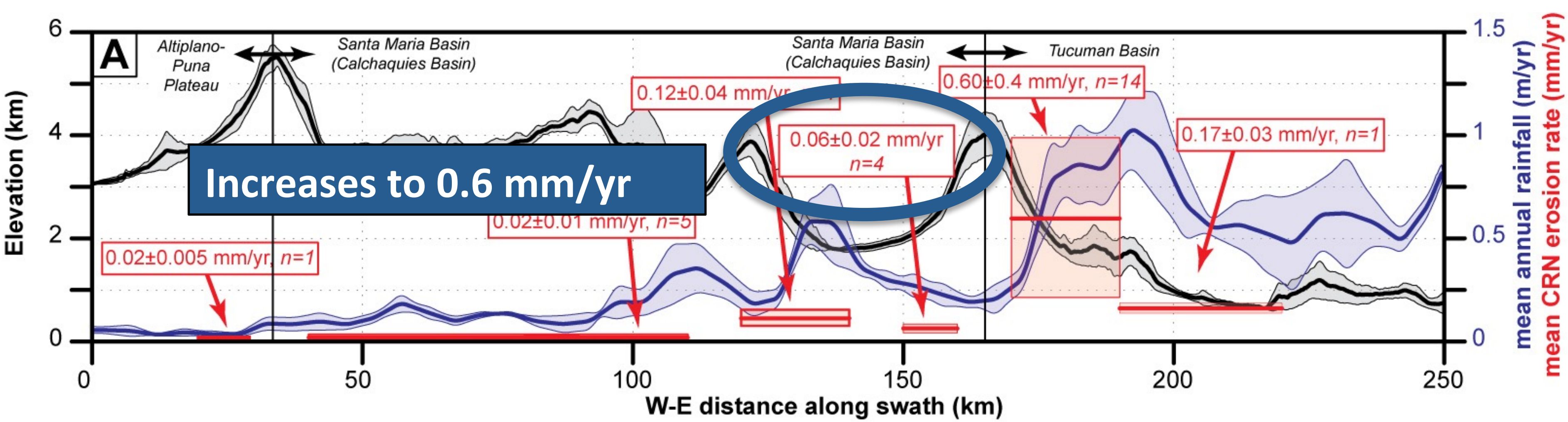
Erosion rates increased 10-fold (one order of magnitude)

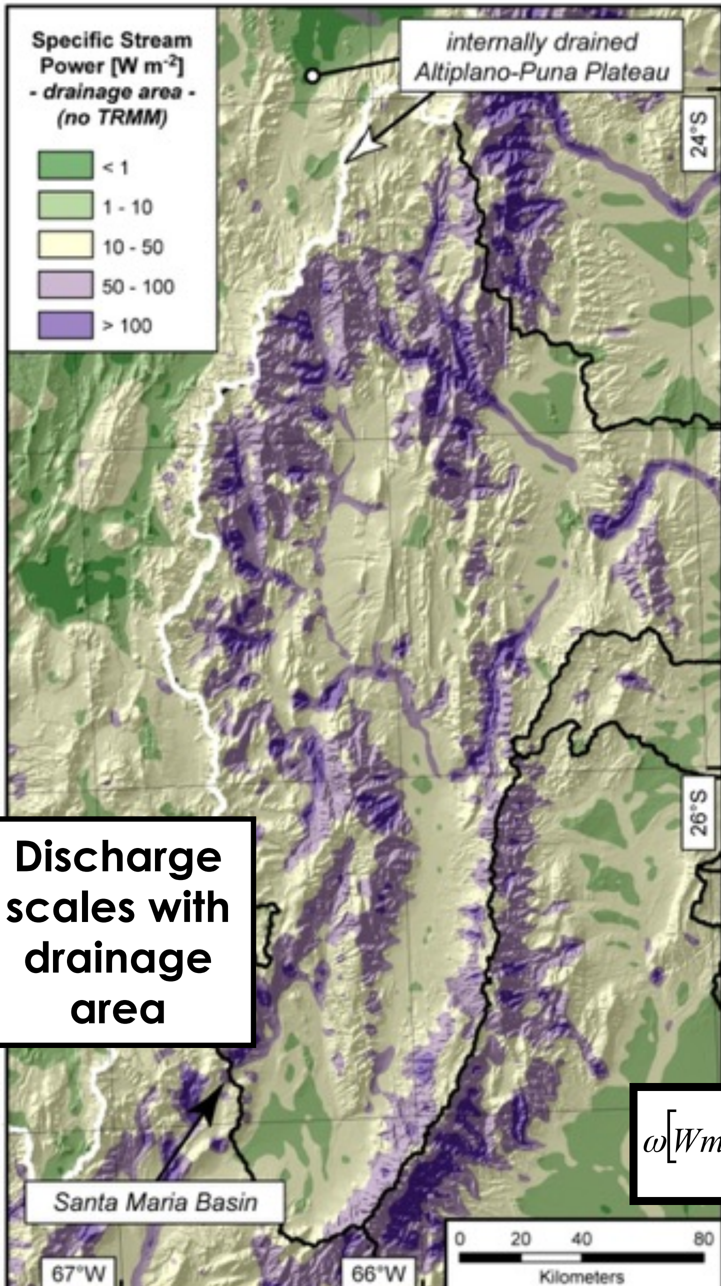




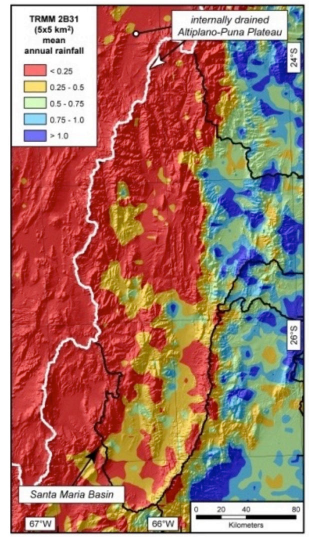
Bookhagen and Strecker, 2012

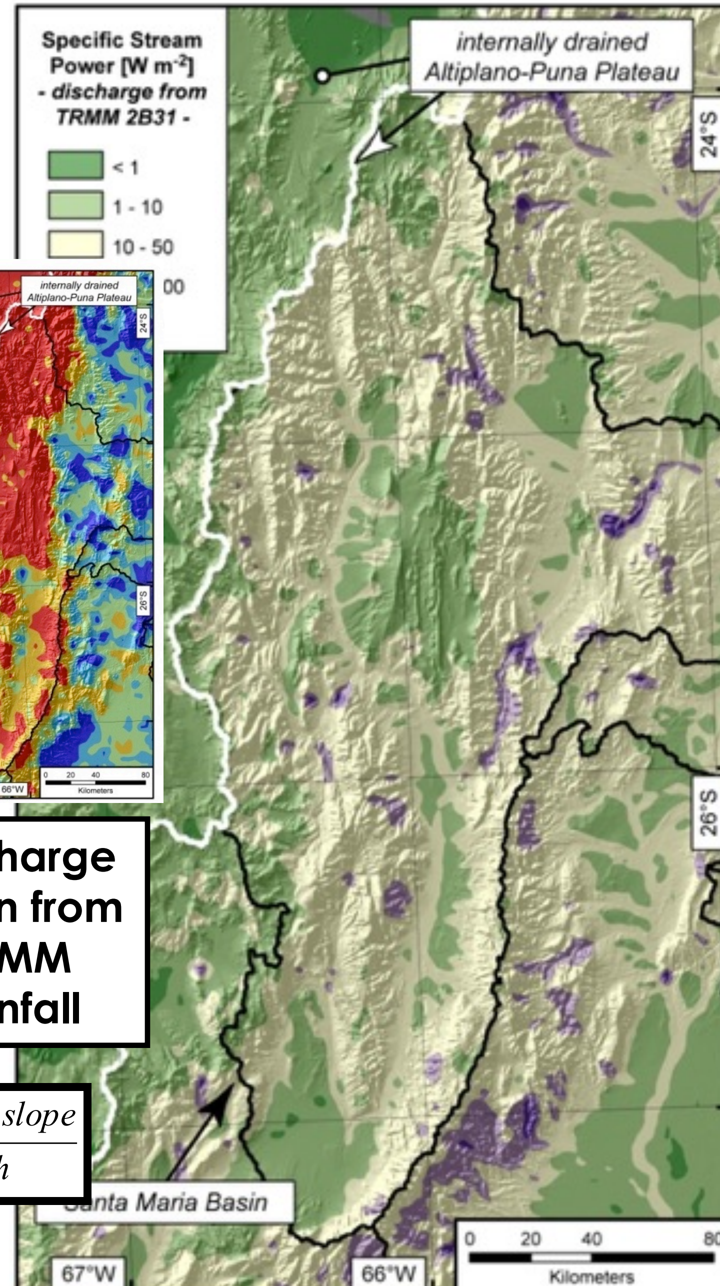


Rainfall Gradient and Specific Stream Power II



Discharge scales with drainage area



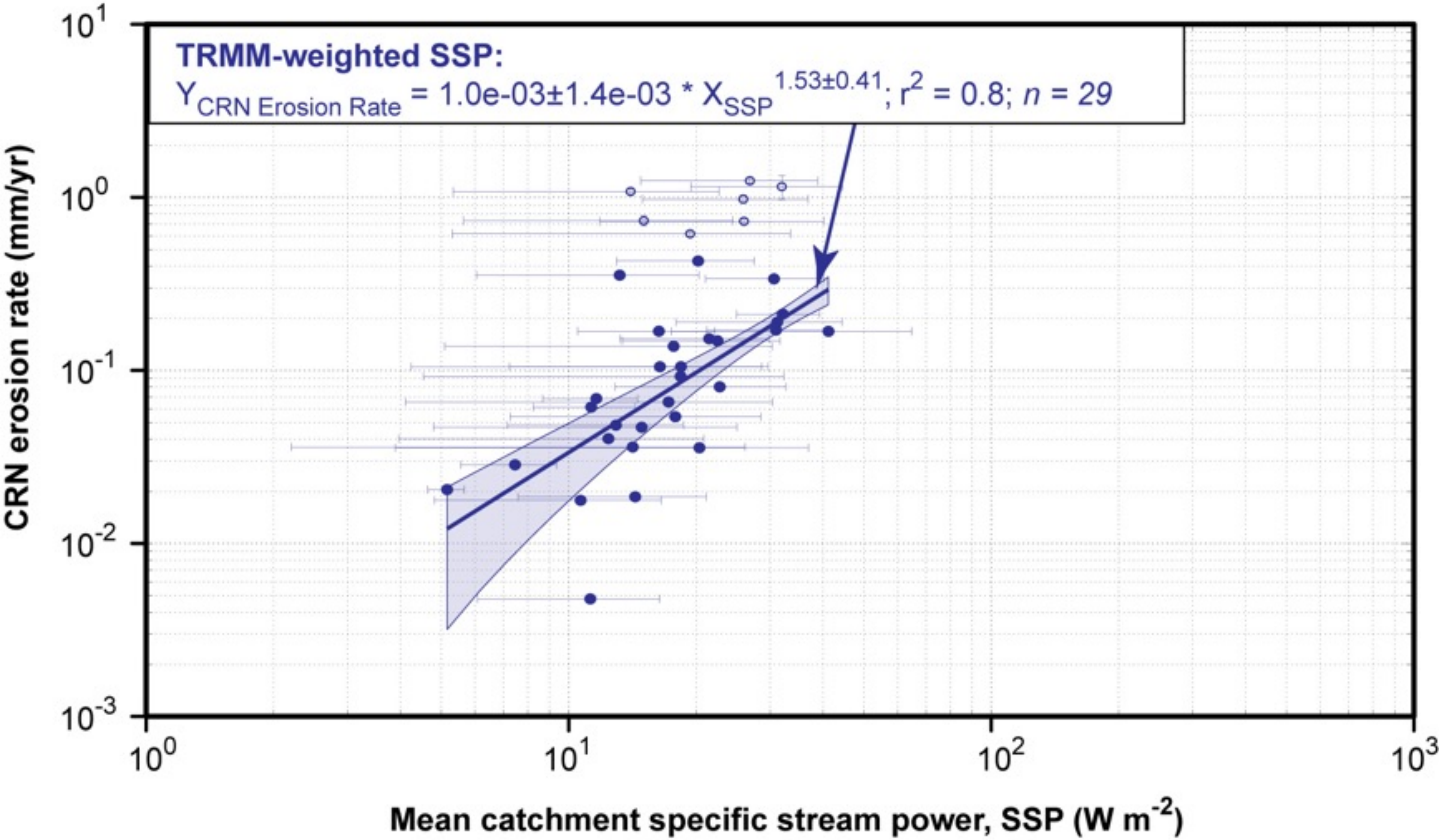


Discharge taken from TRMM rainfall

$$\omega\left[Wm^{-2}\right] = \frac{\rho_w \cdot g \cdot Q \cdot channel\ slope}{channel\ width}$$

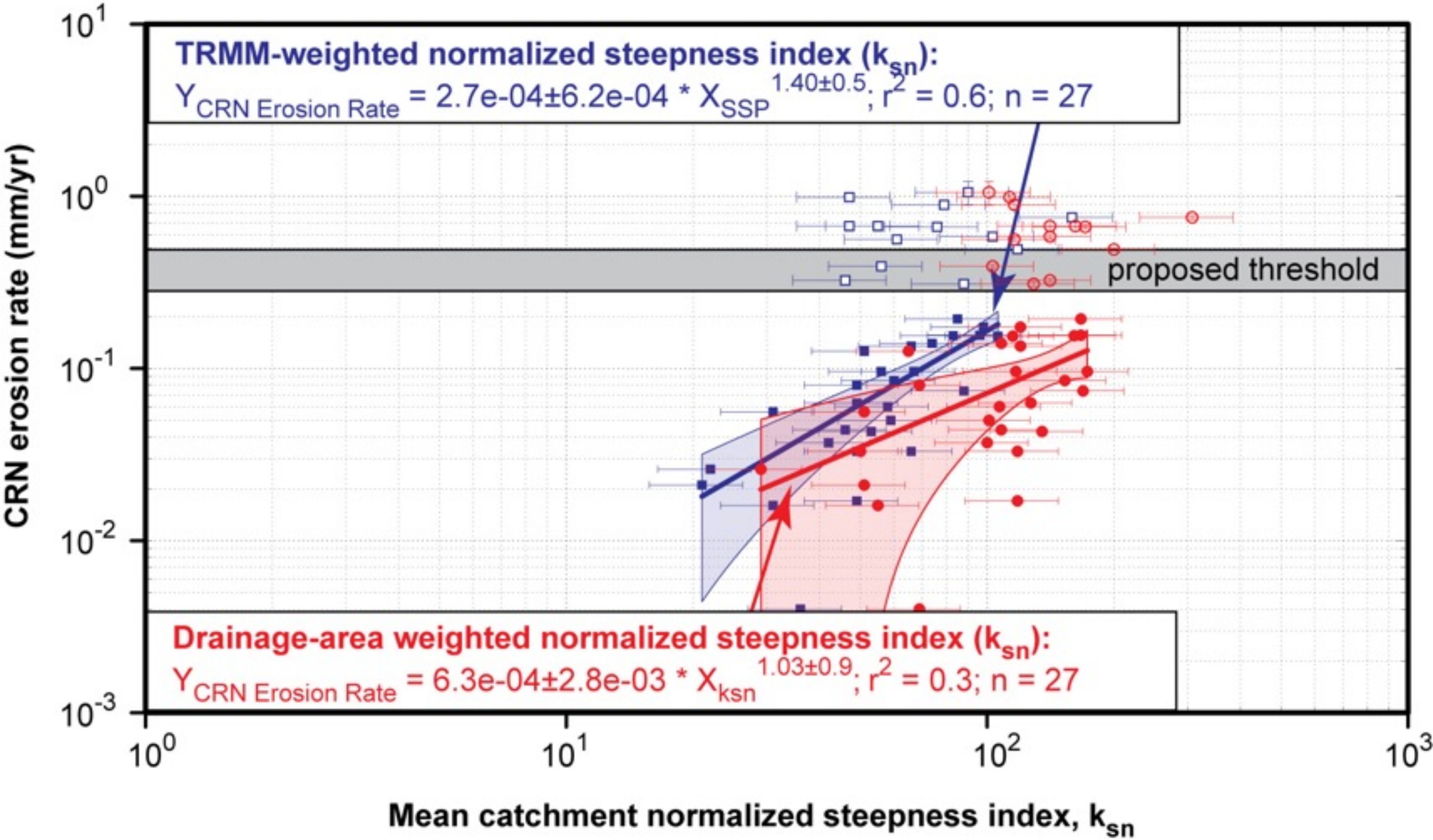
Bookhagen and Strecker, 2012

'Erosion Mapping' with Specific Stream Power I



Bookhagen and Strecker, 2012

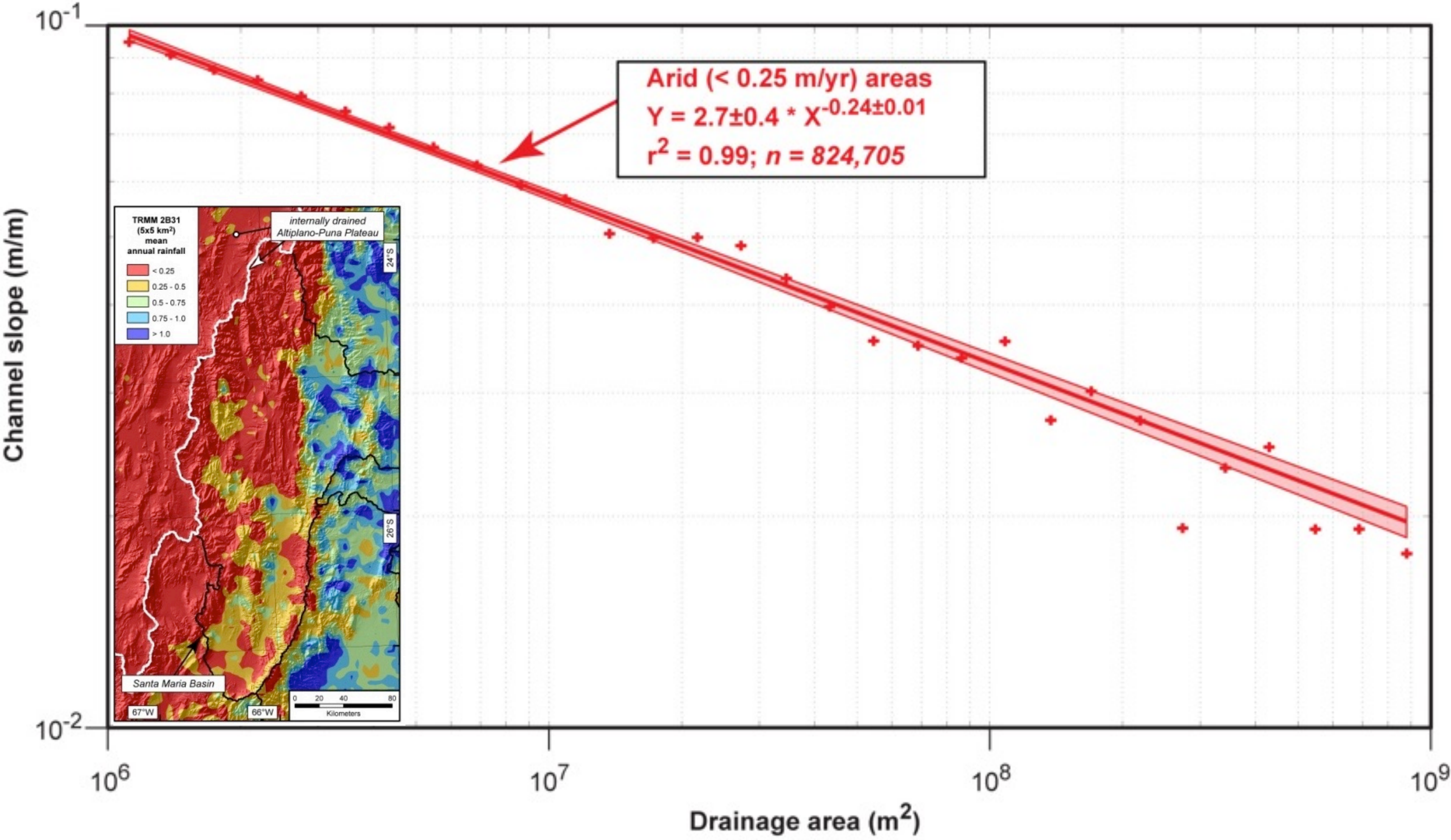
‘Erosion Mapping’ with the channel steepness index



Bookhagen and Strecker, 2012

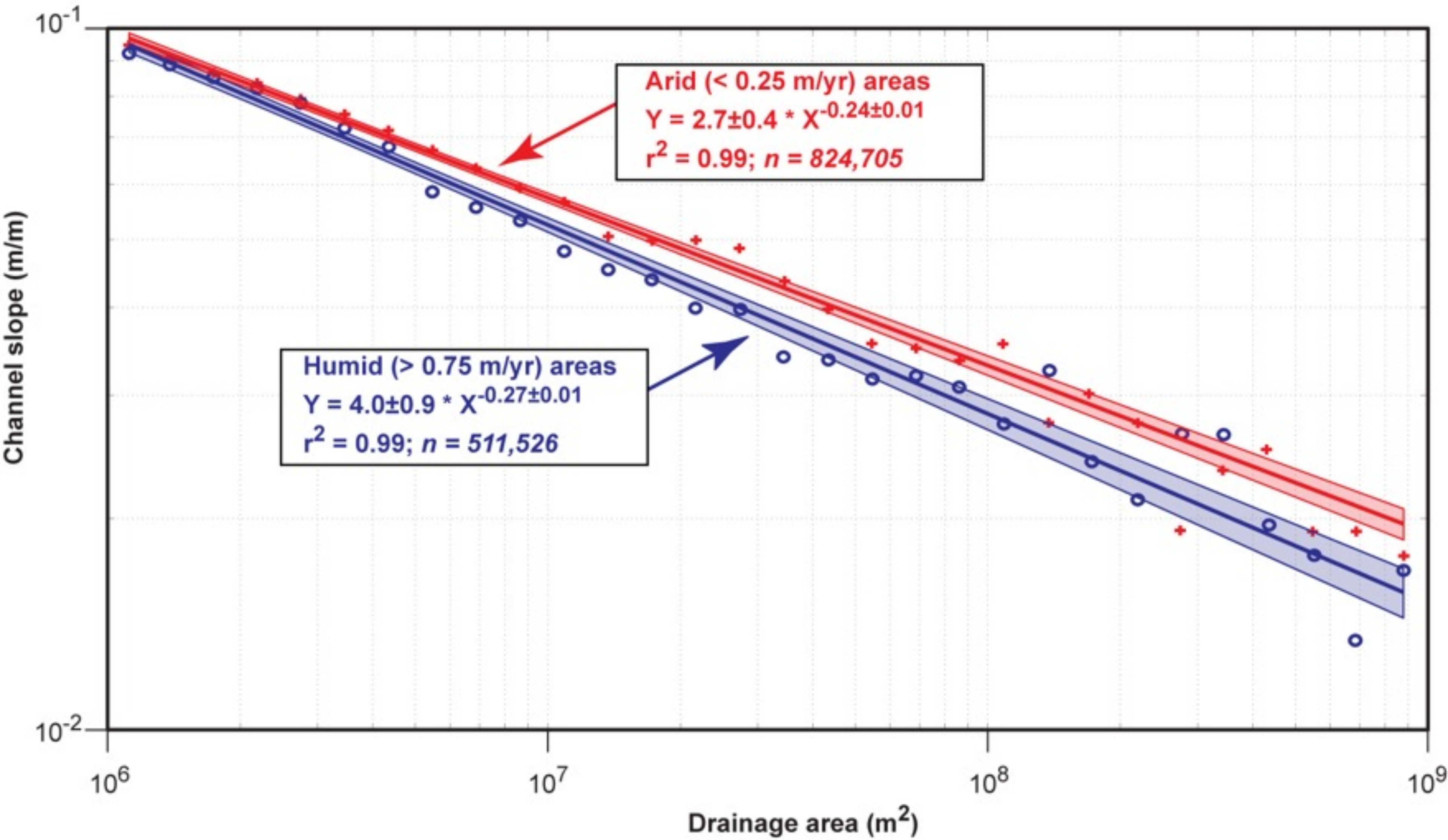
Climatic Impact on Channel Slopes

Climatic Impact on Channel Slopes I



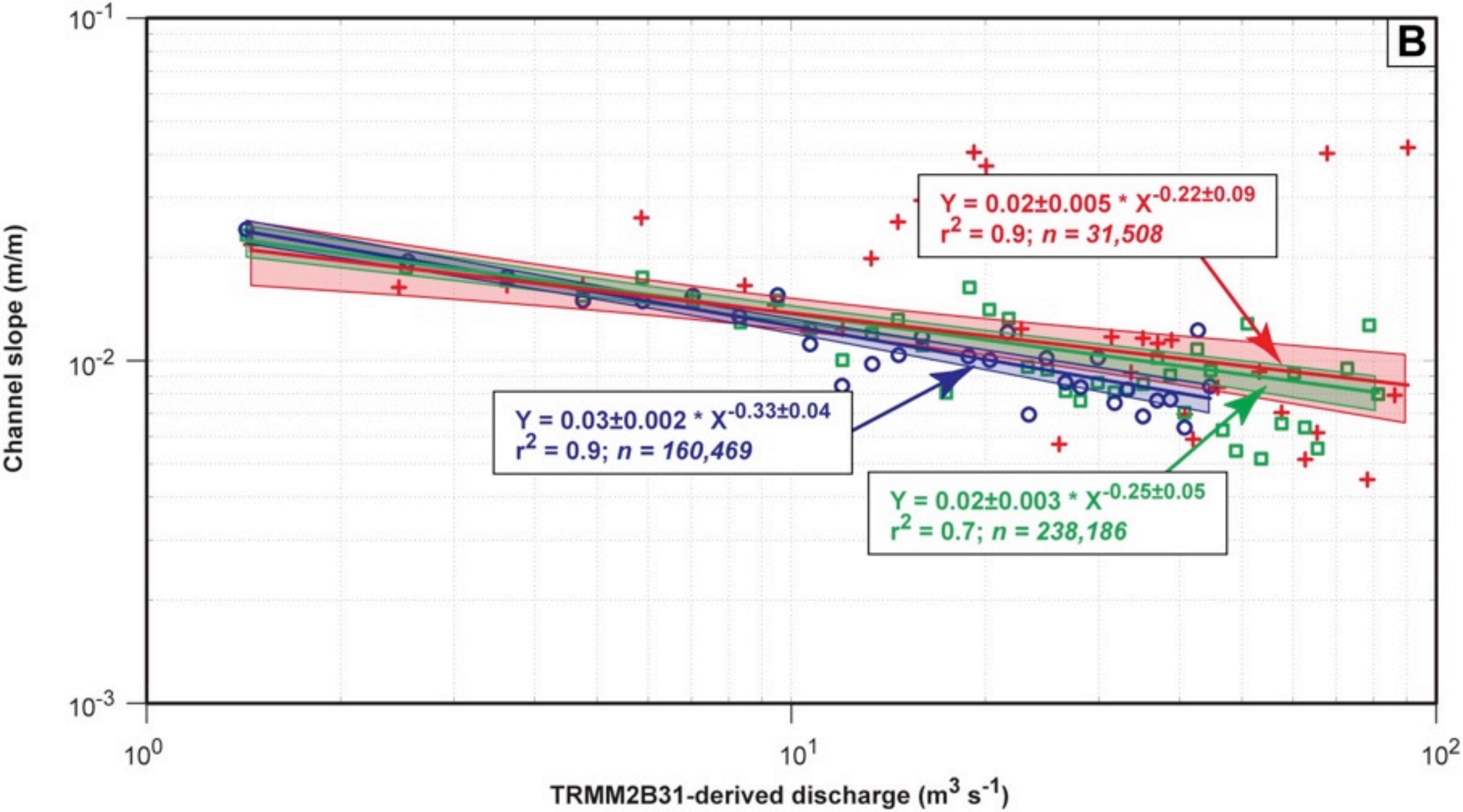
Bookhagen and Strecker, 2012

Climatic Impact on Channel Slopes II



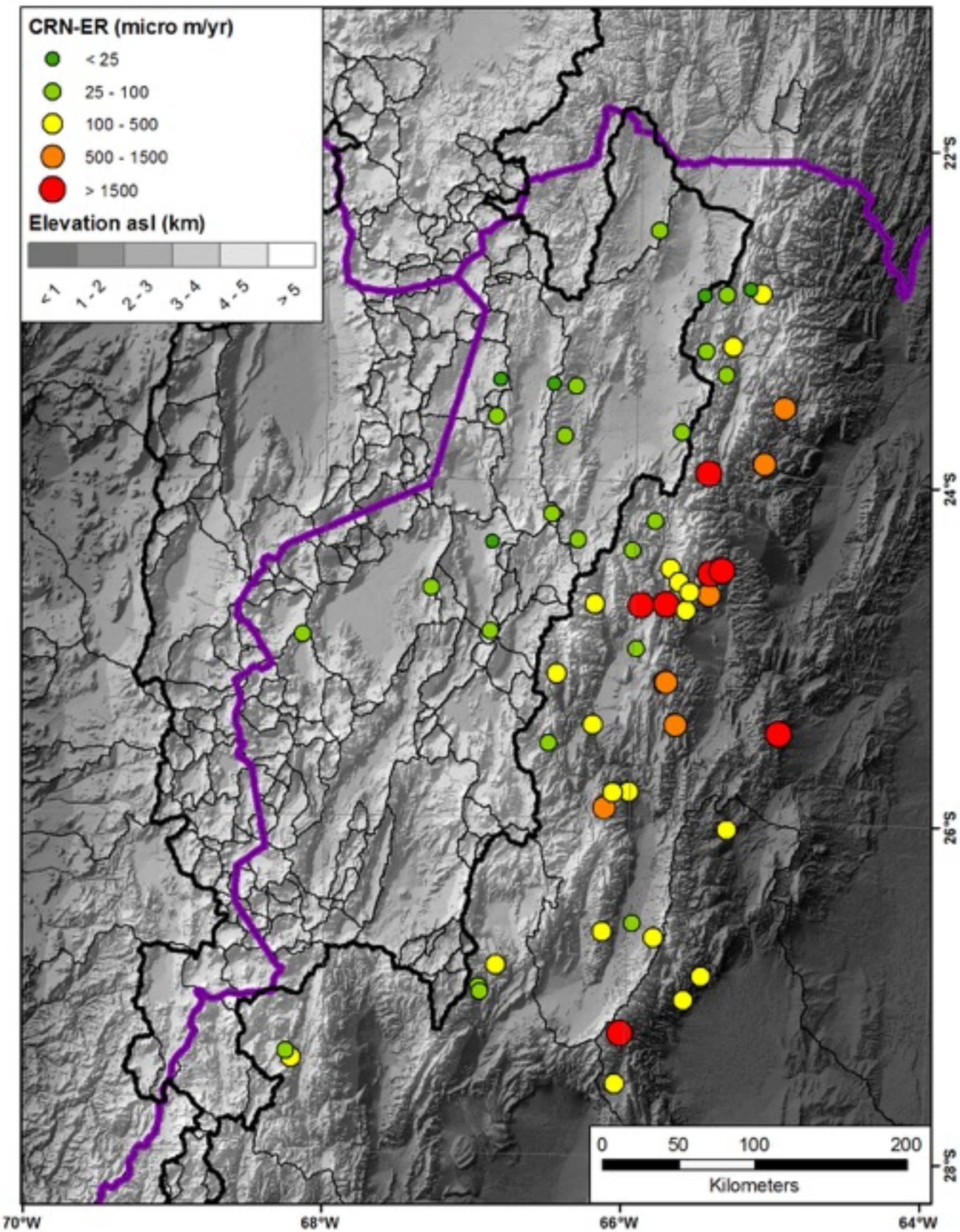
Bookhagen and Strecker, 2012

Climatic Impact on Channel Slopes III

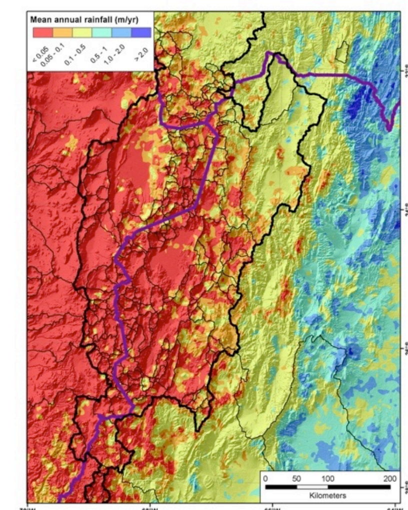


Bookhagen and Strecker, 2012

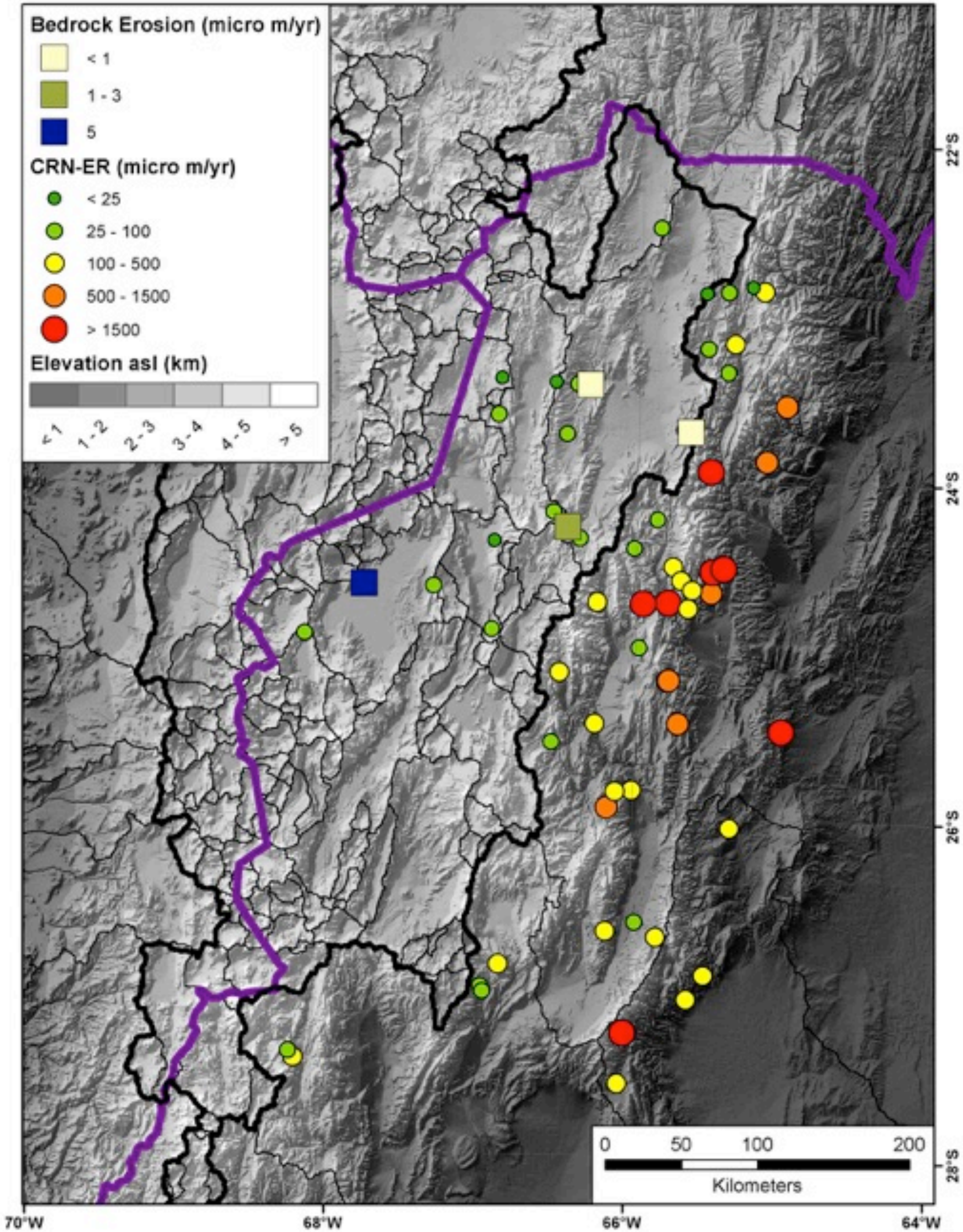
Southern Central Andes – CRN erosion rates



- 59 CRN-derived erosion rates
- East-to-West erosion gradient roughly follows climatic gradient



Bookhagen and Strecker, 2012; Bookhagen and Strecker, in preparation

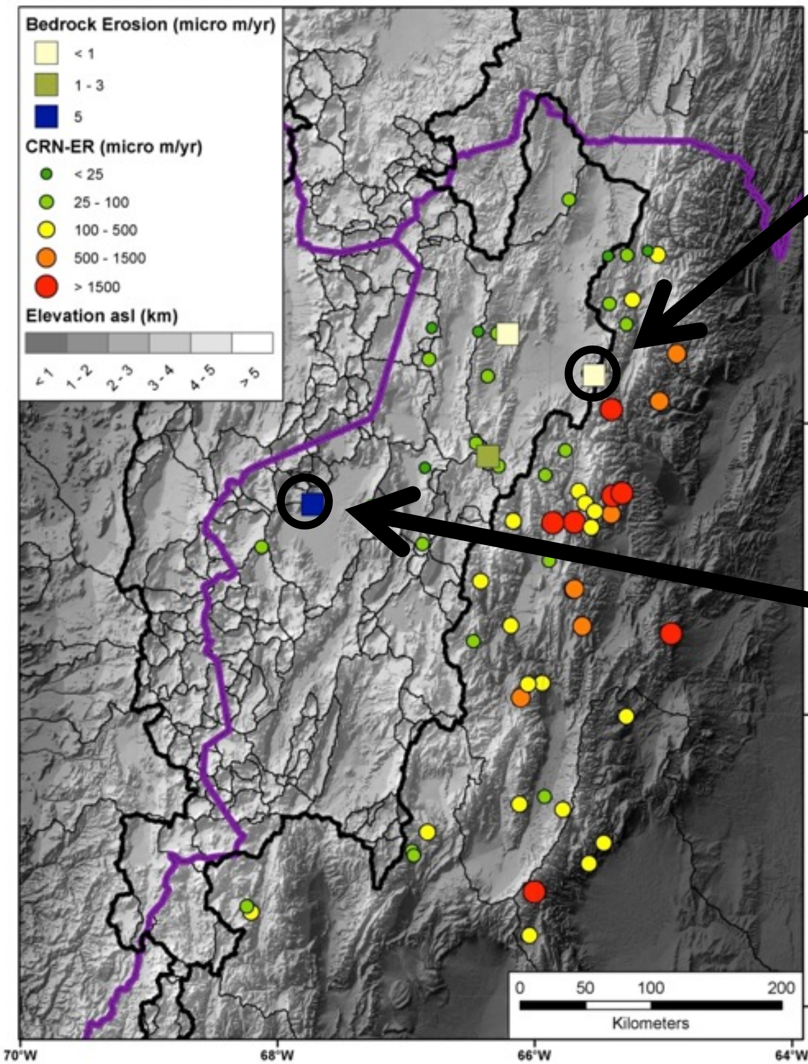


Southern Central Andes – CRN erosion rates

- 6 bedrock erosion-rate samples (10Be/26Al) indicate westward increasing aeolian erosion

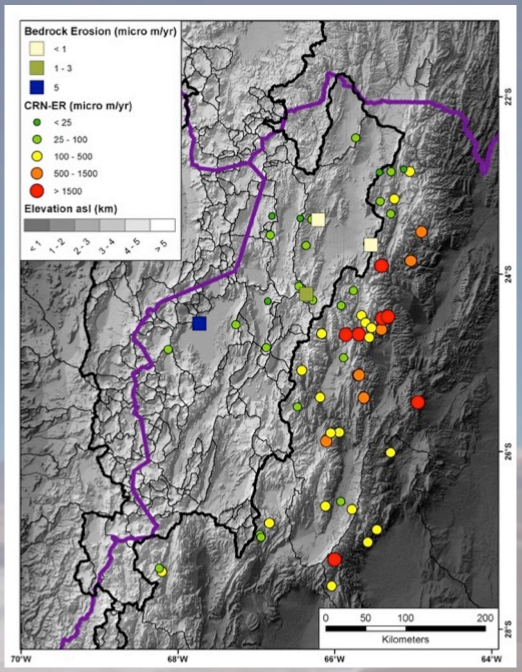
Bookhagen and Strecker, in preparation

Significant Aeolian Erosion on the Puna Plateau

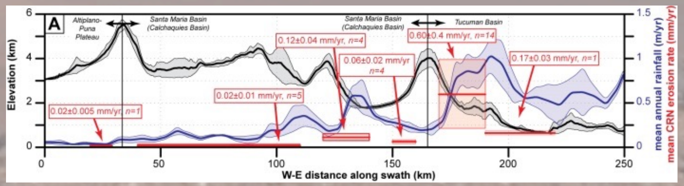


Conclusions

1. Catchment-mean erosion rates **decrease** by two orders of magnitudes across the south-central Andes from east to west. Aeolian erosion **increases** from east to west by ~one order of magnitude.



2. Climatic patterns exert first-order control on erosion rates along the steep climatic gradient.



3. Pluvial Periods may significantly increase erosion rates.