Energy and water balance of the Indus River Basin using CLM - Hillslope Hydrology

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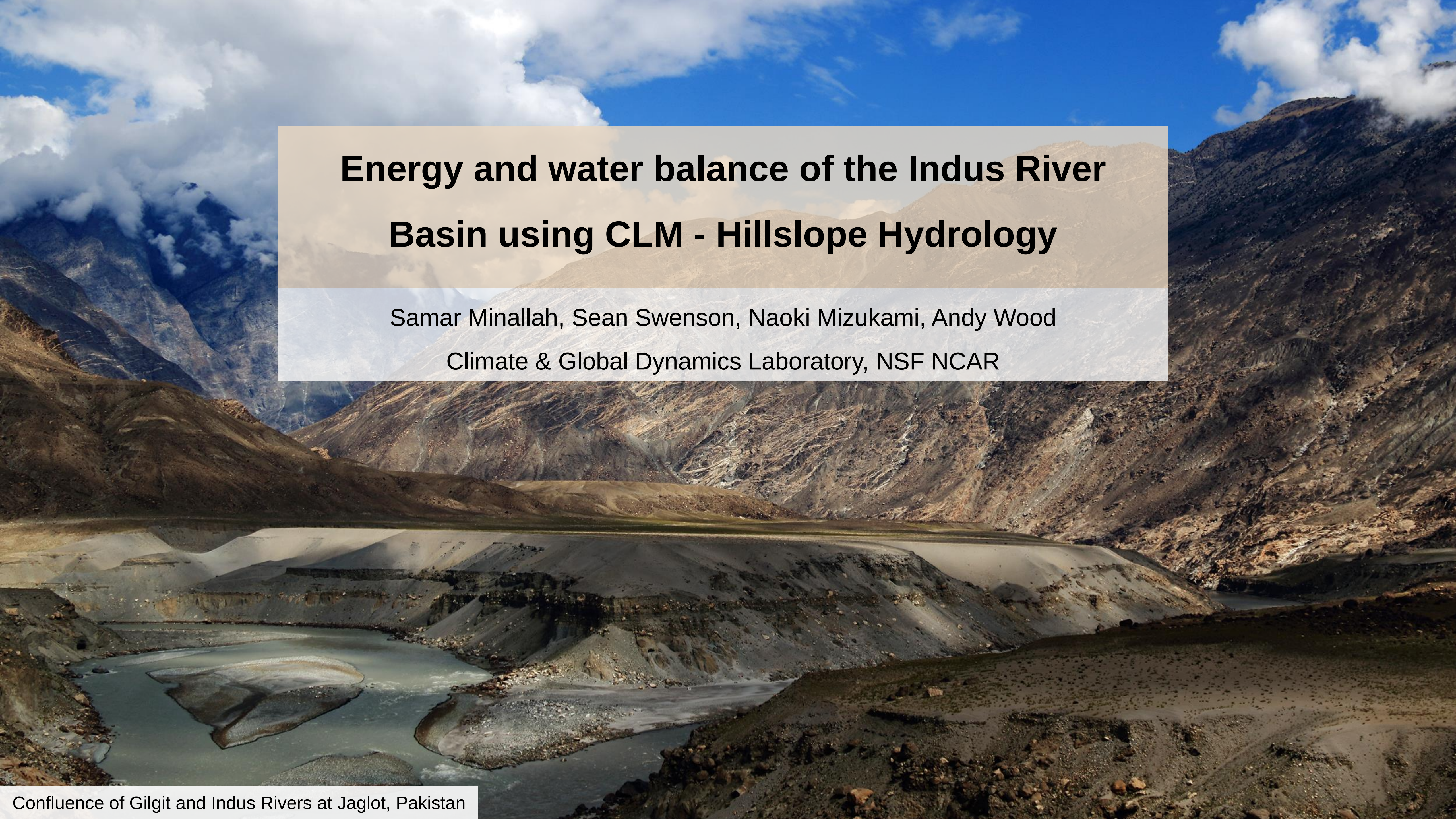
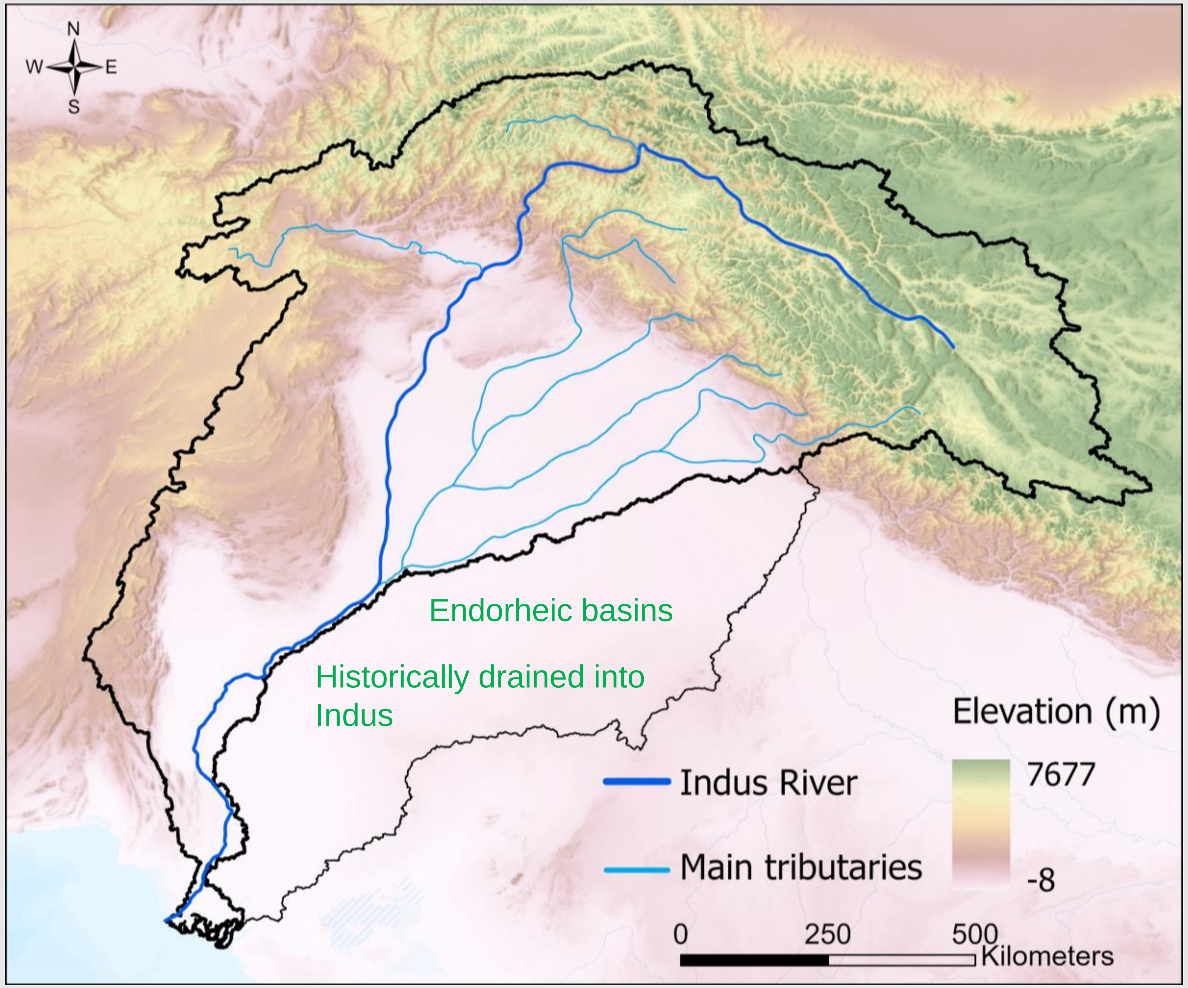


Confluence of Gilgit and Indus Rivers at Jaglot, Pakistan

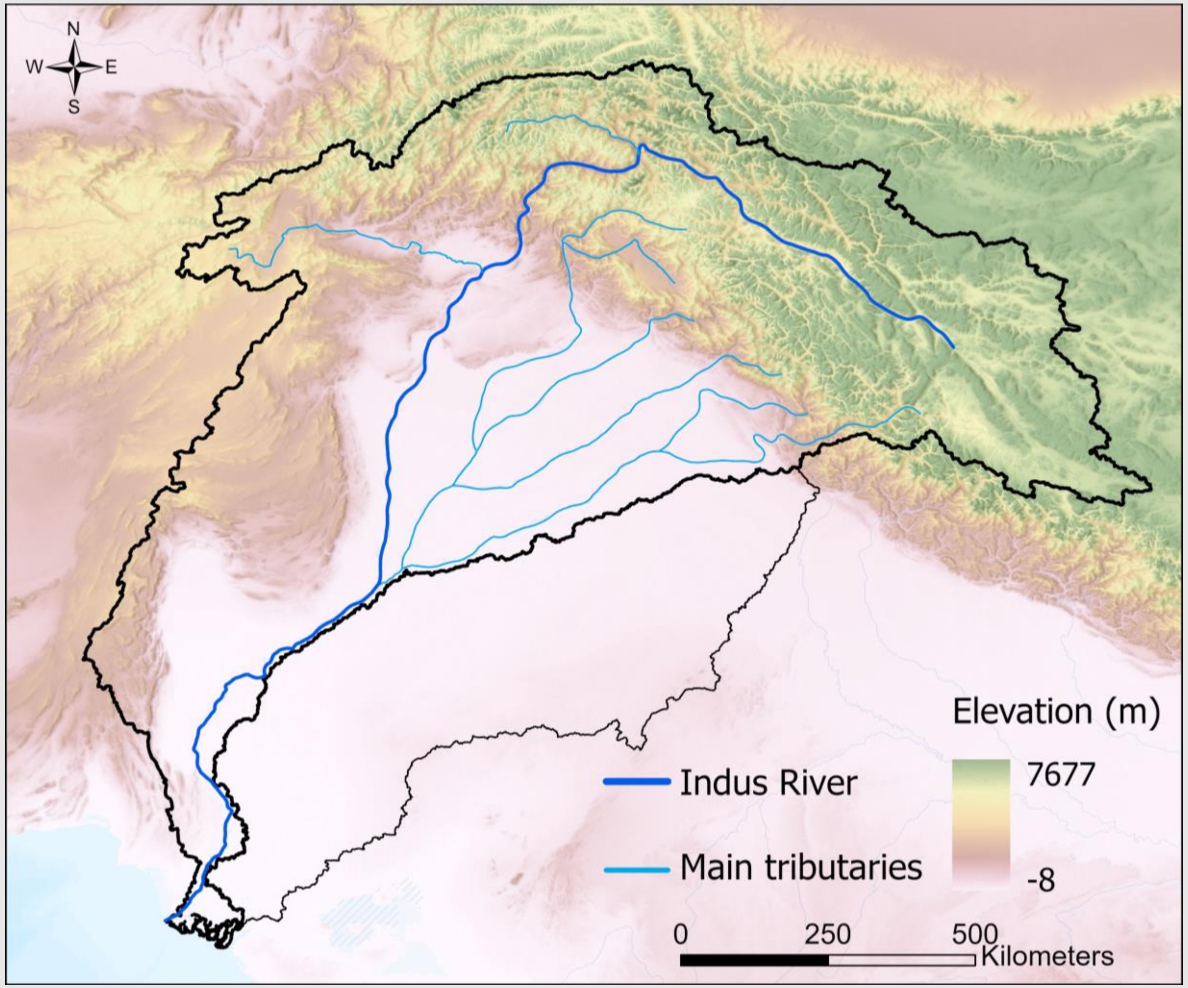
Introduction: Indus basin



Basin area: ~1 million km²

- No consensus on the basin outline
- Historically, southwestern deserts (Thar) were a part of Indus watershed
- Due to climatic shifts over the past 5 millennia and human activities, the Indus watershed diminished

Introduction: Indus hydroclimates

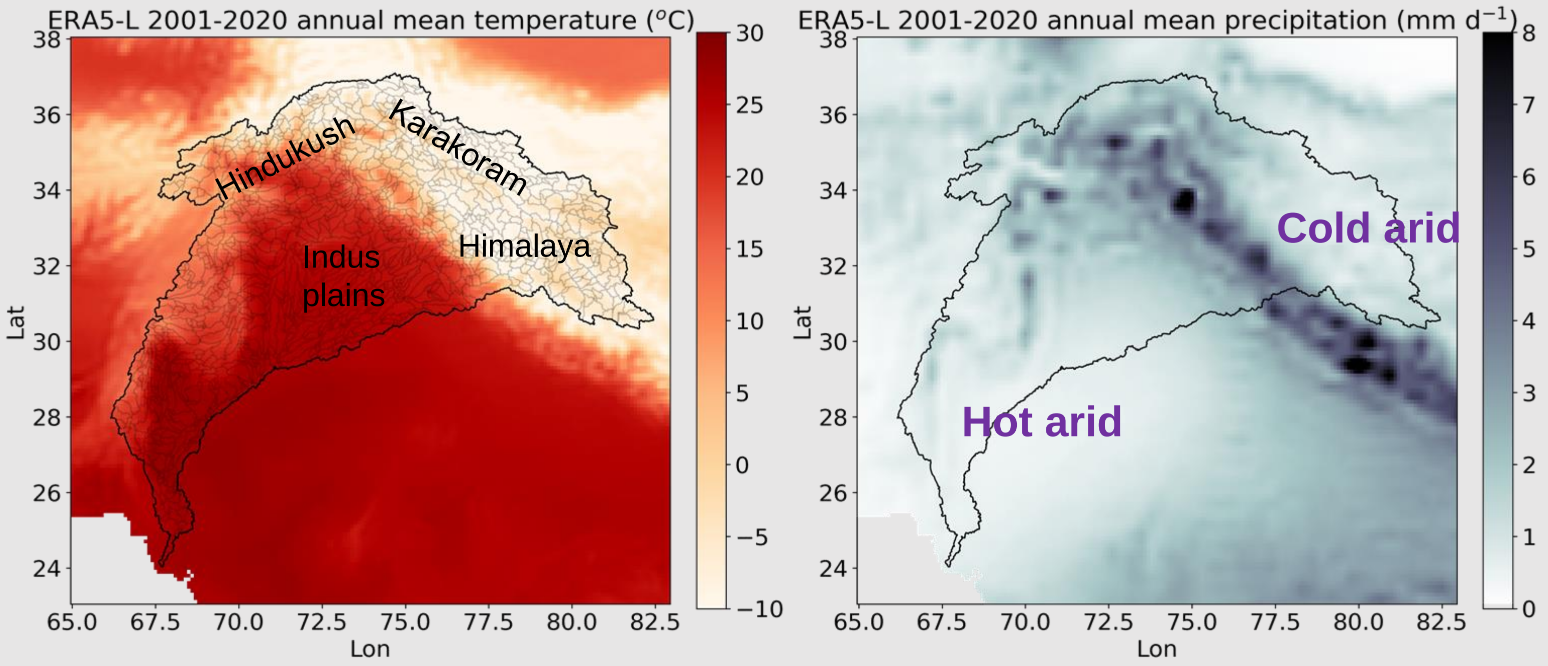


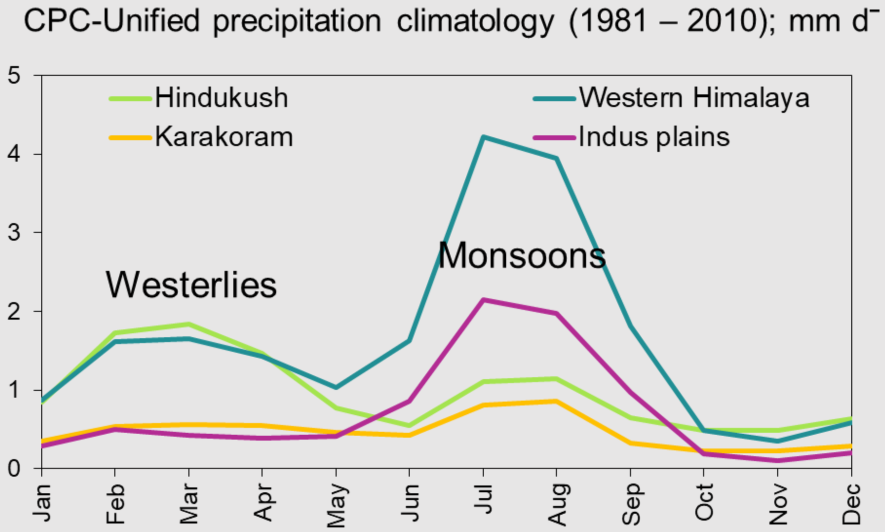
Elevation ranging from ~8600 m to sea level

Hosts various hydroclimates:

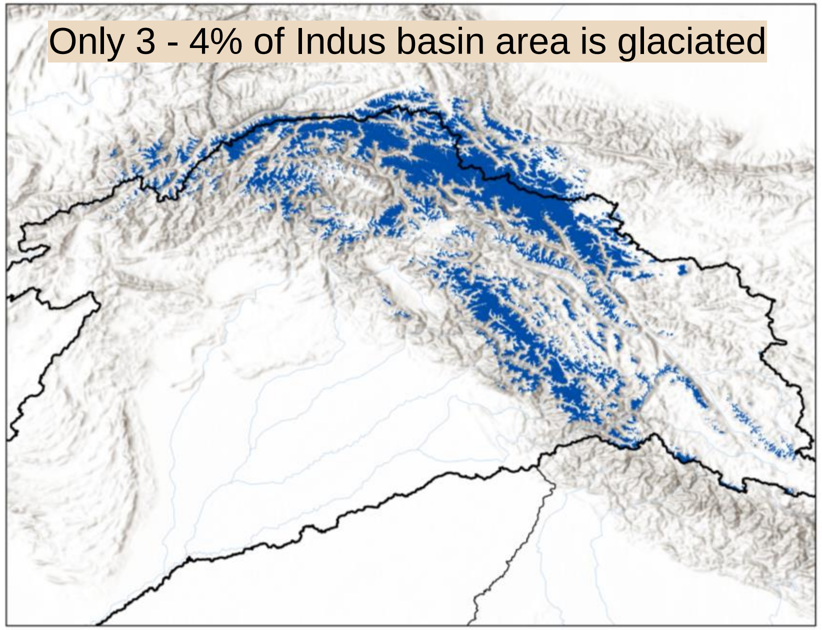
- Highly mountainous, glaciated terrain
- Snow-dominated regions
- Irrigated fertile plains – Monsoon dominated
- Arid highlands
- Hot deserts
- Indus delta (Mangroves)

Introduction: Domain climate

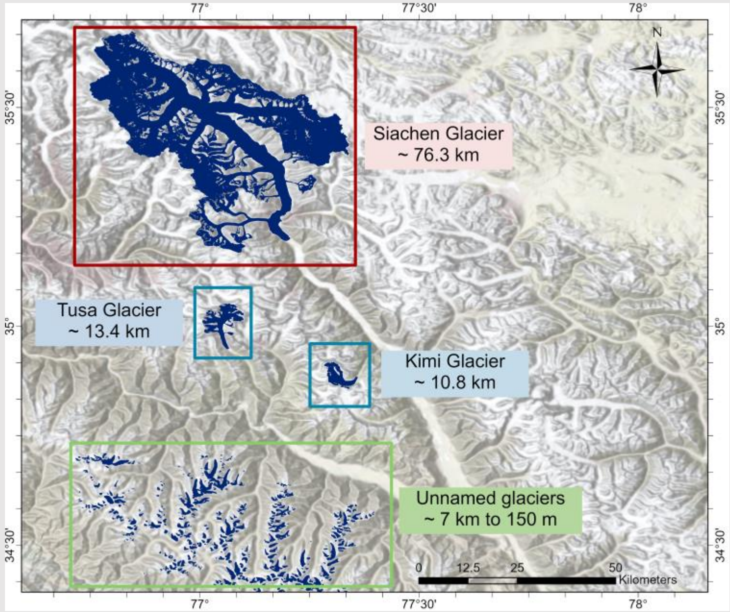




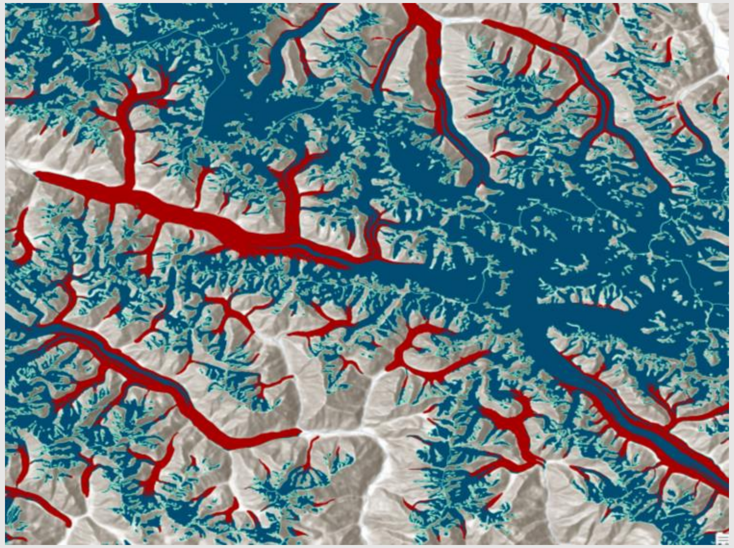
Introduction: Glaciology



	Area (km²)	# of glaciers
RGI v6 glaciers	33,568	27,988
RGI v7 glaciers	33,075	37,562
Debris cover area	3,663	

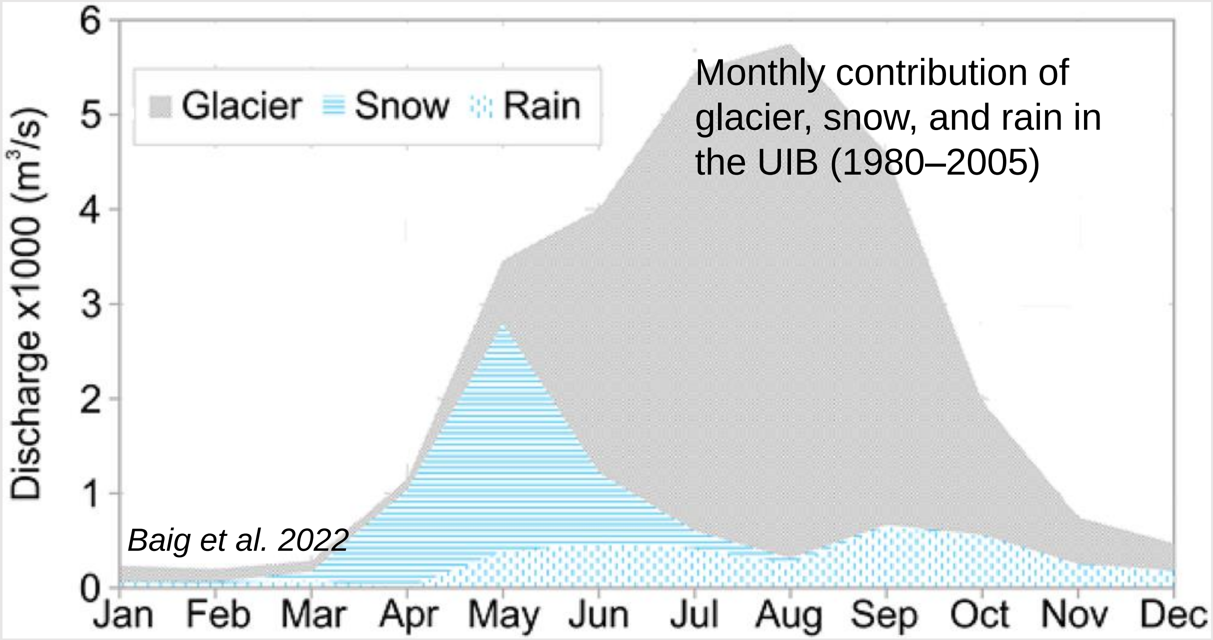


Debris cover over glaciers



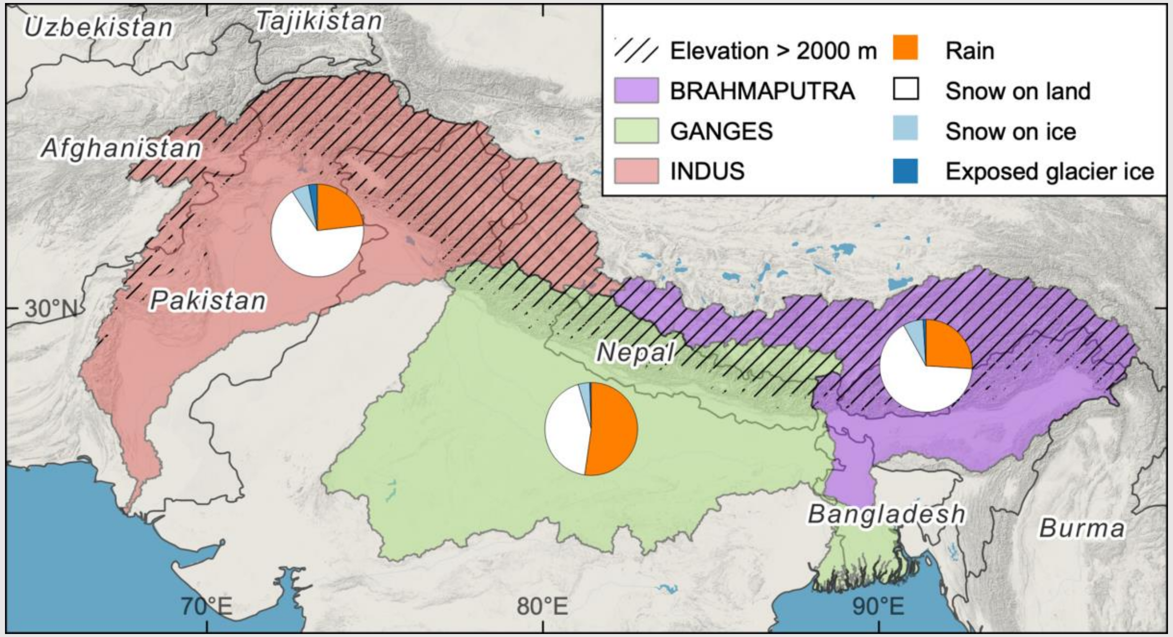
Introduction: River flows

Basin Name	Contribution (%)				Reference
	Snow and Ice	Snow	Glacier	Rainfall	
Upper Indus	72	40	32	–	*Immerzeel et al. 2009*
Upper Indus	>80	–	–	–	*Archer and Fowler 2004*
Indus	–	<50	–	>50	*Bookhagen and Burbank 2010*
From Jeelani et al. 2012					



Monthly contribution of glacier, snow, and rain in the UIB (1980–2005)

Baig et al. 2022



Gascoin 2023, adapted from *Armstrong et al. 2018*

Spring – early summer: Snowmelt

Summer: Glacier melt

Late summer: Monsoons

Study objectives

Characterizing the Indus hydroclimatic regimes

Using CLM - Hillslope Hydrology - mizuRoute model, we are assessing:

1. The terrestrial energy and water budgets
2. Seasonal and sub-seasonal runoffs in the tributaries of the Indus River

Indus in a 1.5° warmer world

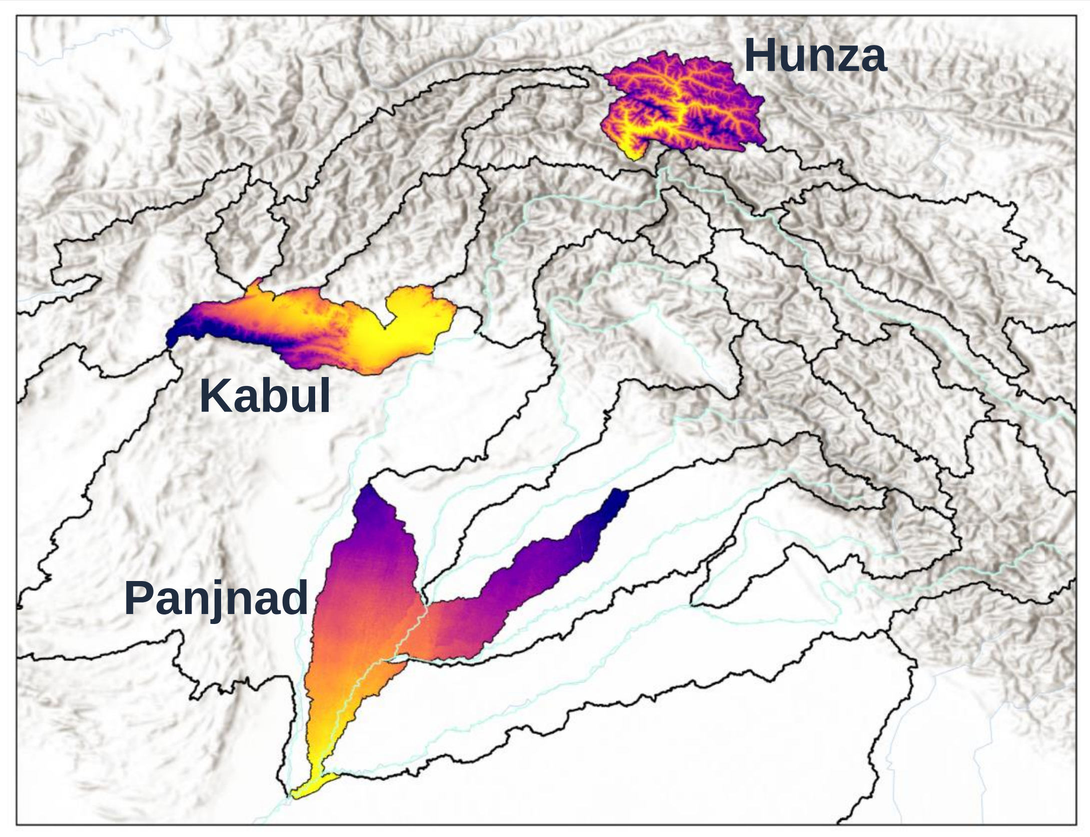
- Impacts of temperature changes on the regional water resources
- Hydrological tipping points where the dominant drivers of variability and sub-basin characteristics shift to a new state

CTSM – Hillslope Hydrology

- Hillslope Hydrology model in CTSM
  - Currently implemented for soil drainage and vegetation dynamics at sub-grid scale
  - Captures differences between valleys vs hilltops or sunny vs shady slopes

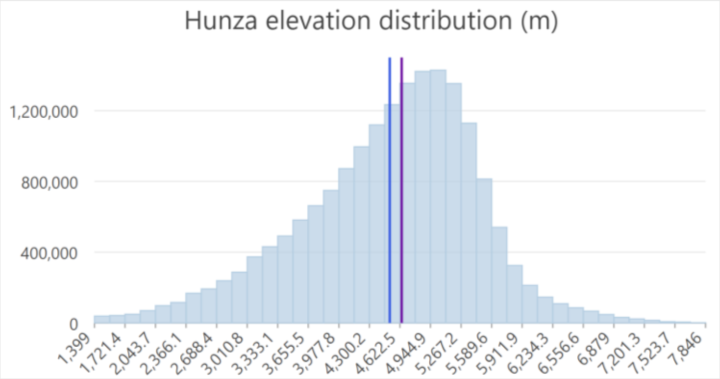
- Adapting the Hillslope model for glacial MB computations
- Inclusion of debris cover

CTSM – Hillslope Hydrology



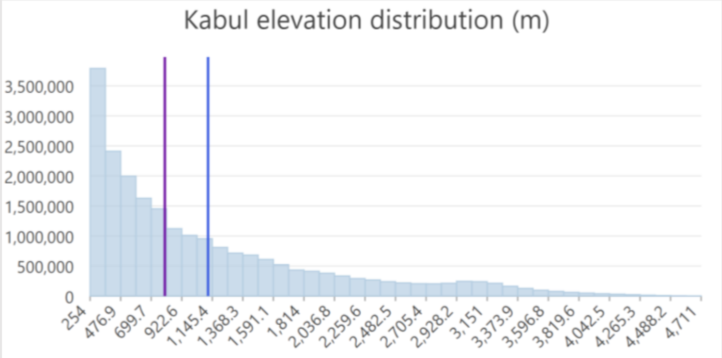
Hunza

Max	7846
Mean	4515
Min	1399



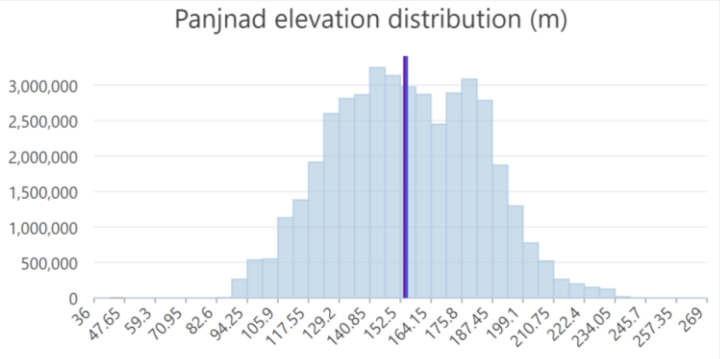
Kabul

Max	4711
Mean	1115
Min	254



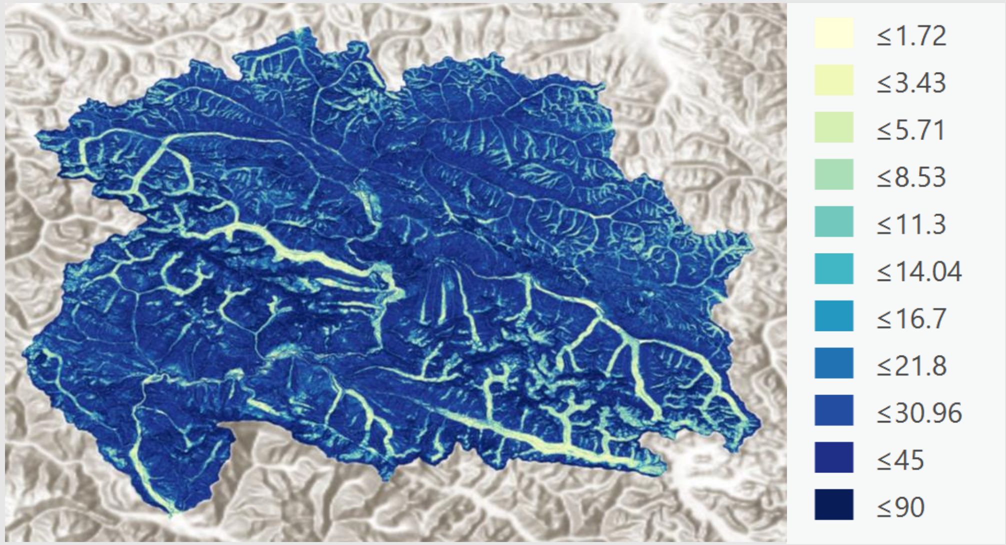
Panjnad

Max	269
Mean	155
Min	36

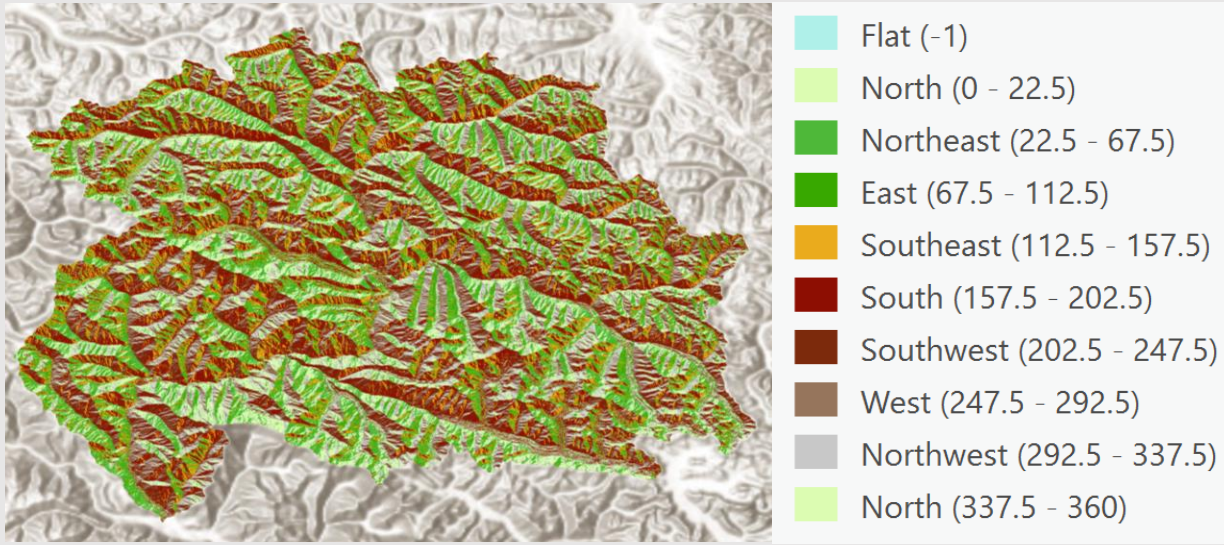


CTSM – Hillslope Hydrology

Slope profile for Hunza watershed



Aspect profile for Hunza watershed

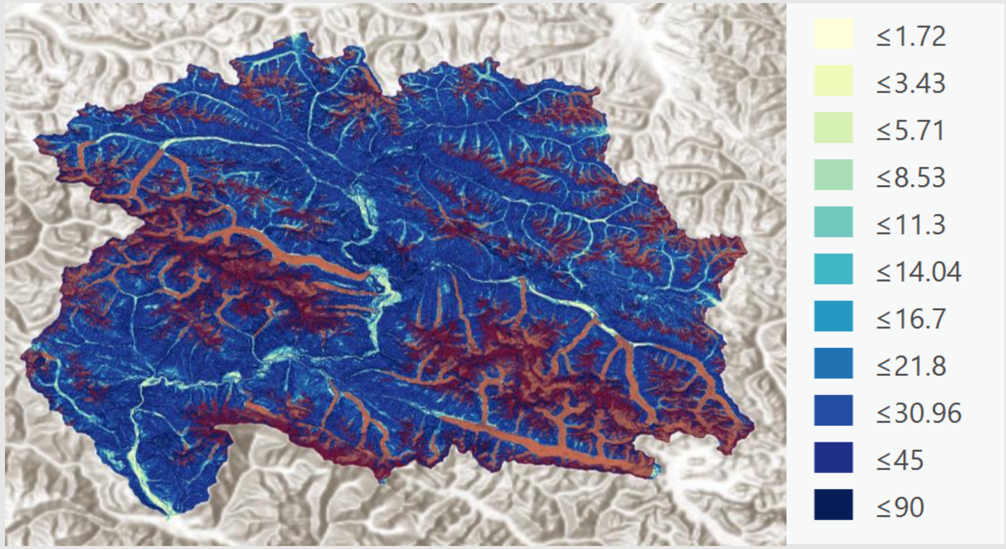


Flow accumulation and drainage patterns

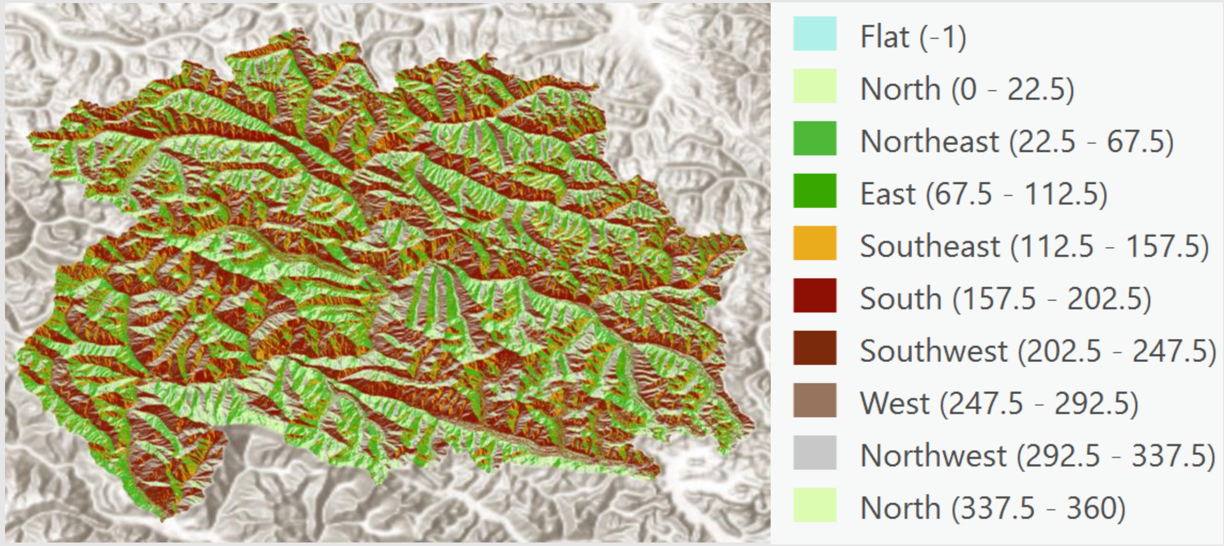
- Snow-covered terrains
- Evolution of valley glaciers: insolation and melt rates

CTSM – Hillslope Hydrology

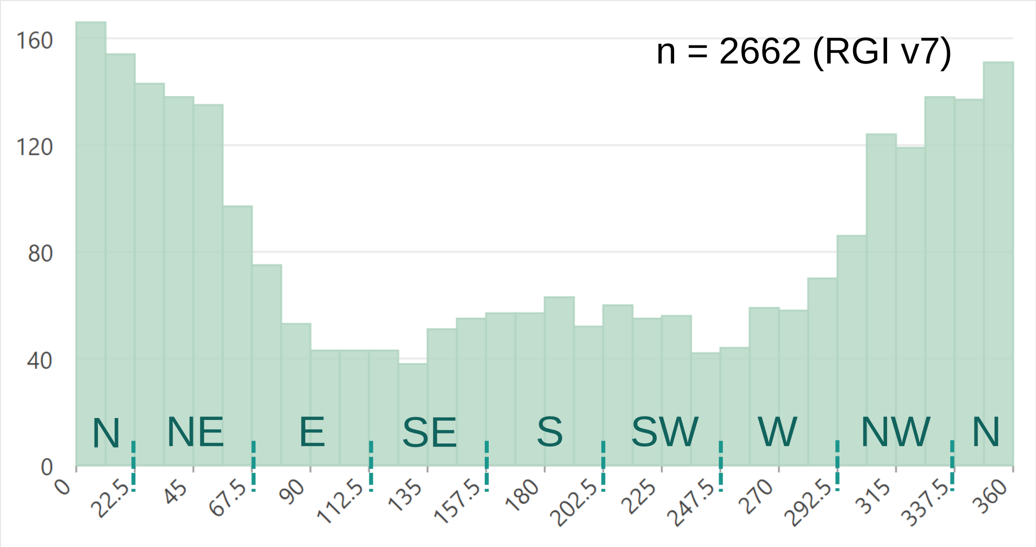
Slope profile for Hunza watershed



Aspect profile for Hunza watershed



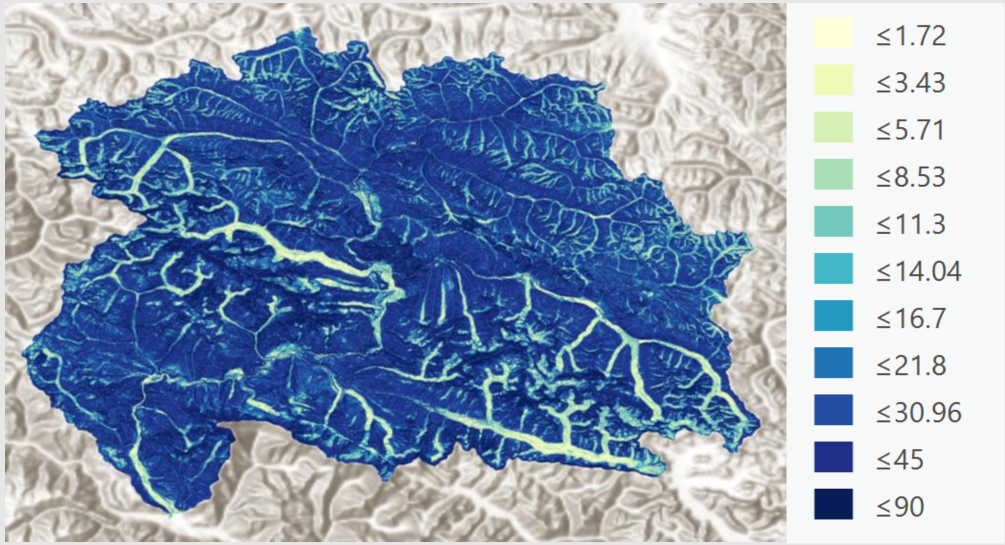
Hunza glacier aspect distribution



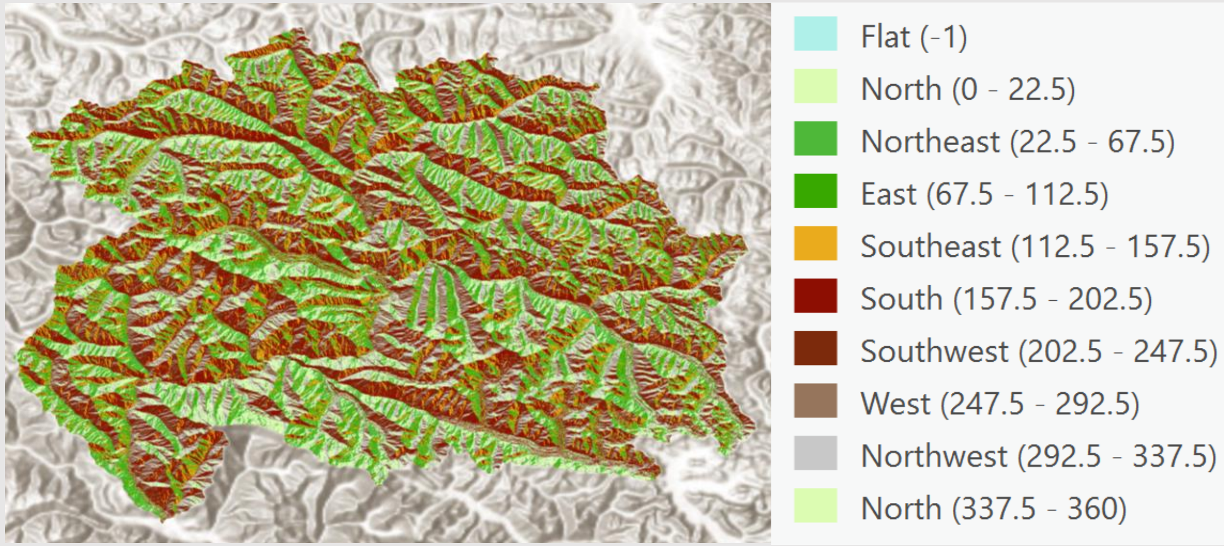
- Most glaciers (60%) on NW-N-NE slope
  24% facing SE-S-SW
- Hunza glaciers are at much higher elevations (> 5200 m)

CTSM – Hillslope Hydrology

Slope profile for Hunza watershed



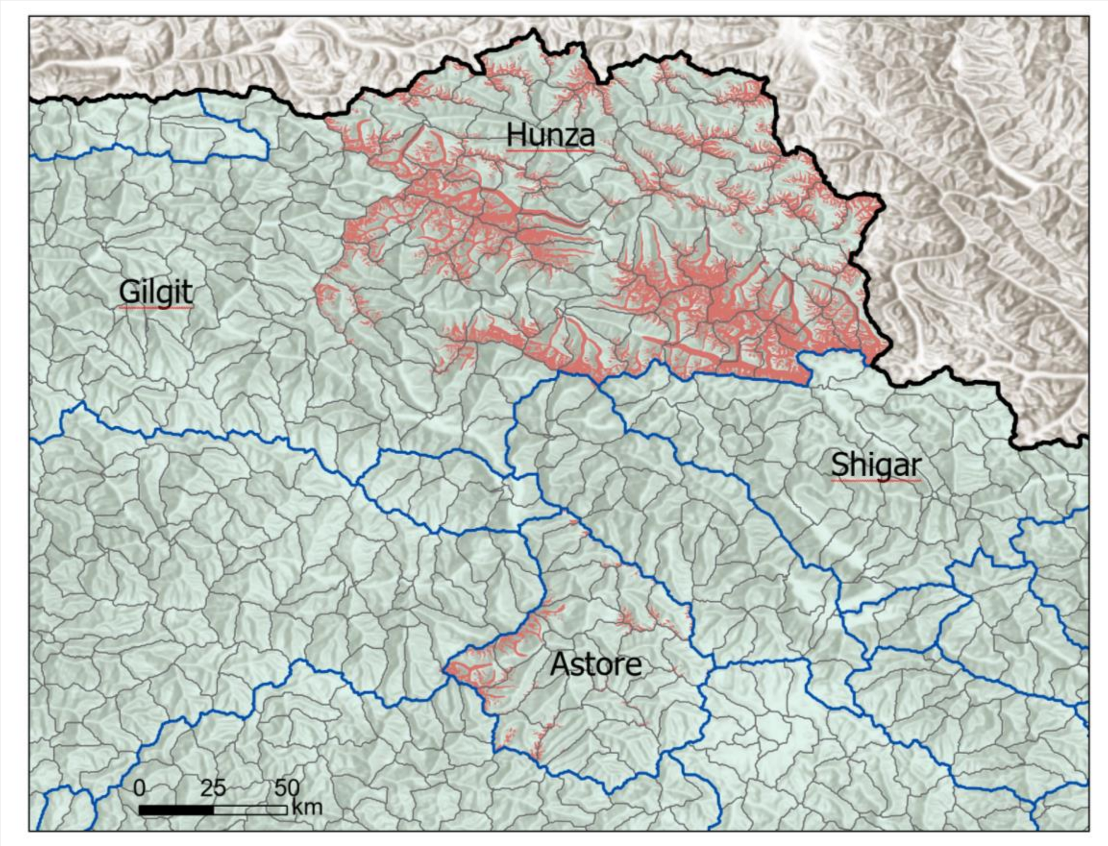
Aspect profile for Hunza watershed



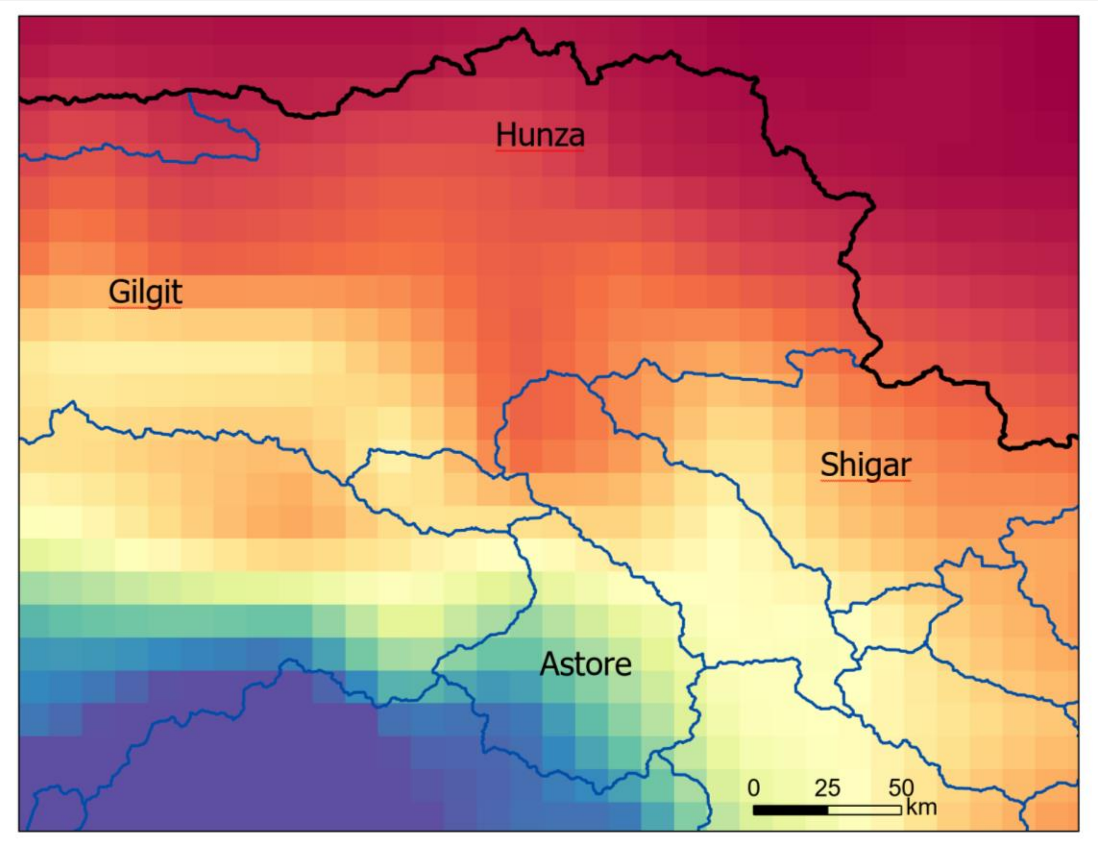
Panjnad watershed

Model domain decisions

HydroBASINS Level 12 (small sub-watersheds)



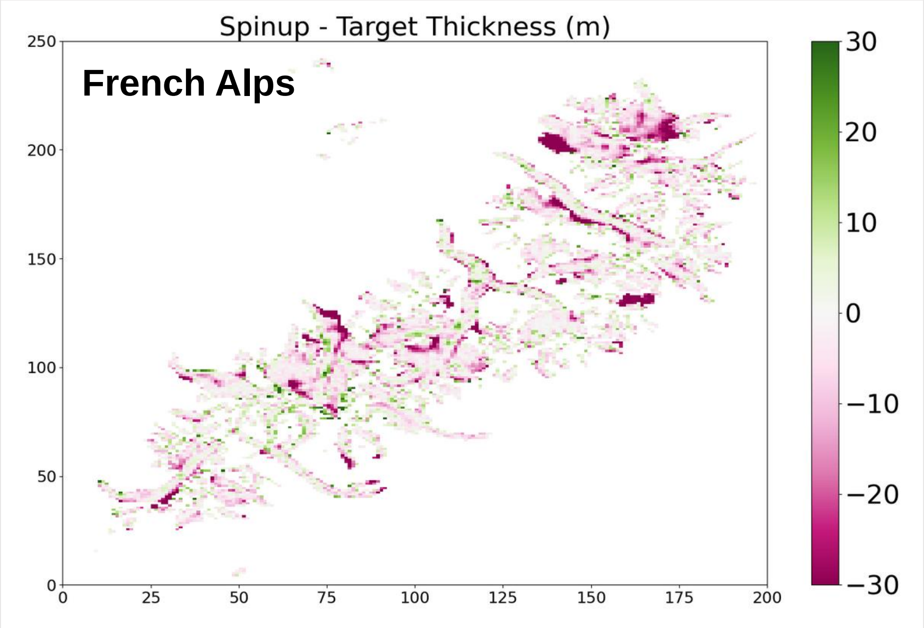
ERA5-Land ~9km grid



- Watershed unit vs rectilinear grid
- Hillslope for sub-grid scale glaciology and hydrology

Future work

- Recently implemented mountain glaciers in the Community Ice Sheet Model (CISM) – the ice dynamics component of CESM
- Found that aspect is important for some glaciated zones



- Model is simulating lower thickness in some regions which correspond with north – northeast facing slopes
- Localized climate allows glacier growth that the model does not capture

- Provide glacier mass balance from CLM-Hillslope to CISM

Questions

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Sentinal-2 false color image of Batura Glacier, Pakistan