Holistic overview of the climate change induced hazards in High Mountains

Debris flows and glacial lakes in the current and future climate

Varvara (Varya) Bazilova

Supervisors: Tjalling de Haas, Walter Immerzeel

PhD Progress report Seminar (BegCom)

27.02.2024

Christoff Andermann
@ChrisAndermann

Lete Kali Gandaki hydrology station hit by Mustang landslide dam lake outburst flood #LLOF this morning. Maybe it is still recording 🤔 ? I am operating this station since 2012 @GFZ_Potsdam

WIRED

Glacial Lakes Threaten Millions in a Warming World

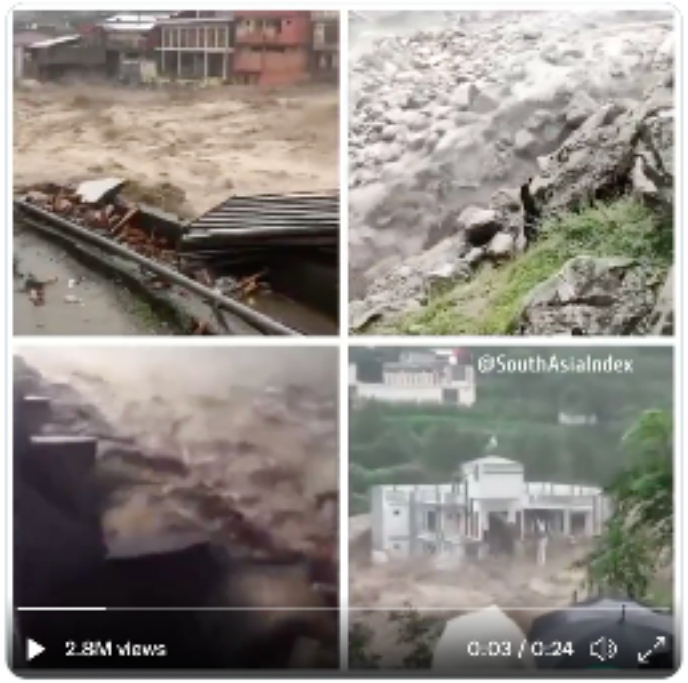
A Himalayan lake fed by melting ice just released a devastating flood in northern India. Thousands of other unstable lakes are getting bigger every year.

Colin McCarthy @US_Stormwatch · Aug 30

Hard to comprehend the scale of the **flood** disaster in Pakistan, the 5th most populated nation in the world.

Nearly 1400 dead, 1 million houses damaged or destroyed, and 50,000,000 people displaced.

1/3 of the country is underwater.



NBC NEWS

Himalayan glacial lake flooding kills 14 and leaves more than 100 missing in India

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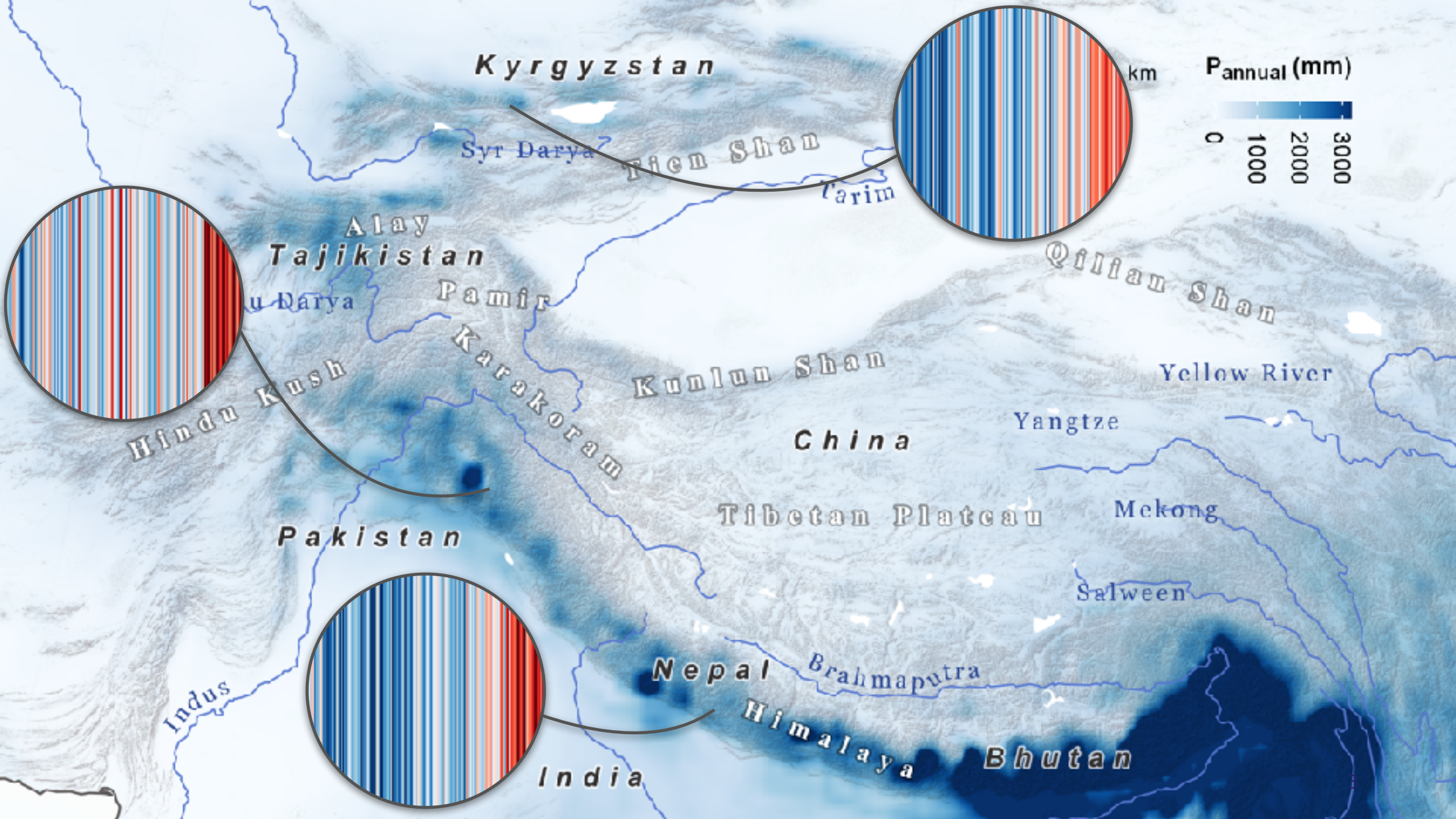
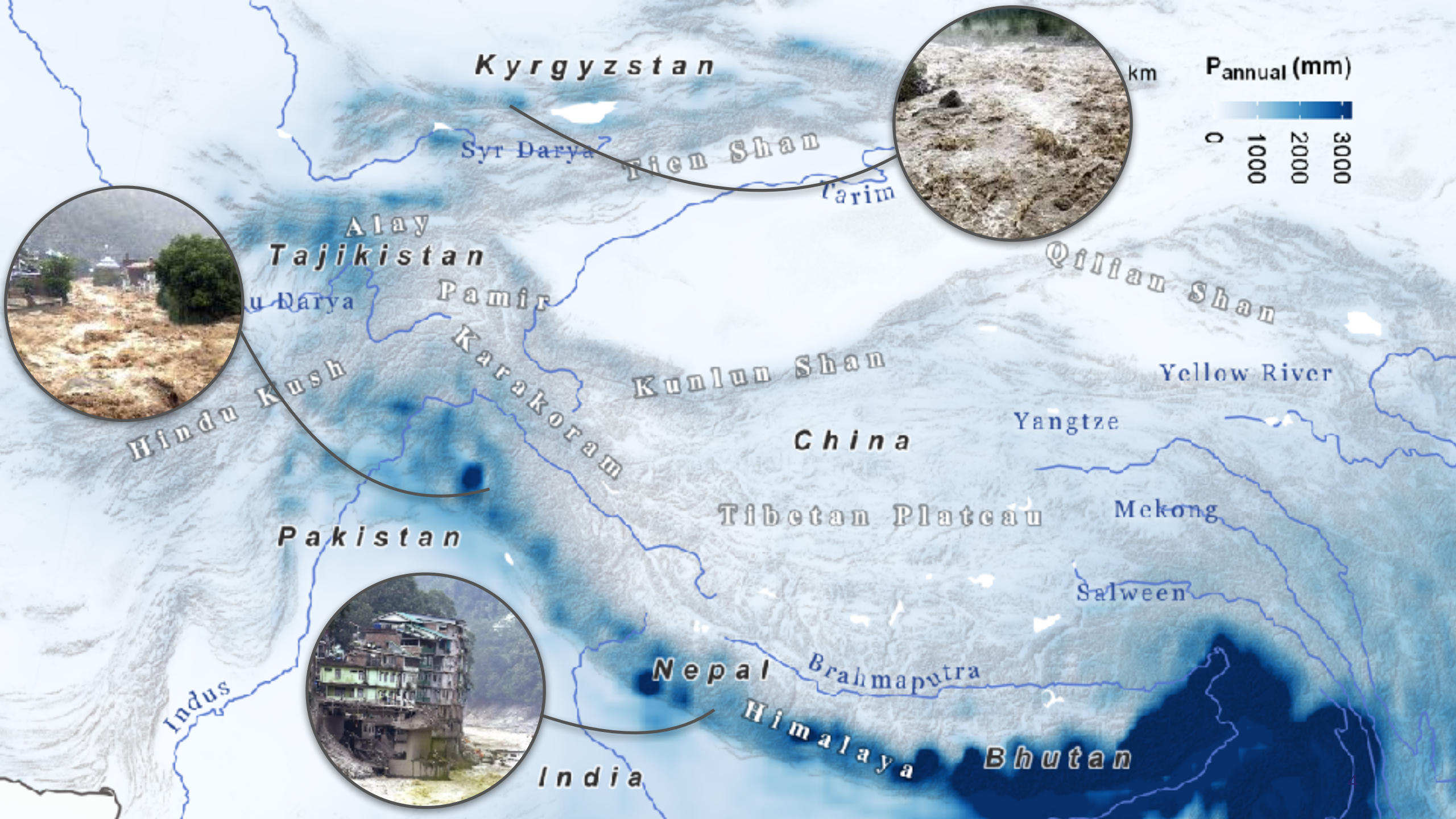
Authorities said the bursting of Lhonak Lake in Sikkim state affected 22,000 people in the latest deadly weather event in South Asia's mountains to be blamed on climate change.


Kyrgyzstan
km
Pannual (mm)
0
1000
2000
3000
Syr Darya
Tien Shan
Tarim
Alay
Tajikistan
u Darya
Pamir
Karakoram
Hindu Kush
Qilian Shan
Kunlun Shan
Yellow River
China
Yangtze
Tibetan Platcau
Mekong
Pakistan
Salween
Nepal
Brahmaputra
Himalaya
Bhutan
Indus
India


Kyrgyzstan
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Mekong
Pakistan
Salween
Nepal
Brahmaputra
Himalaya
Bhutan
Indus
India

- Most types of natural hazards are projected to **change in frequency, magnitude and areas** affected as the cryosphere continues to decline *(high confidence)*.
- Glacier retreat and permafrost thaw are projected to **decrease the stability of mountain slopes** <…> *(high confidence)*. Resulting landslides and floods, and cascading events, will also **emerge where there is no record of previous events** *(high confidence)*.
- The **number and area of glacier lakes has increased** in most regions in recent decades *(high confidence)*, but there is only **limited evidence that the frequency of** glacier lake outburst floods **has changed.**
- At lower elevations < … > climate driven changes such as a **reduction in number of freezing days** are projected to lead to a reduction in debris flows.

IPCC SROCC, 2019

How does climate change and retreat of glaciers affect the hazards and its triggers in High Mountains?

🏔️ Large scale (statistical)
🔍 Small scale (physical)
🥵 Climate change

Debris flow or Flood?
Where are potential hotspots and what are the main drivers?

Paper I.

🏔️

Deglaciation, mountain greening and debris flows:
how does climate change affect the debris flow activity?

Paper II.

🔍🥵

Projections to the future:
how will mass movement hazard change in the next century?
(floods/debris flows/GLOFs)

🏔️🥵

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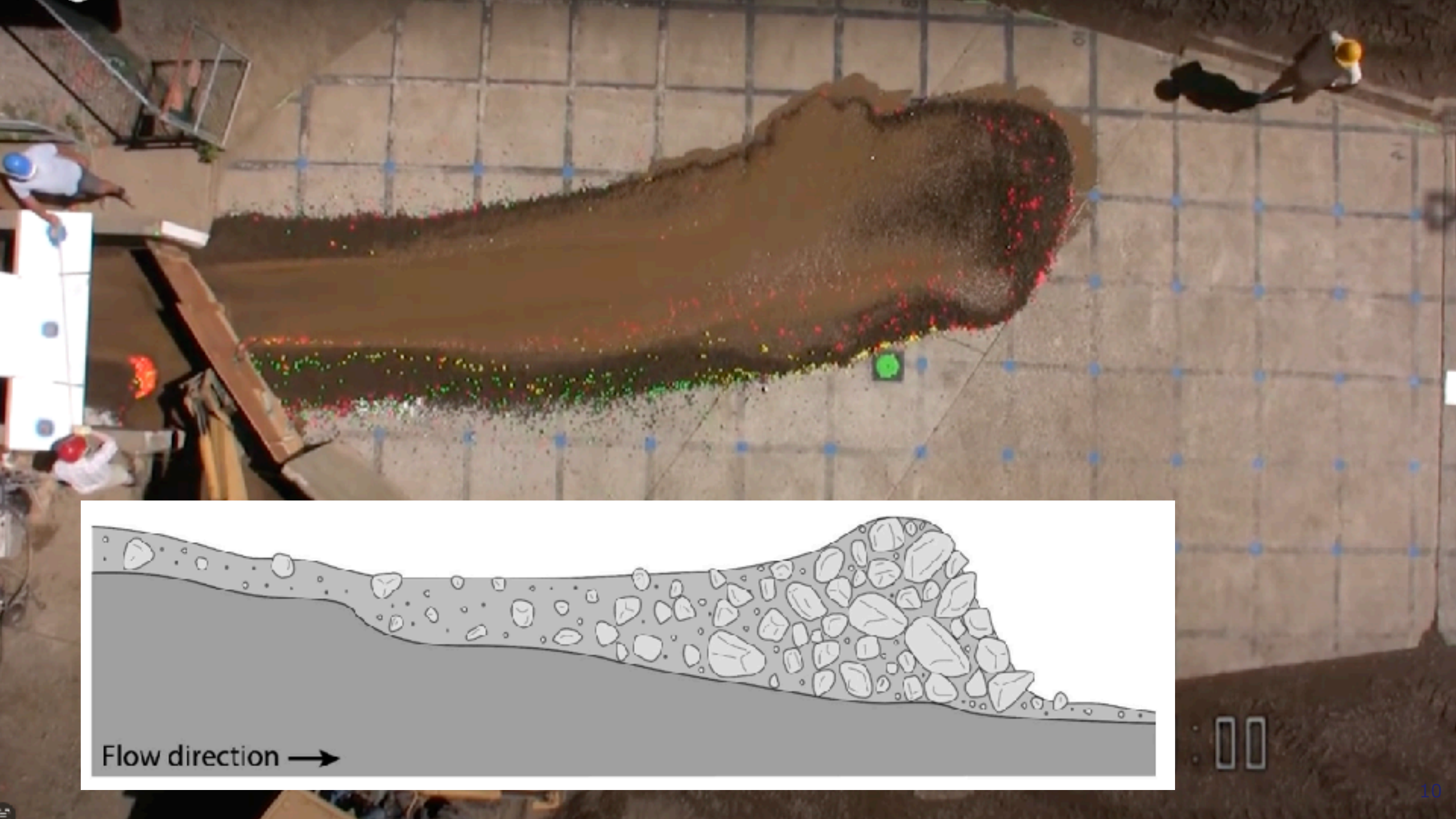
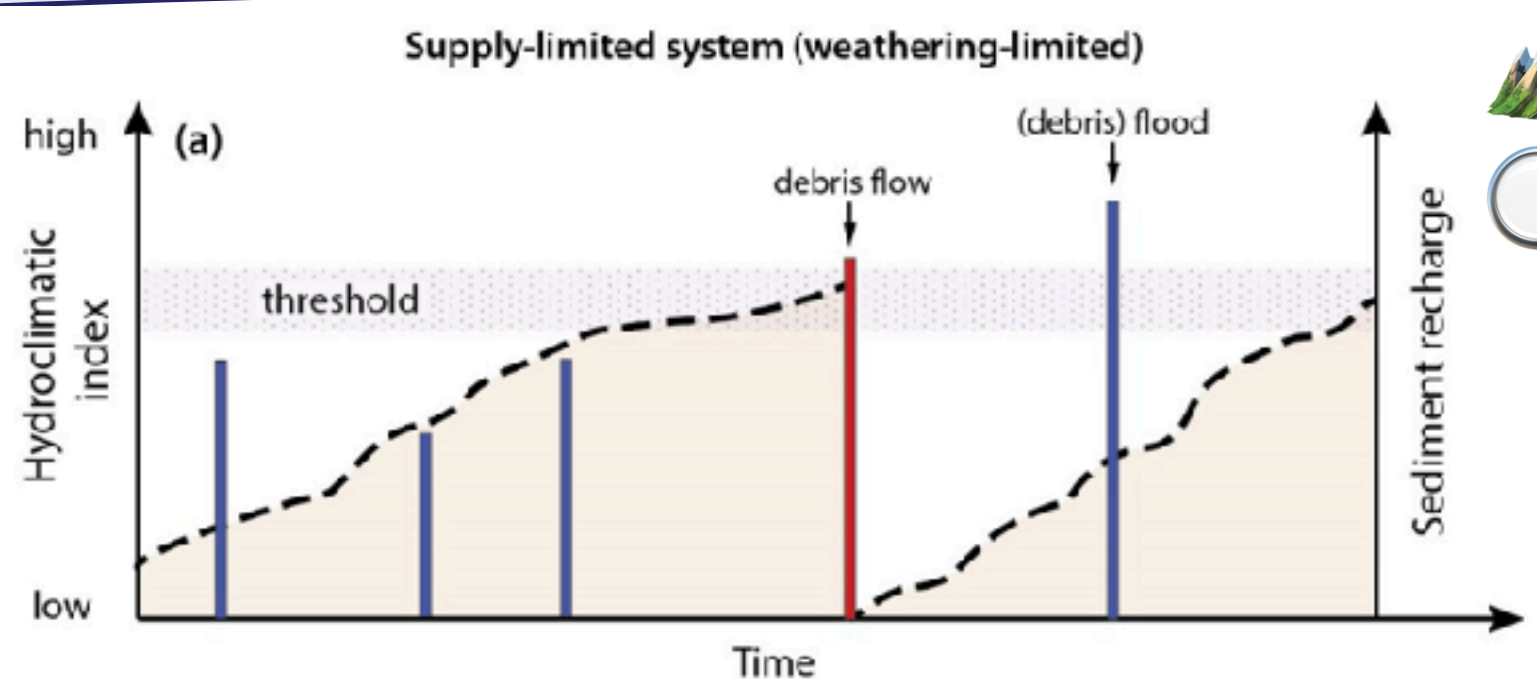
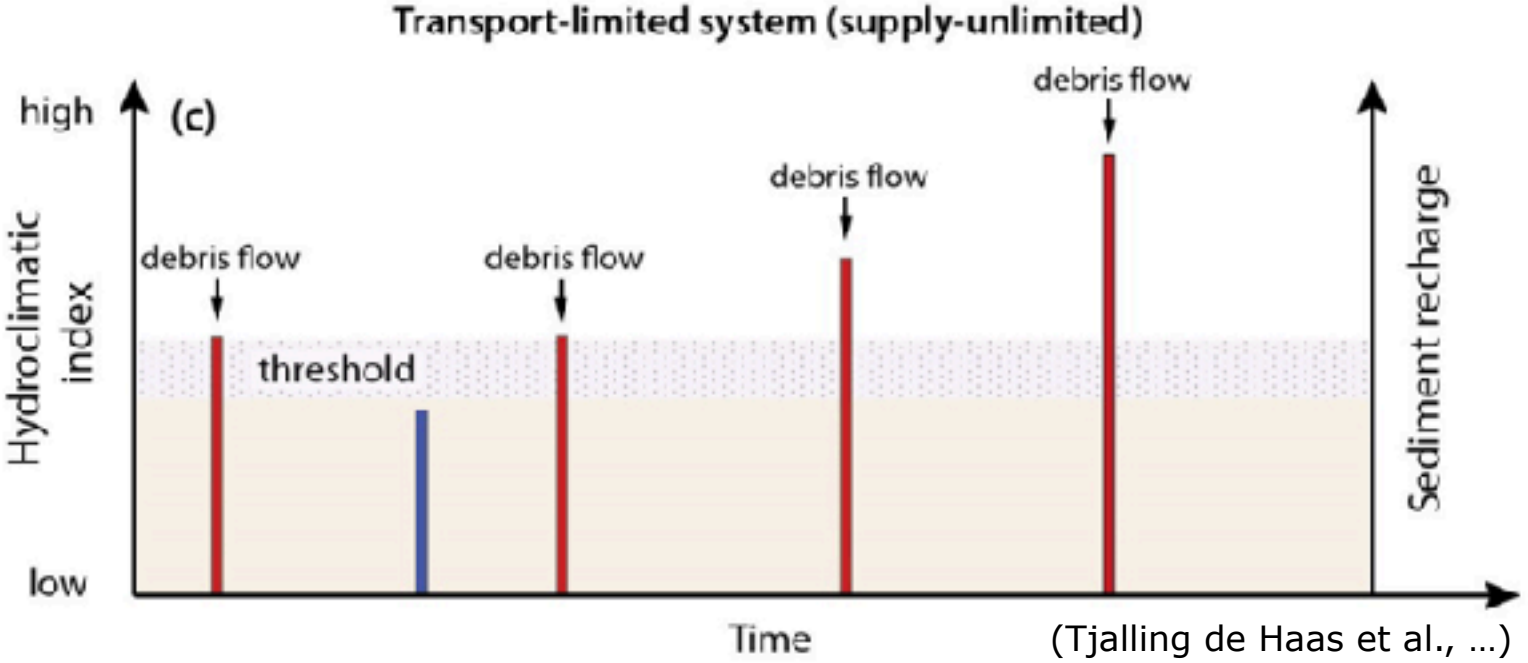

Flow direction


Langtang
Nepal Himalaya

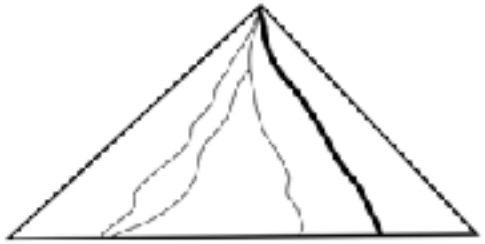
✅ Enough water
❌ Enough sediments

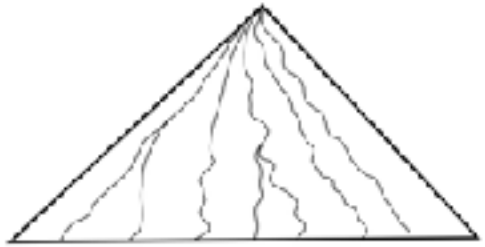


✅ Enough water
✅ Enough sediments



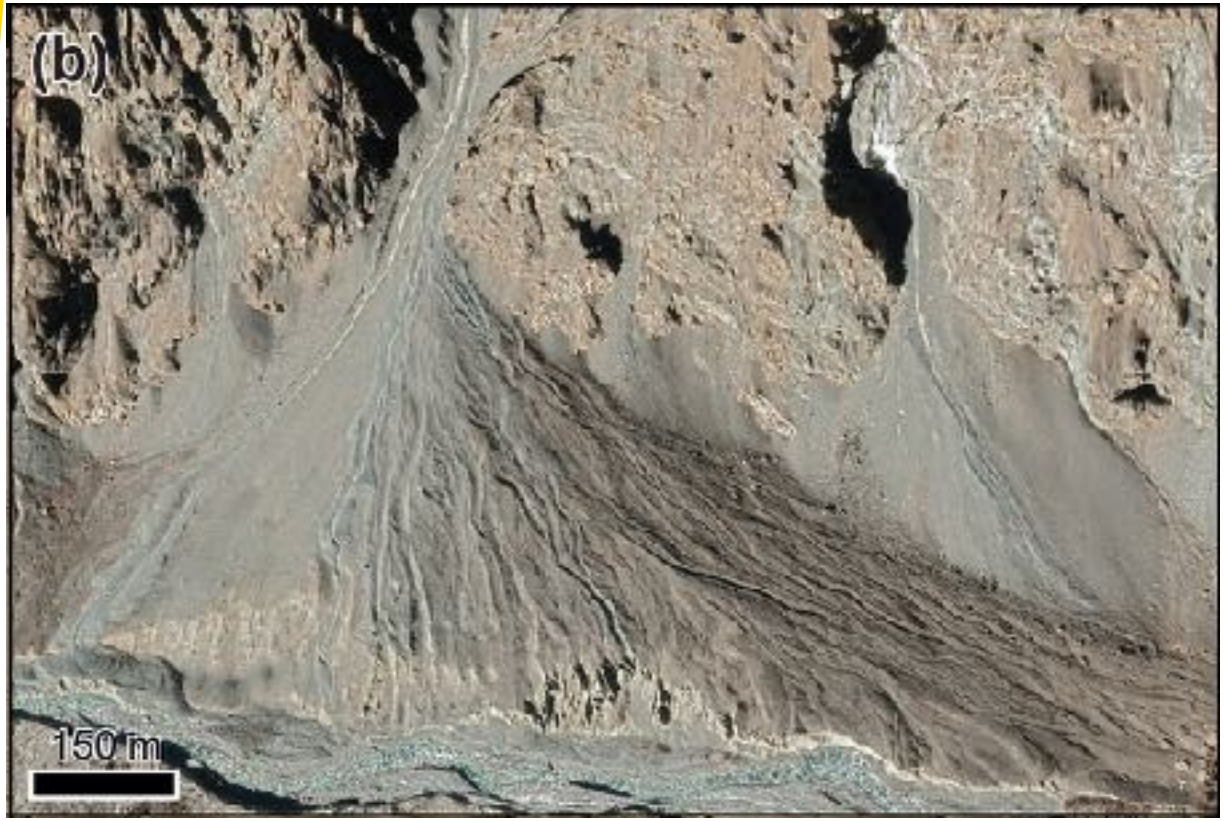
(Tjalling de Haas et al., …)





Debris flow dominated

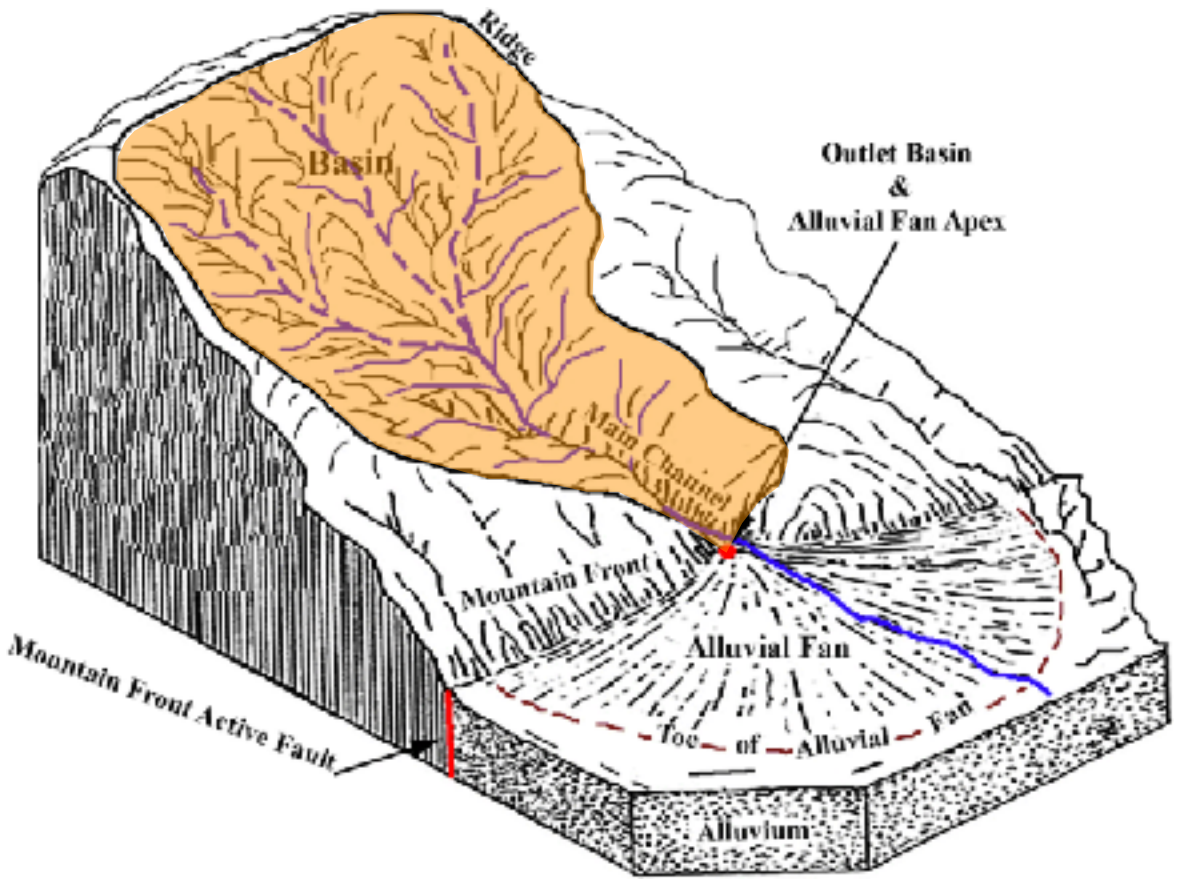
Flood dominated

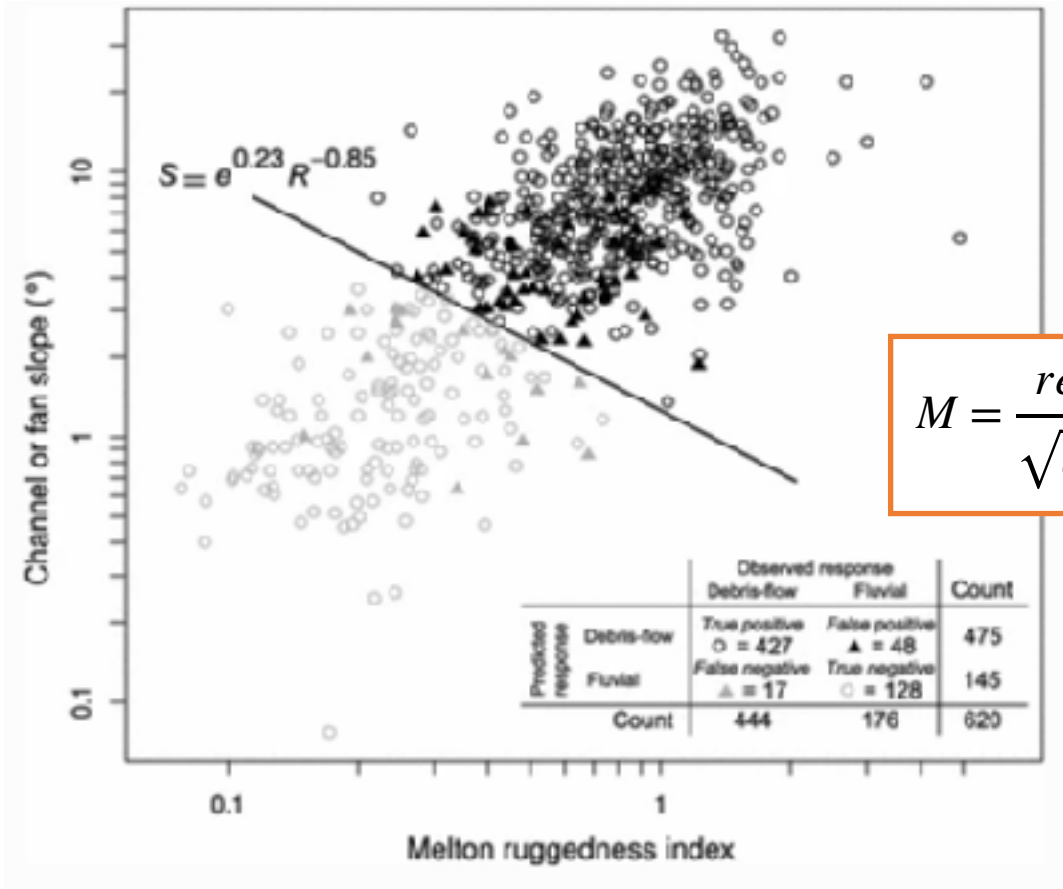


Somewhere in E Hindu Kush

Somewhere in E Himalaya

Morphometry threshold for classification

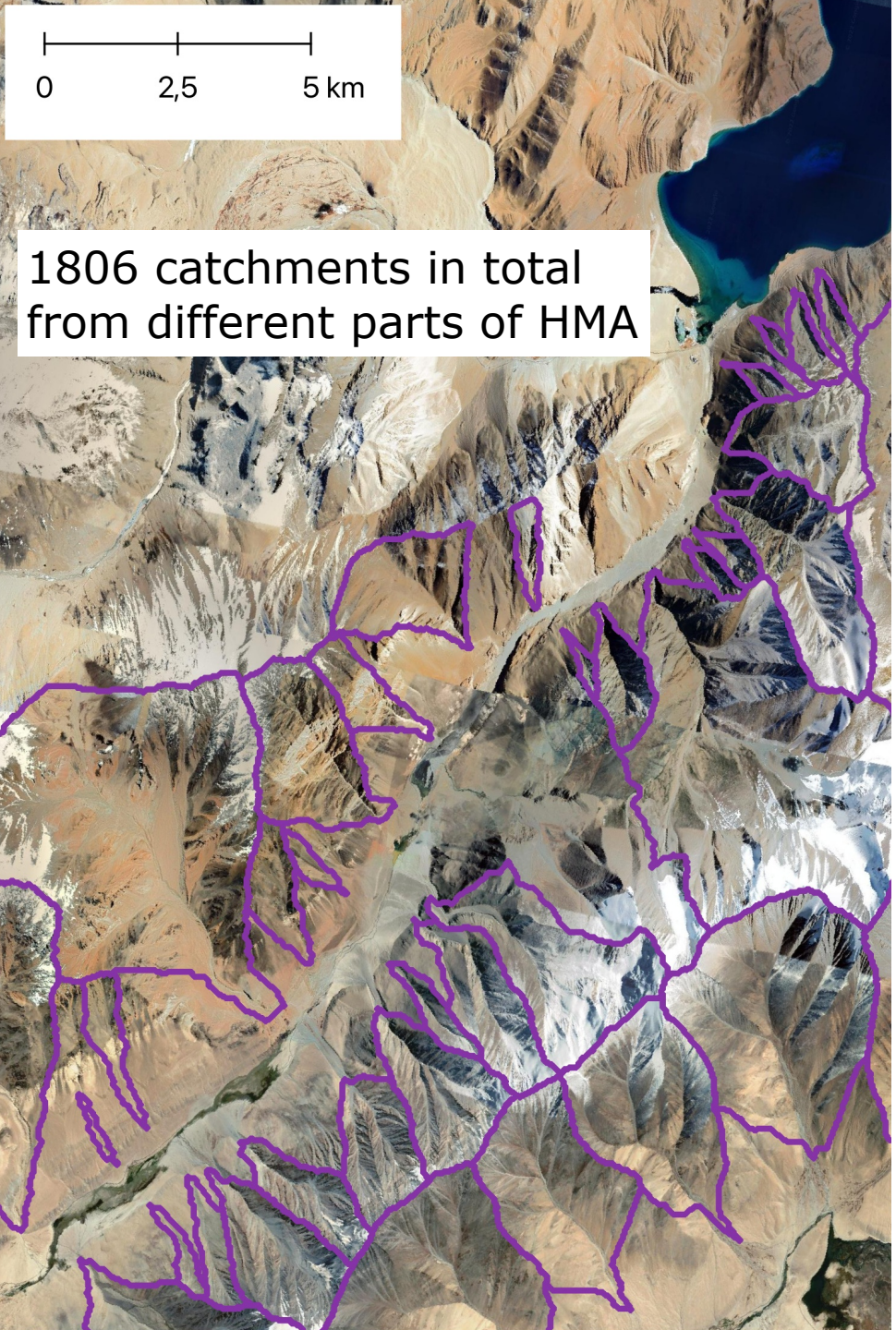




$$M = \frac{relief}{\sqrt{area}}$$

- Dataset from all over the world (review)
- Only Melton index and the fan slope as predictors

(Bertrand et al., 2013)



1806 catchments in total from different parts of HMA

Morphometry

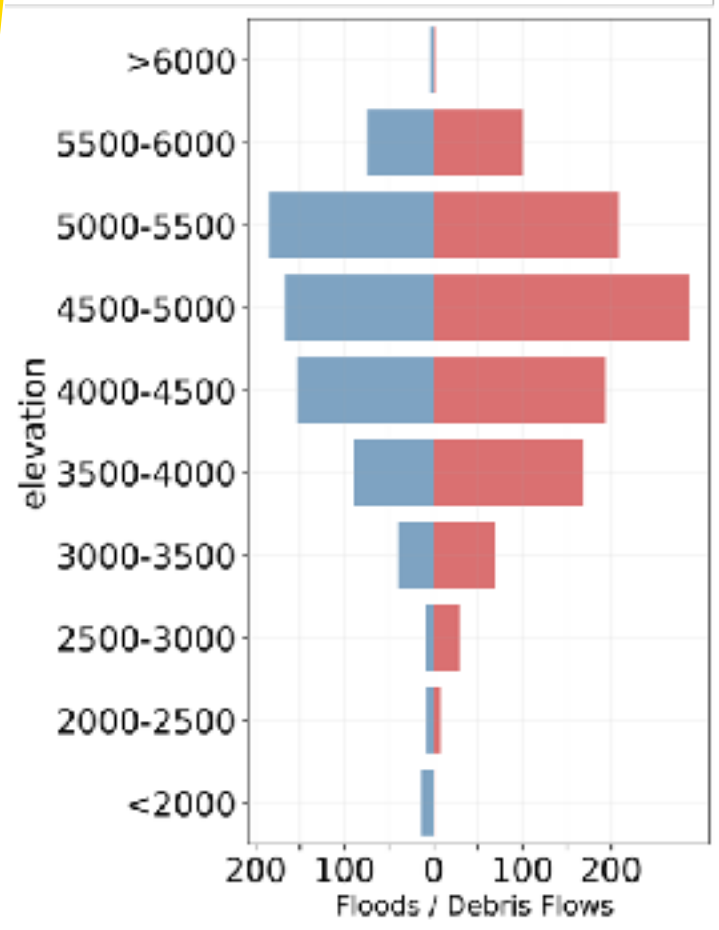
- median elevation
- relief
- area
- perimeter
- median slope
- Melton ratio
- circularity ratio
- compactness

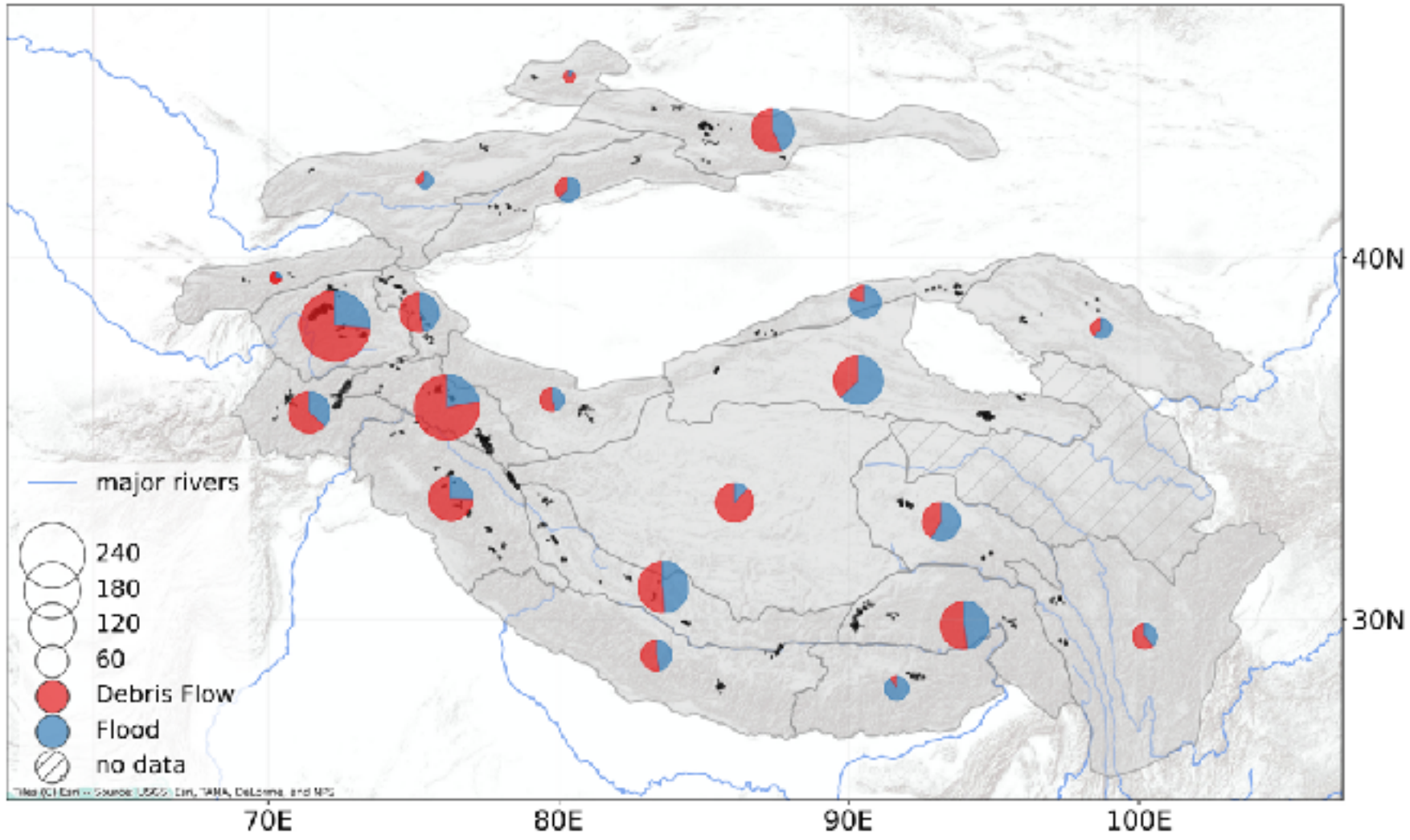
Climate

- total annual precipitation
- max annual precipitation
- N of wet days
- 95% precipitation
- snowfall
- rainfall
- mean annual temperature
- thermal weathering
- frost weathering
- vegetation cover (%)
- continuous permafrost
- glacier

Google Earth images across HMA

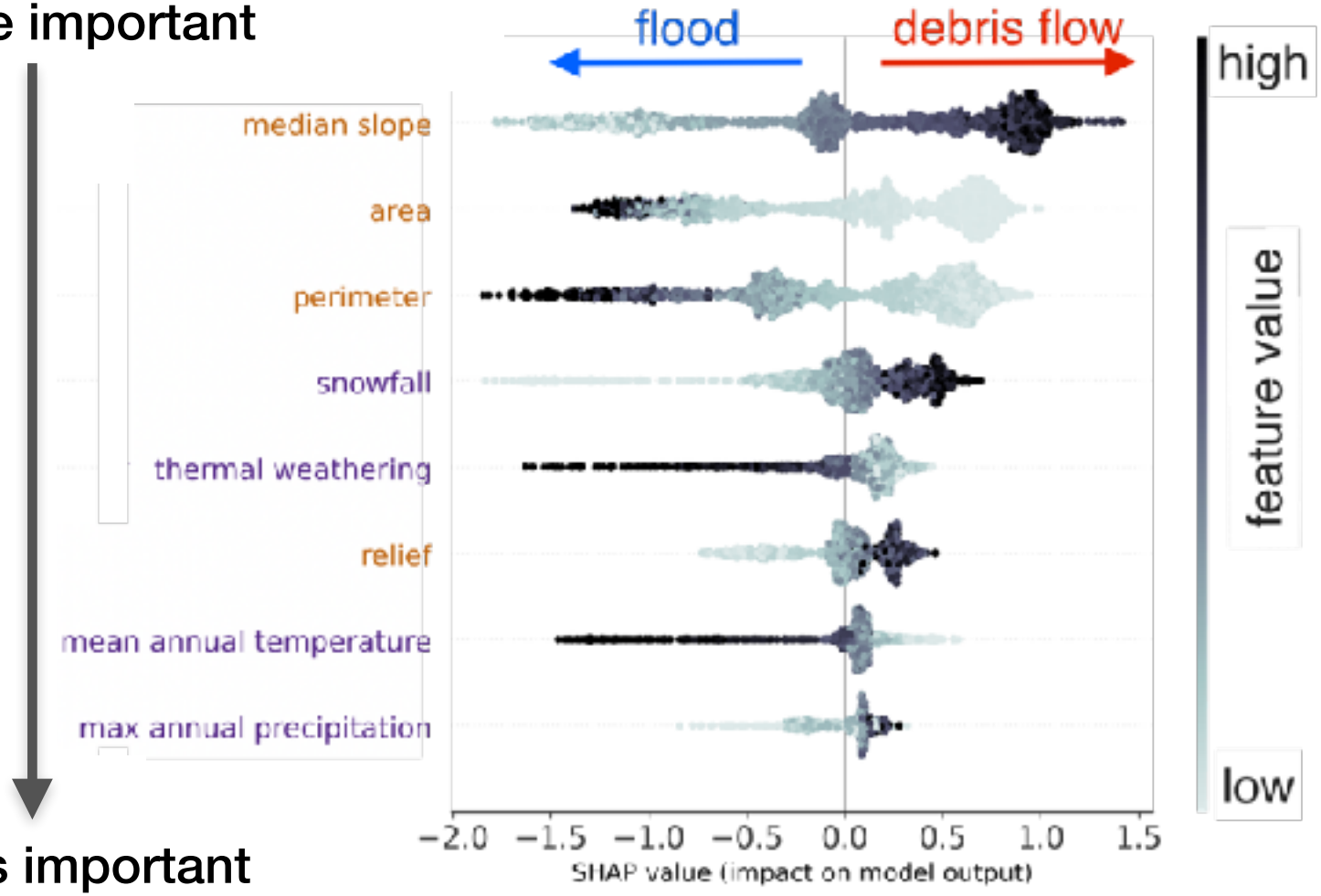
Identified alluvial fans, assigned the dominant process





What is important for the classification?

More important



Less important

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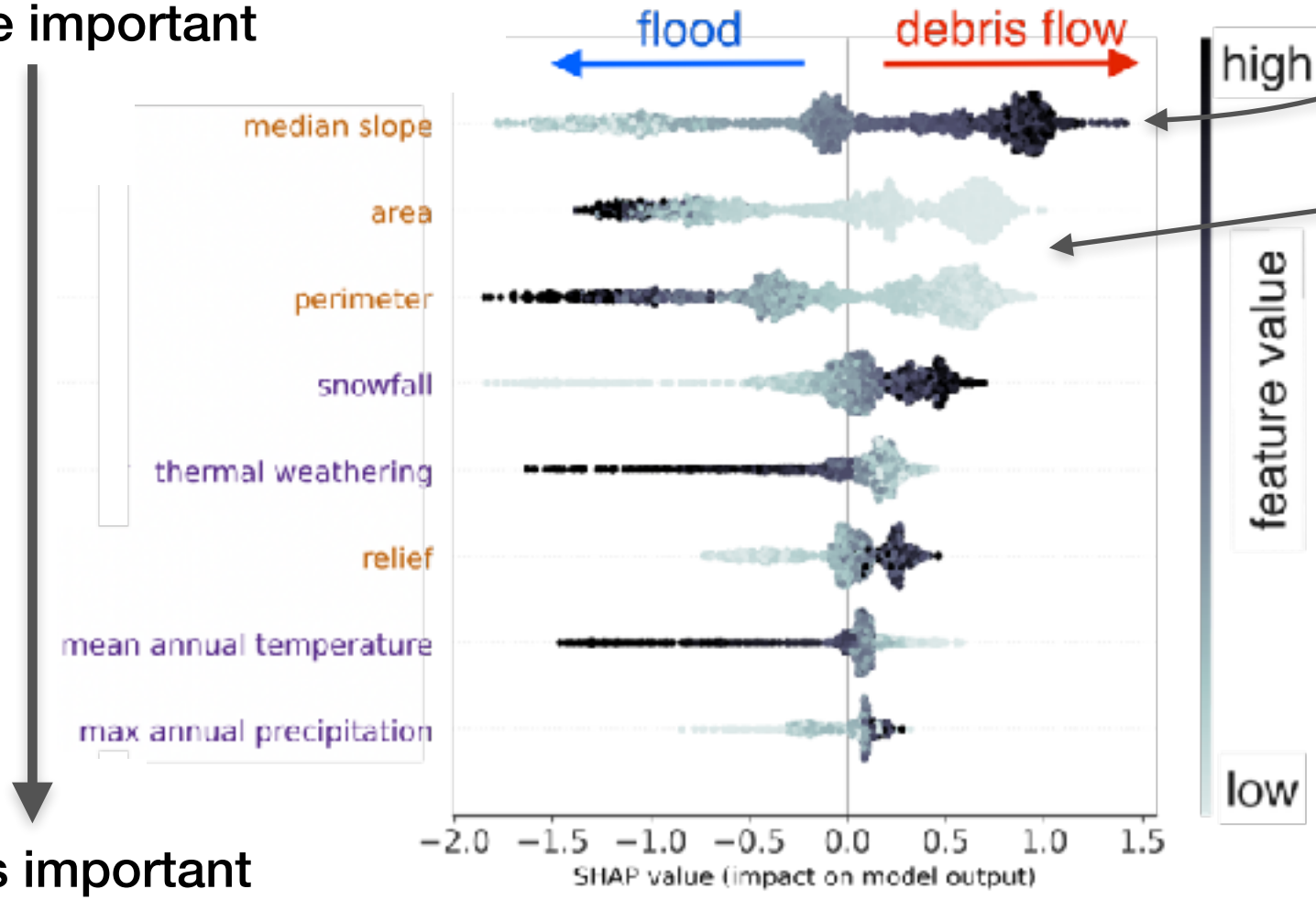
More important



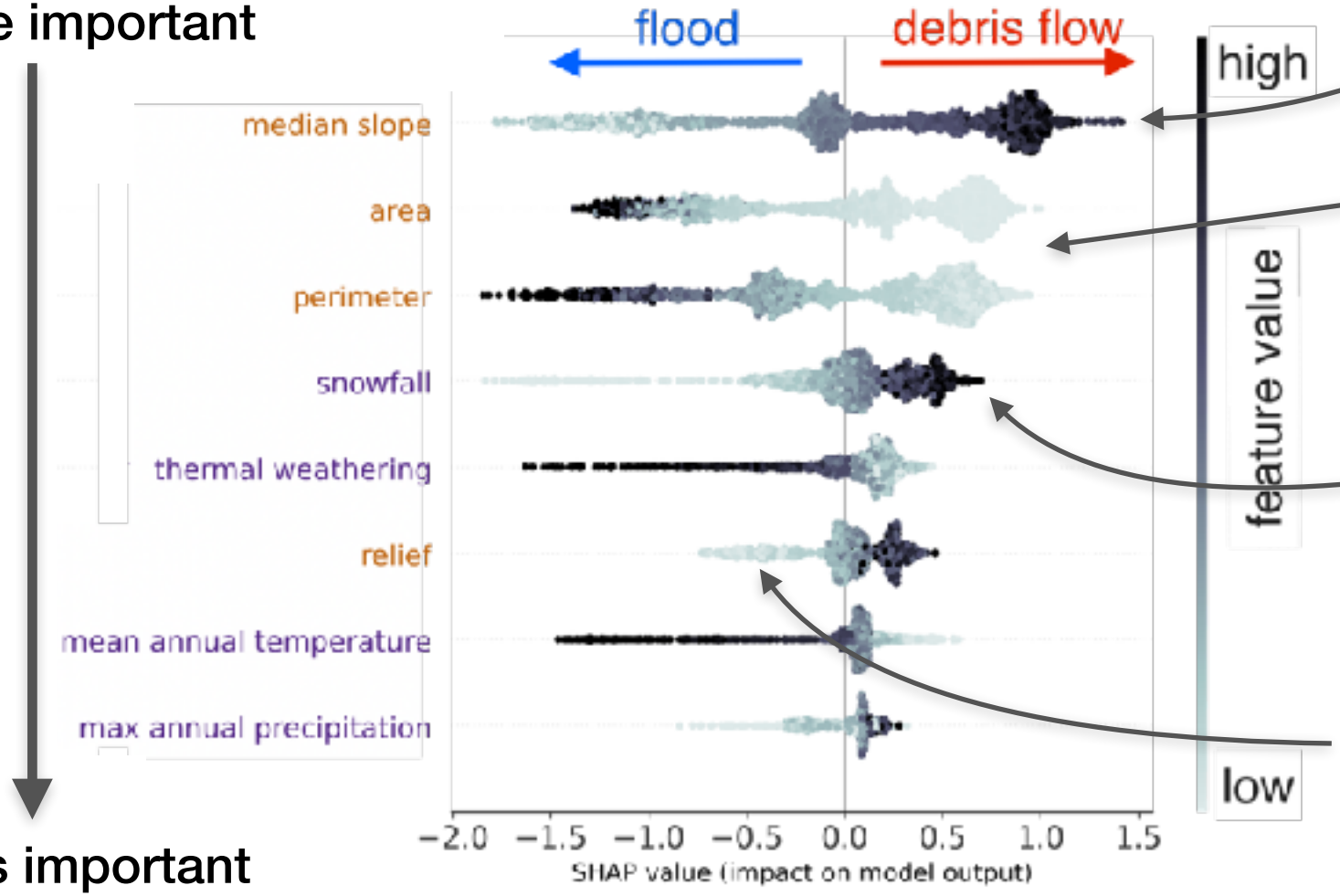
Less important

Catchments with **high median slope** are more likely to produce **debris flows**

Small catchments are more likely to produce **debris flows**

What is important for the classification?

More important



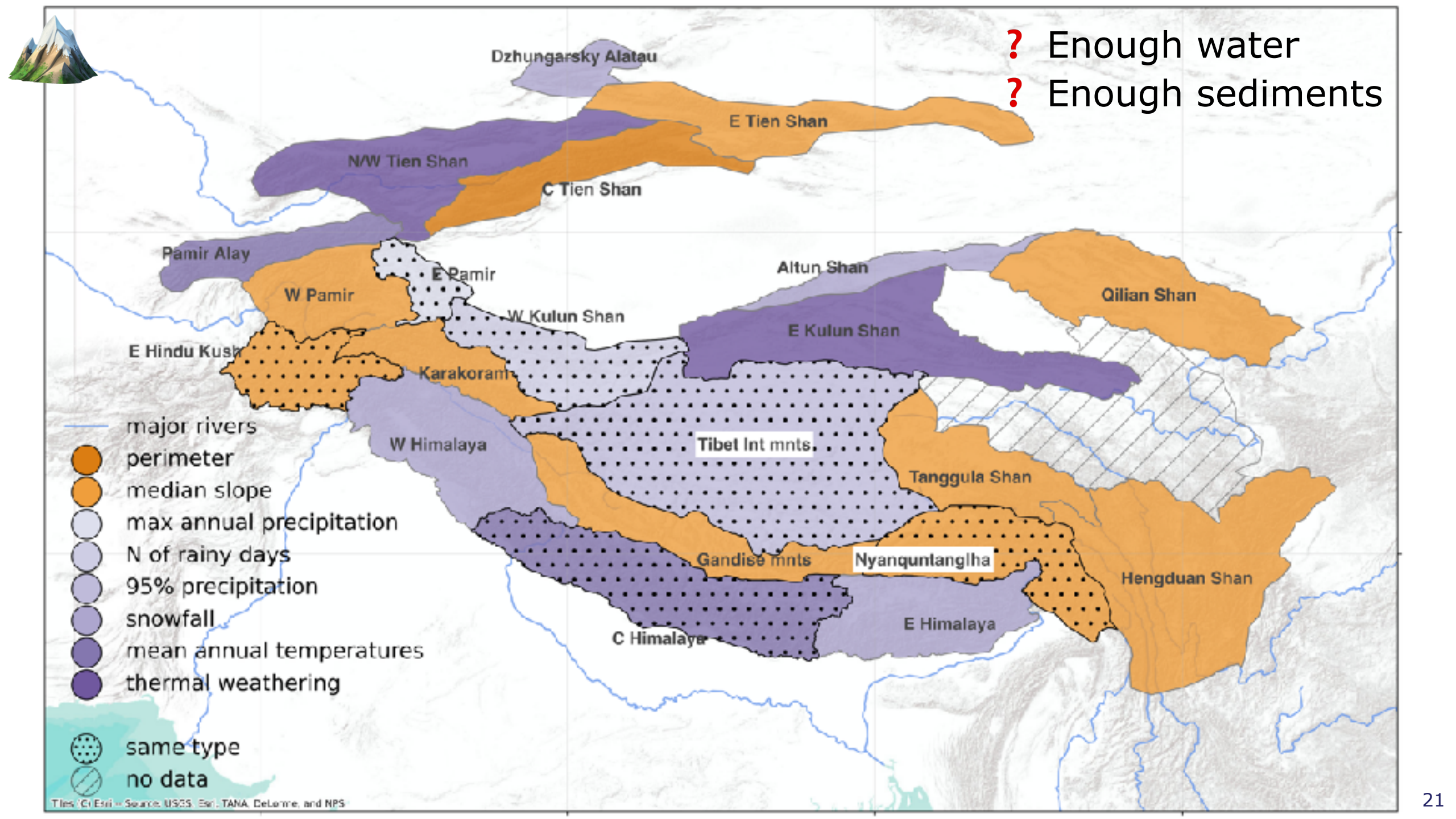
Less important

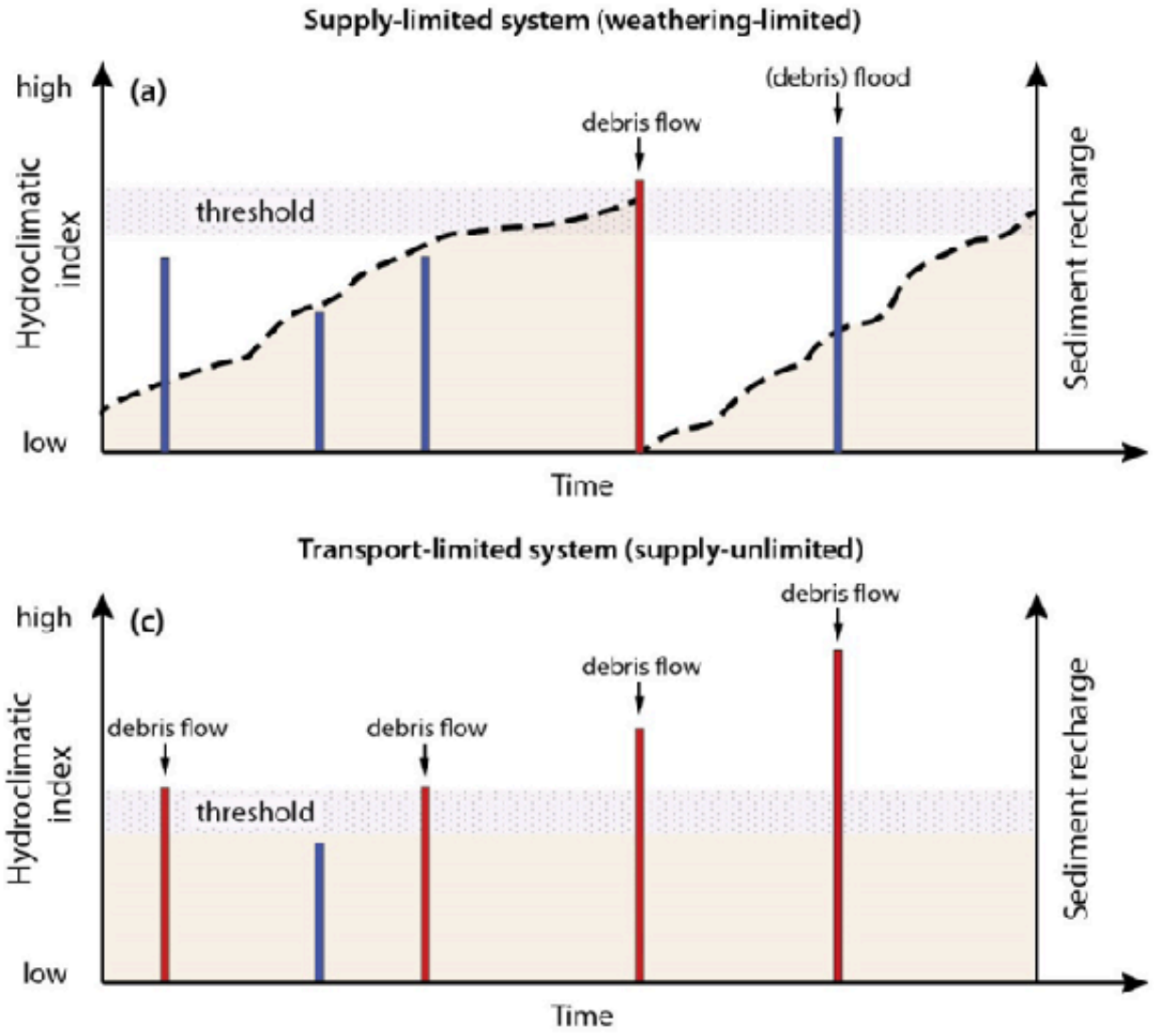
Catchments with **high median slope** are more likely to produce **debris flows**

Small catchments are more likely to produce **debris flows**

Catchments with **high amount of snowfall** are more likely to produce **debris flows**

Catchments with **small elevation range** are more likely to produce **floods**


? Enough water
? Enough sediments
Dzhungarsky Alatau
E Tien Shan
N/W Tien Shan
C Tien Shan
Pamir Alay
E Pamir
W Pamir
Altun Shan
Qilian Shan
W Kulun Shan
E Kulun Shan
E Hindu Kush
Karakoram
W Himalaya
Tibet Int mnts.
Tanggula Shan
Gandise mnts
Nyanquntanglha
Hengduan Shan
E Himalaya
C Himalaya
major rivers
perimeter
median slope
max annual precipitation
N of rainy days
95% precipitation
snowfall
mean annual temperatures
thermal weathering
same type
no data
Tiles (C) Esri – Source: USGS, Esri, TANA, DeLorme, and NPS



✅ water availability
✅ sediment availability

x

🔶 size and slope

(Tjalling de Haas et al., …)

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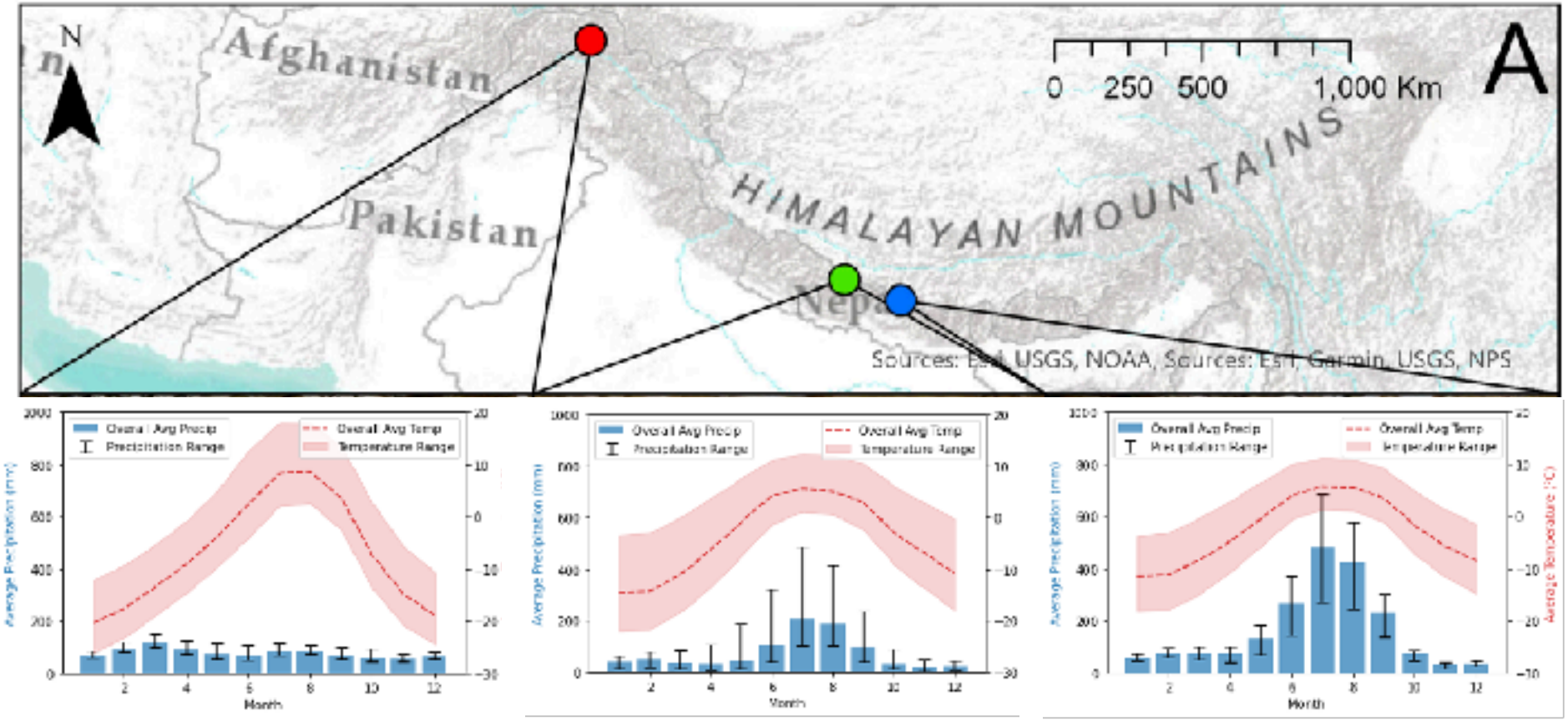
3 locations to model sediment yield under different conditions:
transport-limited case



(Duurkoop, 2024)

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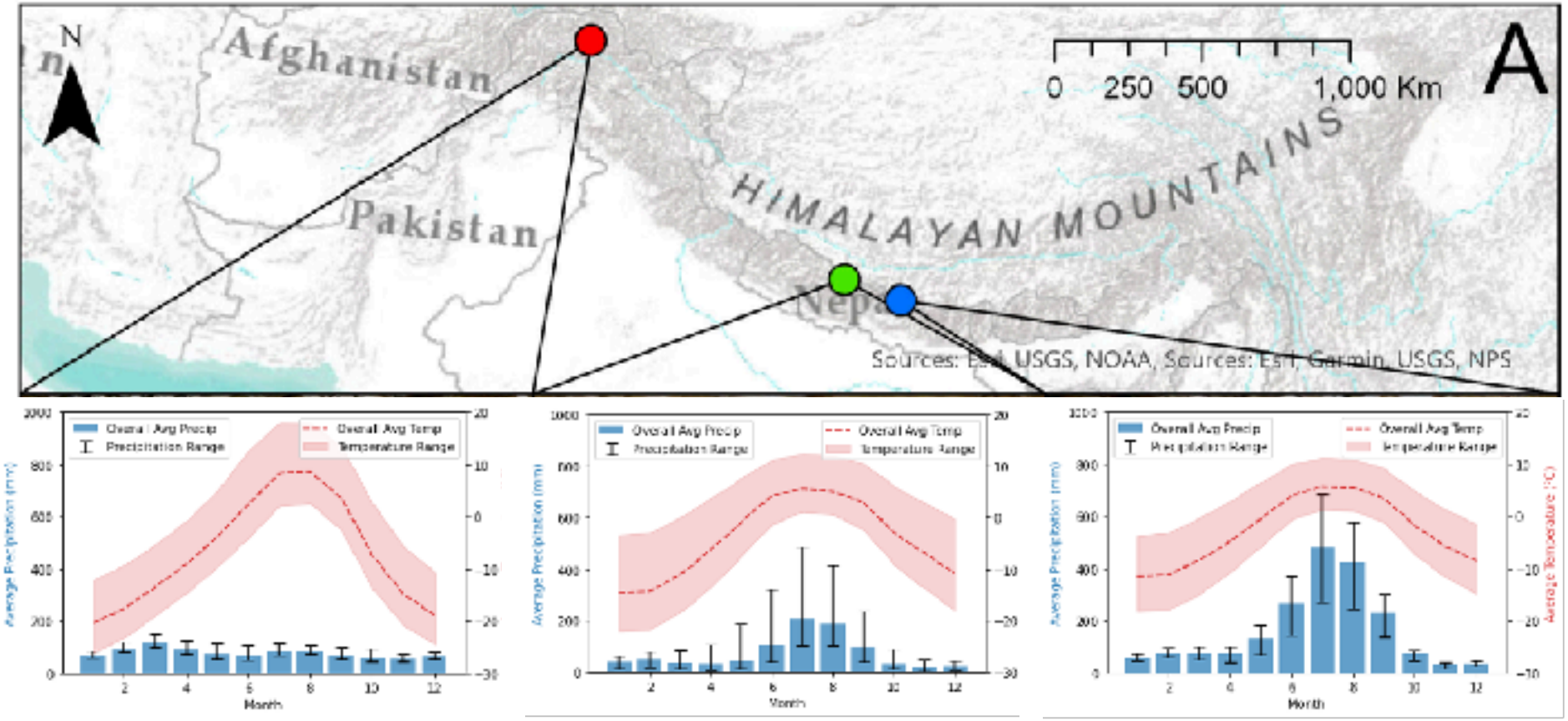

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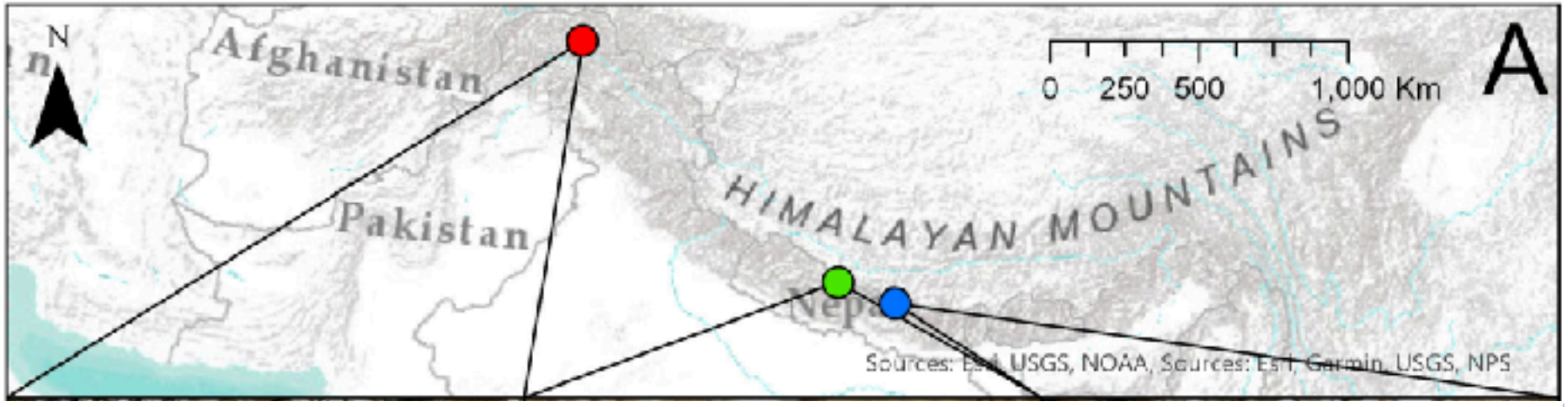

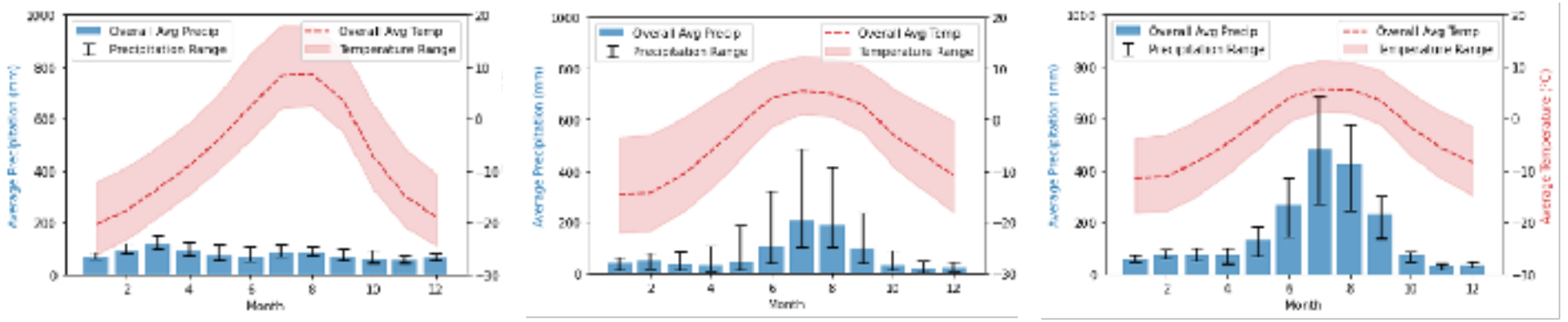

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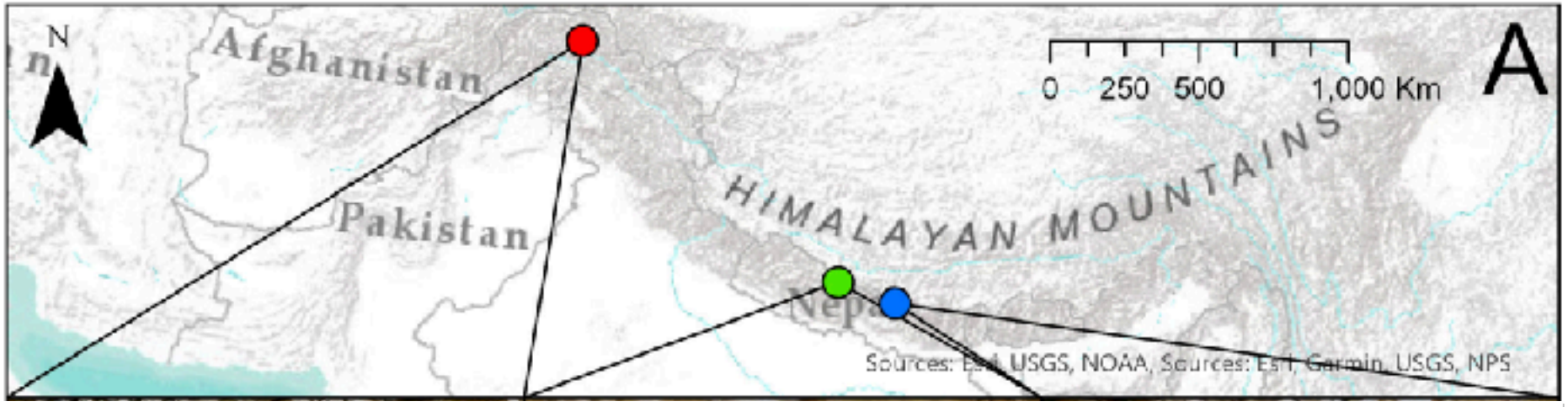
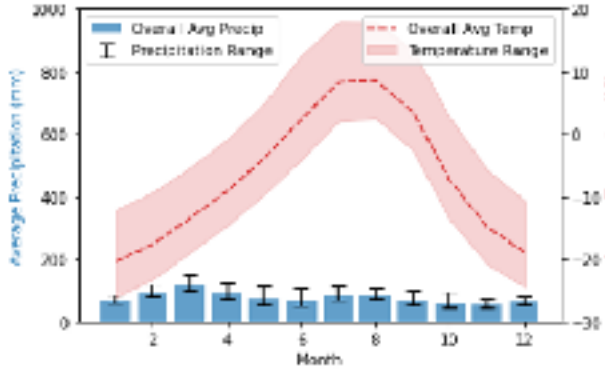
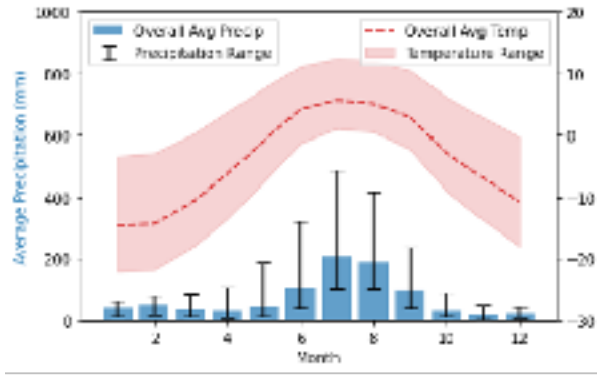
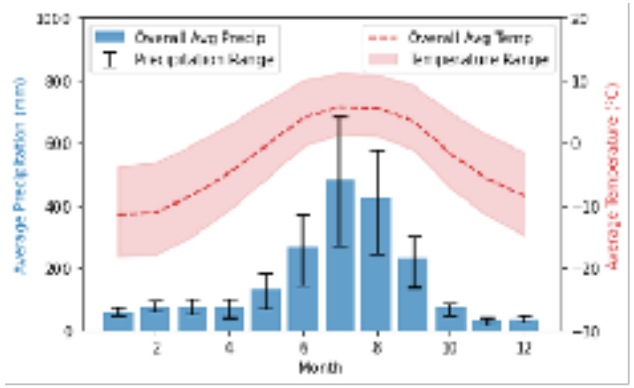






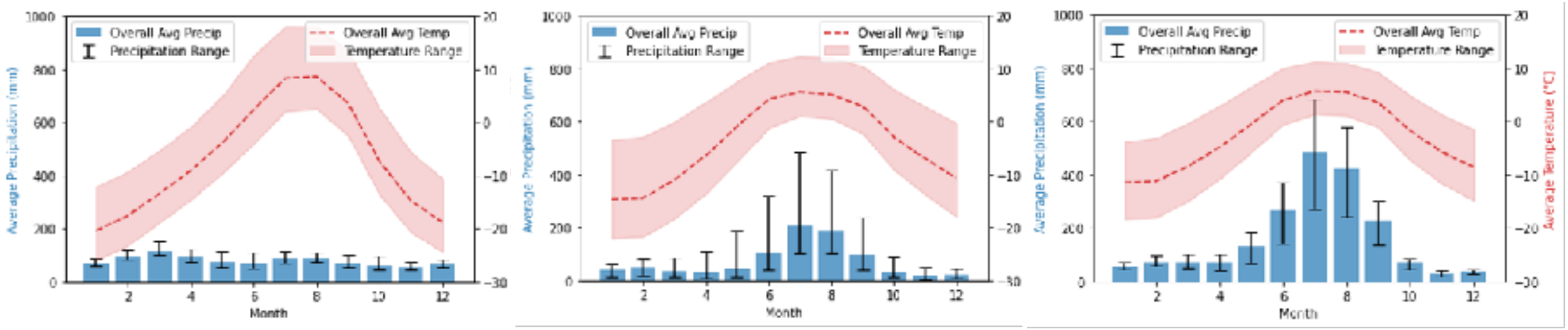


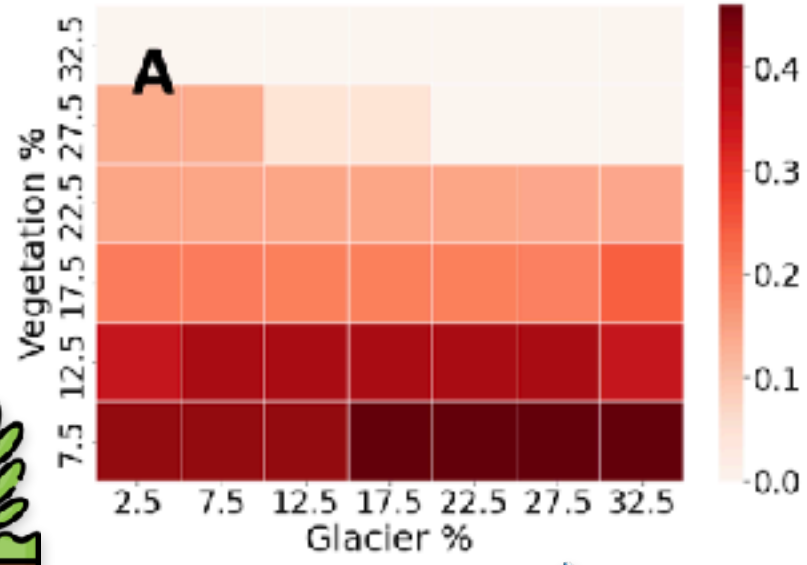
(Duurkoop, 2024)

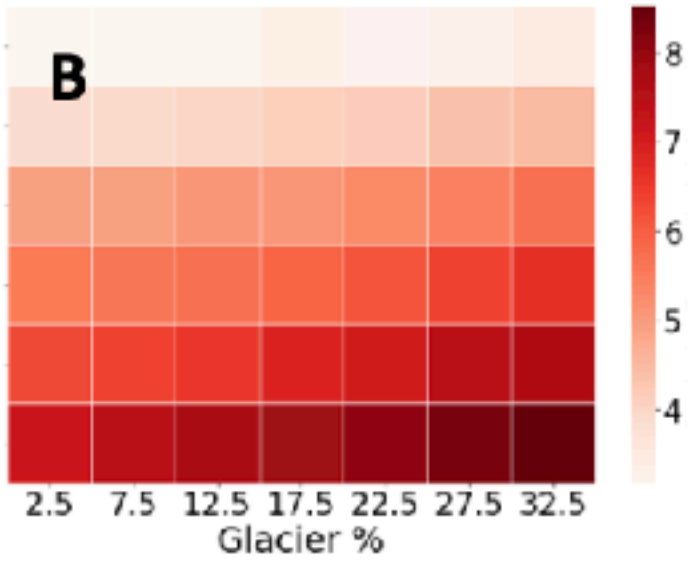
Bagrot (Karakoram)

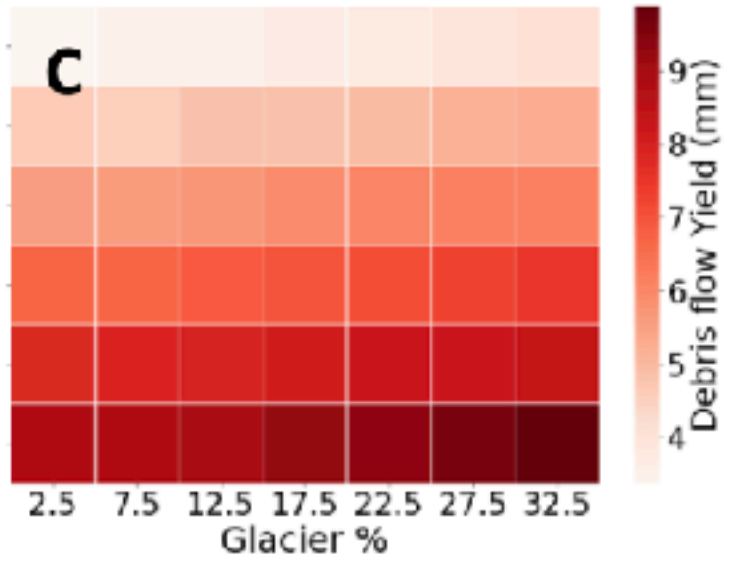
Mustang (Central Himalaya)

Langtang (Central Himalaya)









(Duurkoop, 2024)

1950-1986

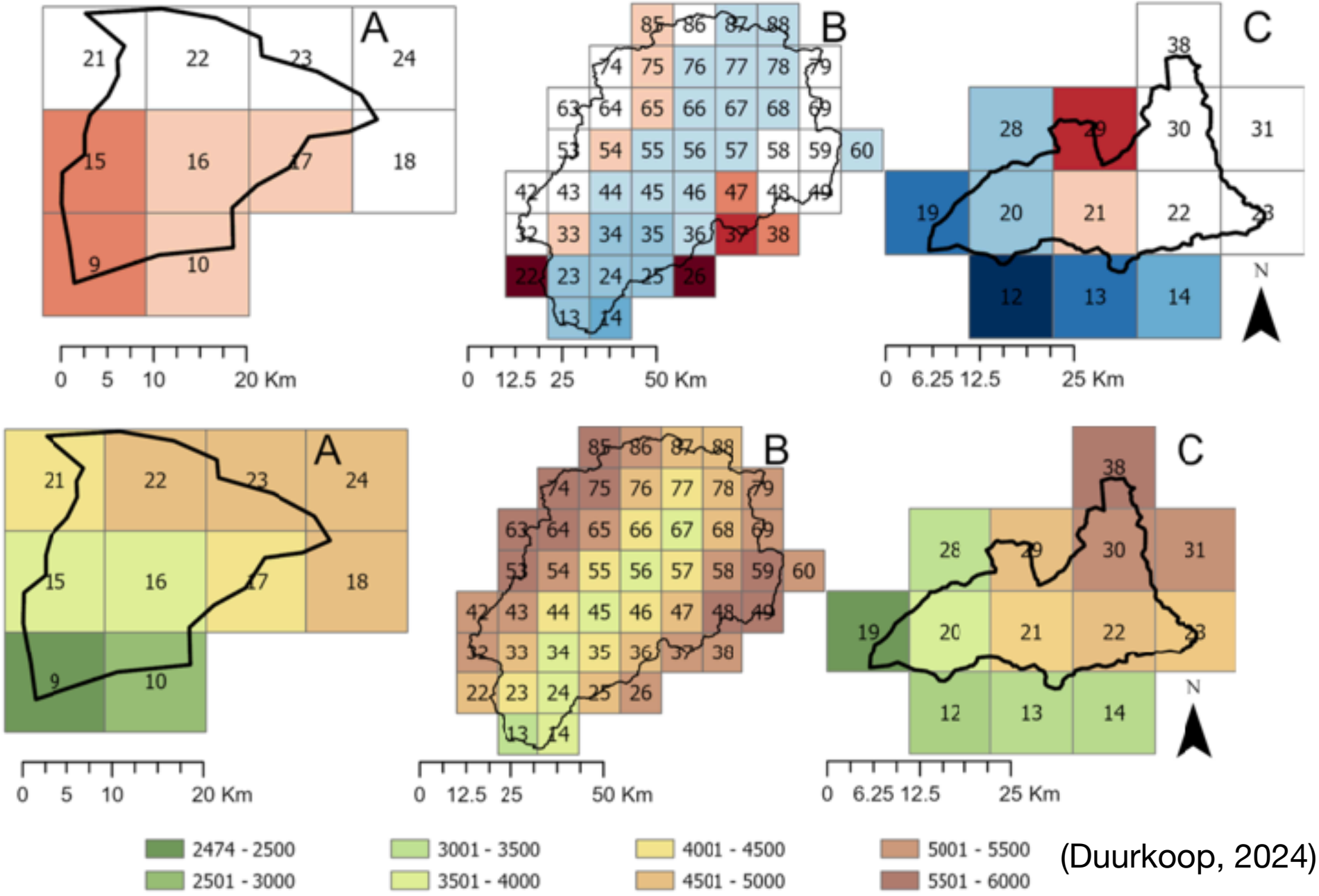
vs

1986-2022

Increase

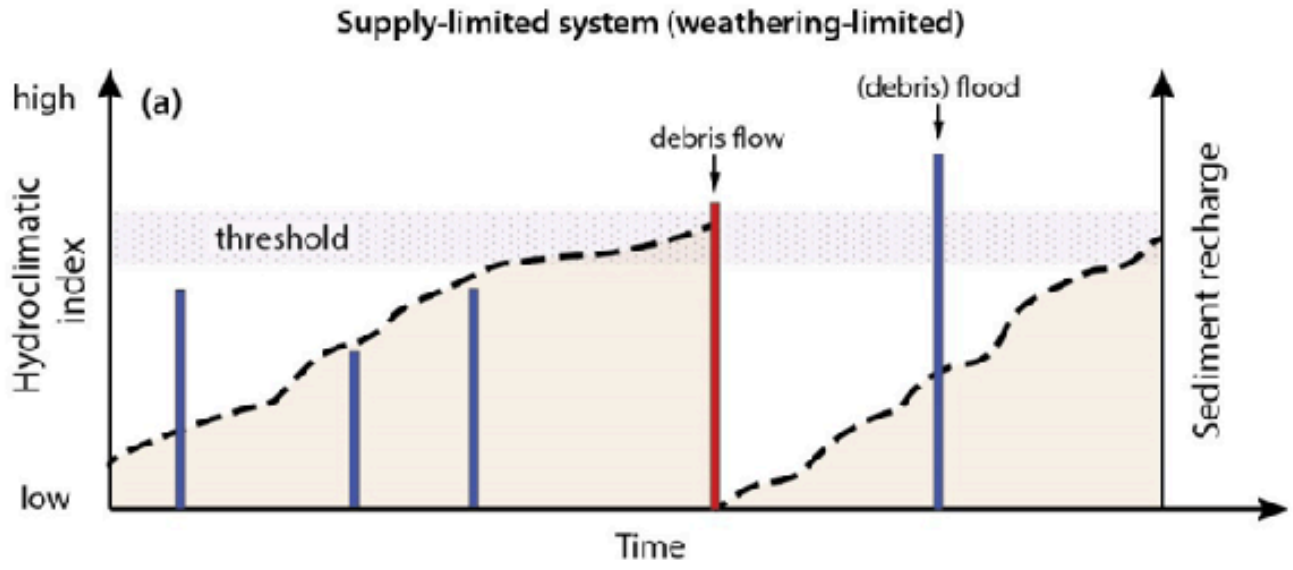
No change

Decrease



(Duurkoop, 2024)

Sediment production and sediment yield under different conditions:
supply-limited case



? sediment availability

Different erosion mechanisms and recharge rates

** Varvara Bazilova, Leon Duurkoop, Jacob Hirschberg, Tjalling de Haas, Walter Immerzeel. "Deglaciation and debris flow dynamics: how does glacier retreat affects debris flow activity in High Mountain Asia " (in prep.)*

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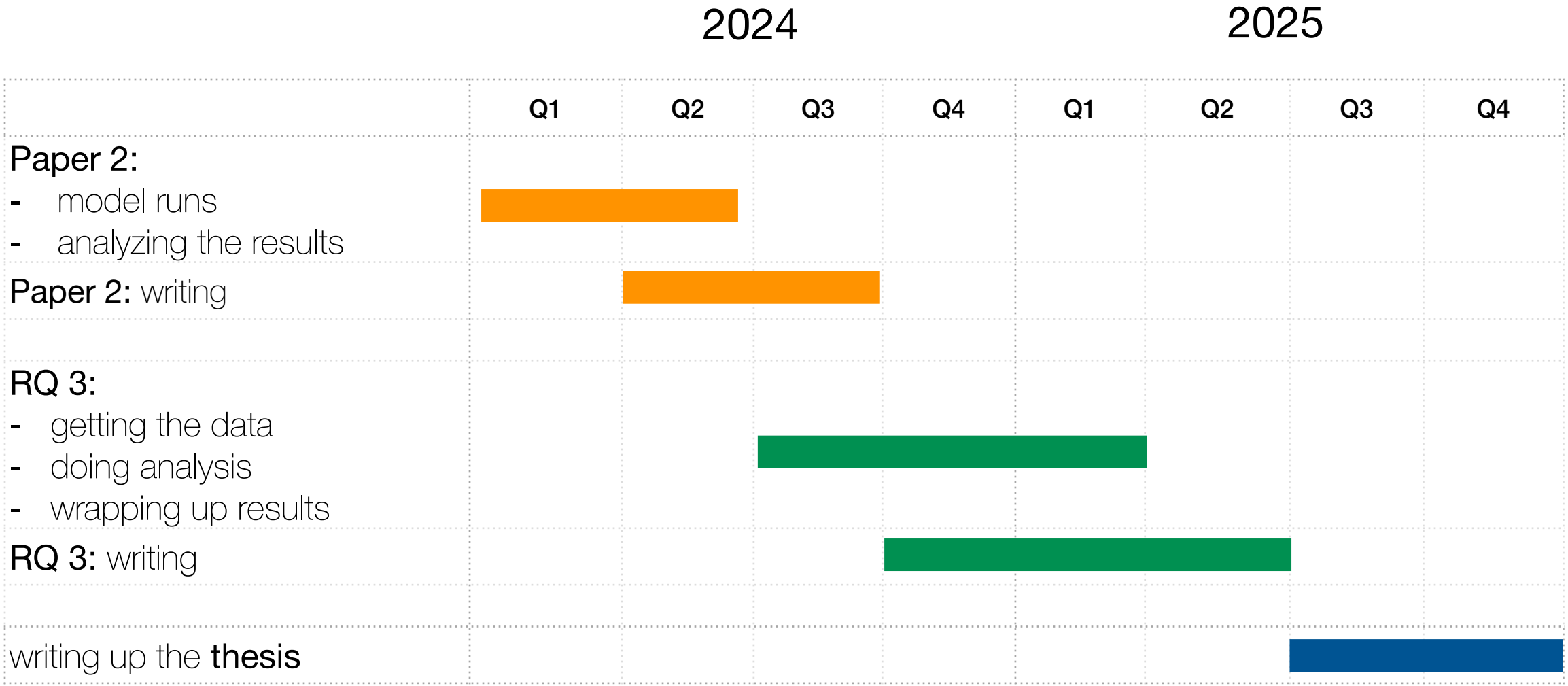
2024
2025
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Paper 2:
- model runs
- analyzing the results
Paper 2: writing
RQ 3:
- getting the data
- doing analysis
- wrapping up results
RQ 3: writing
writing up the thesis

Thesis outline

🏔️ Large scale (statistical)
🔍 Small scale (physical)
🥵 Climate change

Introduction

I. **Debris flow or flood:** Spatial distribution and controlling factors of the debris flow hazard in High Mountain Asia: a machine learning approach *(Under review)*

II. **Deglaciation and debris flow dynamics:** how does glacier retreat affects debris flow activity in High Mountain Asia *(In prep.)*

III. **Glacial lakes:** growth rates and outburst flood hazard

IV. **Projections into the future:** future change in hazard hotspots and triggering mechanisms

Synthesis

Teaching and Student supervision

☑ Completed
☐ Ongoing

Teaching:

- ☑ (1) Natural Hazards (Spring ’22)
- ☑ (2) CC, Cryosphere and Hydrology (Spring ’22)
- ☑ (3) Natural Hazards (Spring ’23)
- ☑ (4) Natural Hazards and Risk Assessment (Spring ’23)
- ☑ (5) CC, Cryosphere and Hydrology (Spring ’23)
- ☑ (6) Statistics and data analysis in PG (Fall ’23)
- ☐ (7) CC, Cryosphere and Hydrology (Spring ’24)

Supervision:

- ☑ “Impacts on climate change on debris flow activity in HMA” (MSc thesis)
- ☐ “Understanding the rates of glacial lakes growth across HMA”
- ☐ ADS topic: “Spatial distribution and uncertainty of the climate change impact on the debris flow hazard in HMA”

Co-Supervision:

- ☑ “Behaviour of lake terminating glaciers in Greenland” (Guided Research)
- ☐ Improving representation of sediment fluxes due to glacial retreat in catchment-scale fluvial modelling (MSc. Thesis)

Research-related Activities

☑ Completed
☐ Ongoing

Papers:

☑ **Bazilova, Varvara,** and Andreas Kääb. "Mapping Area Changes of Glacial Lakes Using Stacks of Optical Satellite Images." *Remote Sensing* 14.23 (2022): 5973.

☑ Kääb, Andreas, **Varvara Bazilova**, Paul Willem Leclercq, Erik Schytt Mannerfelt, and Tazio Strozzi. "Global clustering of recent glacier surges from radar backscatter data, 2017–2022." *Journal of Glaciology* 69, no. 277 (2023): 1515-1523.

PhD Papers:

☐ *Varvara Bazilova, Tjalling de Haas, Walter Immerzeel. "Spatial distribution and controlling factors of the debris flow hazard in High Mountain Asia: a machine learning approach" (Submitted to GJR Earth Surface) (Project1)*

☐ *Varvara Bazilova, Leon Duurkoop, Jacob Hirschberg, Tjalling de Haas, Walter Immerzeel. "Deglaciation and debris flow dynamics: how does glacier retreat affects debris flow activity in High Mountain Asia " (in prep.) (Project2)*

Other:

☑ Research Visit at WSL (Zürich) - October 2022 (Project2)

☐ Research Visit at ETH Zürich - May 2024 (Project2)

Education, development, communication and outreach

Courses and workshops @UU:

- ☑ Start to teach (May-June 2023)
- ☑ UU can blog
- ☑ Writing for Scientists (May - June 2023)
- ☑ RCR (parts 1, 2 and 3)
- ☑ UU Career Services workshops: (1) Manage your supervisor (2) Conflict and influencing

Other:

- ☑ IMC Student to Student Summer School on Geohazards
- ☑ Driven Data Hackathon on Seasonal hydrological forecasting using data driven methods (5th place so far)

Conferences:

- ☑ EGU 2022 - Talk
- ☑ International Mountain Conference (IMC) 2022 - Poster
- ☑ EGU 2023 - Poster
- ☐ EGU 2024 - Poster

Other presentations:

- ☑ IMC Student to Student Summer School on Geohazards (September 2022)
- ☑ WSL Guest Seminar (October 2022)
- ☑ University of Oslo Lunch Seminar (August 2023)

Communication to a broader audience:

- ☑ EGU Cryosphere Blog: Himalayan Fieldwork in Numbers

How does climate change and retreat of glaciers affect the hazards and its triggers in High Mountains?

🏔️ Large scale (statistical)
🔍 Small scale (physical)
🥵 Climate change

Debris flow or Flood?
Climate is one of the main drivers for the classifications and must be considered

Paper I.

Deglaciation, mountain greening and debris flows:
glacier retreat -> more debris flows
greening -> less debris flows
climate change -> less debris flows

Paper II.

Projections to the future:
how will mass movement hazard change in the next century?
(floods/debris flows/GLOFs)

- Most types of natural hazards are projected to **change in frequency, magnitude and areas** affected as the cryosphere continues to decline *(high confidence)*.
- Glacier retreat and permafrost thaw are projected to **decrease the stability of mountain slopes** <…> *(high confidence)*. Resulting landslides and floods, and cascading events, will also **emerge where there is no record of previous events** *(high confidence)*.
- The **number and area of glacier lakes has increased** in most regions in recent decades *(high confidence)*, but there is only **limited evidence that the frequency of** glacier lake outburst floods **has changed.**
- At lower elevations < … > climate driven changes such as a **reduction in number of freezing days** are projected to lead to a reduction in debris flows.

IPCC SROCC, 2019