中国科学院 西北生态环境资源研究院
Northwest Institute of Eco-Environment and Resources,CAS

中国-巴基斯坦地球科学研究中心
China-Pakistan Joint Research Center on Earth Sciences

SKLCS 冰冻圈科学国家重点实验室
State Key Laboratory of Cryospheric Sciences

Cryosphere observation, Monitoring and research along the Belt and Road

Cryospheric hazards

Shangguan Donghui, Kang Shichang, Ding Yongjian

Northwest Institute of Eco-Environment and Resources, CAS
State key Laboratory of Cryospheric Science

2024-8-19
Lanzhou
dhguan@lzb.ac.cn

冰冻圈科学国家重点实验室

Outline

1. Cryosphere and its Rapid Changes

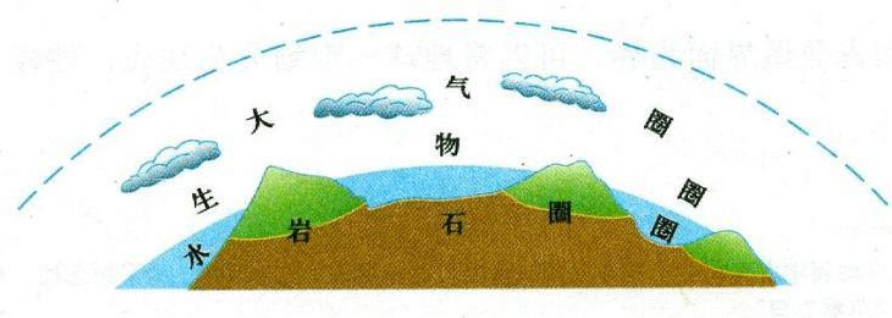
2.Cryosphere hazards

3. Several cases study

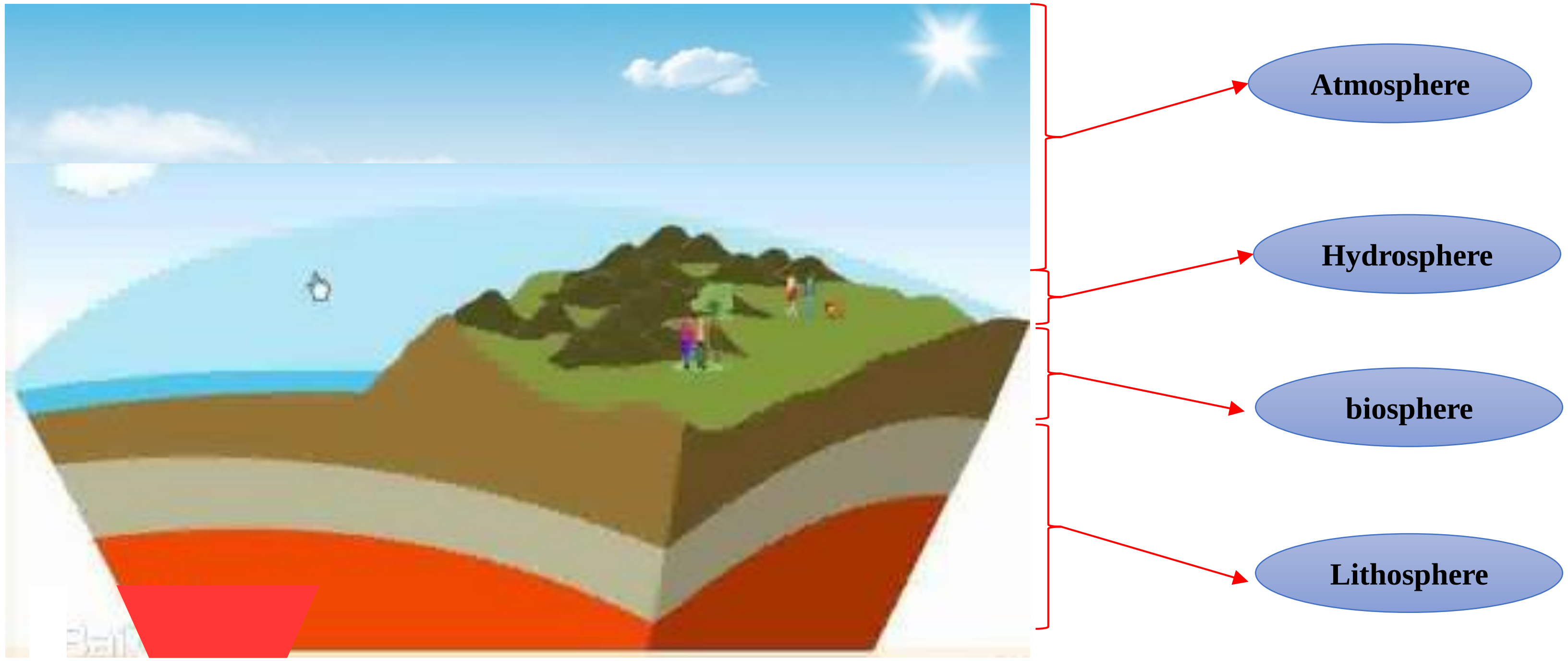
  -Snow avalanche
  -Snow disaster in pasturing area
  -Ice collapse
  -Glacier surging
  -GLOF
  -Thaw slumping

4. Observation and early warming system

1 Earth system



Four Spheres



Atmosphere

Hydrosphere

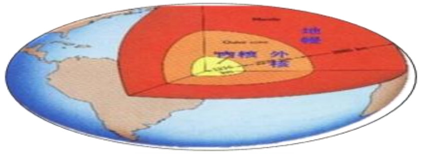
biosphere

Lithosphere

Atmosphere

Hydrosphere

Biosphere



Lithosphere

1 Cryosphere

Climate system：

Climate： The average state of atmospheric elements over a period of time

Climate system： Atmosphere, hydrosphere, biosphere and lithosphere,**cryosphere**

Solid water+Low Temperature

＋

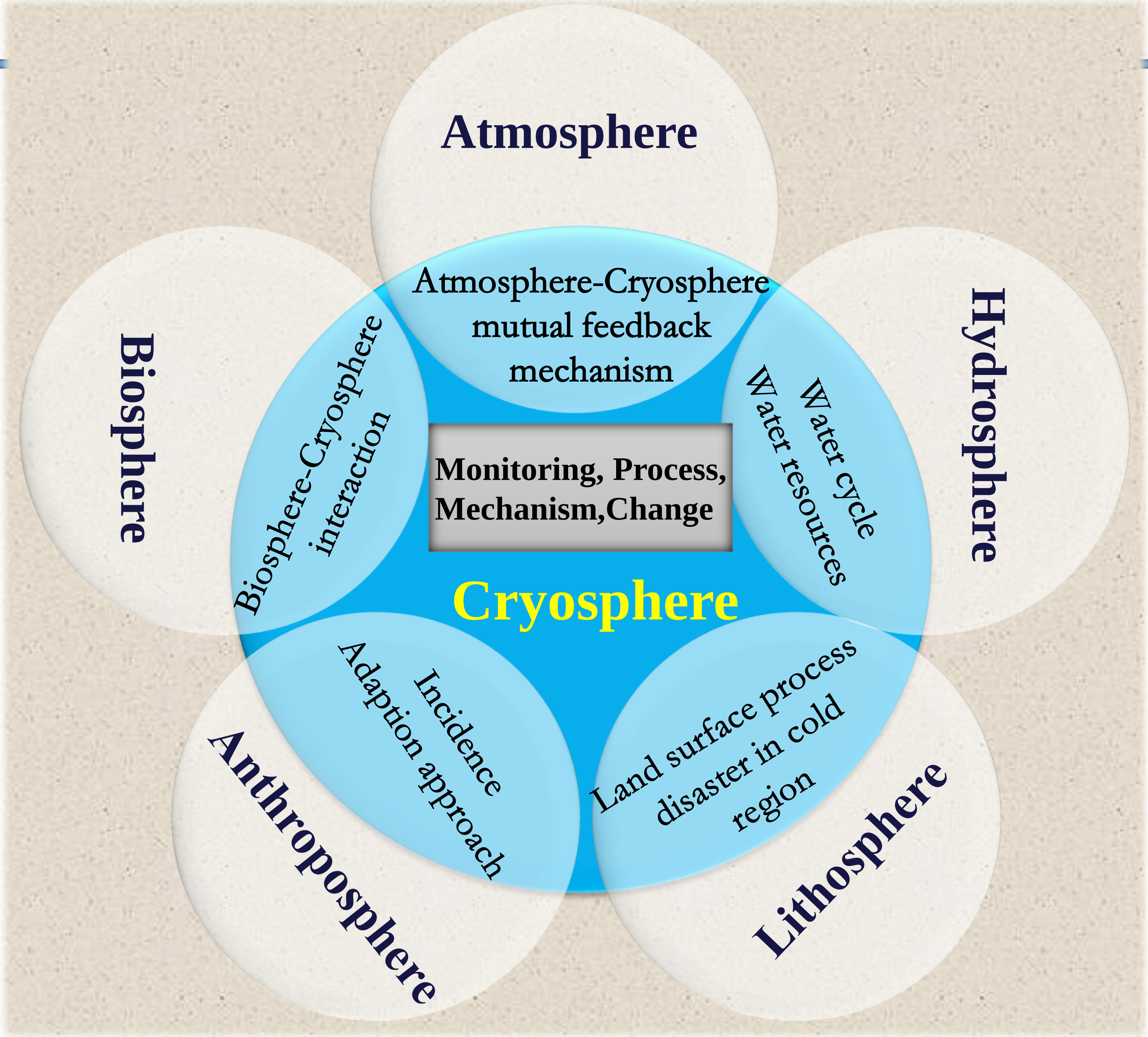
Cryosphere

？

1 Cryosphere science

The key research objectives of cryospheric science include the formation, dynamic process, changes and monitoring of the cryosphere. Cryospheric changes interact with other spheres， such as hydrosphere, biosphere, lithosphere and anthroposphere.

Such as sea level rising due to ice melt water; pioneer plant in glacier shrinkage.



Atmosphere

Atmosphere-Cryosphere mutual feedback mechanism

Hydrosphere

Water cycle

Water resources

Lithosphere

Land surface process disaster in cold region

Anthroposphere

Incidence

Adaption approach

Biosphere

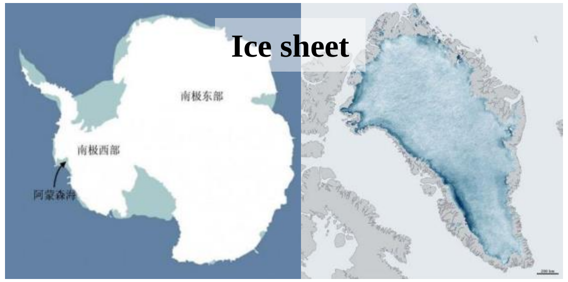
Biosphere-Cryosphere interaction

Monitoring, Process, Mechanism,Change

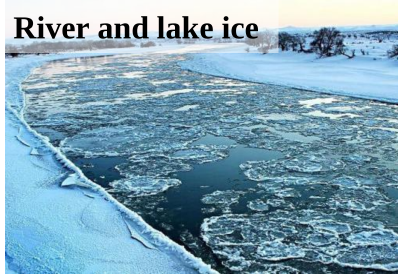
Cryosphere

1 Cryospheric components


Glacier


Ice sheet


Snow


River and lake ice

Cryosphere: the sphere with certain thickness and temperature below 0 ^{o}C on the Earth.


Permafrost


Undersea permafrost


Sea ice


Iceberg


Ice shelf


Icy rain


Glaze


Atmosperic ice crystal


Snowfall

- ✓ Marine cryosphere
- ✓ Continental cryosphere
- ✓ Aerial cryosphere

1 Cryosphere

Most of permafrost in Tibetan and Mongolia , Then in Alaska and Canada

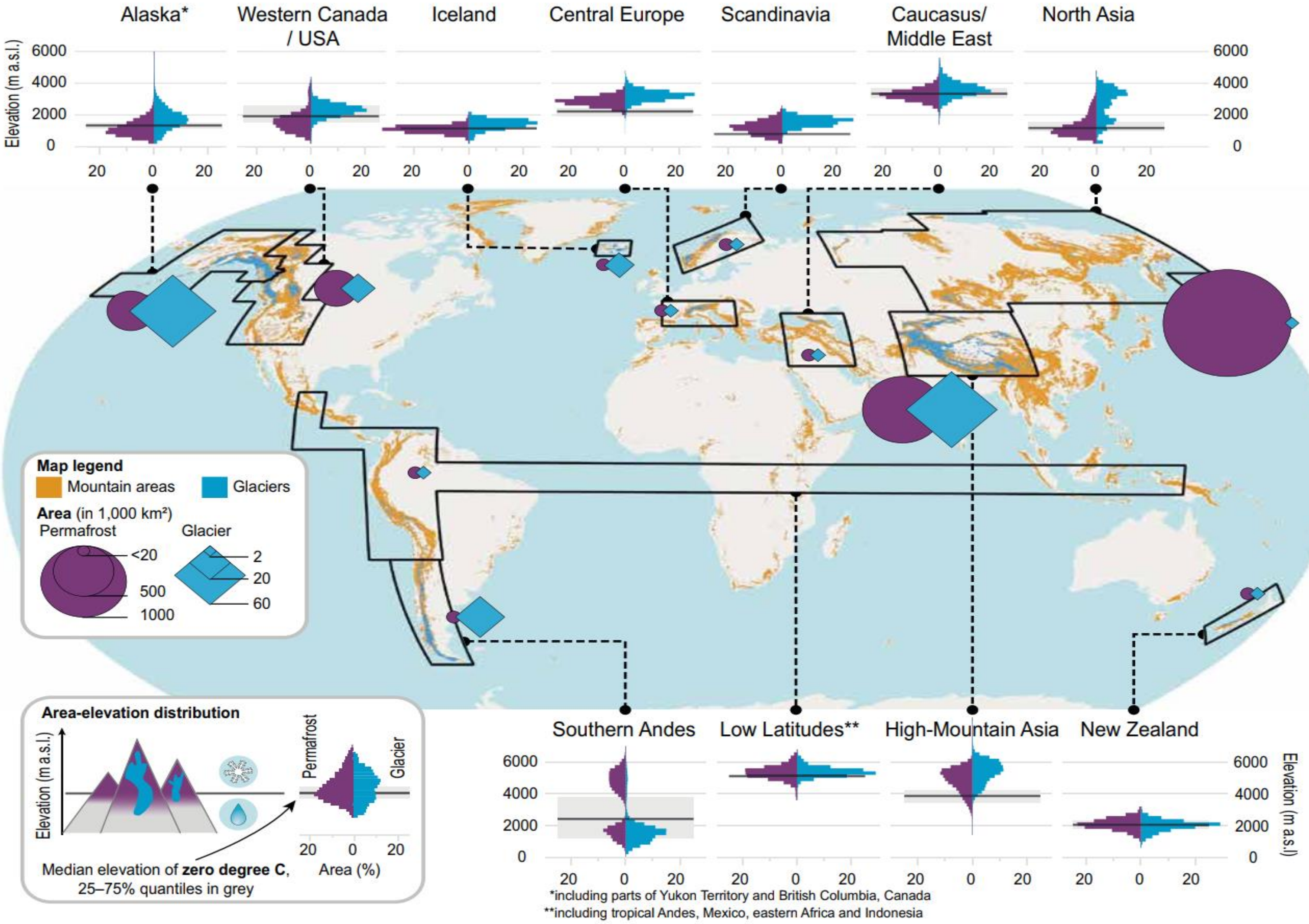
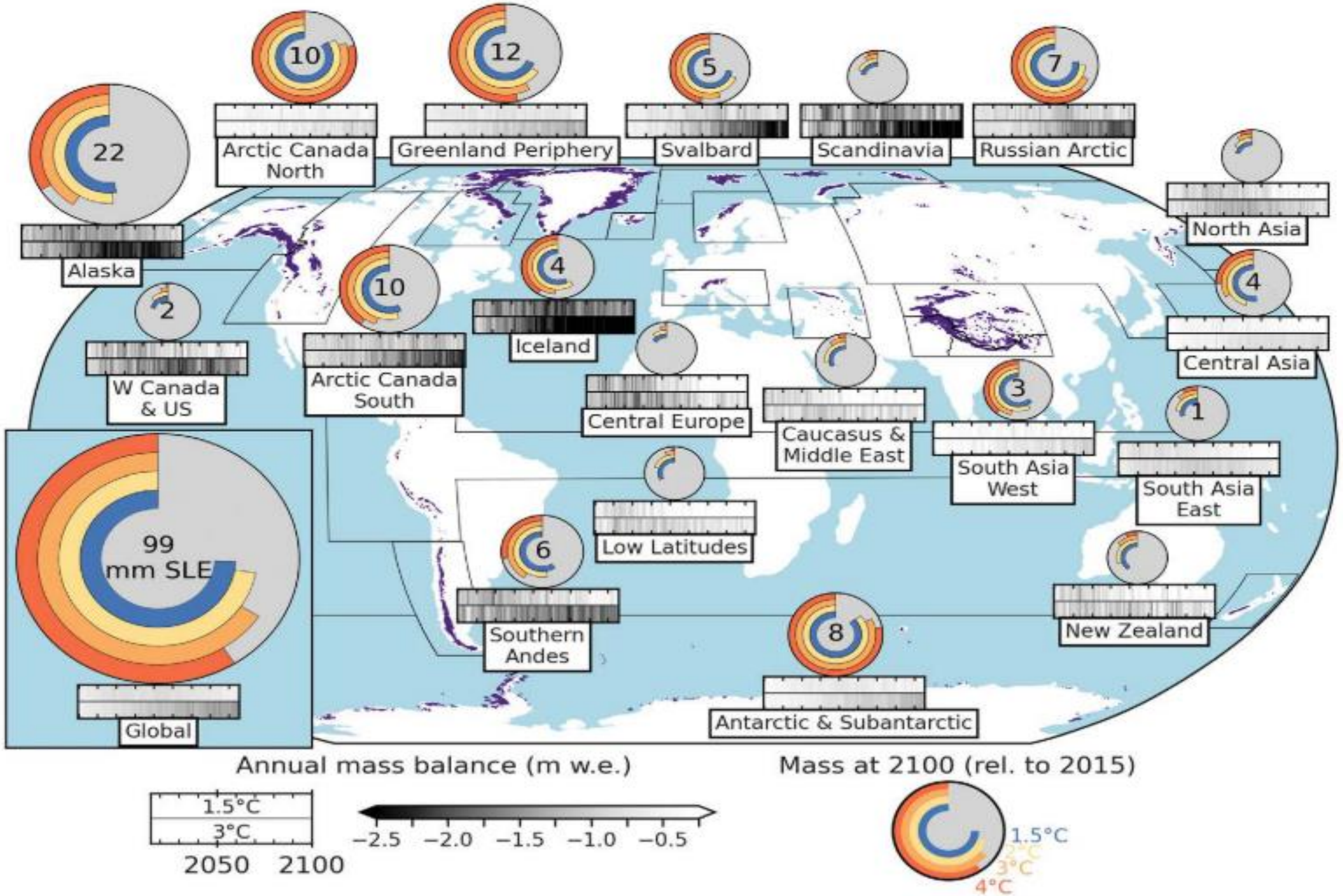


Figure 2.1 | Distribution of mountain areas (orange shading) and glaciers (blue) as well as regional summary statistics for glaciers and permafrost in mountains. Mountains are distinguished based on a ruggedness index (>3.5), a logarithmically scaled measure of relative relief (Gruber, 2012). Eleven distinct regions with glaciers, generally corresponding to the primary regions in the Randolph Glacier Inventory, RGI v6.0 (RGI Consortium, 2017) are outlined, although some cryosphere related impacts presented in this chapter may go beyond these regions. Region names correspond to those in the RGI. Diamonds represent regional glacier area (RGI 6.0) and circles the permafrost area in all mountains within each region boundary (Obu et al., 2019). Histograms for each region show glacier and permafrost area in 200 m elevation bins as a percentage of total regional glacier/permafrost area, respectively. Also shown is the median elevation of the annual mean 0ºC free-atmosphere isotherm calculated from the ERA-5 re-analysis of the European Centre for Medium Range Weather Forecasts over each region's mountain area for the period 2006–2015, with 25–75% quantiles in grey. The annual 0ºC isotherm elevation roughly separates the areas where precipitation predominantly falls as snow and rain. Areas above and below this elevation are loosely referred to as high and low elevations, respectively, in this chapter.

Hock et al., 2019

1 Glacier shrinkage

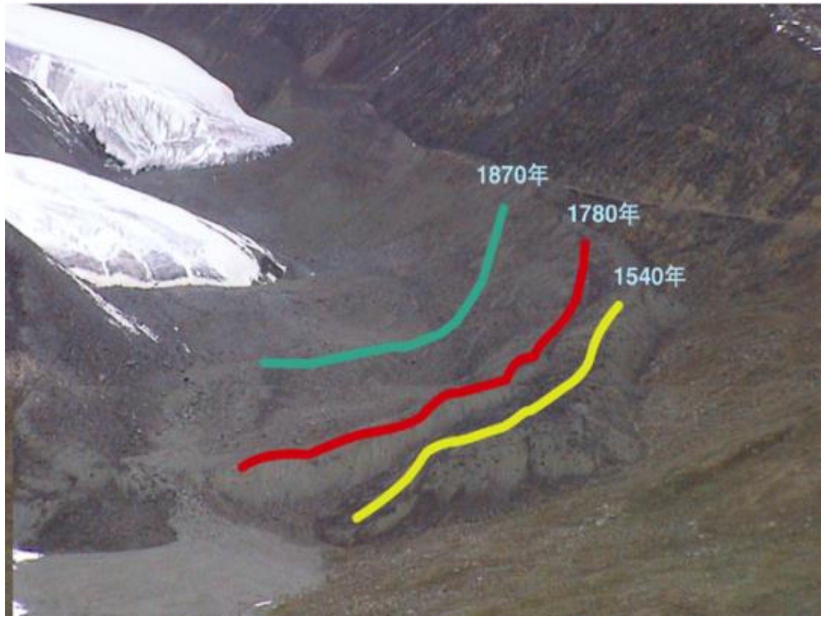
Gardner et al., 2013, **Science**
Ding et al., 2019, **Science bulletin**
David et al., 2023, **science**



Glaciers are affected by temperatures rising and the instability of glaciers increases due to glacier retreat.

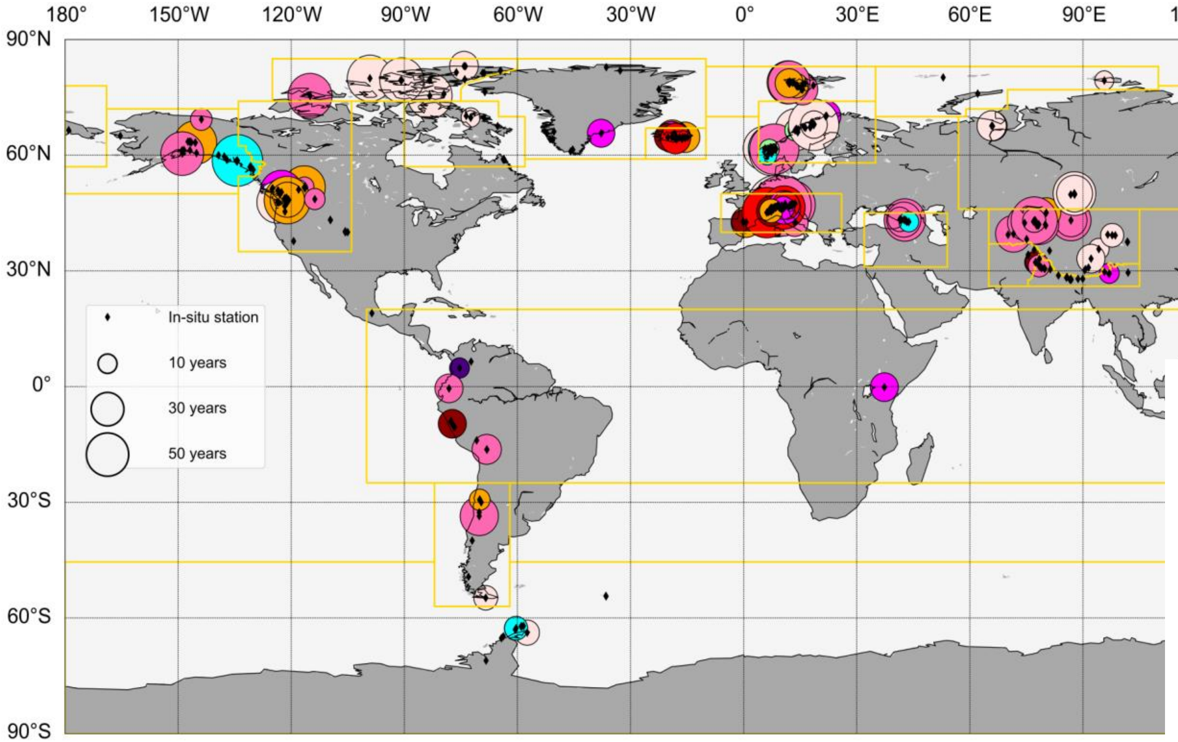
1 Glacier shrinkage in Urumuqi River

Changes in Glacier No. 1 at the headwater of Urumuqi river in Tienshan

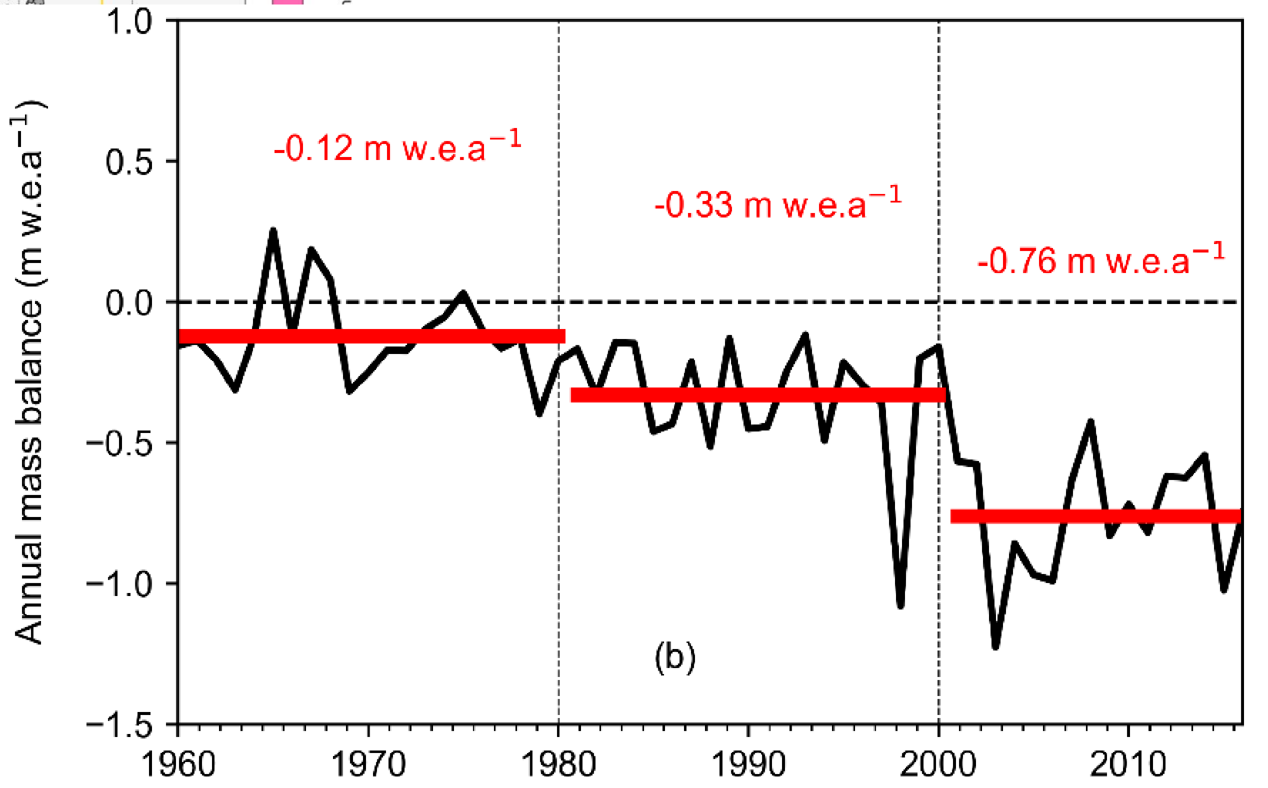


disinteegrate

1 Glacier mass balance from WGMS

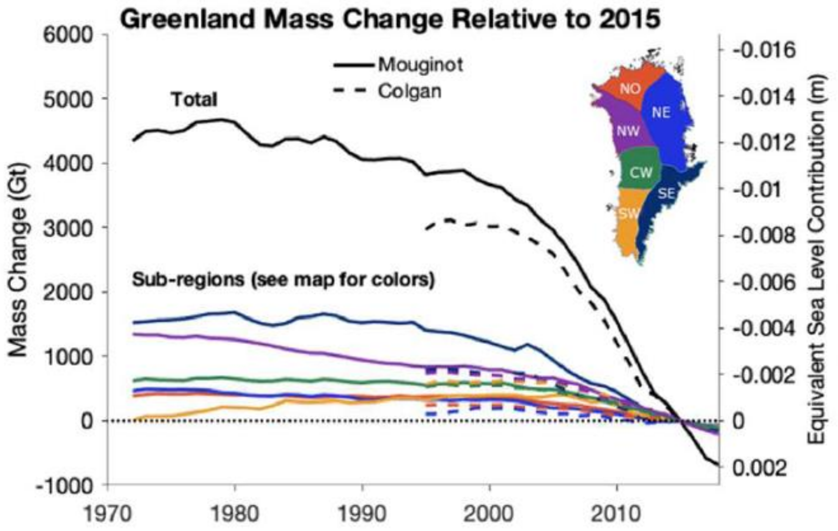


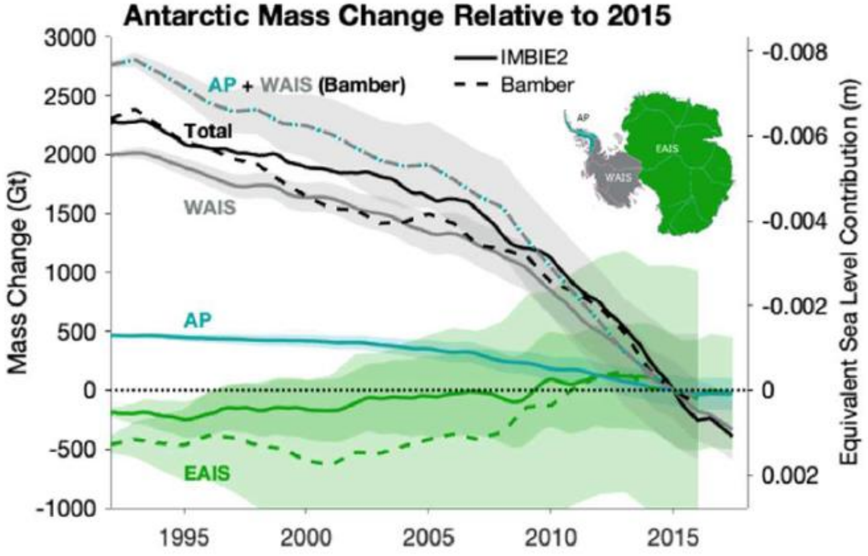
Location of observed glaciers for which data is available from the World Glacier Monitoring Service(WGMS)



Annual mean mass balance variation since 1960 at global scale

1 Greenland and Antarctic ice sheets have been losing mass





(IPCC, 2021)

Greenland ice sheet

34 [−6 - 74] Gt/yr 1992–2001
215 [157 - 274] Gt/yr 2002–2009
278 ± 11 Gt/yr 2006–2015
243 [197 - 290] Gt/yr 2010–2019

Antarctic ice sheet

30 [−37 - 97] Gt/yr 1992–2001
147[72 - 221] Gt/yr 2002–2011
155 ± 19 Gt/yr 2006–2015
148 [94 - 202] Gt/yr 2010–2016

1Observed Increasing in ground temperature of permafrost

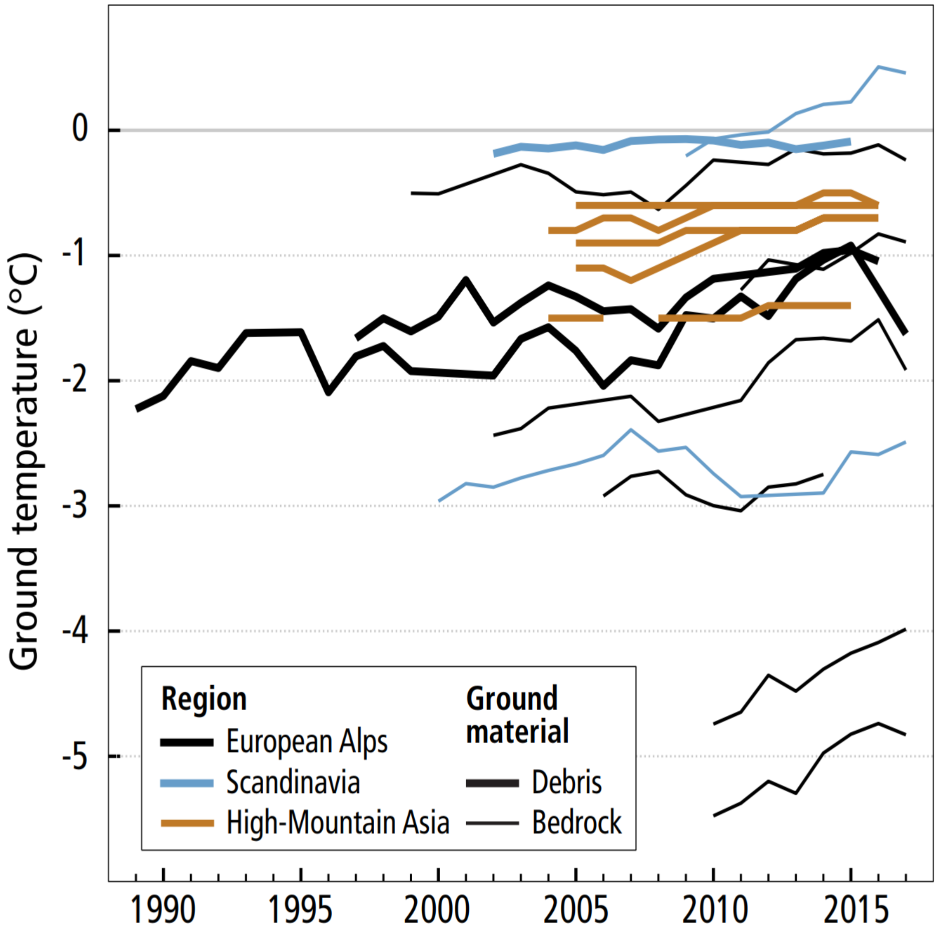
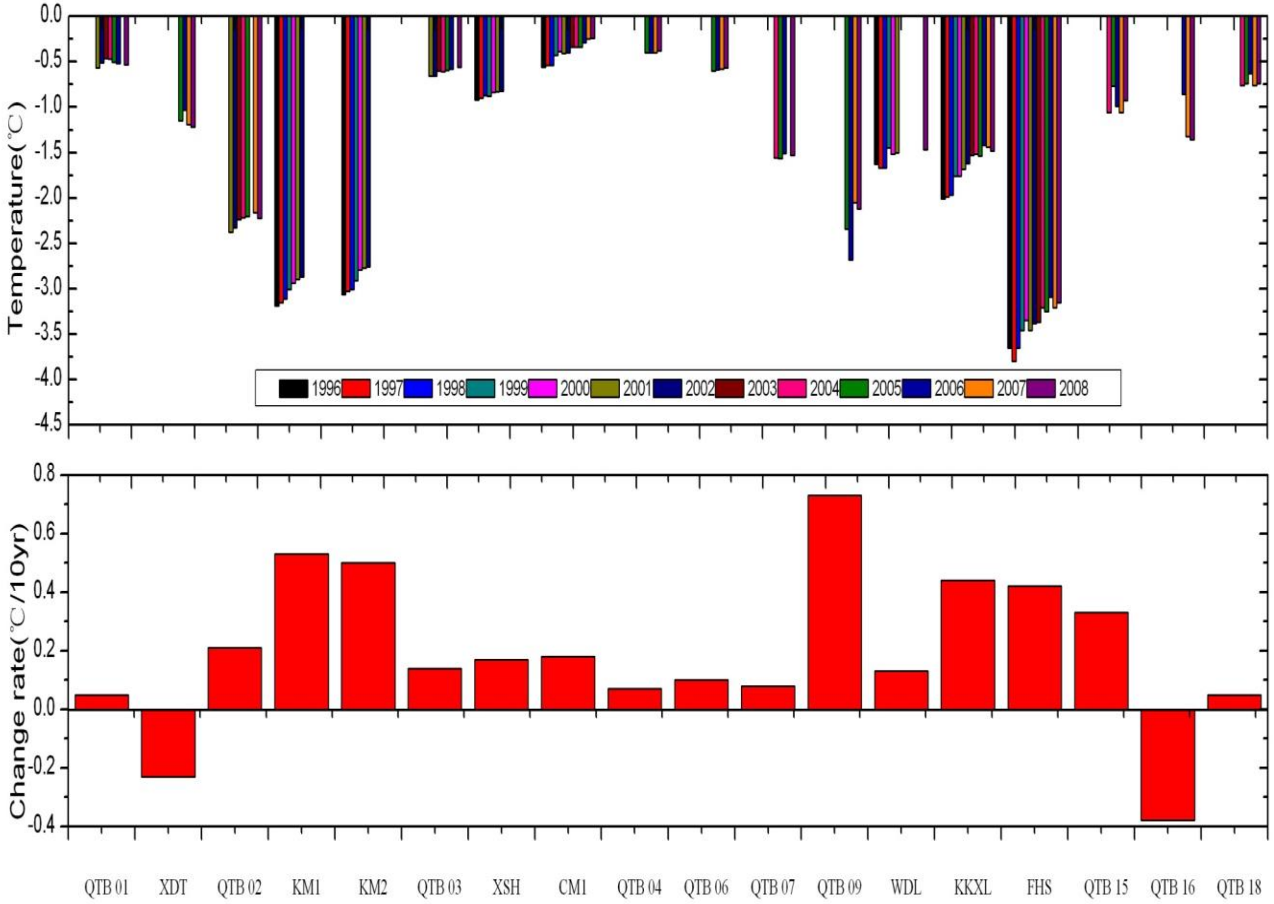


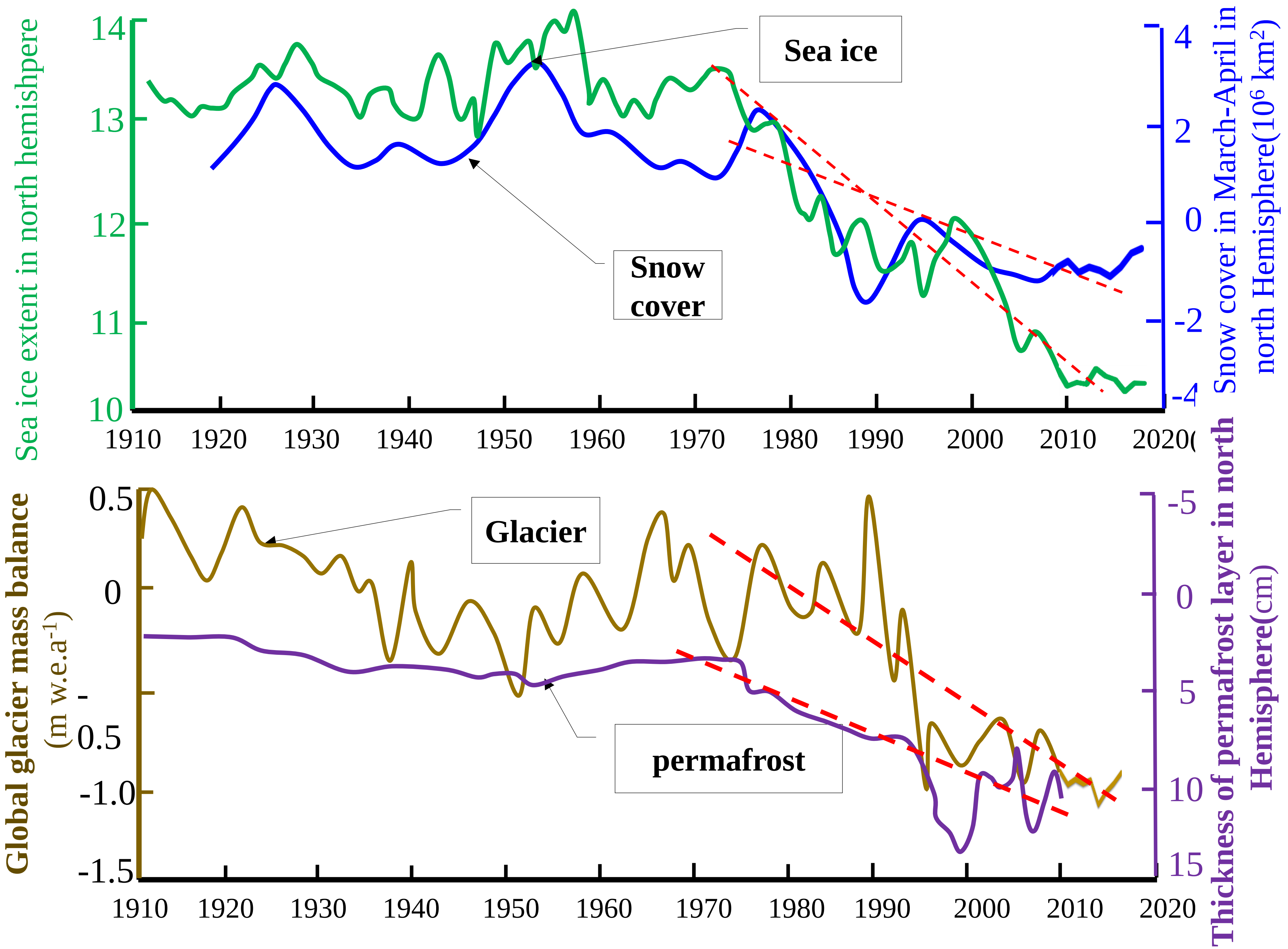
Figure 2.5: Mean annual ground temperature from boreholes in debris and bedrock in the European Alps, Scandinavia and High-Mountain Asia. Temperatures differ between locations and warming trends can be interspersed by short periods of cooling. One location shows degrading of permafrost. Overall, the number of observed boreholes is small and most records are short. The depth of measurements is approximately 10 m, and years without sufficient data are omitted (Noetzli et al., 2018).



GTs at 6-m-deep and the change rates along the Qinghai-Tibetan Highway

Hock et al., 2019

1Permafrost degradation



There are several profiles to show sea ice, snow cover, glacier and permafrost changes. They have a common characteristic, that is, after 1970, they all retreated in some degree.

Outline

1. Cryosphere and its Rapid Changes

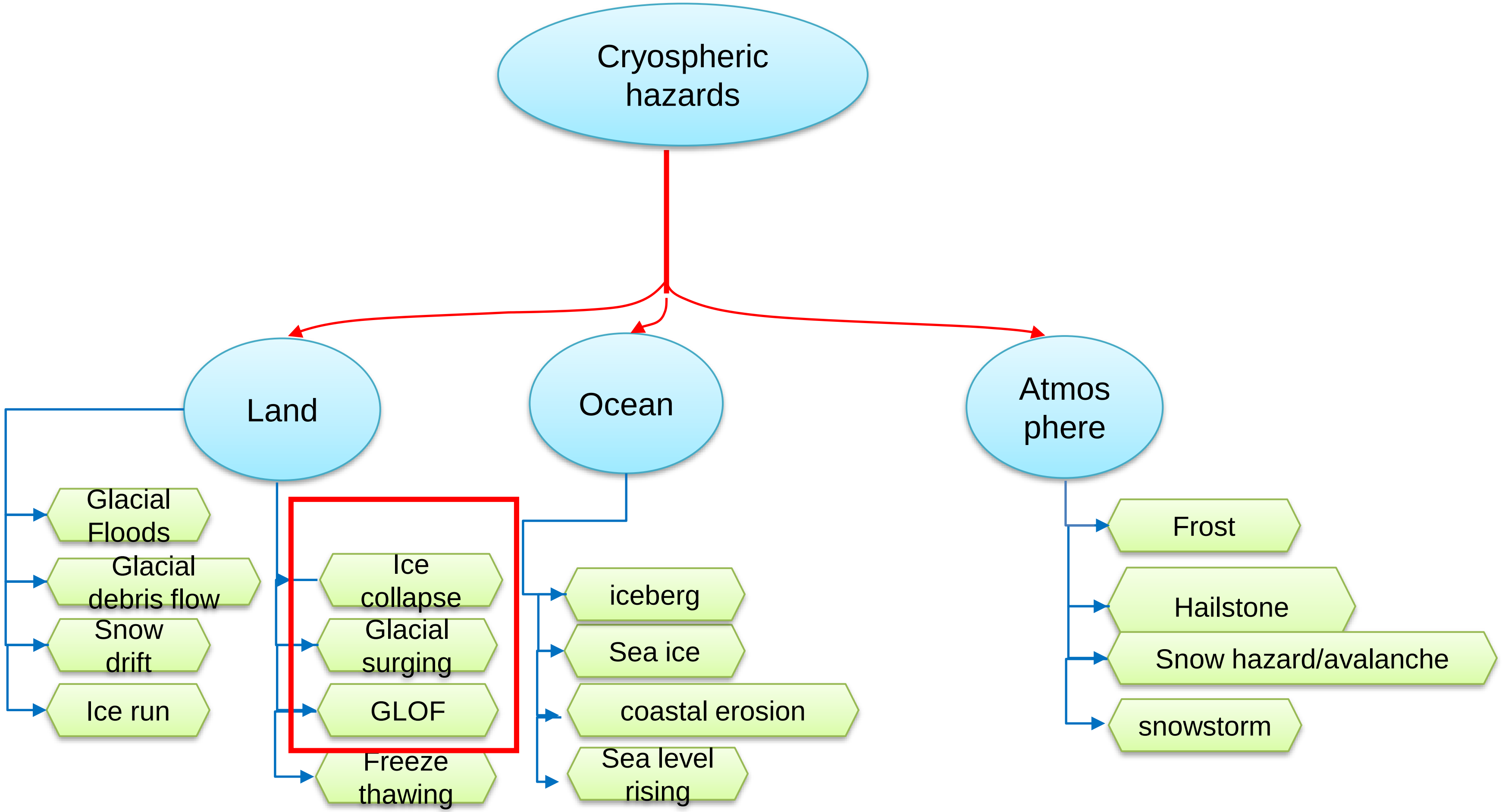
2.Cryosphere hazards

3. Several cases study

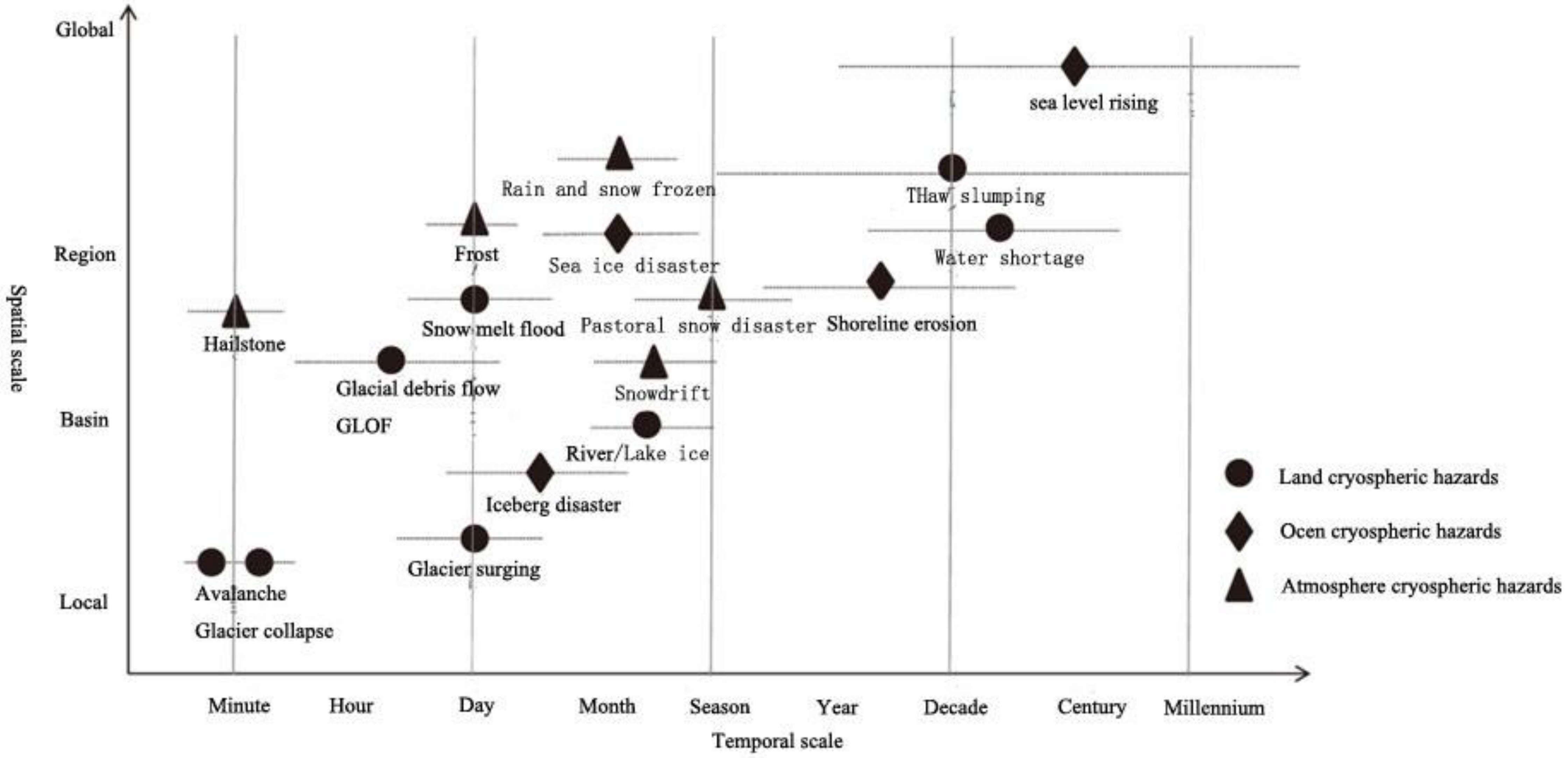
   -Snow avalanche
   -Snow disaster in pasturing area
   -Ice collapse
   -Glacier surging
   -GLOF
   -Thaw slumping

4. Observation and early warming system

2 Cryospheric hazards



2 Cryospheric hazards-Temporal and spatial scales



2 Cryospheric hazards

☐ Land hazards：Avalanche, ice collapse, glacier surging, GLOF, thaw slumping

☐ Atmosphere hazards：Pastoral snow avalanche

2 Cryospheric hazards

Shocking visuals: Glacier breaks in Uttarakhand's Chamoli, several feared dead

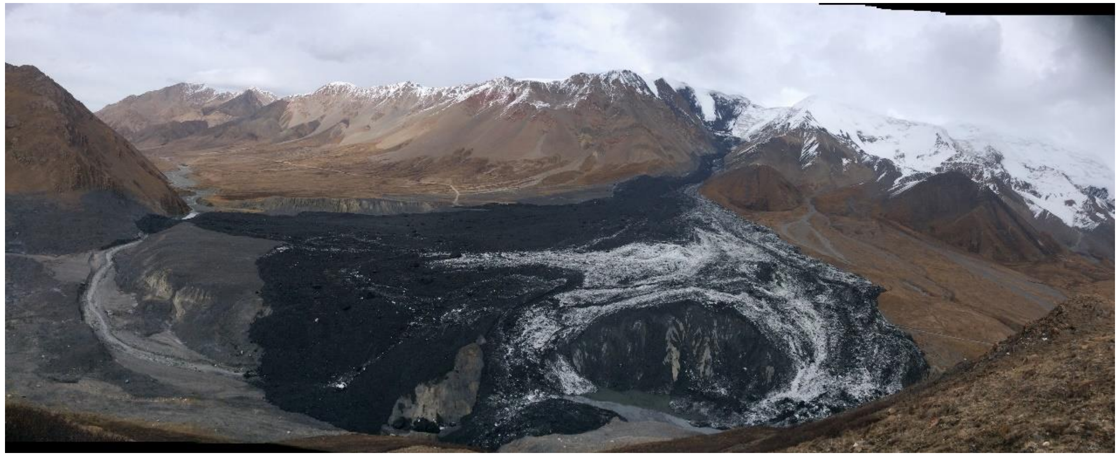
February 7, 2021: Massive floods caused by an ice collapse in northern India kill more than 100.

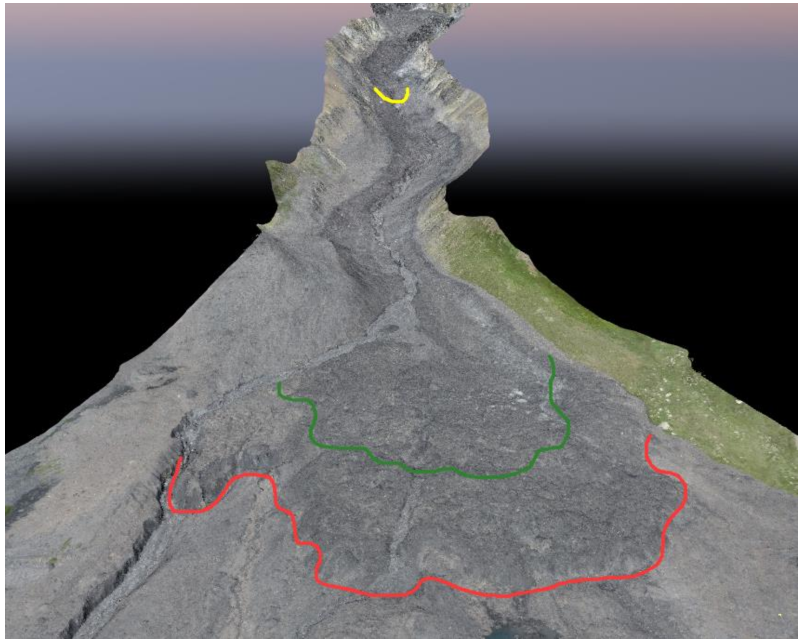
2 Cryospheric hazards

Ice collapse in Tianhan

2 Cryospheric hazards

Ice collapse and GLOF in Anymaqin, 2022

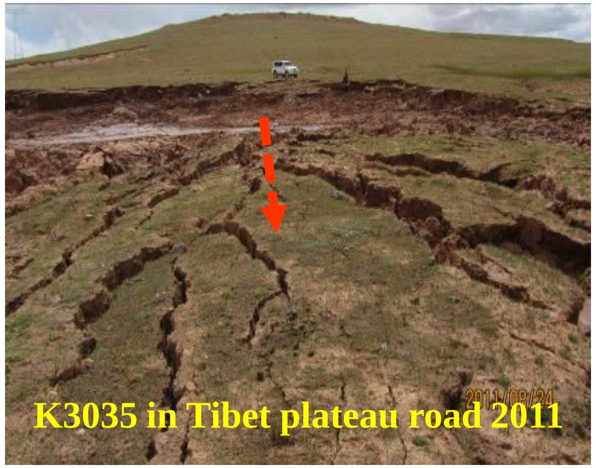




Red: ice collapse in 2016
Green:in 2019
Yellow: tongue in 2022

2 Cryospheric hazards

Retrogressive thaw slumps

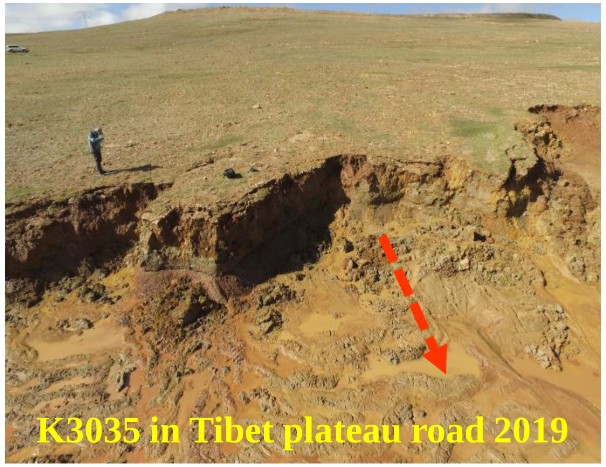


K3035 in Tibet plateau road 2011


G214 Wenquan in 2018

Railway fenghuoshan 2018


Isolated hill in bailuhe, 2019


K3035 in Tibet plateau road 2019


Hongliianghe in 2018

Outline

1. Cryosphere and its Rapid Changes

2.Cryosphere hazards

3. **Several cases study**

  -Snow avalanche
  -Snow disaster in pasturing area
  -Ice collapse
  -Glacier surging
  -GLOF
  -Thaw slumping

4. Observation and early warming system

3 Snow Hazards

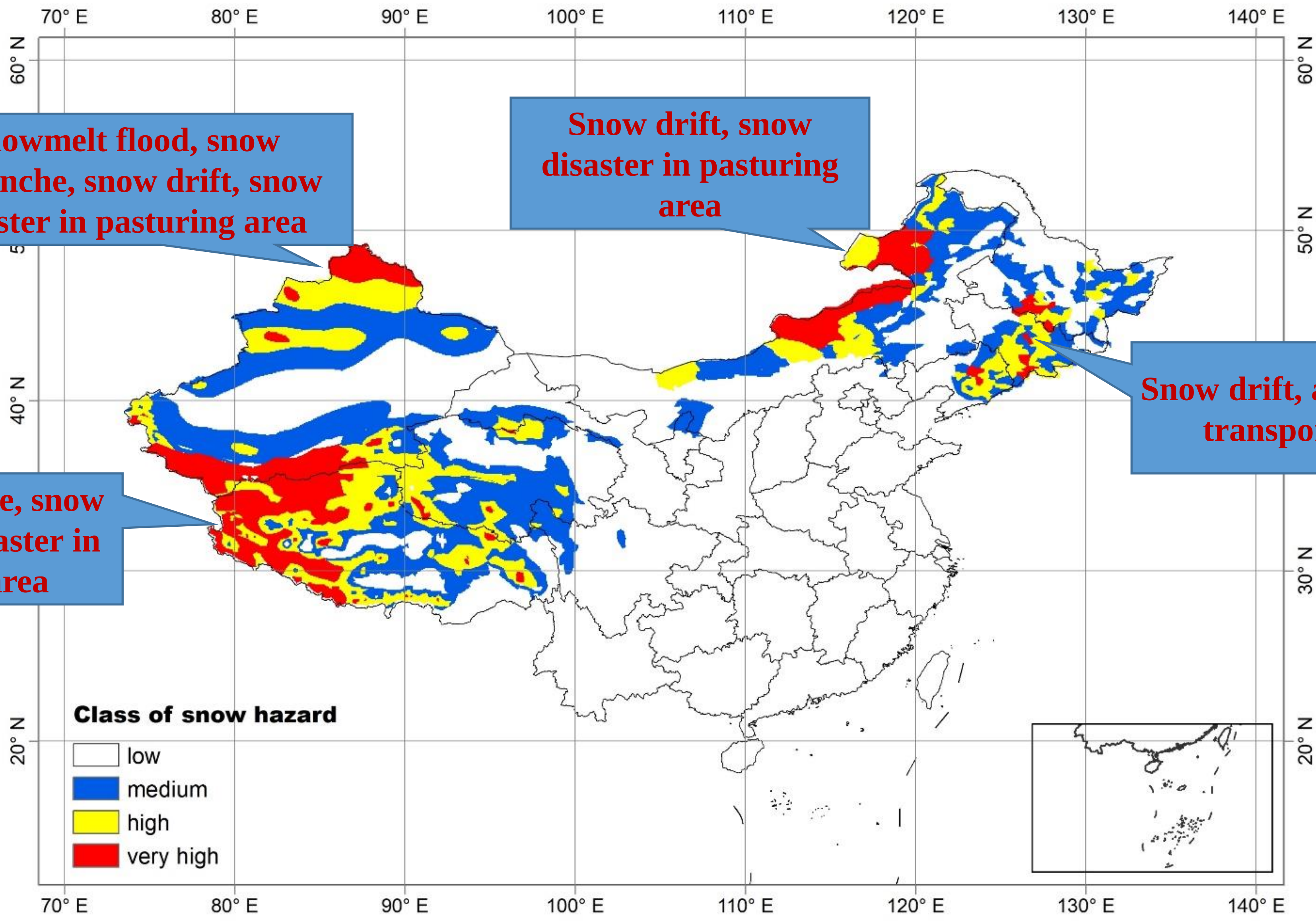
Snow avalanche

Snow drift

Snowmelt flood

Snow disaster in pasturing area

Snow Hazards distribution across China



Snowmelt flood, snow avalanche, snow drift, snow disaster in pasturing area

Snow drift, snow disaster in pasturing area

Snow drift, agriculture, transportation

Snow avalanche, snow drift, snow disaster in pasturing area

(Zhong et al., 2021)

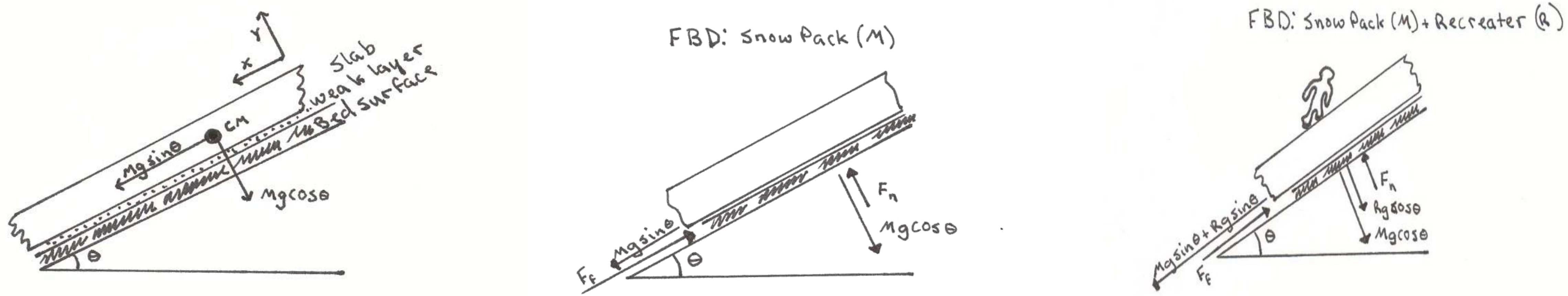
3 Several Case study

- **Snow avalanche**
- Snow disaster in pasturing area
- Ice collapse
- Glacier surging
- GLOF
- Thaw slumping

Avalanche in Mount Manaslu, Nepal,20220927

In January 2020, avalanches in Pakistan-administered Kashmir killed at least 76 people and injured 53 others

3.1 Snow avalanche



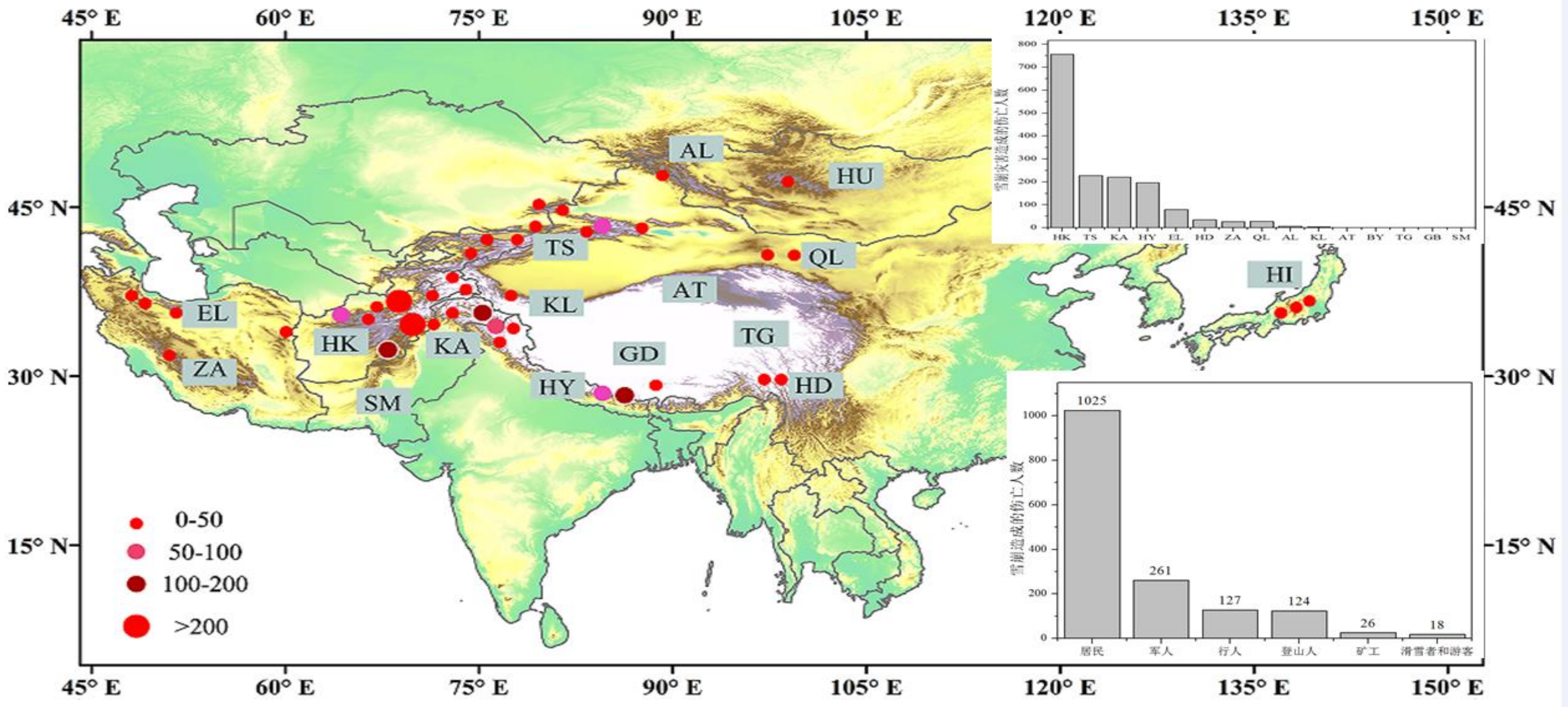
(http://ffden-2.phys.uaf.edu/211_fall2004.web.dir/tamar_young2/page4forcesonthesnowpack.html)

- **Snow avalanches are snow masses that rapidly descend steep slopes, its formation is the complex interaction between terrain, snowpack and meteorological conditions (Schweizer et al., 2003).**

- **The contributory factors are terrain, new snow, wind, temperature, snow cover stratigraphy and selected snow properties (Schweizer et al., 2003).**

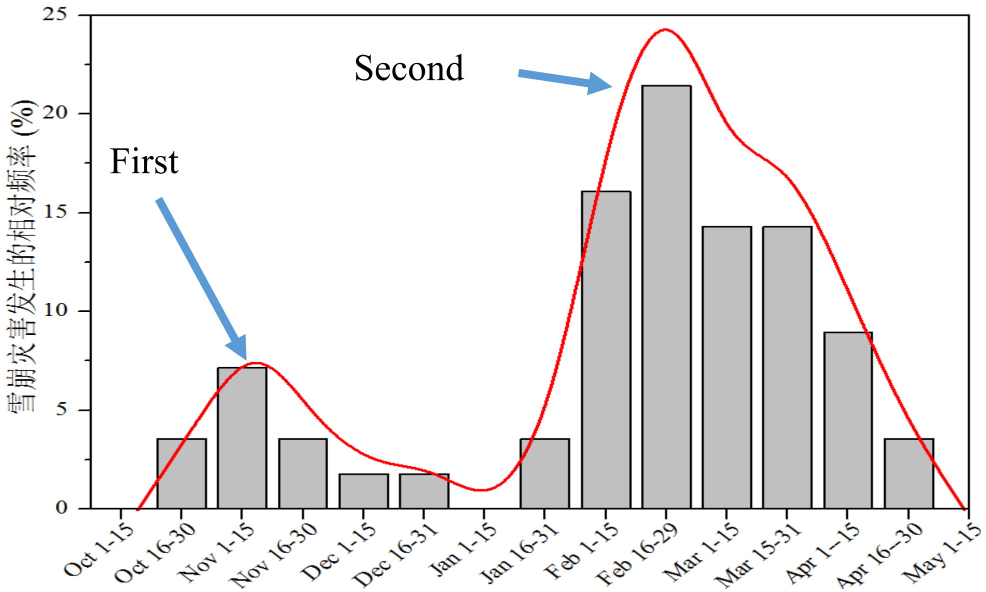
- **A human-triggered avalanche occurs when the snow is at a critical balance between strength and strain.**

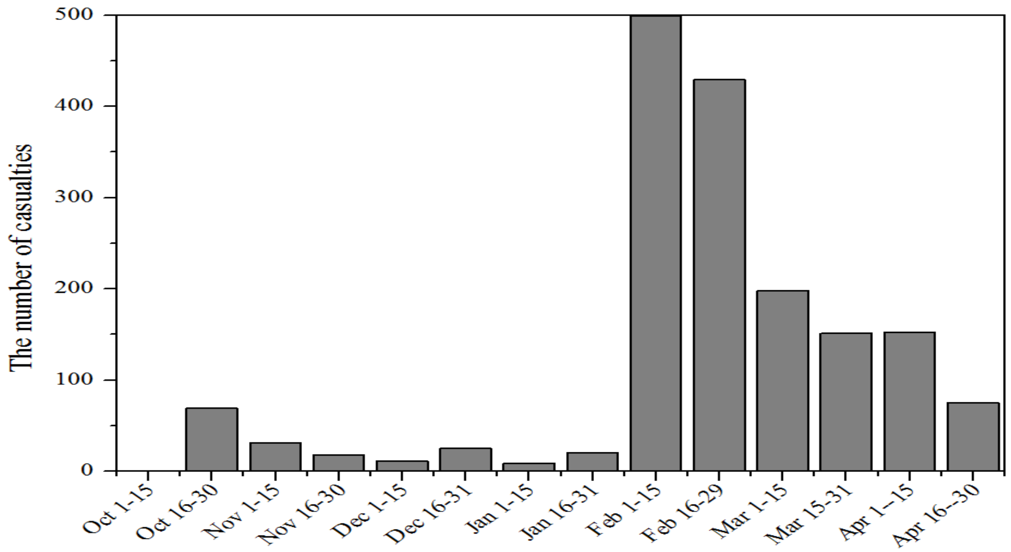
3.1 Snow Avalanche in Tienshan(Li lanhai)



Avalanche casualties during 2009-2019 in Asia

Temporal distribution of Snow Avalanche





Inducing factors and condition

Heavy snow fall in 10, Dec， SF=35cm

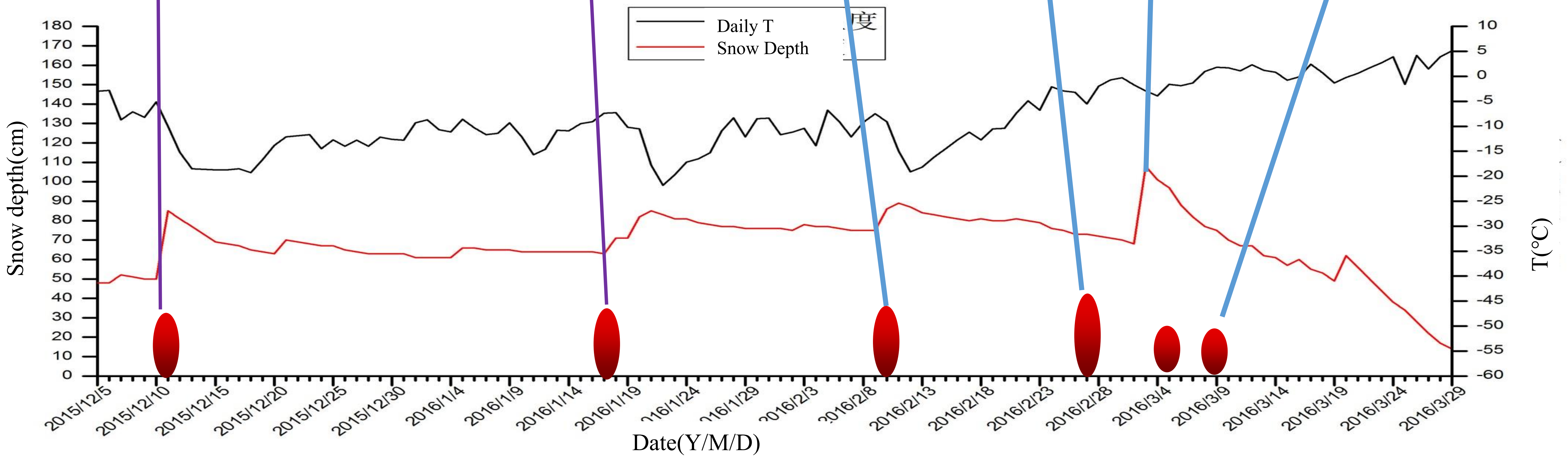
Persistent snowfall between 17-21, Jan SF=22cm

10,Feb. M5.1 earthquake d=120km

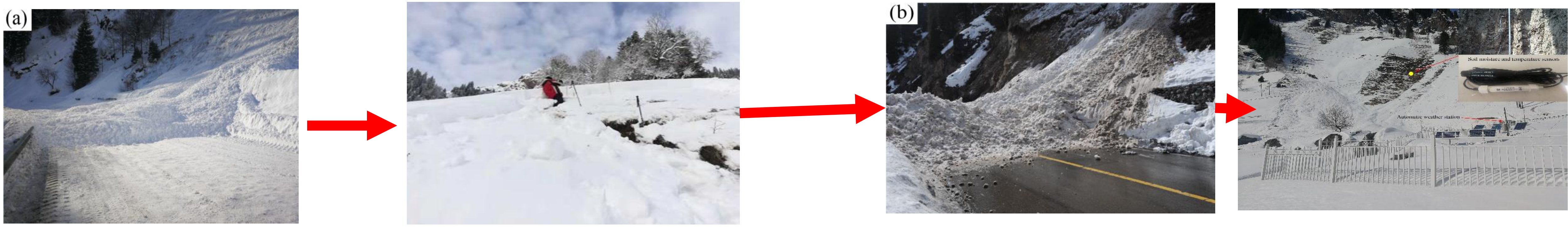
T rose fastly in a short time

Blizzard in 2 Mar. SF=50cm

T rise

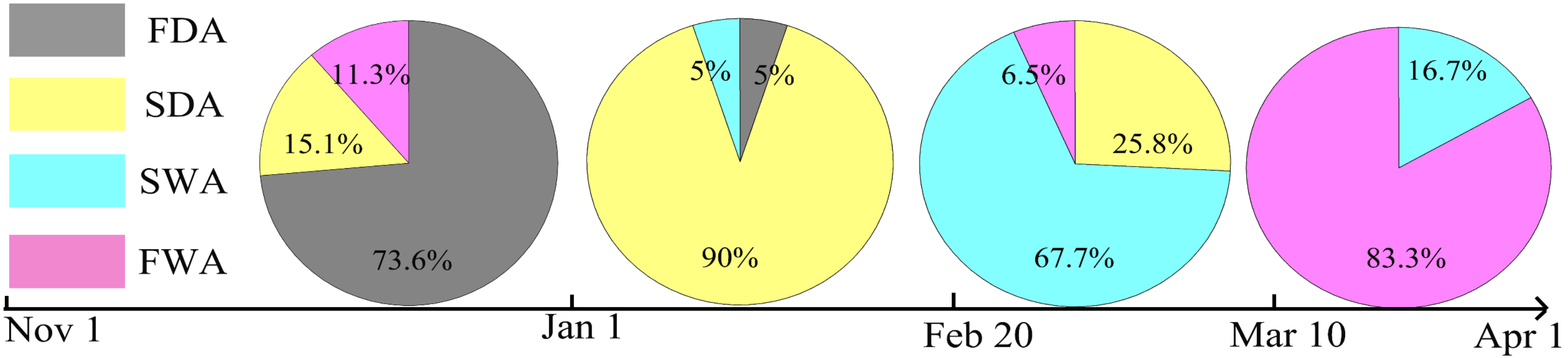


Avalanche types

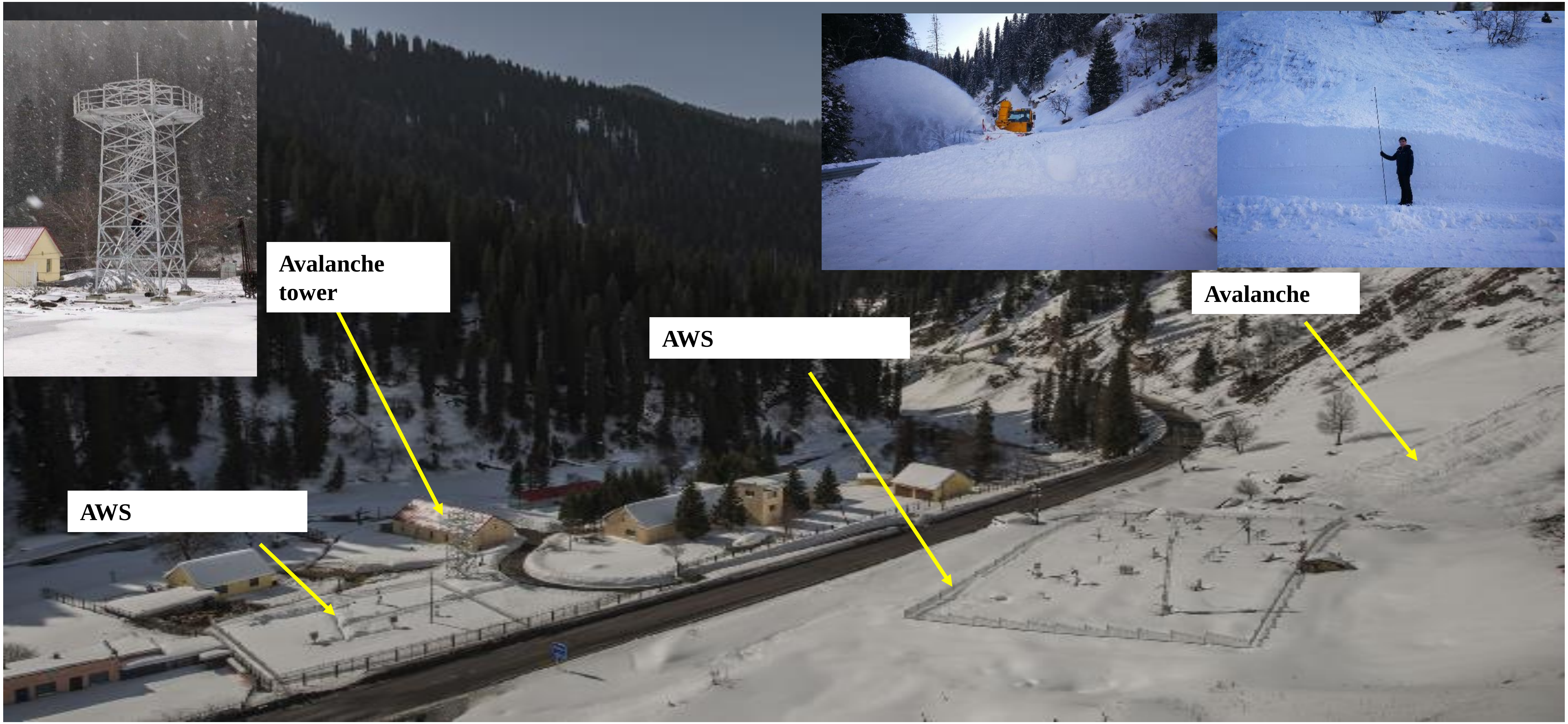


Full layer dry avalanche(FDA) **Surface dry avalanche(SDA)** **Surface wet avalanche)** **Full wet avalanche(FWA)**

Nov. 1 Jan. 1 Feb.21 Mar. 10



Avalanche observation



Avalanche tower

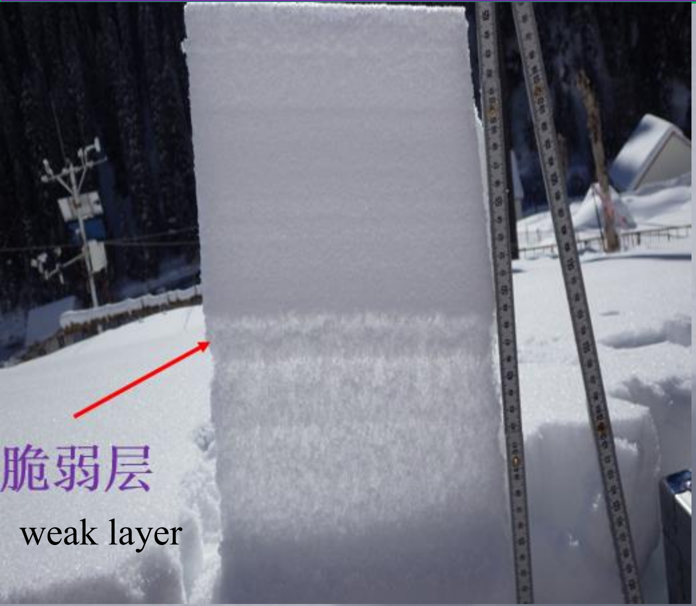
AWS

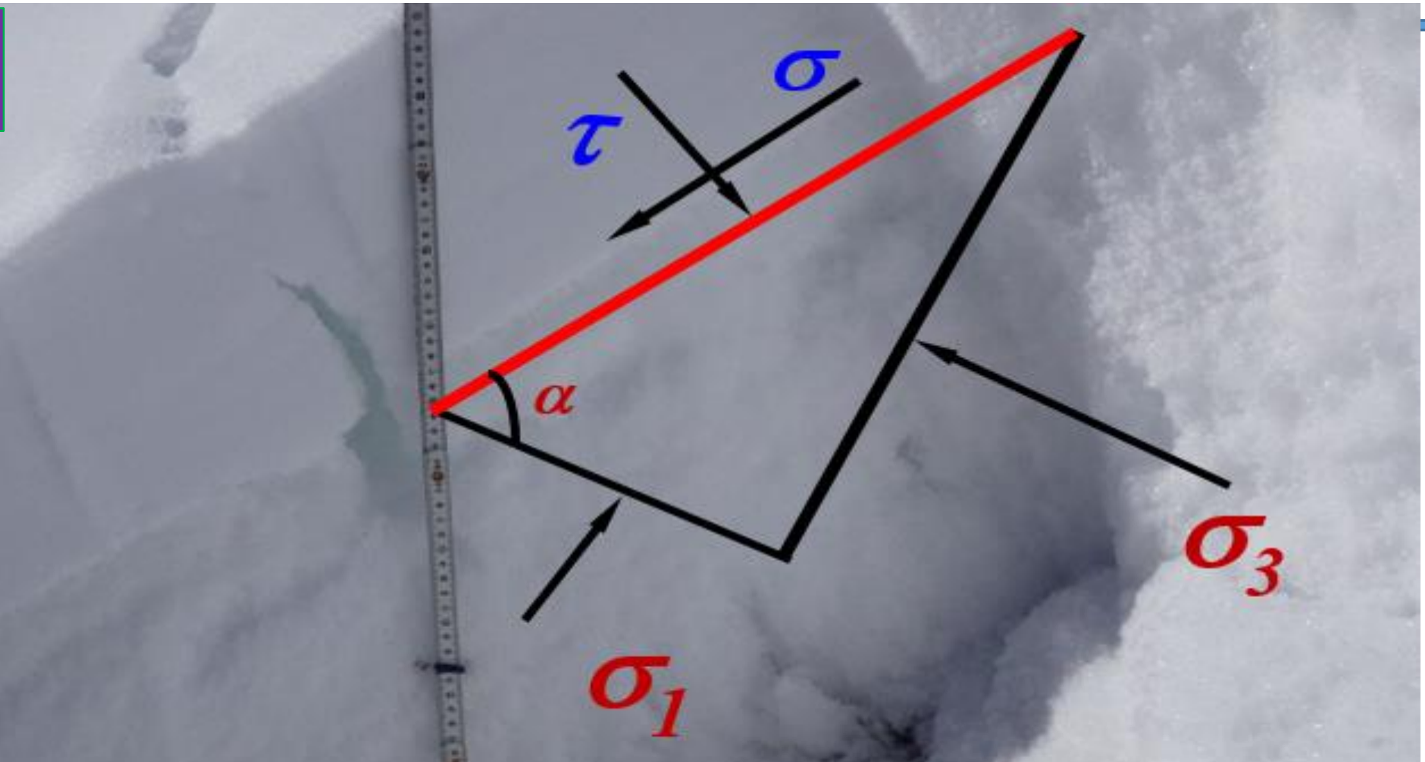
Avalanche

AWS

Avalanche Mechanism

Snow shear stress



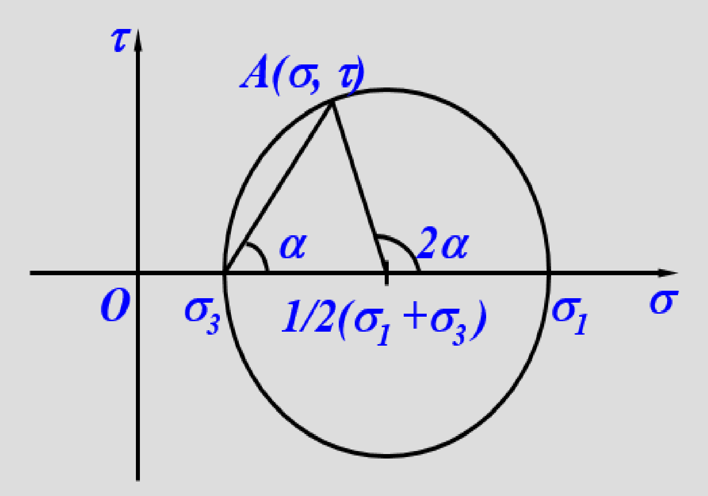


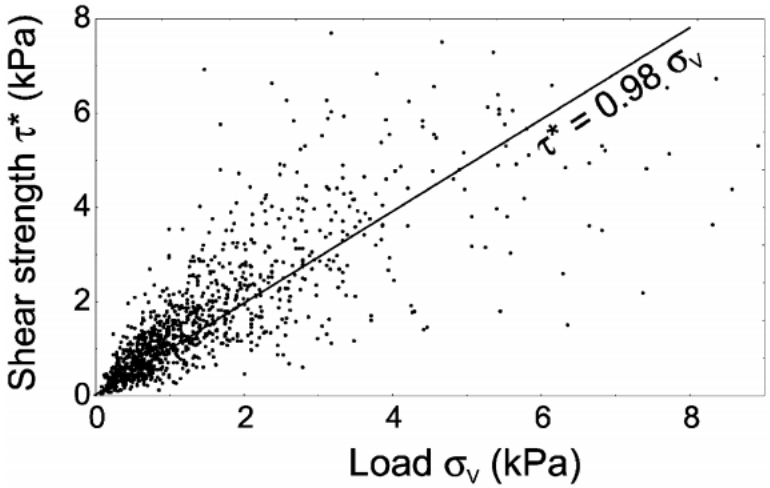
$$\sigma_3 dl\sin\alpha - \sigma dl\sin\alpha + \tau dl\cos\alpha = 0$$

$$\sigma_1 dl\cos\alpha - \sigma dl\cos\alpha + \tau dl\sin\alpha = 0$$

$$\sigma = \frac{1}{2}(\sigma_1 + \sigma_3) + \frac{1}{2}(\sigma_1 - \sigma_3)\cos 2\alpha$$

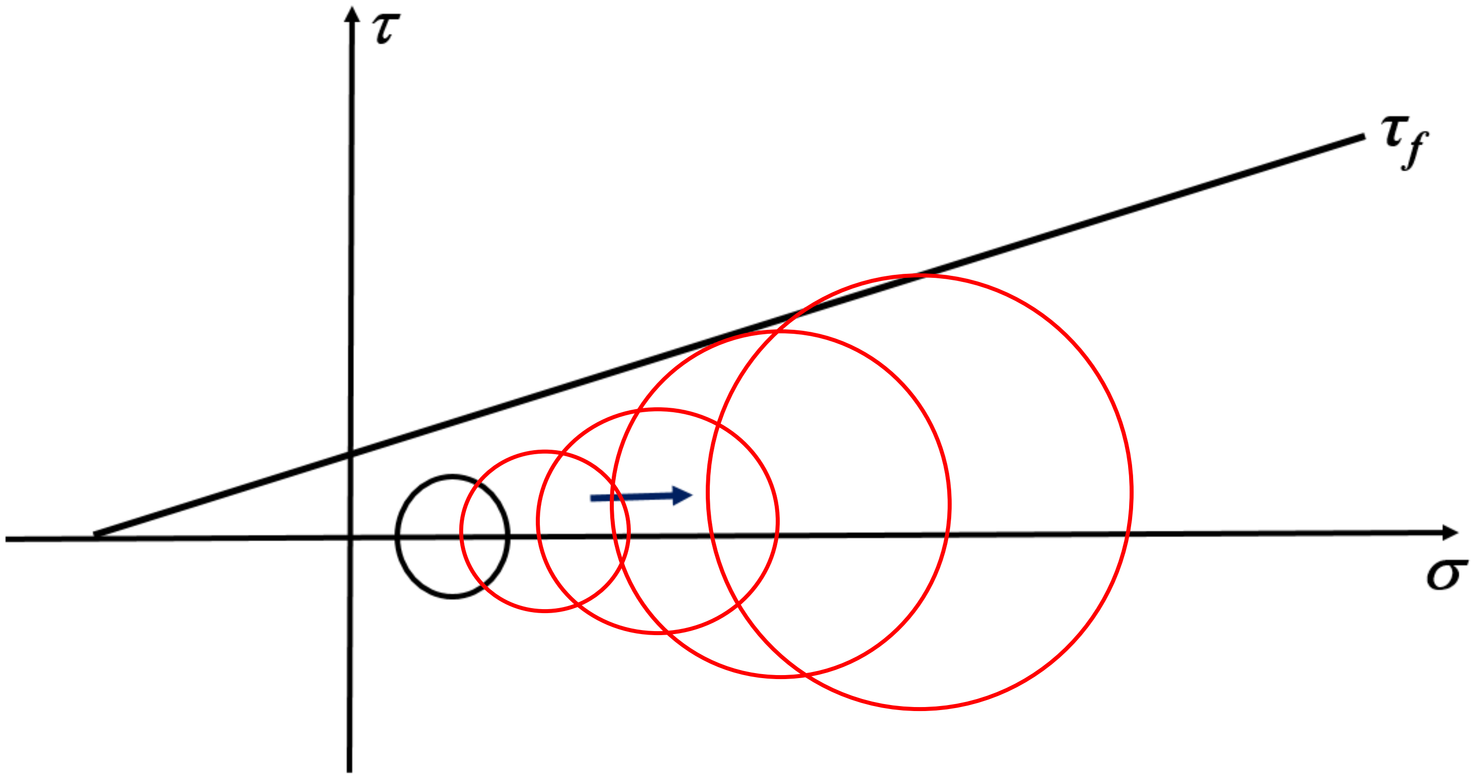
$$\tau = \frac{1}{2}(\sigma_1 - \sigma_3)\sin 2\alpha$$





Avalanche Mechanism

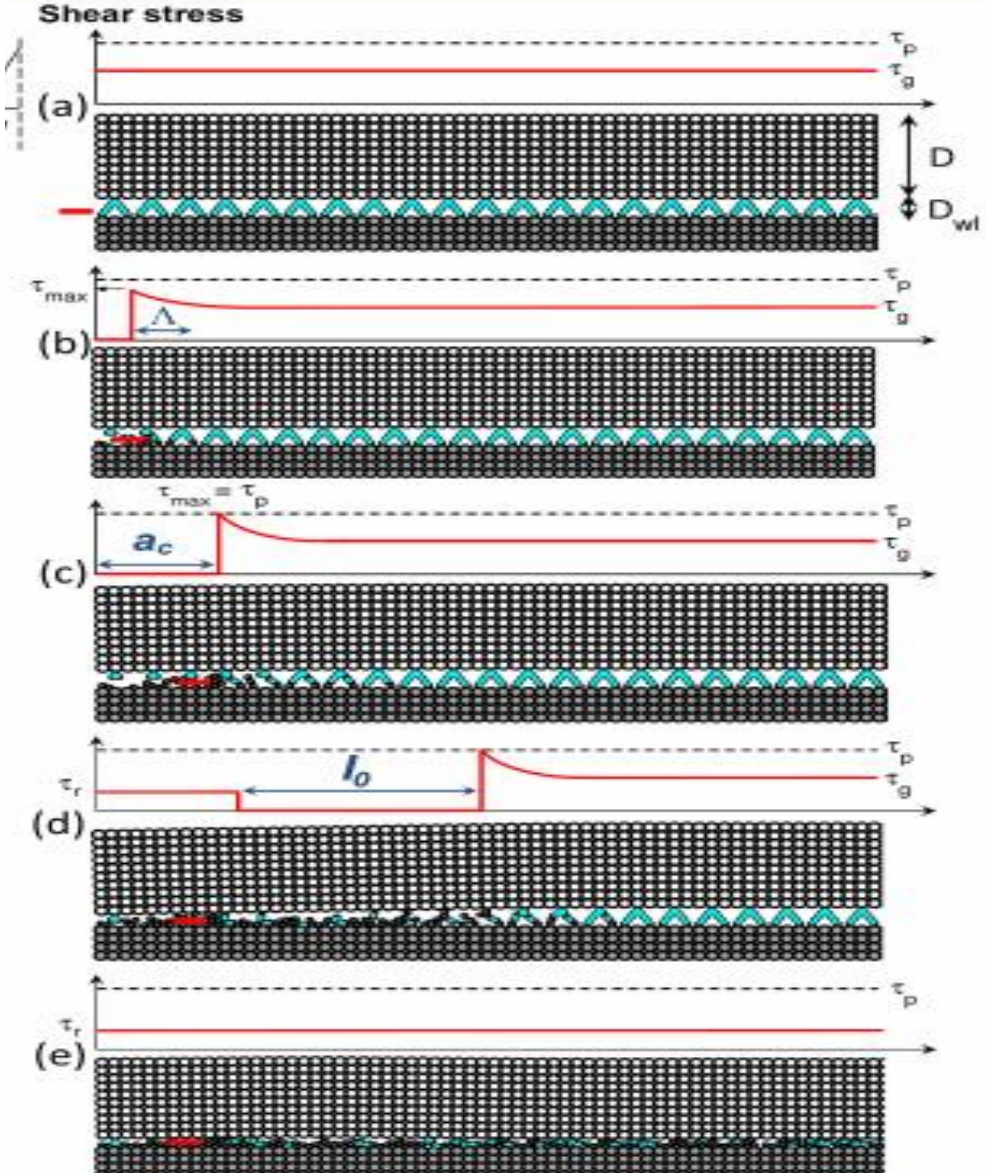
Shear failure



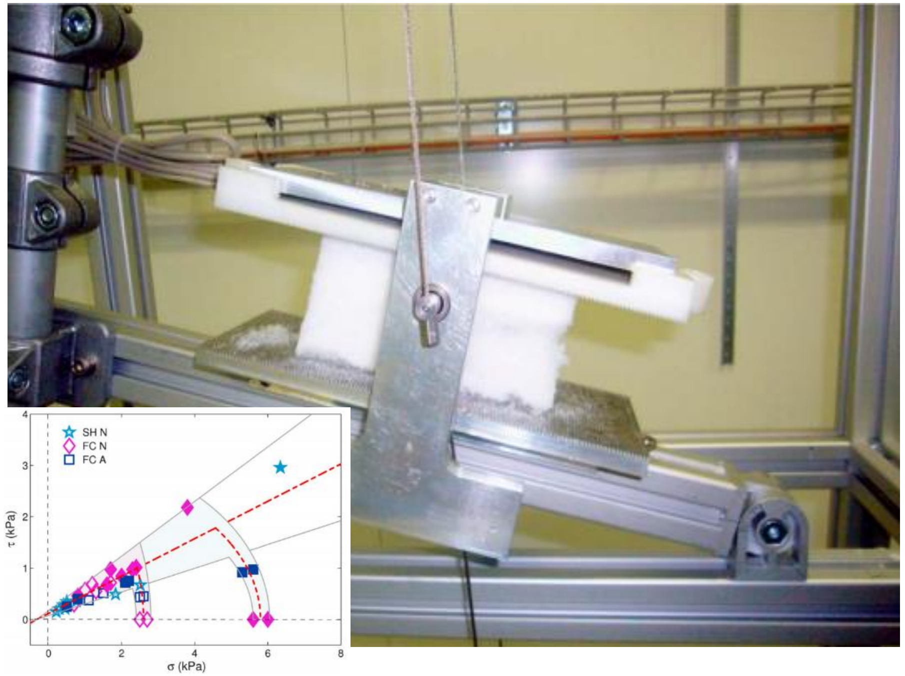
$$\sigma_1 = \cos\theta(\rho_o g h_o + \rho_n g h_n)$$

$$\sigma_3 = \sigma_1 \tan^2(45^o - {}^{\phi}\!/_{2}) - 2c\tan(45^o - {}^{\phi}\!/_{2})$$

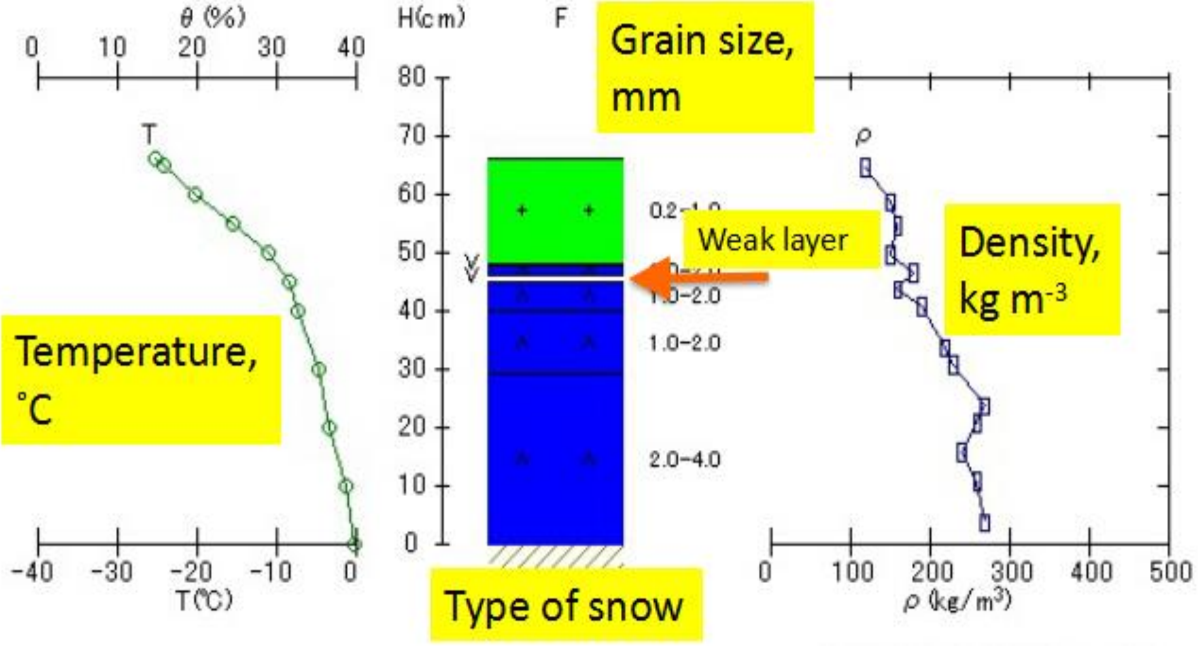
Fissure diffusion

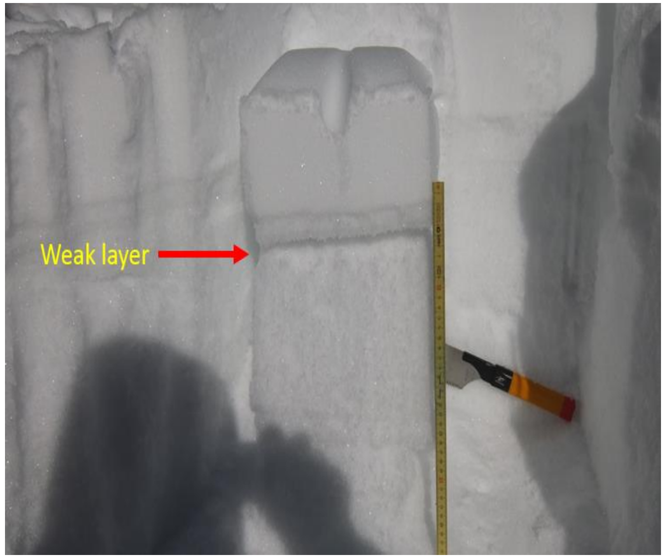


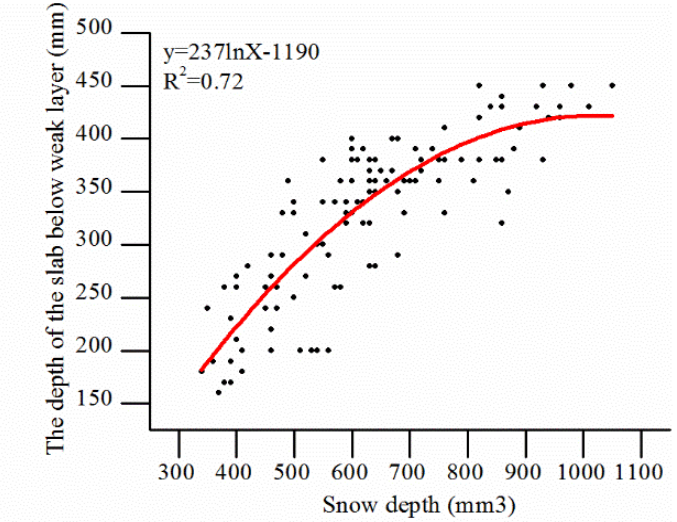
Snow parameters



$\tan\phi = 0.21 \sim 0.53, c \approx 170pa$







Avalanche early warming system

RS and ground monitoring

Data analysis and warming releas

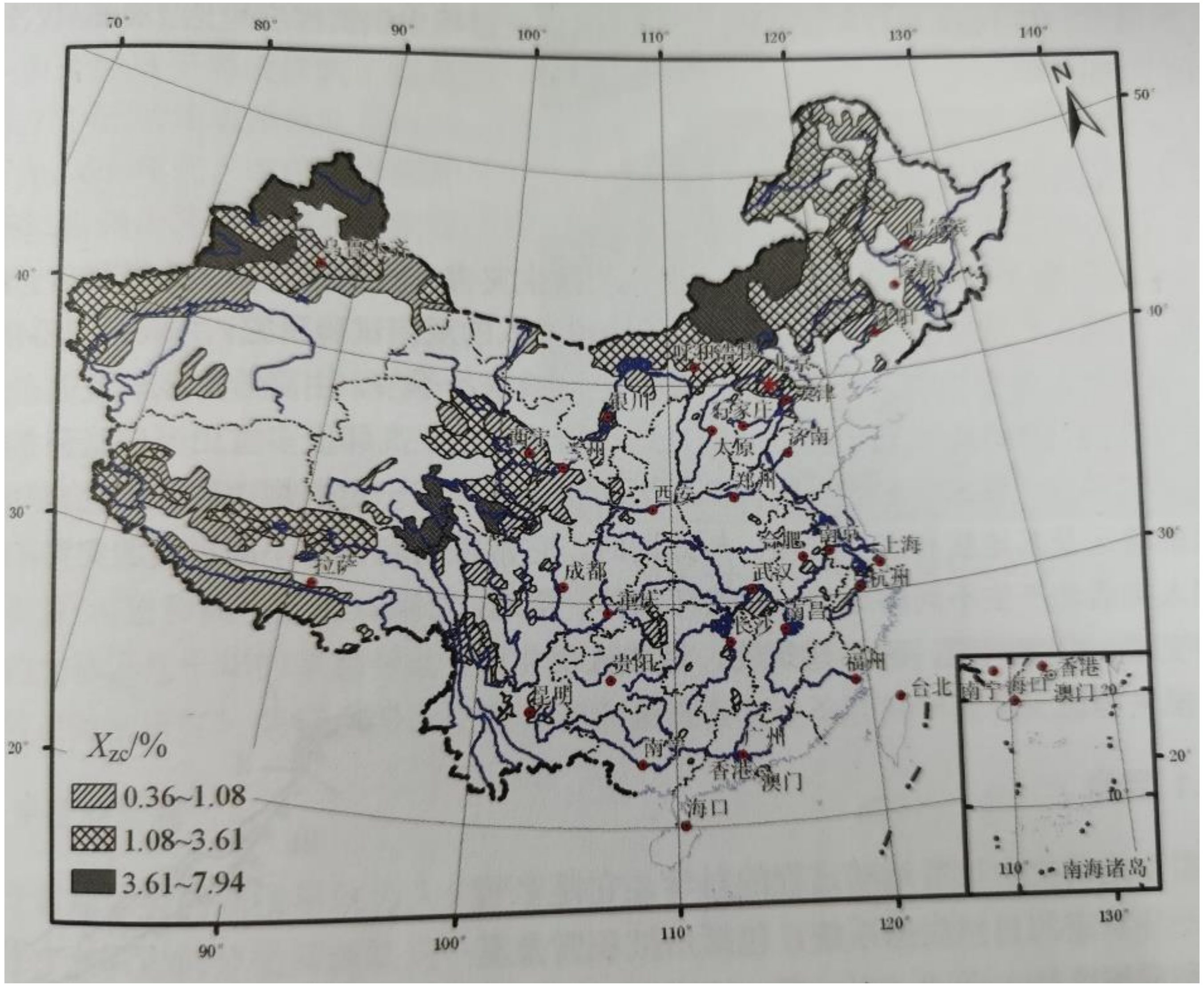
Receive early warming

Emergency and hedging

3.2 Several Case study

- Snow avalanche
- **Snow disaster in pasturing area**
- Ice collapse
- Glacier surging
- GLOF
- Thaw slumping

3.2 Snow disaster in pasturing area



Snow disaster level in pasturing areas across China from 1994 to 2000 (Hu, 2013)

- **Snowstorm is the main form of snow disaster in the pasturing area, which seriously threatens the livestock in winter.**
- **Snow disasters in the pasturing area are distributed in Xinjiang, the Tibetan Plateau, and inner Mongolia across China.**

Loss of snow disaster in pasturing areas (Hu, 2013)

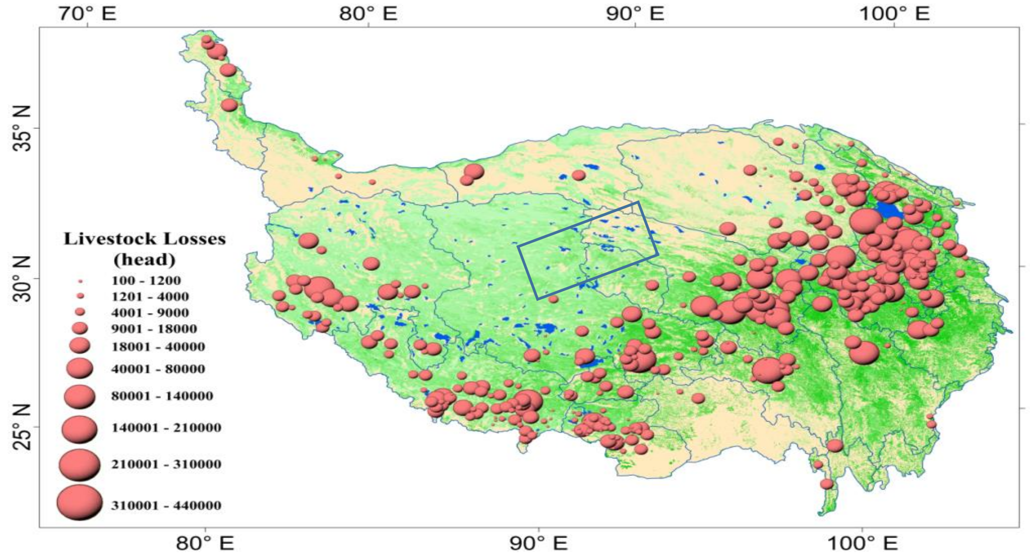
Time	Region	Livestock loss	Economic loss
1977	Xilin Gol	3 million	0.17 billion
1990	Tibet	/	0.6 billion
1994	North Tibet	11,000	/

Jeopardize/Loss

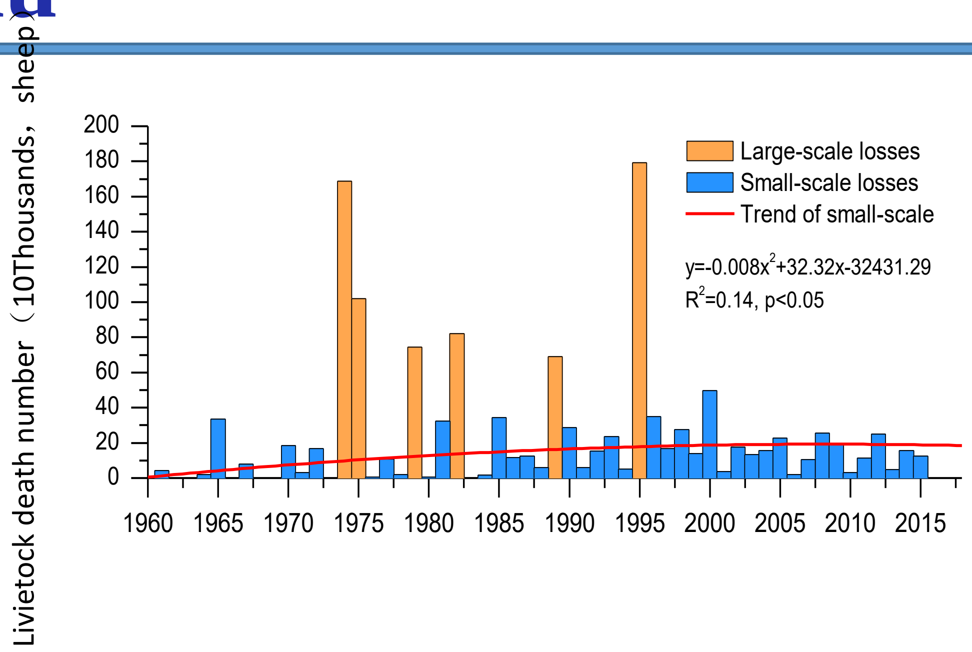
Snow disaster is a kind of meteorological disaster or cryosphere disaster caused by excessive snowfall, too deep snow, too long duration of snow and low temperature, and the lack of emergency measures to cause casualties of people and livestock, damage to transportation, and the economic and social system.

- ☐ In the winter of 1999-2003, Mongolia suffered the most severe snow disaster in nearly 50 years. **8.5 million livestock** (25%) died as a result of the snow.
- ☐ In the winter of 1970-71, a catastrophic snowfall in Georgia killed **39 people**. In the winter of 1975-78, heavy snow killed 42 people, and in 1986-87, heavy snow killed 80 people. Economic losses amounted to $60, 200,500 million, and about 20,000 residents were forced to change their homes.
- ☐ In the winter of 1999/2000-2009/2010, the total number of deaths due to snowstorms in Japan was 1,769, with an annual average of 495 snowstorms.

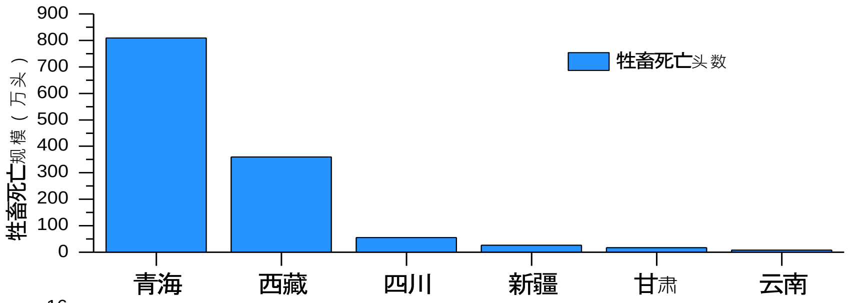
Jeopardize/Loss In Tibetan Plateau

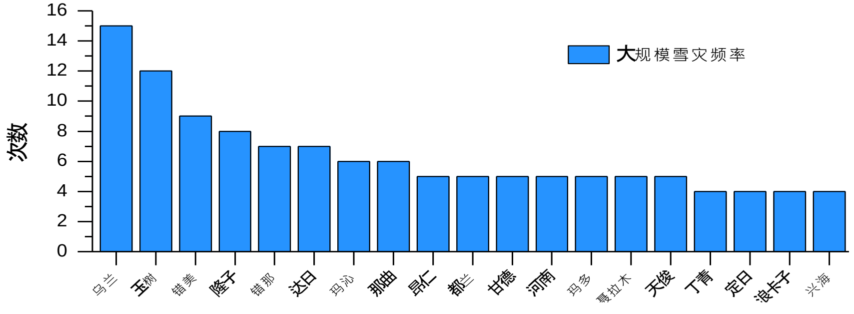


Spatial and temporal distribution of snow disasters on the Tibetan Plateau from 1961 to



In the past 50 years, 238 snow events were recorded, with (more than 600,000 livestock deaths) occurring in 1974-75, 1979, 1982, 1989, and 1995. In recent years, small numbers (less than 600,000) have occurred, but the total number of deaths has increased. Snow disasters mainly occurred in Hainan, Yushu and Guoluo prefectures in the south and southeast of Qinghai Province, as well as Nagqu, Shigatse and Shannan regions in the Tibet Autonomous Region.



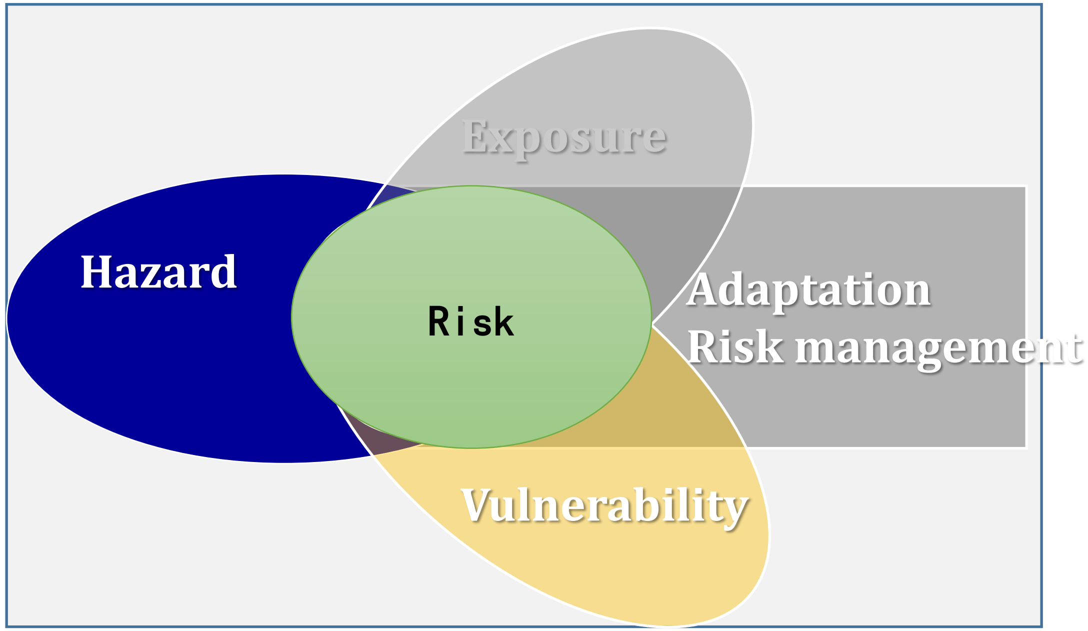


Jeopardize/Loss

From the end of December 2018 to March 2019, a large-scale snowstorm occurred in the headwaters of the Lancang River, the source of the Three rivers on the Qinghai-Tibet Plateau， which led to livestock death

Mechanism

A natural event that causes livestock casualties and losses due to excessive, deep and prolonged snowfall, low temperatures and lack of forage stocks and emergency response (human).



The risk of snow disaster refers to the potential loss caused by dangerous snowfall and snow events to the economy, society and environment of the affected area. Therefore, Integrated risk, R) can be expressed as A function of the cryospheric event risk (D), Exposure (E), Vulnerability (V) and Adaptation (A) of the affected area

$$R = f(D, E, V, A)$$

Risk evaluation

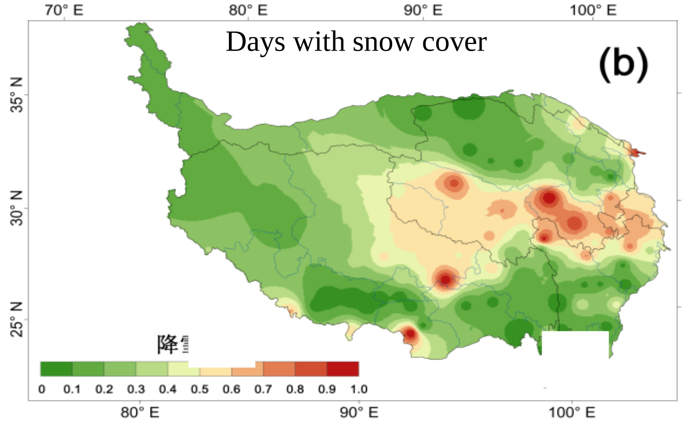
Target	Domain	Factors	Unit	Remark
综合风险指数（IRI）	致灾体与孕灾体危险度指数（HI）	累计雪深（X1）	mm	致灾体规模
		积雪日数（X2）	天	致灾体规模
		低温日数（X3）	天	低温-孕灾环境
		产草量(NDVI)（X4）	-	草地-孕灾环境
	承灾体暴露度指数（EI）	牲畜超载率（X5）	%	承灾体暴露程度
	承灾体脆弱度指数（VI）	羊占牲畜总数比例（X6）	%	表明抗灾能力程度
	适应度指数（AI）	人均收入（X7）	元/人	个人适应
		人均固定资产投资（X8）	元/人	政府适应

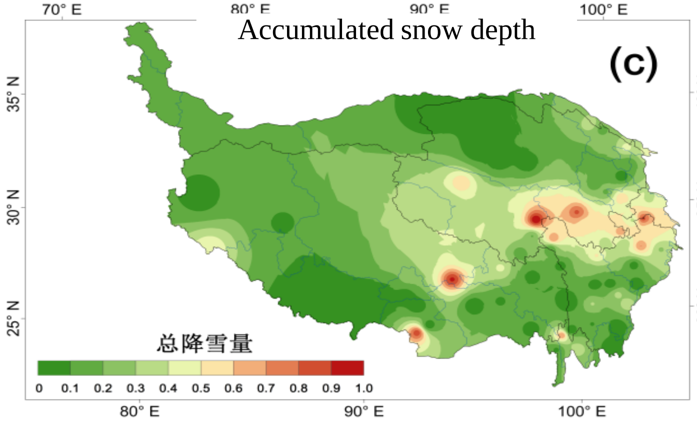
snow

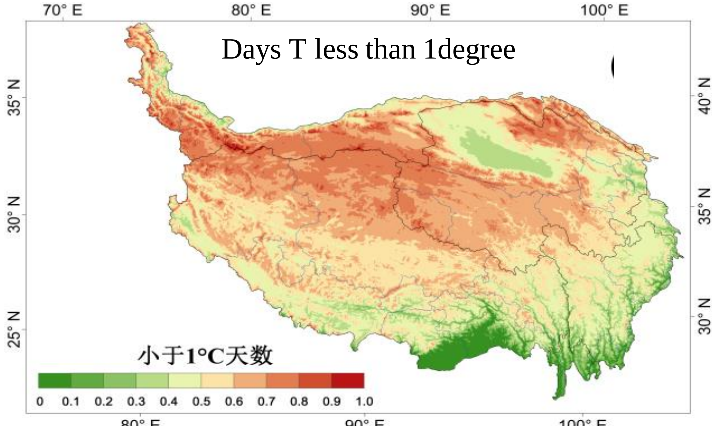
Grass

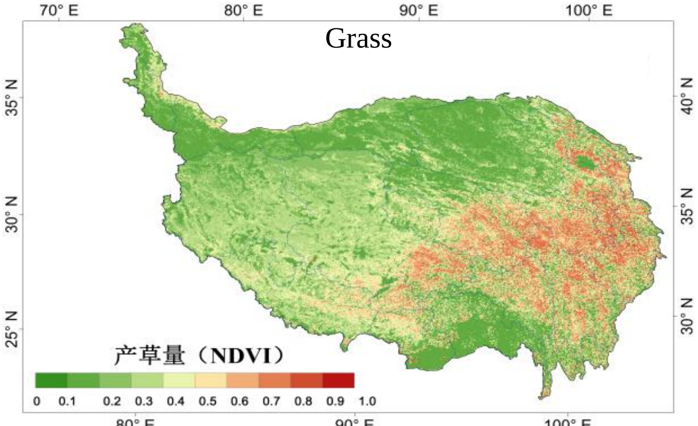
Livestock

human









Risk evaluation

通过回归分析样本数据集，进行二值Logistic回归，建立其雪灾发生概率模型：

$$\log\left(\frac{p}{1-p}\right) = -24.562 + 1.22\times x_1 + 0.46\times x_2 + 0.76\times x_3 + 0.99\times x_4$$
$$+2.17\times x_5 + 1.37\times x_6 + 1.29\times x_7 + 1.06\times x_8$$

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
因子	累计雪深	积雪日数	低温日数	产草量	超载率	羊比例	人均收入	固定资产投资
回归系数	1.21	0.46	0.76	0.99	2.17	1.37	1.29	1.06
指标权重	0.13	0.03	0.06	0.10	0.28	0.15	0.14	0.11

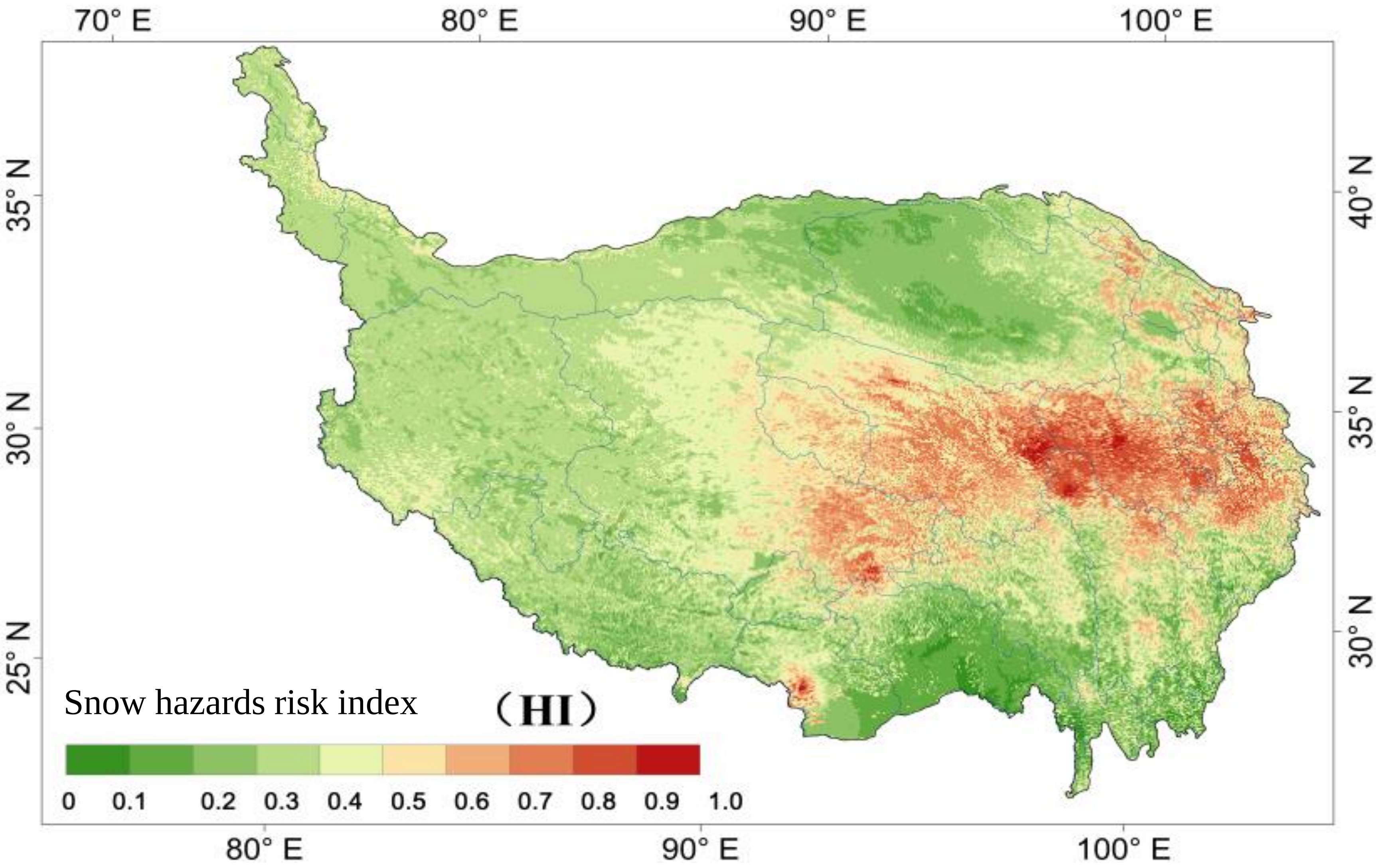
Snow

Lack food

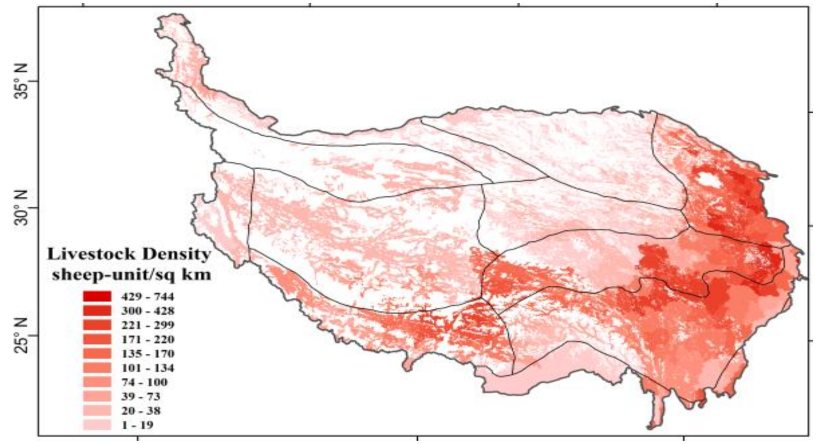
Livestock

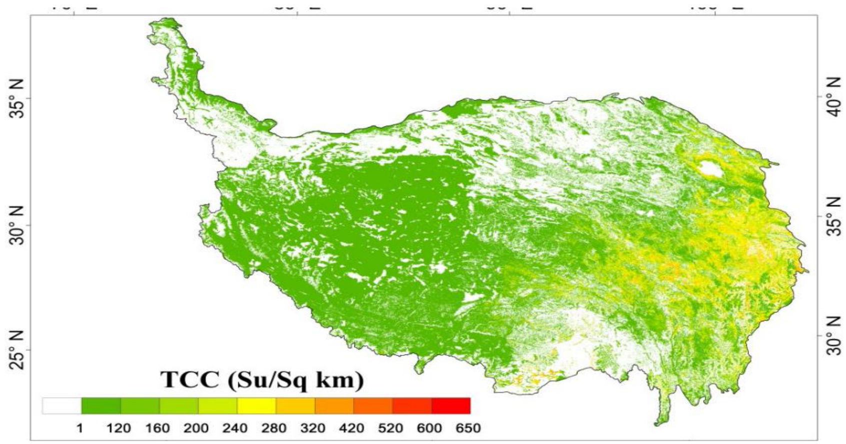
human

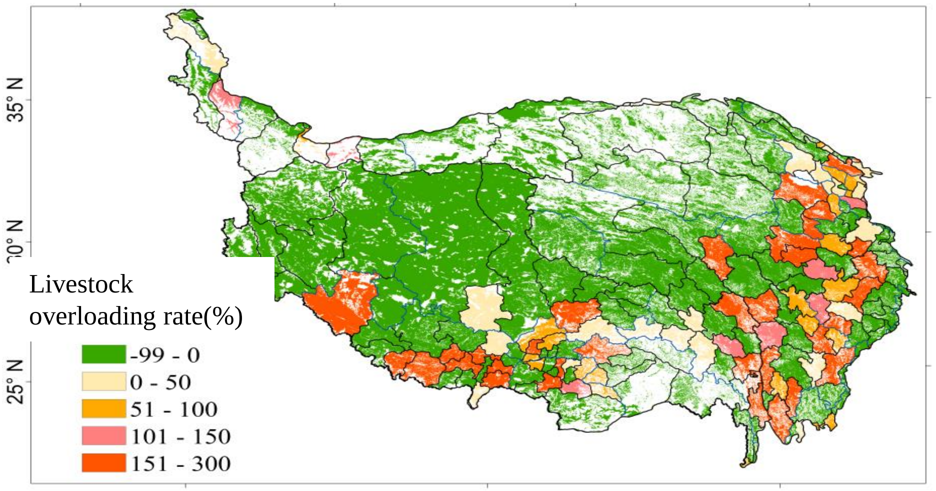
Hazards index

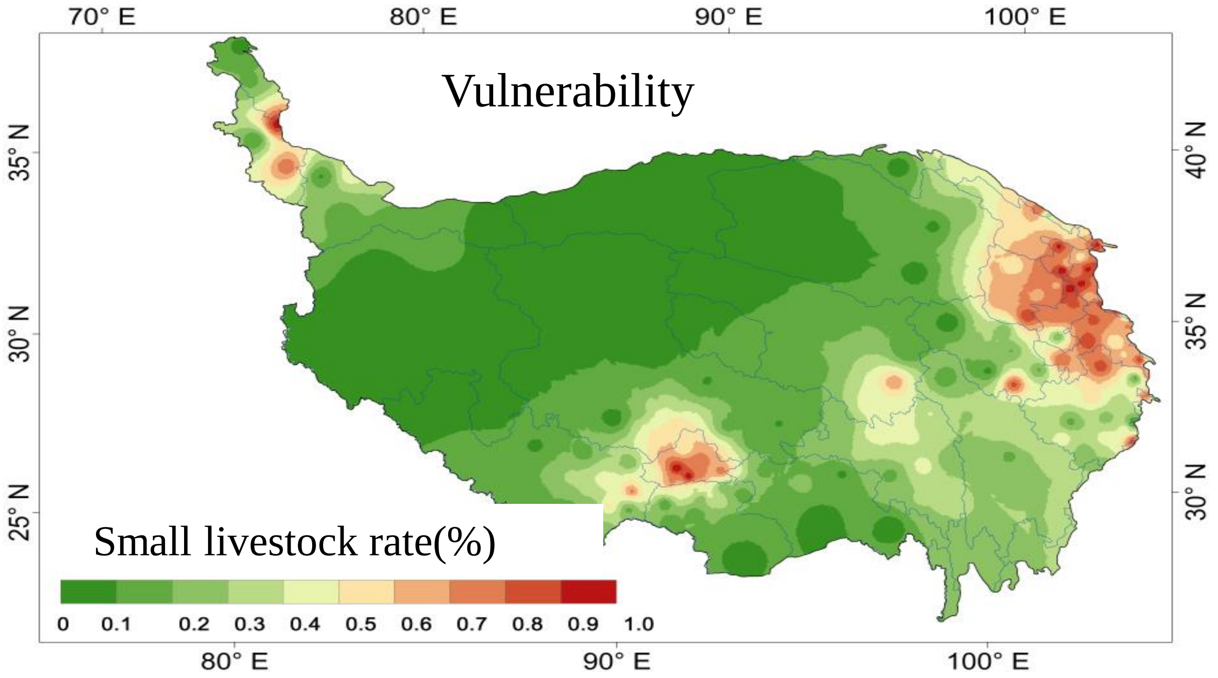


Exposure and vulnerability

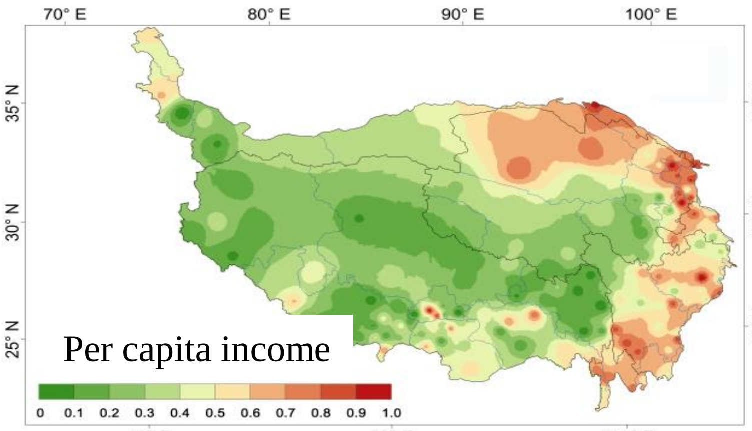




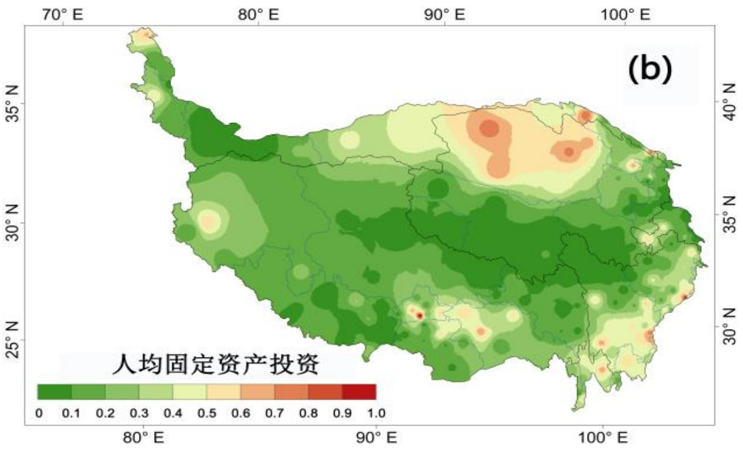




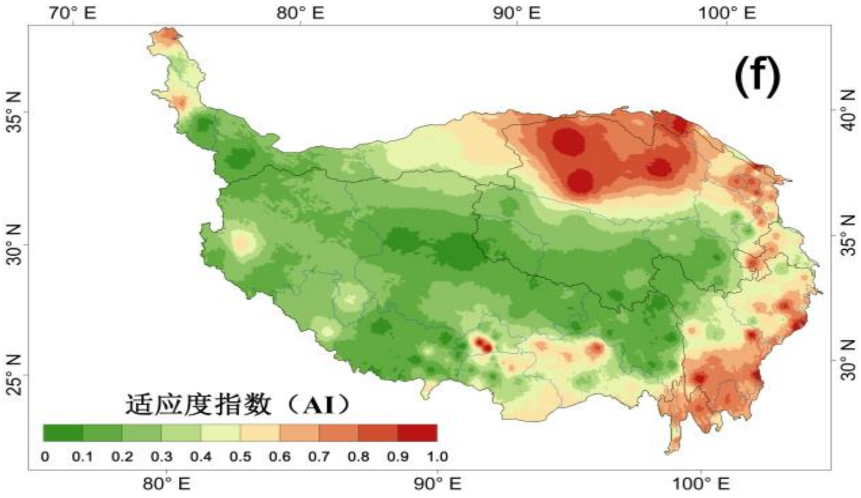
Adaptation



Per capita income

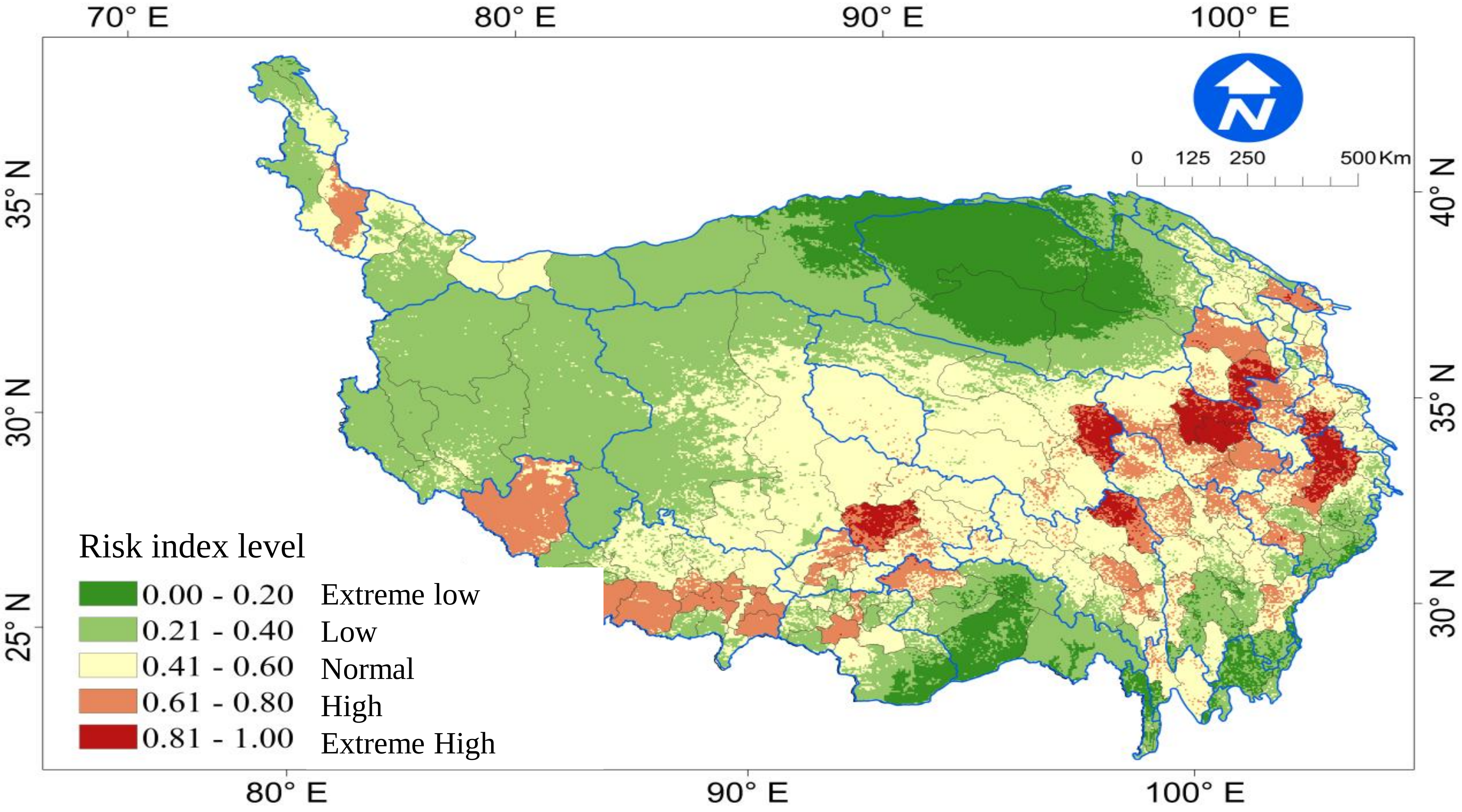


Per capita input in fixed assets

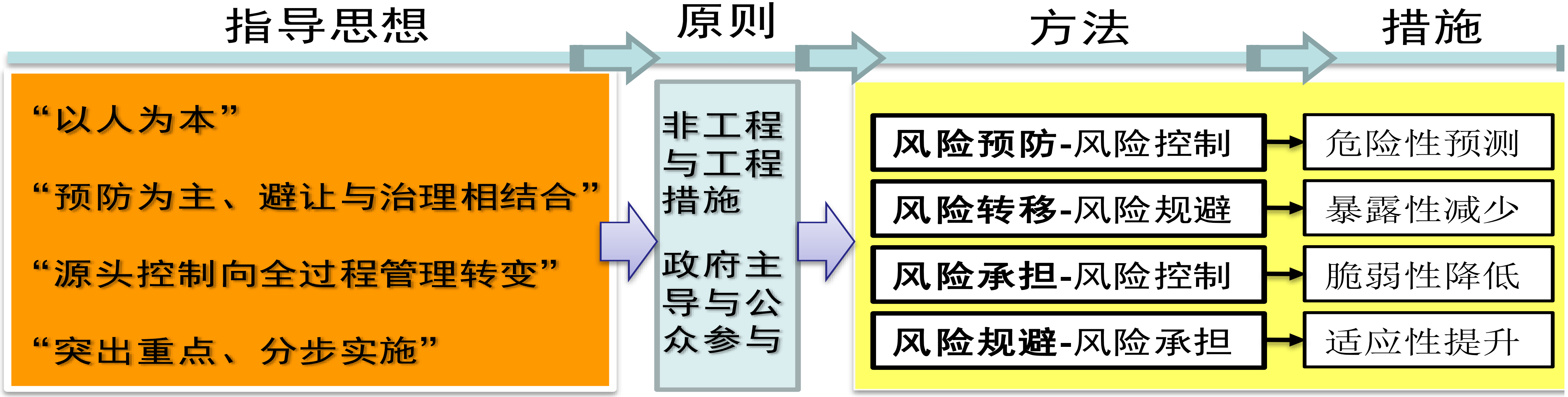


Adaptation index

Risk Index


70° E
80° E
90° E
100° E
35° N
30° N
25° N
40° N
35° N
30° N
N
0
125
250
500 Km
Risk index level
🟩 0.00 - 0.20 Extreme low
🟩 0.21 - 0.40 Low
🟨 0.41 - 0.60 Normal
🟧 0.61 - 0.80 High
🟥 0.81 - 1.00 Extreme High
80° E
90° E
100° E

Risk management



指导思想

“以人为本”

“预防为主、避让与治理相结合”

“源头控制向全过程管理转变”

“突出重点、分步实施”

原则

非工程与工程措施

政府主导与公众参与

方法

措施

风险预防-风险控制 → 危险性预测

风险转移-风险规避 → 暴露性减少

风险承担-风险控制 → 脆弱性降低

风险规避-风险承担 → 适应性提升

3.3 Several Case study

- Snow avalanche
- Snow disaster in pasturing area
- **Ice collapse**
- Glacier surging
- GLOF
- Thaw slumping

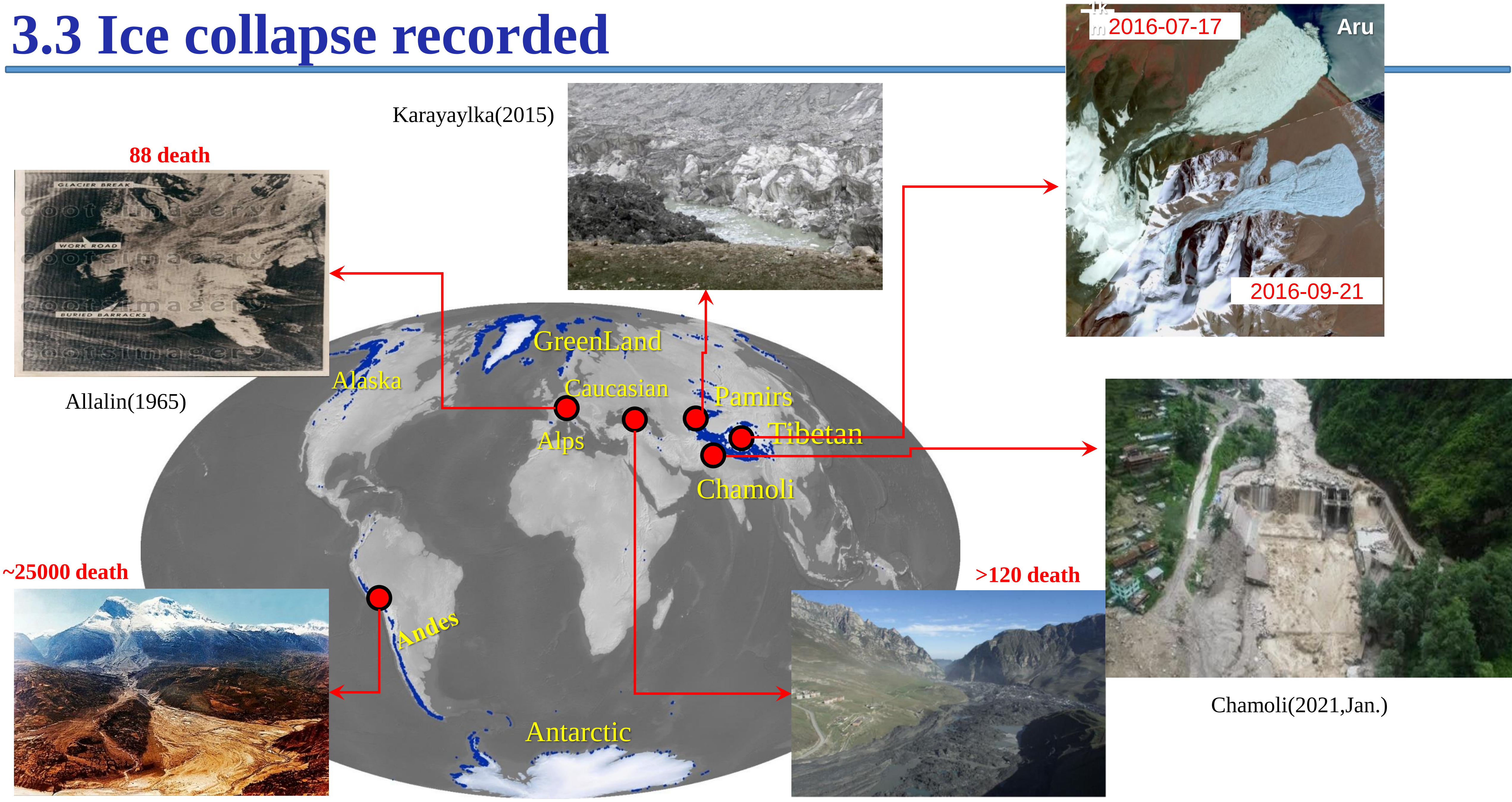
3.3 Ice collapse

Ice collapse/glacier avalanche/icefall

An icefall is a portion of certain glaciers characterized by relatively rapid flow and chaotic crevassed surface, caused in part by gravity. The term icefall is formed by analogy with the word **waterfall**, which is a similar phenomenon of the liquid phase but at a more spectacular speed. When ice movement of a glacier is faster than elsewhere, because the glacier bed steepens or narrows, and the flow cannot be accommodated by plastic deformation, the ice fractures, forming crevasses. Where two fractures meet, seracs (or ice towers) can be formed. When the movement of the ice slows down, the crevasses can coalesce, resulting in the surface of the glacier becoming smoother.

Wikipedia

3.3 Ice collapse recorded



88 death

Allalin(1965)

Karayaylka(2015)

~25000 death

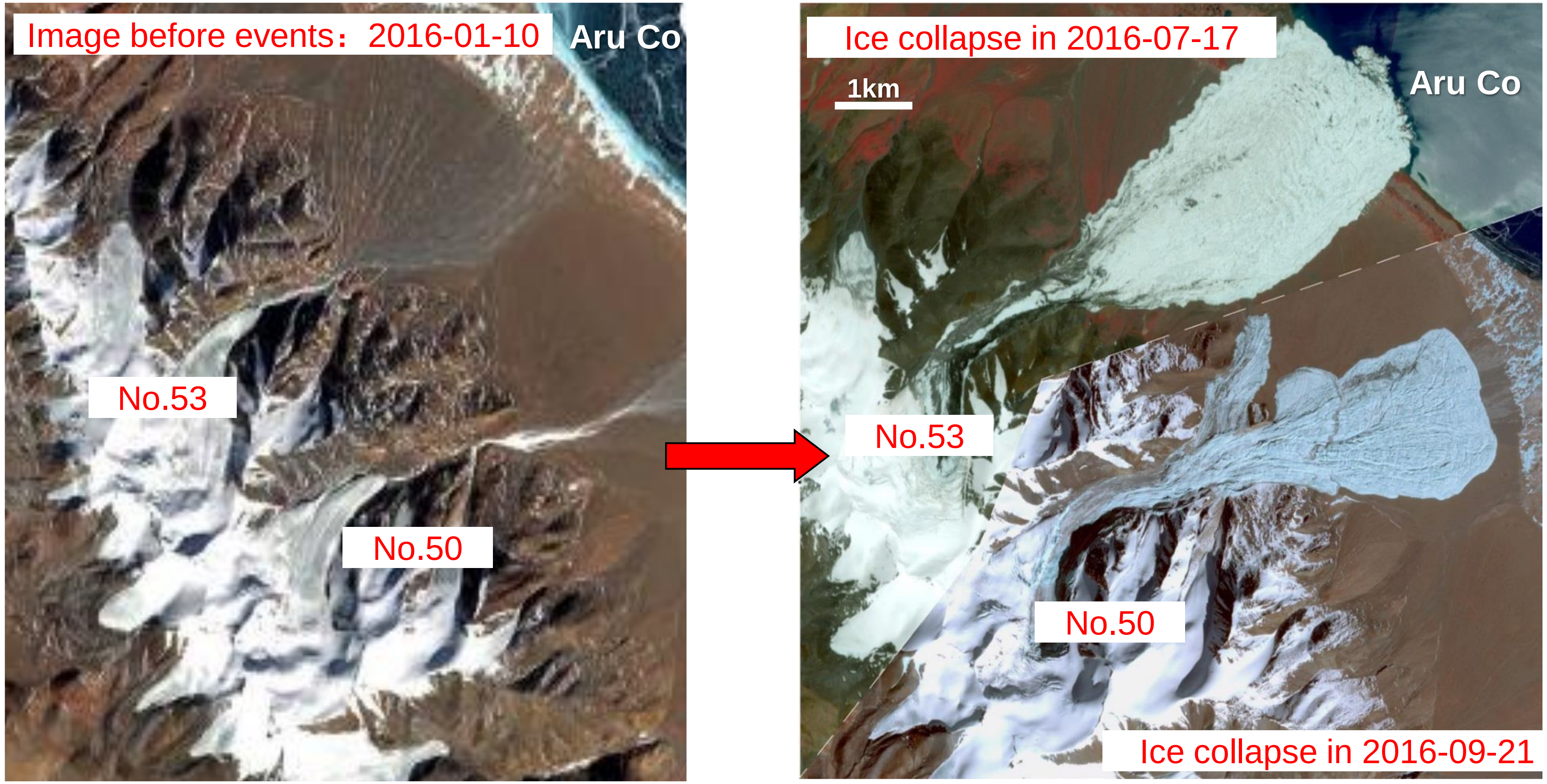
Huascaran(1970)

>120 death

Kolka-Karmadon(2002)

Chamoli(2021,Jan.)

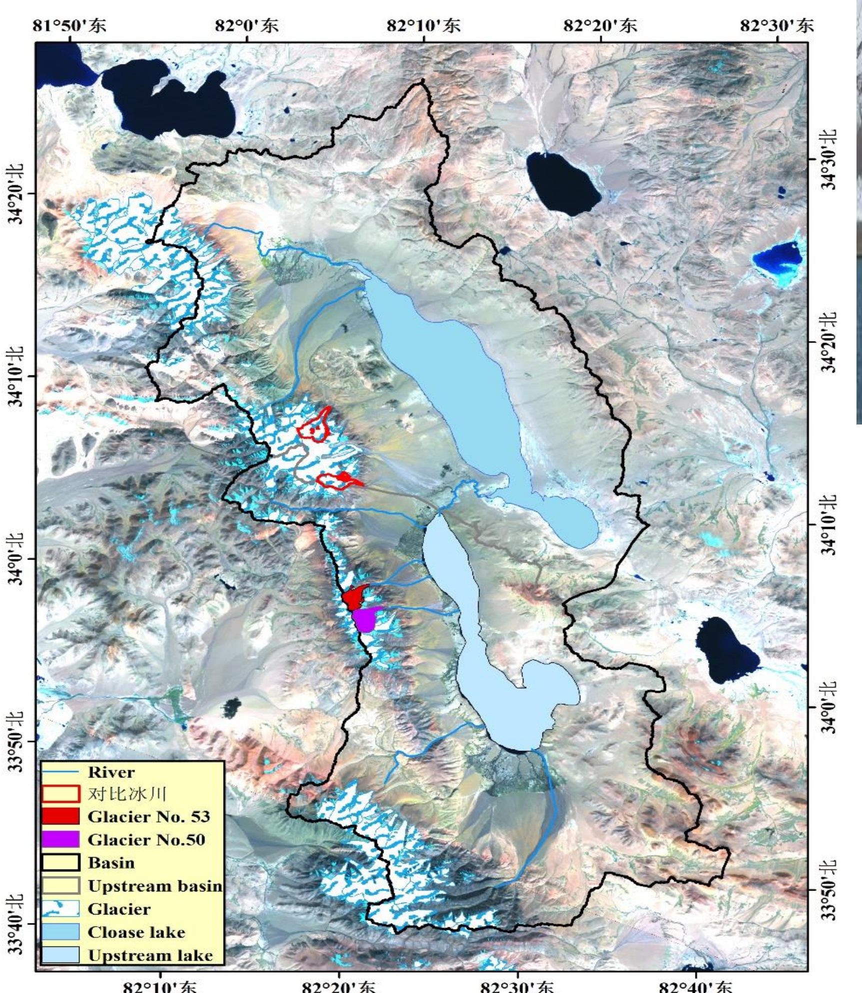
Aru Ice collapse scale



No. 53 ice avalanche fan: 5.7 km long, 2.4 km wide, 9.4 km2 area, average thickness of about 7.5 m, volume of 70 million m3

No. 50 ice avalanche fan: 4.7km long, 1.9km wide, 6.5 km2 area, average thickness of more than 30 m, volume of 100 million m3

Aru Ice collapse-Wu guangjian

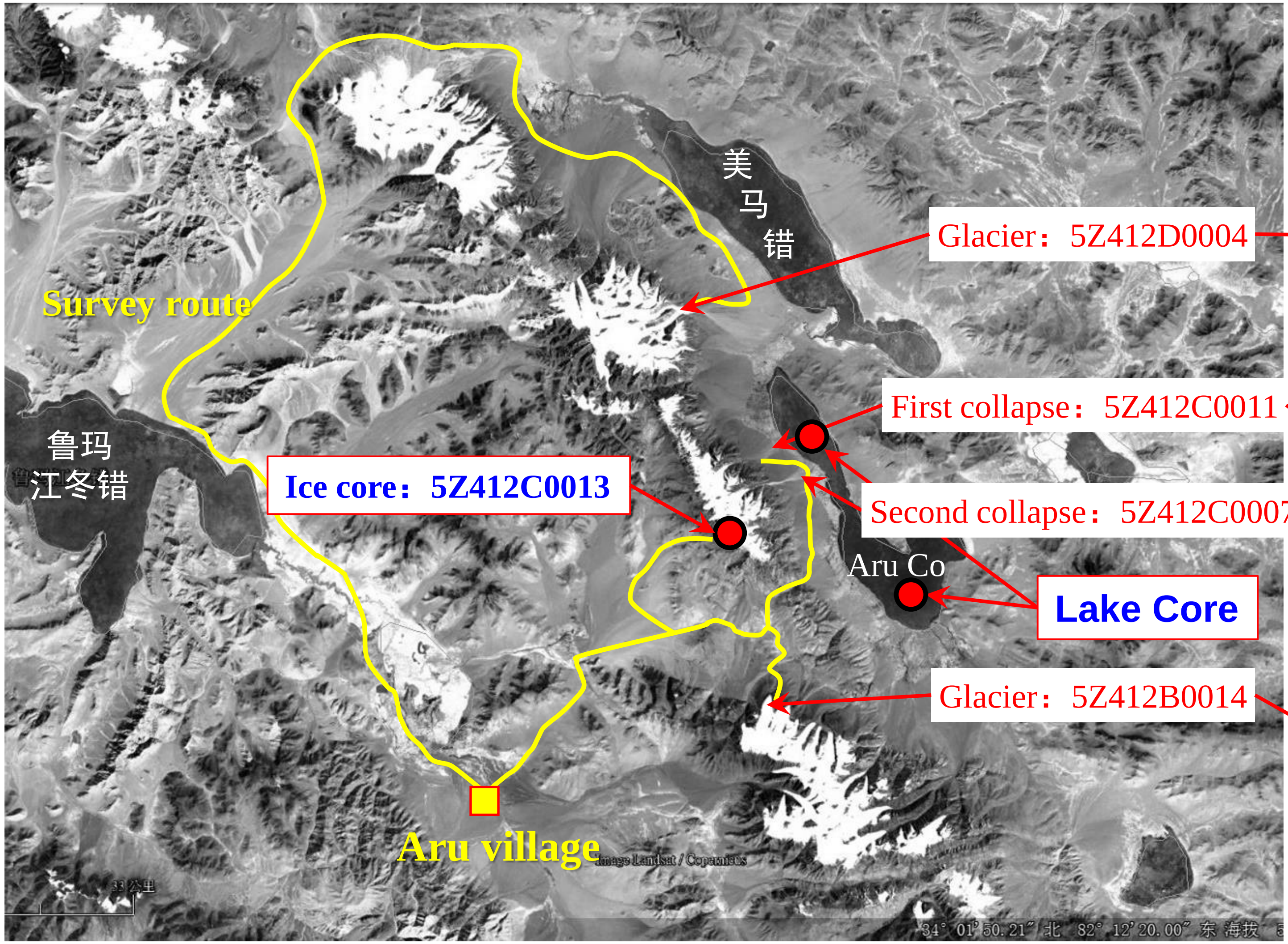


No.50
2016-9-21

No.53
2016-7-17

No.50
2016-9-21

Aru Ice collapse-monitoring



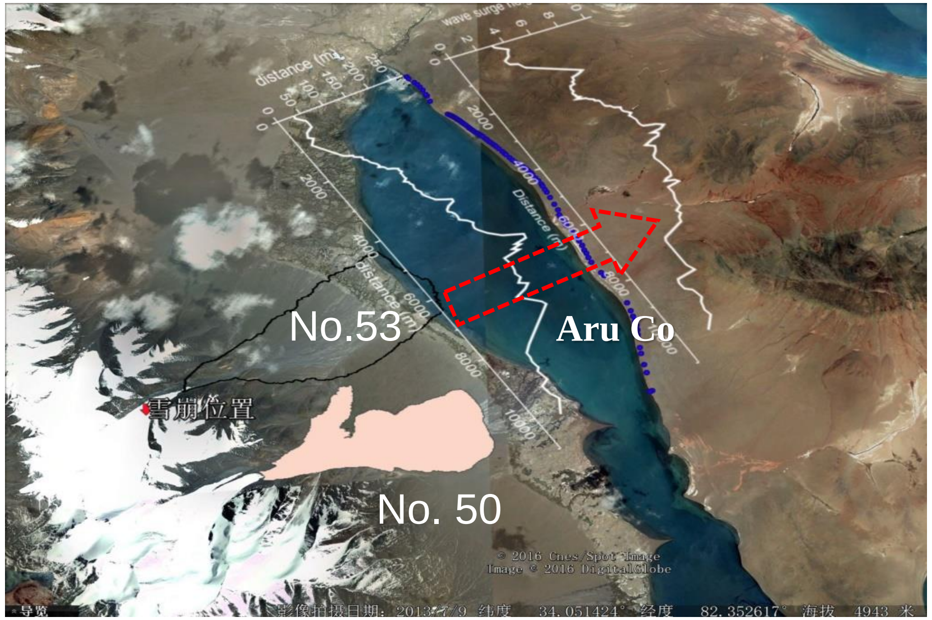
Wide band Seimograph
AWS

Ice collapse deposition
AWS
Auto Camera

cGPS
Wide band seimograph
Ice depth
Mass balance
Ice Temperature

Aru Ice collapse induced Seiche(lake wave/lake tsunami)

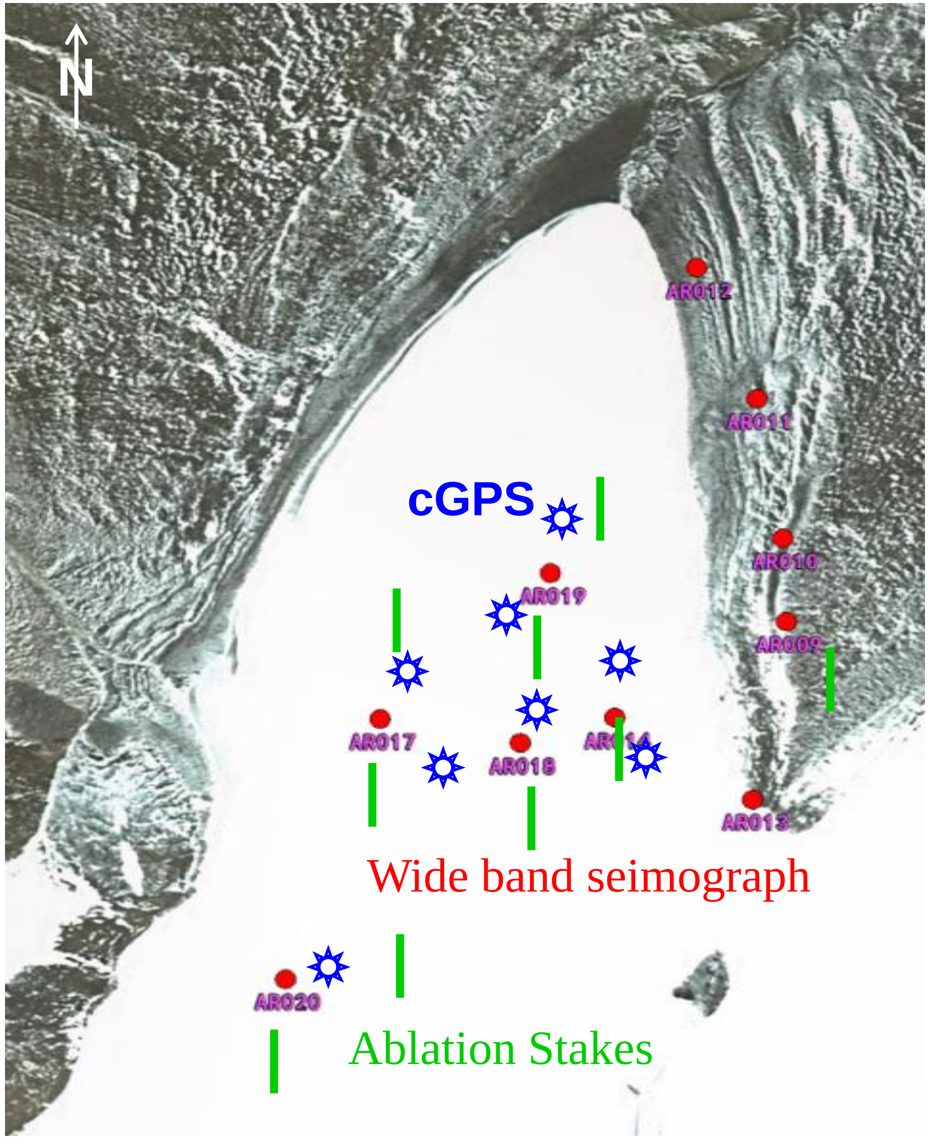
Ice avalanche of glacier No.53 quickly rushed into Aru Co and formed a lake tsunami with a maximum of more than 20 meters on other side of lake.



Influence range of lake tsunami

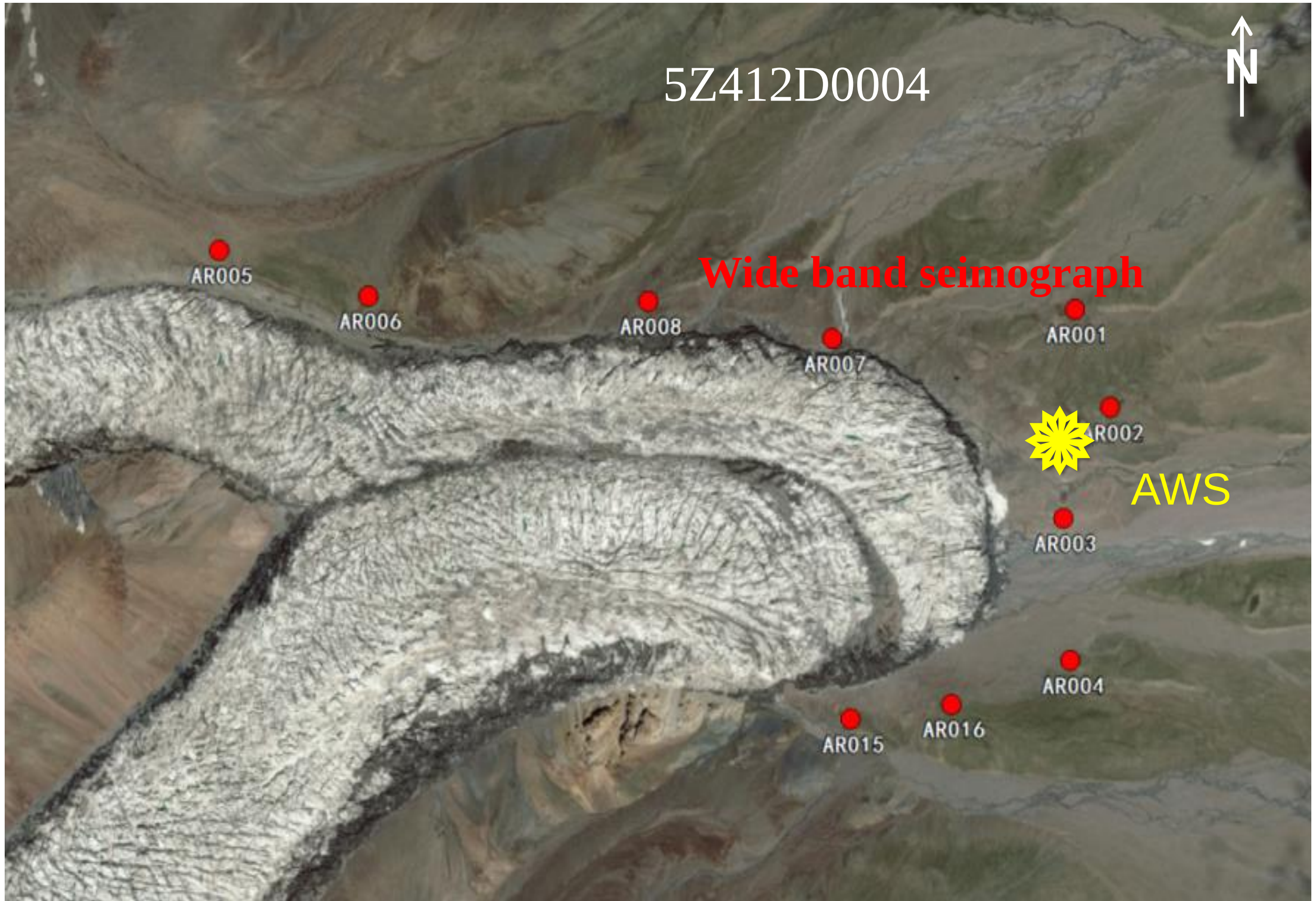
Lake tsunami traces

Aru Ice collapse-equipment

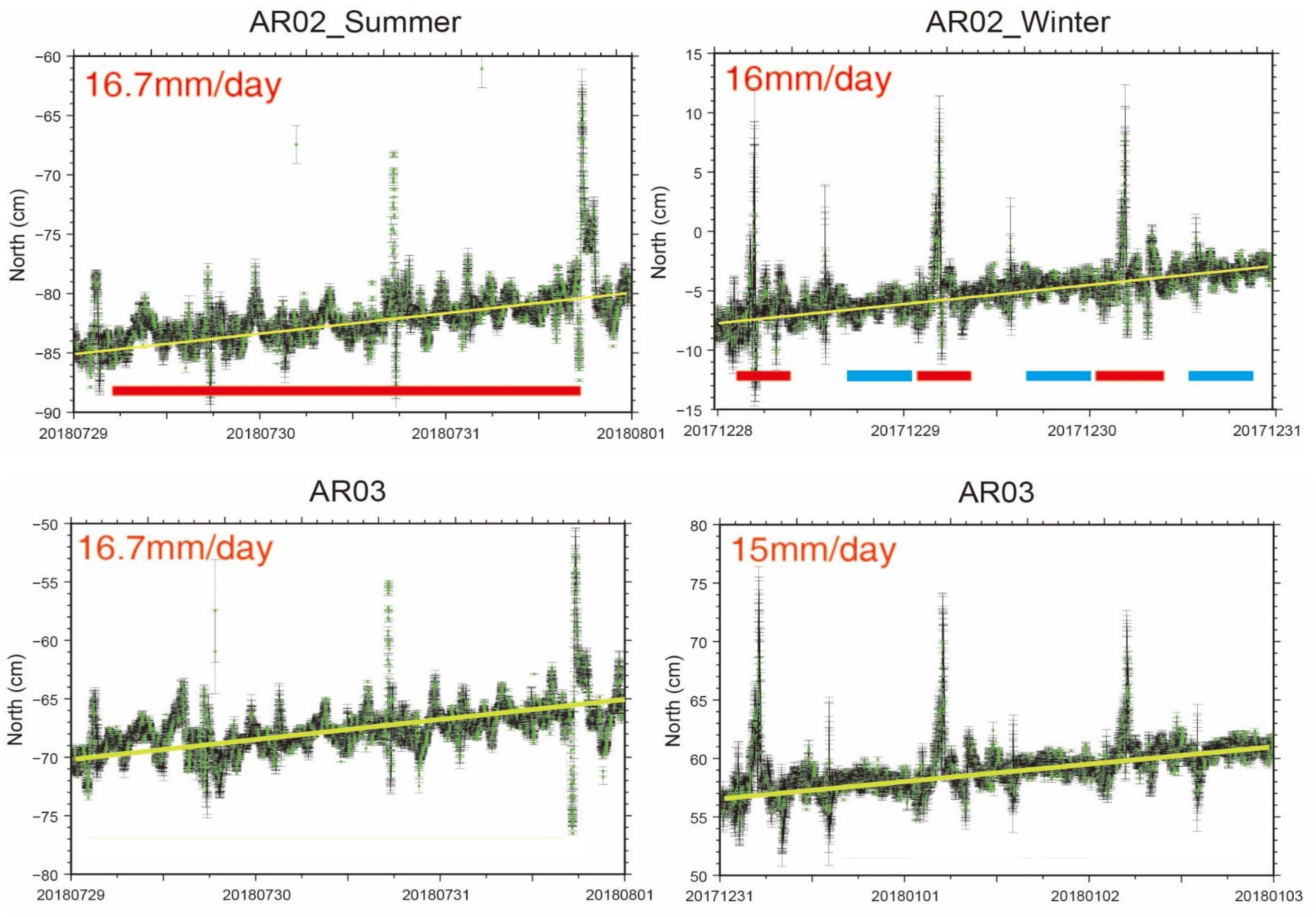


5Z412B0014:

- ☐ cGPS
- ☐ Wide band seimograph
- ☐ **Mass balance**

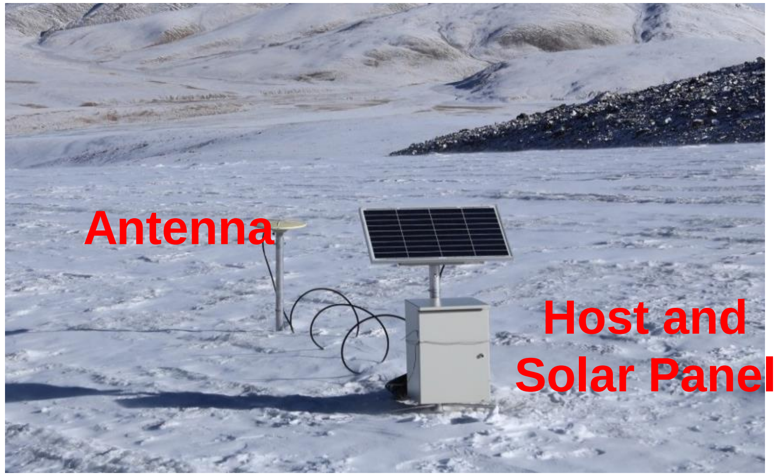


Aru Ice collapse-Aru Glacier daily velocity

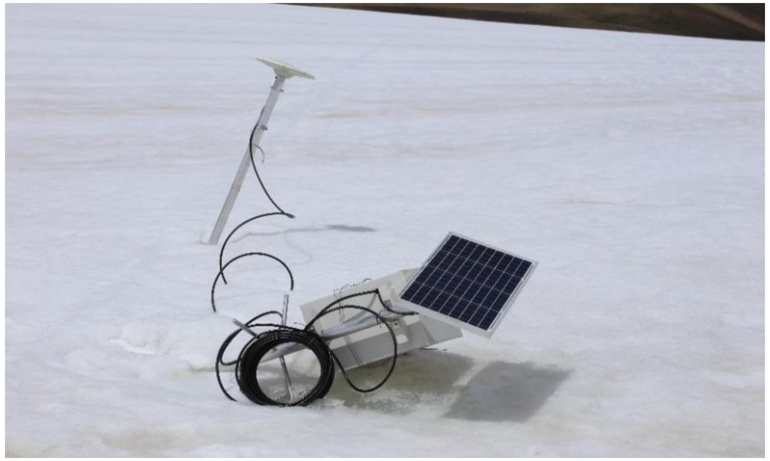


Aru Ice collapse-Glacier velocity

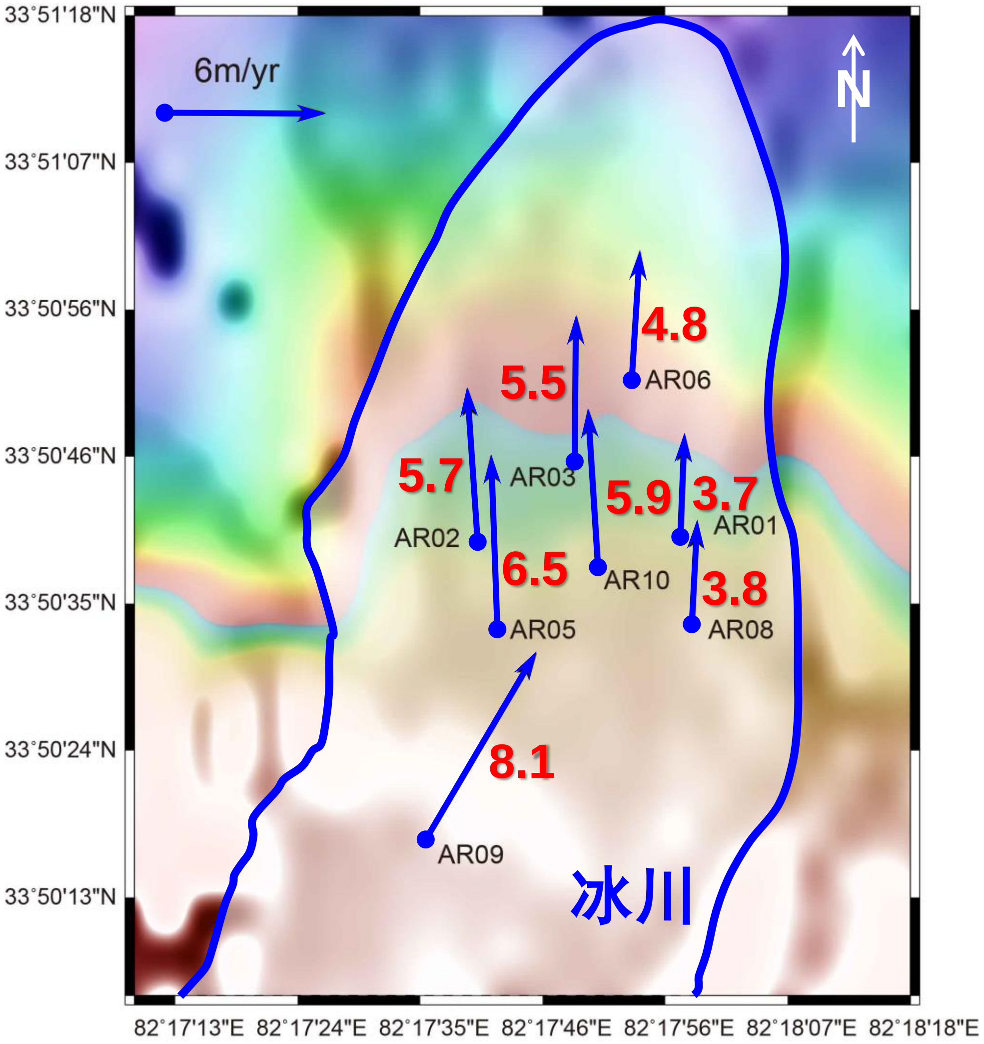
cGPS on ice surface in Jan. 2018



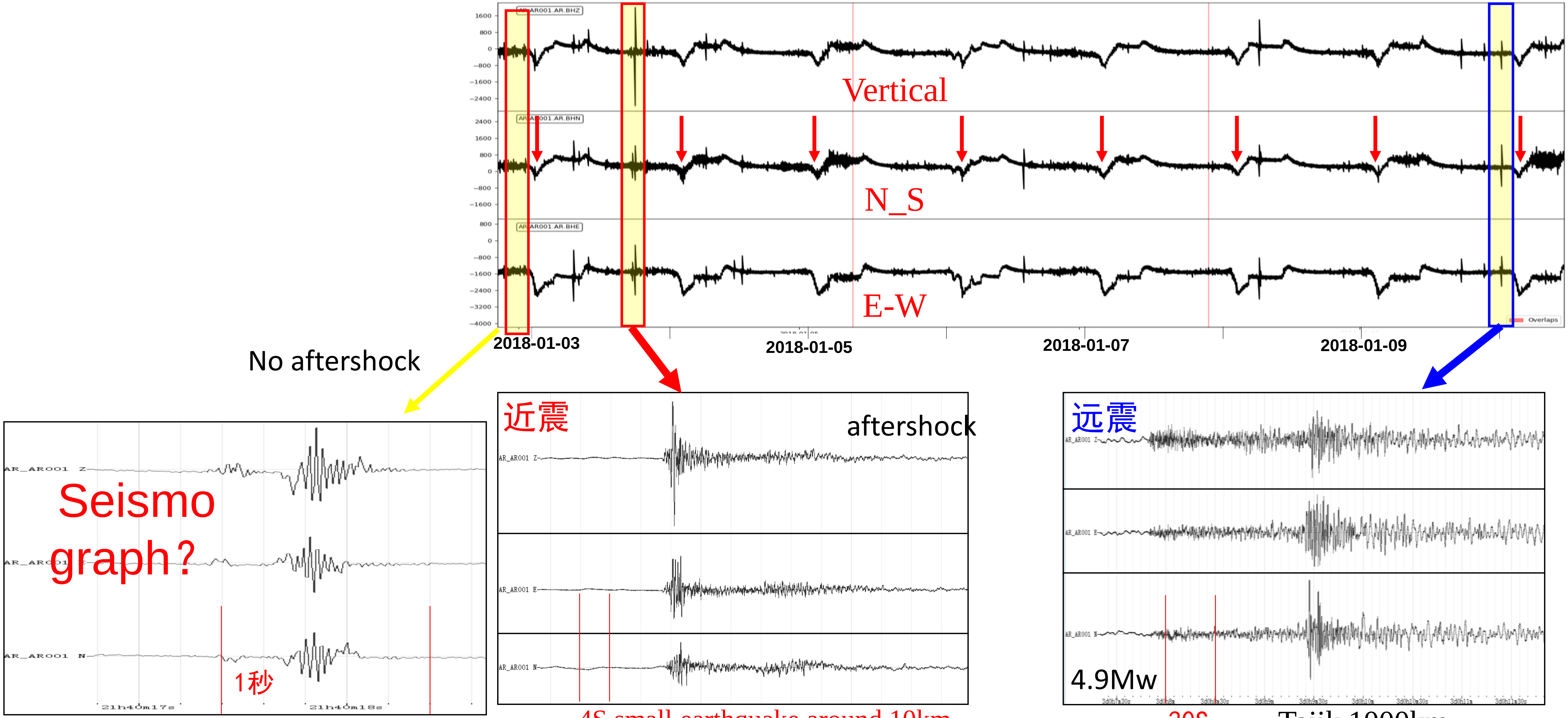
cGPS topple and fall in July,2018



Glacier velocity:3.7-8.1m/a



Aru Ice collapse-Seismograph



No aftershock

Seismo graph?

1秒

近震

aftershock

4S small earthquake around 10km

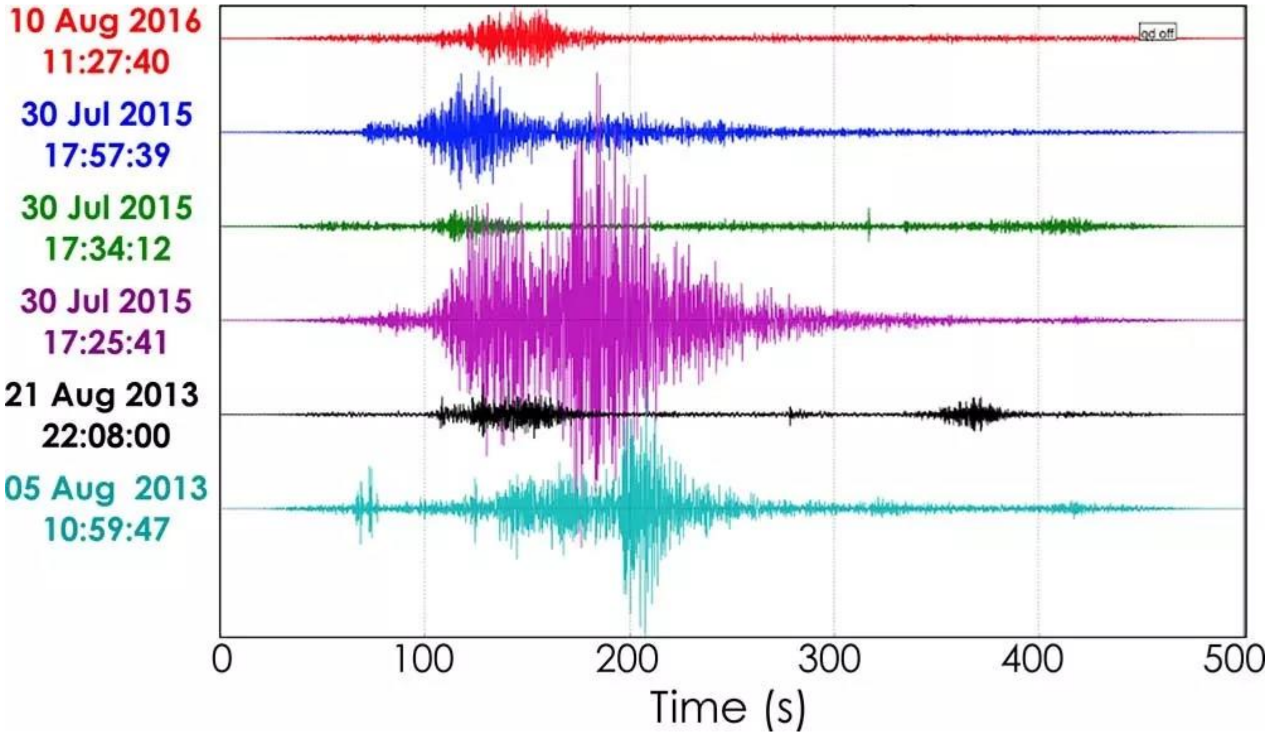
远震

4.9Mw

30S

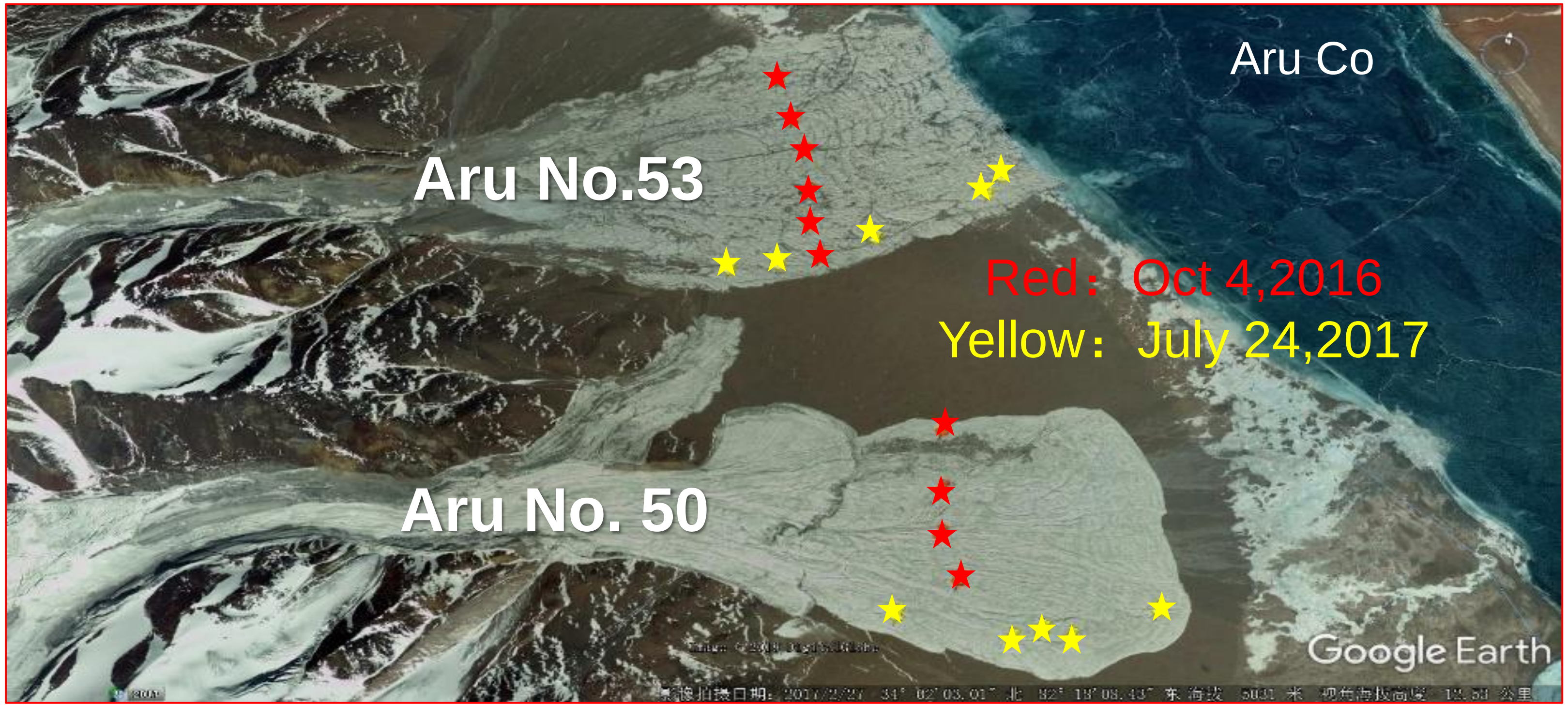
Tajik 1000km

3.X Ice collapse-alaska



https://www.nps.gov/articles/aps-18-1-3.htm#:~:text=Debris

Aru Ice collapse-Ablation stakes



- From October 4, 2016 to July 24, 2017, Fan of No. 53 melted about 3 meters (3.07 to 3.41 meters) and Fan of No.50 melted about 2 meters (1.97 to 2.40 meters).
- From July 24, 2017 to September 24, 2017, Fan No. 53 melted 2.95 to 5.14 meters and Fan No. 50 melted 3.49 to 3.80 meters

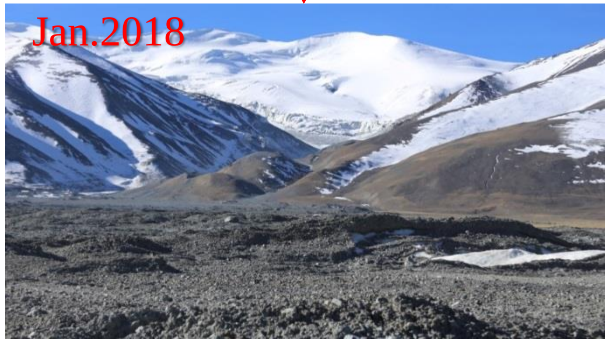
Aru Ice collapse-

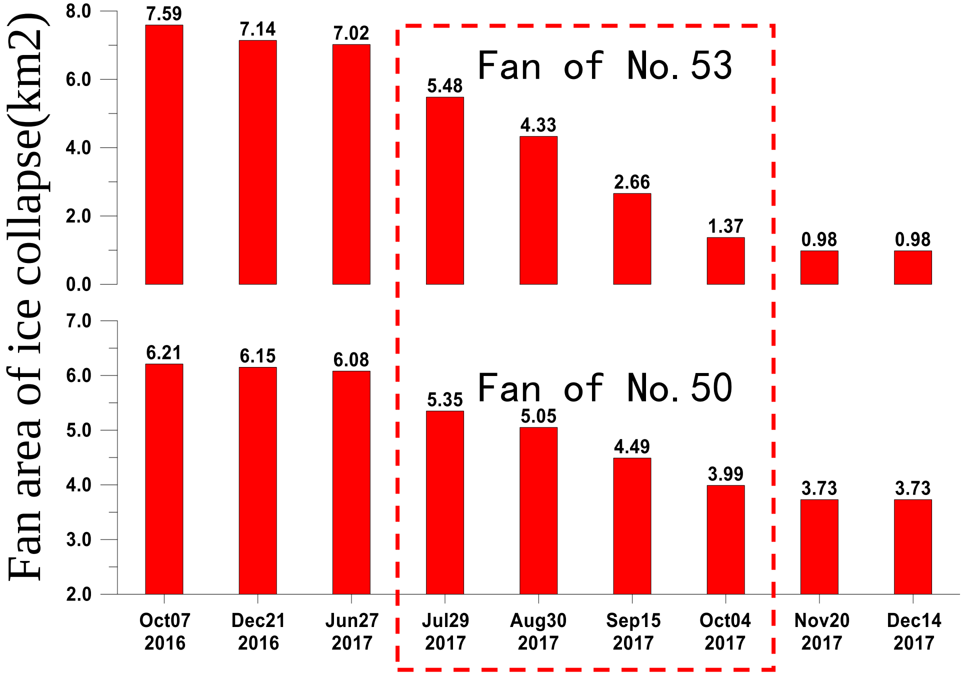
Fan of No.53


July,2016


Sep.,2016


July,2017

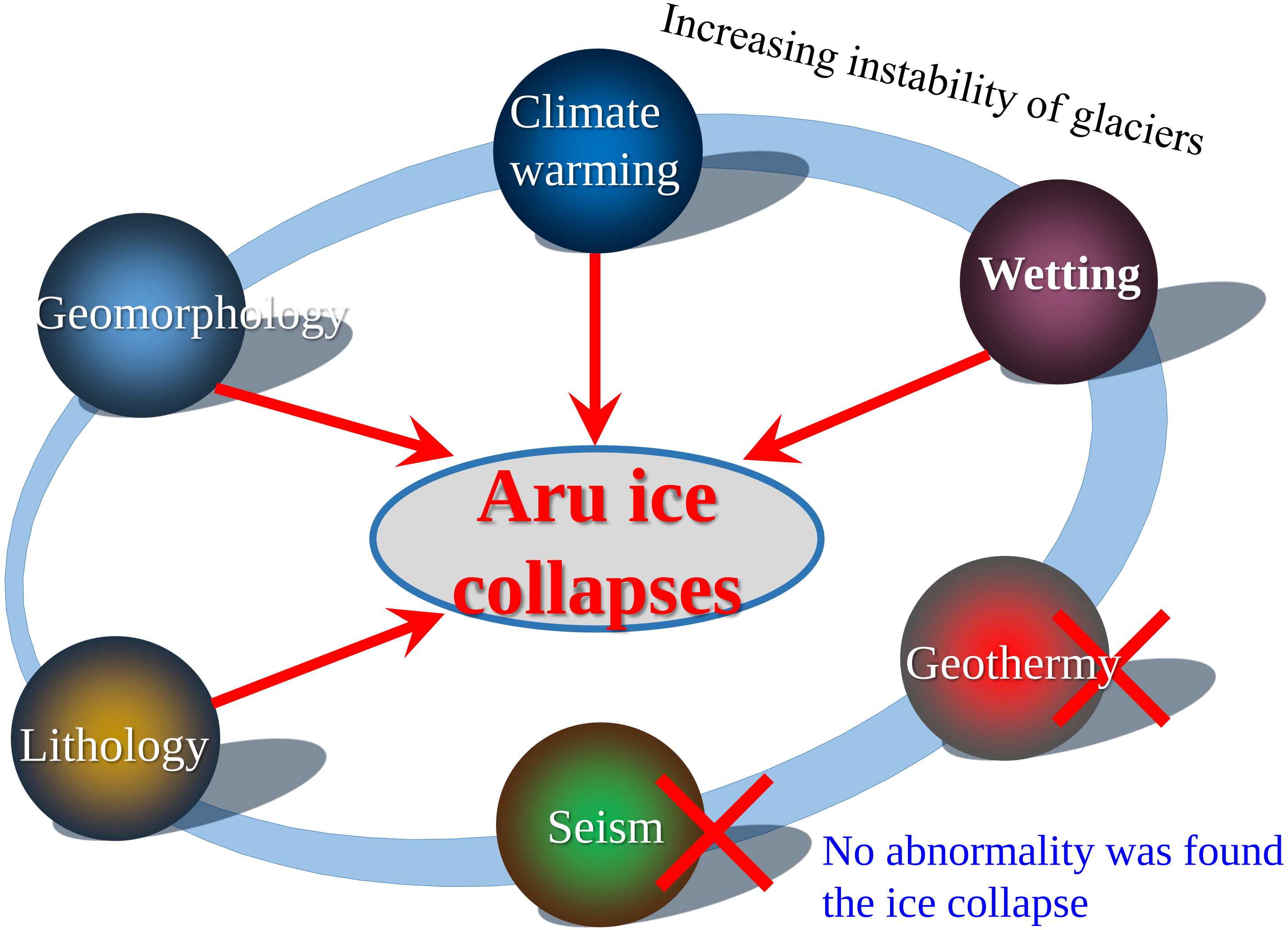

Jan.2018



Intense Ablation in summer

Aru Ice collapse-Inducing factors

Warming, wetting and special geological and geomorphological conditions

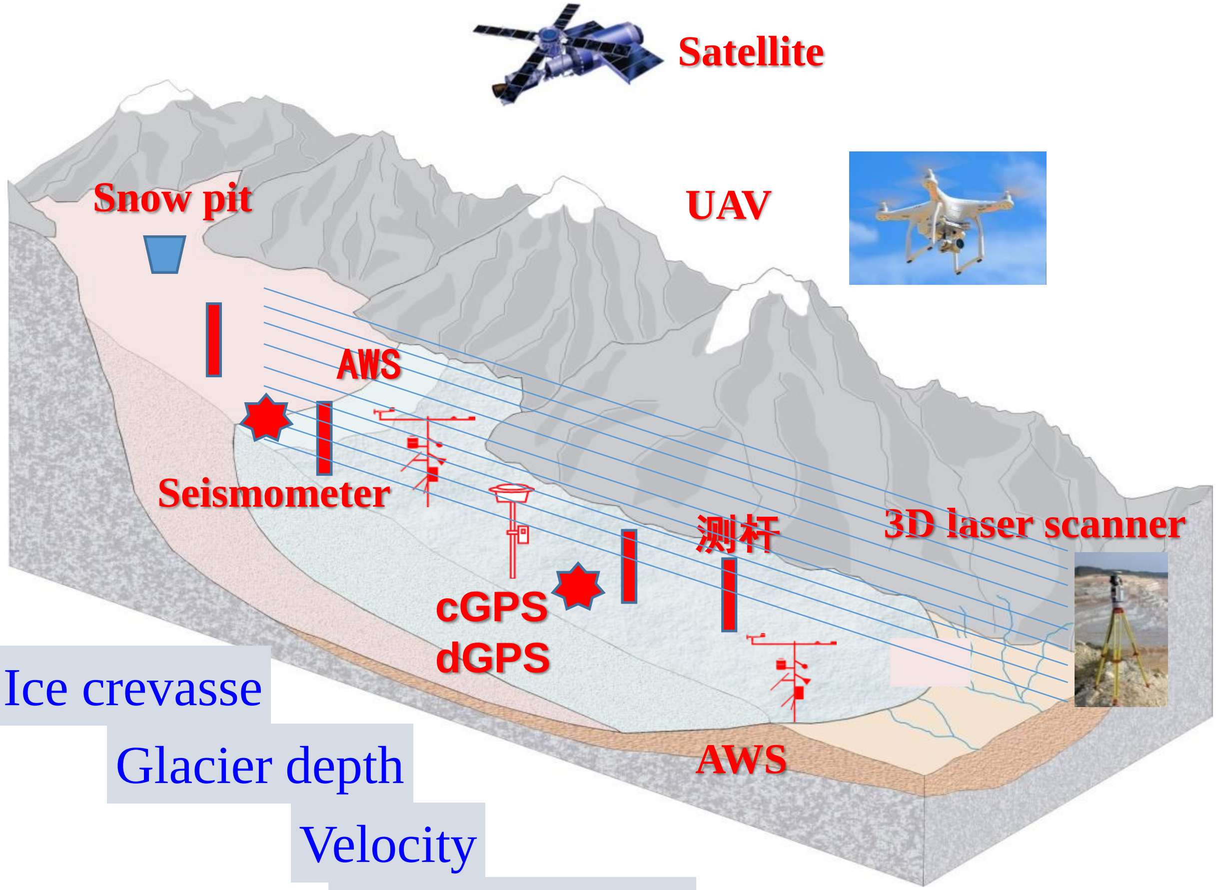


Provides favorable terrain for ice collapse

The soft bedrock facilitates the flow of the glacier

No abnormality was found before and after the ice collapse

Aru Ice collapse-early warming



Ice crevasse

Glacier depth

Velocity

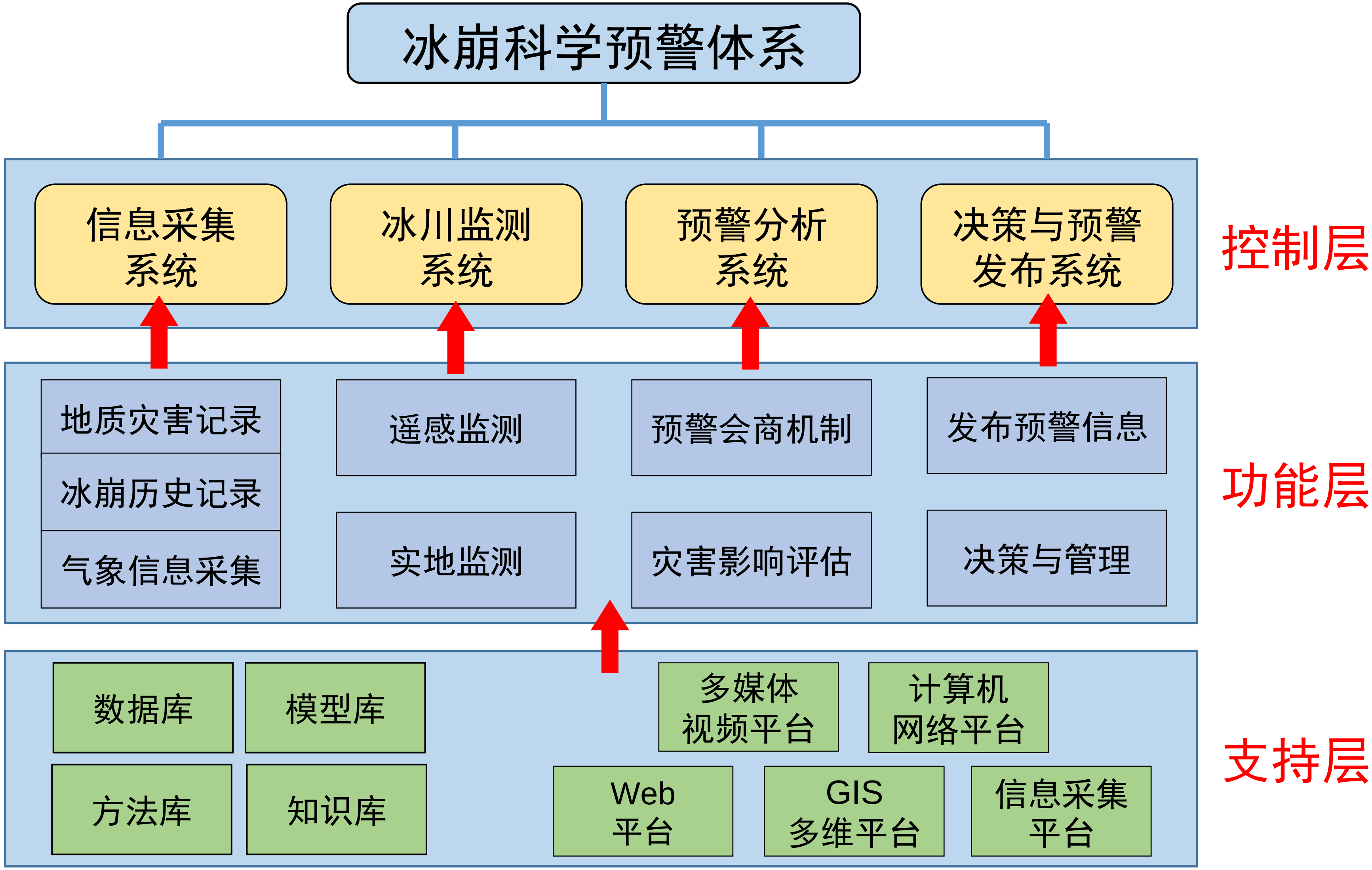
Cryoseismology

Glacial surface elevation

- Remote sensing(Landsat, Sentinel, PALSAR, GF）
- UAV(DEM+surface infrared survey)
- 3D survey
- Mass balance-energy balance （AWS）
- Glacier velocity, depth, snow pit et al.
- Cryoseismology

Wu Guangjian

Aru Ice collapse-early warming system



冰崩科学预警体系

信息采集系统

冰川监测系统

预警分析系统

决策与预警发布系统

控制层

地质灾害记录

冰崩历史记录

气象信息采集

遥感监测

实地监测

预警会商机制

灾害影响评估

发布预警信息

决策与管理

功能层

数据库

模型库

方法库

知识库

多媒体视频平台

计算机网络平台

Web平台

GIS多维平台

信息采集平台

支持层

3 Several Case study

- Snow avalanche
- Snow disaster in pasturing area
- Ice collapse
- **Glacier surging**
- GLOF
- Thaw slumping

3.4 Several Case study

Glacier surging is a quasiperiodic oscillation between long periods (tens to hundreds of years) of slow flow, called quiescent phase or quiescence, and shorter periods of typically 10–1000 times faster flow, called surge phase, active phase, or surge.

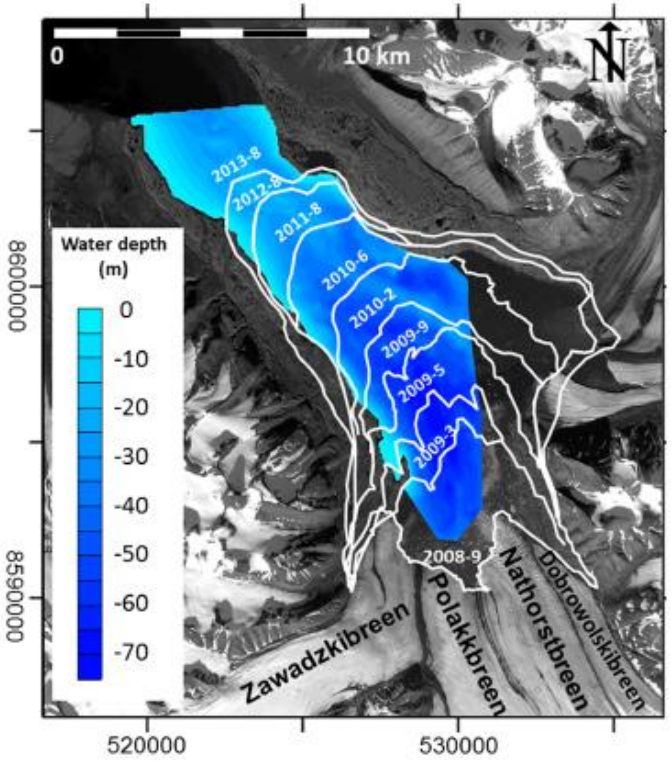


Fig. 7. Front positions (year and month) of Nathorstbreen glacier system during the advancing stage (3) of the surge. Advance by 2013 is 15 km. Bed topography modified from Carlsen (2004). The minimum depth is 11 m, while the maximum depth is 76 m. Background image from 1 September 2008 by SPOT SPIRIT©.

1.Surge Cycle （Ten years； hundred years)

2.Rare: Less than 1% of glaciers

3.Rapid velocity: 2-10 times

4.hazard: Dammed lake or others

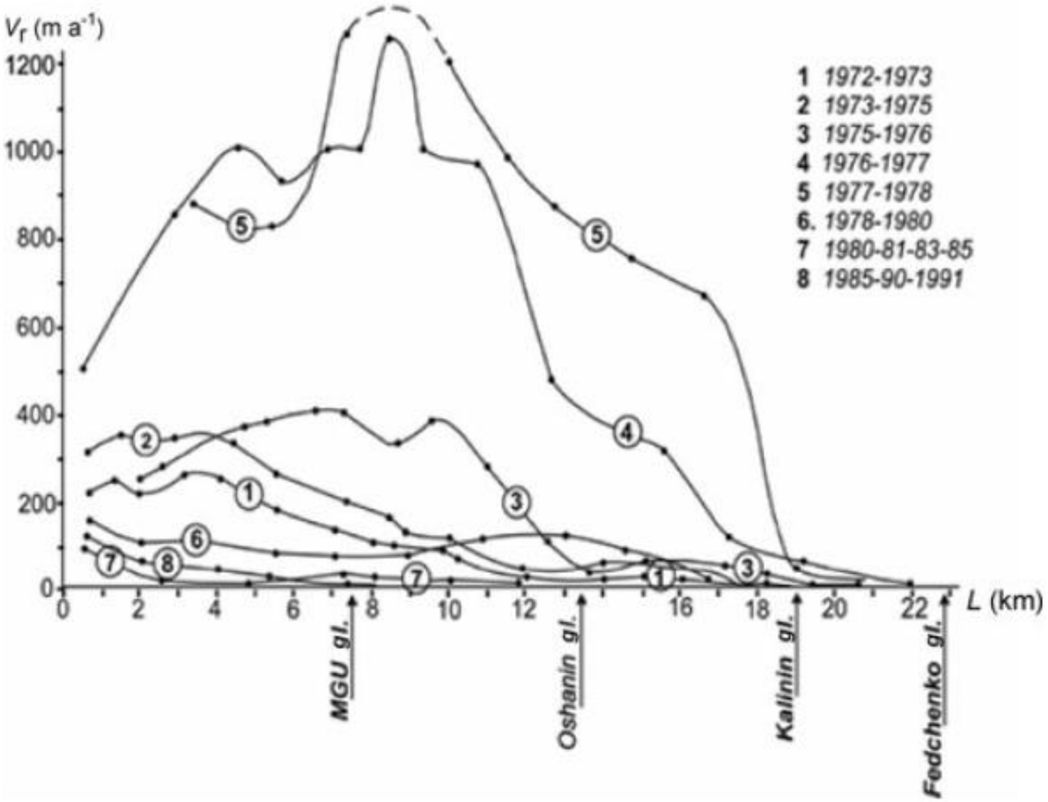
5.Last time （Most last a few weeks or months, in some cases and regions, several years)

（Sund et al., 2014) Cryosphere

3.4 Glacier surging

Example-velocity change of Surge Glacier in Tajikistan

Fig. 2. Bivachny glacier (fragment of ETM+ image, 16 September 2000). The longitudinal axis (*L*), along which the ice-velocity measurements were carried out, is shown by dots. Numbers indicate distance along the longitudinal axis, in km. Traces of clean 'drops' of MGU glacier are distinctly visible. They are formed as a result of the surges of the main Bivachny glacier body, which dragged the MGU glacier tongue into the movement.

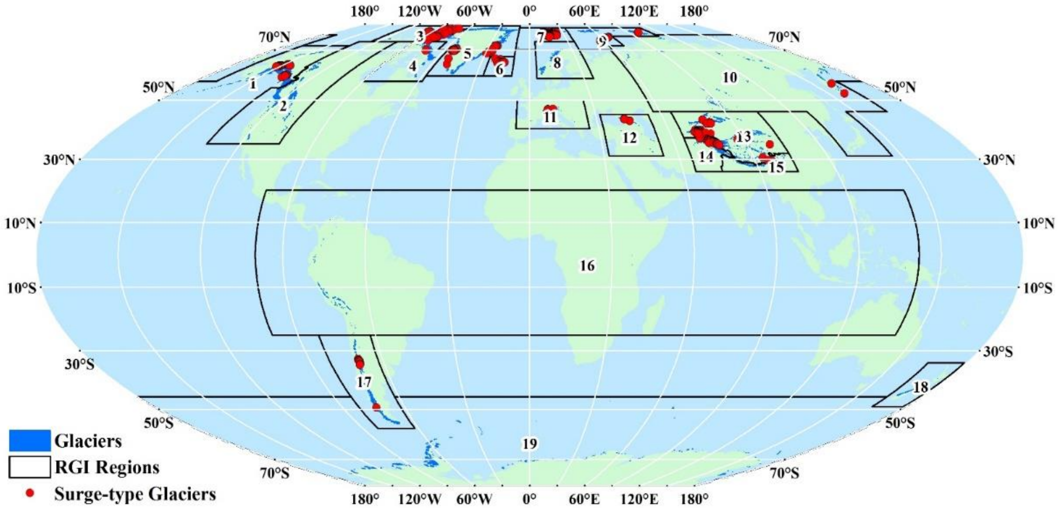


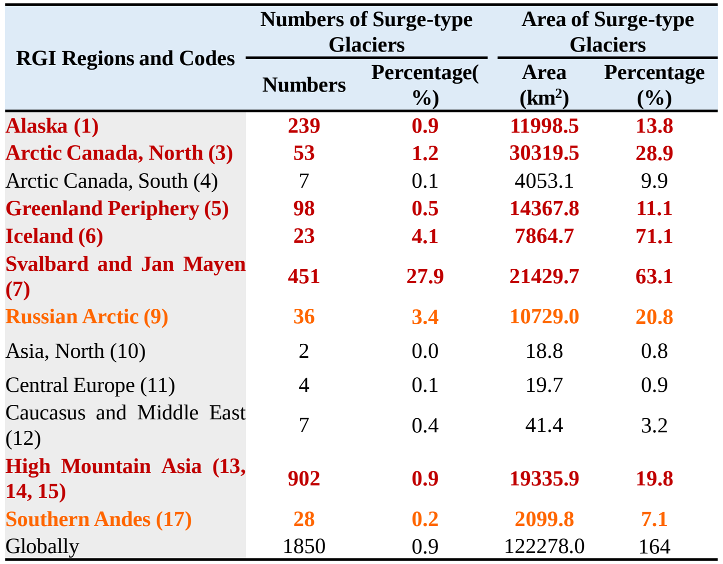
Last 4 years

(Kotlyakov et al., 2008) Annals of glaciology

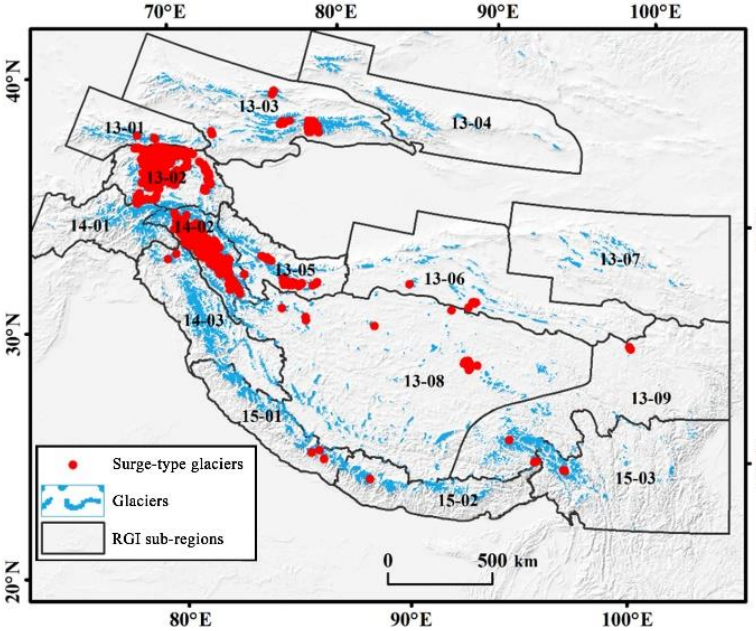
Glacier surge related hazards

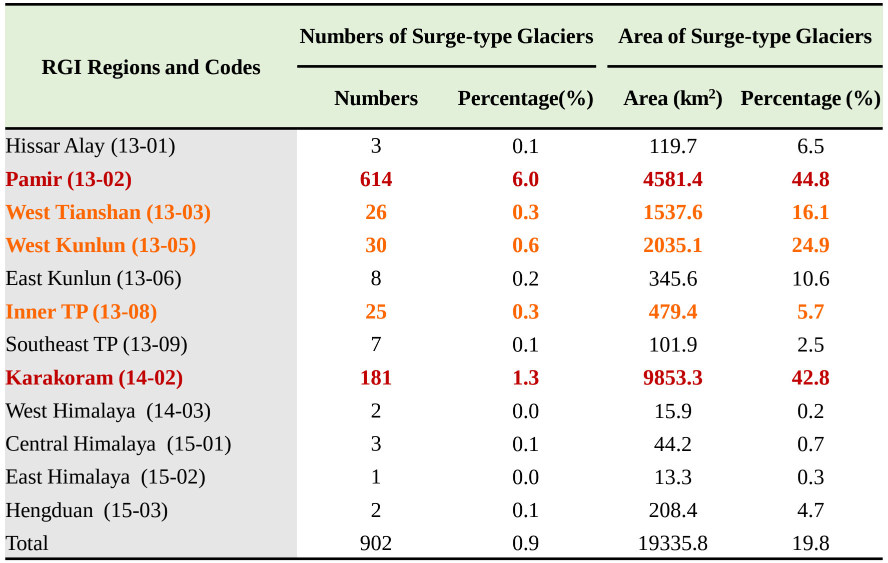
Distribution of surge-type glaciers globally and over High Mountain Asia (HMA) from current knowledge





RGI Regions and Codes	Numbers of Surge-type Glaciers		Area of Surge-type Glaciers	
	Numbers	Percentage(%)	Area (km²)	Percentage (%)
Alaska (1)	239	0.9	11998.5	13.8
Arctic Canada, North (3)	53	1.2	30319.5	28.9
Arctic Canada, South (4)	7	0.1	4053.1	9.9
Greenland Periphery (5)	98	0.5	14367.8	11.1
Iceland (6)	23	4.1	7864.7	71.1
Svalbard and Jan Mayen (7)	451	27.9	21429.7	63.1
Russian Arctic (9)	36	3.4	10729.0	20.8
Asia, North (10)	2	0.0	18.8	0.8
Central Europe (11)	4	0.1	19.7	0.9
Caucasus and Middle East (12)	7	0.4	41.4	3.2
High Mountain Asia (13, 14, 15)	902	0.9	19335.9	19.8
Southern Andes (17)	28	0.2	2099.8	7.1
Globally	1850	0.9	122278.0	164





RGI Regions and Codes	Numbers of Surge-type Glaciers		Area of Surge-type Glaciers	
	Numbers	Percentage(%)	Area (km²)	Percentage (%)
Hissar Alay (13-01)	3	0.1	119.7	6.5
Pamir (13-02)	614	6.0	4581.4	44.8
West Tianshan (13-03)	26	0.3	1537.6	16.1
West Kunlun (13-05)	30	0.6	2035.1	24.9
East Kunlun (13-06)	8	0.2	345.6	10.6
Inner TP (13-08)	25	0.3	479.4	5.7
Southeast TP (13-09)	7	0.1	101.9	2.5
Karakoram (14-02)	181	1.3	9853.3	42.8
West Himalaya (14-03)	2	0.0	15.9	0.2
Central Himalaya (15-01)	3	0.1	44.2	0.7
East Himalaya (15-02)	1	0.0	13.3	0.3
Hengduan (15-03)	2	0.1	208.4	4.7
Total	902	0.9	19335.8	19.8

- Globally there are at least 1850 surge-type glaciers
- Most surge-type glaciers are distributing in Circum-Arctic (49.0%) and HMA (48.8%)
- Pamir and Karakoram are the two centers of surge-type glacier distribution among HMA
- More surge-type glaciers are supposed to be found following the technical advances and under climate change

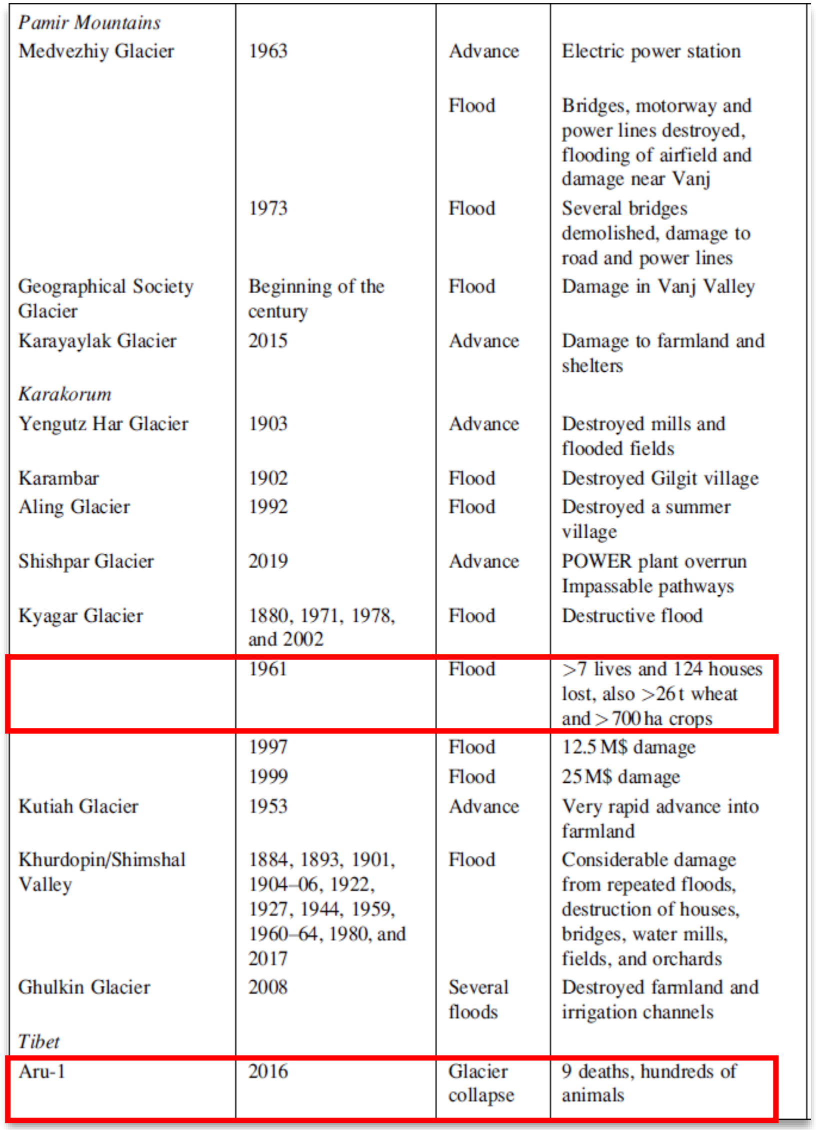
(Guo *et al.*, 2022)

Known catastrophic disasters caused by glacier surges

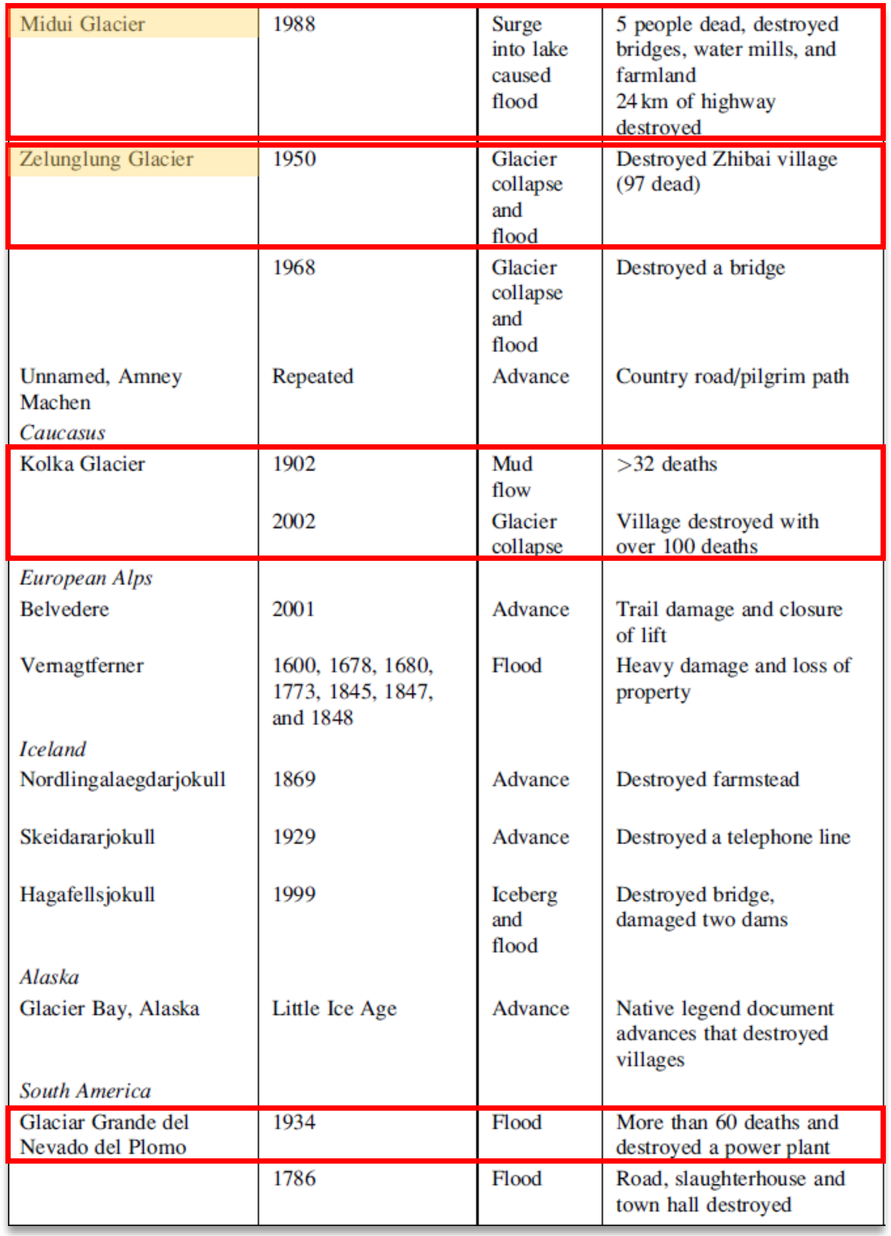
According to literature records:

- Glacier surges have caused **more than 50 catastrophic disasters** all over the world
- **More than 310 peoples were killed** by glacier surge

Recent media reports and scientific publications suggested an **increasing frequency** of glacier surge events and related disasters, and **rising threats** to infrastructures and human lives



Pamir Mountains			
Medvezhiy Glacier	1963	Advance	Electric power station
		Flood	Bridges, motorway and power lines destroyed, flooding of airfield and damage near Vanj
	1973	Flood	Several bridges demolished, damage to road and power lines
Geographical Society Glacier	Beginning of the century	Flood	Damage in Vanj Valley
Karayaylak Glacier	2015	Advance	Damage to farmland and shelters
Karakorum			
Yengutz Har Glacier	1903	Advance	Destroyed mills and flooded fields
Karambar	1902	Flood	Destroyed Gilgit village
Aling Glacier	1992	Flood	Destroyed a summer village
Shishpar Glacier	2019	Advance	POWER plant overrun Impassable pathways
Kyagar Glacier	1880, 1971, 1978, and 2002	Flood	Destructive flood
	1961	Flood	>7 lives and 124 houses lost, also >26 t wheat and > 700 ha crops
	1997	Flood	12.5 M$ damage
	1999	Flood	25 M$ damage
Kutiah Glacier	1953	Advance	Very rapid advance into farmland
Khurdopin/Shimshal Valley	1884, 1893, 1901, 1904–06, 1922, 1927, 1944, 1959, 1960–64, 1980, and 2017	Flood	Considerable damage from repeated floods, destruction of houses, bridges, water mills, fields, and orchards
Ghulkin Glacier	2008	Several floods	Destroyed farmland and irrigation channels
Tibet			
Aru-1	2016	Glacier collapse	9 deaths, hundreds of animals

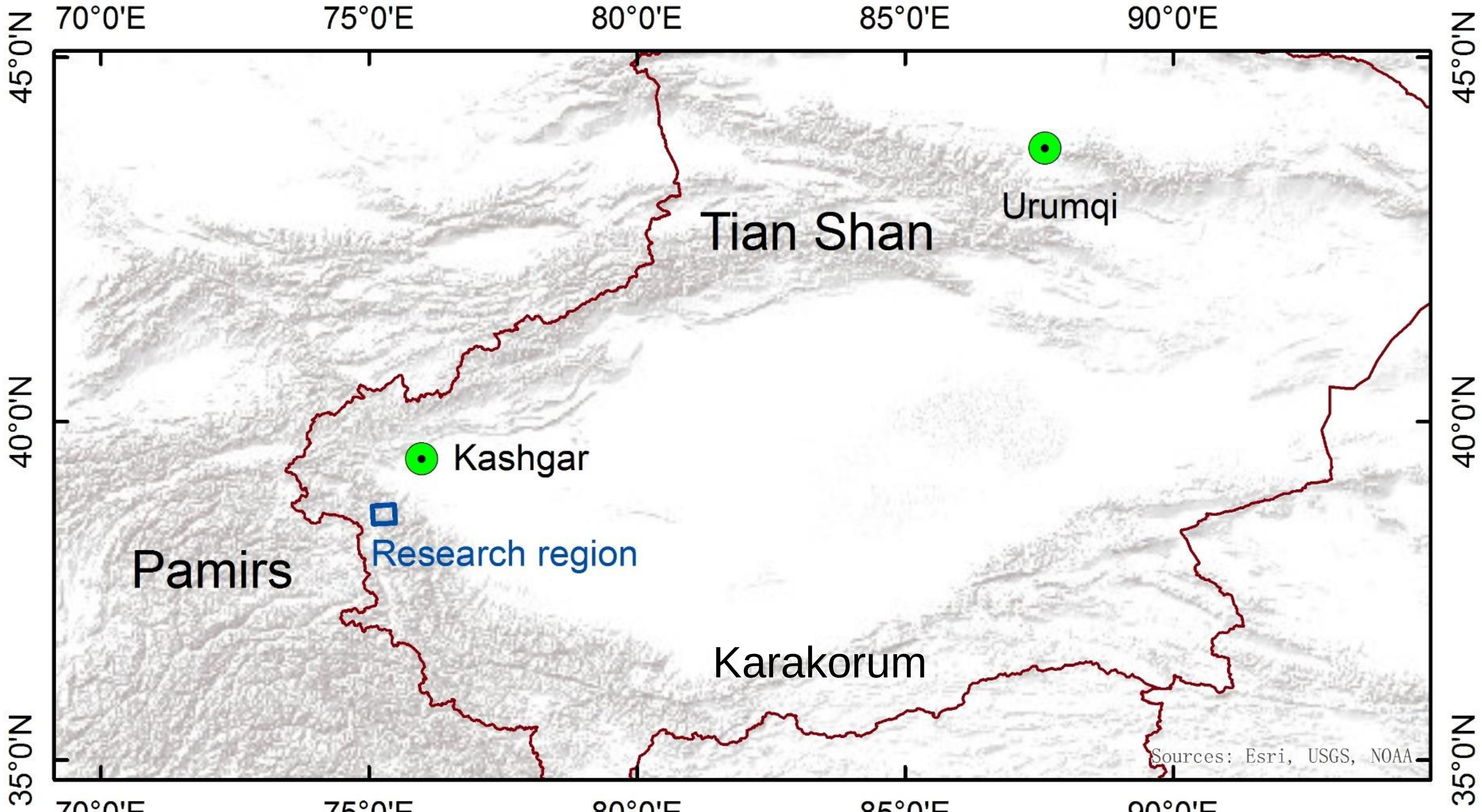


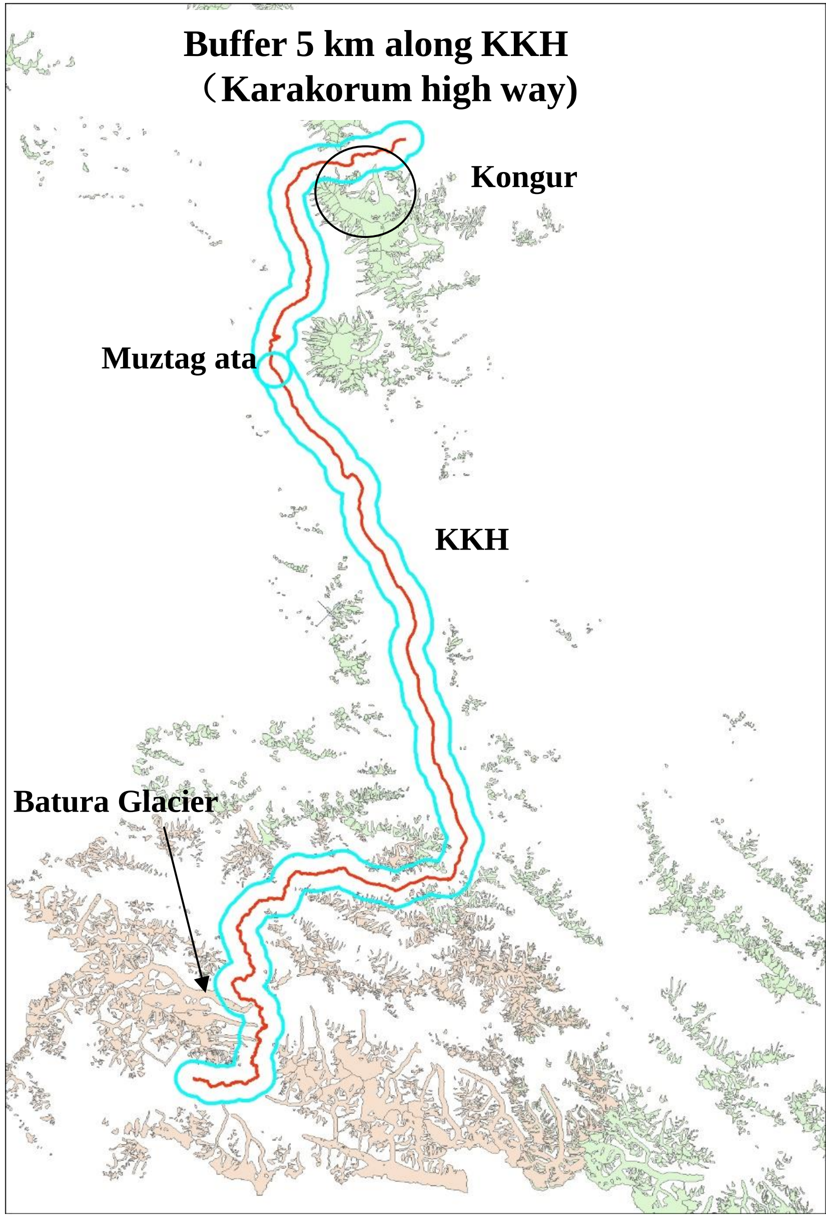
Midui Glacier	1988	Surge into lake caused flood	5 people dead, destroyed bridges, water mills, and farmland 24 km of highway destroyed
Zelunglung Glacier	1950	Glacier collapse and flood	Destroyed Zhibai village (97 dead)
	1968	Glacier collapse and flood	Destroyed a bridge
Unnamed, Amney Machen	Repeated	Advance	Country road/pilgrim path
Caucasus			
Kolka Glacier	1902 2002	Mud flow Glacier collapse	>32 deaths Village destroyed with over 100 deaths
European Alps			
Belvedere	2001	Advance	Trail damage and closure of lift
Vernagtferner	1600, 1678, 1680, 1773, 1845, 1847, and 1848	Flood	Heavy damage and loss of property
Iceland			
Nordlingalaegdarjokull	1869	Advance	Destroyed farmstead
Skeidararjokull	1929	Advance	Destroyed a telephone line
Hagafellsjokull	1999	Iceberg and flood	Destroyed bridge, damaged two dams
Alaska			
Glacier Bay, Alaska	Little Ice Age	Advance	Native legend document advances that destroyed villages
South America			
Glaciar Grande del Nevado del Plomo	1934	Flood	More than 60 deaths and destroyed a power plant
	1786	Flood	Road, slaughterhouse and town hall destroyed

(Truffer *et al.*, 2021)

3.4 Glacier surging

Region

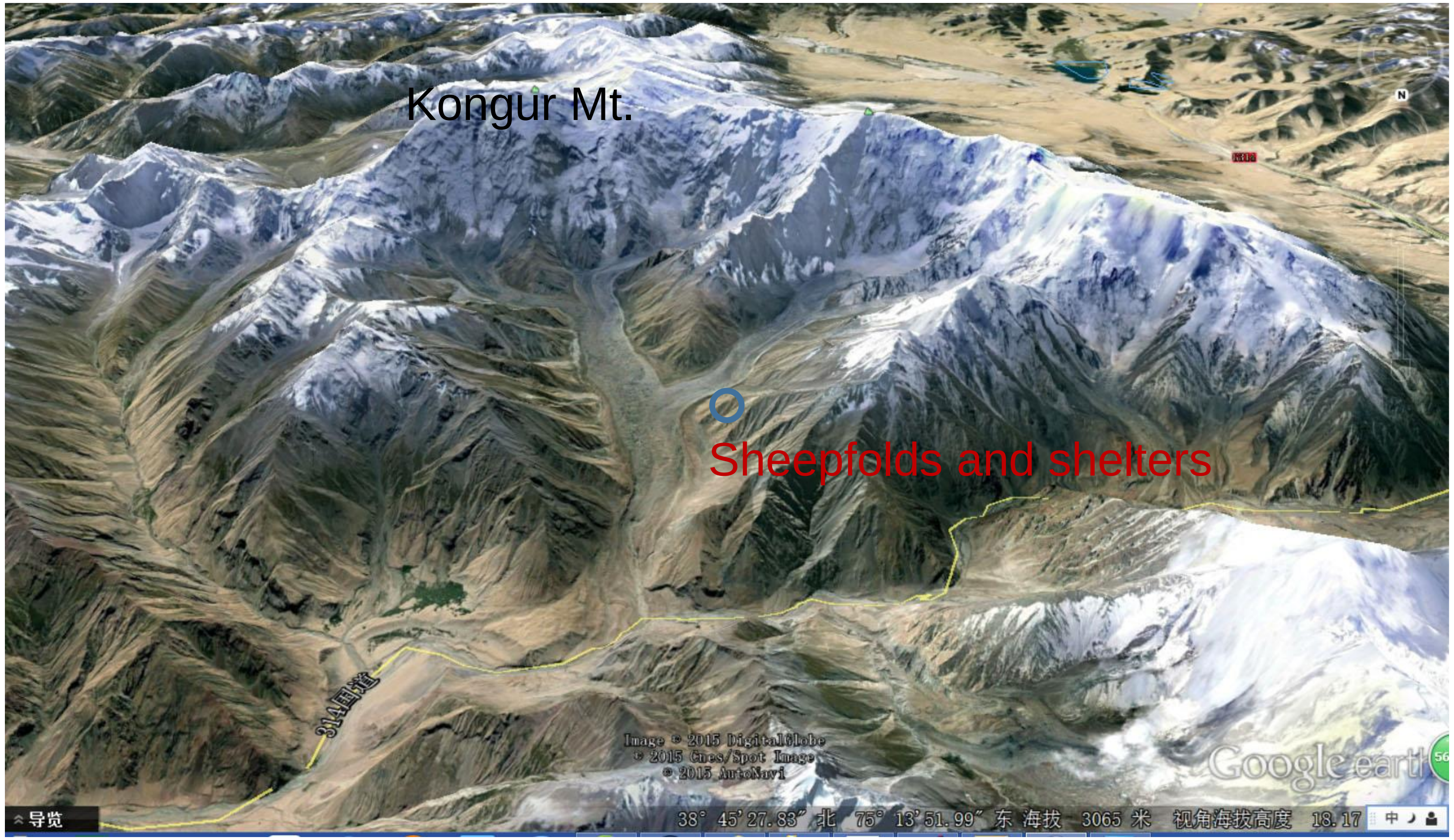




There are a lot of surge glaciers in Karakorum and Pamirs

May, 2015

3.4 Glacier surging

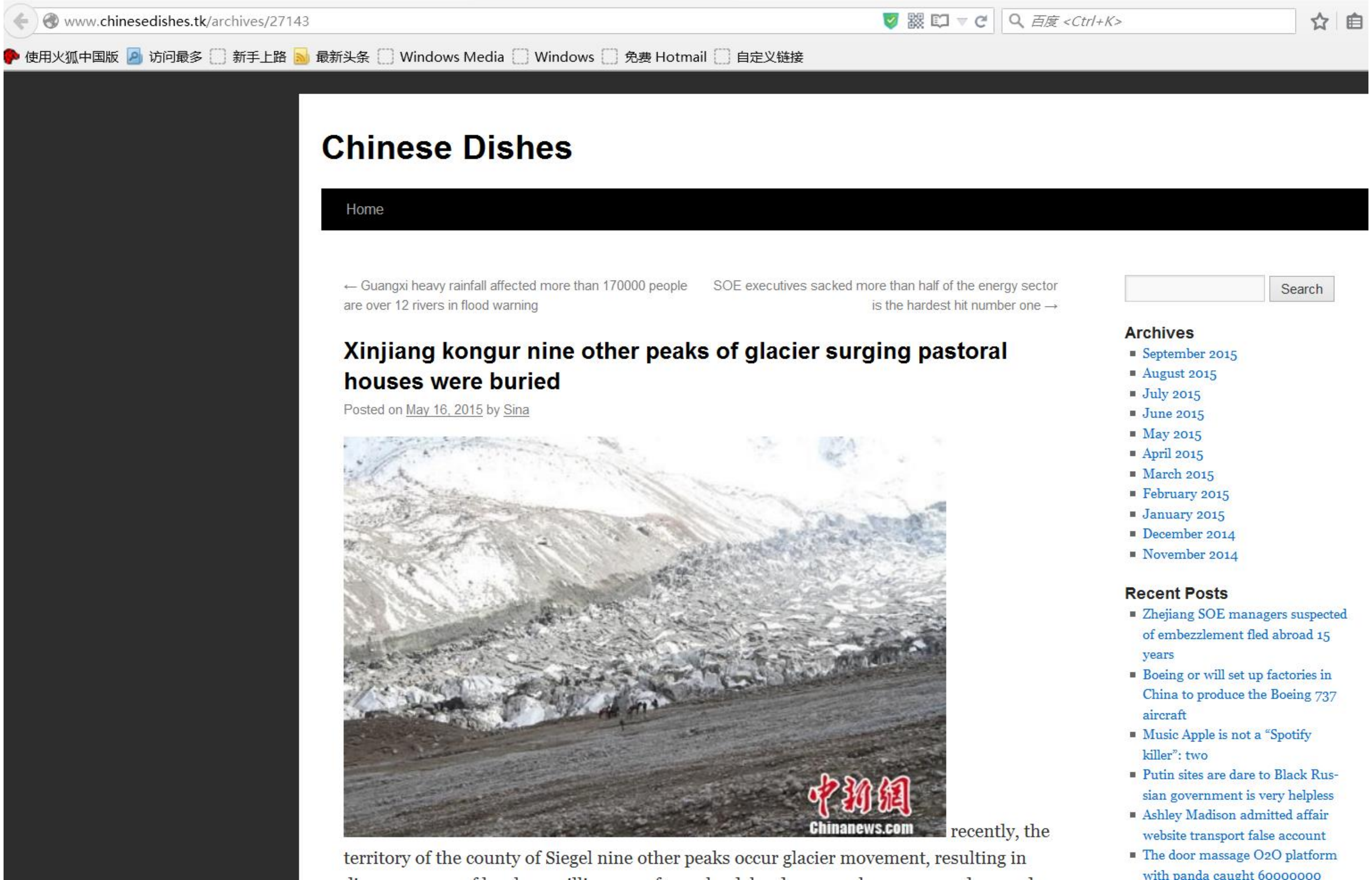


A local people said that this glacier was in surging a matter of one hundred years. But it was not recorded.

Karayaylak Glacier (GLIMS ID: G075254E38623N)
Area:115km^2
Length: 20 km
Debris cover area: 25.6 km^2 : summer pasture

3.4 Glacier surging

Event



Chinese Dishes

Home

← Guangxi heavy rainfall affected more than 170000 people are over 12 rivers in flood warning

SOE executives sacked more than half of the energy sector is the hardest hit number one →

Xinjiang kongur nine other peaks of glacier surging pastoral houses were buried

Posted on May 16, 2015 by Sina

recently, the territory of the county of Siegel nine other peaks occur glacier movement, resulting in

Search

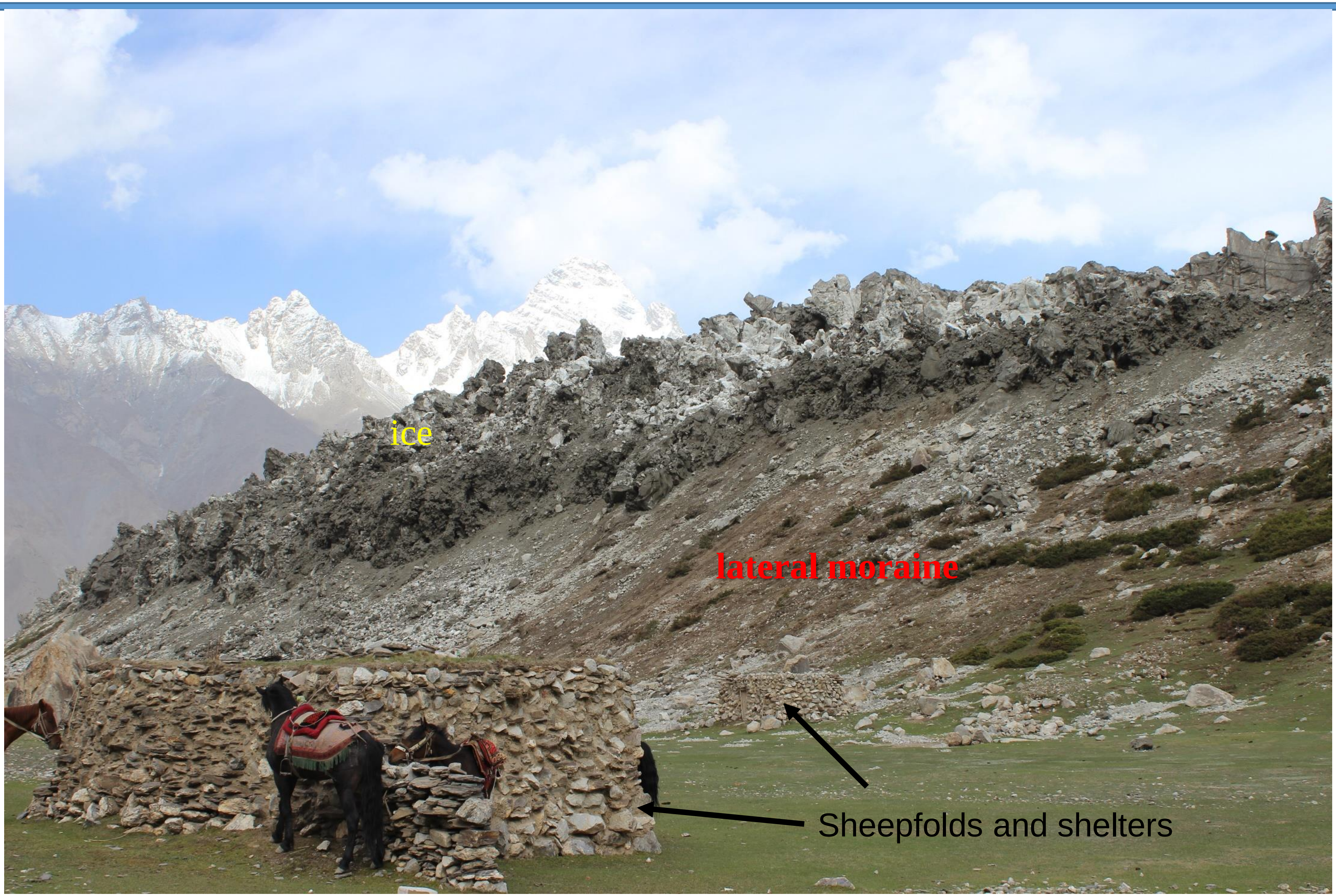
Archives

- September 2015
- August 2015
- July 2015
- June 2015
- May 2015
- April 2015
- March 2015
- February 2015
- January 2015
- December 2014
- November 2014

Recent Posts

- Zhejiang SOE managers suspected of embezzlement fled abroad 15 years
- Boeing or will set up factories in China to produce the Boeing 737 aircraft
- Music Apple is not a “Spotify killer”: two
- Putin sites are dare to Black Russian government is very helpless
- Ashley Madison admitted affair website transport false account
- The door massage O2O platform with panda caught 60000000

3.4 Glacier surging



3.4 Glacier surging

Data sources

Satellite	Year/Month/Day	Path/Row	Resolution (m)
Landsat 8 OLI L1T	2014/10/3	150/33	15/30
Landsat 8 OLI L1T	2015/4/22	149/33	15/30
Landsat 8 OLI L1T	2015/4/29	150/33	15/30
Landsat 8 OLI L1T	2015/5/8	149/33	15/30
Landsat 8 OLI L1T	2015/5/15	150/33	15/30
Landsat 8 OLI L1T	2015/6/16	150/33	15/30
Gaofen-1	2015/5/16	11068	2/8

3.4 Glacier surging

◆-Velocity

- Feature tracking of Landsat 8 OLI L1T data using CosiCorr and CIAS
- Postprocessing (e.g. filtering)

◆-Extent

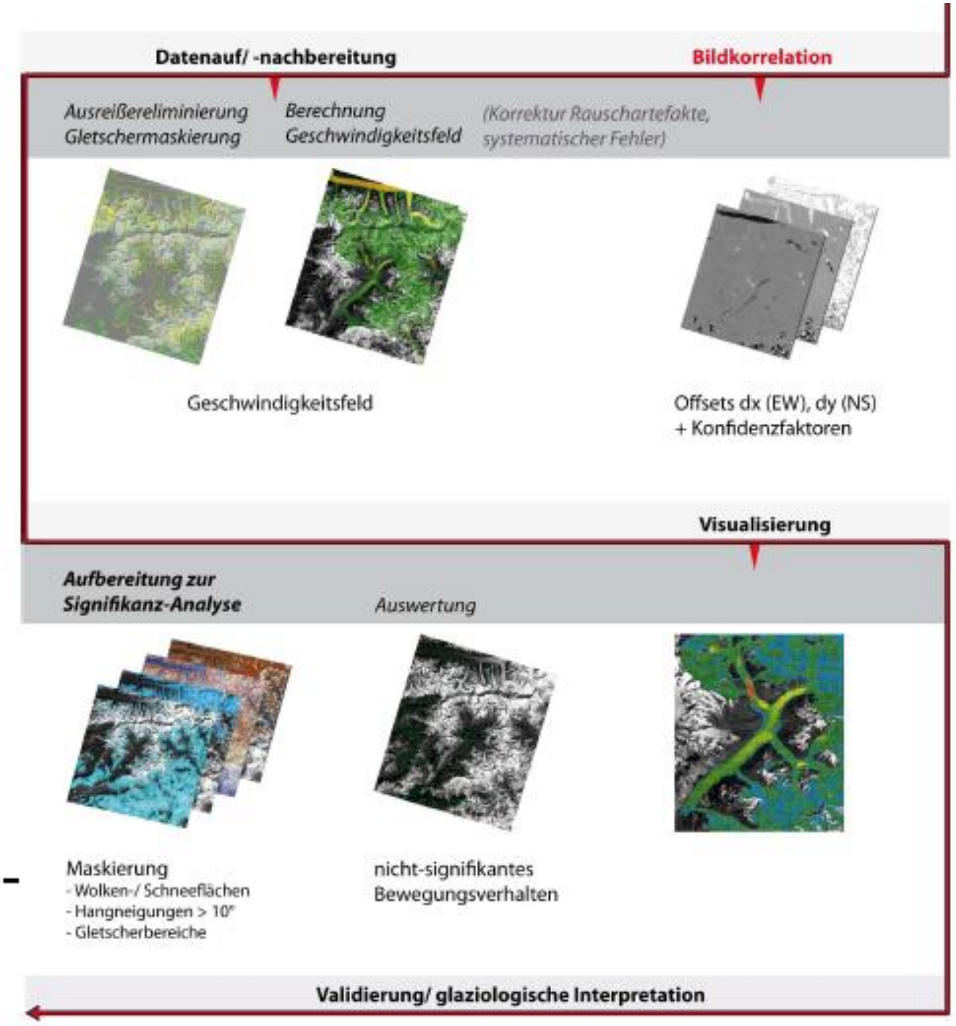
- Manual delineation

◆Crevasse

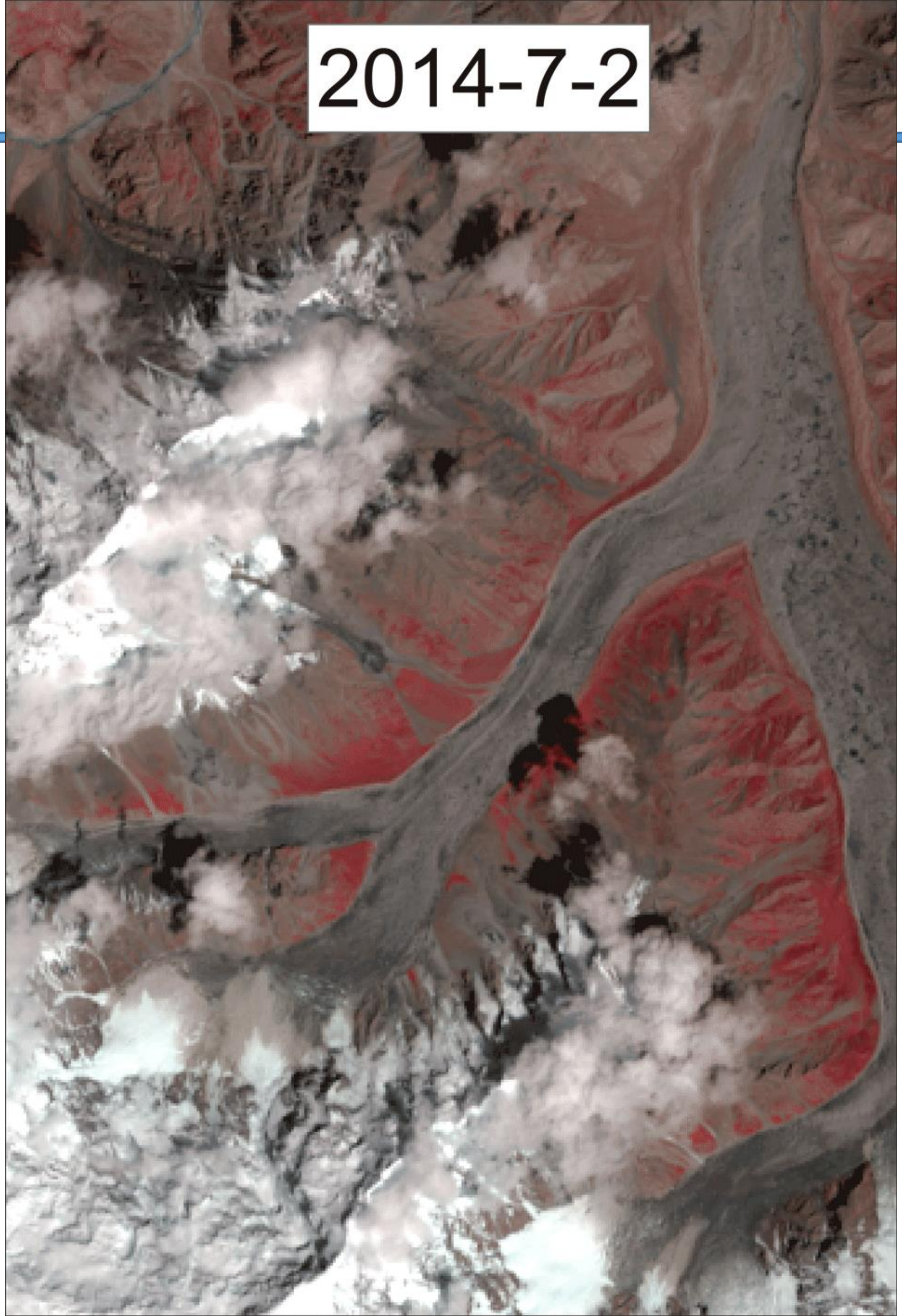
Uncertainty

- Multi-temporal images of Landsat 8 OLI were successfully co-registered to an accuracy of 0.4 pixels
- The displacement uncertainty (μ) can be calculated by the formula:

$$\mu = \sqrt{\theta_1^2 + \theta_2^2}$$

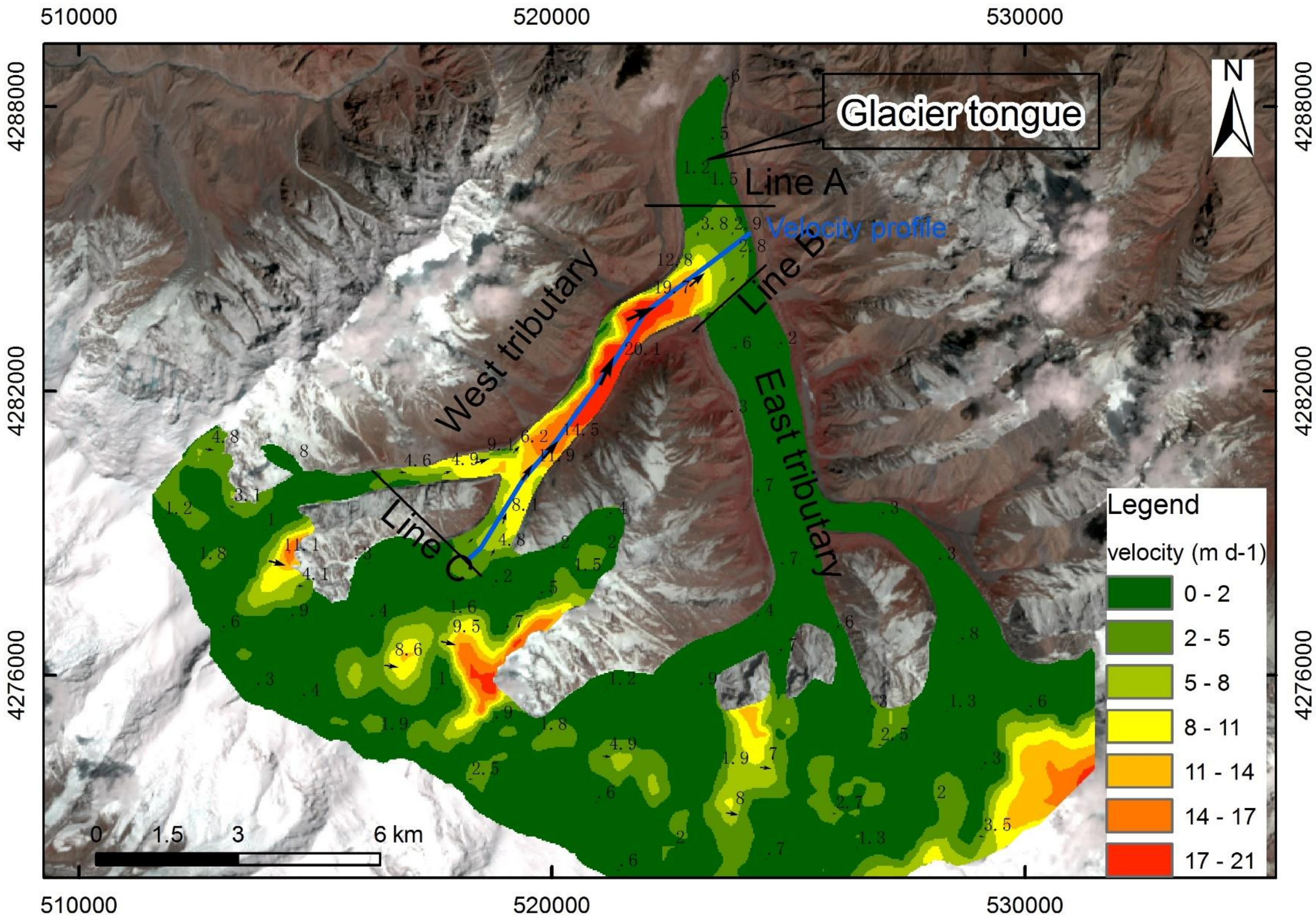


3.4 Glacier surging



3.4 Glacier surging

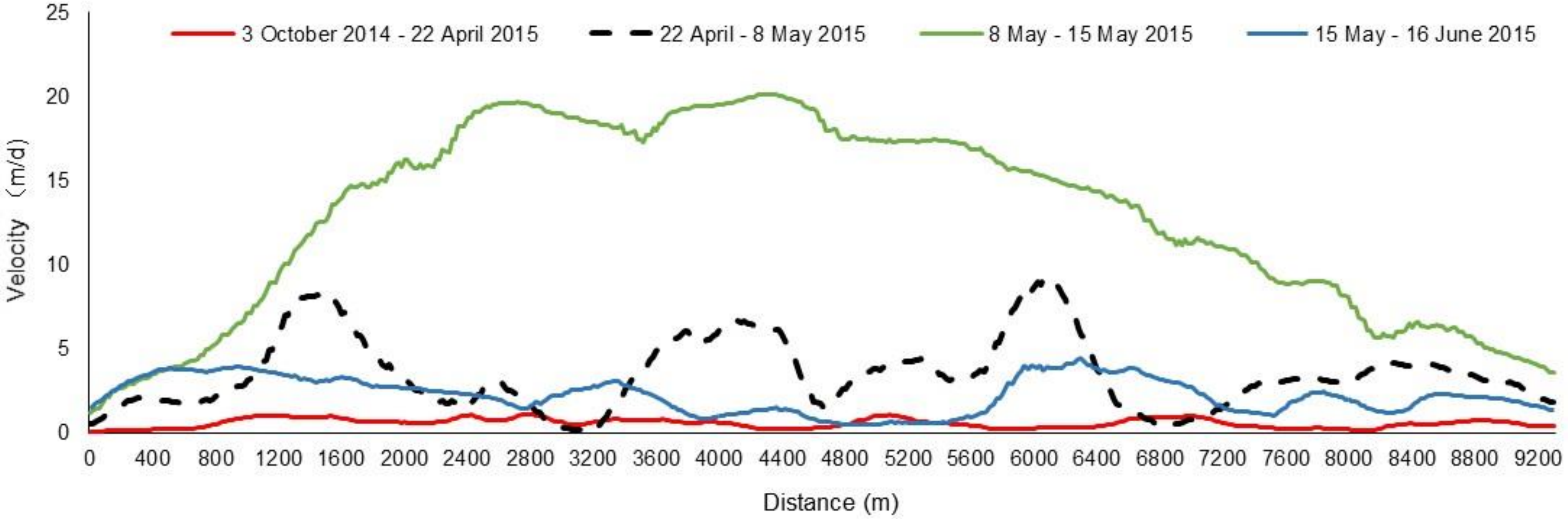
Velocity



8 August 2015-15 August 2015

3.4 Glacier surging

Velocity-Profiles



3.4 Glacier surging

Surge Tongue extent

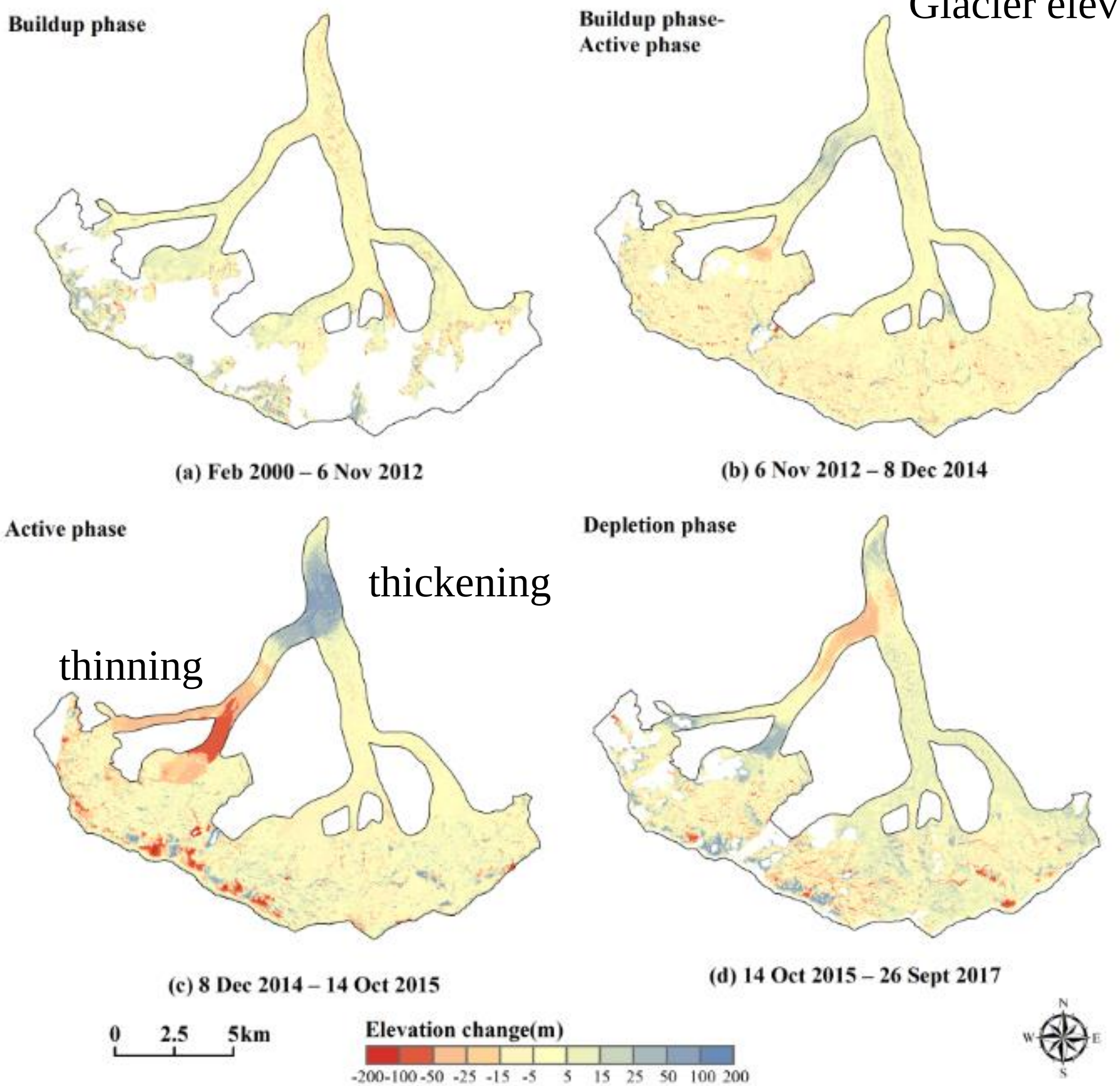
Surge Crevasse

4.2 Glacier surging

UAV by Xinjiang Institute after event

3.4 Glacier surging

Glacier elevation changes



(a) Feb 2000 – 6 Nov 2012

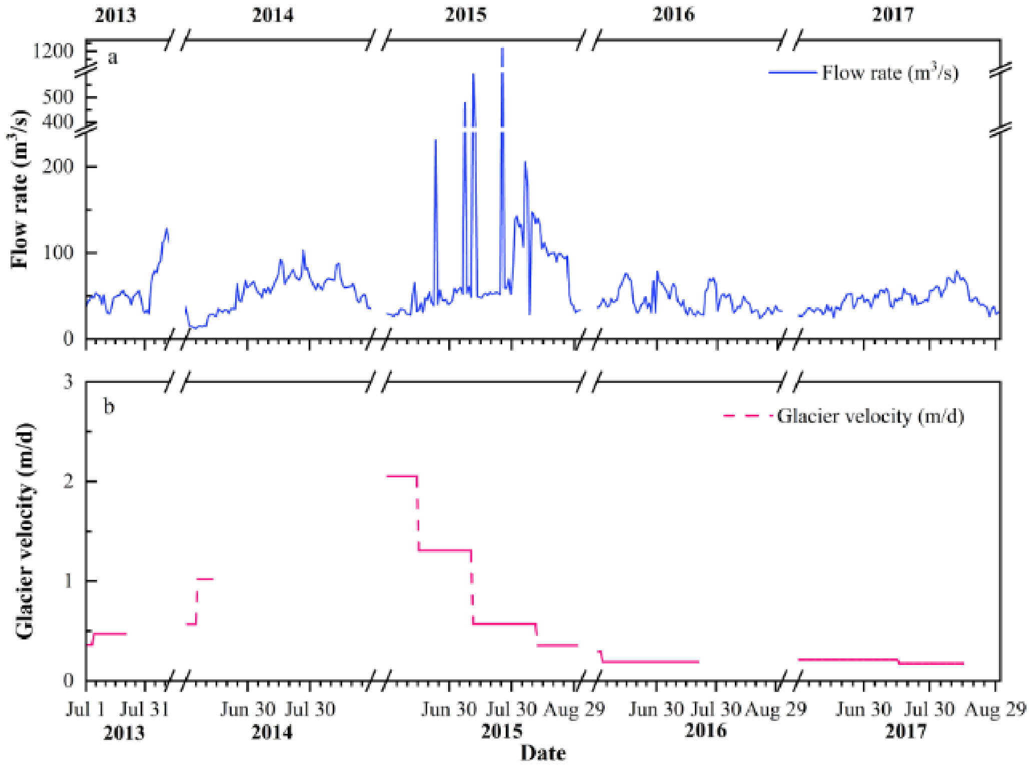
(b) 6 Nov 2012 – 8 Dec 2014

(c) 8 Dec 2014 – 14 Oct 2015

(d) 14 Oct 2015 – 26 Sept 2017

thickening

thinning



(Zhang et al., 2022)

3.4 Glacier surging

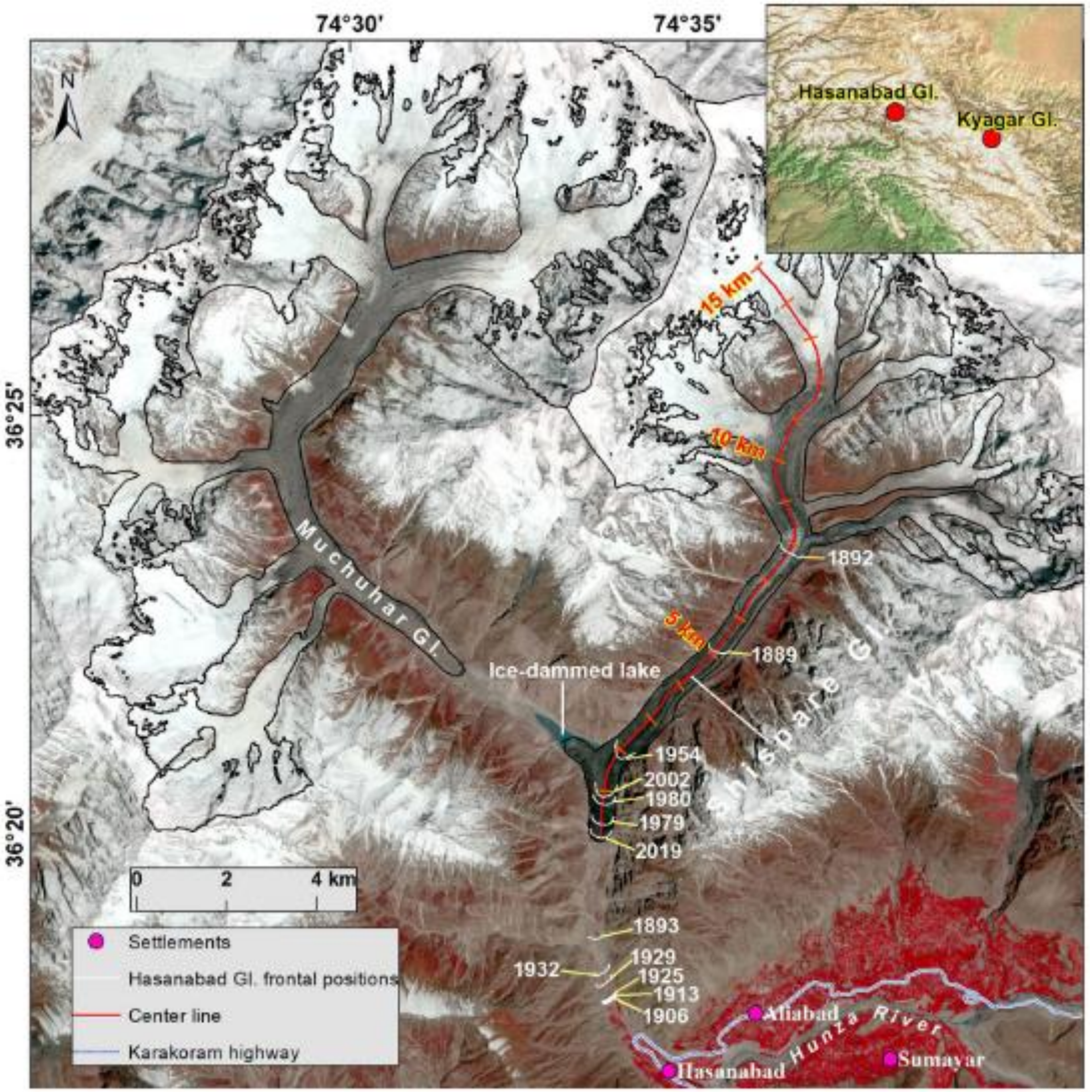
✓The western tributary of Karayaylak Glacier has been surging no later than 22 April 2015, burying grassland in the northwest lateral moraine

✓The glacier in the surge region is heavily broken, with many crevasses.

✓The profile velocity after 22 April was faster than before

✓It was controlled by hydrology

3.4 Glacier surging



Shisper lake and glacier surges(Bhambri et al., 2021)

3.5 Several Case study

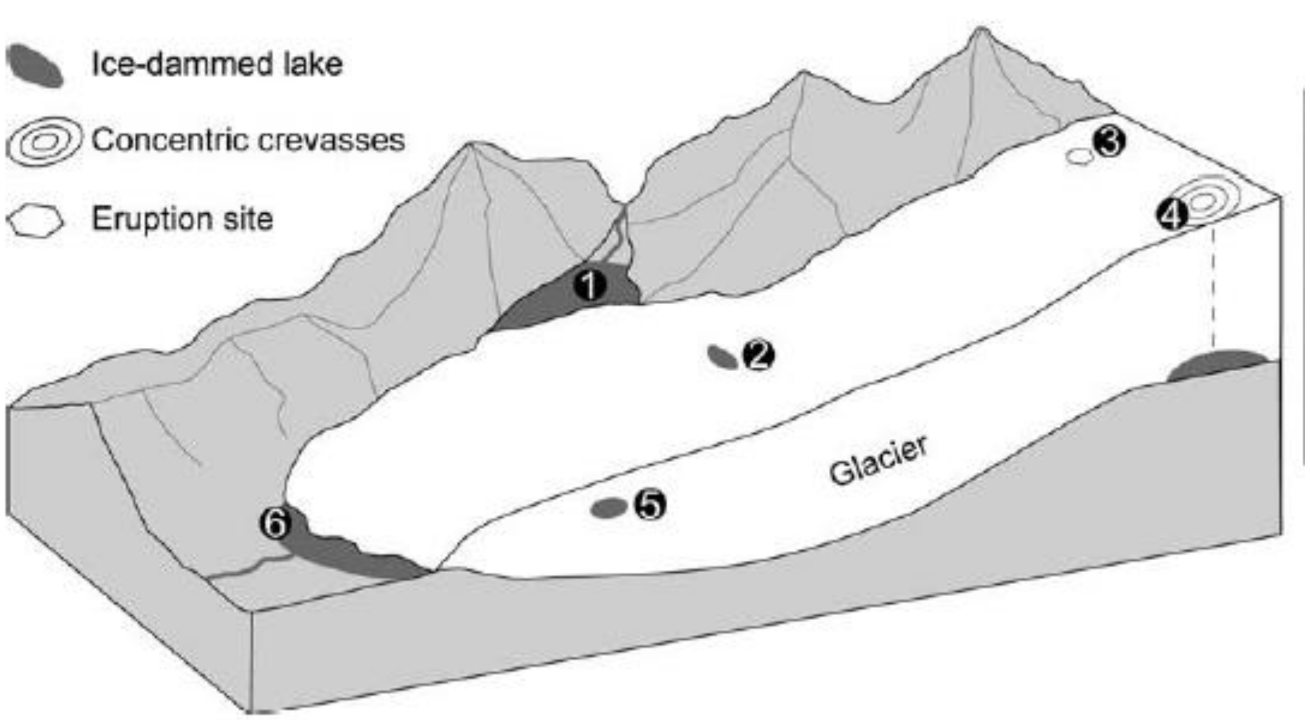
- Snow avalanche
- Snow disaster in pasturing area
- Ice collapse
- Glacier surging
- **GLOF**
- Thaw slumping

3.5 Several Case study

Jökulhlaups (glacier outburst floods) -usually glacial lake outburst floods

Jökulhlaups is an **Icelandic term** derived from the word **jökull**（glacier）and **hlaups**(spring or burst). It means a sudden release of meltwater from a glacier or a moraine-dammed lake (Sturm and benson, 1985; Paterson, 1994; Roberts, 2015)

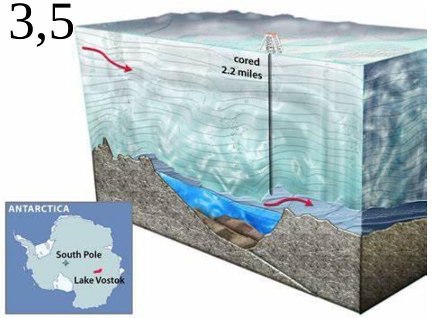
1,6Lateral moraine lake, end moraine lake




1,6


2 supraglacial lake

3,5



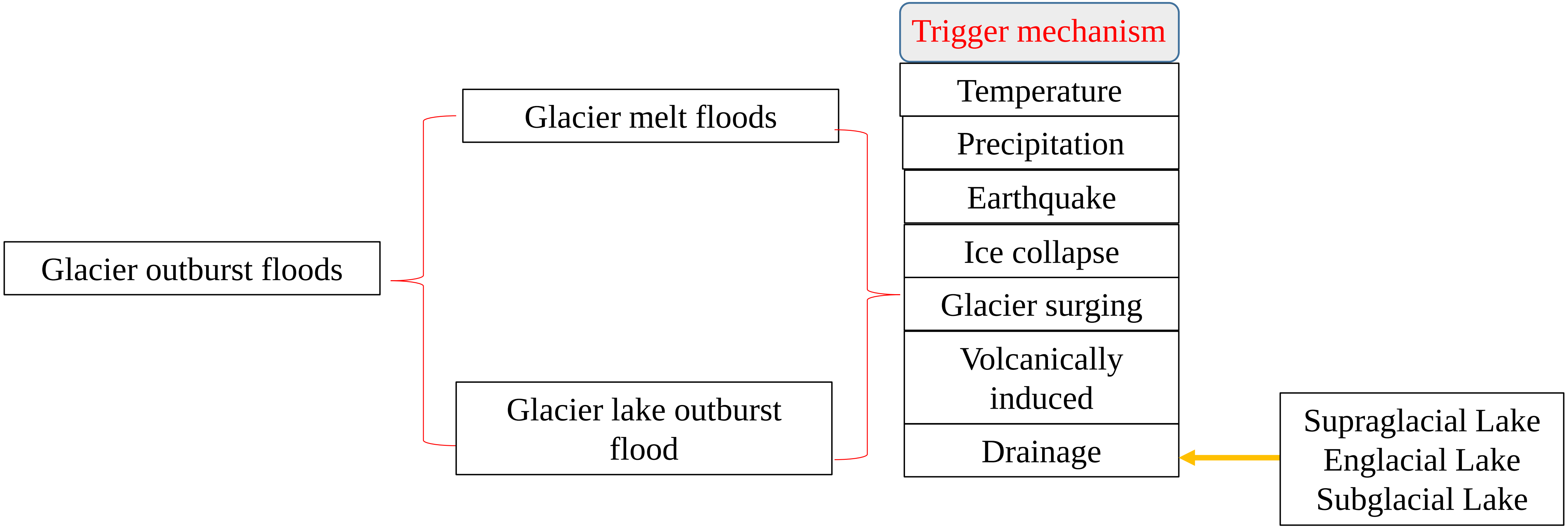
Subglacial or englacial


4 crevaasse

Sudden release,fast and significant increase in meltwater discharge

Glacier and Glacier lake

Jökulhlaups (glacier outburst floods)



Glacier outburst floods

Glacier melt floods

Glacier lake outburst flood

Trigger mechanism

Temperature

Precipitation

Earthquake

Ice collapse

Glacier surging

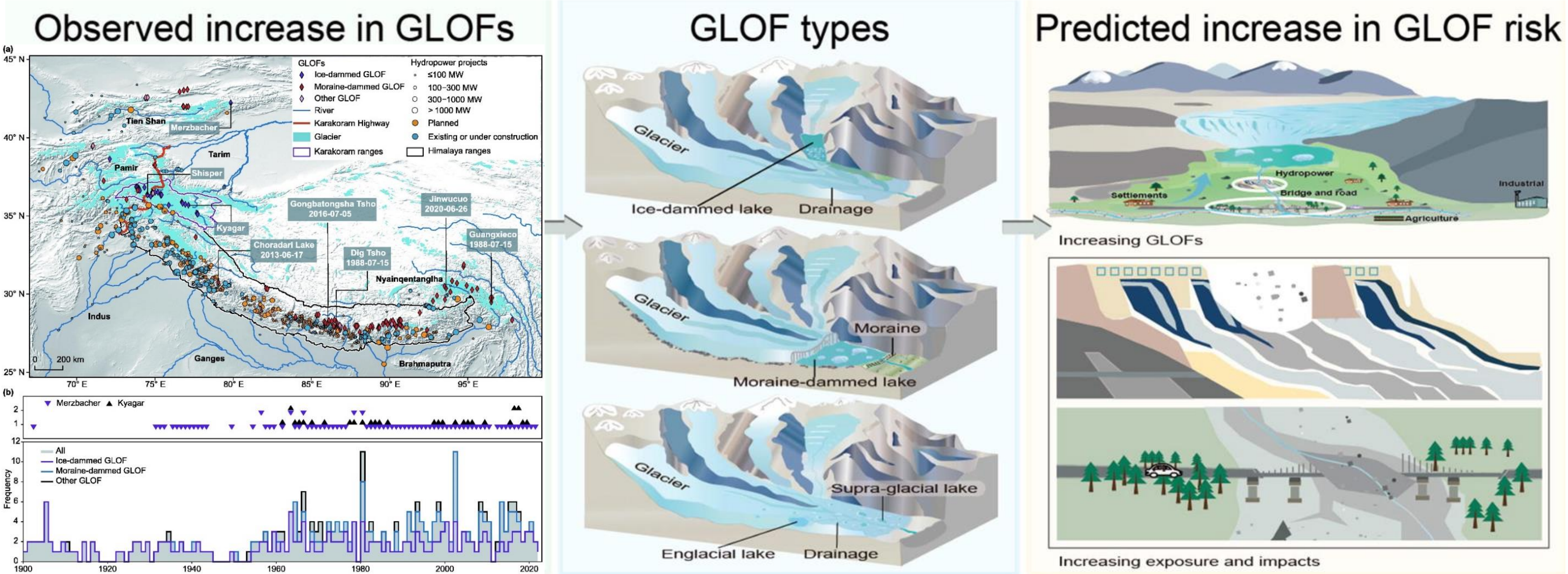
Volcanically induced

Drainage

Supraglacial Lake
Englacial Lake
Subglacial Lake

- ☐ Climate change-extreme climate
- ☐ Englacial lake drainage

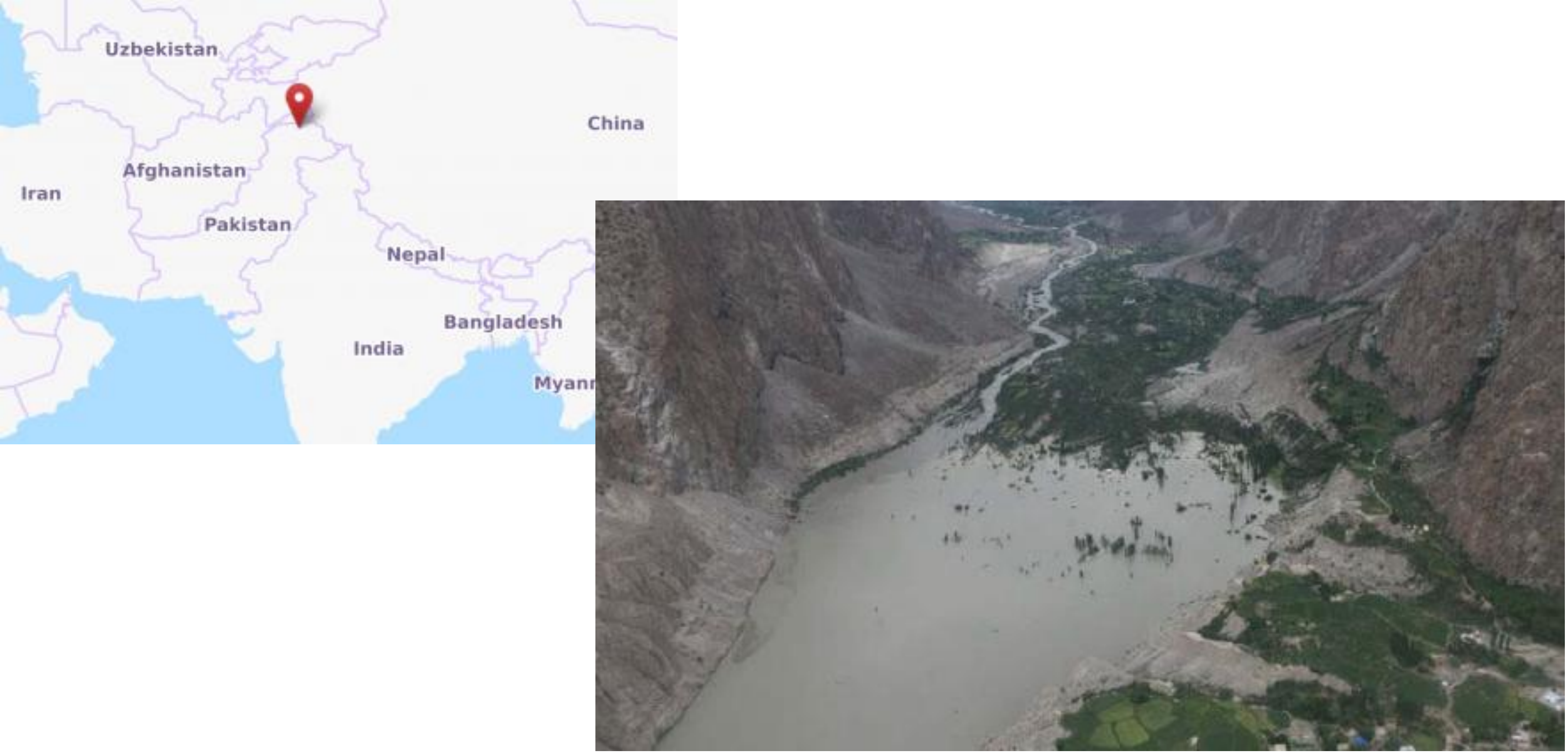
GLOFs threaten Asian's infrastructure



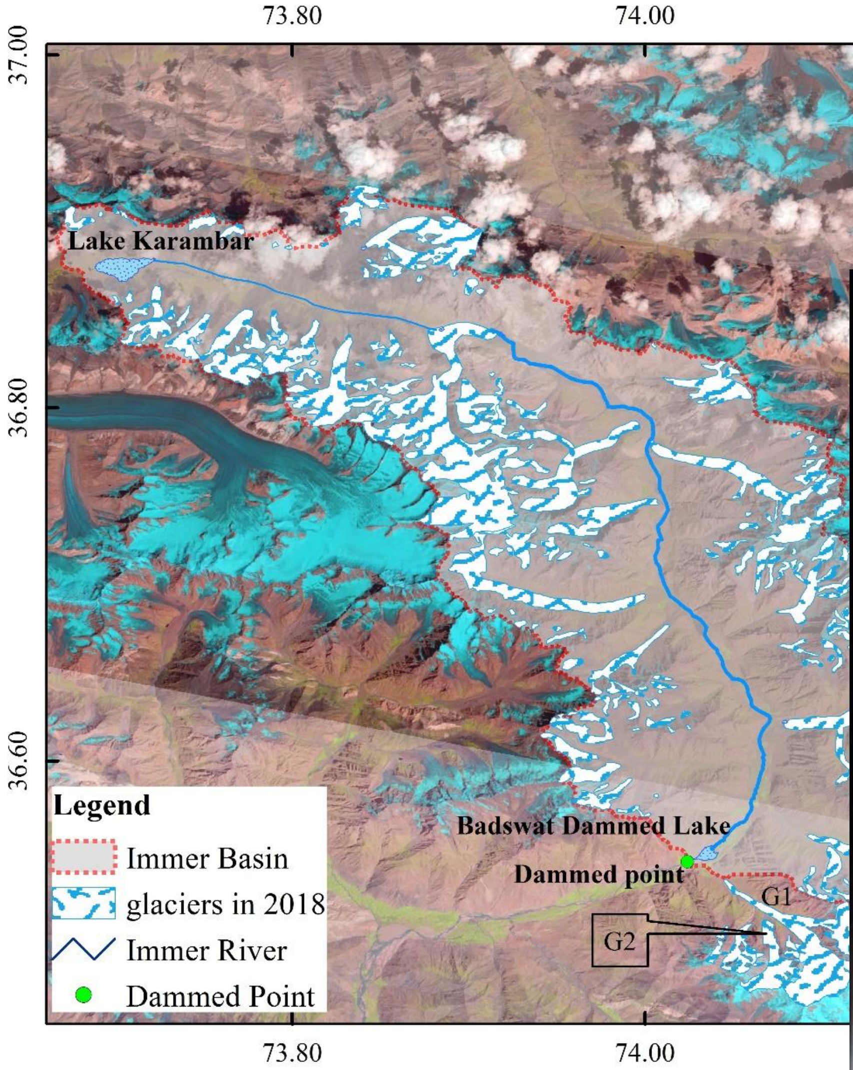
(Nie et al., 2023, SCI. BULL.)

- 298 GLOF events (categorized as moraine-dammed, ice-dammed or "other" GLOF) were reported with increasing frequency from 1900 to 2022, .
- Multiple GLOFs recorded have severely damaged Asian infrastructure (such as bridge, road and hydropower) since 1964.
- A boom in investment in transport and hydropower infrastructure is underway in Asia's high mountains while downstream populations are growing rapidly, combined with climate change, are raising the risk of GLOF.
- The lack of in-situ observation and key knowledge gaps of GLOF risk restrict the prevention and control of cryospheric hazards.

3.5 GLOF-Badswat

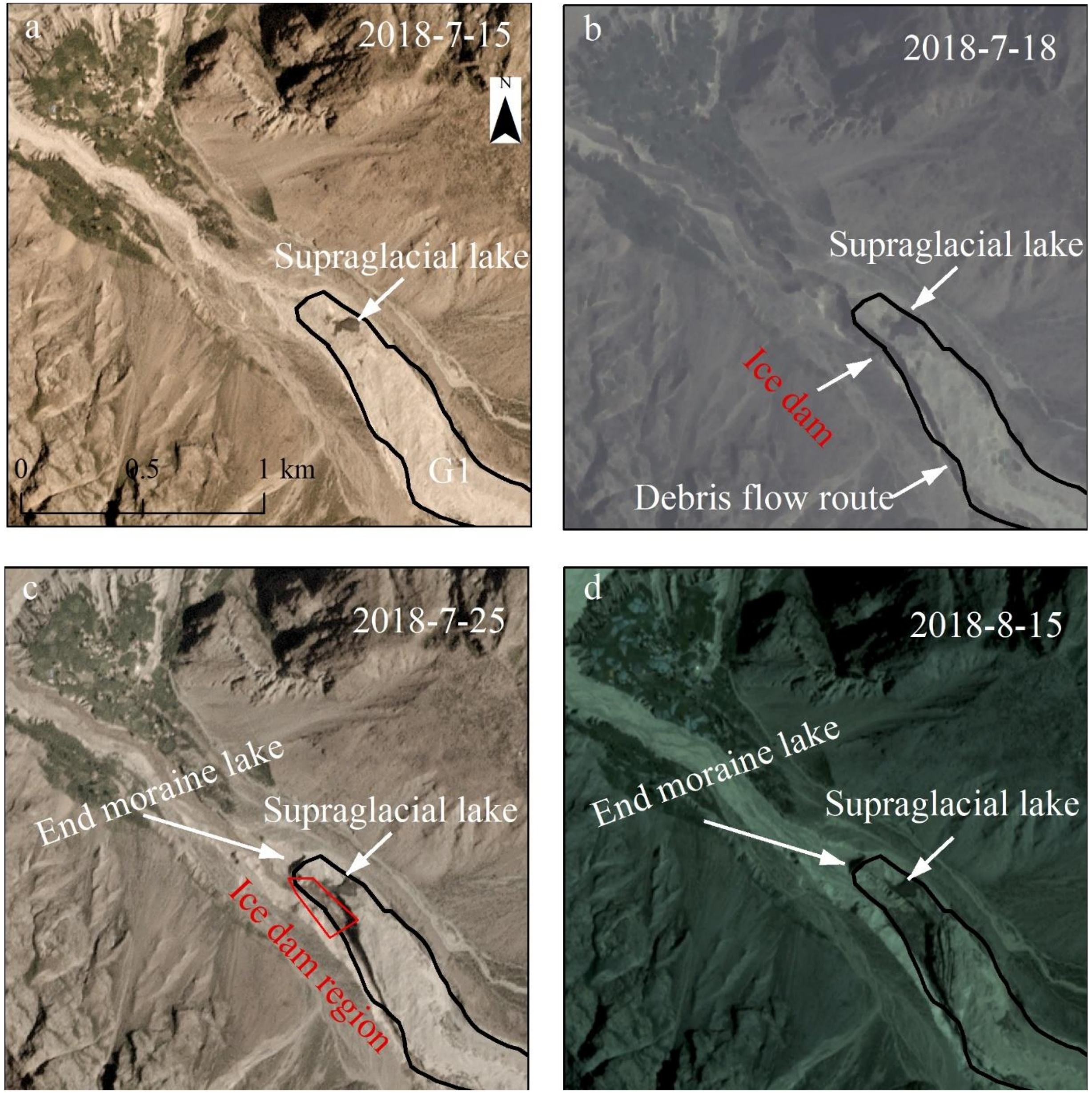


3.5 GLOF-Badswat



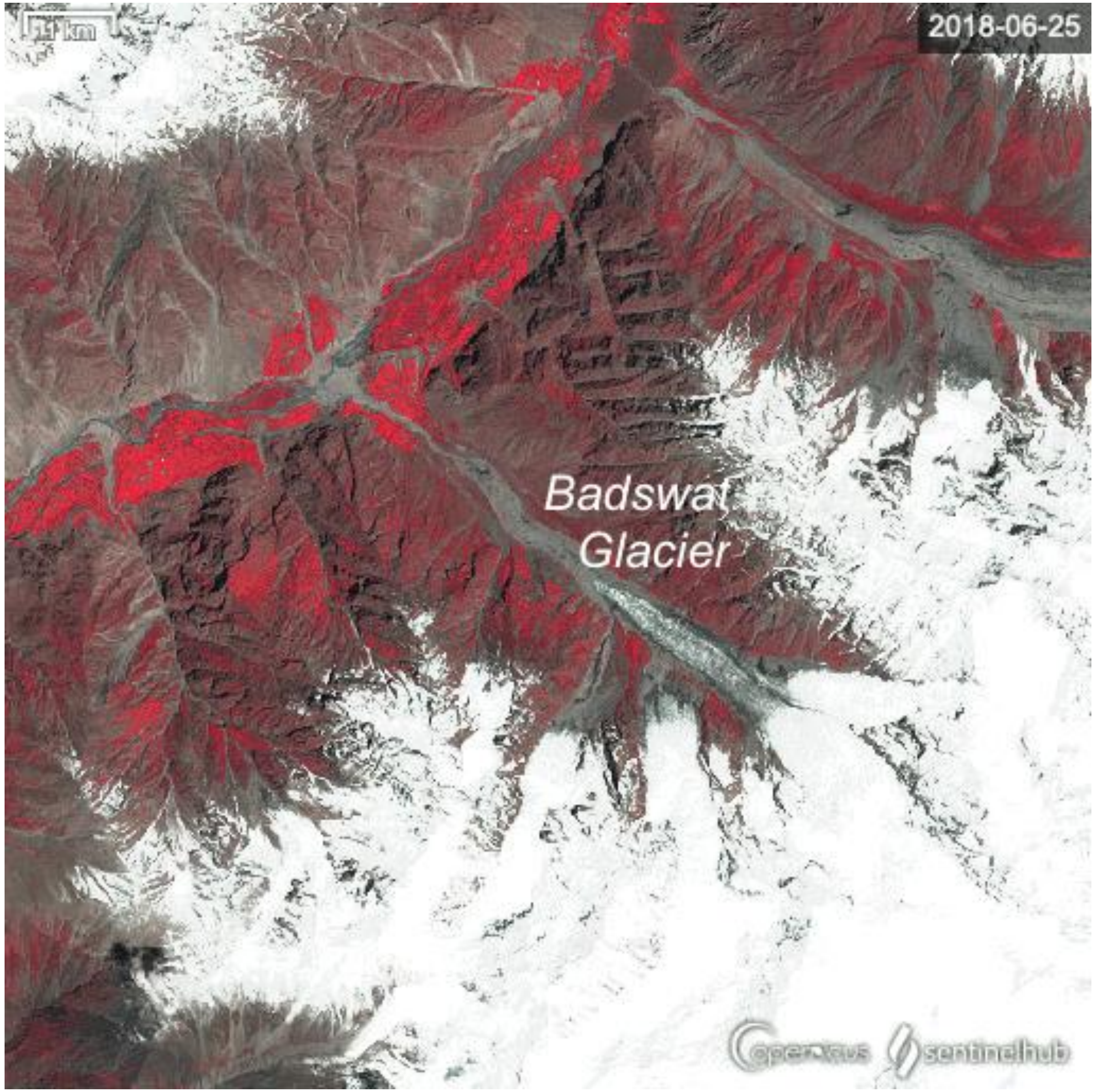
Lake Badswat 2018, July,17

3.5 GLOF



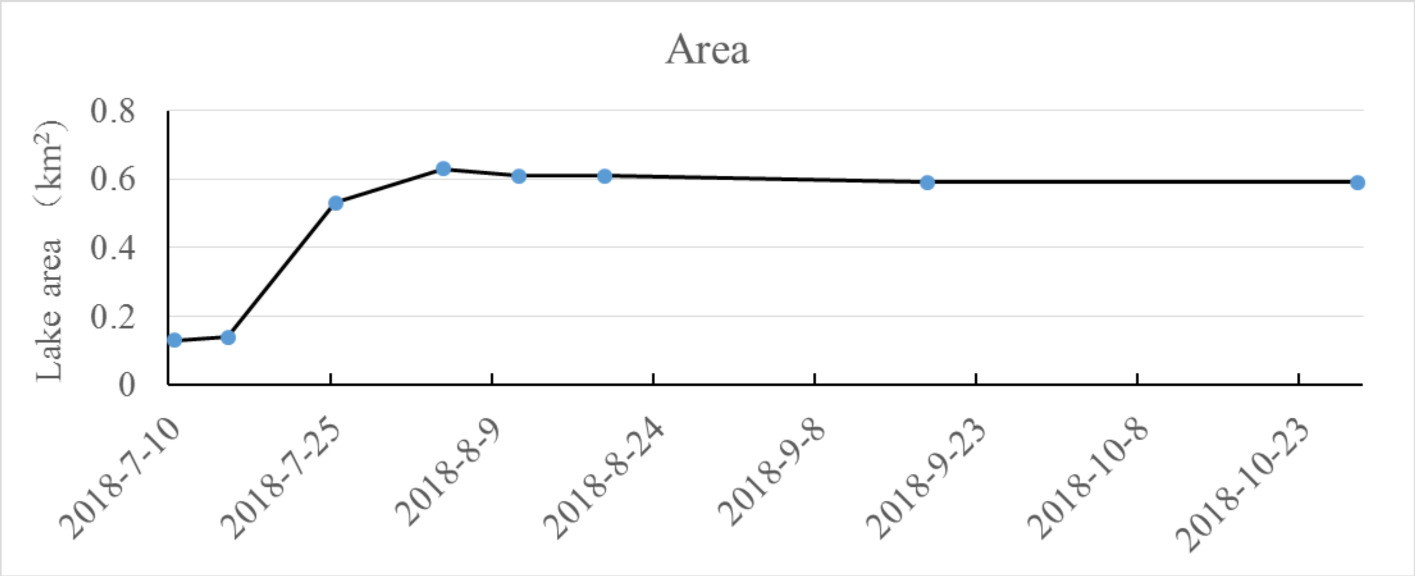
- Supraglacial lake have always existed before and after event
- Debris flow route is clear showed in 18, July
- Ice dam region also showed in 18, 25 July
- End moraine lake develop in 15 August.

3.5 GLOF

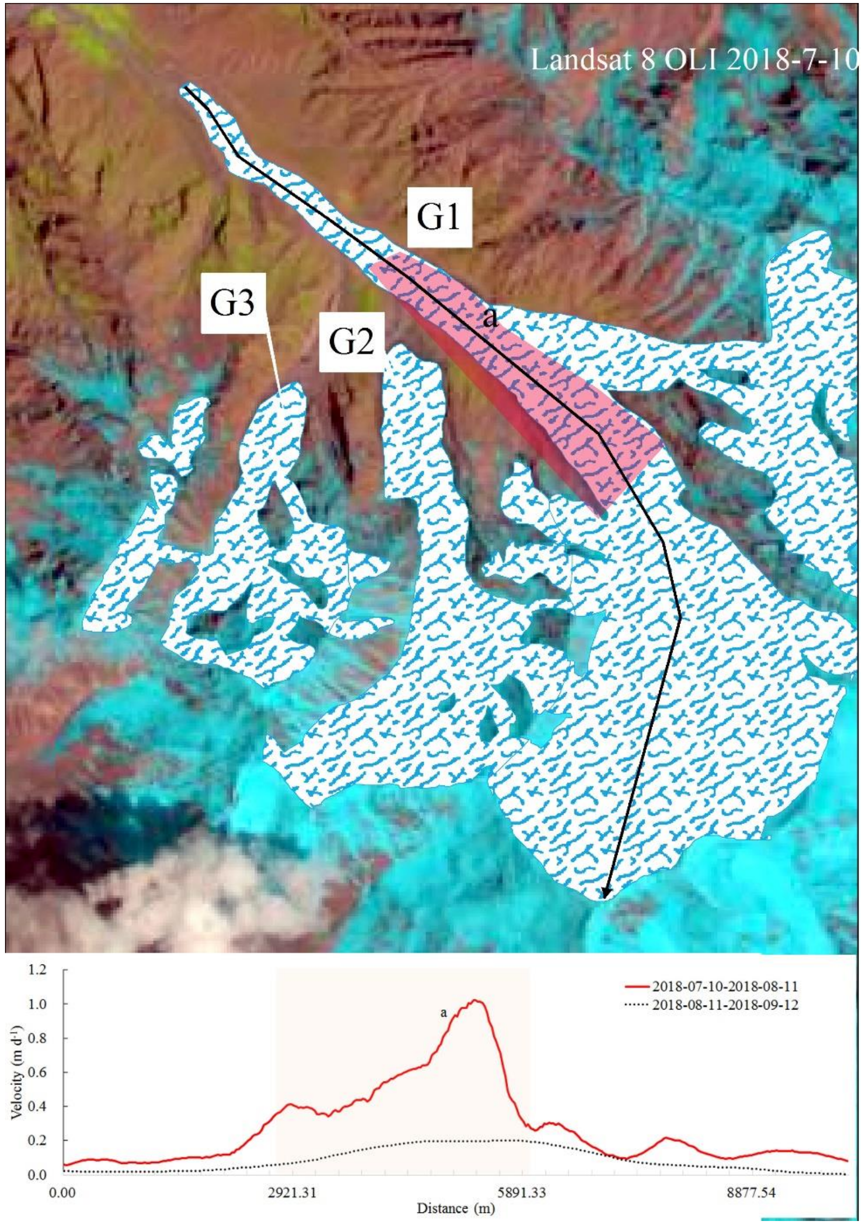


3.5 GLOF

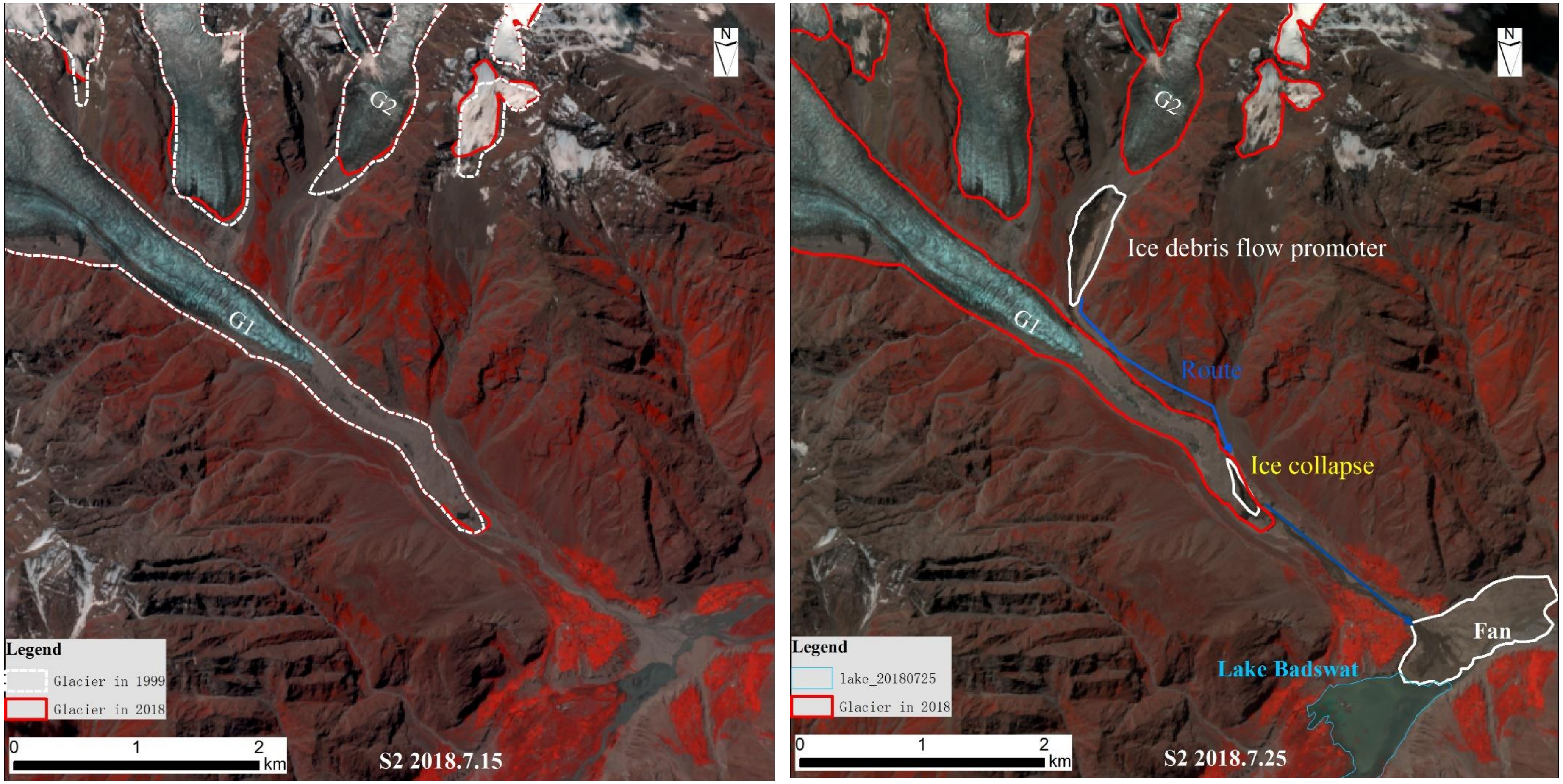
Lake Badswat area



Glacier velocity



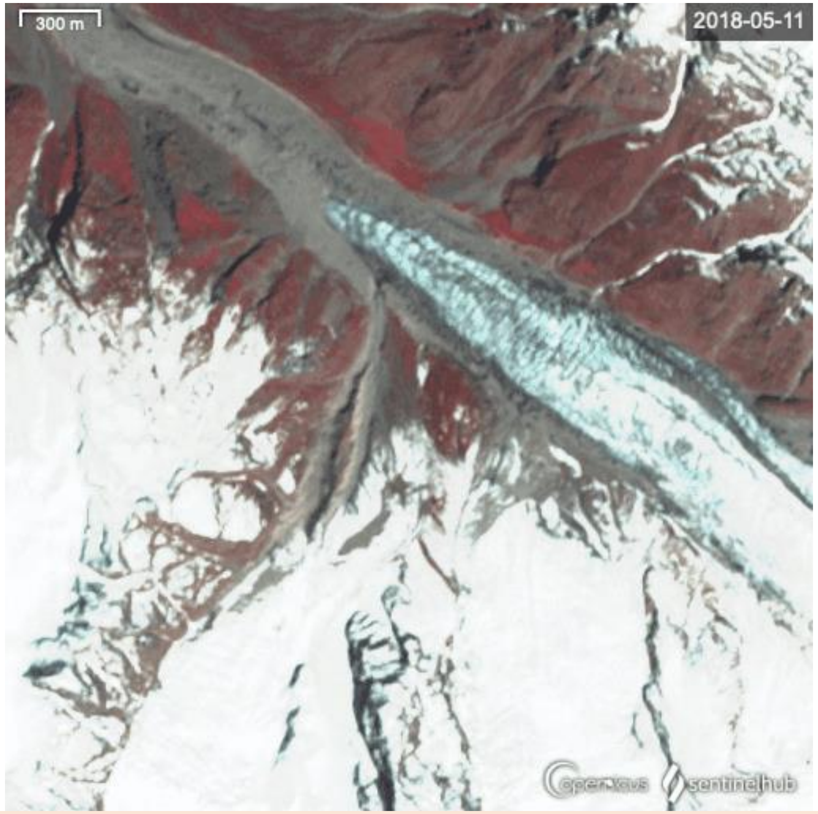
3.5 GLOF

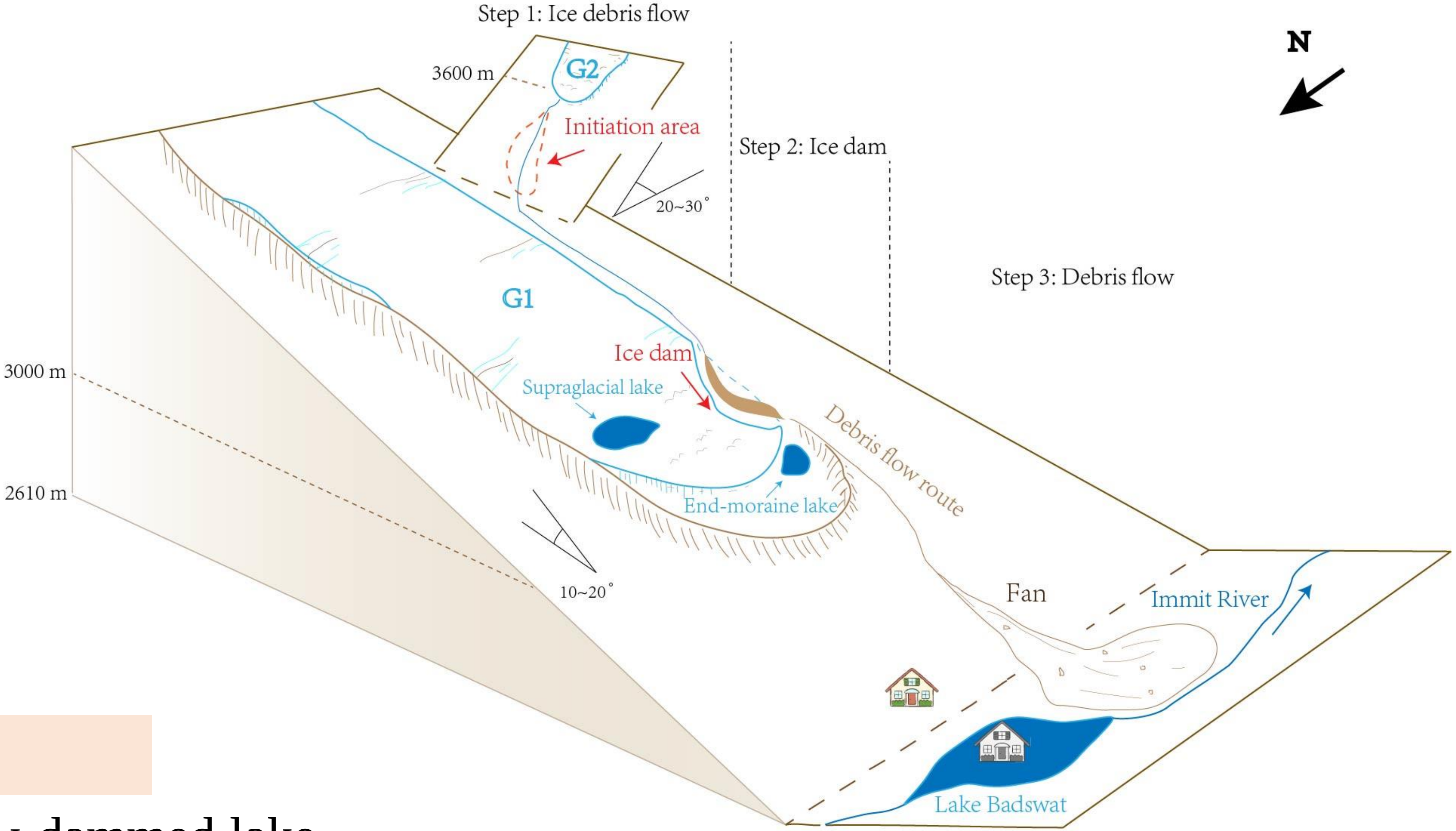


What' happen

Lake Badswat- other blocked lake

3.5 GLOF





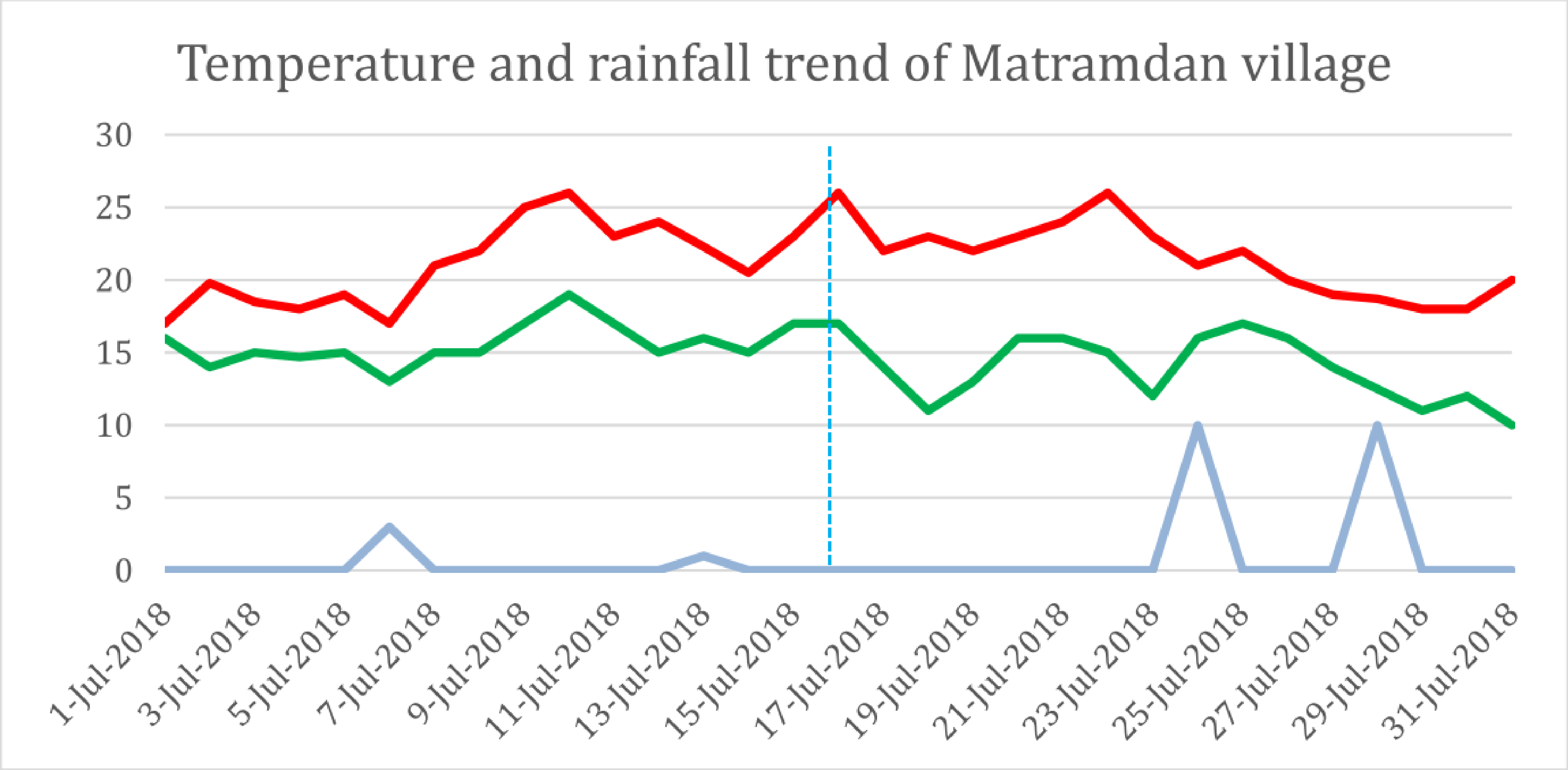
What did we know about?

- flood-dammed ditch-debris flow-dammed lake
- High temperature and heavy precipitation before event(in early stage),High temperature and no precipitation when event occurred.

What drives the GLOF and debris flow?

3.5 GLOF

Weather monitoring post (WMP) 8km far away



Red line: maximum T
Green Line: minimum T
Blue Line: rainfall

Anwar et al., 2020

3.5 GLOF

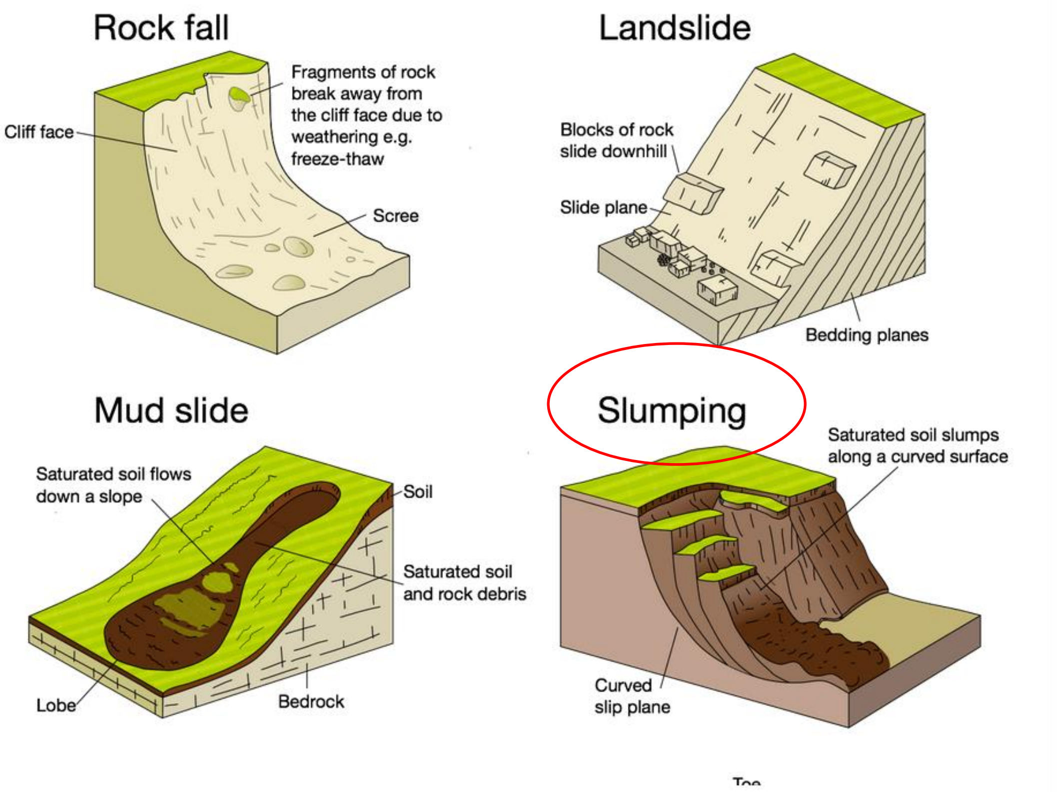
- 1341 glacial lakes were extracted along the China-Pakistan Economic Corridor, of which 492 are Blocked lake, 723 are Erosion lake, 86 are Supraglacial lake and 40 are Other glacial lake, with a total area of 109.76 km² in 2018. And most of those lakes in CPEC are concentrated between 4100-4500 m.a.s.l.
- the number of glacial lakes had been increased from 1144 to 1341 and area from 89.17 km2 to 109.76 km2 (18.8%) during 2000-2018. End-moraine lake and Supraglacial lake have changed significantly. Furthermore the area and quantity of glacial lakes in high altitude areas(more than 4000 m.a.s.l) changed more obviously.
- Other blocked glacial lakes are related to disaster chain which theatens the property.

3.6 Several Case study

- Snow avalanche
- Snow disaster in pasturing area
- Ice collapse
- Glacier surging
- GLOF
- **Thaw slumping**

3.6 Thaw slumping disaster

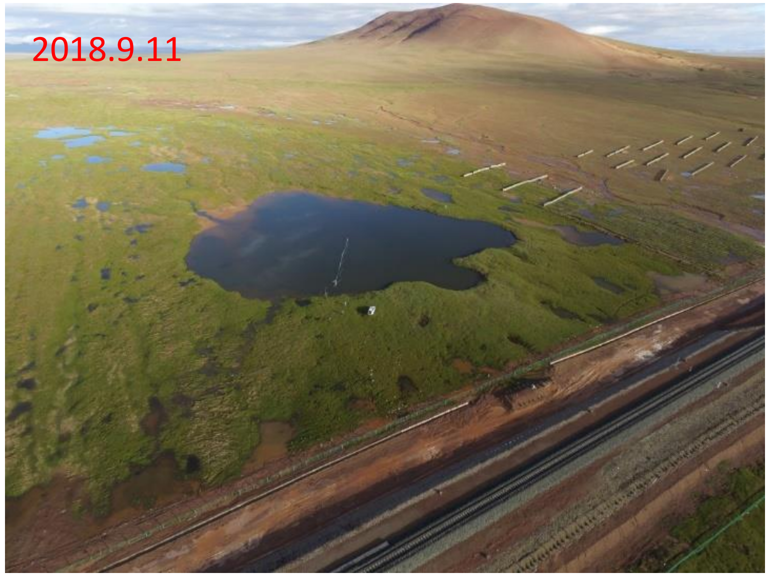
A slope failure mechanism characterized by the melting of ground ice, and downslope sliding and flowing of the resulting debris.



Types of mass movement

Thaw slumping is a periglacial process that occurs on slopes in cold environments, where **the ground becomes unstable and the surface slides downhill** due to saturation with water during thawing.

3.6 Thaw slumping



Thaw slumping near Tibetan railway in Beiluhe Basin

Thaw slumping near foothills in Beiluhe Basin

Thermal karst formation conditions:

1) permafrost with high ice

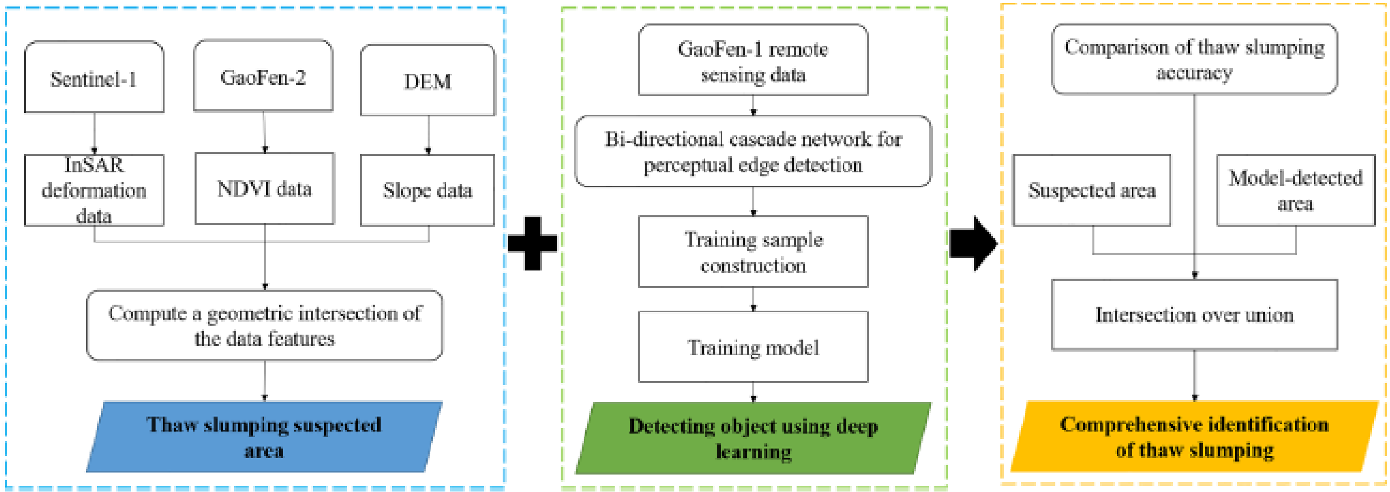
2) The heat exchange conditions that can melt the permafrost with high ice are actually the disturbance or destruction of the surface energy balance;

3) With the topographic conditions of meltwater accumulation, thermokarst processes will generally form thermokarst erosion in mountainous and hilly areas.

Survey methods:

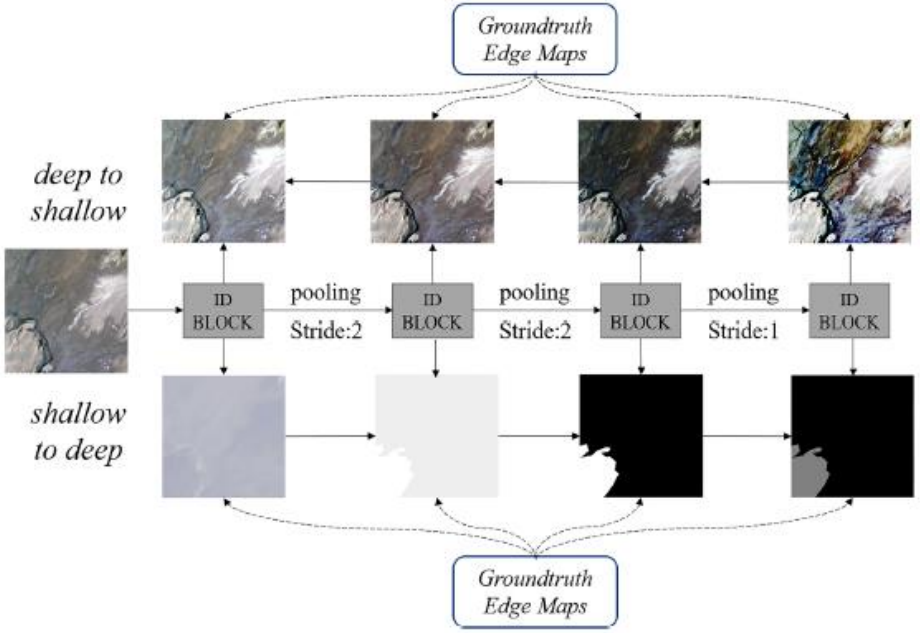
- ◆ Drone aerial photography;
- ◆ GMR nuclear magnetic resonance water finder
- ◆ DISCUS nuclear magnetic resonance moisture content tester
- ◆ High resolution remote sensing data

3.6 Thaw slumping-distribution near Tibetan railway

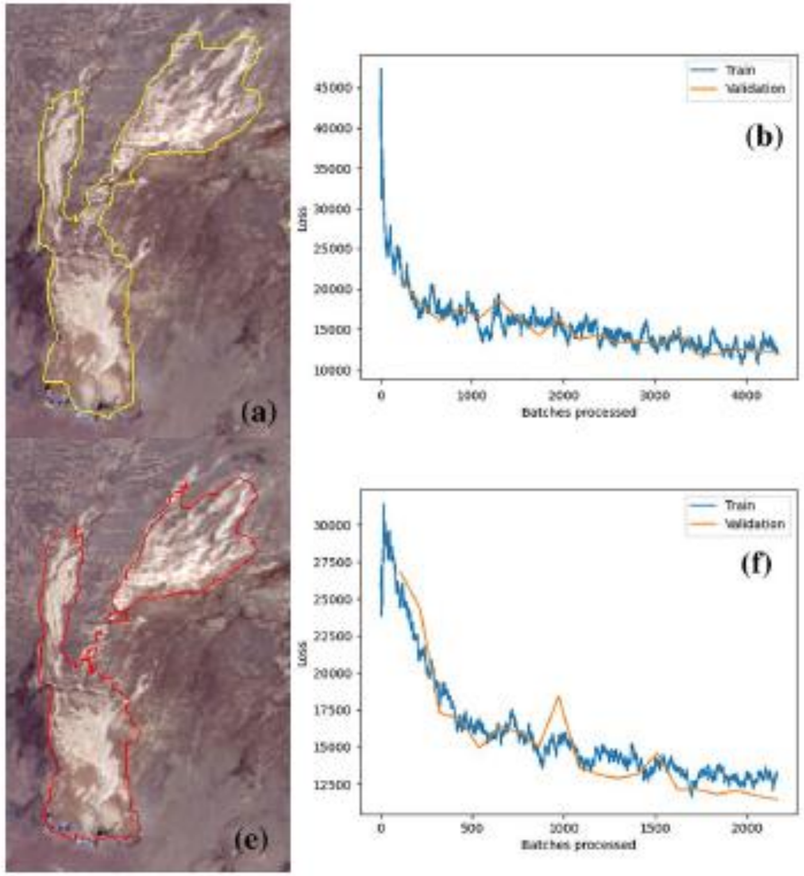

Sentinel-1
GaoFen-2
DEM
InSAR deformation data
NDVI data
Slope data
Compute a geometric intersection of the data features
Thaw slumping suspected area

GaoFen-1 remote sensing data
Bi-directional cascade network for perceptual edge detection
Training sample construction
Training model
Detecting object using deep learning

Comparison of thaw slumping accuracy
Suspected area
Model-detected area
Intersection over union
Comprehensive identification of thaw slumping

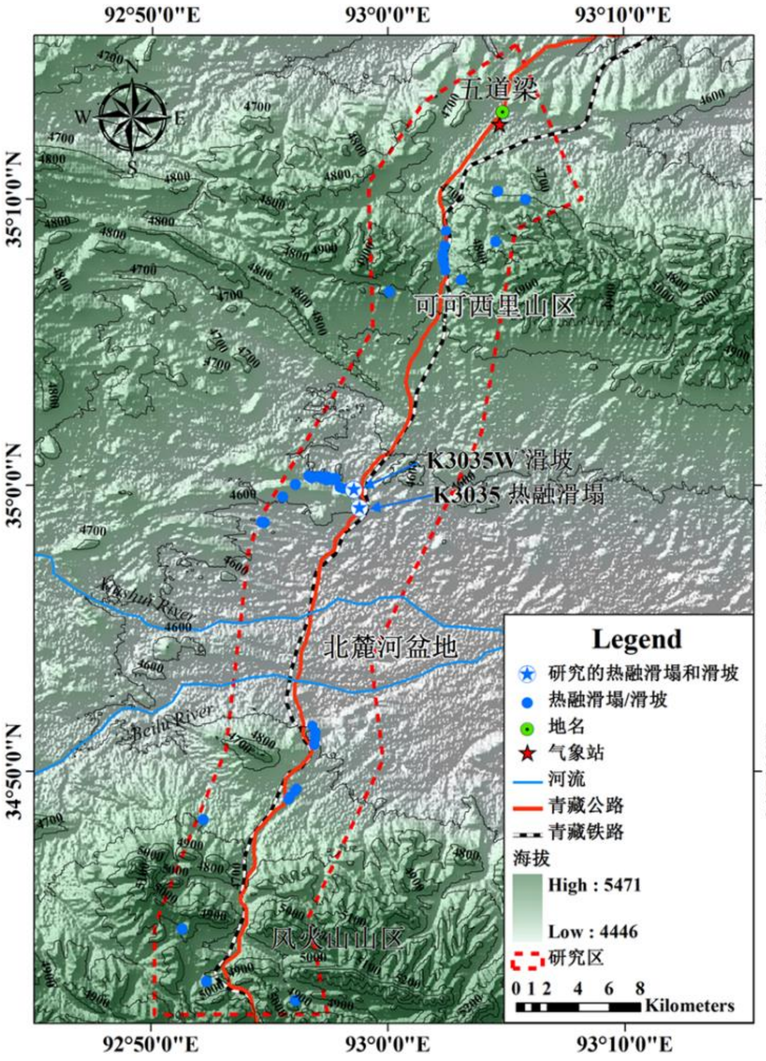


The overall architecture of a bi-directional cascade network (BDCN). The incremental detection (ID) block is a fundamental component of a BDCN, which is trained using layer-specific supervisions inferred by a bi-directional cascade structure.

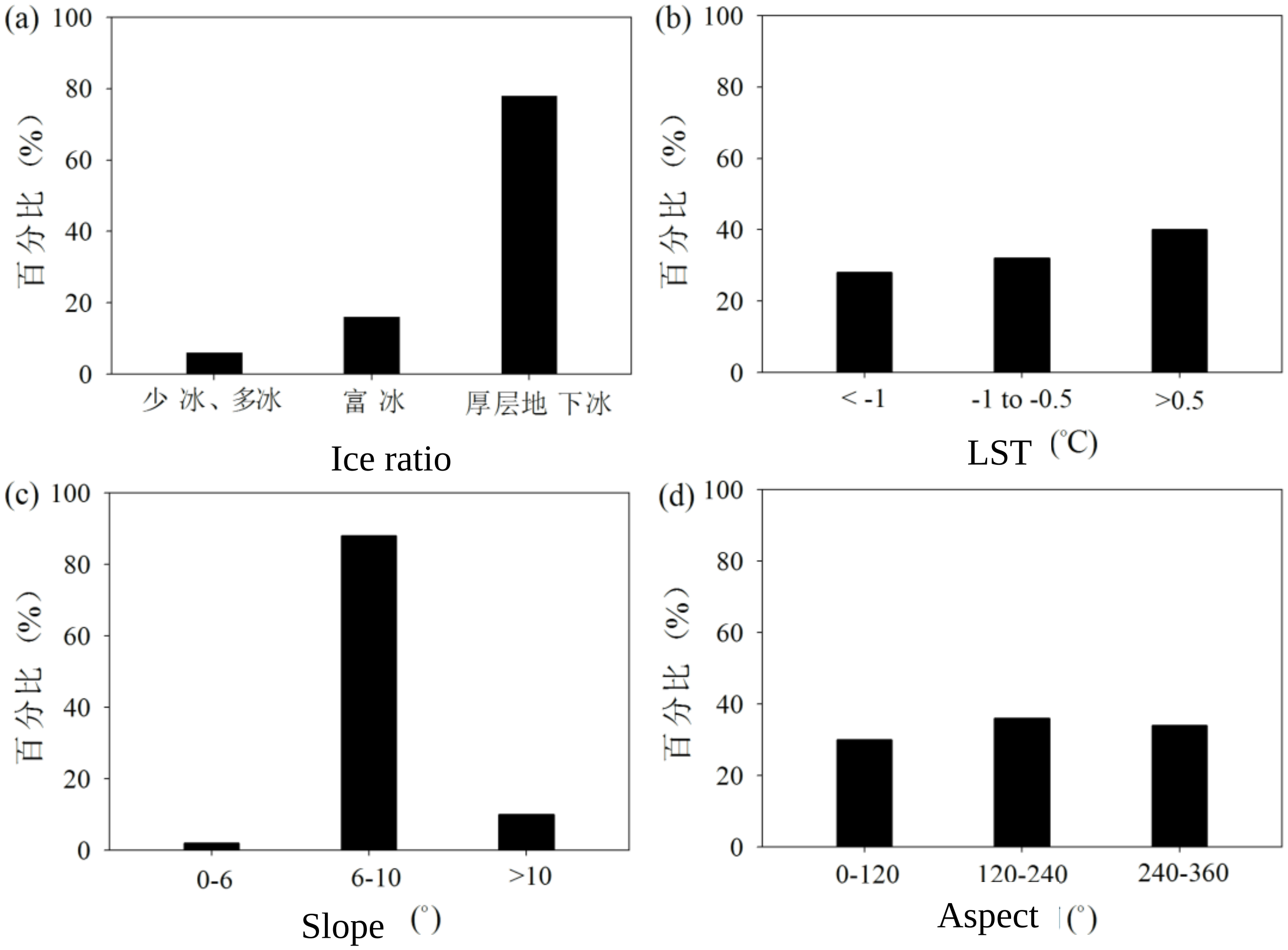


Models identifying the contour of the same landslide: a ResNet101,

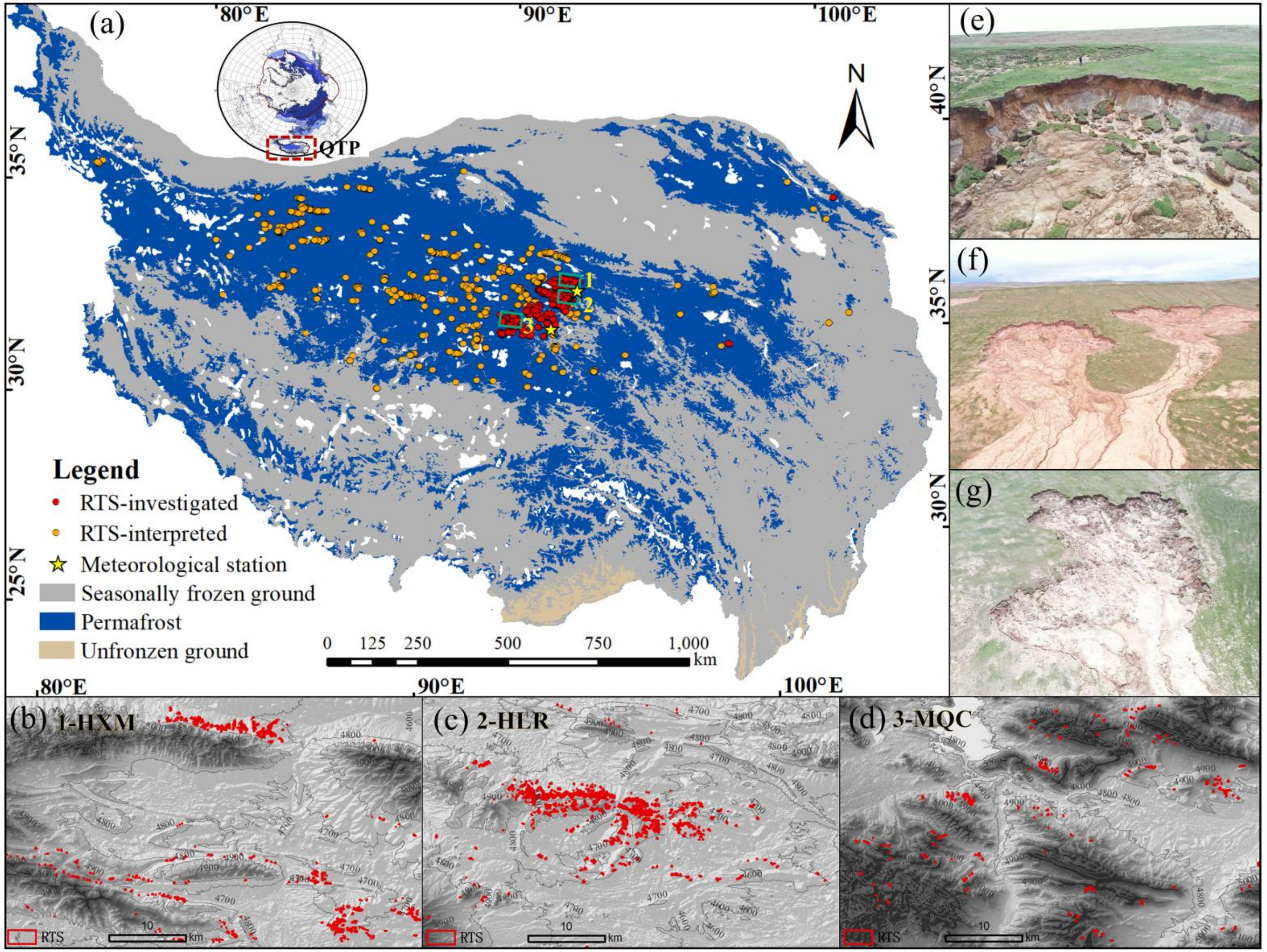
3.6 Thaw slumping-distribution near Tibetan railway



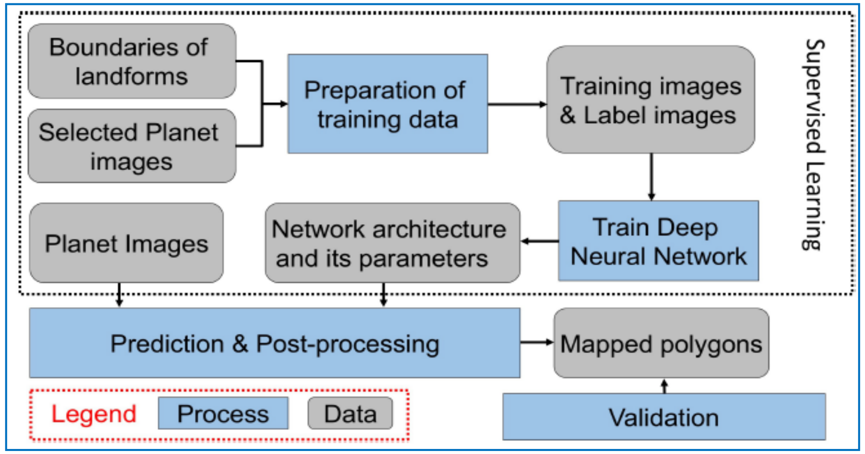
Thaw slumping distribution



Thaw slump hazards of permafrost in the Tibetan Plateau



2020,number of 2669,area of 38.49 km^2


Boundaries of landforms

Selected Planet images

Preparation of training data

Training images & Label images

Planet Images

Network architecture and its parameters

Train Deep Neural Network

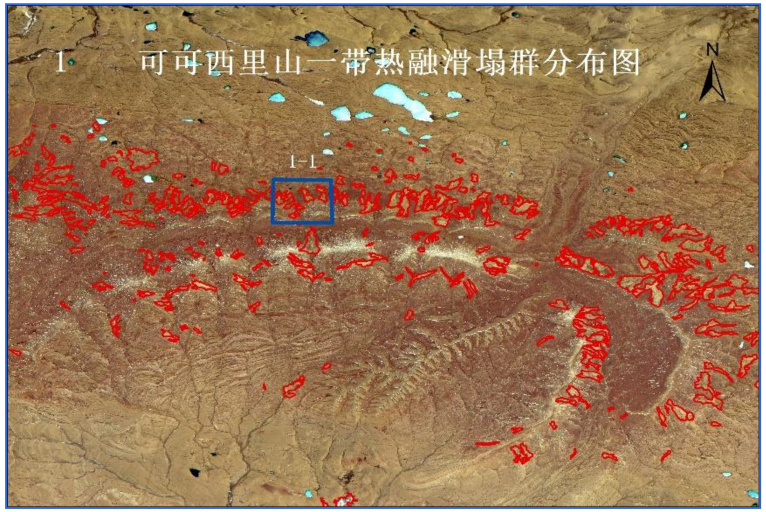
Supervised Learning

Prediction & Post-processing

Mapped polygons

Validation

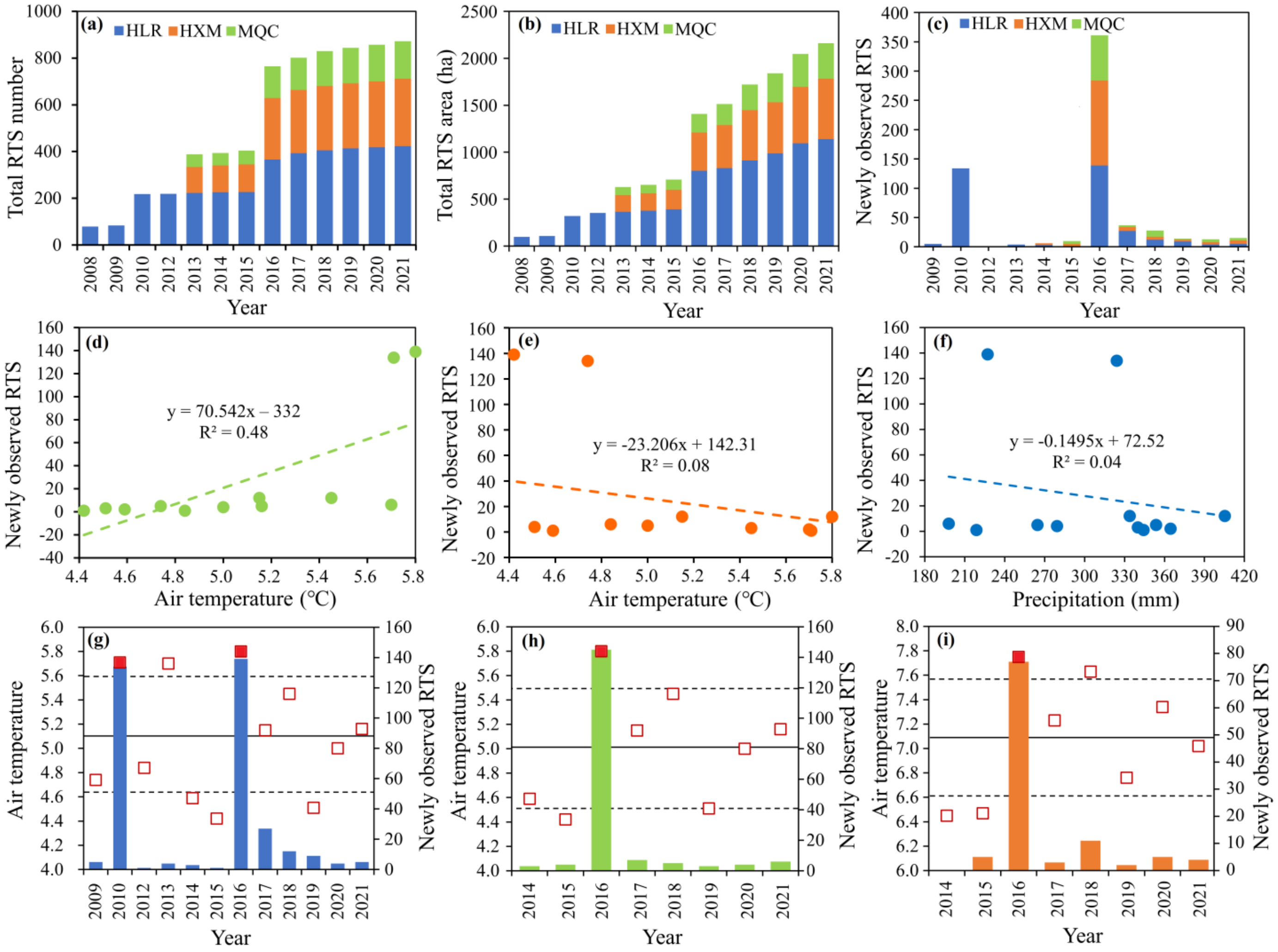
Legend Process Data



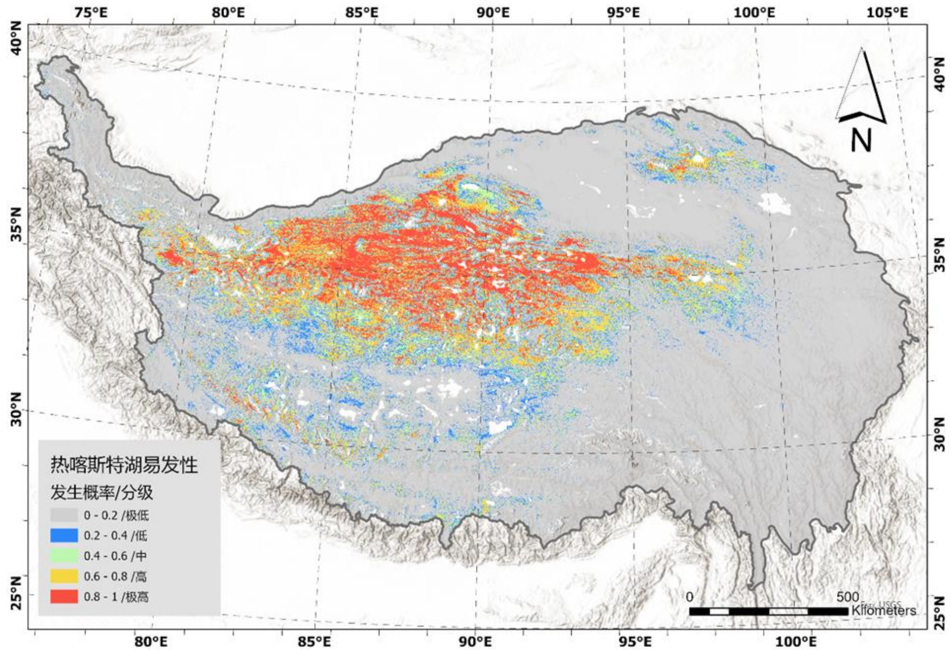
(Niu et al., 2022)

Thaw slump hazards of permafrost in the Tibetan Plateau

HLR-Honglianghe Region; HXM-Hoh Xil Mts; MQC-Maqu County

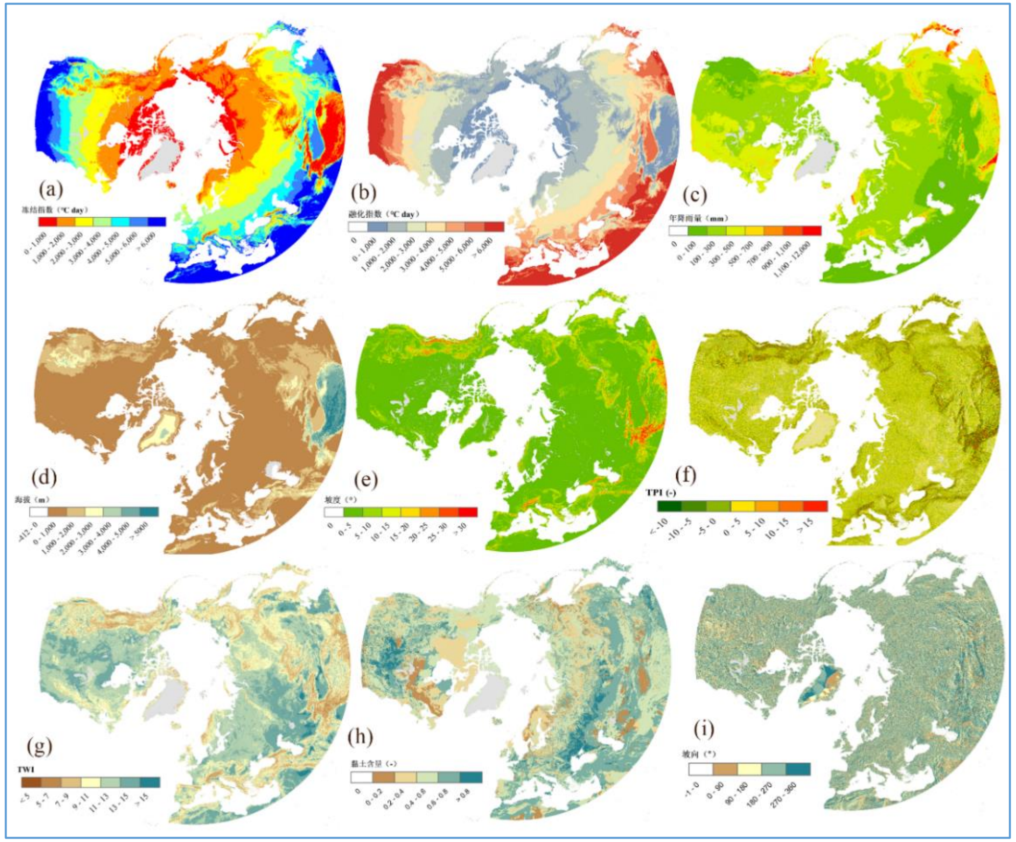


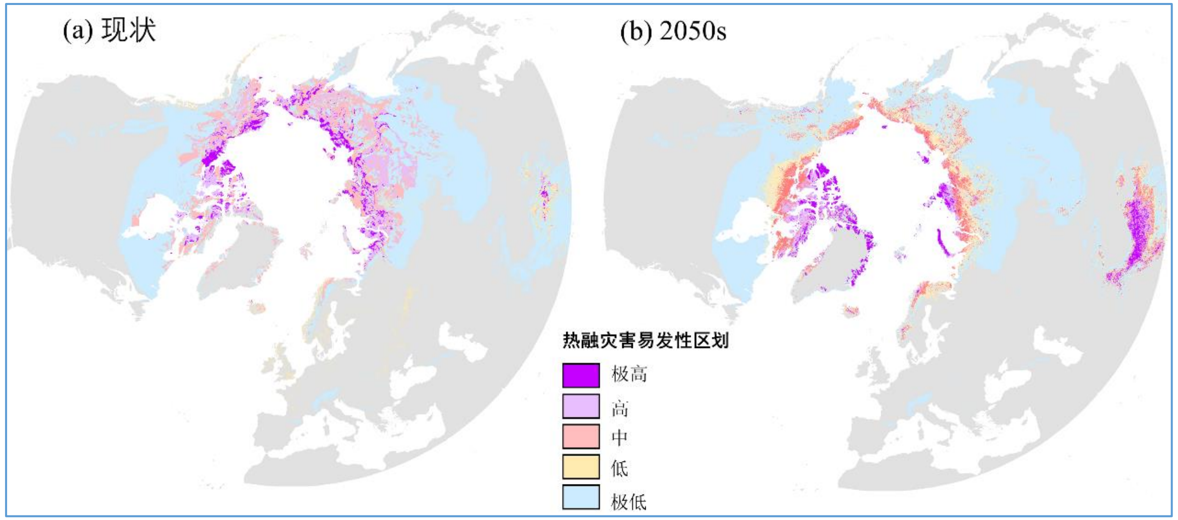
- **Number and aera retrogressive thaw slumps (RTS) increased in three regions**
- **Increased air temperature caused RTS (2016)**
- **More susceptibility of thermokarst hazards will be in Hoh Xil region**



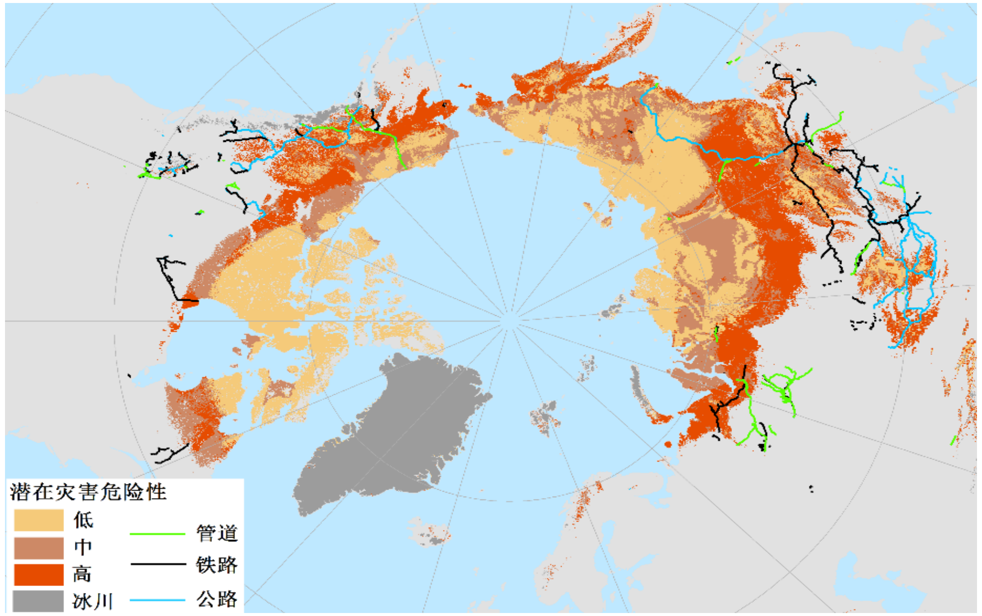
(Niu et al., 2022)

Thaw slump hazards of permafrost in the Northern Hemisphere





Susceptibility assessment of thaw slump hazard



Risks of thaw slump hazard during 2041-2060

(Niu et al., 2022)

3.6 Effects of Thaw slumping

Major projects, resource development and environmental protection in cryosphere

- Qinghai-Tibet railway
- Qinghai-Tibet highway
- Mining engineering
- West-east gas transmission project
- China-Russia oil pipeline

- Golmud-lhasa Pipeline
- Sanjiangyuan Ecological protection project
- Qilian Mountain, Tianshan Mountain ecological protection project

3.6 Thaw slumping-mitigation and adaption

Active cooling

- ☐Regulated radiation by sunshield
- ☐Controlled convection by ventilation pipe, heat pipe, block stone base and slope protection subgrade
- ☐Regulated conduction by "thermal semiconductor"
- ☐Enhanced cooling by multi-control methods

Major engineering initiatives - Active insulation

Sunshield of Qinghai-Tibet railway

Pipeline ventilation roadbed of Qinghai-Tibet railway

3.6 Thaw slumping-mitigation and adaption

Block stone roadbed

Heat pipe subgrade

Sod protection cut slope

Overbridge

Outline

1. Cryosphere and its Rapid Changes

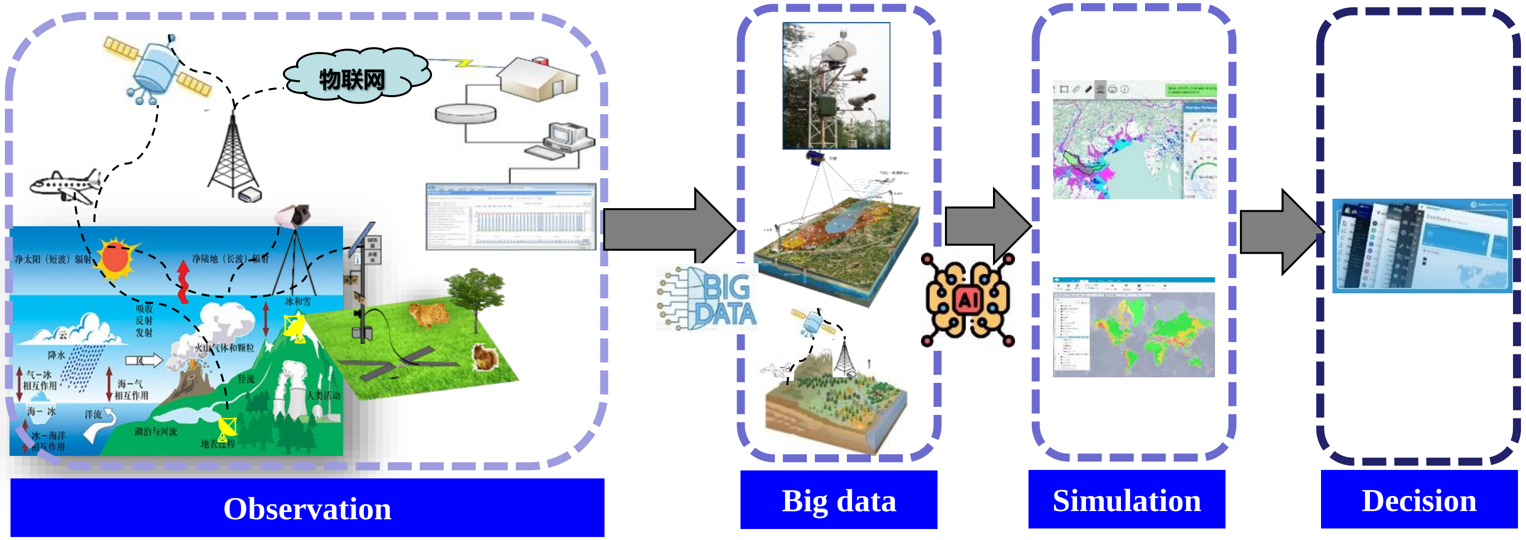
2.Cryosphere hazards

3. Several cases study

  -Snow avalanche
  -Snow disaster in pasturing area
  -Ice collapse
  -Glacier surging
  -GLOF
  -Thaw slumping

4. **Observation and early warming system**

Observation and early warning system of cryospheric hazards



Observation

Big data

Simulation

Decision

- Investigation and database of cryospheric related hazard
- Mechanism and prediction of cryospheric hazards
- Intensive observation and early alarm system

Predictable:
- GLOFs
- Snow hazards
- Thaw slump hazard
- … …

Unpredictable:
- Glacier surge
- glacier discharge floods
- Ice and snow avalanche
- ……

Thank you！