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ADB

GREEN CLIMATE FUND

TECHNICAL PRESENTATION 1:

"Glaciers to Farms (G2F): Glaciers, climate change and water supplies in High Mountain Asia: what we know and what we don't know"

Stephan Harrison, Professor of Climate and Environmental Change

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University of Reading

PEGASYS
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Stephan Harrison

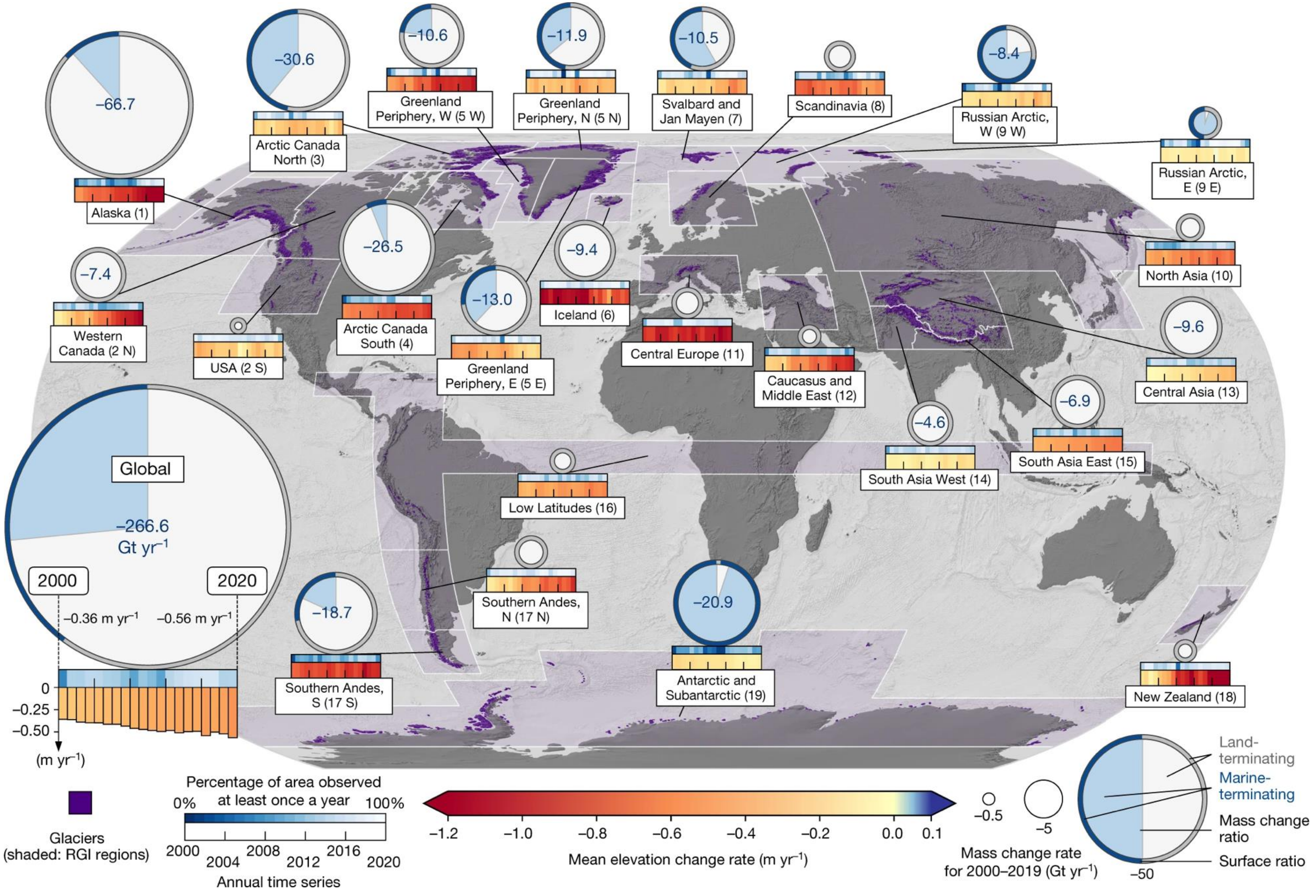
Pegasys Ltd., ADB Consultant

Professor Stephan Harrison is a globally recognized climate scientist with over 30 years of research experience in geomorphology and the impacts of climate change on high mountain glacial systems. He is a Professor of Climate and Environmental Change at the University of Exeter and currently serves as the Climate Change Lead for the UN GEO-7 Report. Listed among Reuters' top global climate scientists, he has advised governments, international organizations, and NGOs—including Lloyd's of London, the UK Foreign and Commonwealth Office, DFID, and Oxfam—on climate risk and adaptation. He previously chaired the UK Government's Climate Change Expert Committee (2011–2017) and Natural Hazards Risk Committee (2017–2021). His pioneering research includes the first 3D reconstruction of the Patagonian Ice Sheet, global assessments of glacial lake outburst floods (GLOFs), and studies on rock glaciers as water sources in arid regions. He has conducted fieldwork across South America, High Mountain Asia, the European Alps, and Scandinavia, and has published widely in both geomorphology and climate science. Professor Harrison holds a BSc from the University of Leicester and a PhD from the Council for National Academic Awards (CNAA) and continues to lead climate modelling and risk projects across Africa and Asia while speaking at major international scientific and policy forums.

We know:

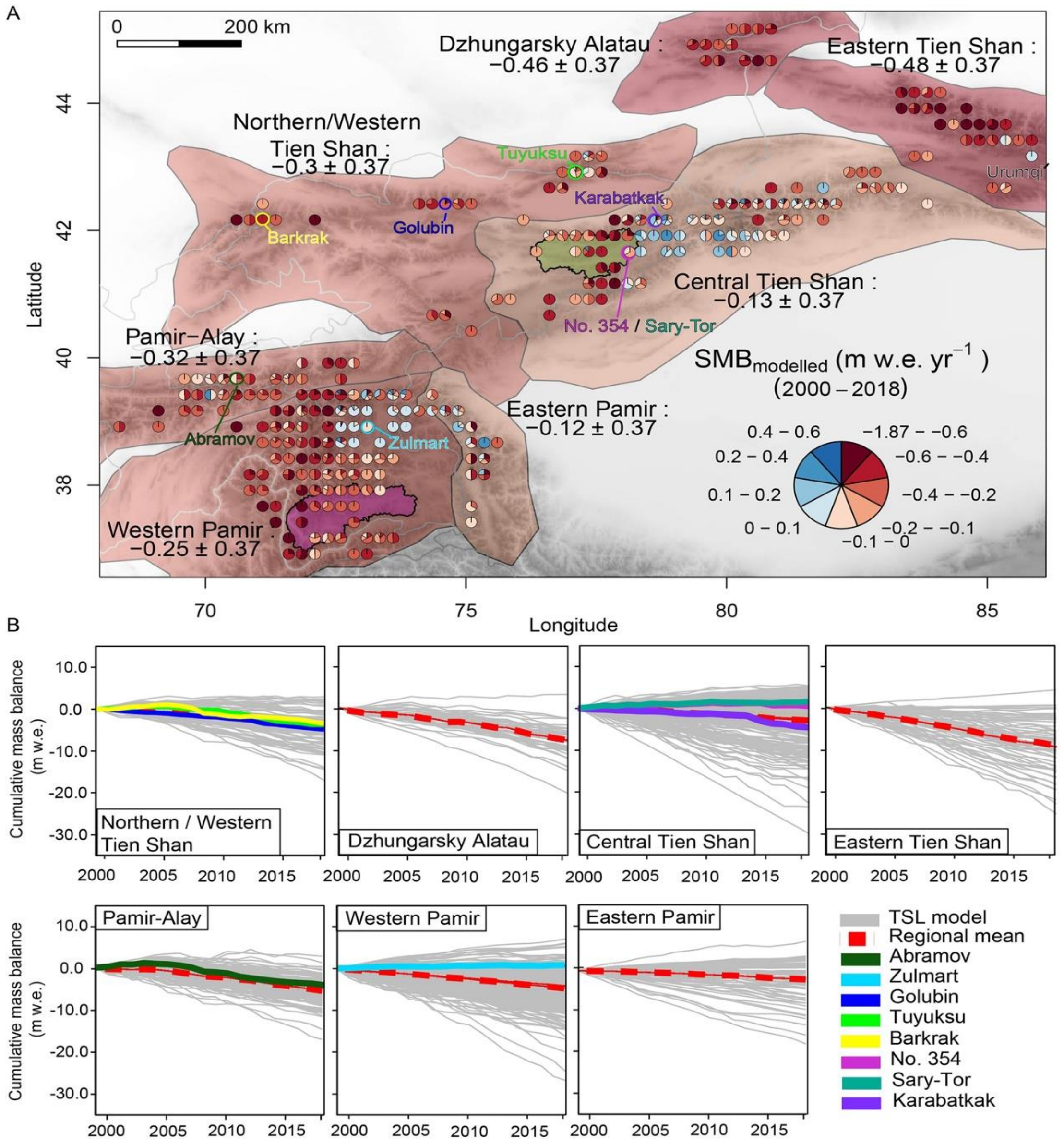
- Climate change is happening and glacier mass balance is overall negative
- These trends will continue
- This will impact future water supplies
- Glacier hazards will change in frequency and magnitude

Global mass balance trends



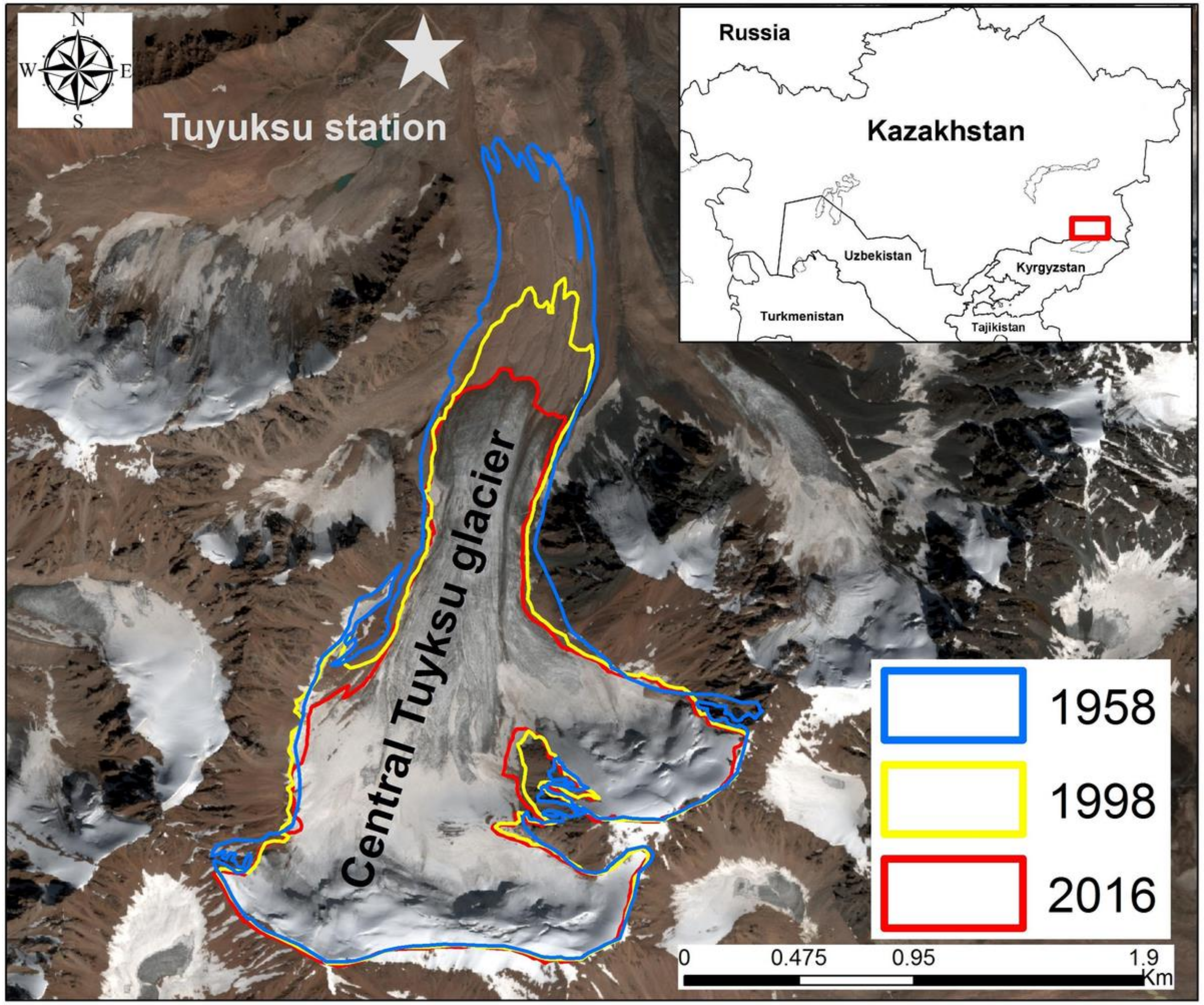
Huggonet et al. 2021

Regional mass balance

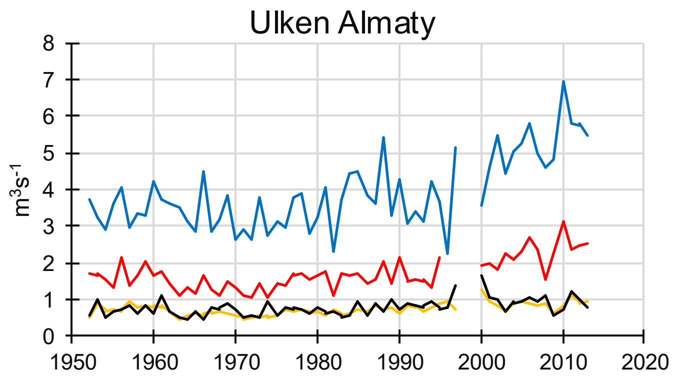


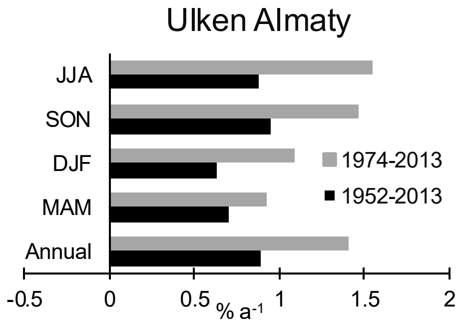
Barandun et al. (2021) doi.org/10.1029/2020GL092084

Local mass balance

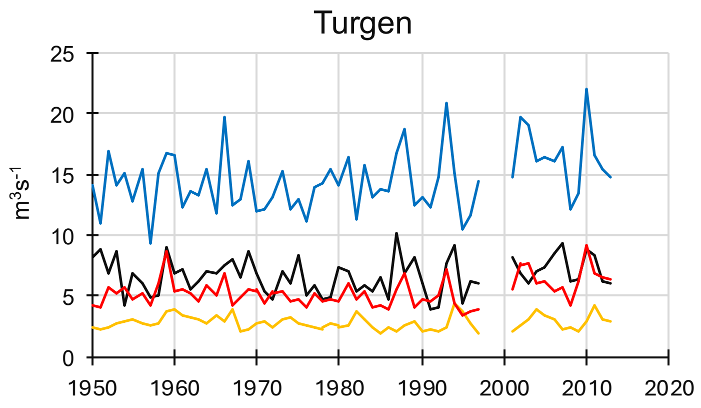


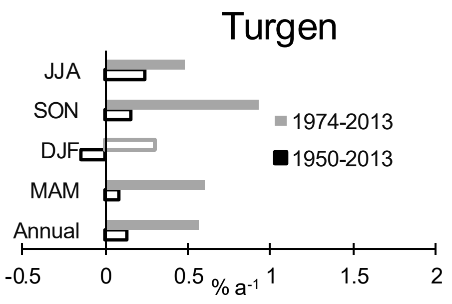
Kapitsa et al 2020





High glacierisation (15%)

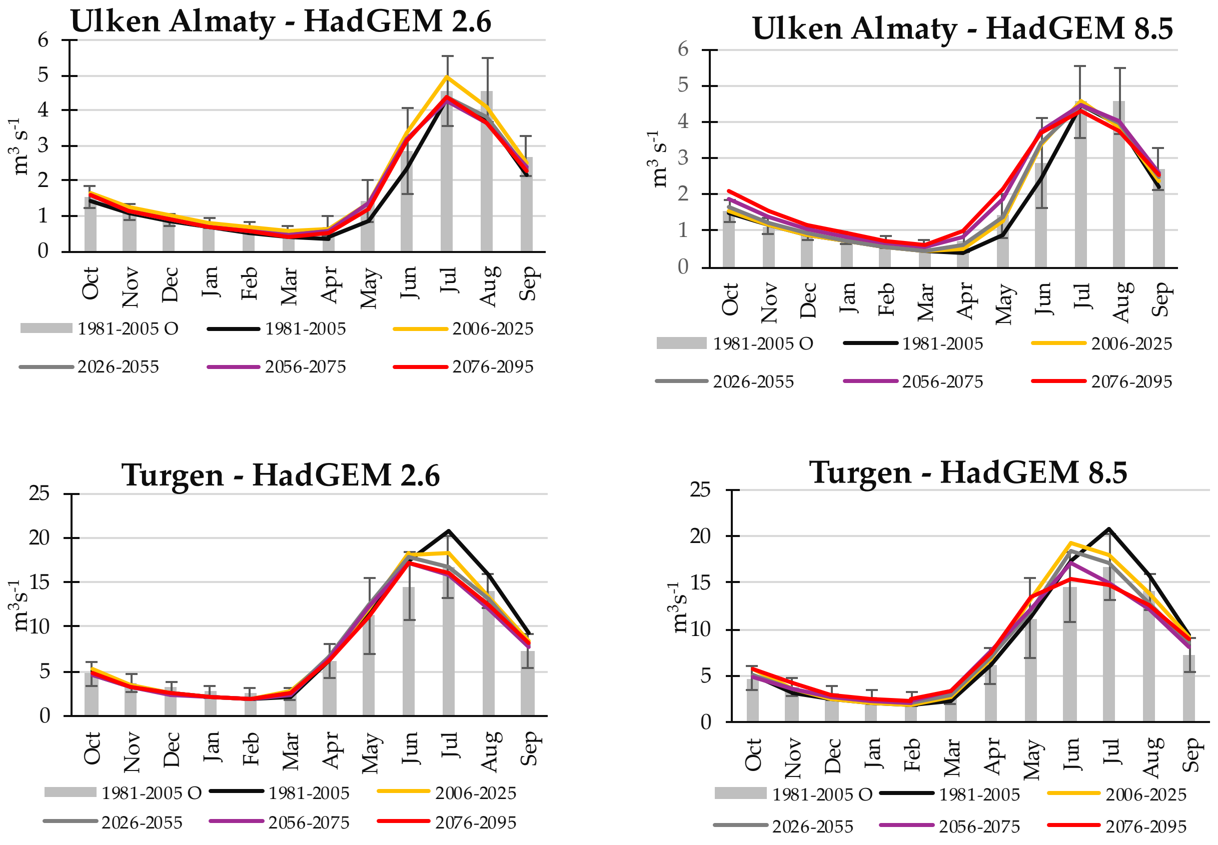




Low glacierisation (4%)

Shahgedanova et al. (2018) 10.1016/j.jhydrol.2018.08.001:

- Streamflow is modified throughout the region except headwaters
- In natural catchments, there is no evidence for streamflow reduction
- Increase in JJA flow in catchments with glacierization >10% (e.g. UA)



Shahgedanova et al. (2020) doi.org/10.3390/w12030627:

- Future projections for several catchments in Ile Alatau using multi-model downscaled ensemble of climate projections for RCP2.6 and RCP8.5
- Peak water has been reached
- Decline in July-August flow (glacier melt) in catchments with glacierization <10%
- Increase in April-June flow (snow melt)

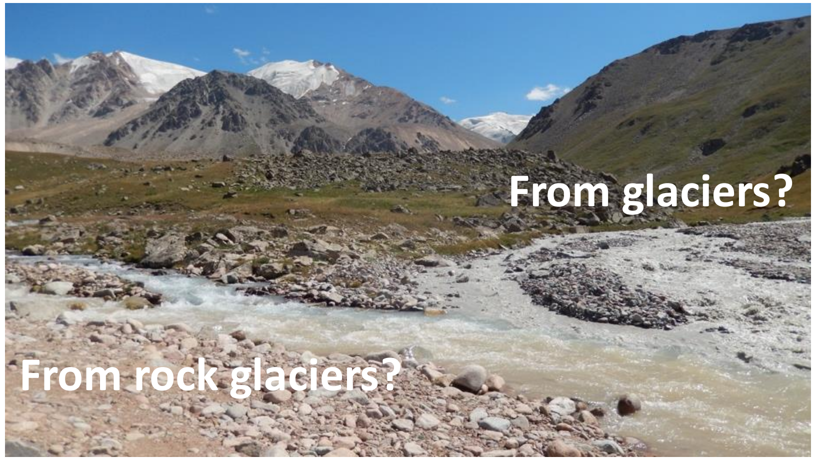
What we don’t know:

- How regional-scale catchments will respond to climate change
- Whether GLOFs will increase in frequency and/or magnitude
- How glaciers will respond to warming
- The role of rock glaciers in regional hydrology
- Whether extreme events are stochastic or climate-related

Gap in Knowledge and Policy-relevant Issue: Sources of Water

Timing of peak flow depends on:

- Projected temperature change
- Projected precipitation change and share of solid / liquid precipitation
- Glacierization of catchments and characteristics of glaciers (size, elevation)
- How glacier cover will change in the future
- Timing of glacier melt in relation to seasonal precipitation maximum (minimum)
- Contribution of various sources to total runoff



Ulken Almaty, Ile Alatau, Kazakhstan

- Liquid precipitation
- Snow melt
- Glacier melt (including snow and ice)

} Included in hydrological models

- Permafrost
- Rock glaciers
- Ground water

} Not included in models but are important on regional / local scales

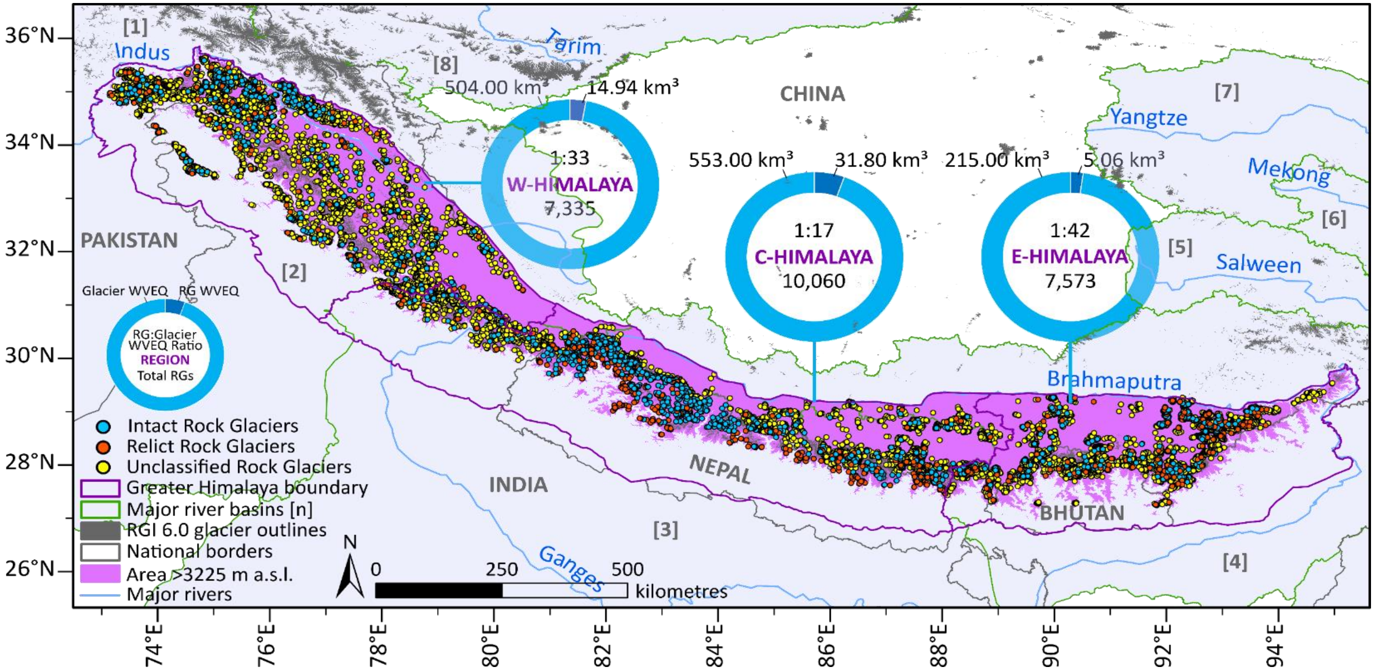
Adaptation is affected by:

- Relative contributions of renewable (rain, seasonal snow) and non- or slowly renewable (glacier and ground ice) sources
- Different response time: Snow – instant, glaciers – medium (years), ground ice – slow (decades)

Analysis of isotopic (oxygen, hydrogen) composition of water is the best way to obtain this knowledge and constrain models. Extensive regional project coordinated by the University of Reading and IAEA.

Rock Glaciers and catchment hydrology

Bob Wester



More than 44,000 rock glaciers in Tibet (Sun et al 2024)

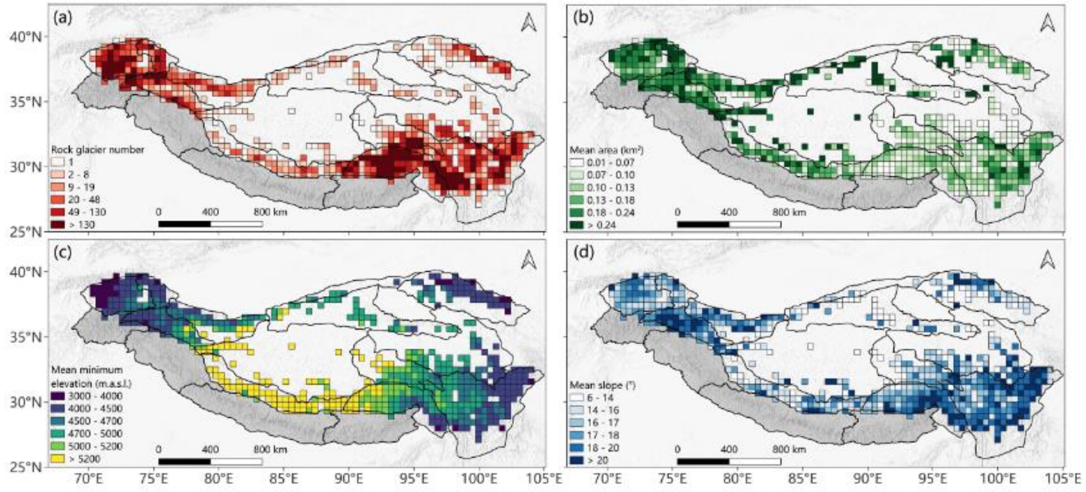


Figure 7. Rock glacier (a) density, (b) area, (c) minimum elevation and (d) slope averaged over grid cells of 50 km × 50 km.

The first systematic rock glacier inventory for the Greater Himalaya ~25,000 rock glaciers with an estimated areal coverage of 3,747 km².

Rock glaciers are estimated to contain a WVEQ of 51.80 ± 10.36 km³ (47.48 ± 9.50 Gt).

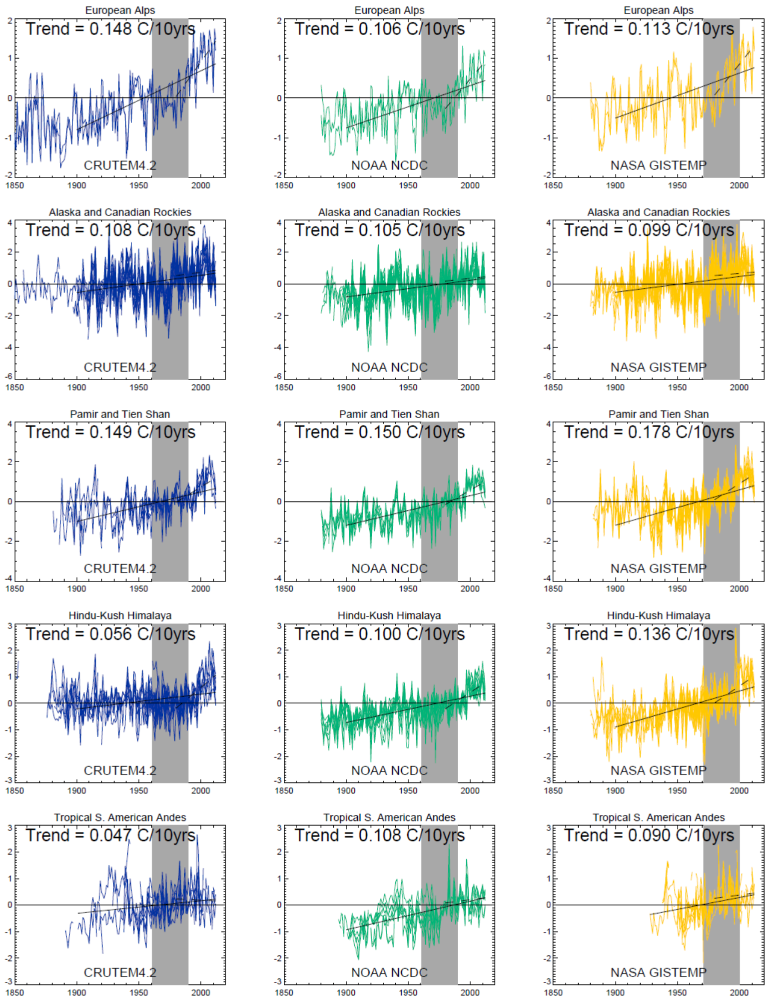
Equates to a rock glacier: glacier WVEQ ratio of 1:24, ranging from 1:42 to 1:17 in the East and Central Himalaya, respectively.

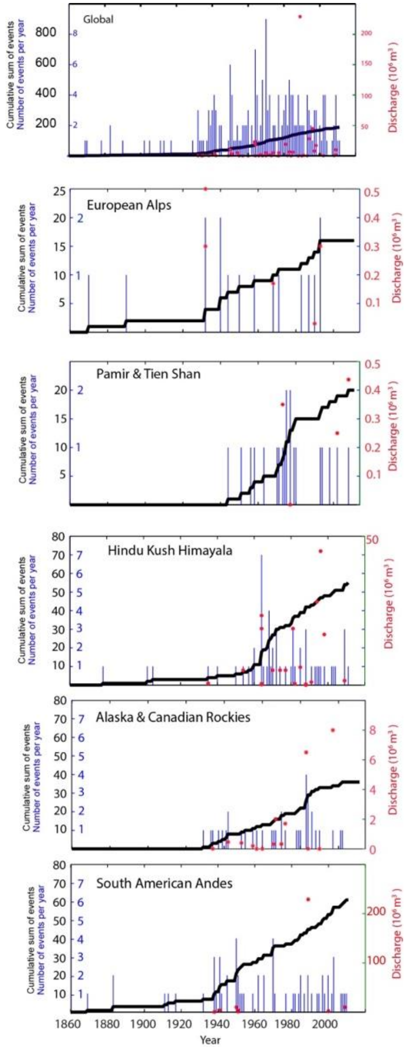
Jones et al 2021; Harrison et al 2024

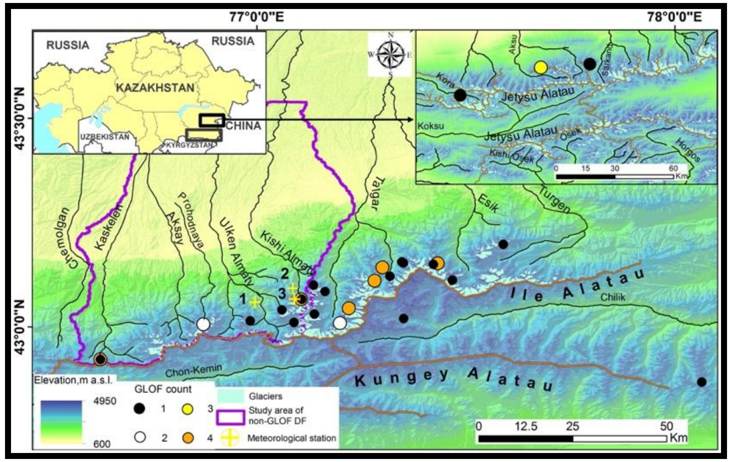
Glacial Lake Outburst Floods: Global and Regional

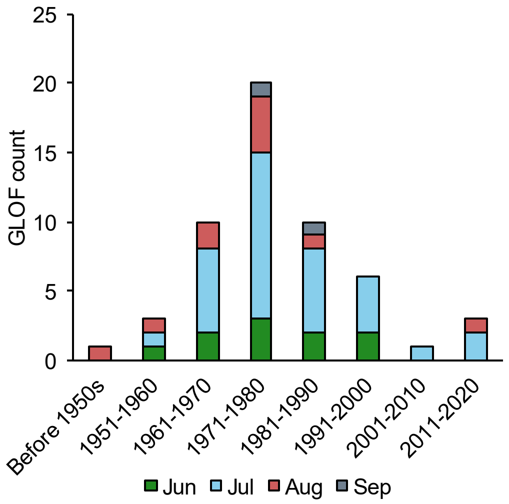
Global pattern of glacial lake outburst floods

1. Warming in all mountain regions
2. GLOF peak in 1970s and 80s
3. Delayed response to LIA glacier recession
4. Implications for the future





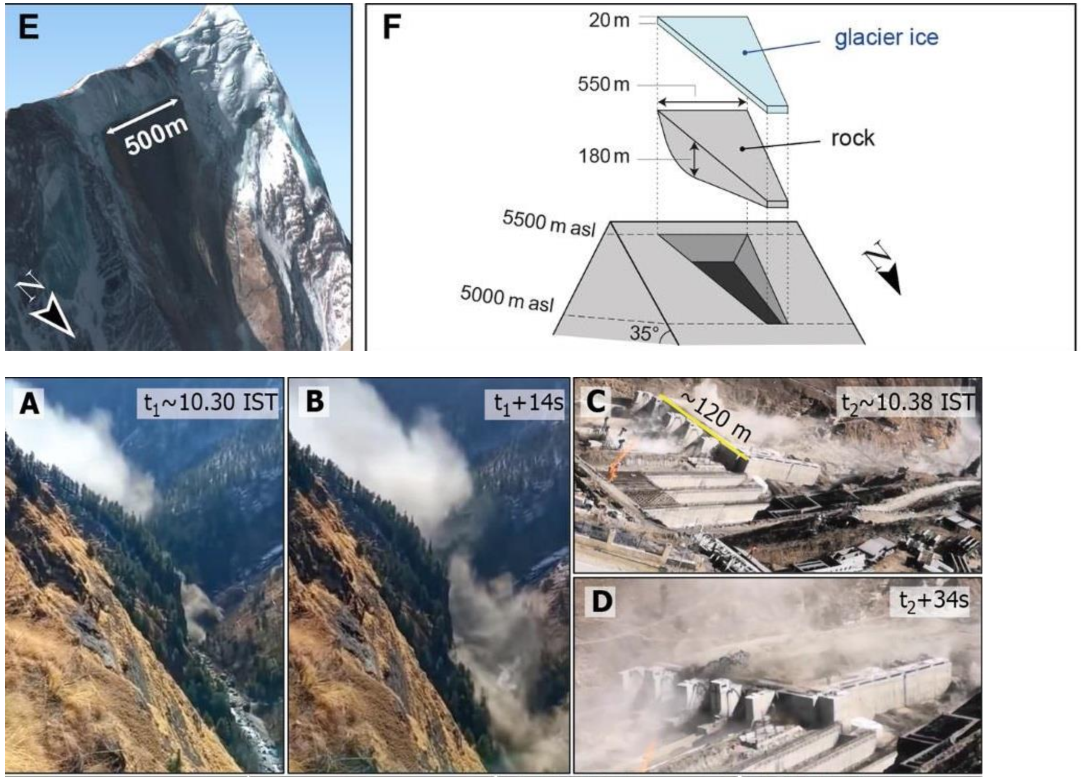




Shahgedanova et al., 2024

Harrison *et al.*, 2018

Extreme Events: rock falls and debris flows



2021 Chamoli disaster

27M cubic metres

Shugar et al 2021

3700m fall

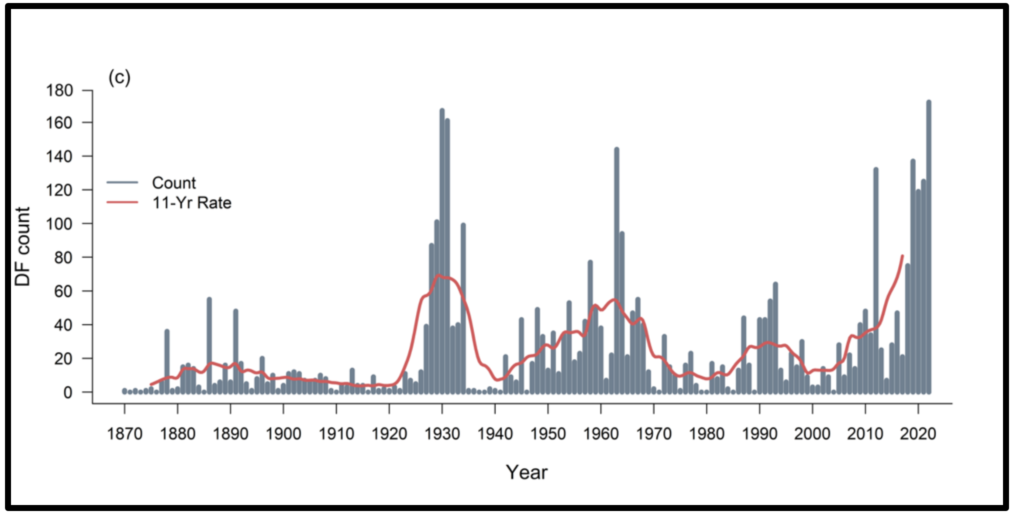
Over 200 fatalities

Cascading Risk:

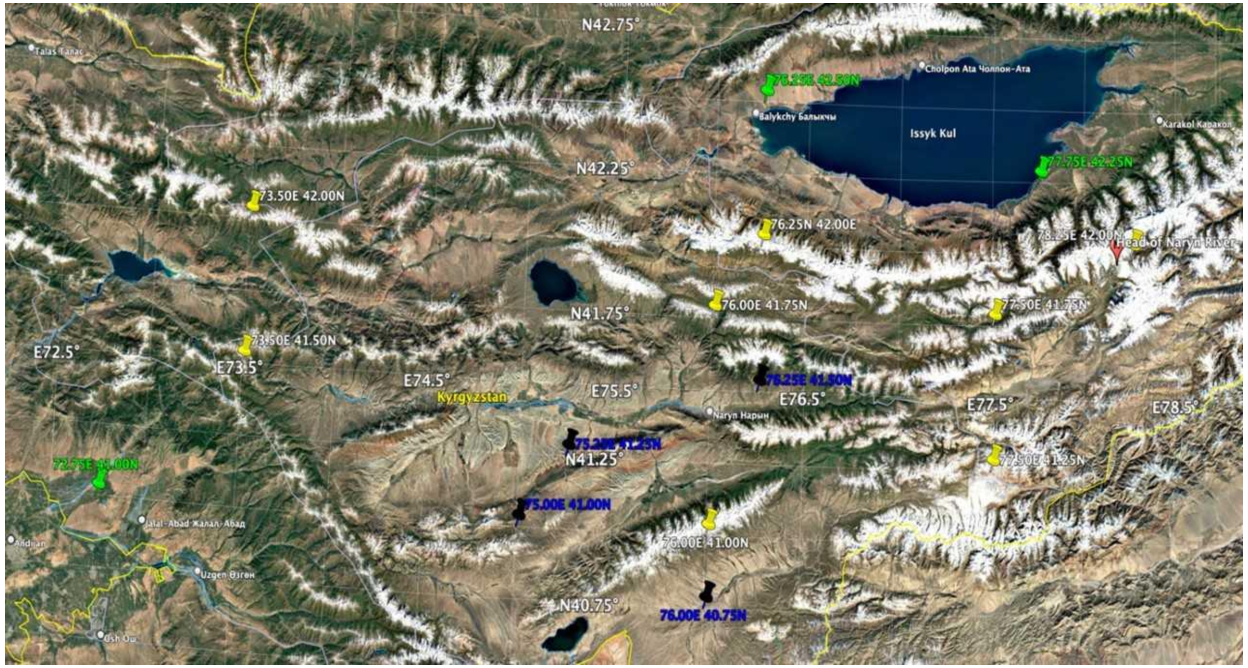
- rock fall melted glacier
- produced debris flow
- killed over 200 people and
- destroyed HEP scheme

- Largest such event on record
- Was it caused by climate change?

Debris Flows (Mamadjanova et al., 2018



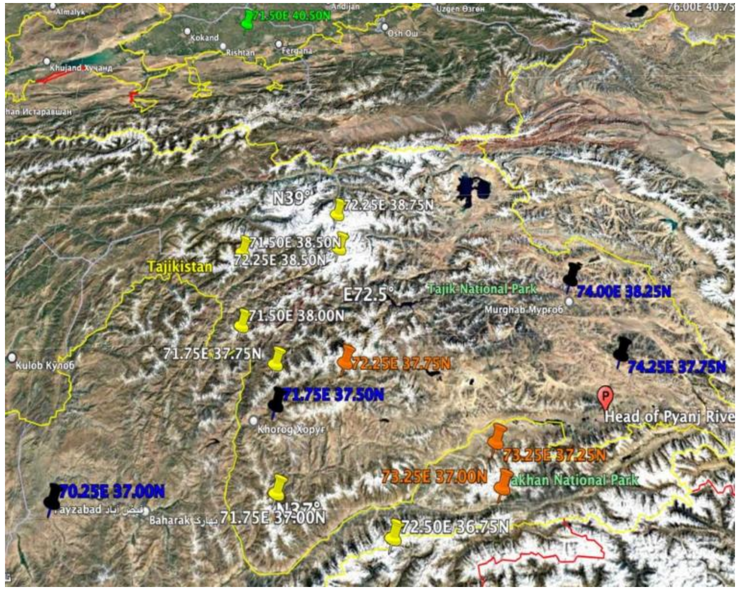
ADB G2F catchments



Catchments:
Top left: Kura

Top right: Naryn

Bottom left: Pyanj



- White – grid points centred near mountain ridges, above the snow line, that best represent the glaciated regions, for point is 683mwhich the ERA5 snow data appear reasonable. All points are above 4000m elevation.
- Orange – grid points centred near mountain ridges, above the snow line, that best represent the glaciated regions, but for which the ERA5 snow data do not appear reasonable and have been ignored. All points are above 4000m.
- Blue – grid points centred at high elevation below the snow line, and thus providing a wider picture but not indicative of changes to glaciers *per se*. Elevations range from 1906m to 4755m.
- Green – grid points centred at lower levels, perhaps agricultural regions, not necessarily directly within the basin itself, but providing a wider picture. The elevation for the single included grid.

ADB G2F Project 1: model projections

Kura Temperature				
	DJF	MAM	JJA	SON
	SSP 8.5	SSP 8.5	SSP 8.5	SSP 8.5
>=2ºC	100%	100%	100%	100%
>=3ºC	100%	100%	100%	100%
>=4ºC	20%	100%	100%	100%
>=5ºC	0%	35%	100%	65%

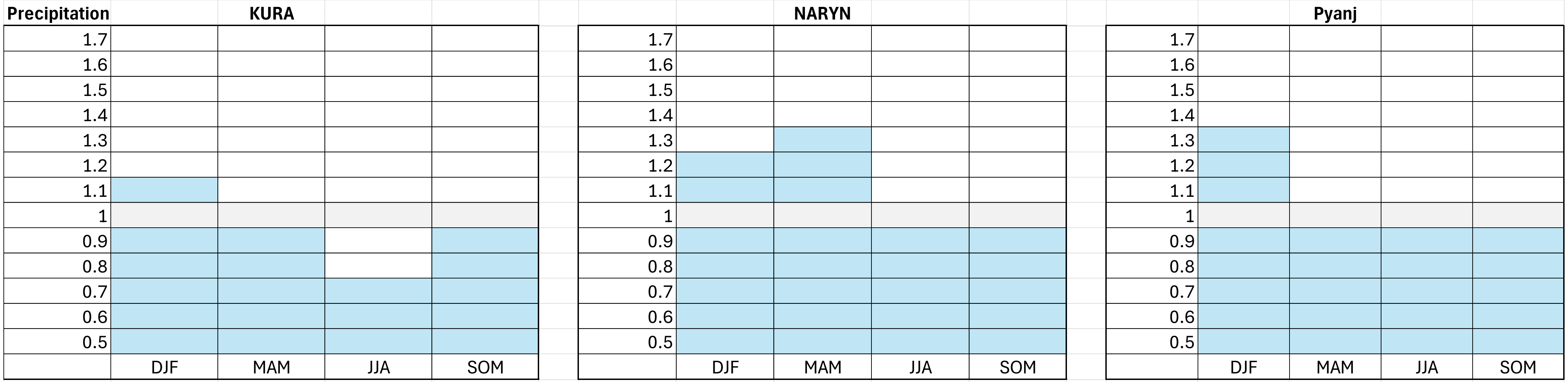
Naryn Temperature				
	DJF	MAM	JJA	SON
	SSP 8.5	SSP 8.5	SSP 8.5	SSP 8.5
>=2ºC	100%	100%	100%	100%
>=3ºC	100%	100%	100%	100%
>=4ºC	100%	55%	100%	85%
>=5ºC	40%	55%	100%	85%

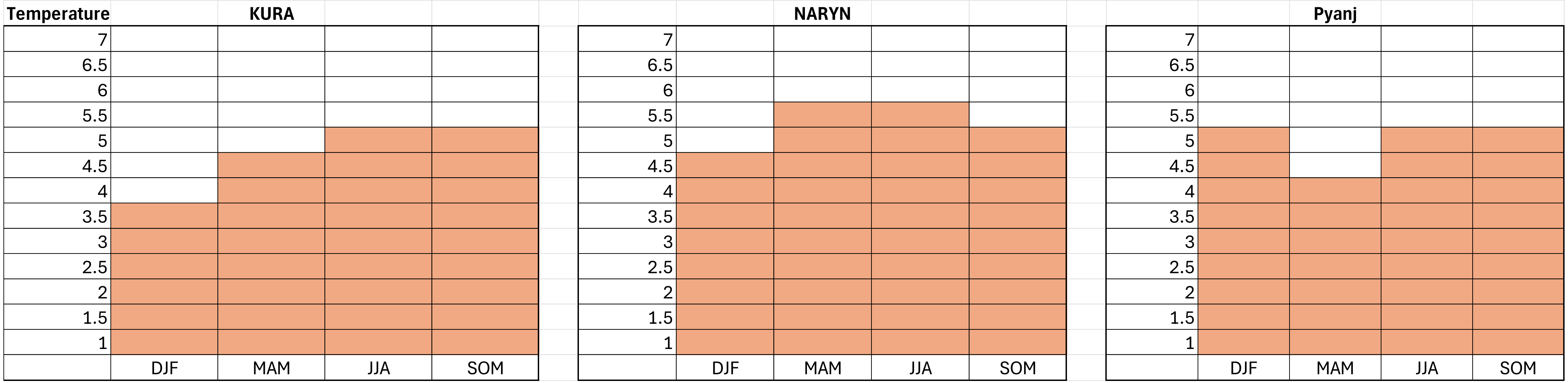
Pyanj Temperature				
	DJF	MAM	JJA	SON
	SSP 8.5	SSP 8.5	SSP 8.5	SSP 8.5
>=2ºC	100%	100%	100%	100%
>=3ºC	100%	100%	100%	100%
>=4ºC	100%	100%	100%	100%
>=5ºC	90%	65%	85%	85%

Kura Precipitation				
	DJF	MAM	JJA	SON
	SSP 8.5	SSP 8.5	SSP 8.5	SSP 8.5
Increase of 10% or more	100%	35%	0%	0%
Change within ±5%	0%	65%	50%	65%
Decrease of 10% or more	0%	0%	50%	35%

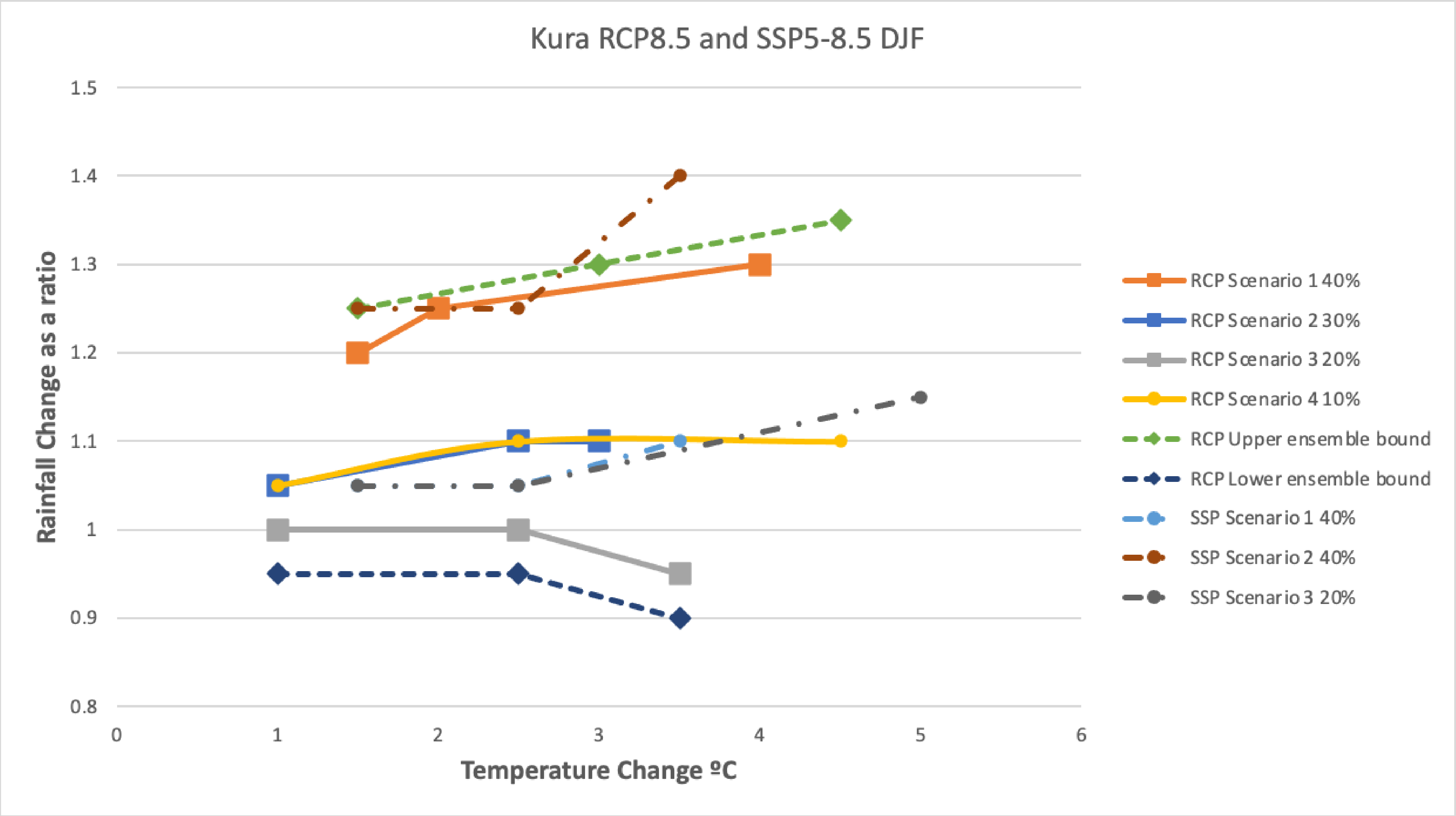
Naryn Precipitation				
	DJF	MAM	JJA	SON
	SSP 8.5	SSP 8.5	SSP 8.5	SSP 8.5
Increase of 10% or more	100%	70%	0%	0%
Change within ±5%	0%	30%	70%	65%
Decrease of 10% or more	0%	0%	30%	35%

Pyanj Precipitation				
	DJF	MAM	JJA	SON
	SSP 8.5	SSP 8.5	SSP 8.5	SSP 8.5
Increase of 10% or more	80%	35%	15%	25%
Change within ±5%	0%	35%	60%	60%
Decrease of 10% or more	20%	30%	25%	15%


Precipitation
KURA
NARYN
Pyanj
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
DJF
MAM
JJA
SOM


Temperature
KURA
NARYN
Pyanj
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
DJF
MAM
JJA
SOM

ADB G2F Project 2: SOMs

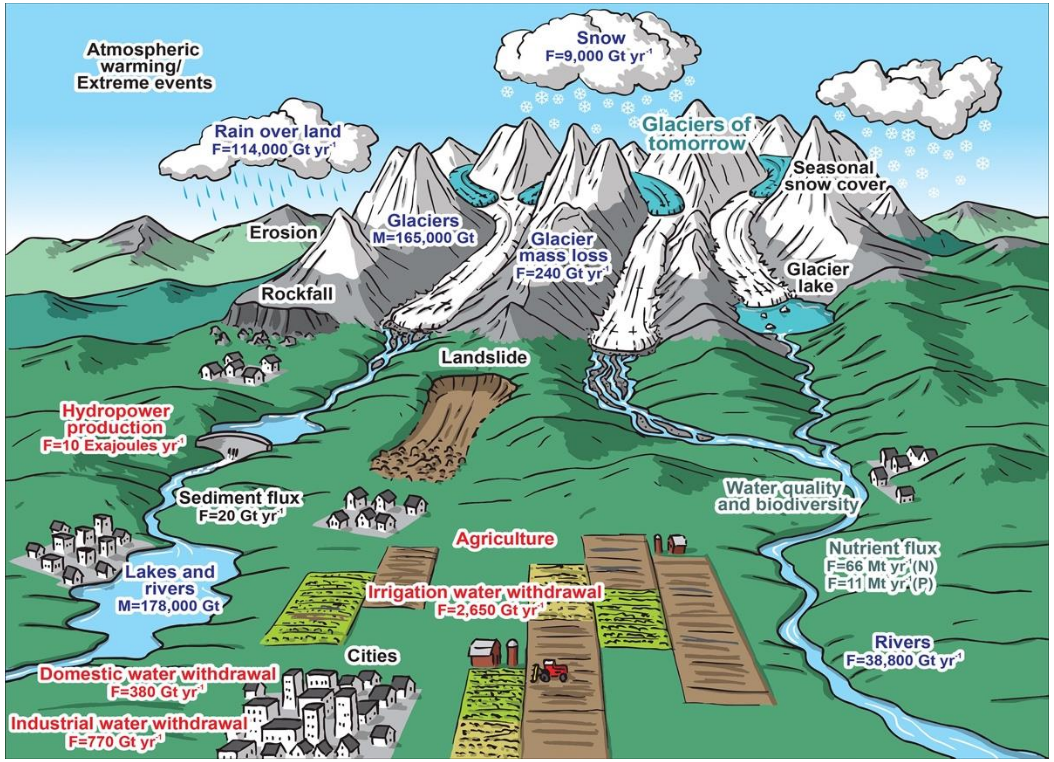


ADB G2F Project 3:

Climate Risk Assessment

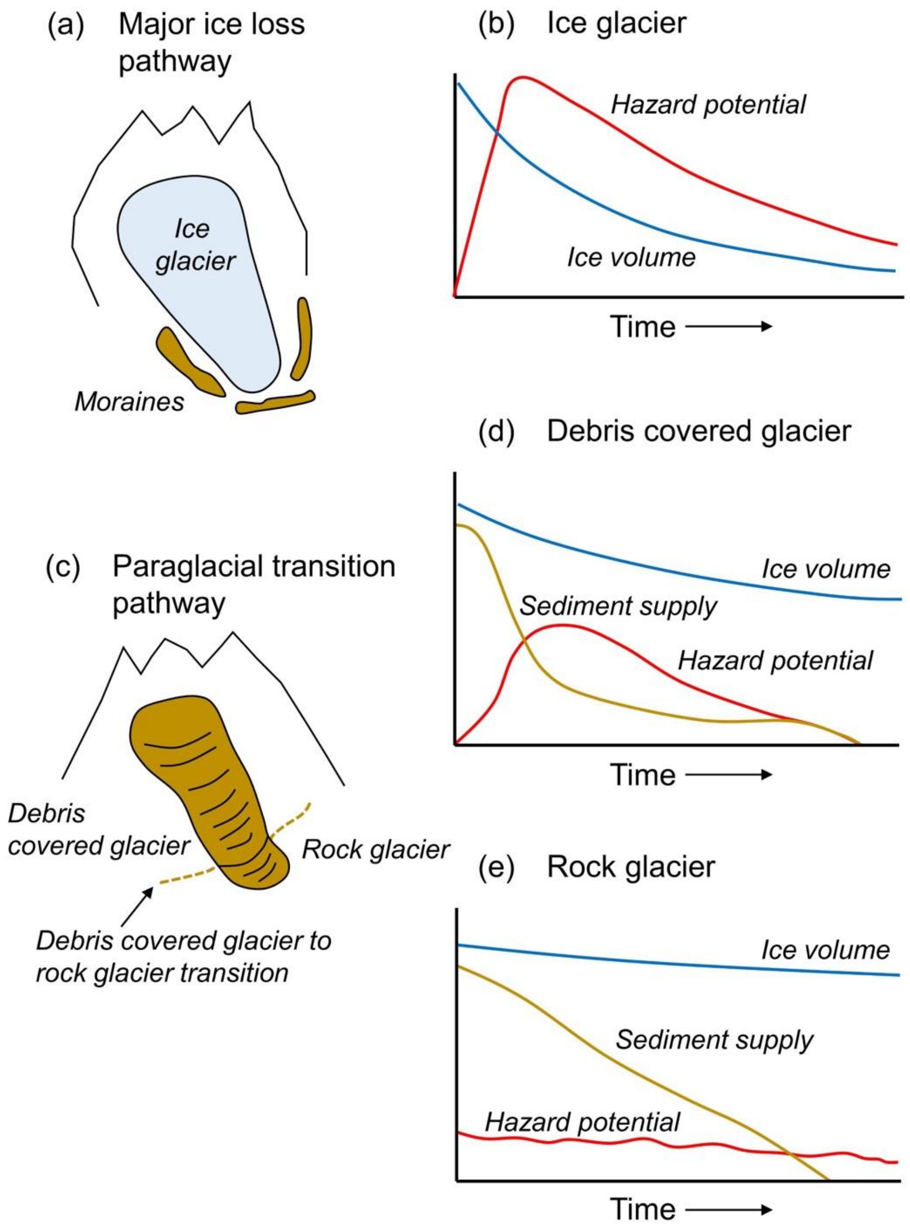
Hazard (Climatic)	Hazard (Glacial)	Kura current	Kura Future	Residual Risk
Increase in temperature (long term trend)	Glacier retreat	Very Low	Very Low	Very low
		Very Low	Very Low	Very Low
		Very Low	Low	Very low
		Very Low	Low	Low
		Moderate	Moderate	Very low
	Melting permafrost	No Risk	No Risk	No Risk
	Shorter snow season duration	Extreme	Extreme	High
		Moderate	Moderate	Low
	Melting of rock glaciers and acceleration of creep	No Risk	No Risk	No Risk
Change in accumulation seasons percipitation	Decline in precipitation: Negative glacier mass balance, retreat of glaceirs	Low	Low	Low
	Increase or positive anomalies in precipitation: Oversaturation of soils and substrates	Extreme	Extreme	High
	Decline or negative anomalies in precipitation: reduced accumulation of seasonal snow	Extreme	Extreme	Moderate
Extreme snowfall	Complex interactions with other meteorological variables	High	High	High
		High	High	Moderate
Change in melt season precipitation	Reduced reflectance of glaciers leading to faster melting	Low	Low	Low
	Negative anomalies / drought	Extreme	Extreme	Extreme
	Positive anomalies in precipitation	High	High	Moderate
Change in ratio of snow and rain	Reduced snow accumulation	High	High	Moderate
	More frequent 'rain on snow' events	Extreme	Extreme	High
Heatwaves	Rapid degradation of glaciers	Extreme	Extreme	Moderate
	Degradation of permafrost	No Risk	No Risk	No Risk
	Rapid snow melt	Extreme	Extreme	High
Droughts	Rapid degradation of glaciers	Moderate	Moderate	High
	Long-term impact on permafrost	No Risk	No Risk	No Risk
	Insufficient water supply	Extreme	Extreme	Moderat+L11:L29e

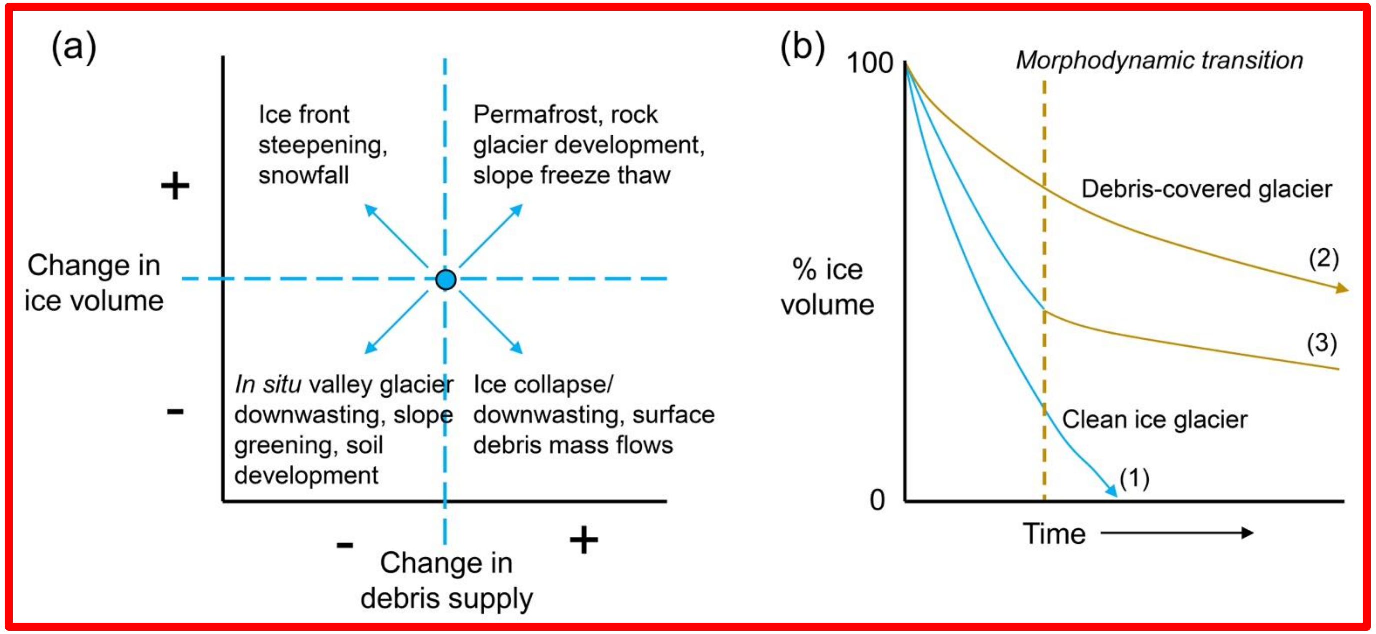
The Future?



- **Increasing abundance and area of glacial lakes especially in Central and High Mountain Asia**
  - Over 4,500 glacial lakes in Tien Shan, covering a combined area of 205.73 ± 0.17 km^2 in 2023 (Chen et al., 2024)
  - Tajikistan (Pamir and Hissar-Alay): ~3330 lakes with individual area >200 m^2 located within 10 km distance from glacier tongues with a combined area of 130.59 km^2
- **Potential increase in frequency of GLOF**
  - Frequency of GLOF peaked in the 1970s-1980s
  - No increase in GLOF frequency to date
  - Increase in frequency of GLOF in the future is possible
- **Increase in intensity of precipitation and frequency of share of rain in total precipitation**
  - Flash floods, landslides and debris flows caused by intense rainfall
  - Upwards extension of the debris flow formation zone in the Tien Shan
  - Increasing frequency of pluvial debris flows in Uzbekistan
- **Snow avalanches**

Another possible Future?





Harrison et al. (in press)

Thank you

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