Landslide Hazard Assessment & Mitigation

DML – 502 Lecture - 10

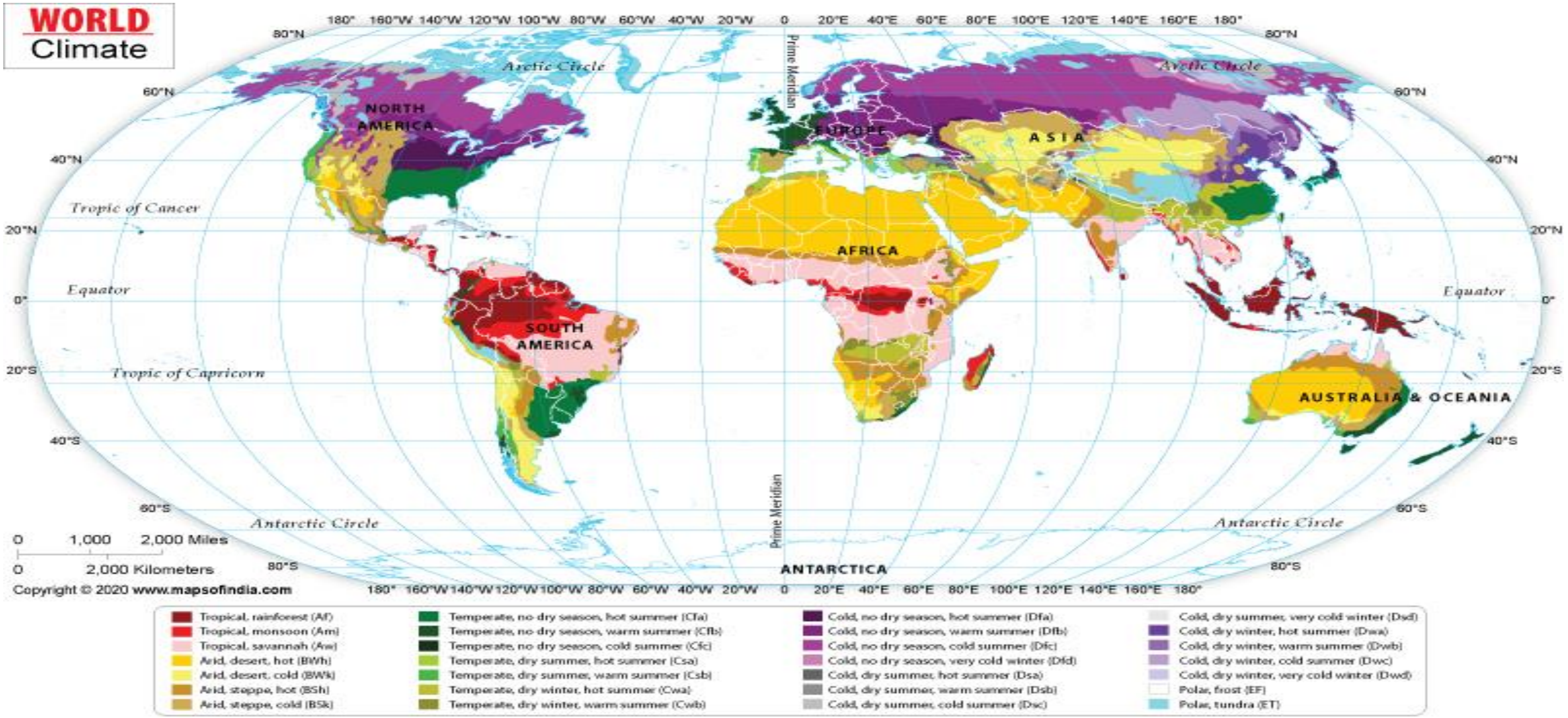
Subject Code: DML-502
Course Title: Landslide Hazard Assessment & Mitigation

"To understand mapping and hazard assessment techniques of landslides and protection against landslide."

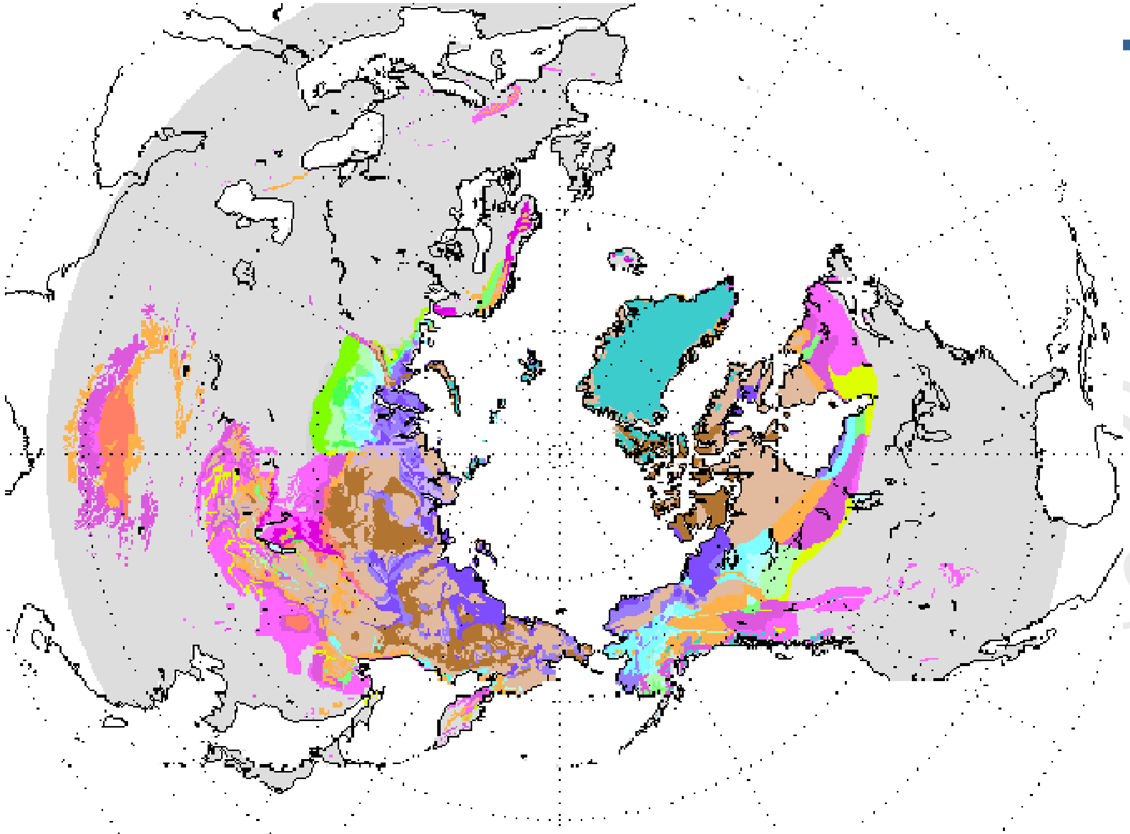
S. No 2

Causative factors of landslides – natural including inherent factors and external factors as well as anthropogenic factors; Impacts of natural causative factors like lithology, structure, slope morphometry, relative relief, hydrogeological conditions and land use and land cover on stability of slopes ; Impacts of external factors like concentrated rain fall and earth quakes on slope stability; Various causes of slope instability in Himalaya; extreme hydro-meteorological conditions leading to landslide dams and related damages; **Landslides in Cold Regions i.e., High Mountain Asia (HMA): snow/rock-ice avalanches, debris flows, cascading events.**

Cold Regions on Earth

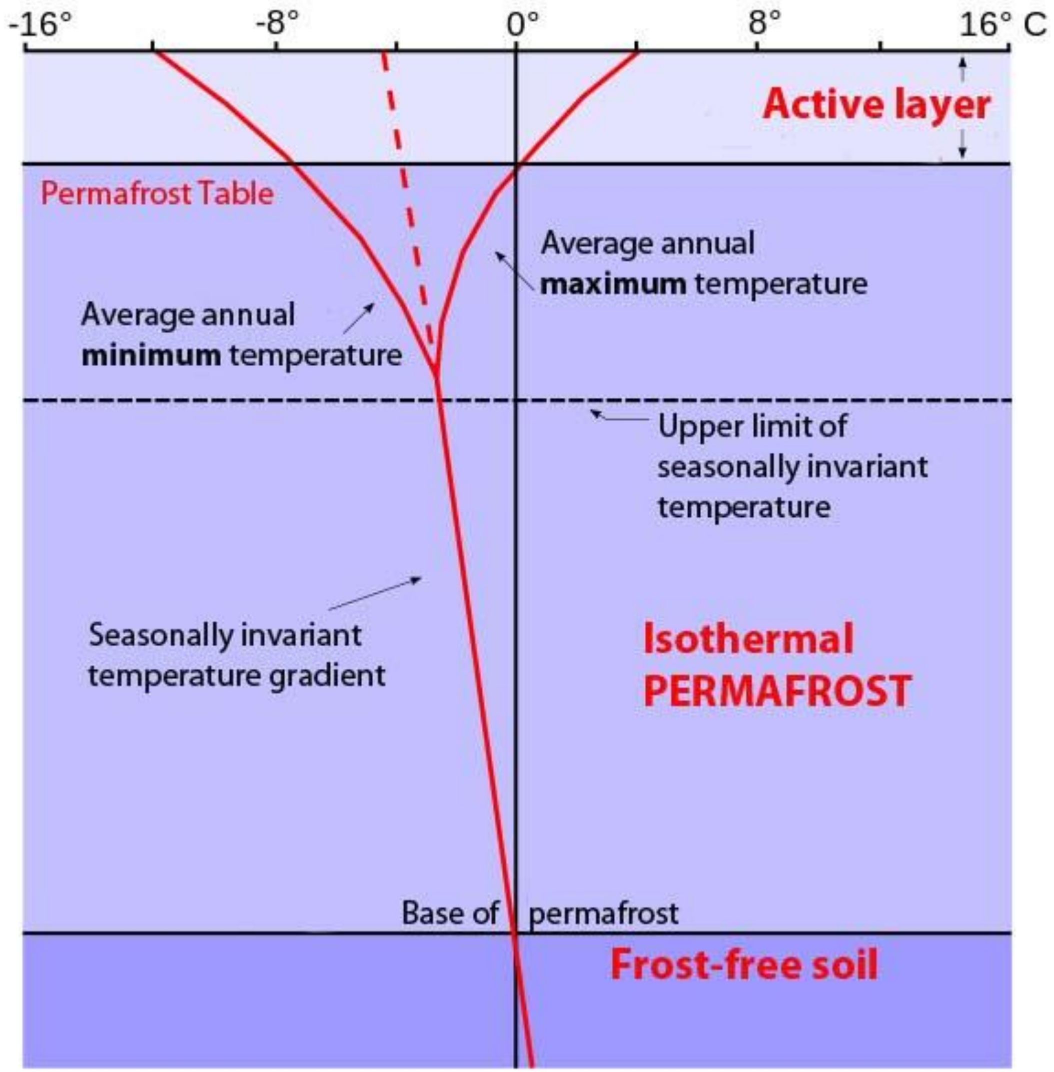


Permafrost and seasonal cold regions

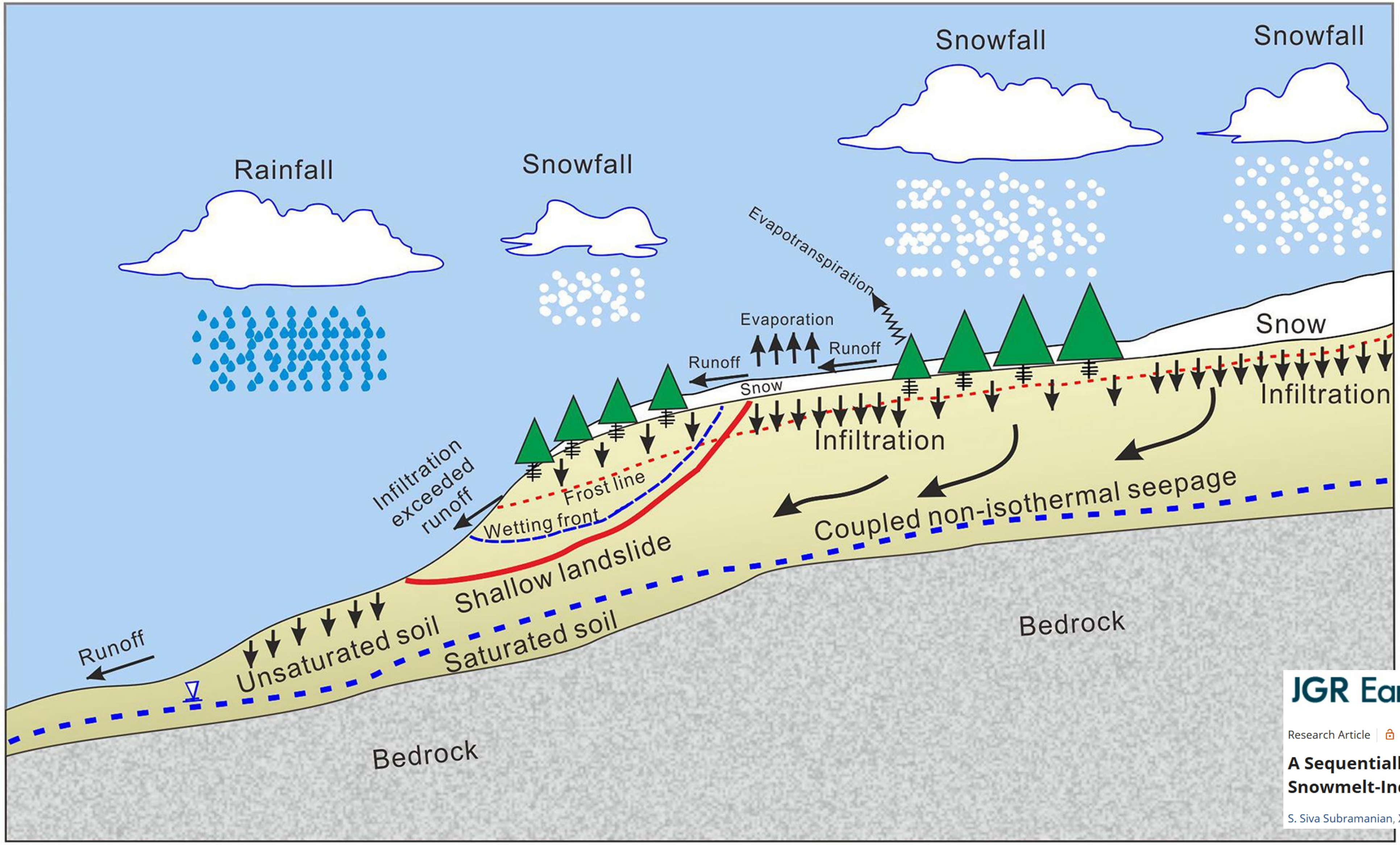


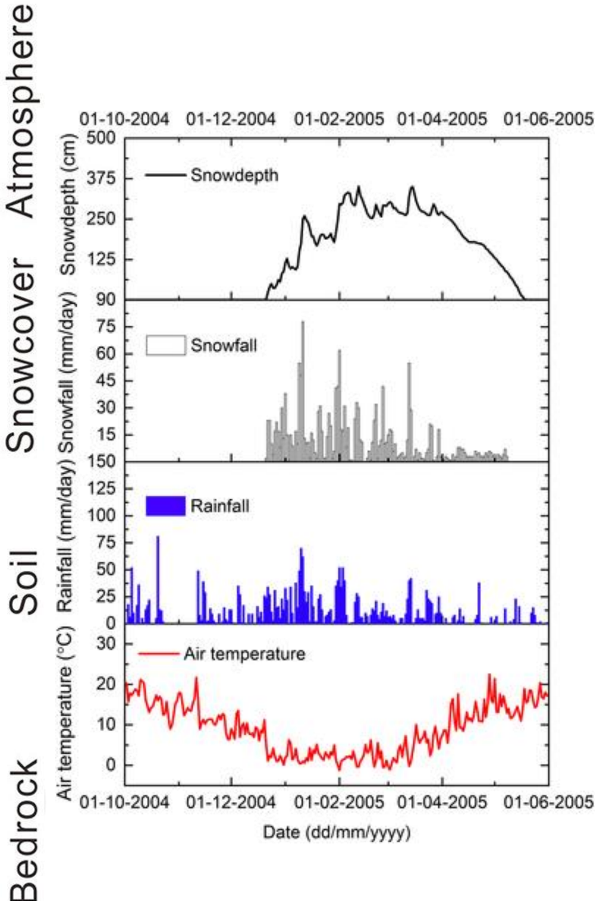
Permafrost Extent (percent of area)	Ground Ice Content (visible ice in the upper 10-20 m of the ground; percent by volume)				
	Lowlands, highlands, and intra-and intermontane depressions characterized by thick overburden cover (>5-10m)			Mountains, highlands, ridges, and plateaus characterized by thin overburden cover (<5-10 m) and exposed bedrock)	
	High (> 20%)	Medium (10-20%)	Low (0-10%)	High to medium (>10%)	Low (0-10%)
Continuous (90-100%)					
Discontinuous (50-90%)					
Sporadic (10-50%)					
Isolated Patches (0-10%)					

Ice caps and glaciers



Predominant hydrological and mechanical processes in seasonally cold regions





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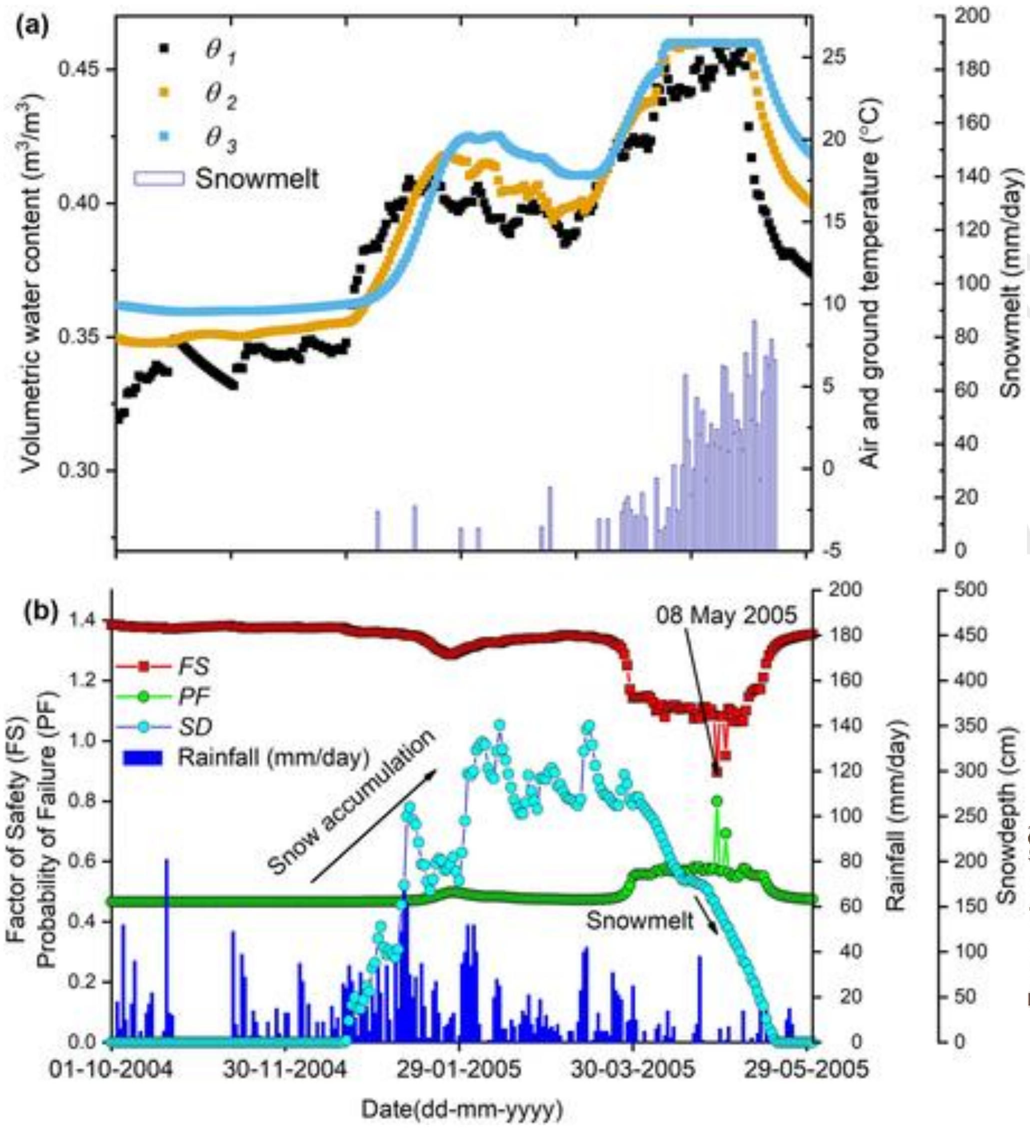
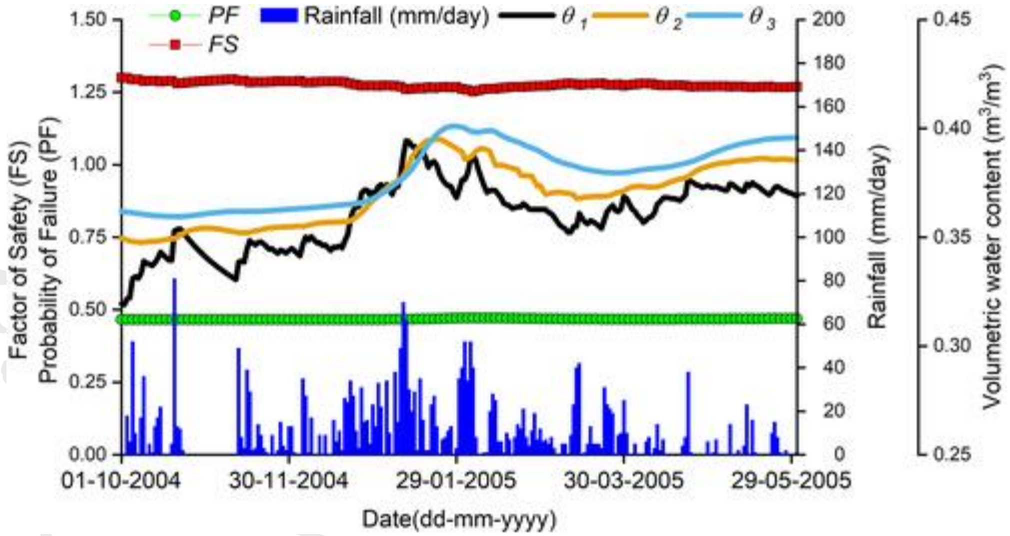
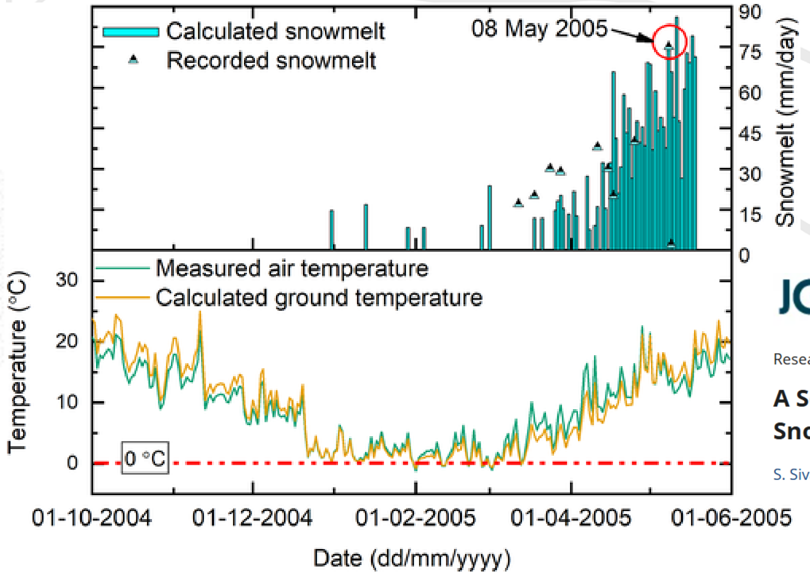
A Sequentially Coupled Catchment-Scale Numerical Model for Snowmelt-Induced Soil Slope Instabilities

S. Siva Subramanian, X. Fan, A. P. Yunus, T. van Asch, G. Scaringi, Q. Xu, L. Dai, T. Ishikawa, R. Huang

Slope instabilities caused by snowmelt and freeze-thaw action







- ❑ The frequency of snowmelt-induced soil slope instabilities is increasing in some seasonally cold regions because of climate change.
- ❑ Reliable hazard assessment and risk mitigation of snowmelt-induced landslides require physically-based prediction models.

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Debris flows from Mountain Cryosphere

Debris flows originating in the mountain cryosphere under a changing climate: A review

Guo-An Yu, Weiwei Yao, [...], and Zhaofei Liu +1 View all authors and affiliations

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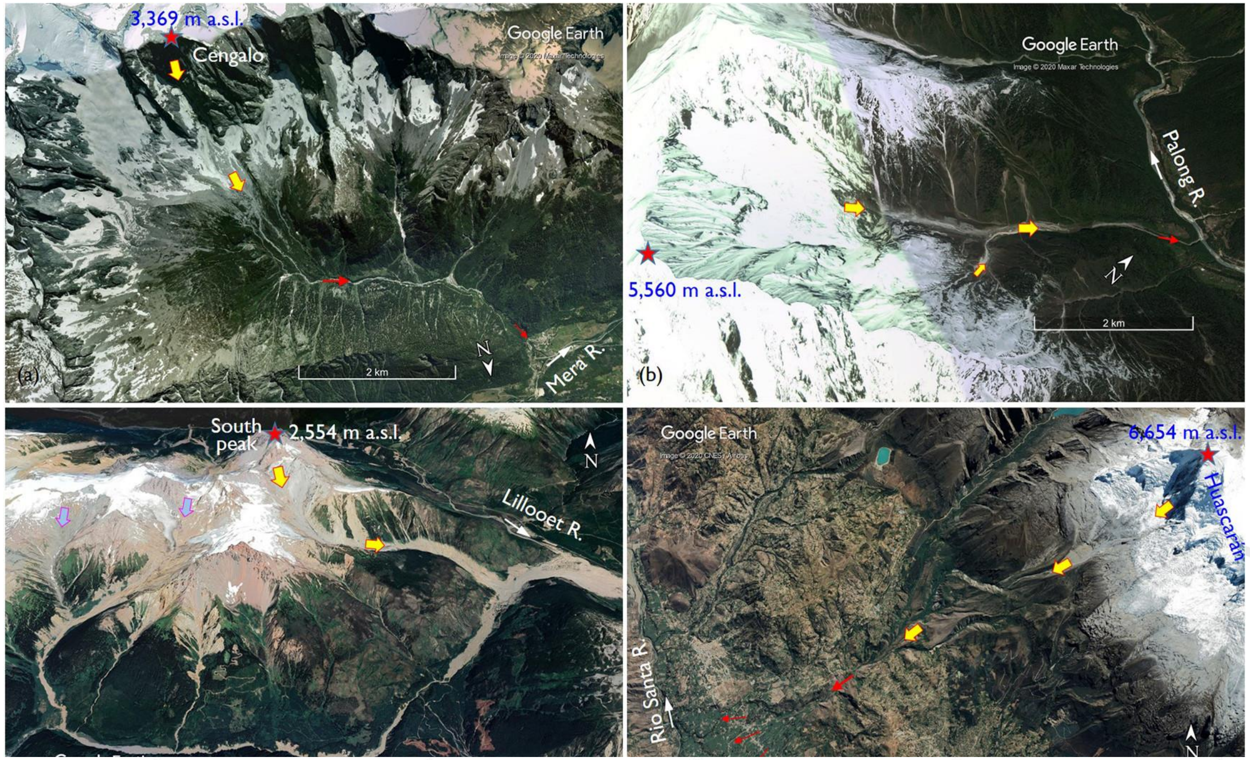
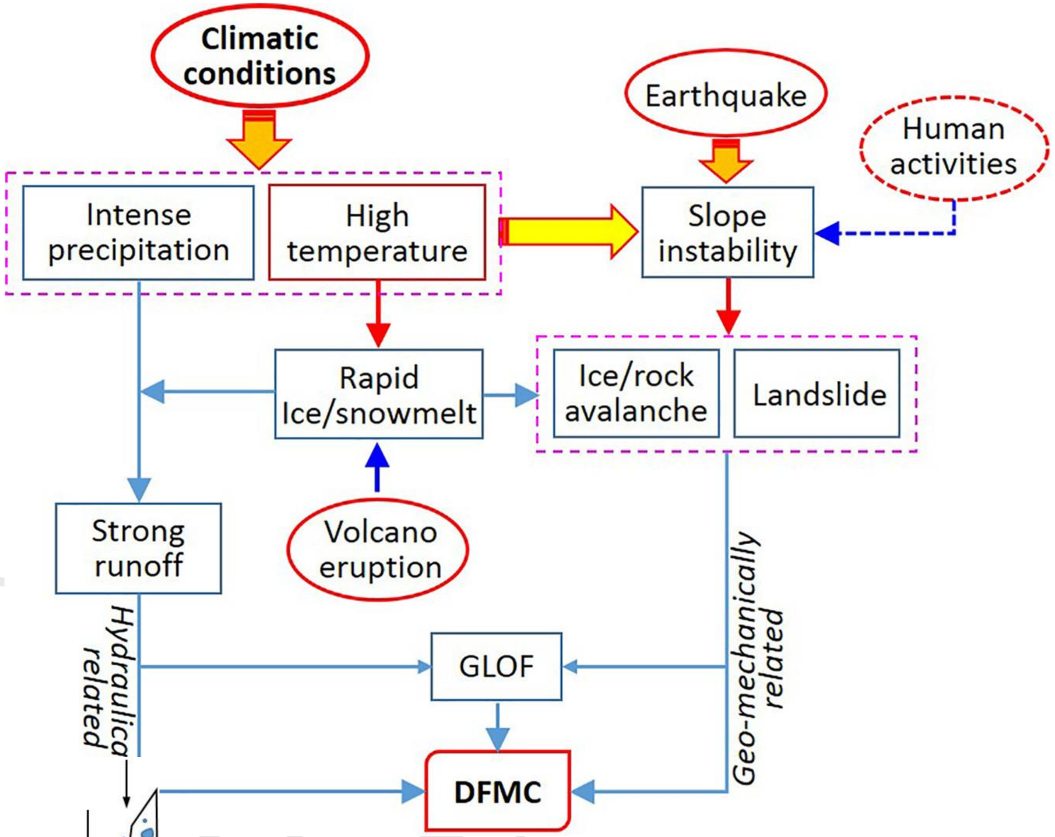
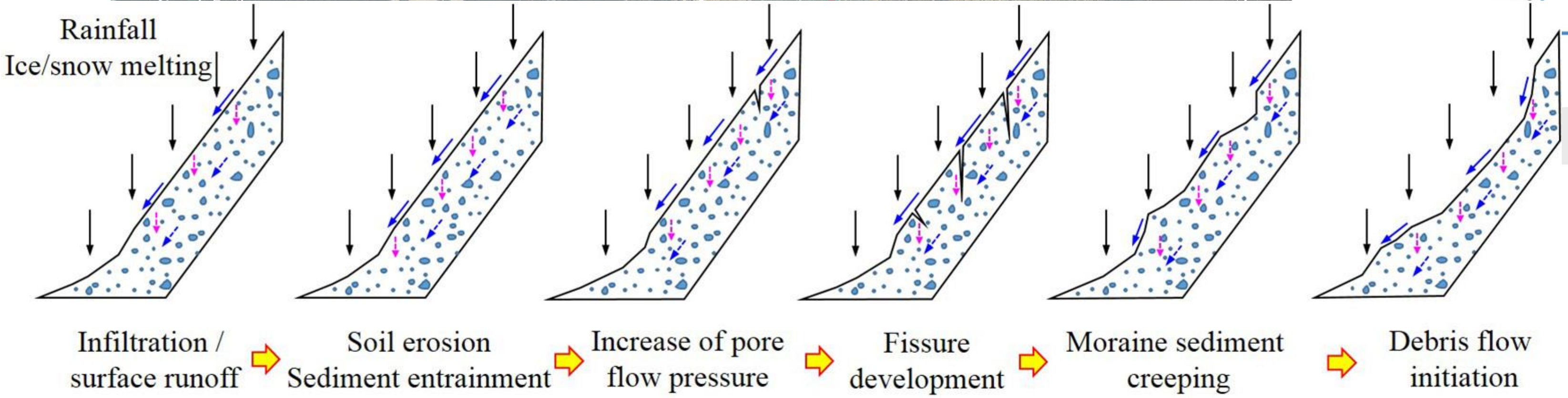
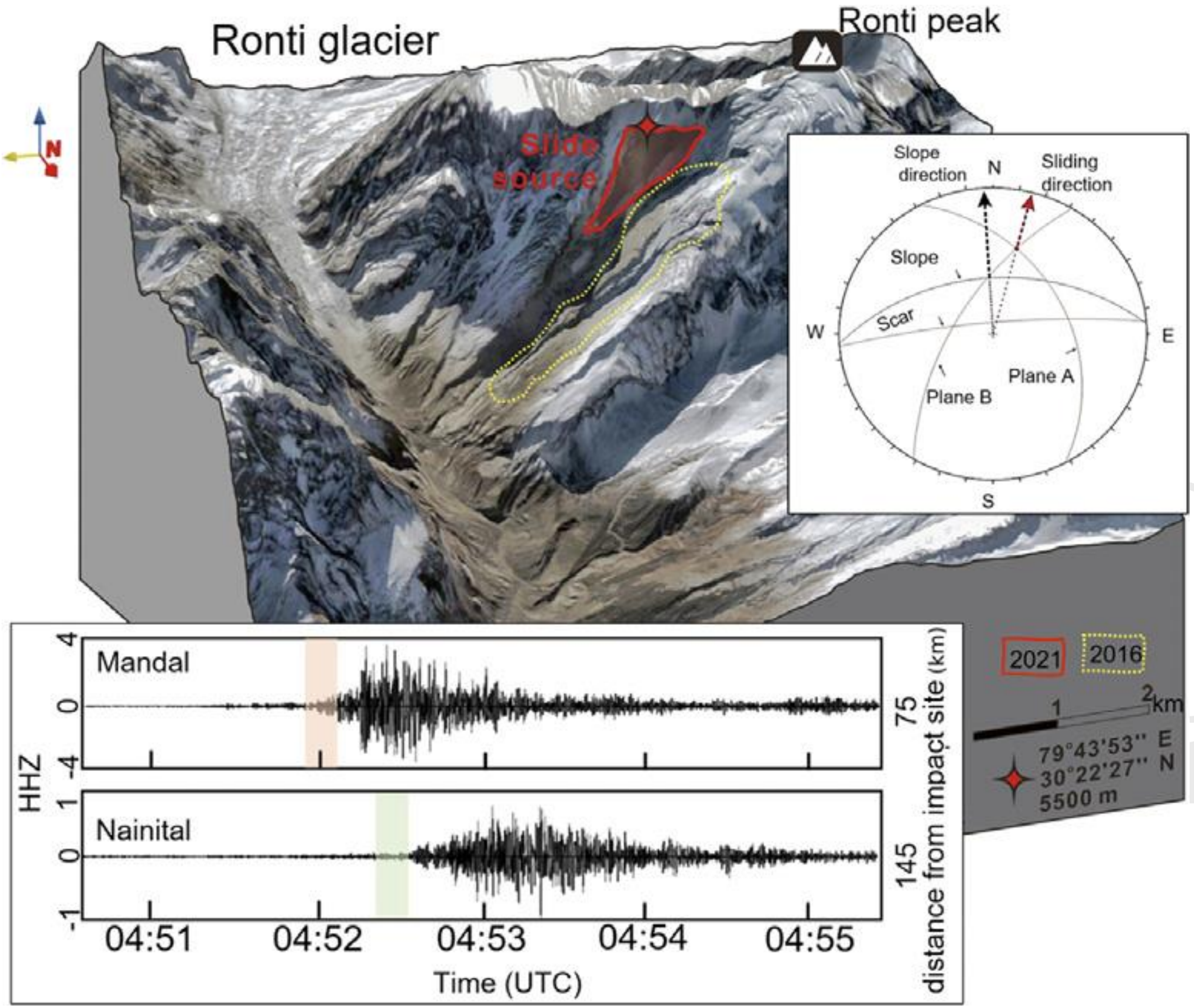






Debris flows originating in the mountain cryosphere (DFMC) are among the most globally important, widely distributed mass flows (and natural geohazards) in mountain areas with a high altitude and/or high latitude.

Landslides in Cold Regions – Rock/Ice/Rock-Ice Avalanches

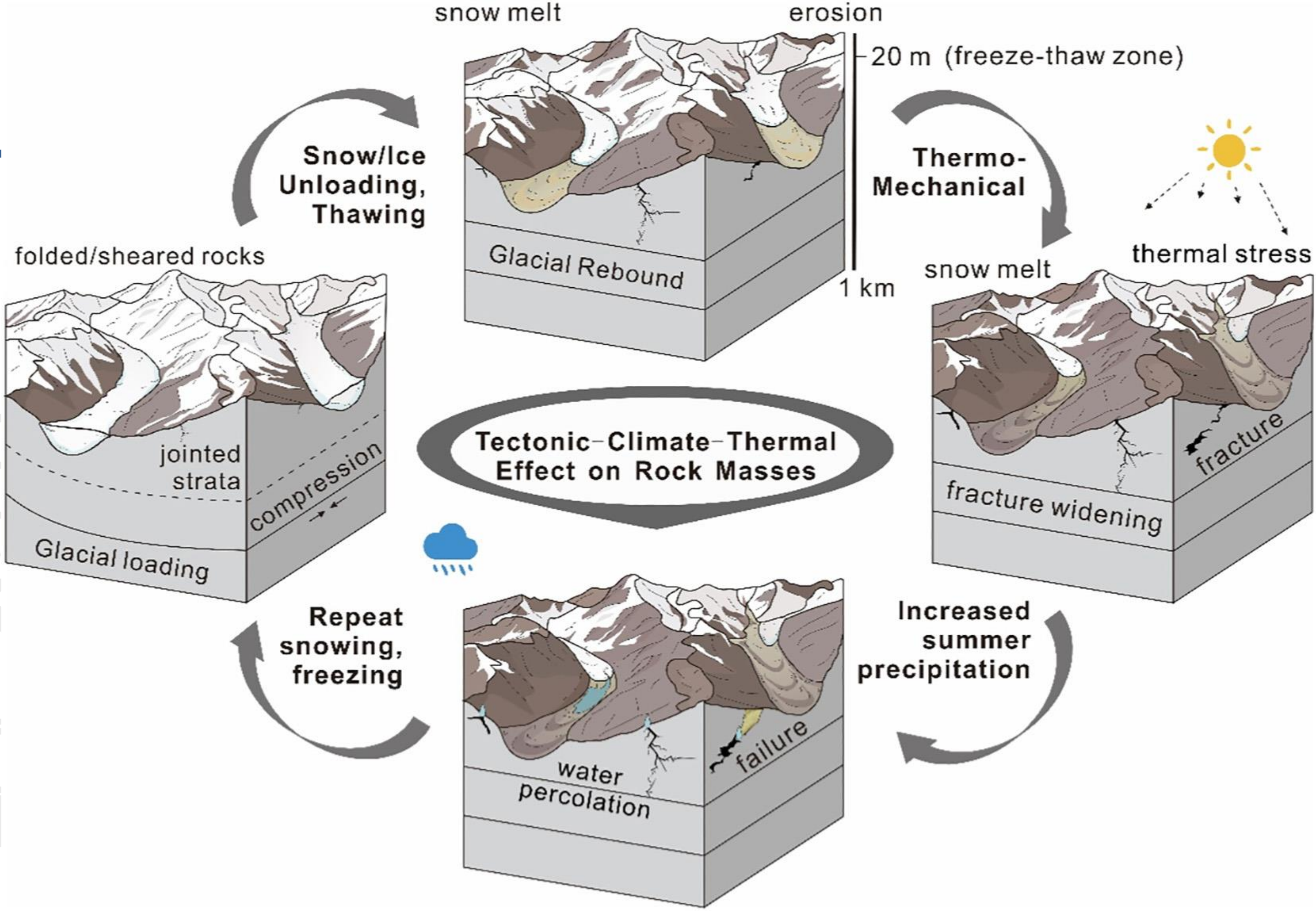


- Upsurge of glacier-related hazards in High Mountain Asia (HMA) has been evident in recent years due to global warming.
- While many glacial-related hazards are instantaneous, some large landslides were preceded by slow gravitational deformation, which can be predicted to evade catastrophes.

Fan, X., Yunus, A. P., Yang, Y. H., Subramanian, S. S., et al.(2022). *Science of the Total Environment*, *836*, 155380.

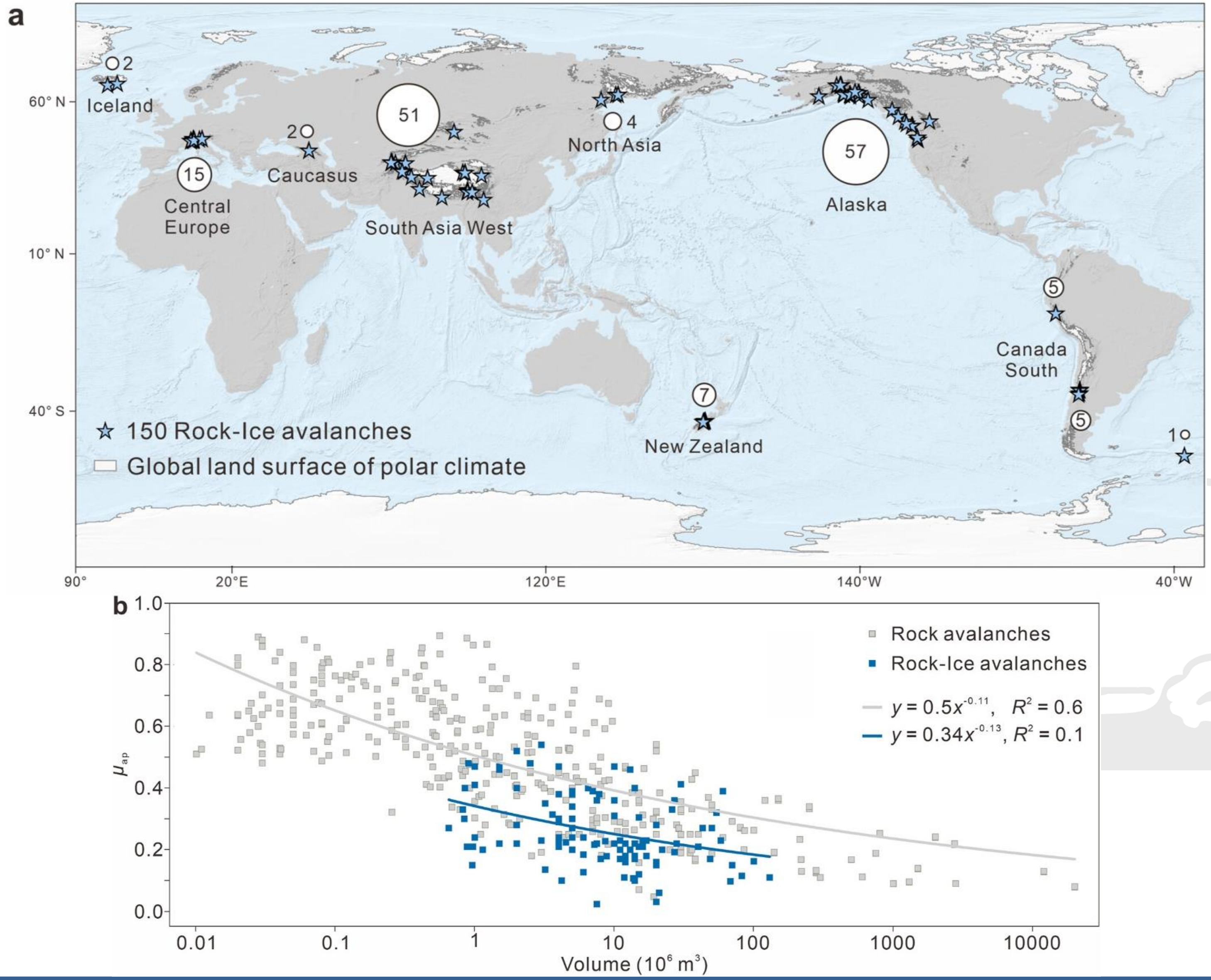
Hypothesis

- **Like ice sheets induced isostatic crustal rebound during deglaciation, the glacial loading-unloading at local scale (and annual cycles) caused by climate warming can be considered for stress failures.**
- **A few meters of snow load enhances compression and reduces the Coulomb failure stress by a few kPa, large enough to modulate the stress buildup.**
- **Thermomechanical stresses and increased summer precipitation may cause more rock slope failures**



Schematics of the impacts of climate warming on tectonic belts

Landslides in Cold Regions – Rock/Ice/Rock-Ice Avalanches



Global distribution of historical large rock-ice avalanche events, with blue pentagrams marking event locations, and numbers within circles of different sizes indicating the frequencies of events near the representative areas; (b) Statistical correlation between the apparent friction coefficient and volume in recorded rock-ice avalanches and rock avalanches.

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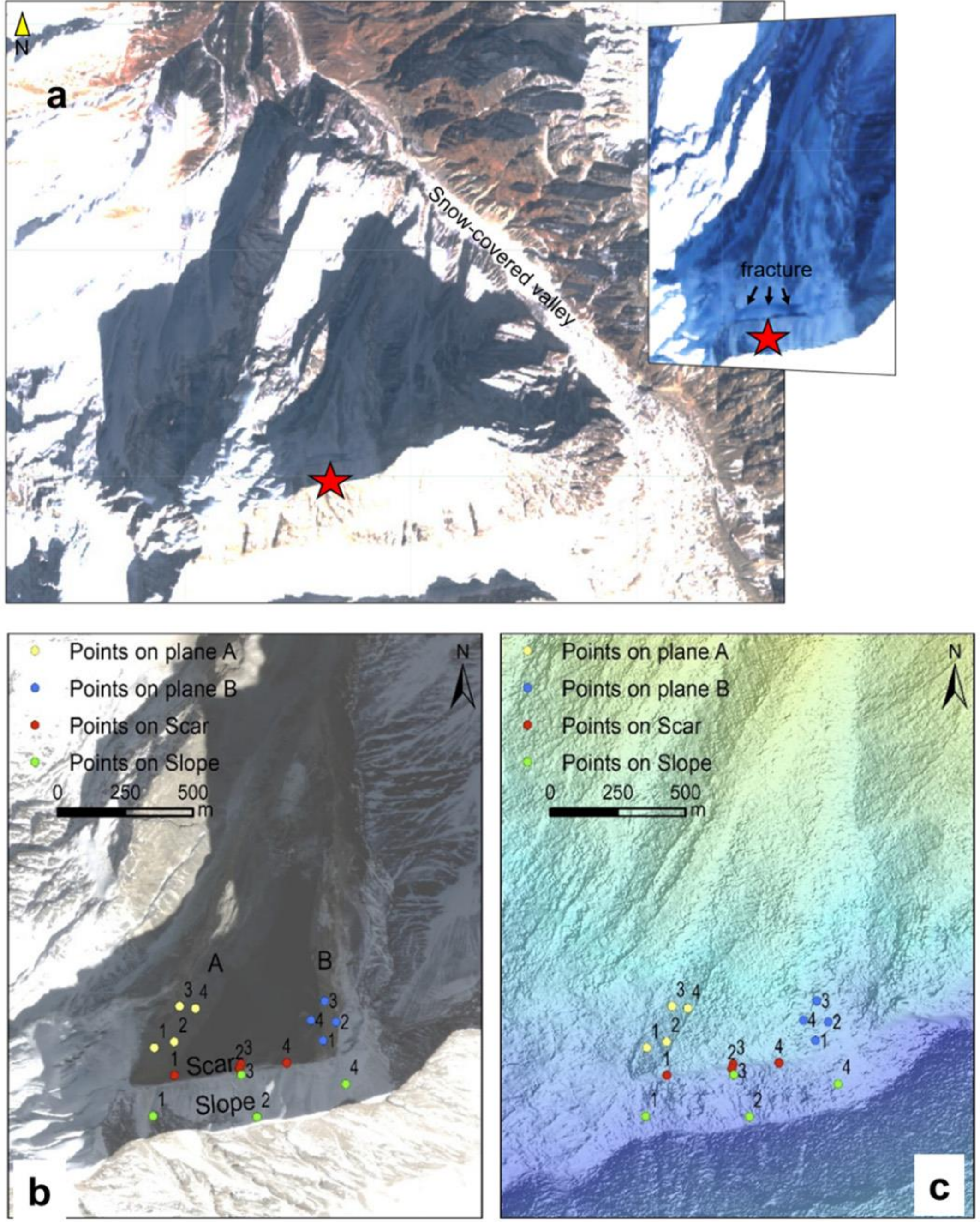
The Friction Behavior of Rock-Ice Avalanches in Relation to Rock-Ice Segregation: Insights From Flume Physical Experiments

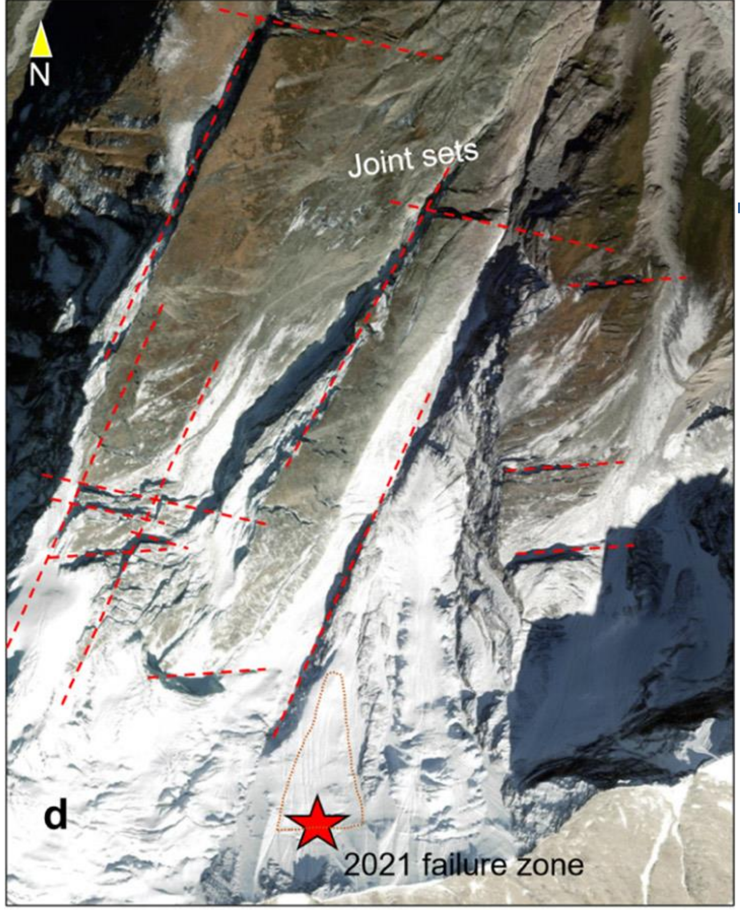
Xuanmei Fan, Zetao Feng, Tao Ni, Yu Deng, Jing Zhang, Lanxin Dai

First published: 03 January 2025 | https://doi.org/10.1029/2024JF007904

Example

Analysis of recent similar cases in HMA supported our inference on global warming-induced glacier retreat and thermomechanical effects in enhancing the weakening of fractured rock masses in tectonically active mountain belts.





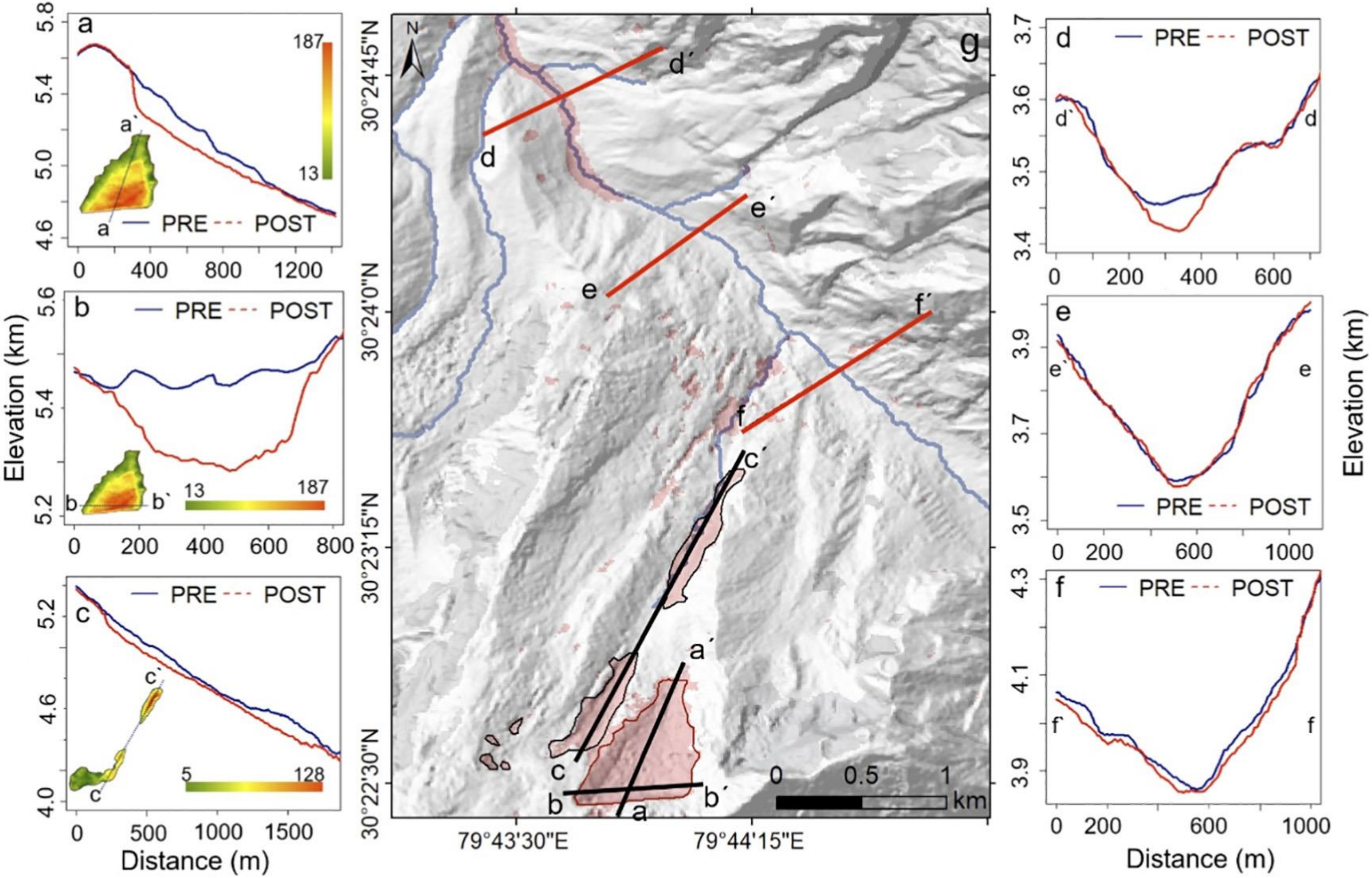
a. Pre-event condition of terrain
b. Stereo plot analysis: satellite image, and
c. Stereo plot analysis: DEM.
d. Joint sets

Pre-event condition of Chamoli region.

Fan, X., Yunus, A. P., Yang, Y. H., Subramanian, S. S., et al.(2022). *Science of the Total Environment*, *836*, 155380.

Slope changes

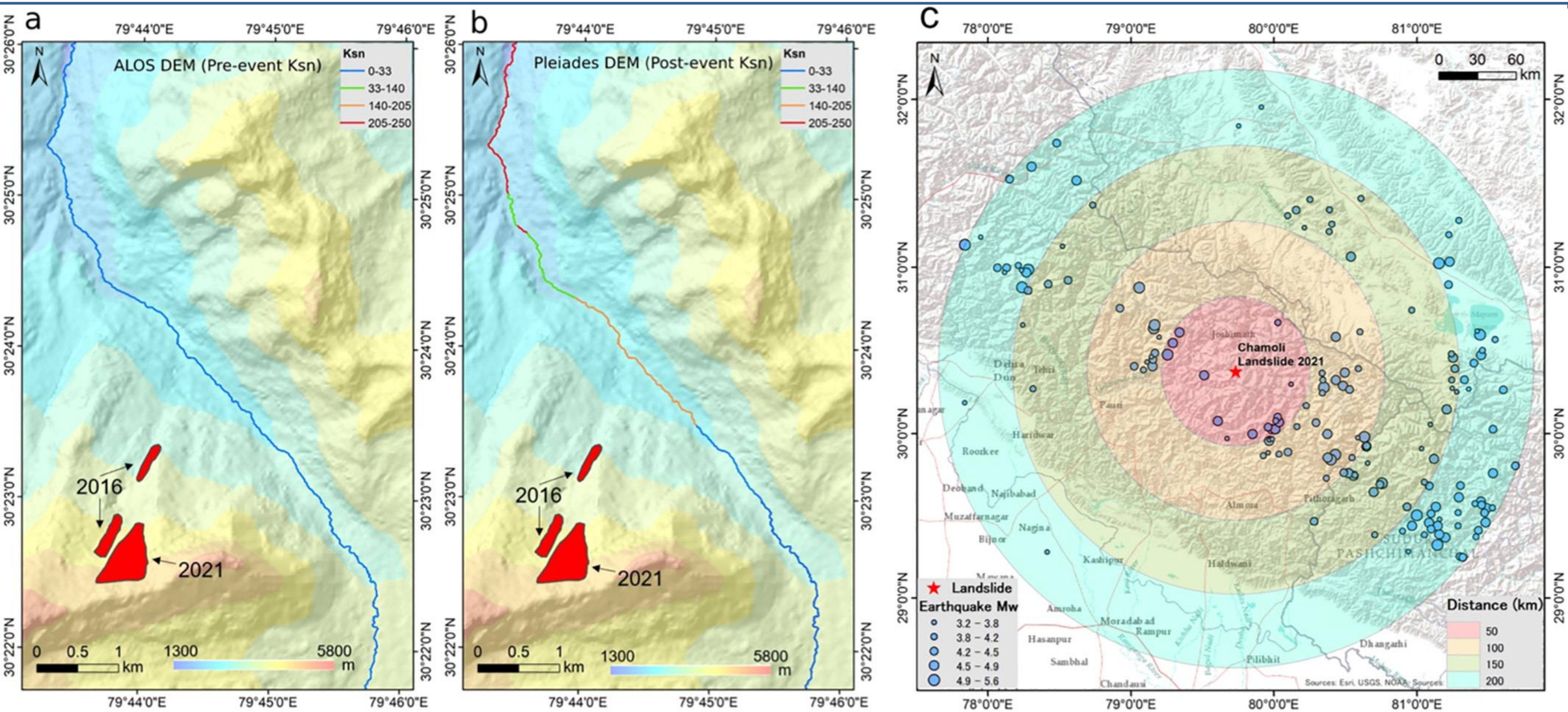
Multi-temporal satellite data provide evidence of a precursor event in 2016 and expansion of a linear fracture along joint planes, indicating 2021 rock-ice avalanche is a retrogressive wedge failure.



Pre-event and post-event condition of Chamoli region.

Fan, X., Yunus, A. P., Yang, Y. H., Subramanian, S. S., et al.(2022). *Science of the Total Environment*, *836*, 155380.

Tectonic stresses and landscape control



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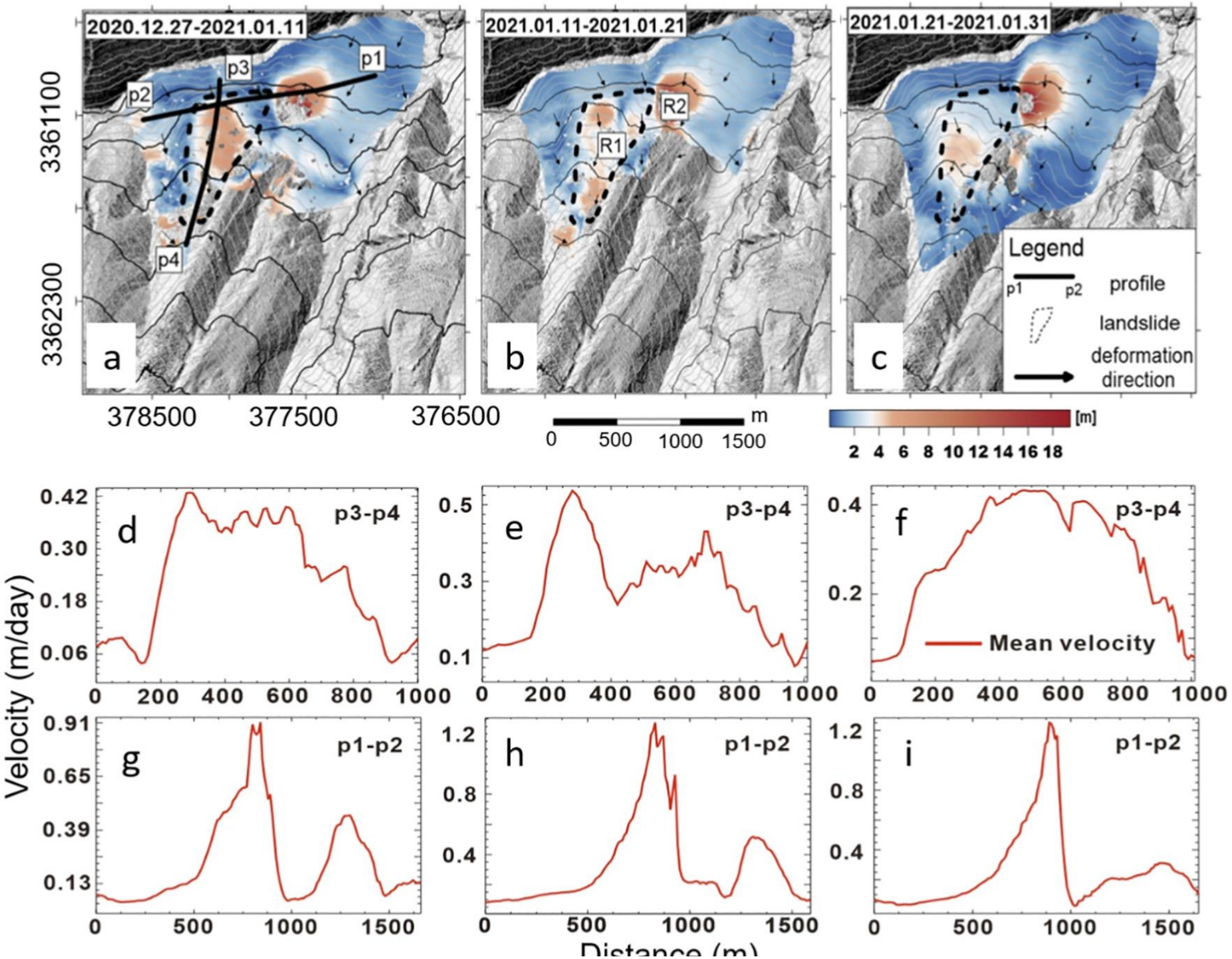
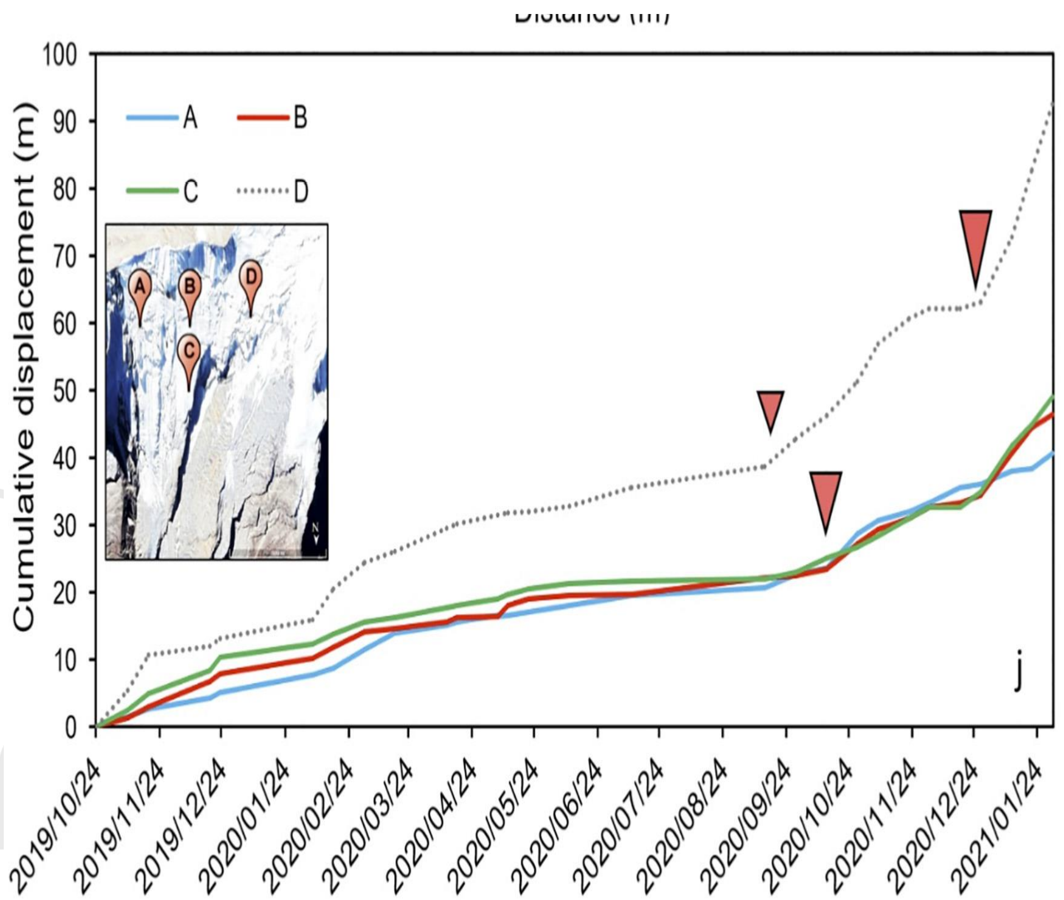
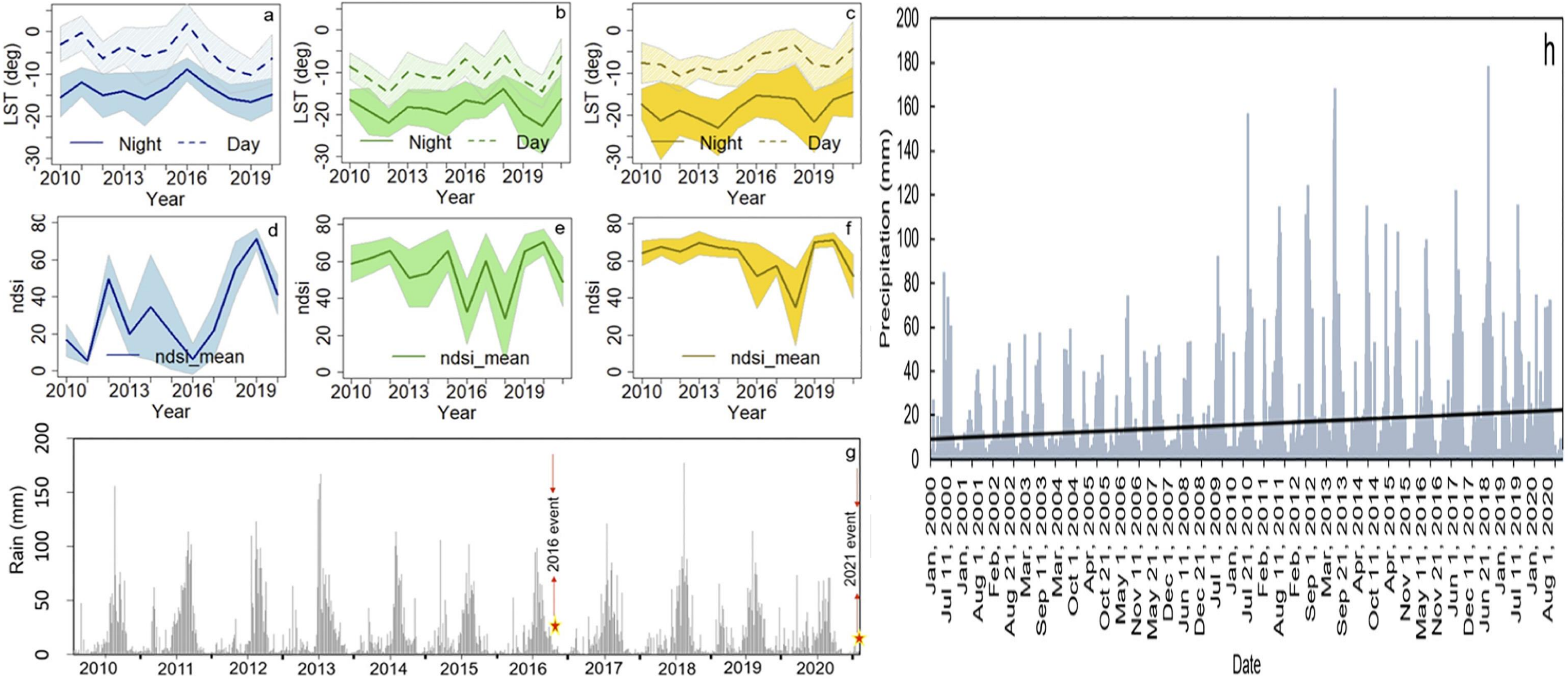
Time series of deformation





Climate controls



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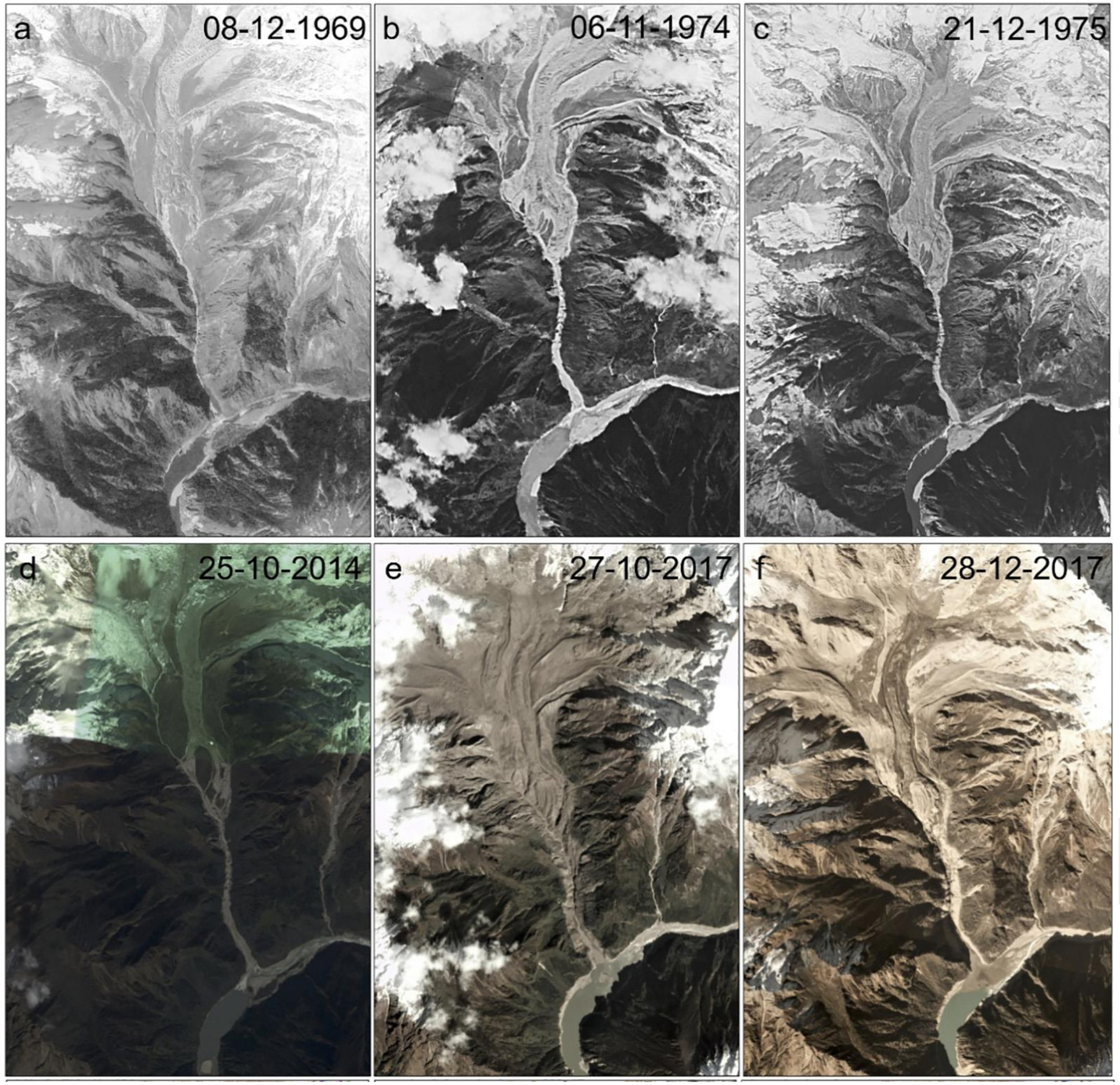
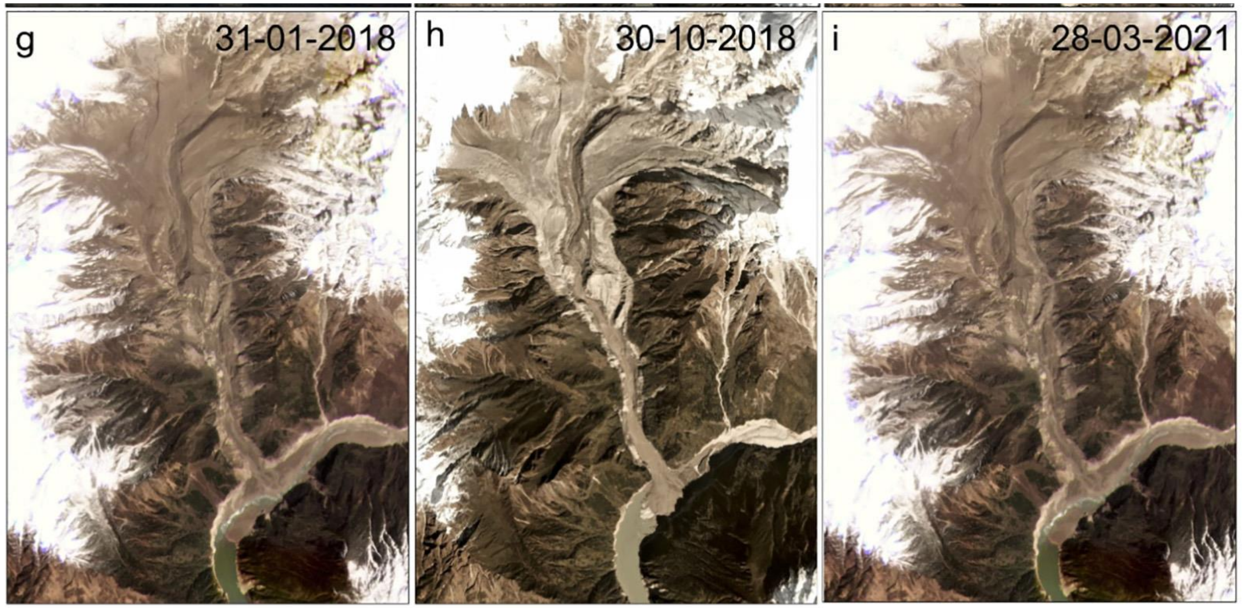
Cases from High Mountain Asia





Multiple rock-ice avalanche in the Yarlong Tsangpu. (a)–(i) show he rock-ice avalanches that blocked the Yarlong River. Note that since 2010, there were at least four failures occurring at the same glacier source.

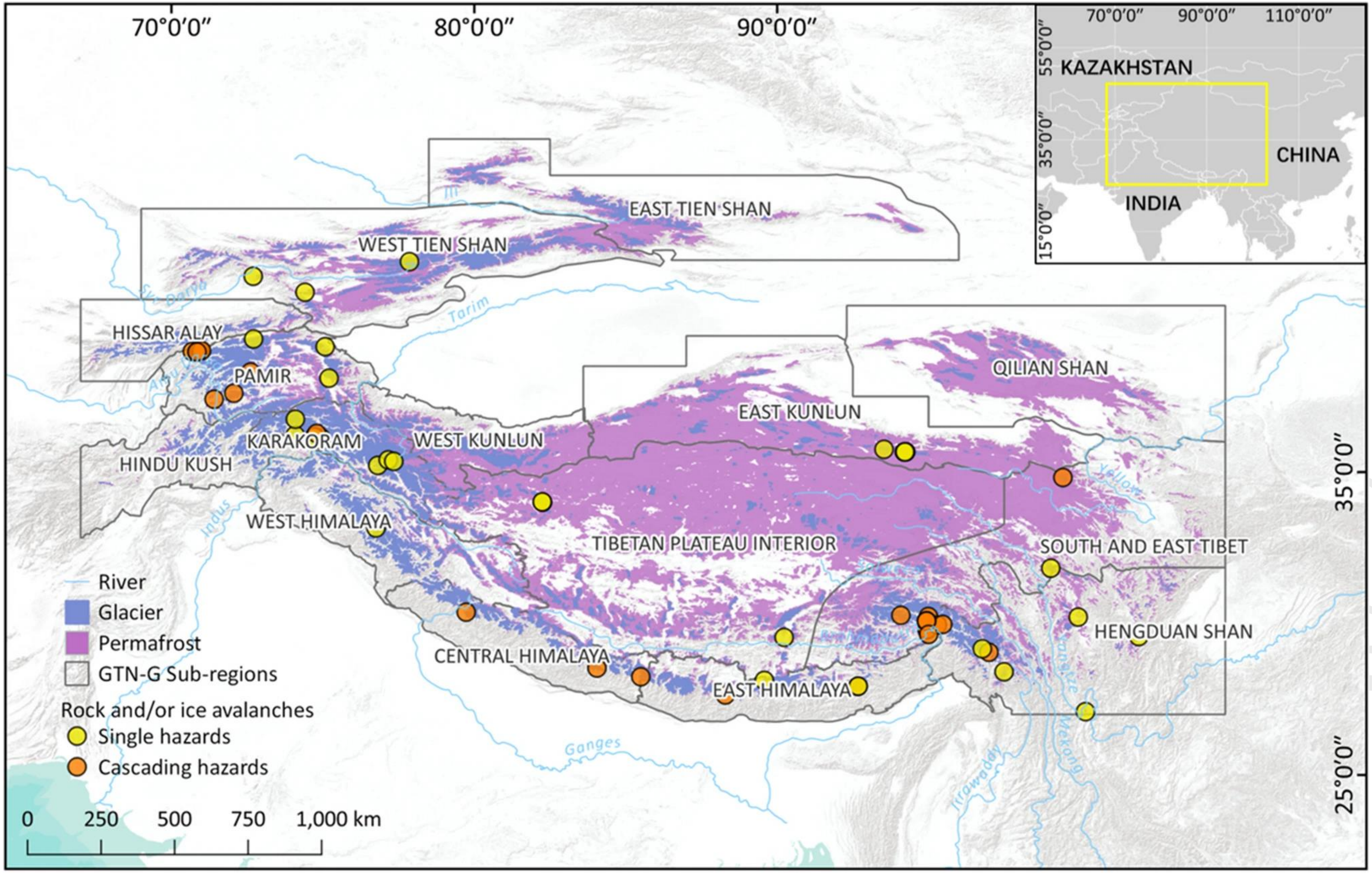
Fan, X., Yunus, A. P., Yang, Y. H., Subramanian, S. S., et al.(2022). *Science of the Total Environment*, *836*, 155380.

Cases from High Mountain Asia

Details of other rock-ice-avalanches and ice avalanches in HMA.

ID	Location	Name	Latitude (° N)	Longitude (° E)	Date	Type	Volume (million m^3)	References
1	Tibetan Plateau	Yigong	30.23	95.00	2000.04.09	Rock-ice avalanche	300	
2	Aru	Aru-1	34.03	82.25	2016.07.17	Glacier/ice avalanche	68 ± 2	(Kääb et al., 2018)
		Aru-2	34.01	82.26	2016.09.21	Glacier/ice avalanche	83 ± 2	
3	Yarlong Tsangpu	Sedong pu	29.81	94.92	Before 2014			(Li et al., 2022; Liqiang et al., 2018)
					2014			
					2017.10.22			
					2017.11			
					2017.12			
					2018.01			
					2018.07.06			
					2018.10.17	Rock-ice avalanche	66	
					2018.10.29	Rock-ice avalanche	7	
4	Qinghai	Amney Machen	34.82	99.43	2004.02.10	Glacier/ice avalanche	21.5	(Zhang et al., 2020; Paul, 2019b)
					2007.10.08		654	
					2016.10.06		425	
5	Yulong Mountain		27.09	100.19	2014.03.12	Rock-ice avalanche	2.13–3.55	(Ningning et al., 2013)
6	Tibetan Plateau	Peilong			1968–1977?	Glacier landslide	–	(Li et al., 2021; Wang et al., 1999)
7	Kongur Mountains	Jiubie Peak	38.71	75.27	2015.05	Glacier surge and ice avalanche	240	(Donghui et al., 2016)
8	Namjagbarwa	Zelong nong	29.62	94.99	1950.08.15	Glacier surge/avalanche	–	
					1968.09.02		–	
					1984.04.13		–	
9	Kunlun Mountain	K1	35.75	93.53	2001.11.14	Ice avalanche	0.15–0.3	(van der Woerd et al., 2004)
	50 km west of Kunlun Pass	K2	35.75	93.53			1–2	
		B1	35.70	94.28			0.5–0.7	
	Burhan Budai Shan	B2	35.69	94.25			1–4	
		B3	35.68	94.21			0.7–1.5	
		B4	35.68	94.20			1–4	
10	North Terong glacier		34.33	77.16	2000.04/05	Rock-ice avalanche	7.6	(Bhutiyani and Mahto, 2018a, 2018b)

Cases from High Mountain Asia



RIA distribution in High Mountain Asia (HMA). Map showing the geographical extent of HMA via Global Terrestrial Network for Glaciers (GTN-G) sub-regions (GTN-G, 2017). Yellow and orange dots are the spatial distributions of RIA.
Light blue lines are major rivers (Lehner and Grill 2013). Blue shades are glaciers (RGI6.0, 2017). Purple shades are permafrost probable areas (defined below) (Obu et al. 2018). Inset is the location of HMA

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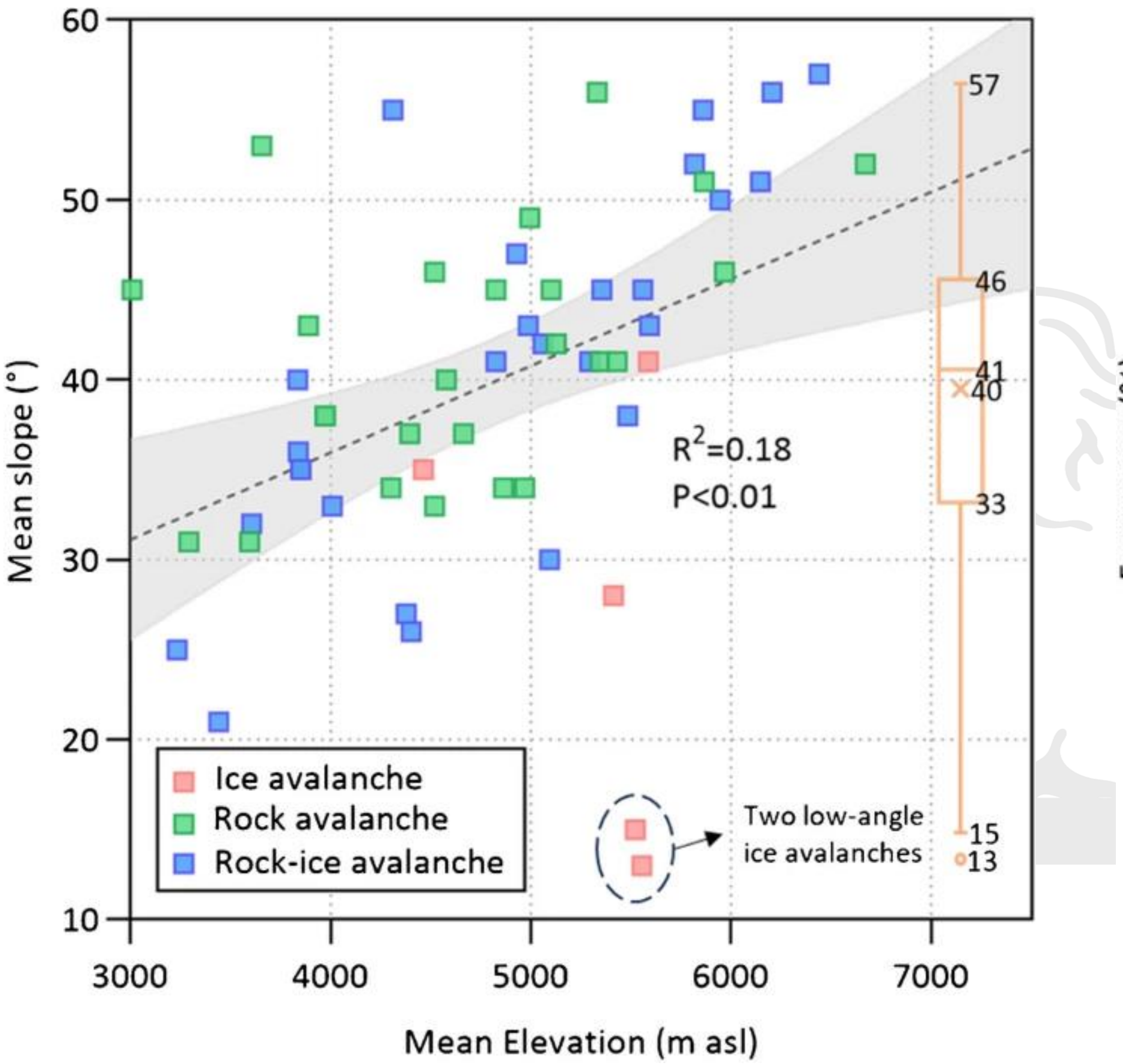
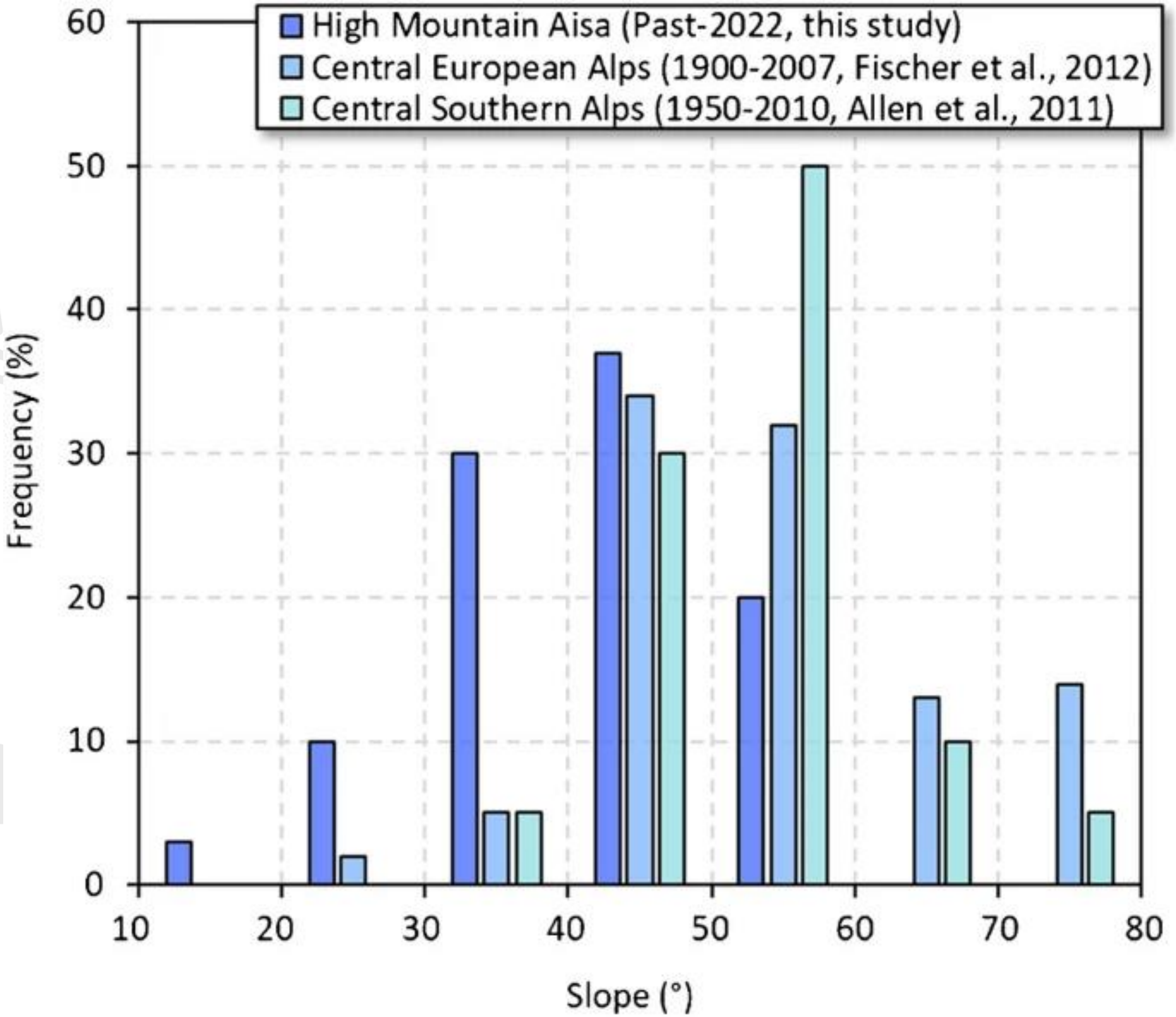
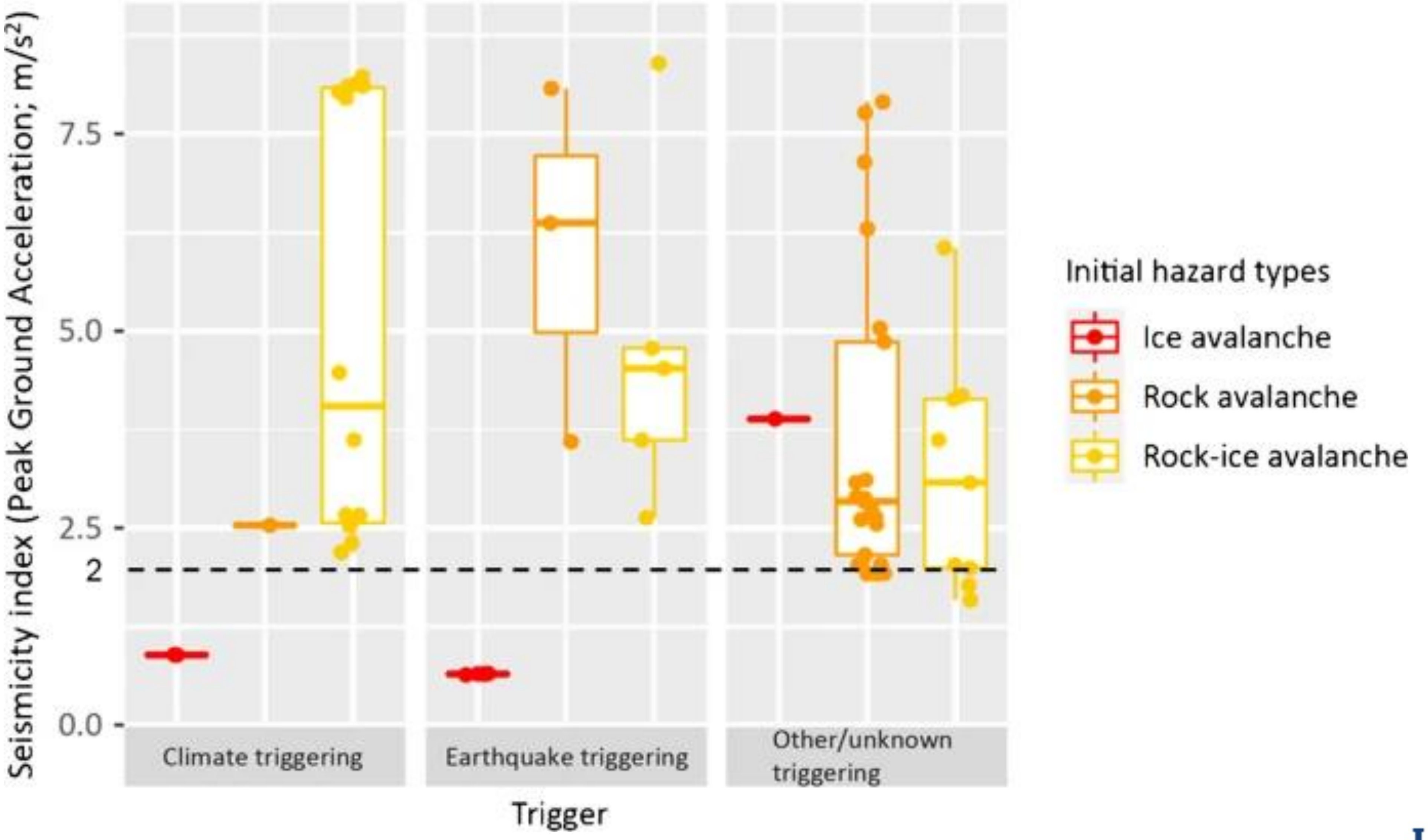
Cases from High Mountain Asia



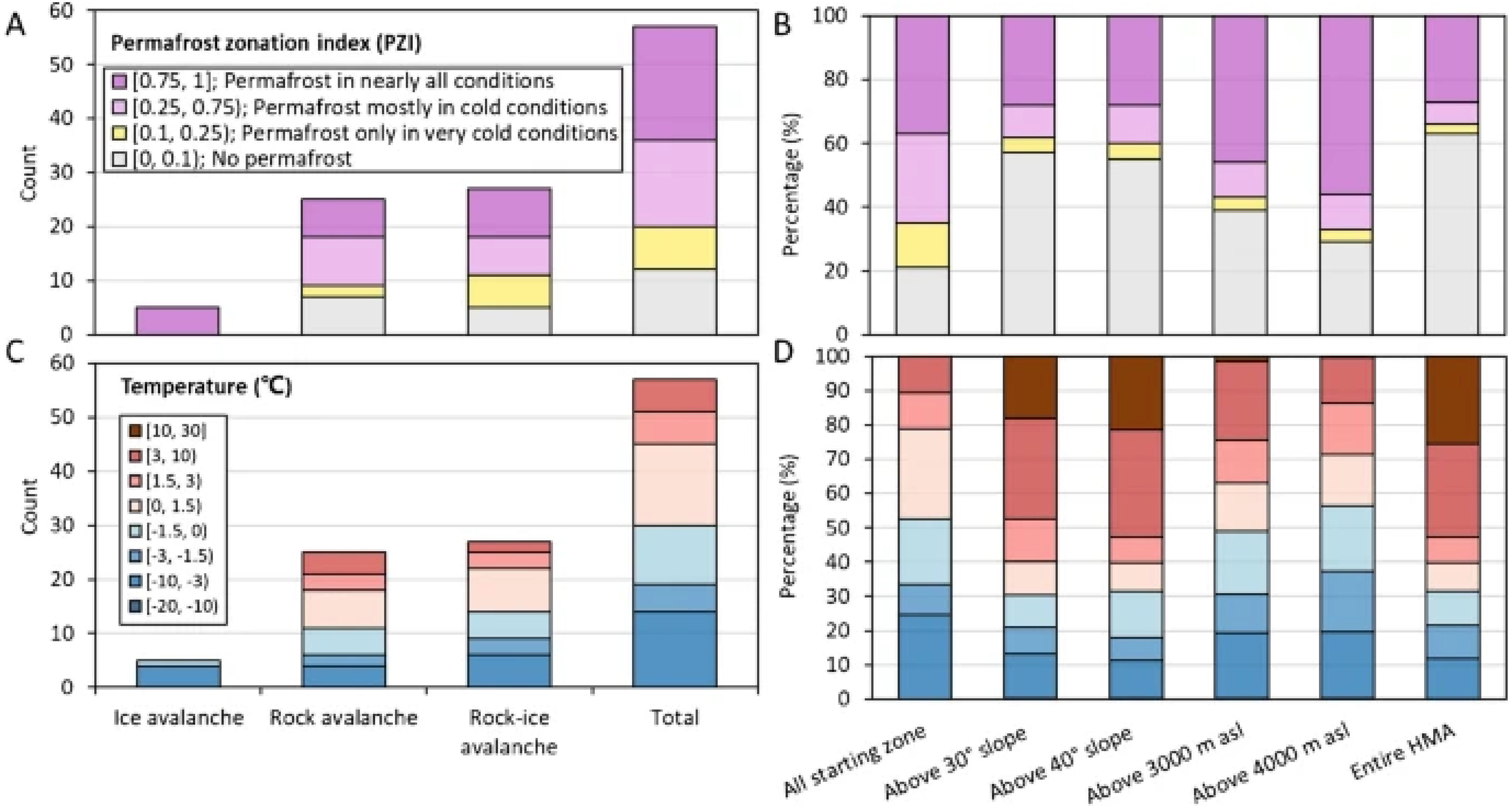


Causes

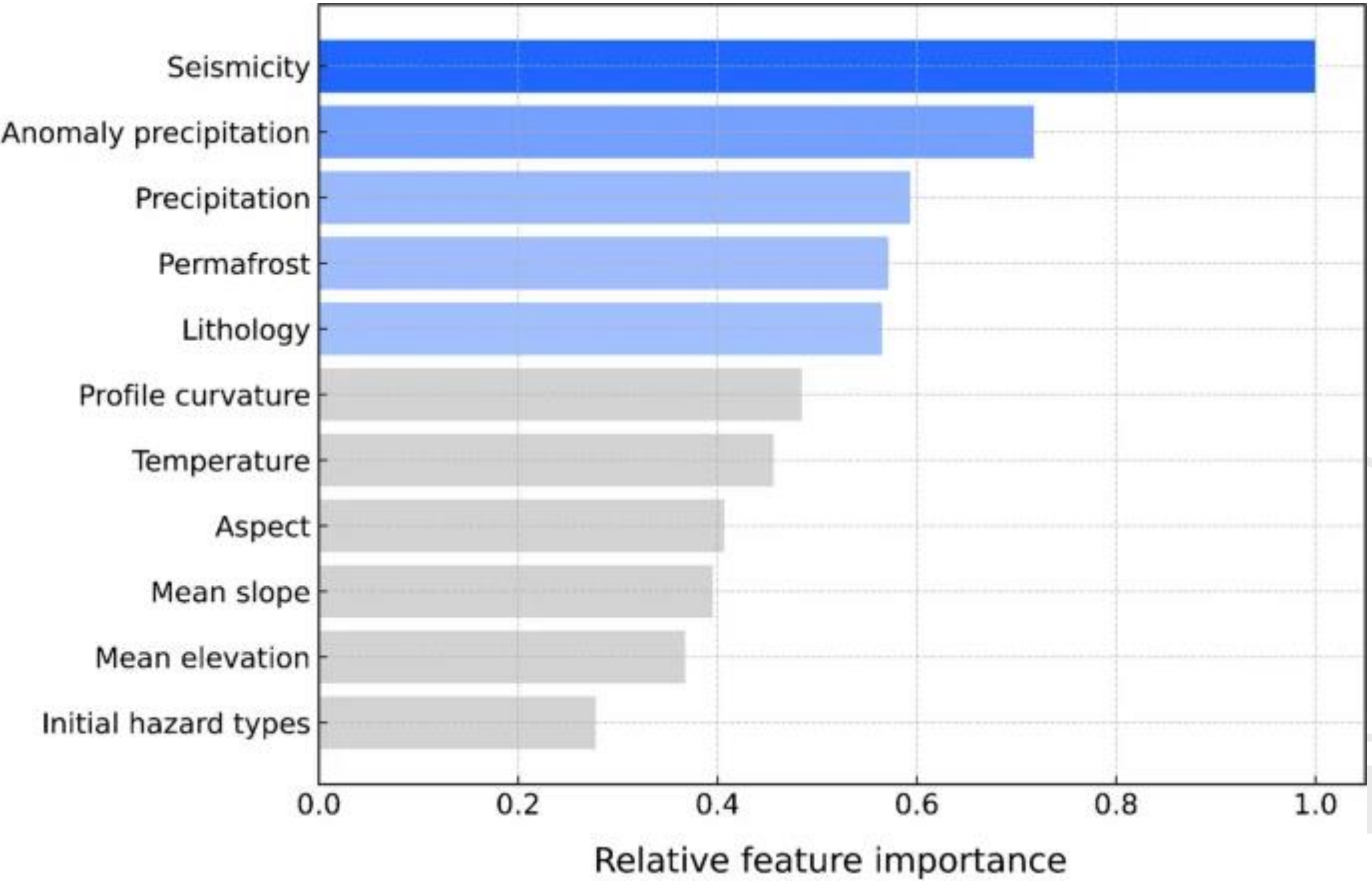


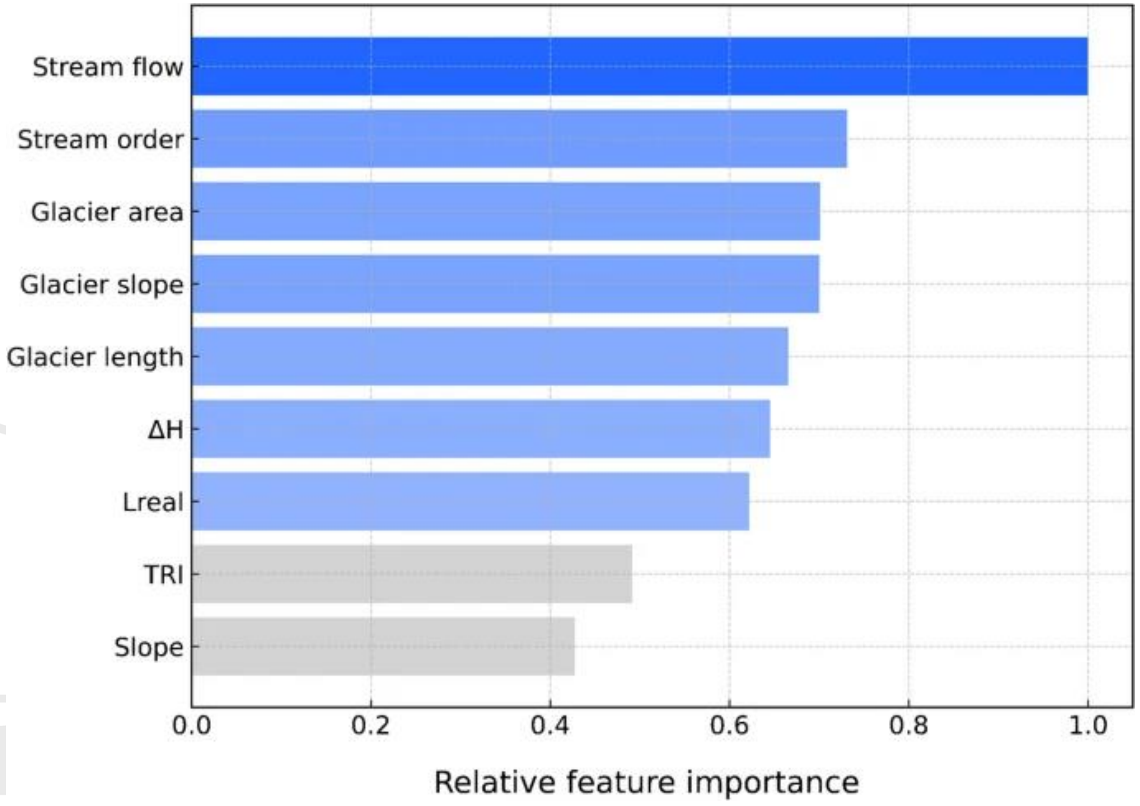
Seismicity index (Peak Ground Acceleration; m/s²)
7.5
5.0
2.5
2
0.0
Climate triggering
Earthquake triggering
Other/unknown triggering
Trigger
Initial hazard types
Ice avalanche
Rock avalanche
Rock-ice avalanche

Contribution of Permafrost

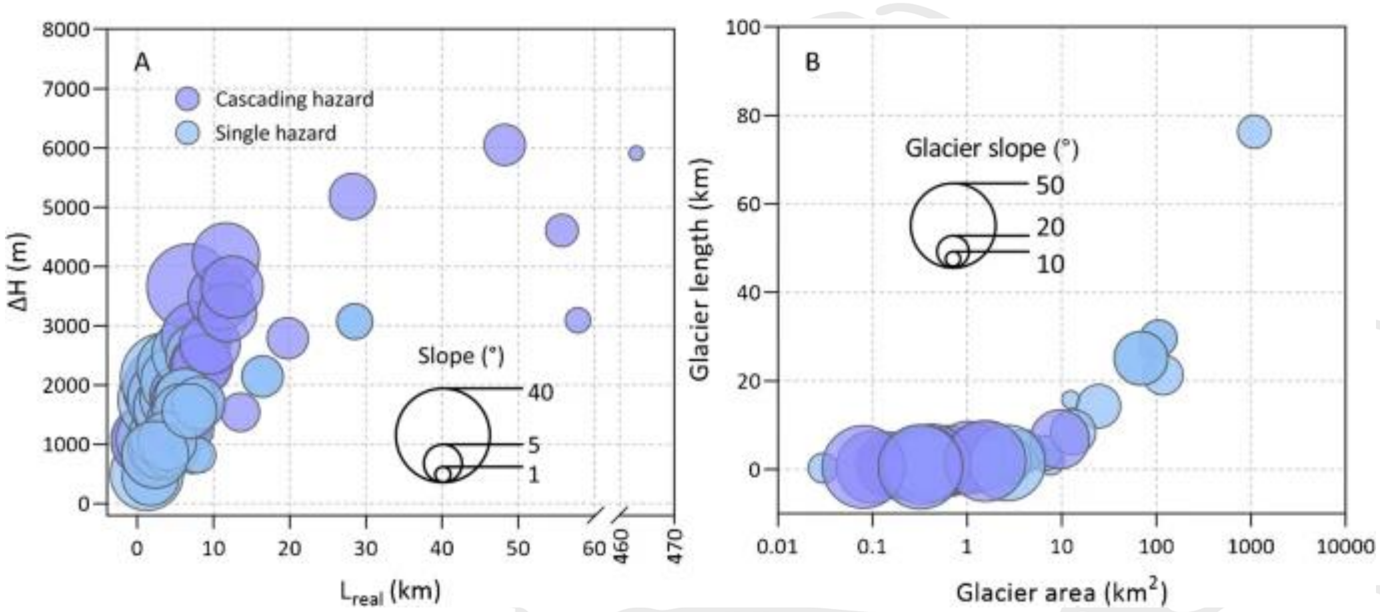


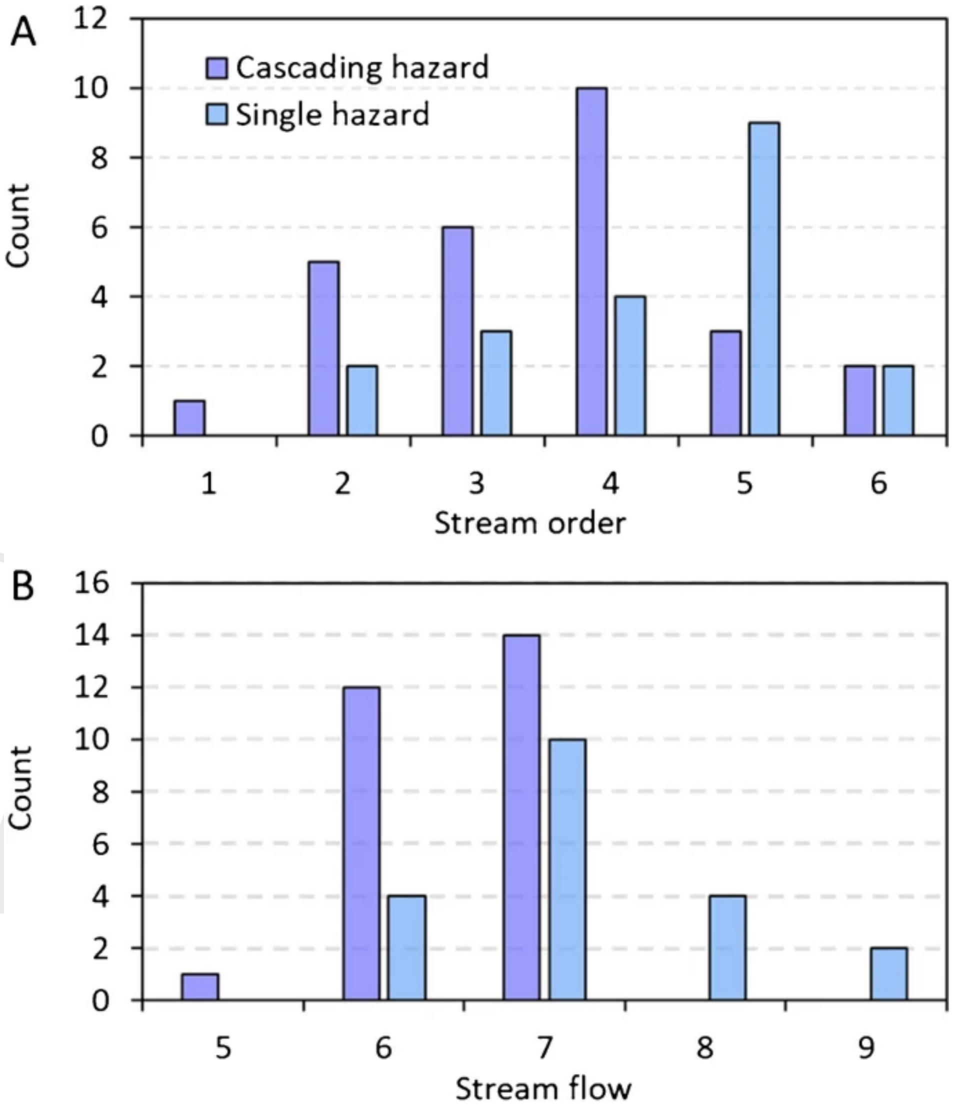
Feature Importance





Cascading Hazards





Thank you very much for your kind attention and time!

Question time