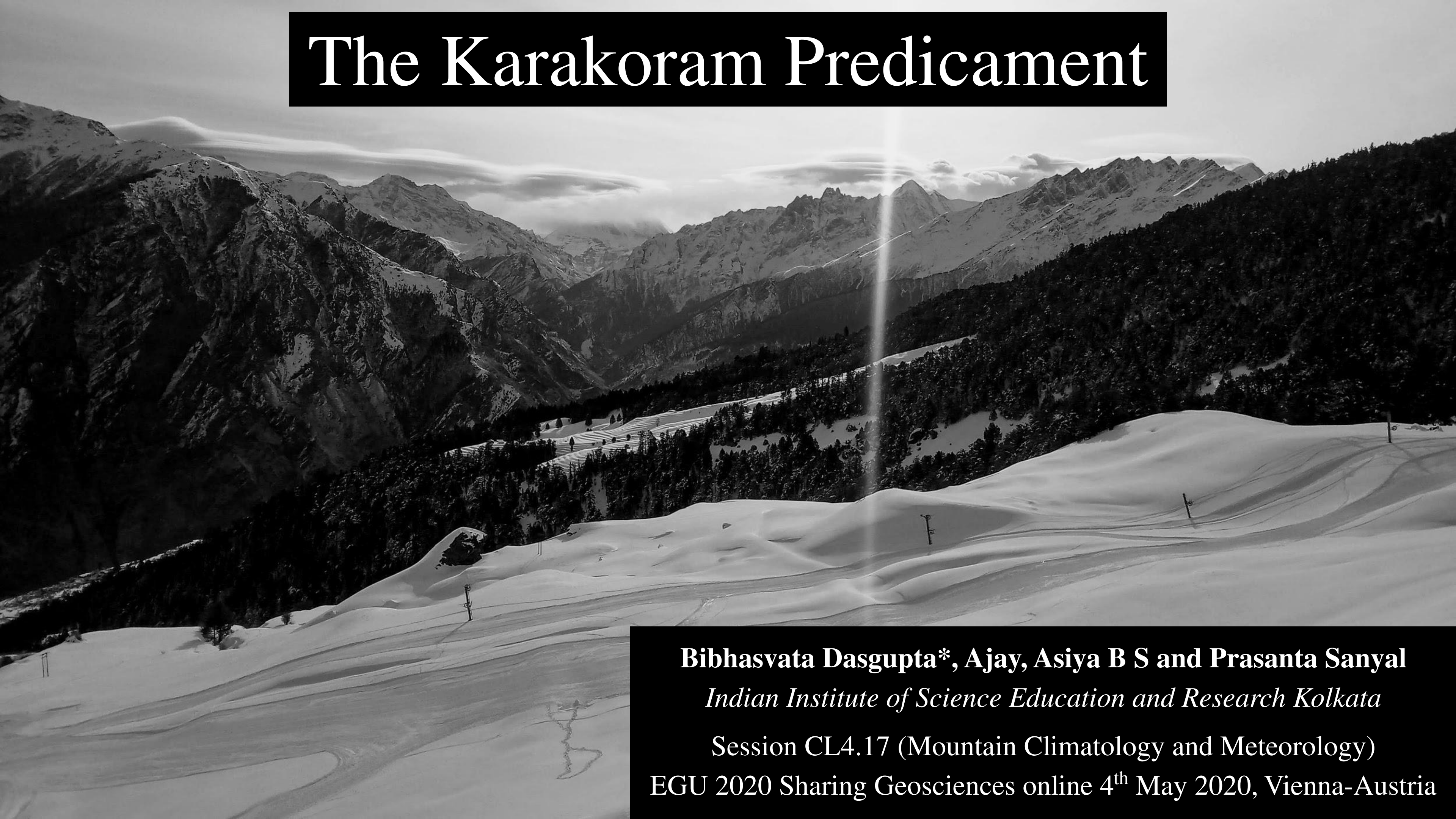

The Karakoram Predicament

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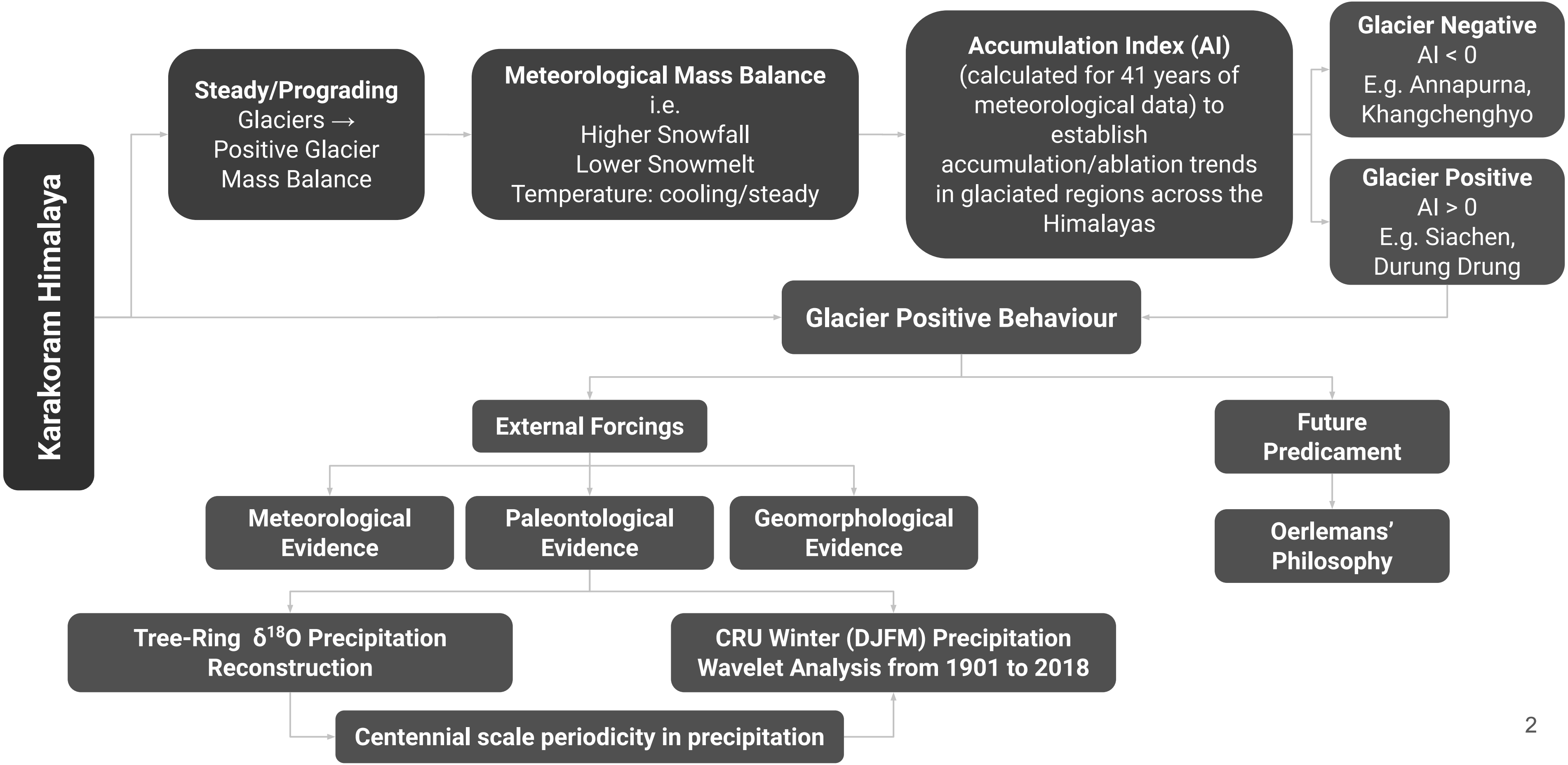
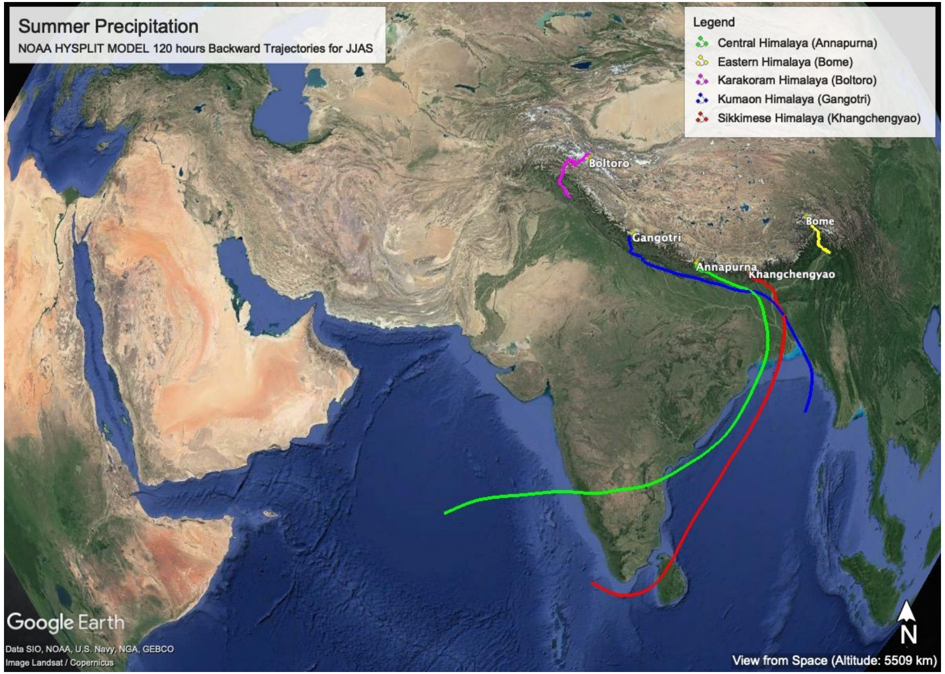
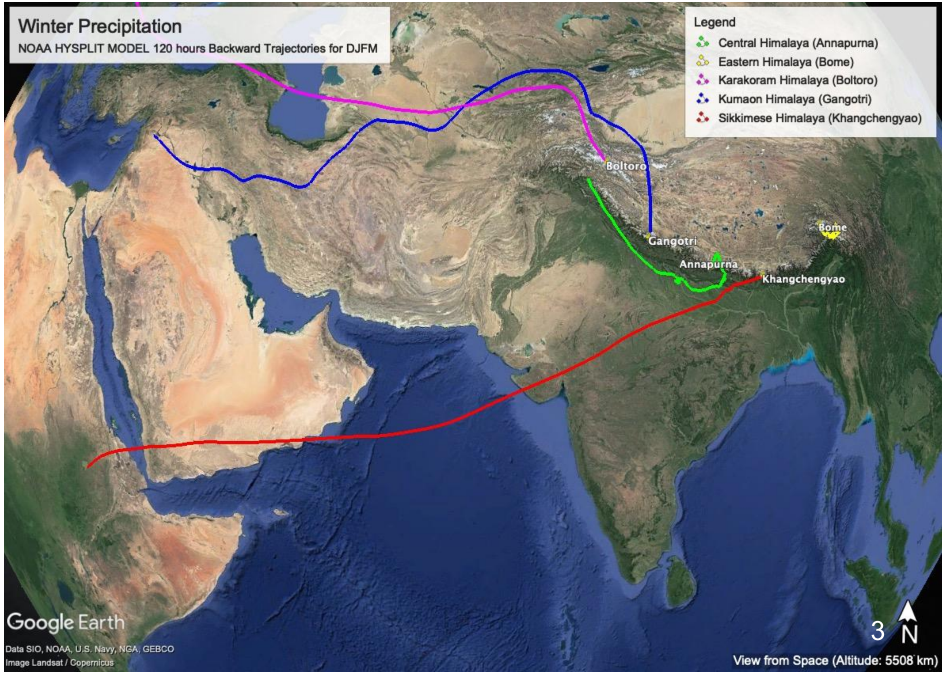
Course of Action



Moisture trajectories and precipitation patterns in the Himalayas

Section of Himalayan (W to E)	Karakoram	Kumaon	Central	Sikkimese	Eastern
Indian Summer Monsoon (JJAS)		✓	✓	✓	
Mid Latitude Westerlies (DJFM)	✓	✓	✓		





Introduction

- The anomalous behaviour of Karakoram Glaciers (Hewitt, 2005) in the backdrop of a warming planet has been a decade long debate baffling climatologists worldwide.
- While a lot of effort has been given to understand this behaviour, very little has been explored with respect to the factors that favour glaciation rates.
- A fundamental approach to glacial mass balance calculation involves an assessment of meteorological mass balance based on snow accumulation and melt.

Meteorological Mass Balance

$$AI = (SF_G - SMLT_A)*(-T_{Ano}) \quad \text{(mm/K/year)}$$

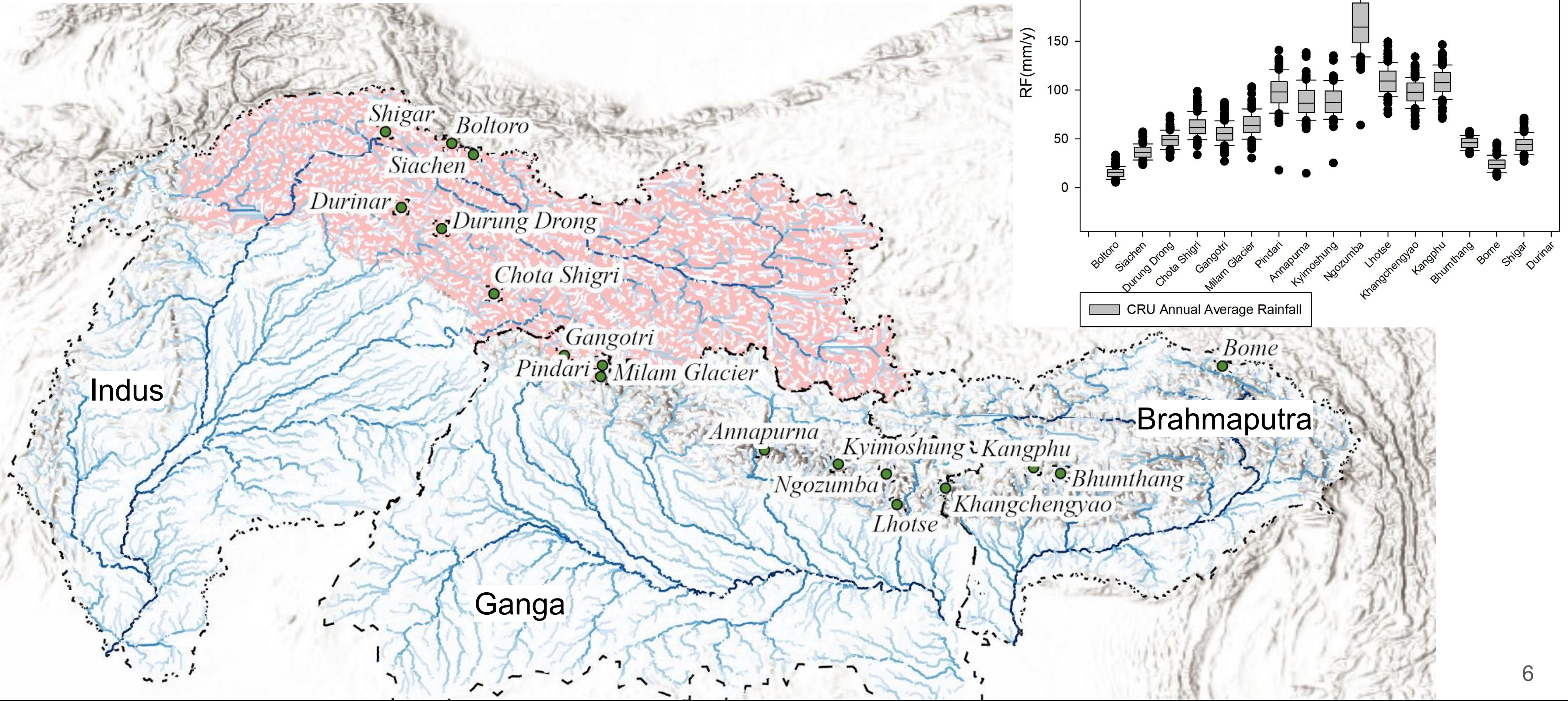
where, AI - **Accumulation Index**

SF_G- Growing Season Snowfall (mm of water equivalent/year)

$SMLT_A$ - Ablation Season Snowmelt (mm of water equivalent/year)

T_{Ano} - Annual Temperature Anomaly (Kelvin^{-1})

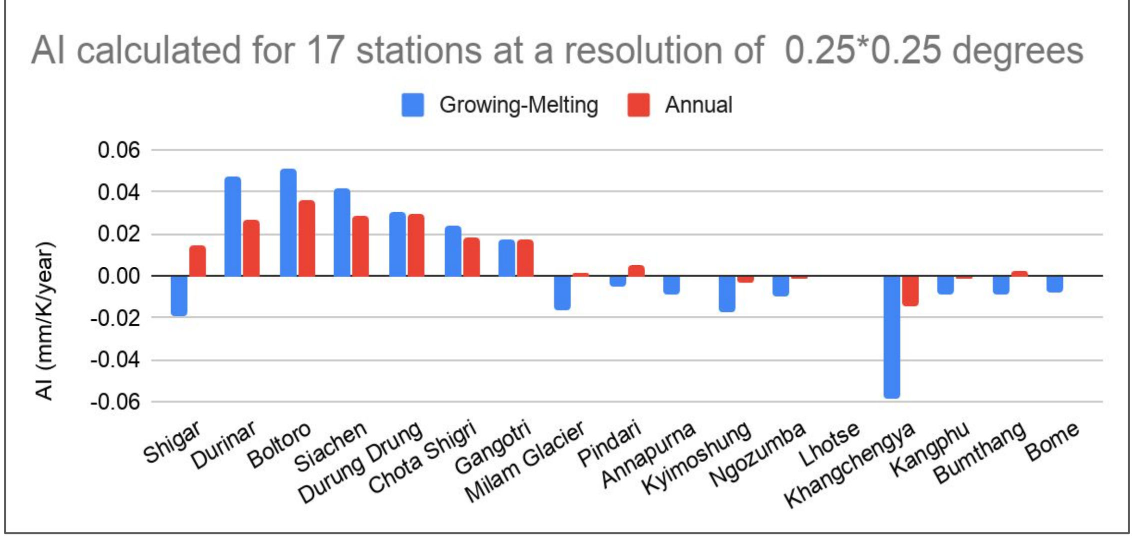
Himalayan Cryosphere



17 Himalayan glaciers were selected for the study and their meteorological variables were analysed

Glacier Positive Stations:

1. Durinar
2. Boltoro
3. Siachen
4. Durung Drung
5. Chota Shigri
6. Gangotri

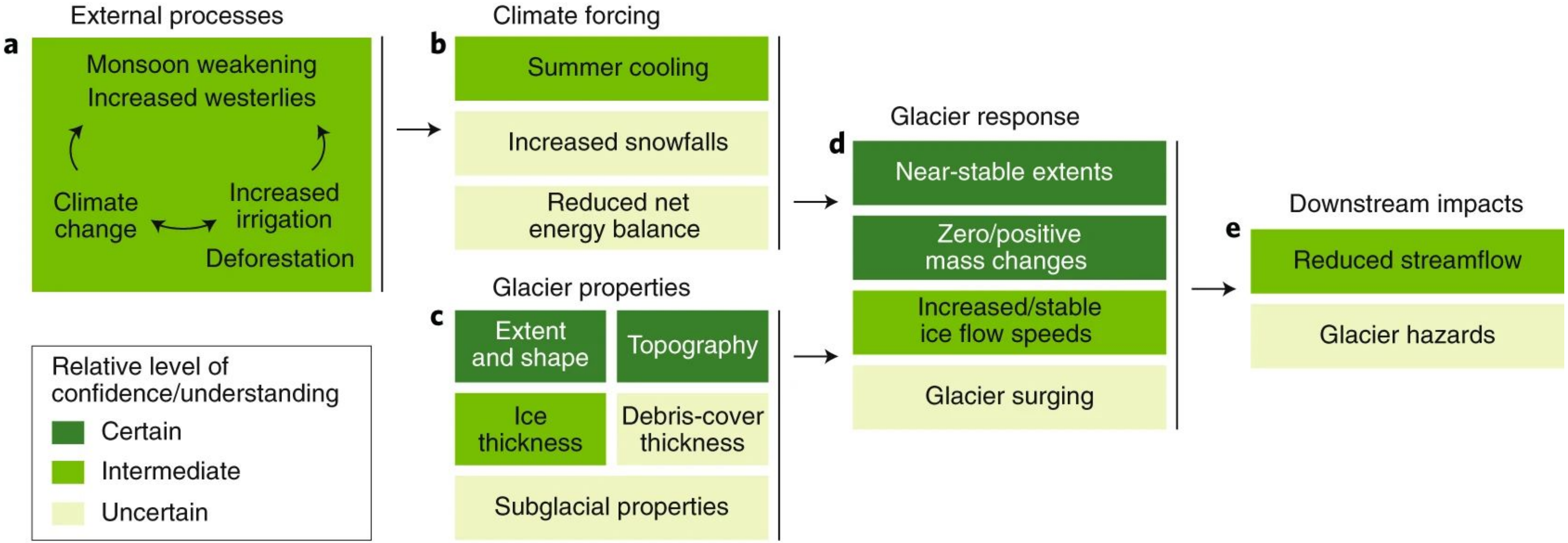


Glacier Negative Stations:

1. Shigar
2. Milam
3. Pindari
4. Annapurna
5. Kyimoshung
6. Ngozumpa
7. Lhotse
8. Khangchengya
9. Kangphu
10. Bumthang
11. Bome

Mean Meteorological Behaviour	Glacier Positive	Glacier Negative
Surface Temperature (K)	263.1 ± 6.4	270.6 ± 6.6
Surface Temperature Anomaly (K^{-1})	-0.8 ± 0.1	-0.5 ± 0.2
Snowfall (mm/m)	3.8 ± 1.0	2.4 ± 1.0
Snowmelt (mm/m)	2.0 ± 1.5	3.5 ± 1.5
AI (mm/K/y)	+0.04 ± 0.01	-0.01 ± 0.01

1. Meteorological Evidence: Strengthening Westerlies/Weakening Monsoons

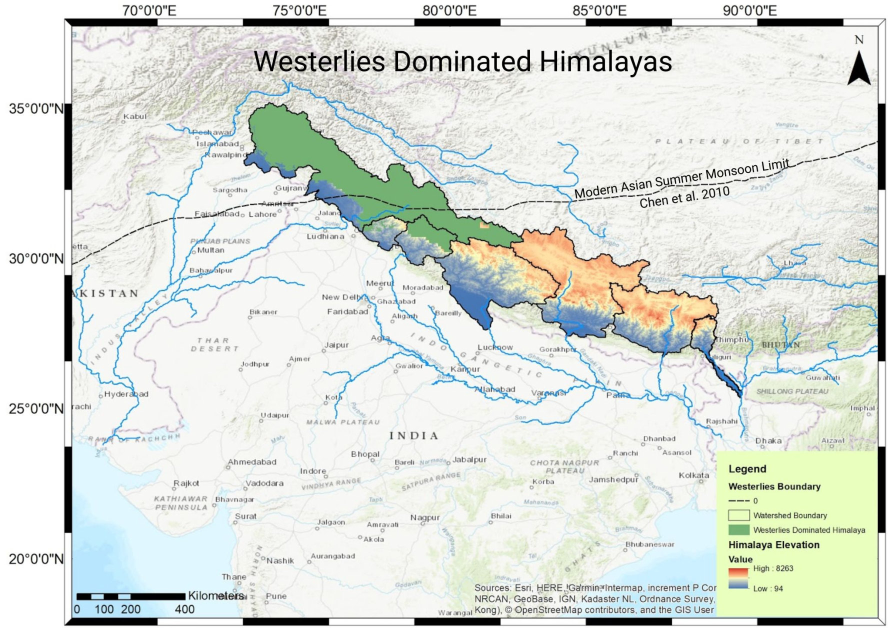


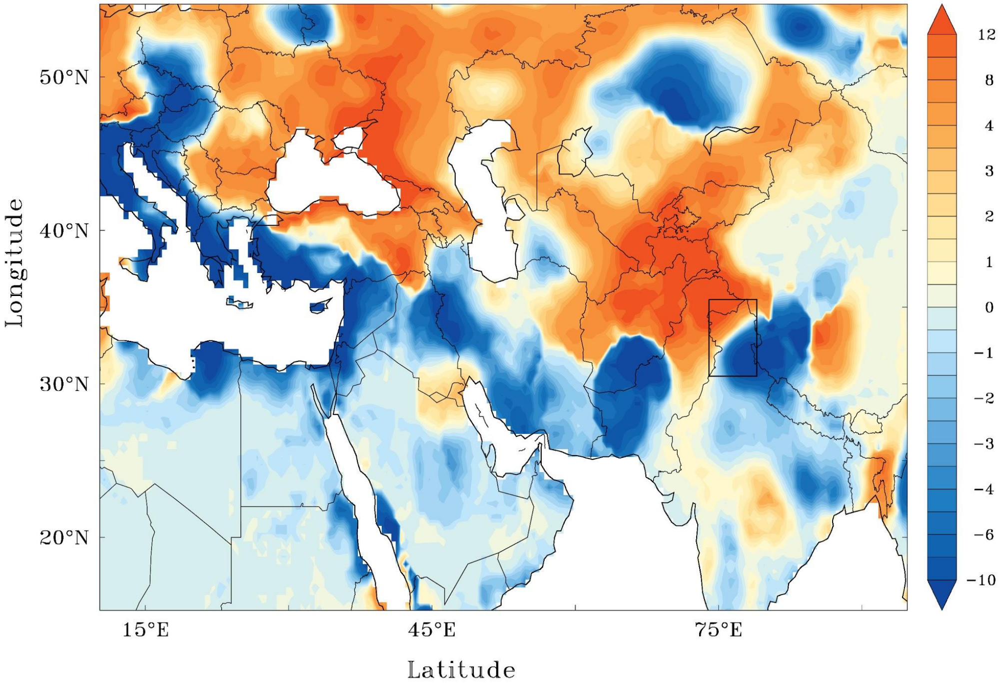
a) External processes. b) Climate forcing. c) Glacier properties. d) Glacier response. e) Downstream impacts. For every element, a relative level of confidence in its characterization or understanding is indicated by the colour shading.

Farinotti et al, 2020; Nature Geosciences

Glacier Positive behaviour in the Karakoram Region

1.1 Strengthening Westerlies





1. Extent of Westerlies precipitation in the region

(Established via paleo-reconstruction studies & GLIMPSE)

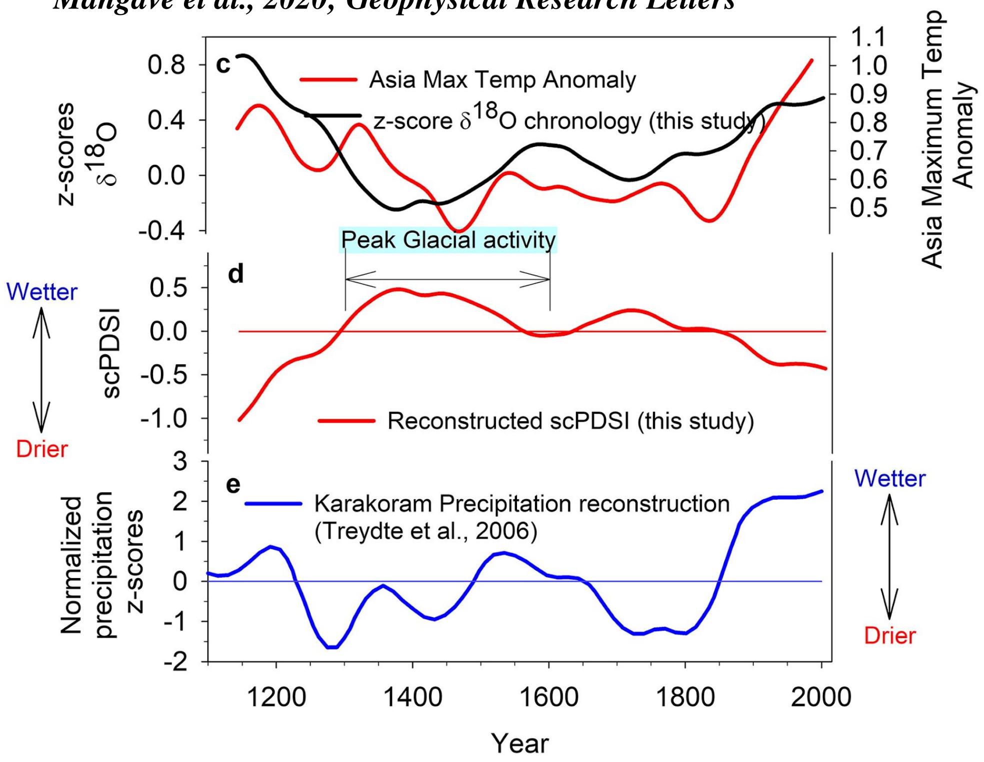
2. Increasing winter-time precipitation trend in Karakoram

(CRU DJFM 1901-2018; mm/464 months)

Glacier Positive behaviour in the Karakoram Region

2. Palaeontological Evidence: Tree Ring Paleoreconstruction

Mangave et al., 2020; Geophysical Research Letters

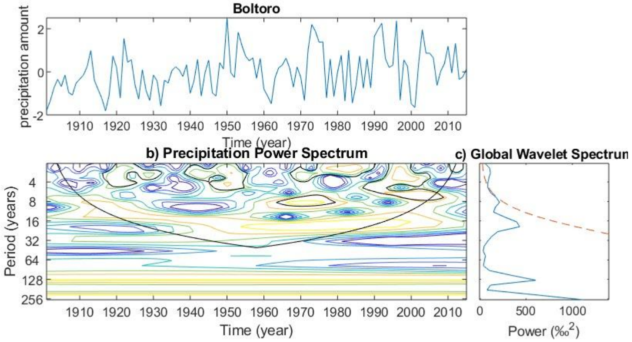


Several independent studies on Himalayan paleoclimate from Tree Ring $\delta^{18}O$ precipitation-reconstruction have reported centennial-scale climate variability.

Treydte (2006) concurred stronger hydrological conditions from lower $\delta^{18}O$ values in the Karakoram region post 1850 CE, as a result of which the region is witnessing increasing winter precipitation paired with decreasing summer temperatures for the given period.

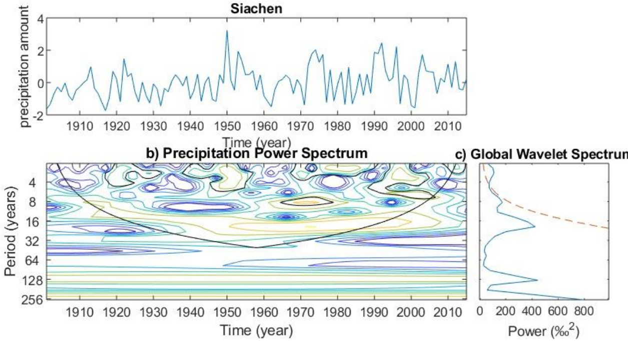
Glacier Positive behaviour in the Karakoram Region

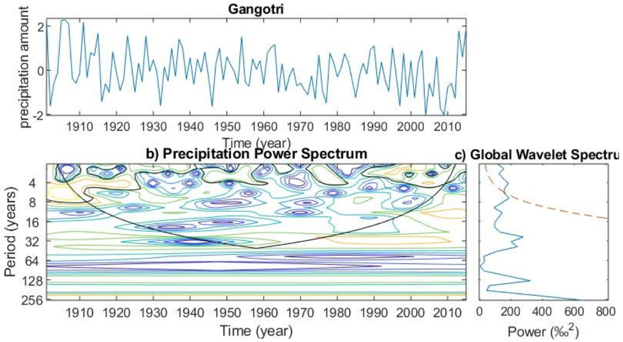
2.1 Centennial scale periodicity (wavelet transform)

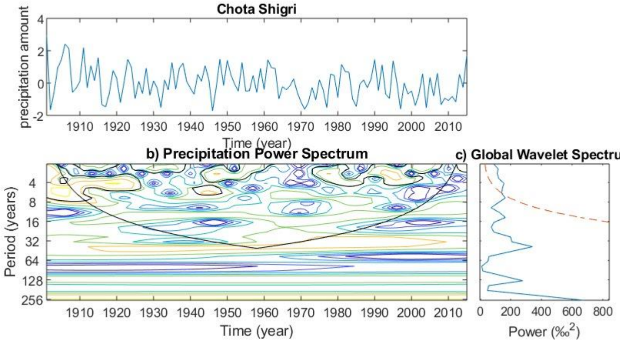


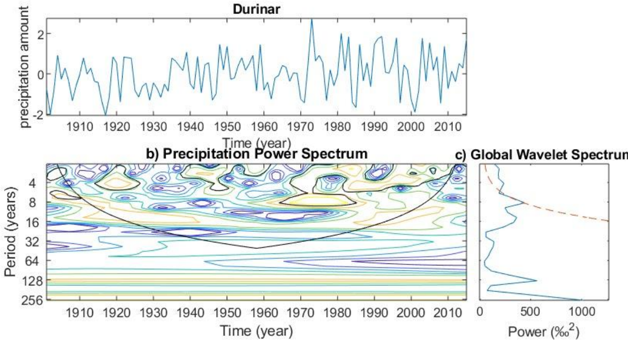
128-256 year periodicity observed in winter (DJFM) precipitation in Glacier Positive stations:

- Boltoro and Siachen (Karakoram)
- Durinar, Chota Shigri and Gangotri (Non-Karakoram)









Caution: CRU precipitation archive provides for 118 years of data. Identifying a 128+ year period from this sample may not be statistically significant. Thus the corresponding amplitudes of the Global Wavelet Spectra lie outside the ‘cone of influence’. However supporting evidence from tree-ring reconstruction provides for a secular judgement. *Absence of evidence is not the evidence of absence.*

Glacier Positive behaviour in the Karakoram Region

3. Geomorphological Evidence: Slope, Aspect and Elevation

The Karakoram glaciers are larger than their central/east Himalayan counterparts and extend over high relief (5-8 km) areas. Precipitation at this altitude is orographically controlled due to relief confinement of westerlies moisture. Moreover, the geopotential height of condensation ensures that the entire moisture influx occurs as snowfall. Despite this high relief, slope within the glacier catchment is considerably lower compared to the remaining areas of High Mountain Asia. At the same time, the mean direction of descent for the glaciers is SW, which allows limited sunlight exposure in the summer months when the angle of zenith is 158 degrees (SSE). Gentle slopes allow greater accumulation of snow while shorter daylight hours help impede snowmelt rates. Debris cover on the glacier surface has been known to provide thermal insulation and reduce ablation.

Mean Geomorphological Behaviour	Karakoram	Glacier Negative
Slope (°)	10.2 ± 0.2	16.8 ± 4.7
Aspect (Cardinal Direction)	SW	S, SE, SSE
Elevation of Accumulation Zone (km)	5.8 ± 0.2	4.5 ± 1.1

Concerns: how rising temperatures can change the trend.

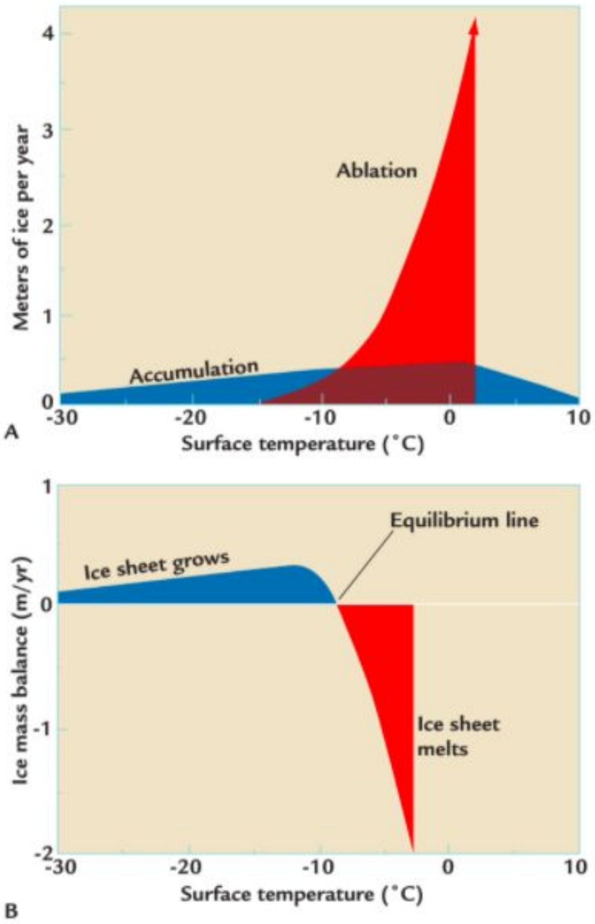
Oerlemans' Philosophy

Temperature is the main factor that determines whether ice sheets are in a regime of net ablation or accumulation.

A. Ice accumulates (initially as snow) at mean annual temperatures below 10℃, but rates of accumulation remain below 0.5 m of ice per year regardless of temperature.

B. The mass balance turns sharply negative at temperatures above -10℃ because ablation accelerates and overwhelms accumulation. The boundary between positive and negative mass balance is called the equilibrium line.

Modified from J. Oerlemans, "the role of ice sheets in the pleistocene climate"



Future Predicament

The Karakoram glaciers still lie in the accumulation range of Oerlemans' mass balance curve (2019: T_{mean}=-16.8℃; T_{max}=-5.1℃), while most of the Central and East Himalayan cryosphere is crossing over to the ablation range. Temperature fluctuations of a few degrees would be sufficient to push the Karakoram Cryosphere in the ablation range. And once ablation succeeds accumulation rates, it is unlikely that the concerned glaciers will revert back to the accumulation range.

References

1. Chen, F.H., Chen, J.H., Holmes, J., Boomer, I., Austin, P., Gates, J.B., Wang, N.L., Brooks, S.J. and Zhang, J.W., 2010. Moisture changes over the last millennium in arid central Asia: a review, synthesis and comparison with monsoon region. Quaternary Science Reviews, 29(7-8), pp.1055-1068.
2. Farinotti, D., Immerzeel, W.W., de Kok, R.J., Quincey, D.J. and Dehecq, A., 2020. Manifestations and mechanisms of the Karakoram glacier Anomaly. Nature Geoscience, 13(1), pp.8-16.
3. GLIMPSE - GLobal Isoscape Mapping and Precipitation Simulation Experiment
4. Hewitt, K., 2005. The Karakoram anomaly? Glacier expansion and the ‘elevation effect,’Karakoram Himalaya. Mountain Research and Development, 25(4), pp.332-340.
5. Managave, S., Shimla, P., Yadav, R.R., Ramesh, R. and Balakrishnan, S., 2020. Contrasting centennial‐scale climate variability in High Mountain Asia revealed by a tree‐ring oxygen isotope record from Lahaul‐Spiti. Geophysical Research Letters.
6. Oerlemans, J.O.H.A.N.N.E.S., 1991. The role of ice sheets in the Pleistocene climate. Norsk Geologisk Tidsskrift, 71, pp.155-161.
7. Treydte, K.S., Schleser, G.H., Helle, G., Frank, D.C., Winiger, M., Haug, G.H. and Esper, J., 2006. The twentieth century was the wettest period in northern Pakistan over the past millennium. Nature, 440(7088), pp.1179-1182.


Thank You

Notes:

Slide 1

This work provides a holistic assessment of the Karakoram Anomaly in the context of its fellow Himalayan glaciers.

Slide 3

Note: Understanding the Precipitation systems which bring moisture to these regions.

Slide 5

Step 1: Quantify Karakoram and Karakoram like behaviour (positive glacier mass balance) in the Hindu Kush Himalaya

Slide 7

Step 2: Calculate AI for the 17 locations i.e. 0.25x0.25 degree boxes and categorize them as (1) Glacier positive and (2) Glacier Negative (Smaller grids do not include entire glaciated region; Larger grid homogenizes the local meteorological signal)

Slide 8

Step 3: Gather evidence for Glacier Positive behaviour from investigation and existing literature:

1. Meteorological
2. Paleontological
3. Geomorphological

Slide 9

Note: GLIMPSE is an ArcGIS based algorithm which characterizes the source of moisture for individual watersheds by simultaneous affirmation from independent parameters calculated for individual watersheds:

1. Occurrence of precipitation
2. d-excess of streams
3. $\delta^{18}O_{streams}$

Slide 10

So, if winter precipitation is in fact increasing, when did this begin and how long shall the trend last?

Slide 11

If the nature of precipitation in the region is periodic, the rising arm of the curve (after 1850) can justify the increase in precipitation and help us predict future variability.

Slide 13

Future of the anomaly: How rising temperatures can change the trend.