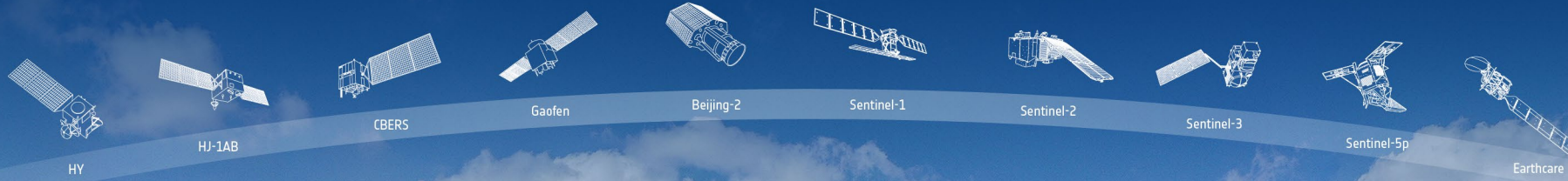




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# 2025 DRAGON 6 SYMPOSIUM 14-18 JULY 2025

[PROJECT ID. 95461]

[SEASONAL CHANGES OF GLACIERS IN HIGH MOUNTAIN ASIA 2016- 2026 AND  
THEIR FATE UNTIL 2100]

LEI HUANG, TOBIAS BOLCH, FRANCESCA BALDACCHINO, YING HUANG





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27 JUNE, 2024

ID. 95461

PROJECT TITLE: SEASONAL CHANGES OF GLACIERS IN HIGH MOUNTAIN ASIA 2016- 2026 AND THEIR FATE UNTIL 2100

PRINCIPAL INVESTIGATORS: TOBIAS BOLCH, LEI HUANG

CO-AUTHORS: FRANCESCA BALDACCHINO, XIN LI, YING HUANG, GUOQING ZHANG, QIUYU WANG, LAN ZHUANG

PRESENTED BY: LEI HUANG

# Background

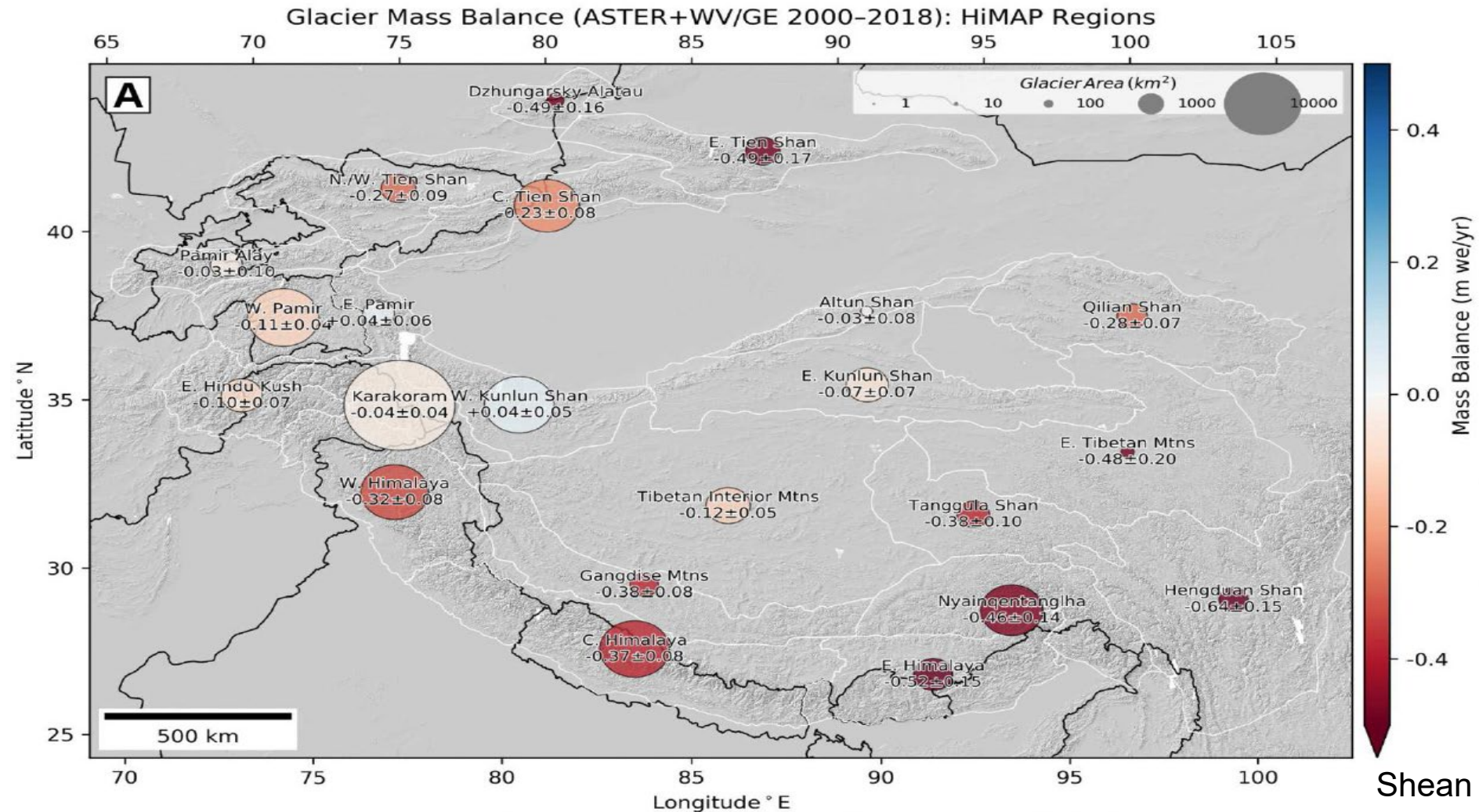


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Glaciers in HMA shows high heterogeneity in mass balance in recent years, but the driver or mechanism is unclear

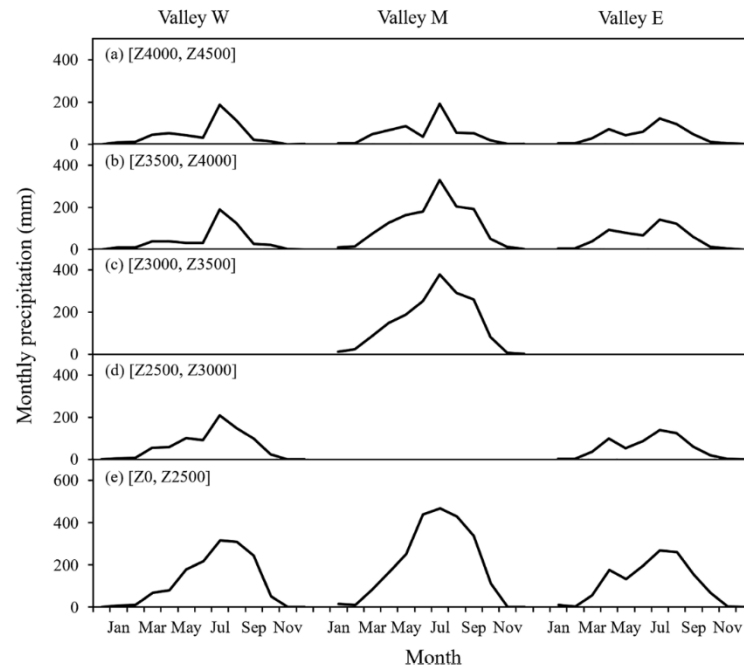


Shean et al., 2020



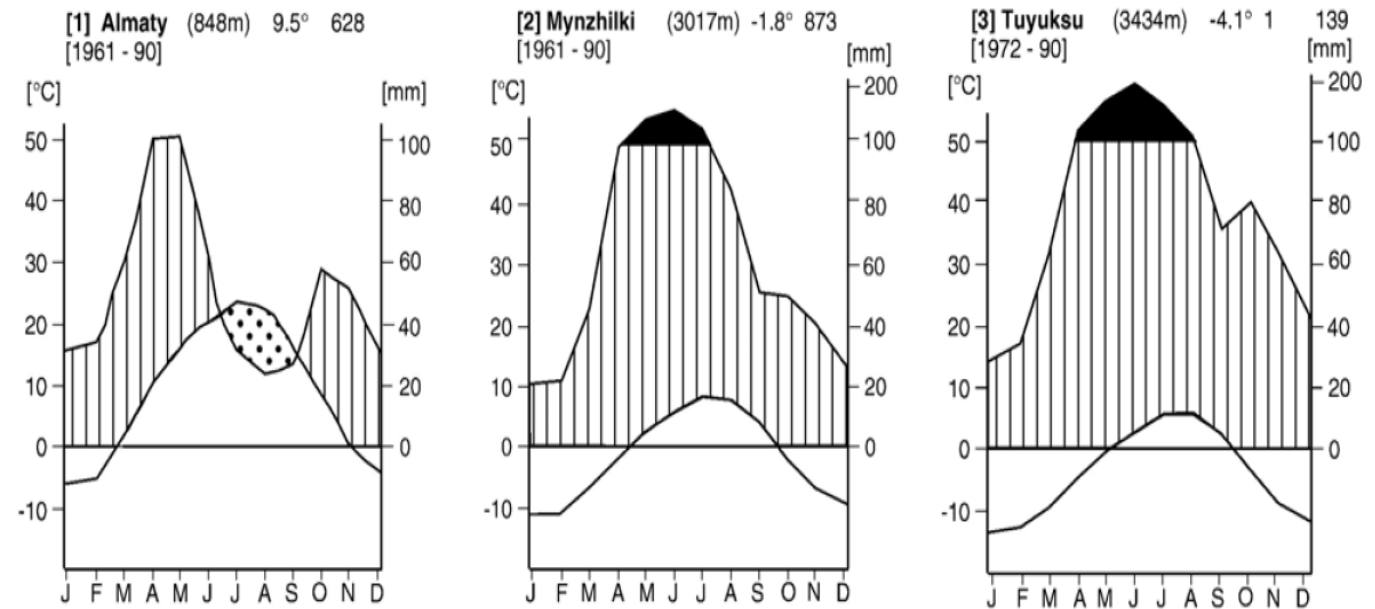
## The complexity of precipitation pattern in HMA

### Central Himalayan



Ouyang et al., 2020

### Central Tianshan



Bolch, 2009

# Background

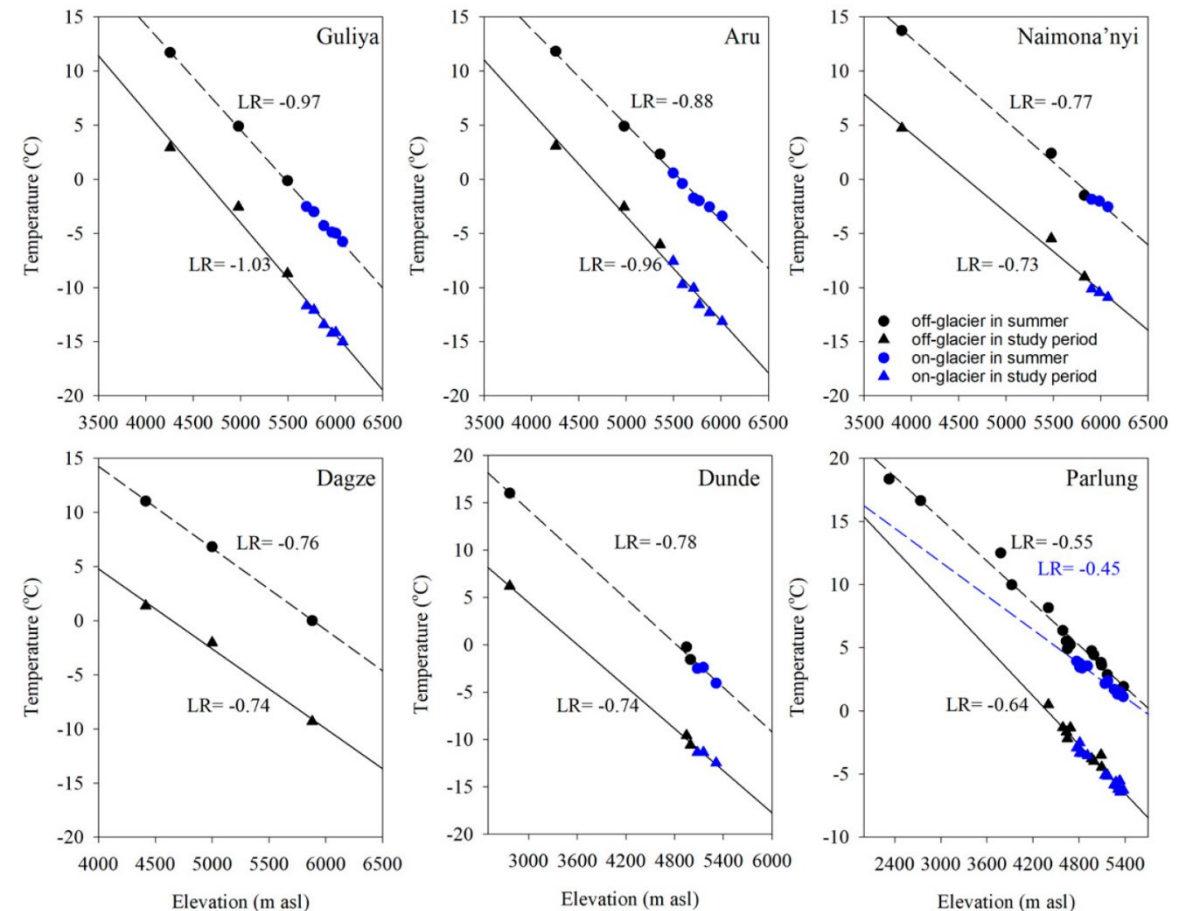
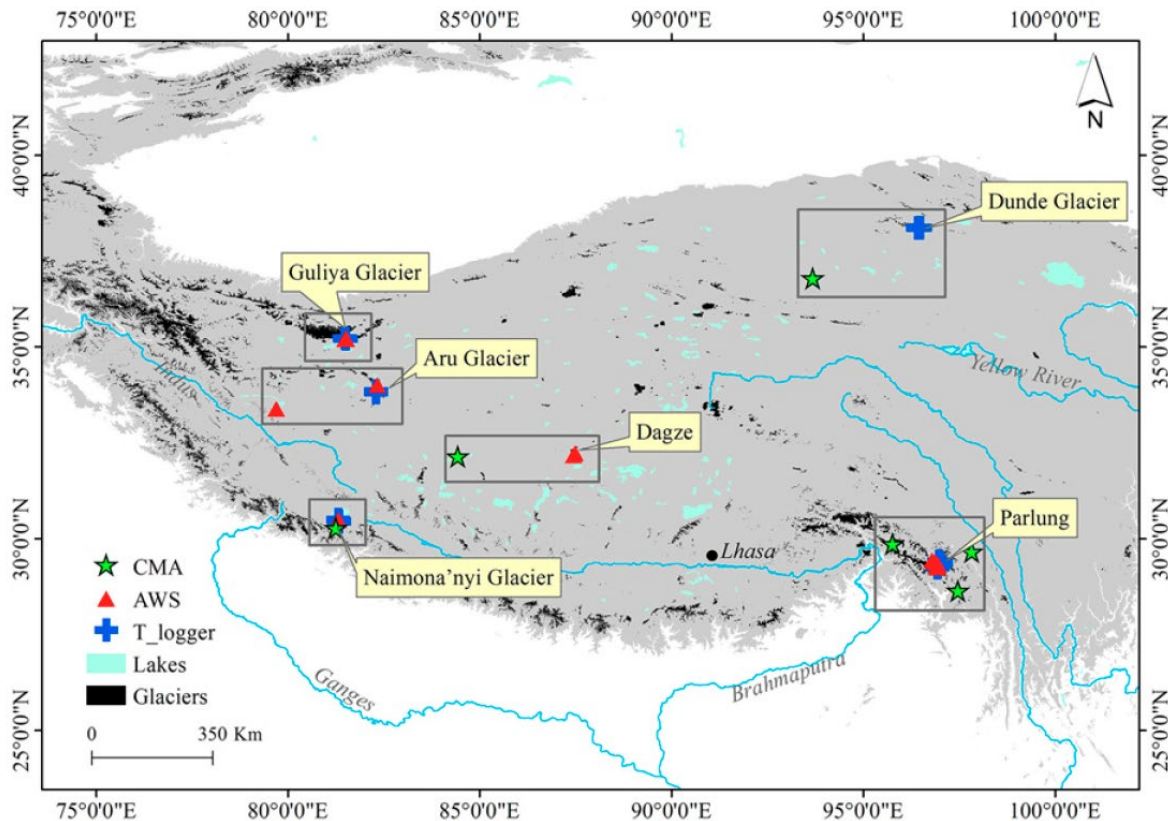


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## The complexity of temperature pattern in HMA

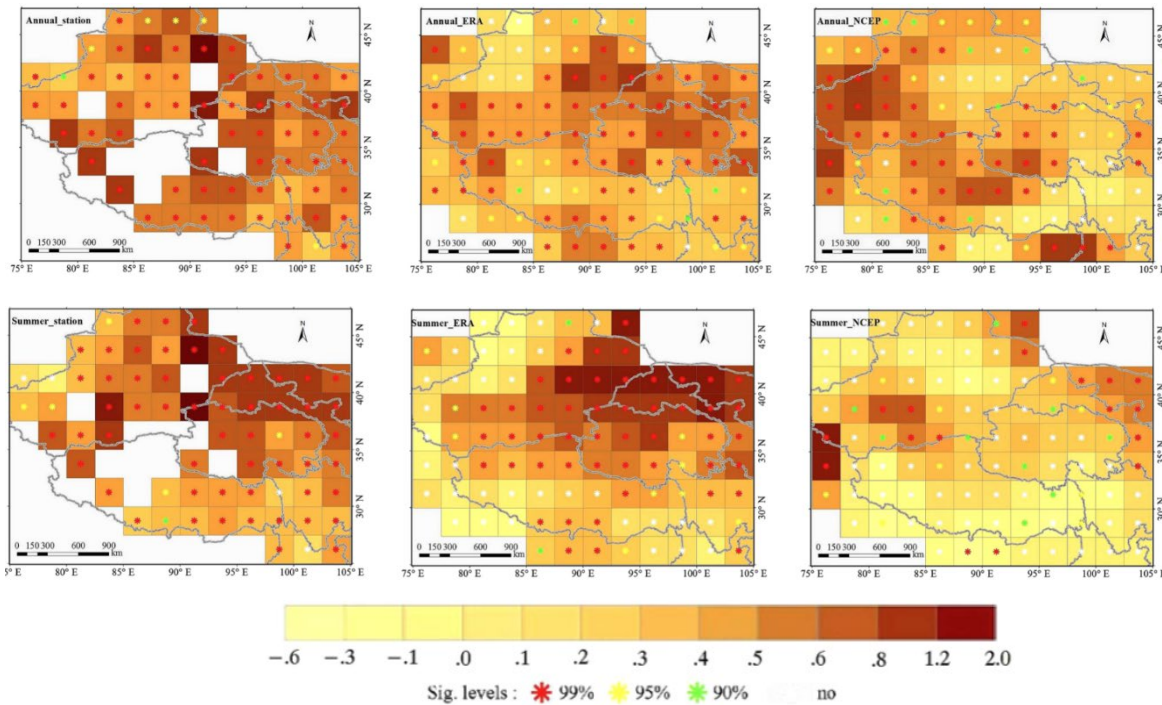


Yang et al., 2022



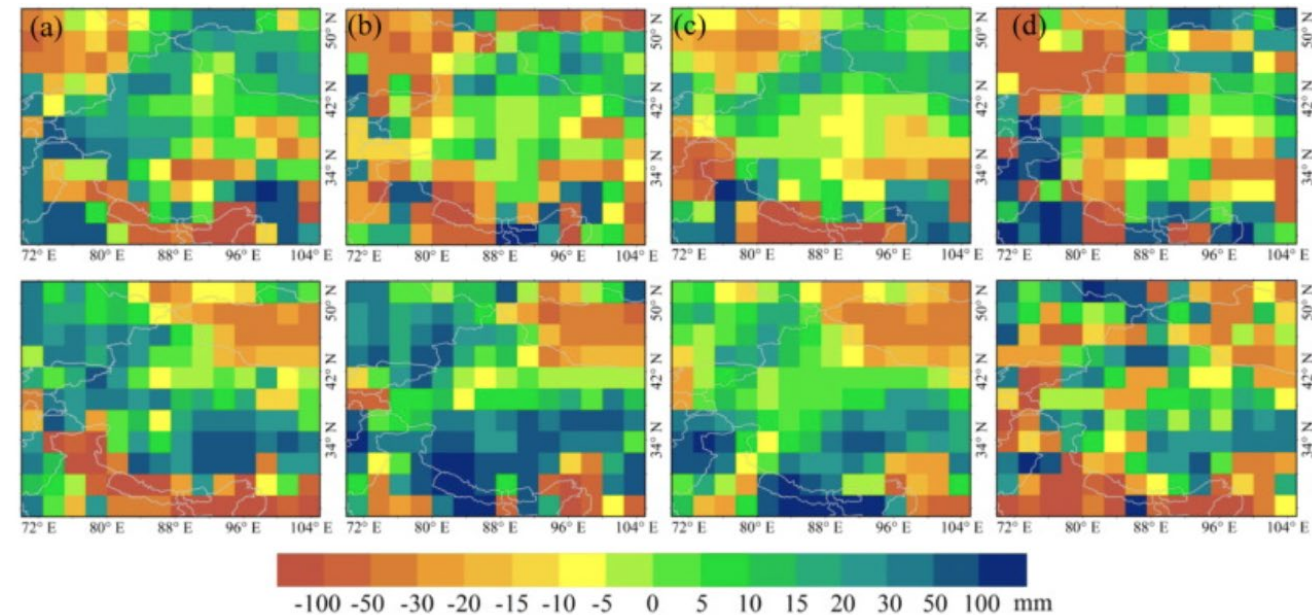
The low-resolution re-analysis data can not detect the seasonal temperature and precipitation accurately

Surface temperature in High Mountain Asia comparison of reanalysis data and station observations

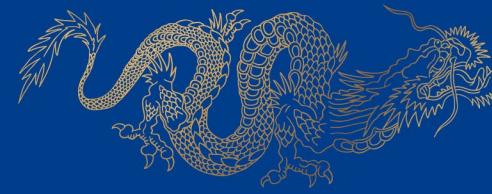


Song et al., 2016

Differences of decadal mean annual precipitation

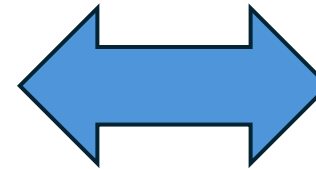
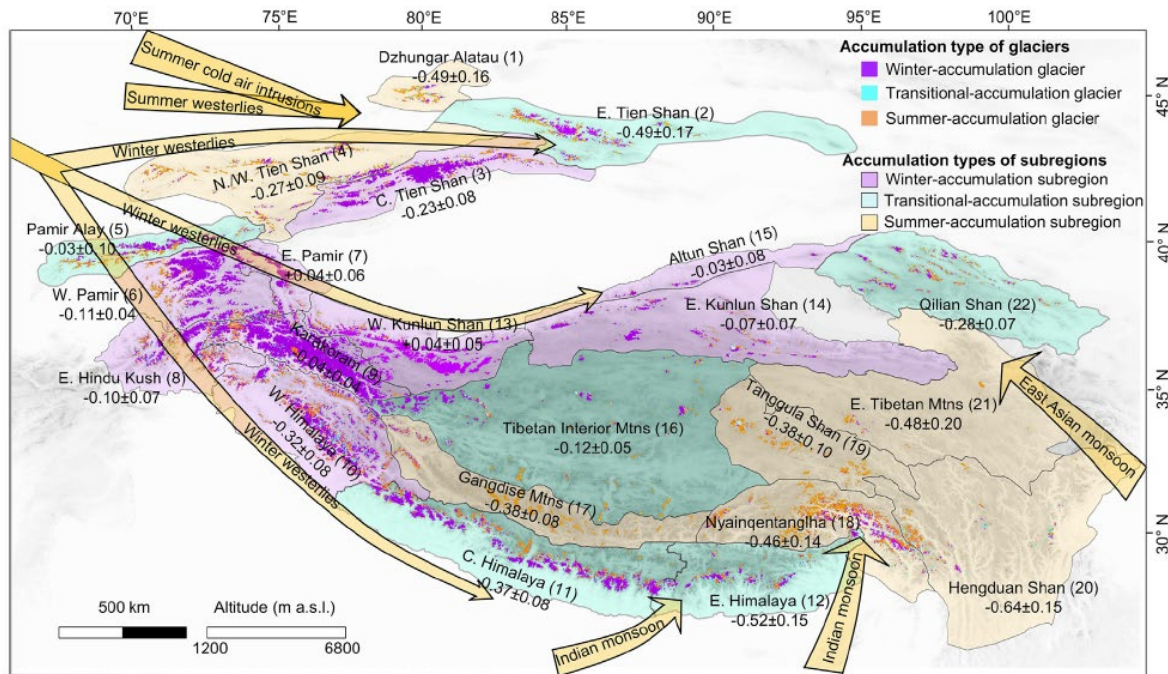


Song et al., 2016

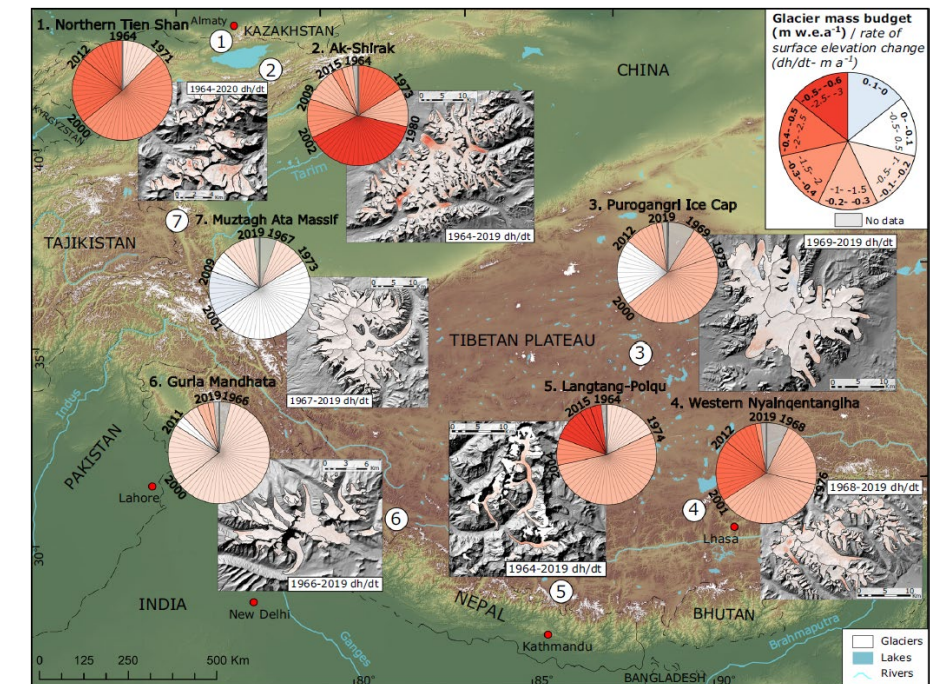


## How seasonal pattern is influencing glacier mass balance ?

Accumulation regime 2016-2018 from SAR



Mass balance from 1964--2019





## *Project's objectives*

The major objective of this proposal

To investigate the potential of seasonal and annual geodetic mass balance estimates using high-resolution optical and SAR satellite data, complemented by satellite altimetry data.

We aim to obtain seasonal mass changes in order to make inferences about glacier

- Ablation and accumulation,
- Seasonal flow velocity,
- Their influences on annual or multi-year mass change.

Different methods using optical and SAR images will be used independently and cross-validated, and will in addition be calibrated and validated by field observations.



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## *Detail the in-situ data measurements and requirements*

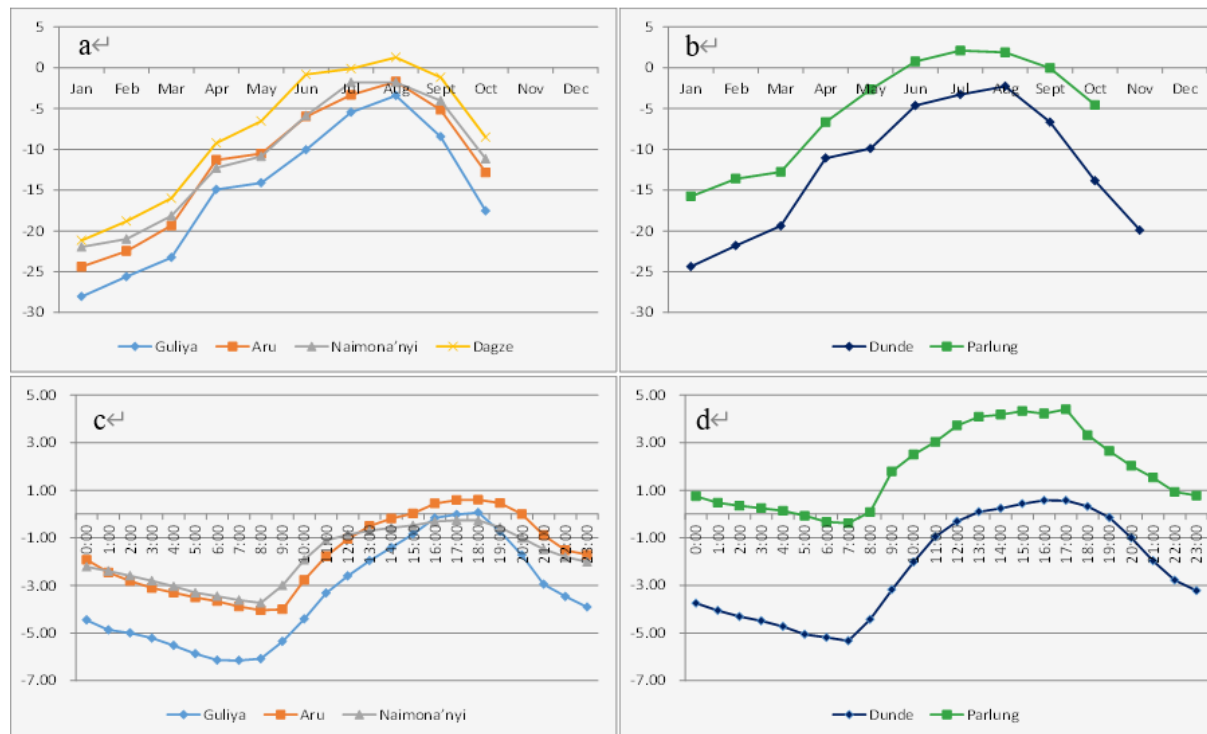
Field mass balance measurement by stations and UAV  
Filed metrological measurement records

Seasonal/ Monthly/ Daily/ Hourly



## *Field data collection campaigns and periods*

- Tobias, Lei, and the young scientist Ying Huang carried out a field work in Qilian Mountain in Sept 2024 to investigate the mass balance of glaciers.
- The young scientists in China also help to collect field precipitation and temperature records.



# Dragon 6 EO Data Delivery



Data access (list all missions and issues if any). NB. in the tables please insert cumulative figures (since June 2024) for no. of scenes of high bit rate data (e.g. S1 100 scenes). If data delivery is low bit rate by ftp, insert “ftp”

| ESA /Copernicus Missions | No. Scenes | ESA Third Party Missions | No. Scenes | Chinese EO data | No. Scenes |
|--------------------------|------------|--------------------------|------------|-----------------|------------|
| 1. S1                    | 4000       | 1.                       |            | 1. GF-2         | 100        |
| 2. S2                    | 2000       | 2.                       |            | 2. ZY-3         | 100        |
| 3.                       |            | 3.                       |            | 3.              |            |
| 4.                       |            | 4.                       |            | 4.              |            |
| 5.                       |            | 5.                       |            | 5.              |            |
| 6.                       |            | 6.                       |            | 6.              |            |
| Total:                   |            | Total:                   |            | Total:          |            |
| Issues:                  |            | Issues:                  |            | Issues:         |            |

# European Young Scientists contributions in Dragon 6



| Name                  | Institution                   | Poster title                                                                                                | Contribution including period of research                     |
|-----------------------|-------------------------------|-------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------|
| Francesca Baldacchino | Graz University of Technology | Investigating Seasonal Velocity Variations Of Debris-covered And Debris-free Glaciers In High Mountain Asia | Jan 2024—July 20025, Seasonal Velocity Variations of glaciers |
| Ying Huang            | Graz University of Technology |                                                                                                             | Sep 2024—July 2025, Seasonal snow changes                     |



# Chinese Young Scientists contributions in Dragon 6

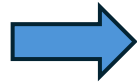


| Name          | Institution                 | Poster title | Contribution including period of research        |
|---------------|-----------------------------|--------------|--------------------------------------------------|
| Guoqing Zhang | ITP, CAS                    |              | July, 2024—Now, Seasonal change of lakes         |
| Drolma Lhakpa | Weather bureau of Tibetan   |              | July, 2024—Now, Field observation and validation |
| Qiuyu Wang    | Chinese Academy of Sciences |              | July,2024—Now, ICESAT data processing            |
| Lan Zhuang    | AIR,CAS                     |              | Jan, 2025– Now, Satellite image processing       |
|               |                             |              |                                                  |

# Frame diagram of the project



Detailed Observation



Analysis and Modelling



Prediction

**Seasonal accumulation/ablation**

**Seasonal flow velocity change**

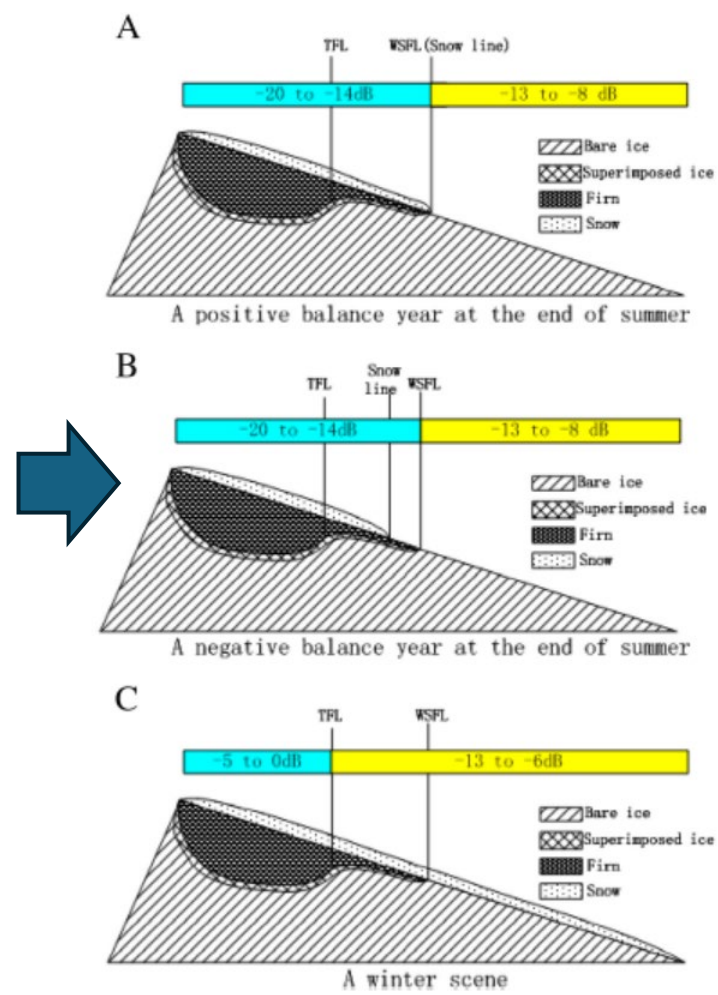
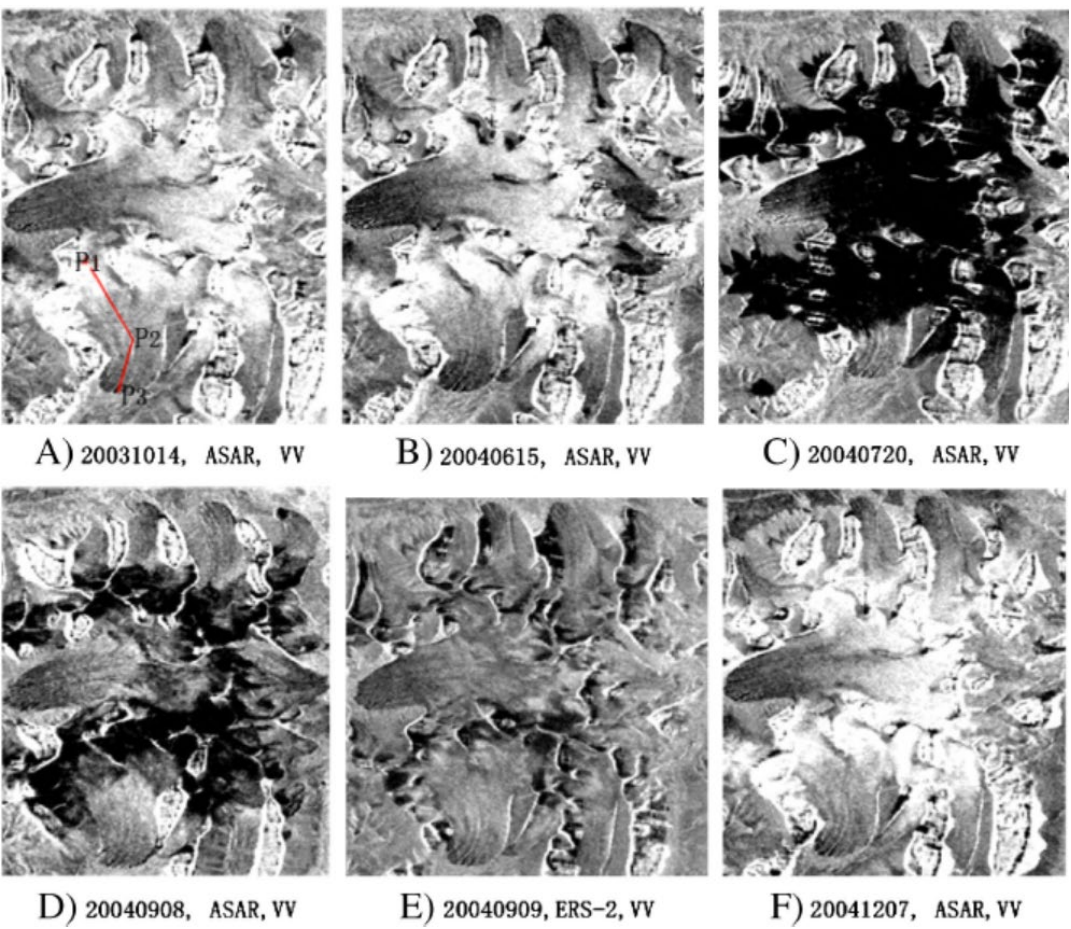
**Seasonal mass balance**

How and why seasonal pattern is  
influencing glacier mass balance

How will it influence glacier  
state change prediction

Current work

# Seasonal accumulation/ablation from both sides

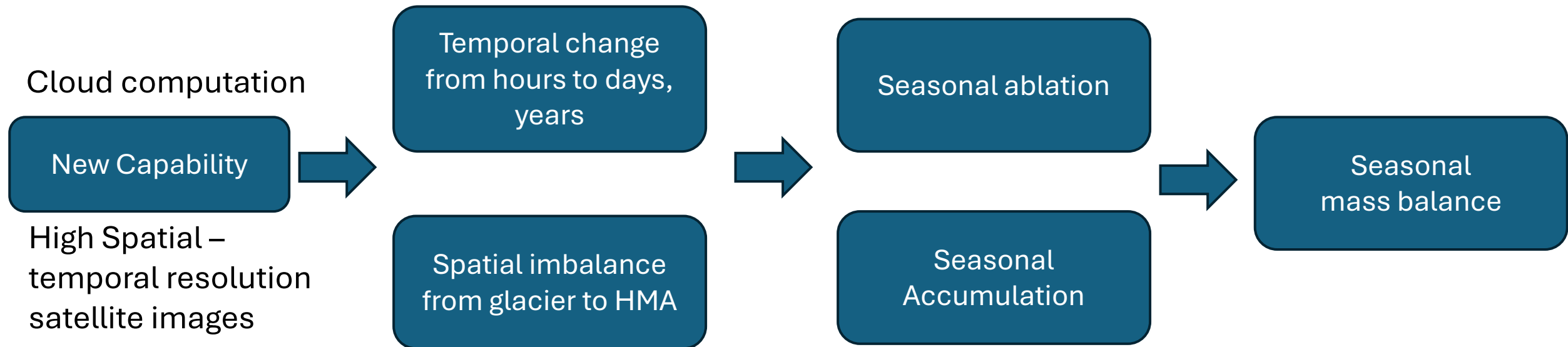


Traditional knowledge

Late summer wet snow line ≈ annual mass balance line

Fine line ≈ Long term mass balance line

# Seasonal accumulation/ablation from both sides



# Seasonal accumulation/ablation from both sides



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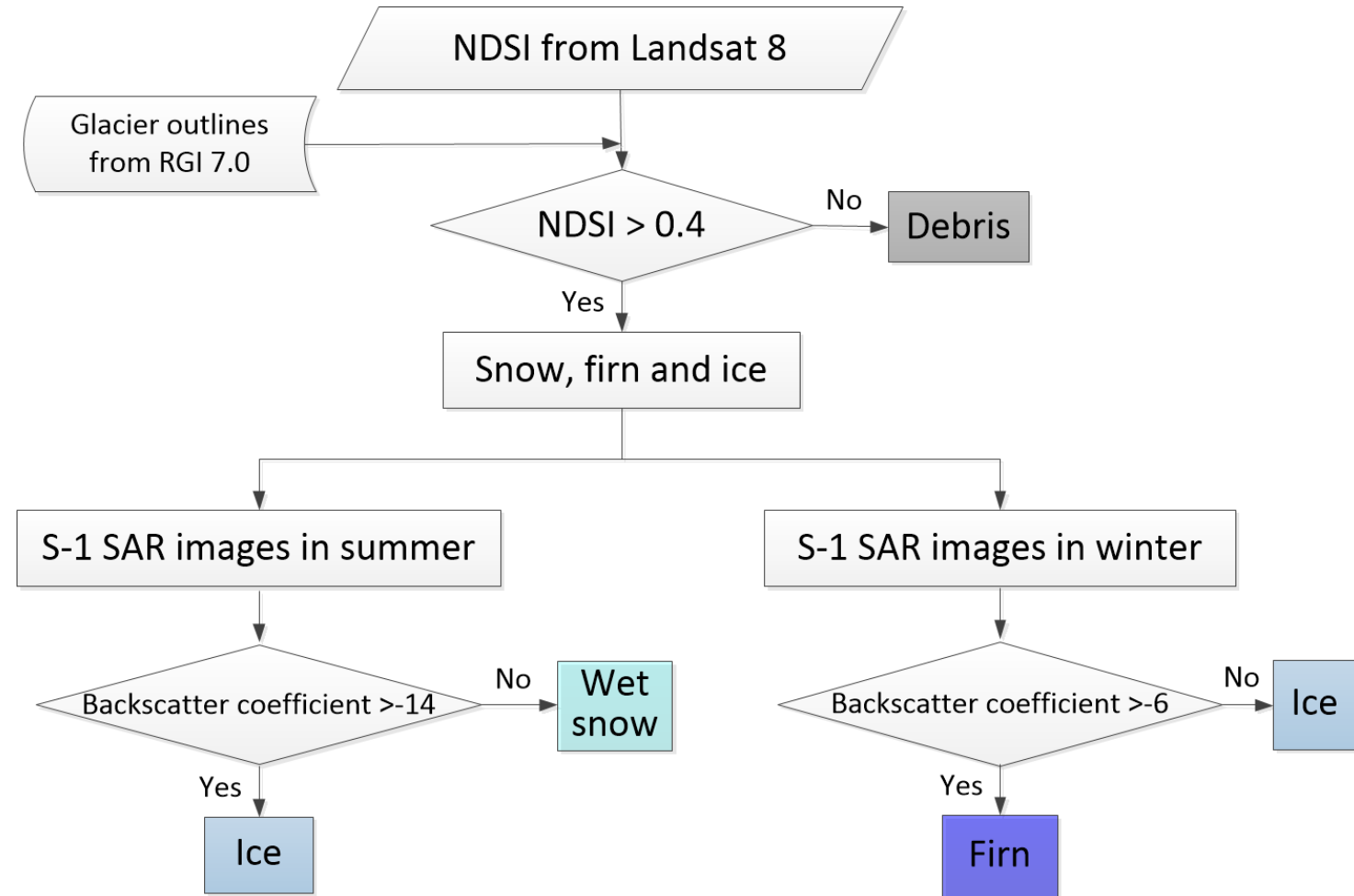
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Snow and firn extraction using  
**Sentinel-1** SAR, and Landsat  
images

**Revisit period:** 6 days

**Ascending orbit:** 18:00 pm

**Descending orbit:** 8:00 am



# Seasonal accumulation/ablation: from both sides



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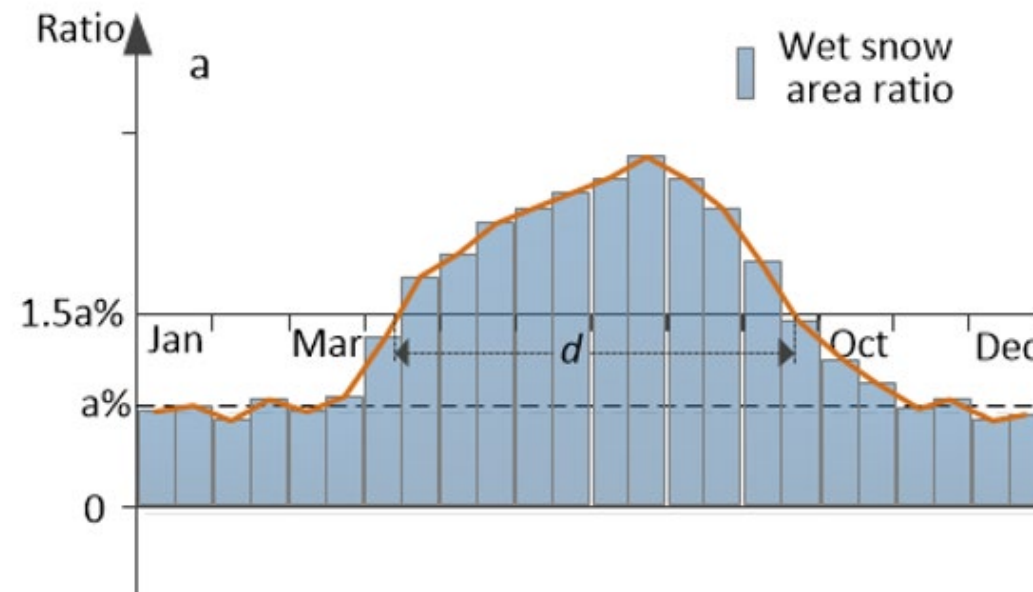
Ablation index:

$$A_m = \sum_{i=1}^d R_i \approx d * \bar{R}$$

Ablation daily intensity:  $R$

$$R = 1 - (R_{wspm} - R_{wsam})$$

Ablation duration:  $d$



# Seasonal accumulation/ablation: from both sides



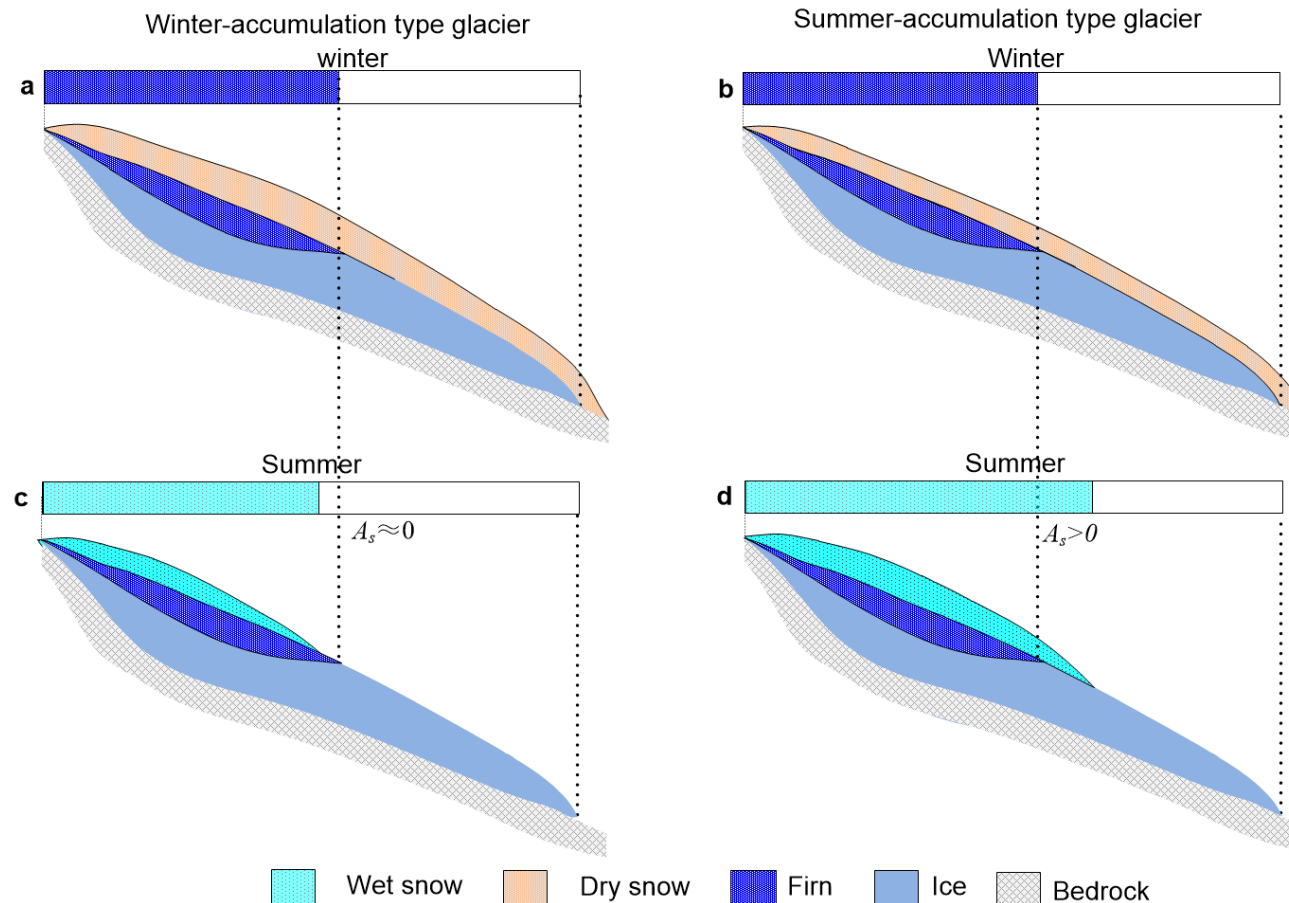
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Accumulation index:

$$A_p = (A_{wspm} - A_f)/A$$



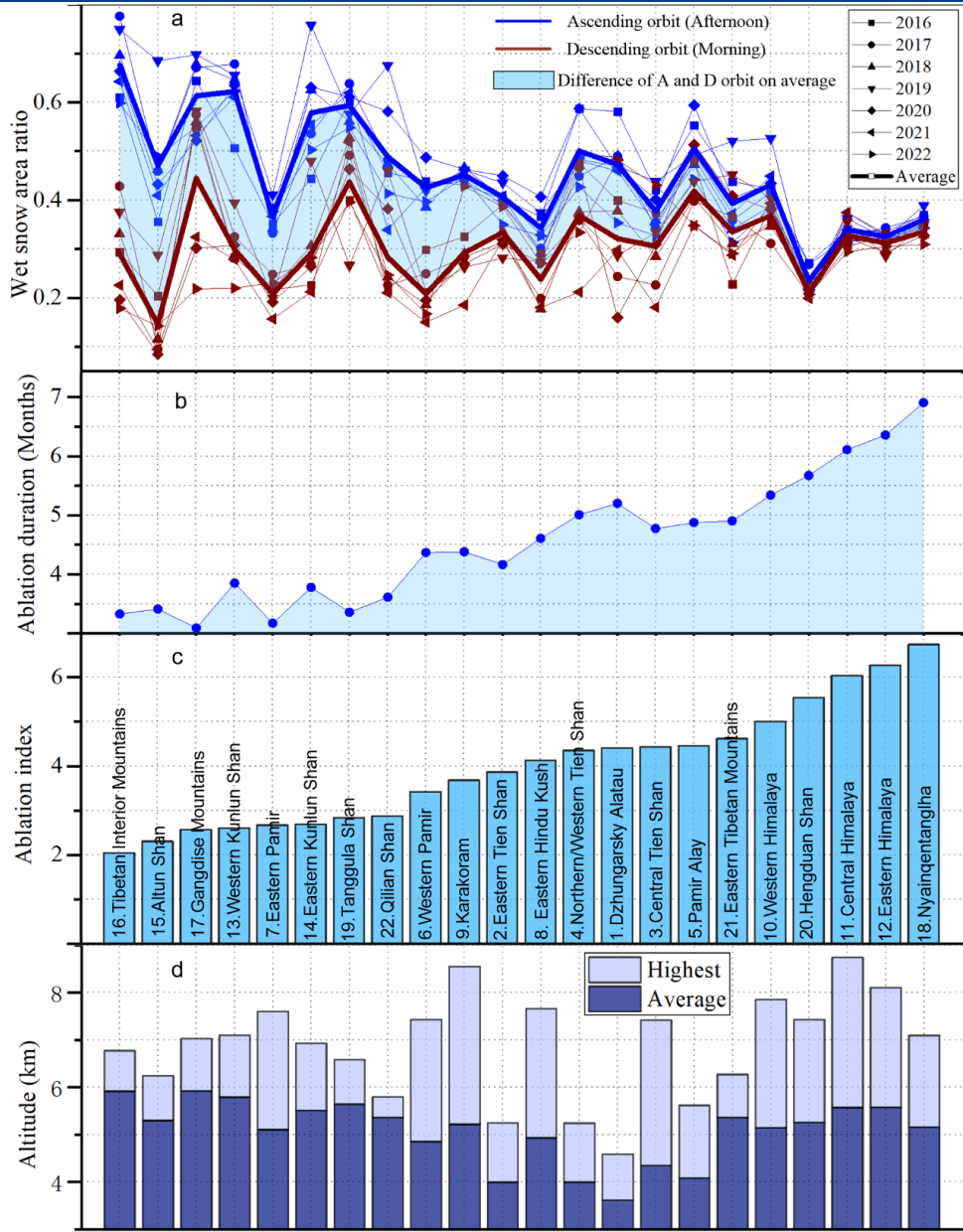
# Seasonal accumulation/ablation: from both sides



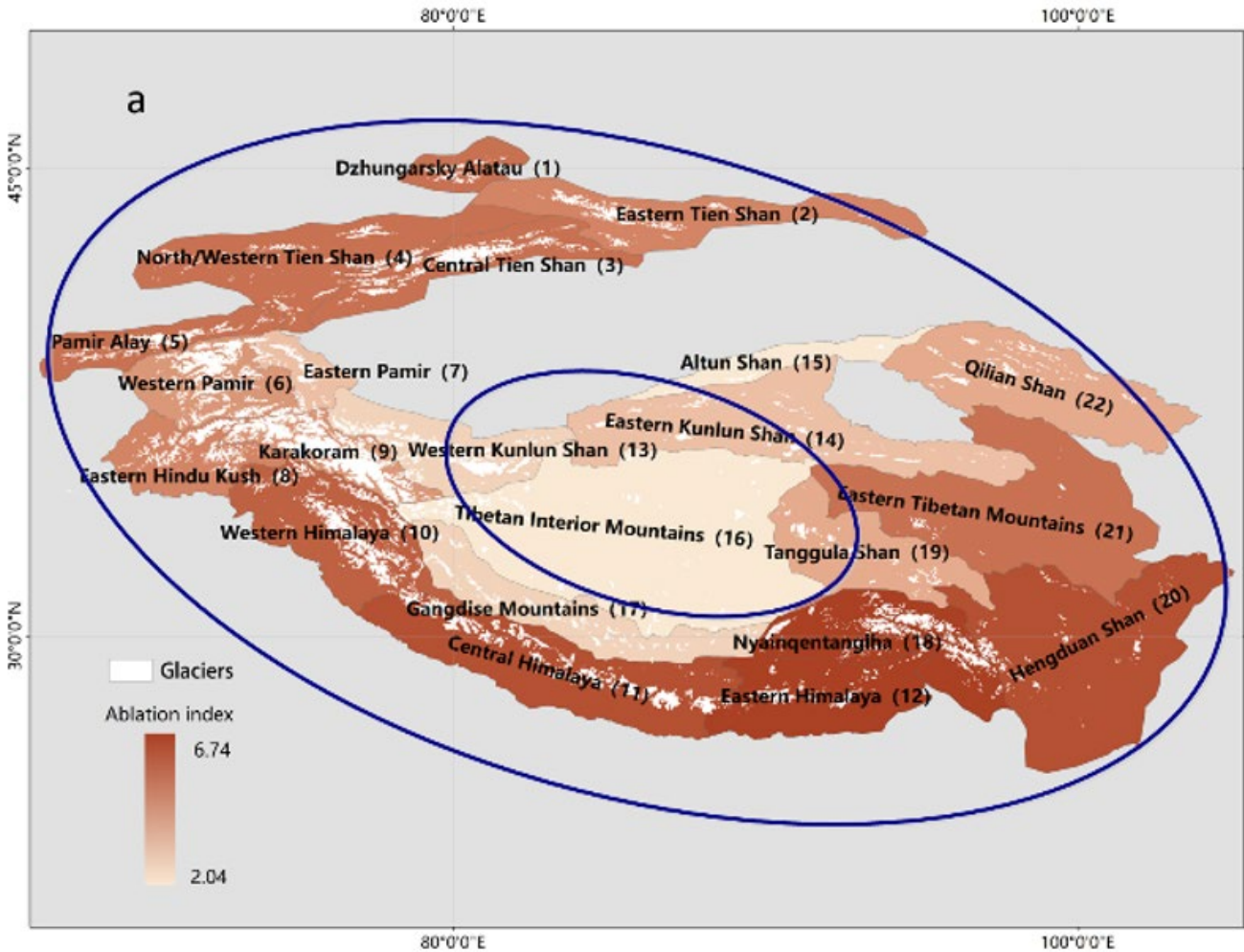
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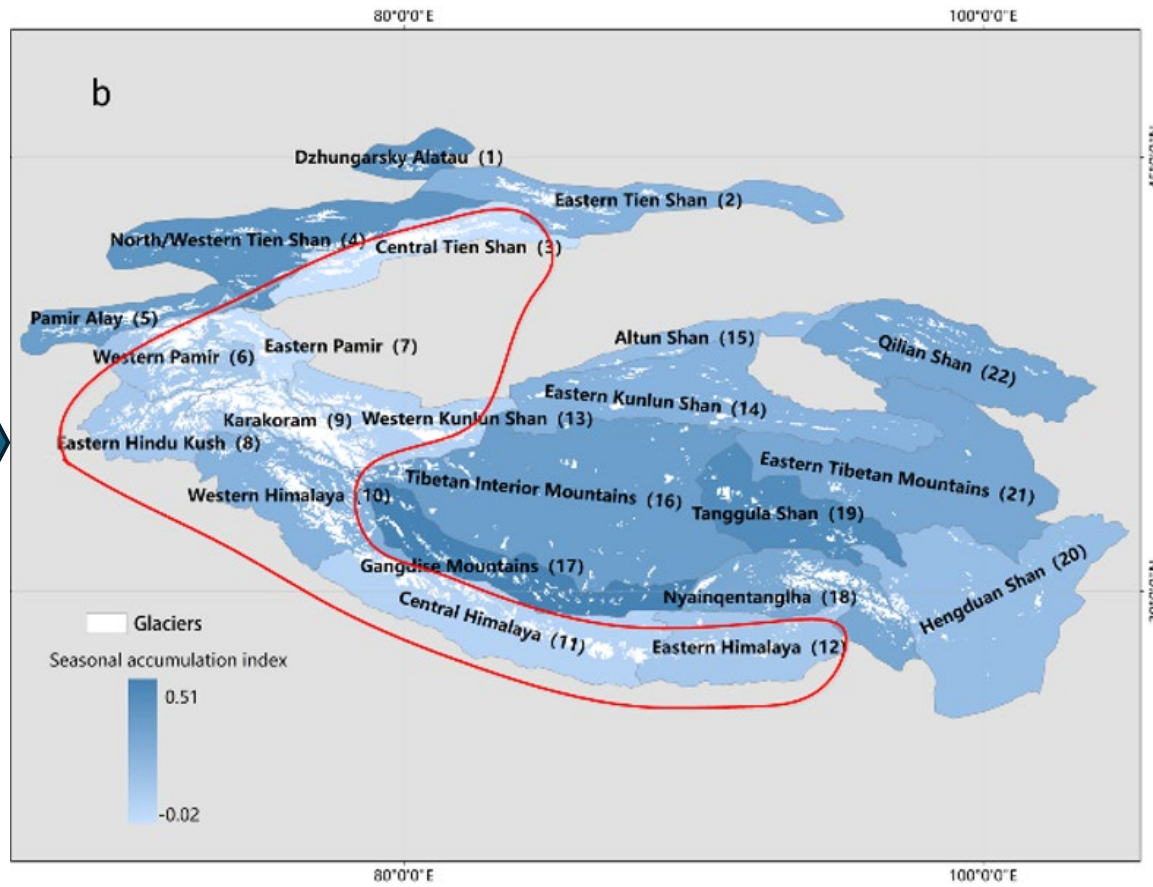
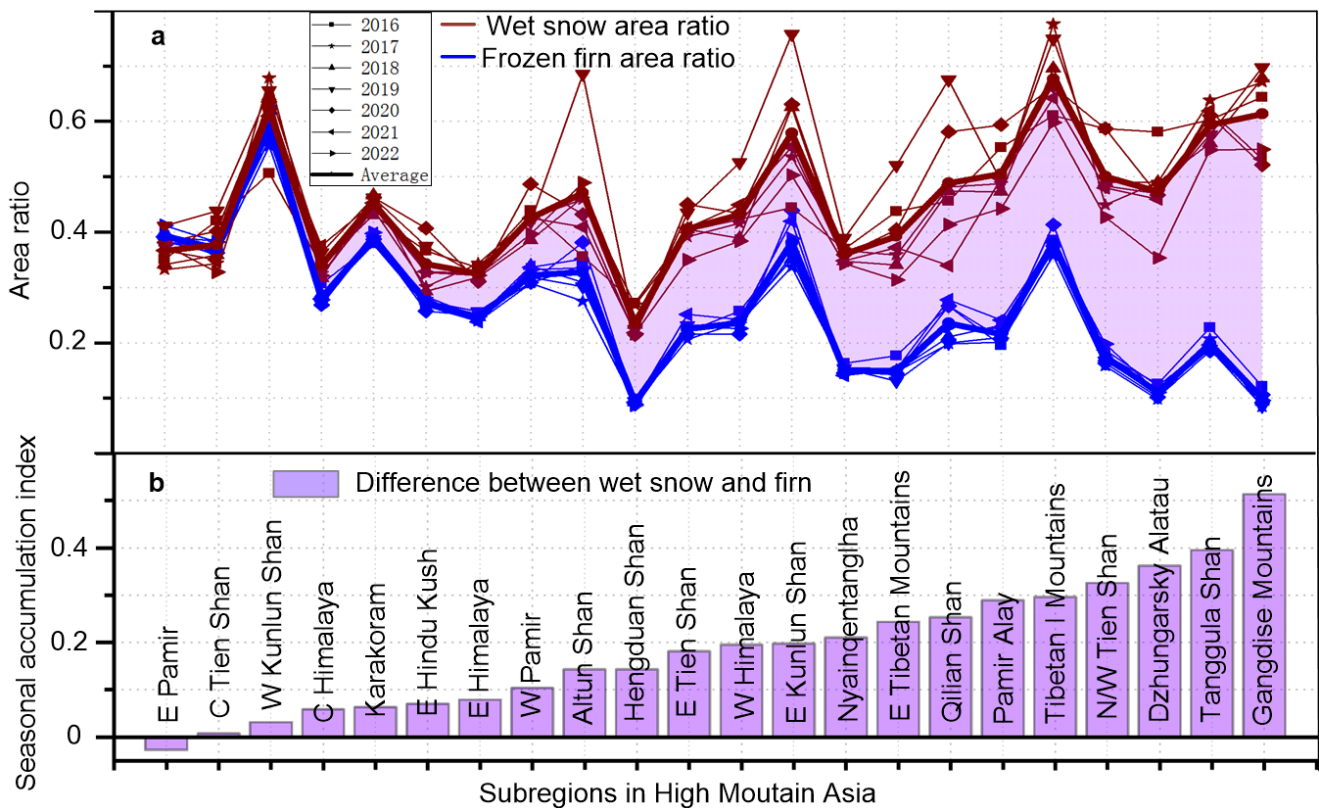
Ablation pattern:



# Seasonal accumulation/ablation: from both sides



## Accumulation pattern:



# Seasonal accumulation/ablation: from both sides

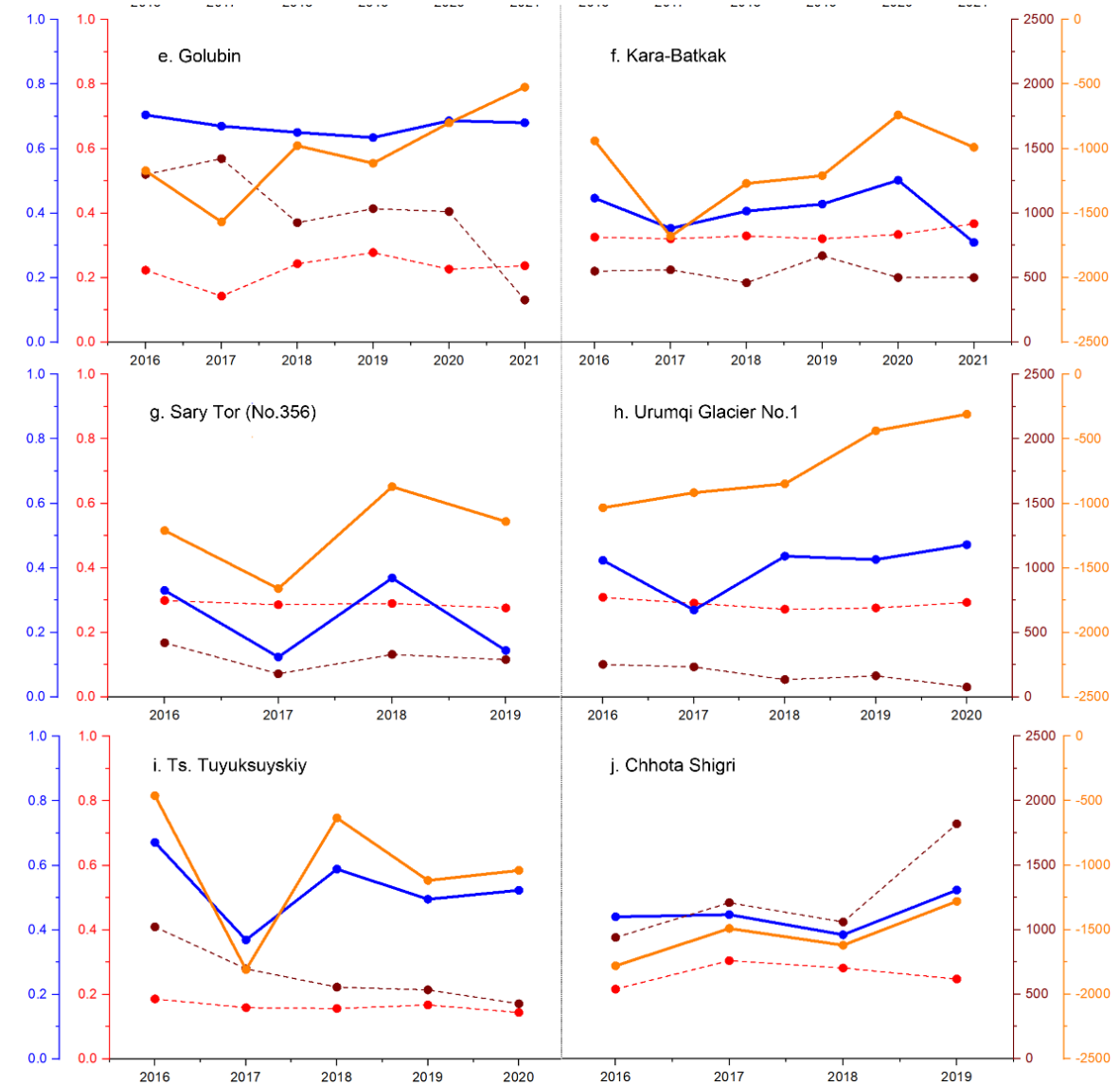
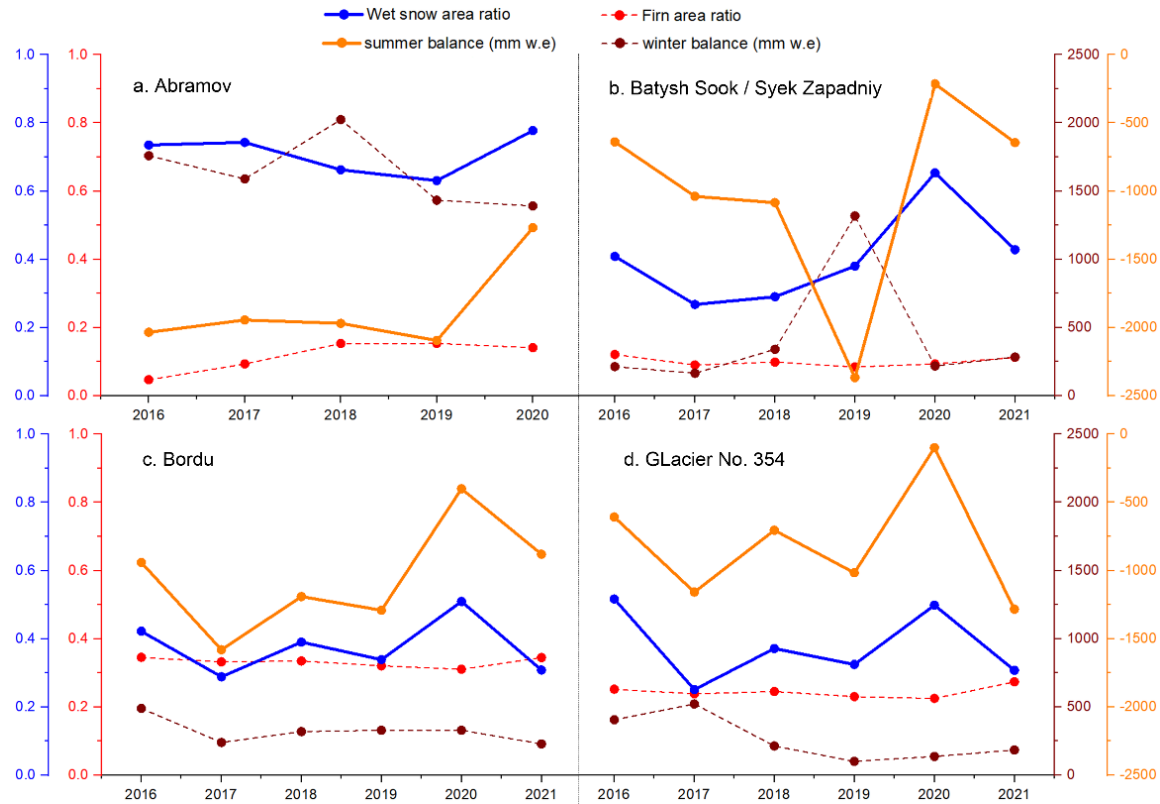


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## Validation: Comparison of the annual mass balance with snow line



# Seasonal accumulation/ablation: from both sides

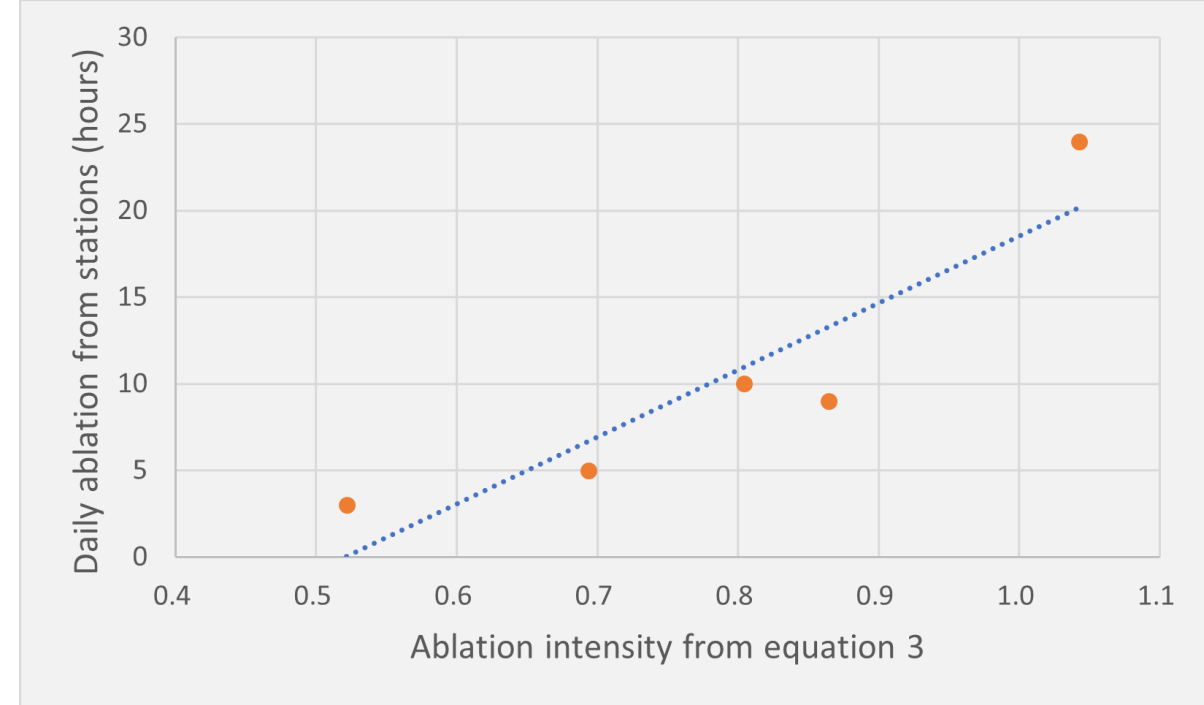
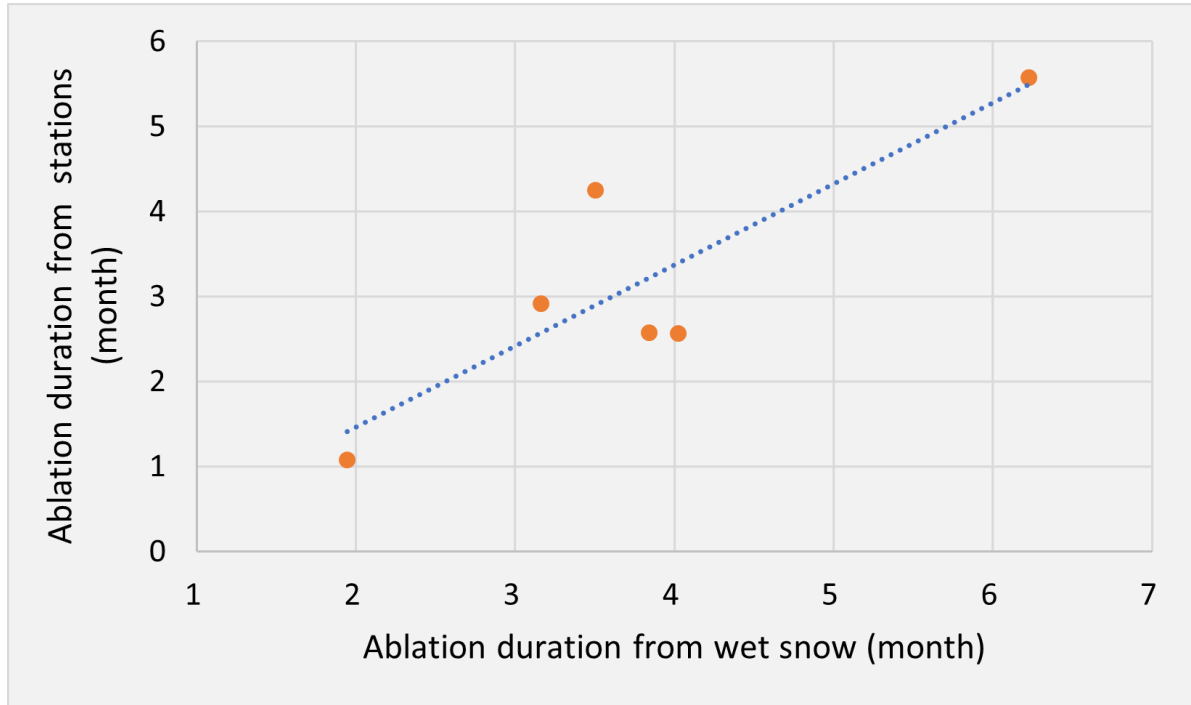


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## Validation: Comparison of the ablation duration and intensity



# Seasonal accumulation/ablation: from both sides

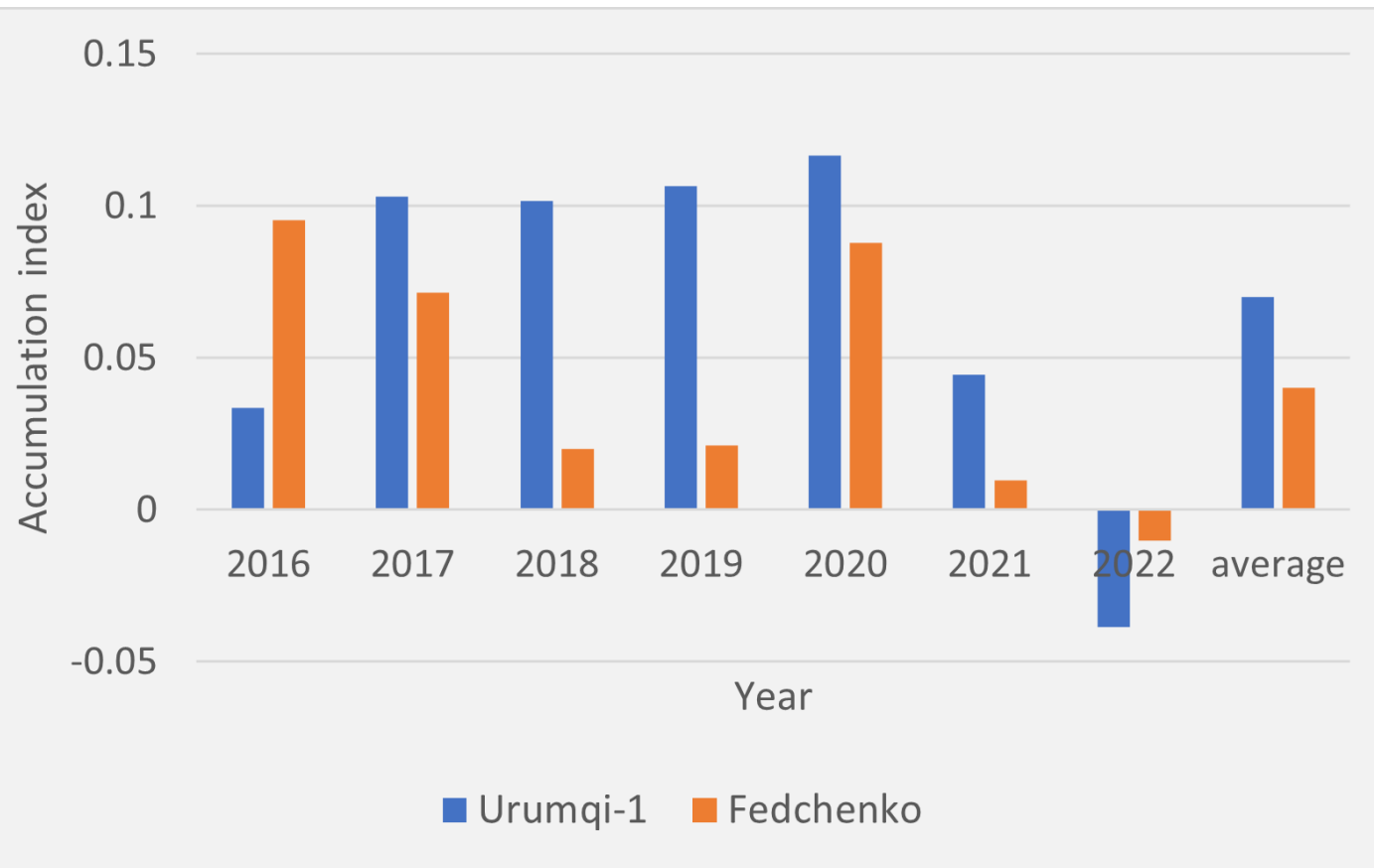


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## Validation: Comparison of the seasonal accumulation



For Fedchenko Glacier in the Western Pamirs, the **majority (68%) of precipitation occurs during the cold season** from November to April

For Urumqi Glacier No. 1 from 2016 to 2022 (Fig14). Precipitation field records from 2018 to 2020 show that about 67% the annual precipitation occurring from June to August. From this, it seems that this is a definitely summer accumulation type glacier. However, more detailed station observation at 3,835 m a.s.l. **show that 57% of the precipitation was liquid and 43% was solid**

# Seasonal accumulation/ablation: from both sides

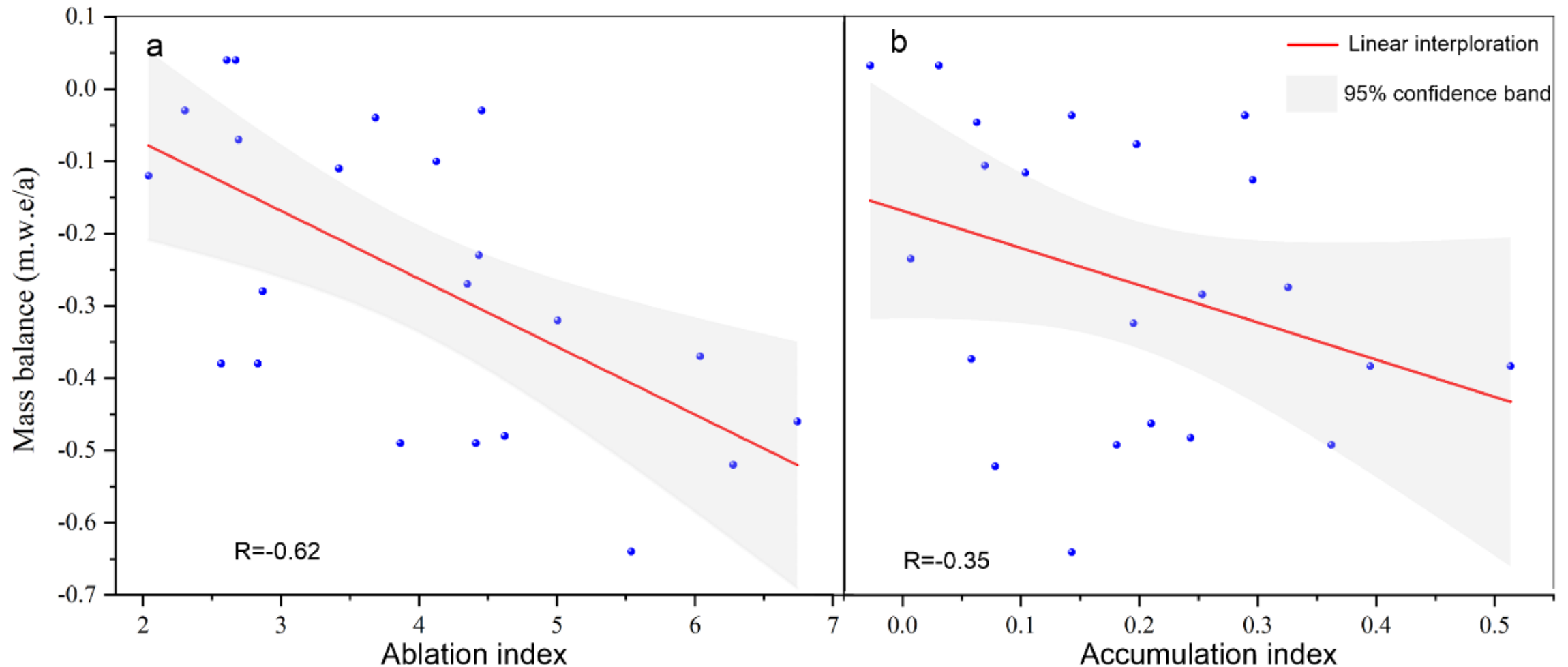


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## Influence of ablation and accumulation on mass balance



# Seasonal accumulation/ablation: from both sides

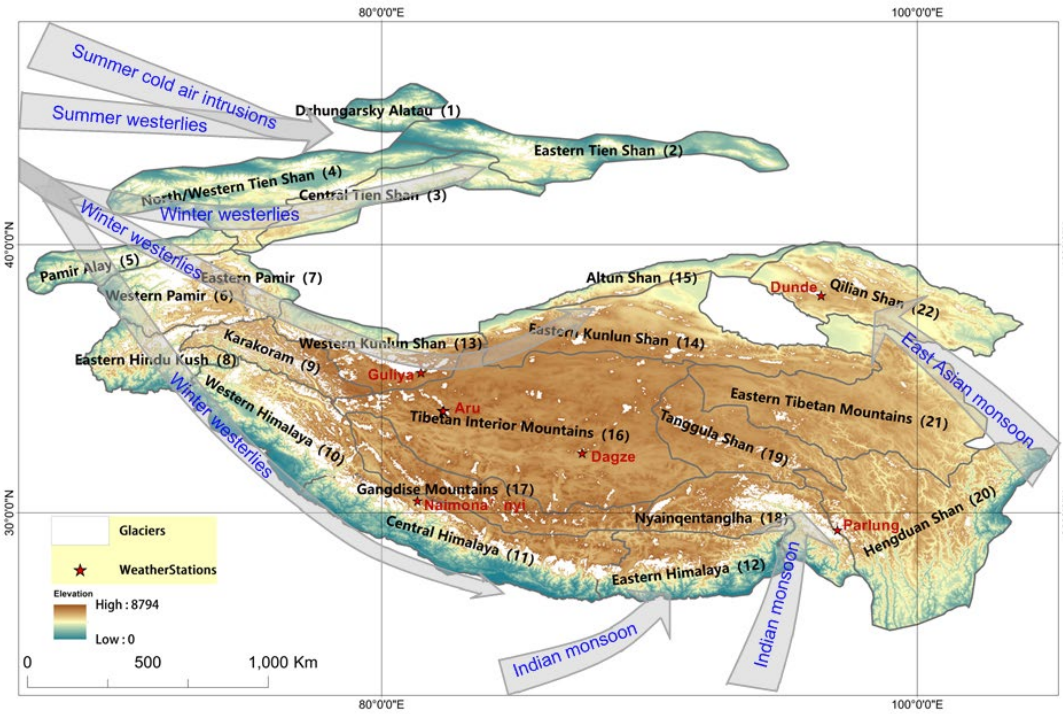
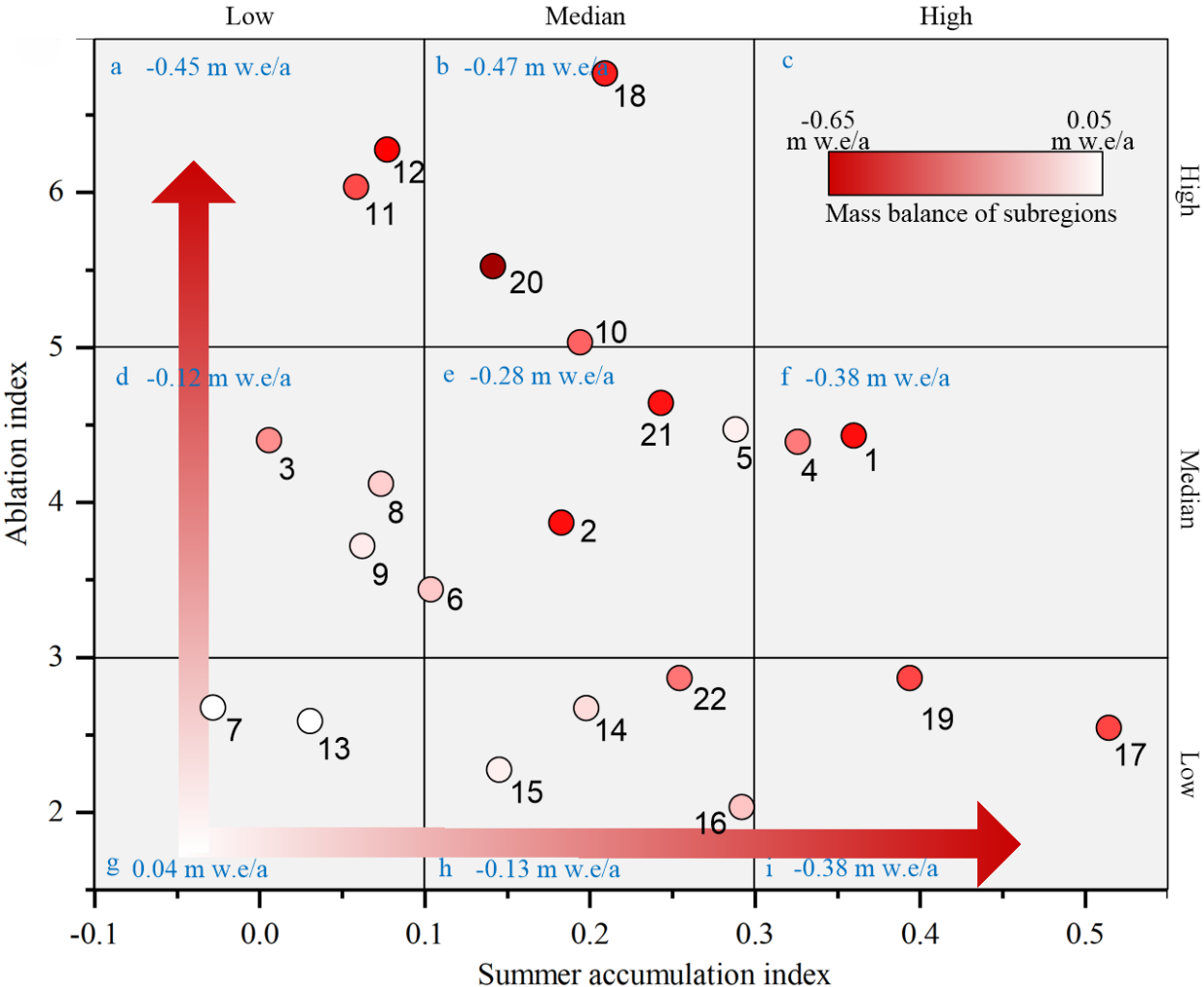


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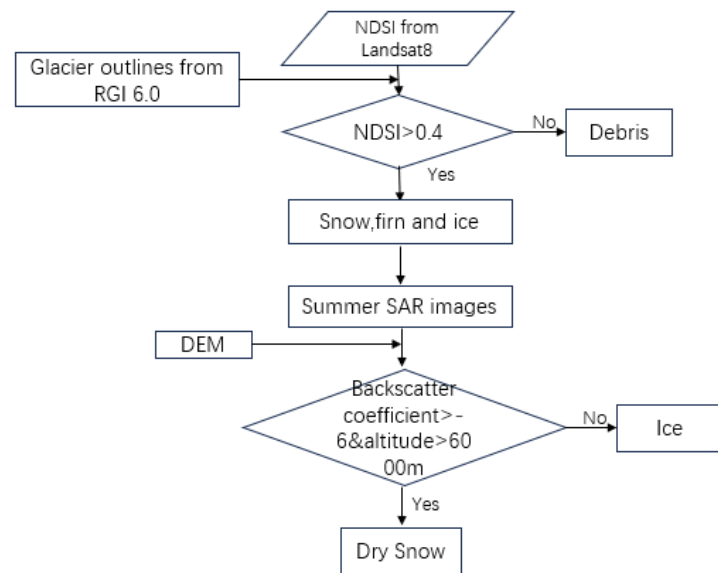
Influence of ablation and accumulation on mass balance



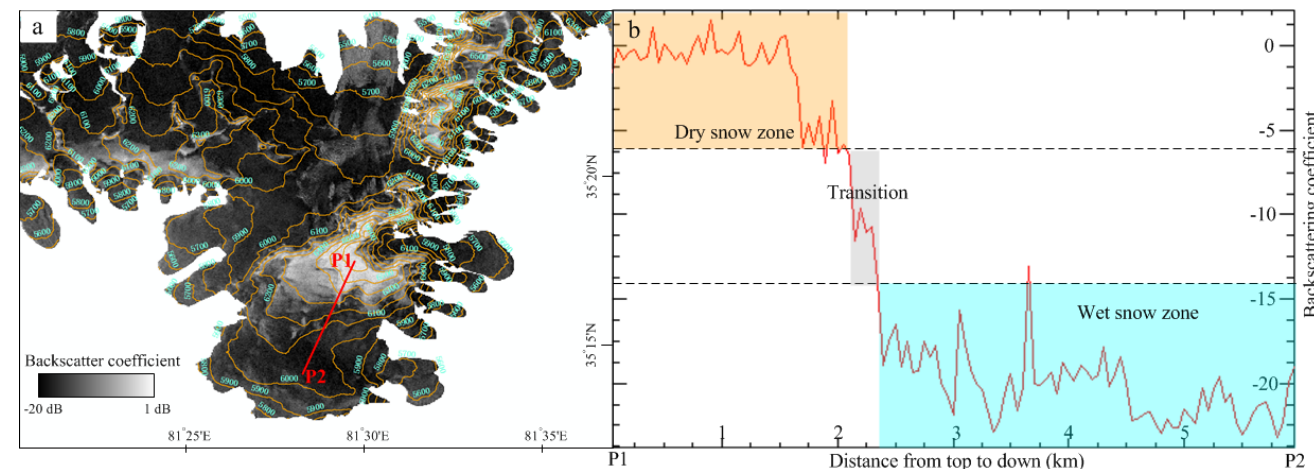


## Dry Snow in HMA-Methodology for Extraction

- **Dry snow zone** is a part of the glacier accumulation area with neither melt nor liquid water, typically located at very high altitudes. It plays a critical role in glacier mass balance and can serve as an indicator of persistent accumulation.
- **Extraction approach:**
  - In C-band SAR (e.g., Sentinel-1), **dry snow is transparent**, while firn below causes high backscatter.
  - We use summer SAR backscatter ( $\sigma^0 > -6$  dB) and **altitude > 6000 m** as constraints.



Decision trees used to classify dry snow.



An example of dry snow zone in the Western Kunlun Shan

# Seasonal accumulation/ablation: from both sides



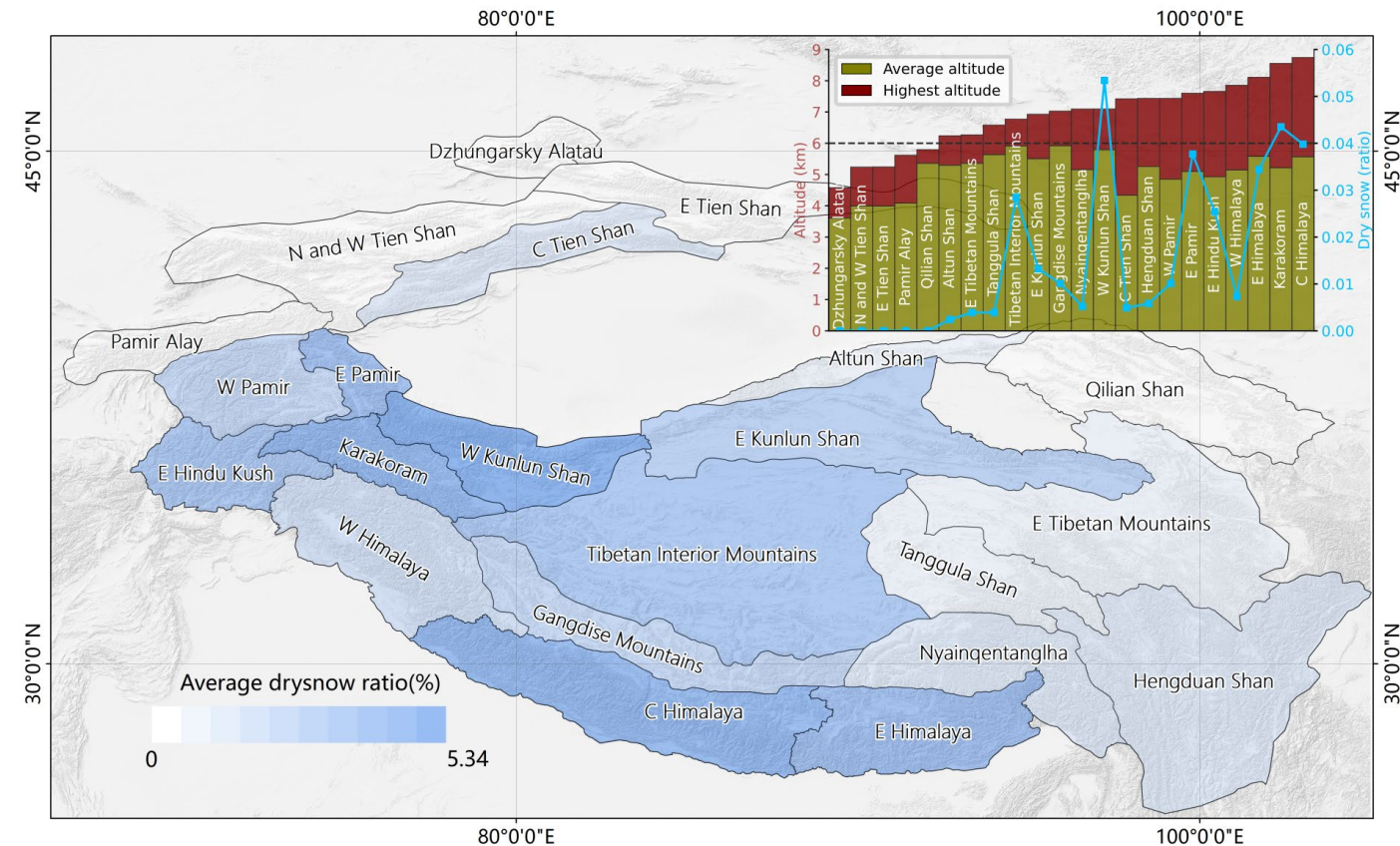
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## Dry Snow Distribution in HMA

- The **average dry snow ratio** in HMA is generally **below 6%**.
- Concentrated in **Karakoram** and **Central Himalaya**, where both **maximum** and **mean elevation** are high.
- Distribution is **not solely dependent on highest peaks**, but also on **regional average altitude**.



Average dry snow ratio (2015–2024) and elevation structure across HMA subregions

# Seasonal accumulation/ablation: from both sides

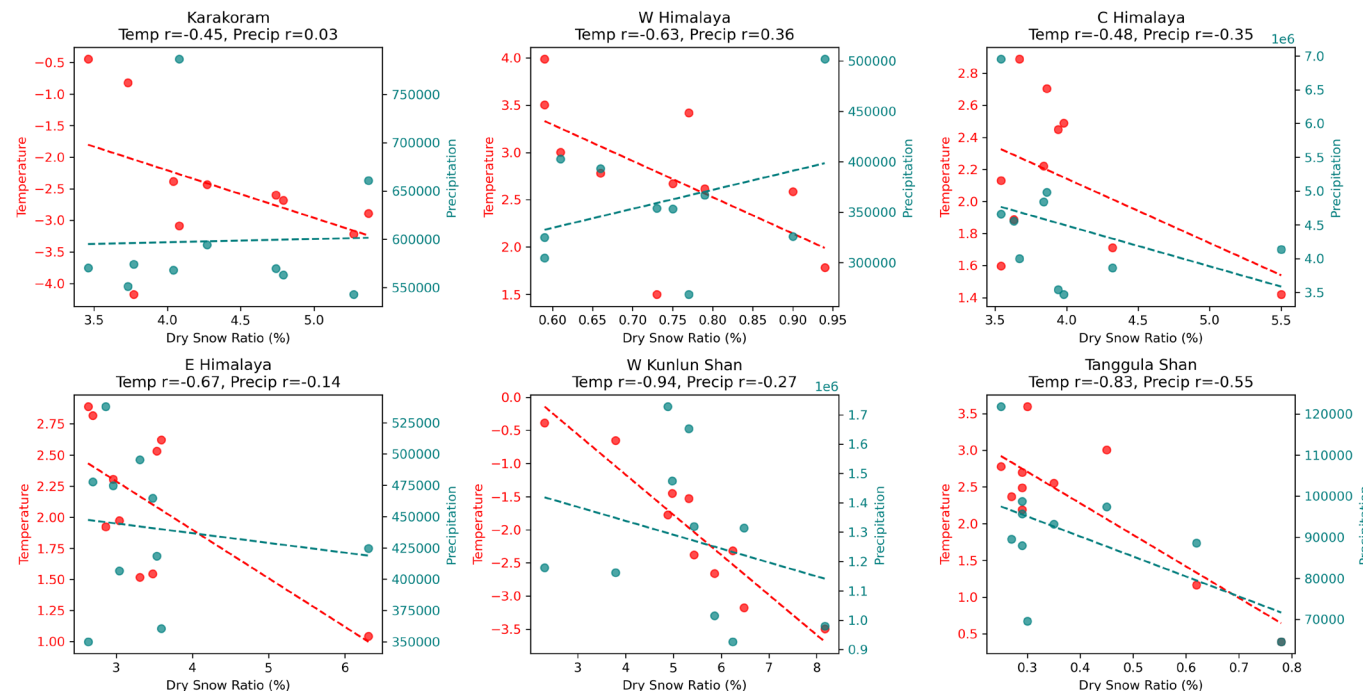


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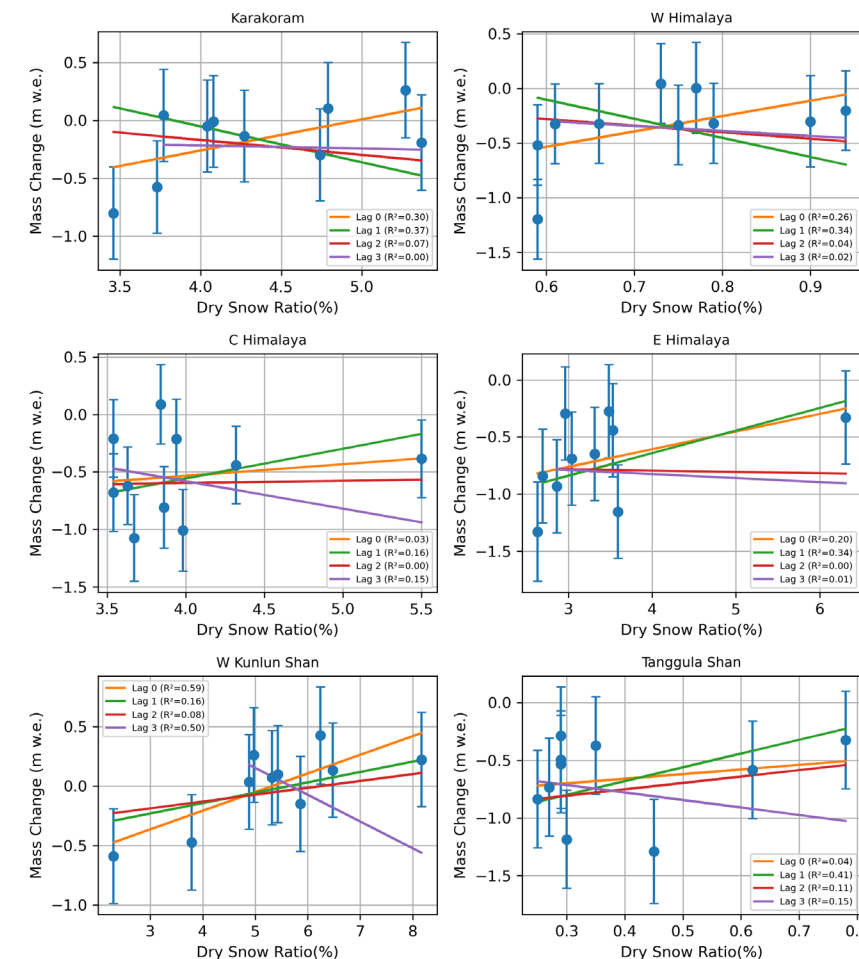


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## Dry Snow – Relationship with Mass Balance and Climate



- Negative correlation with temperature
- Correlation dry snow and precipitation is more complex (or limitation of precipitation product)



Moderate positive correlations with glacier mass balance at same year (lag=0) and next year (lag=1)

**Implications:** Dry Snow as Indicator for Glacier Mass Balance and Climate



## Seasonal velocity signals of debris-covered and debris-free glaciers in High Mountain Asia

### Background:

- Glacial flow is a **sensitive indicator** of glacier health and its long-term changes can be related to glacier mass balance.
- **Seasonal variations** in glacial flow have been attributed to changes in the **subglacial drainage system** (Nanni et al., 2023; Wendleder et al., 2024).

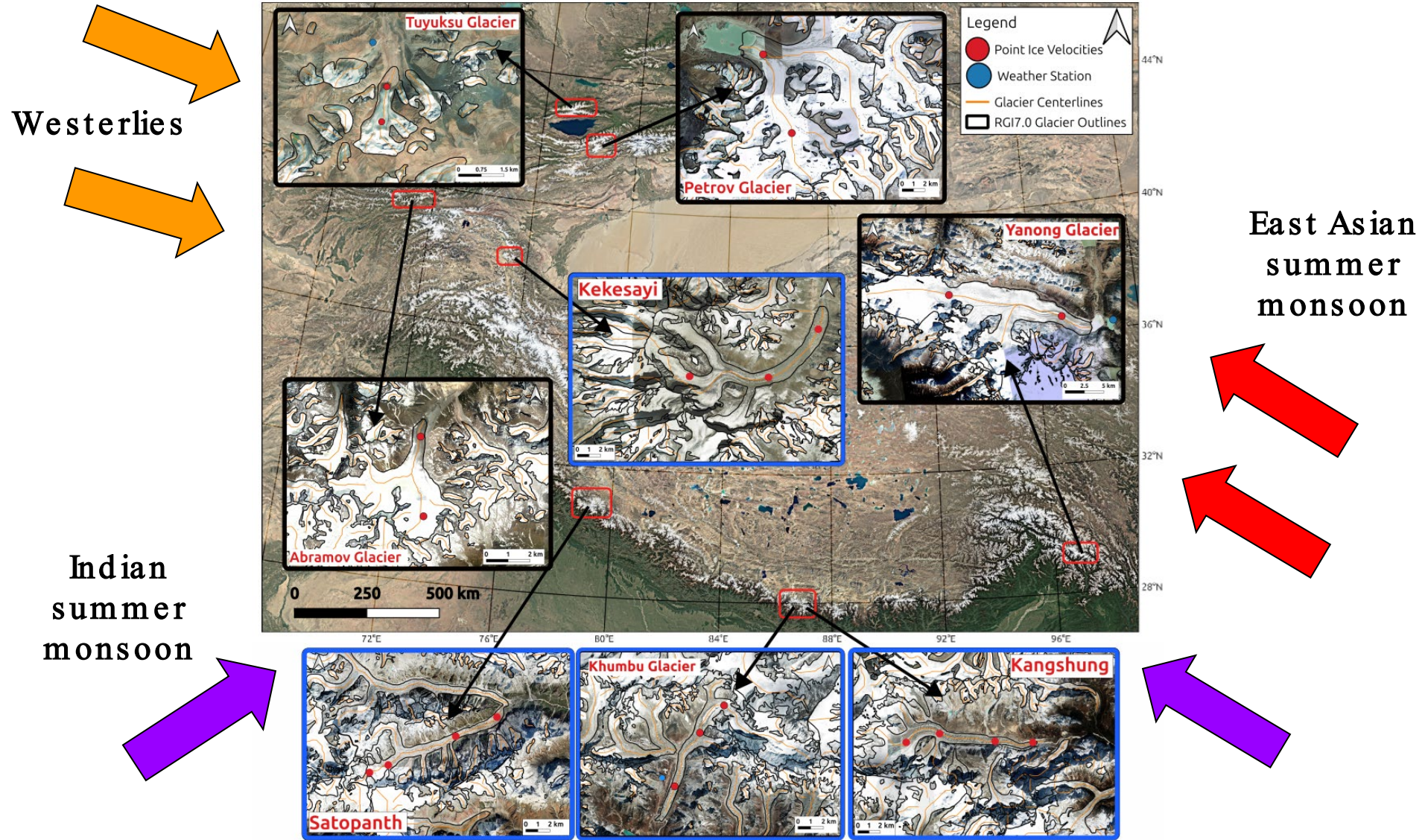
### Methodology:

- **Sentinel-1** (GRD VV) and **Sentinel-2** (L1C B04) for 2017-2025.
- The **feature tracking method within CARST** (Cryosphere And Remote Sensing Toolkit) (Zheng et al., 2021). A **statistical method** (regularized linear inverse model) extracts seasonal variations in glacial velocity with a **6-day sampling interval** and **60 m spatial resolution**:
  - **Assume ice velocity does not change** between any two adjacent sampling locations.
  - Loss function is designed using **weighted least squares** and **Tikhonov regularization**.
  - Two sources of uncertainty (**individual scene-pair maps** and **data gaps**).



## Objectives:

- (1) **Extract** seasonal velocity signals of debris-covered and debris-free glaciers in High Mountain Asia.
- (1) **Explore** the differences in the velocity signals of the debris-covered and debris-free glaciers.
- (1) **Investigate** the potential drivers of the observed velocity signals for the glaciers in this study.



# Seasonal flow velocity: from EU sides



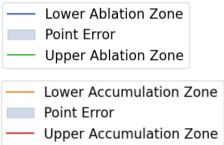
## Results

Faster velocities in spring/summer.

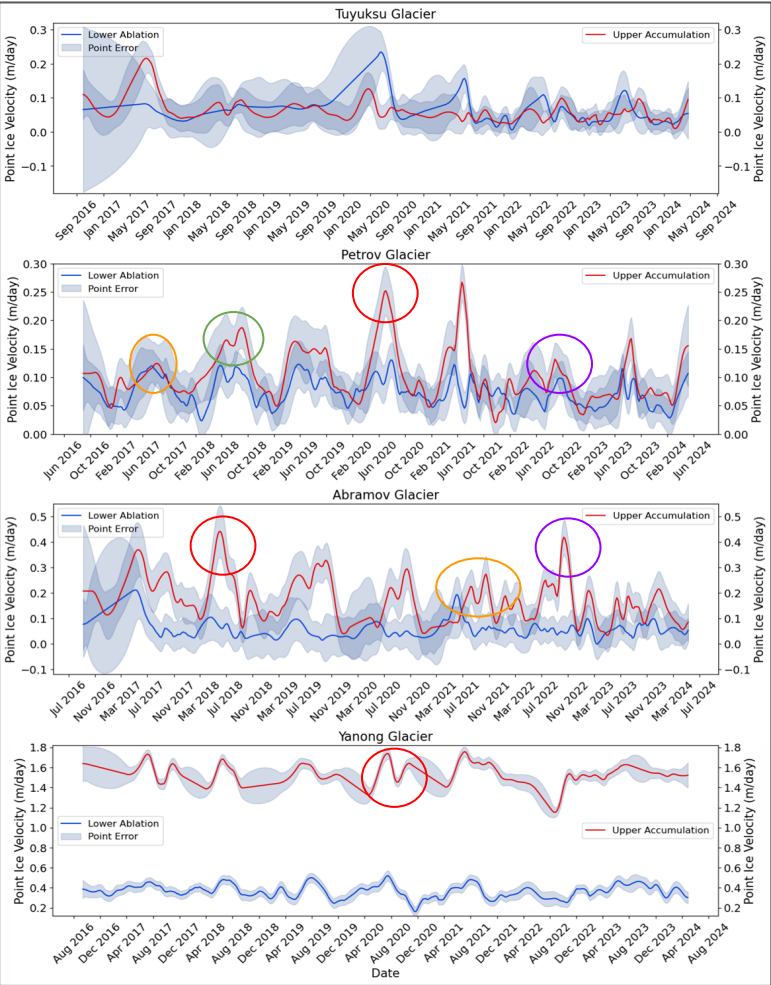
Faster velocities occurring first in ablation zone, followed by faster velocities in the accumulation zone.

Faster velocities in autumn.

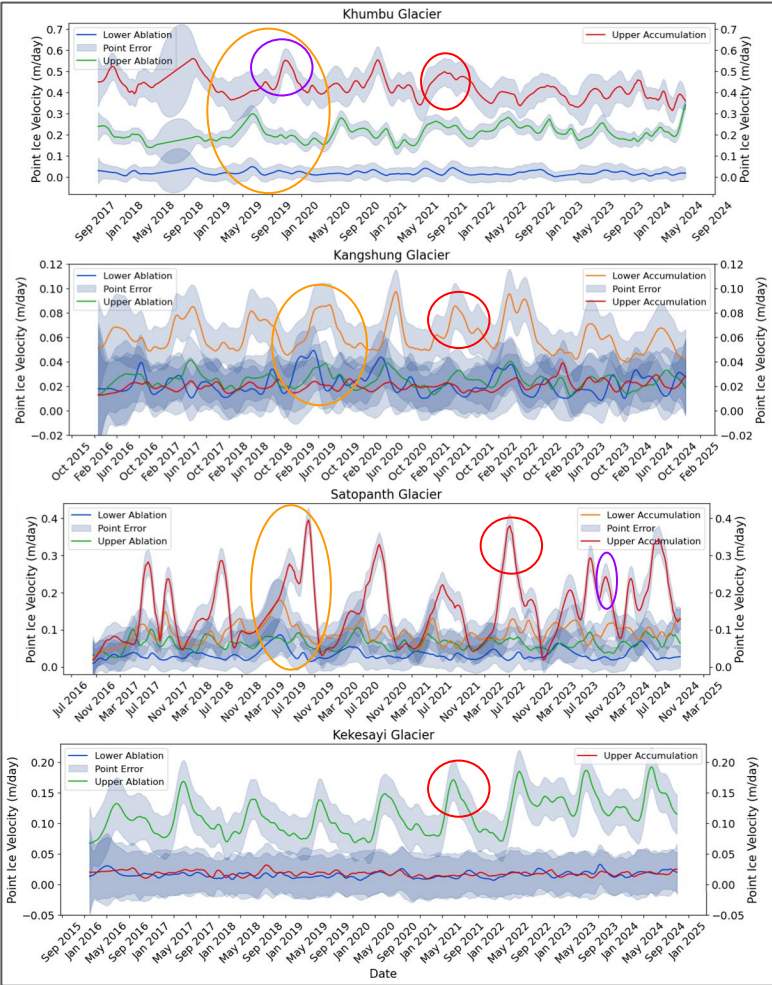
Faster velocities in spring and/or summer, and autumn.



### Debris-free glaciers



### Debris-covered glaciers



# Seasonal flow velocity: from EU sides

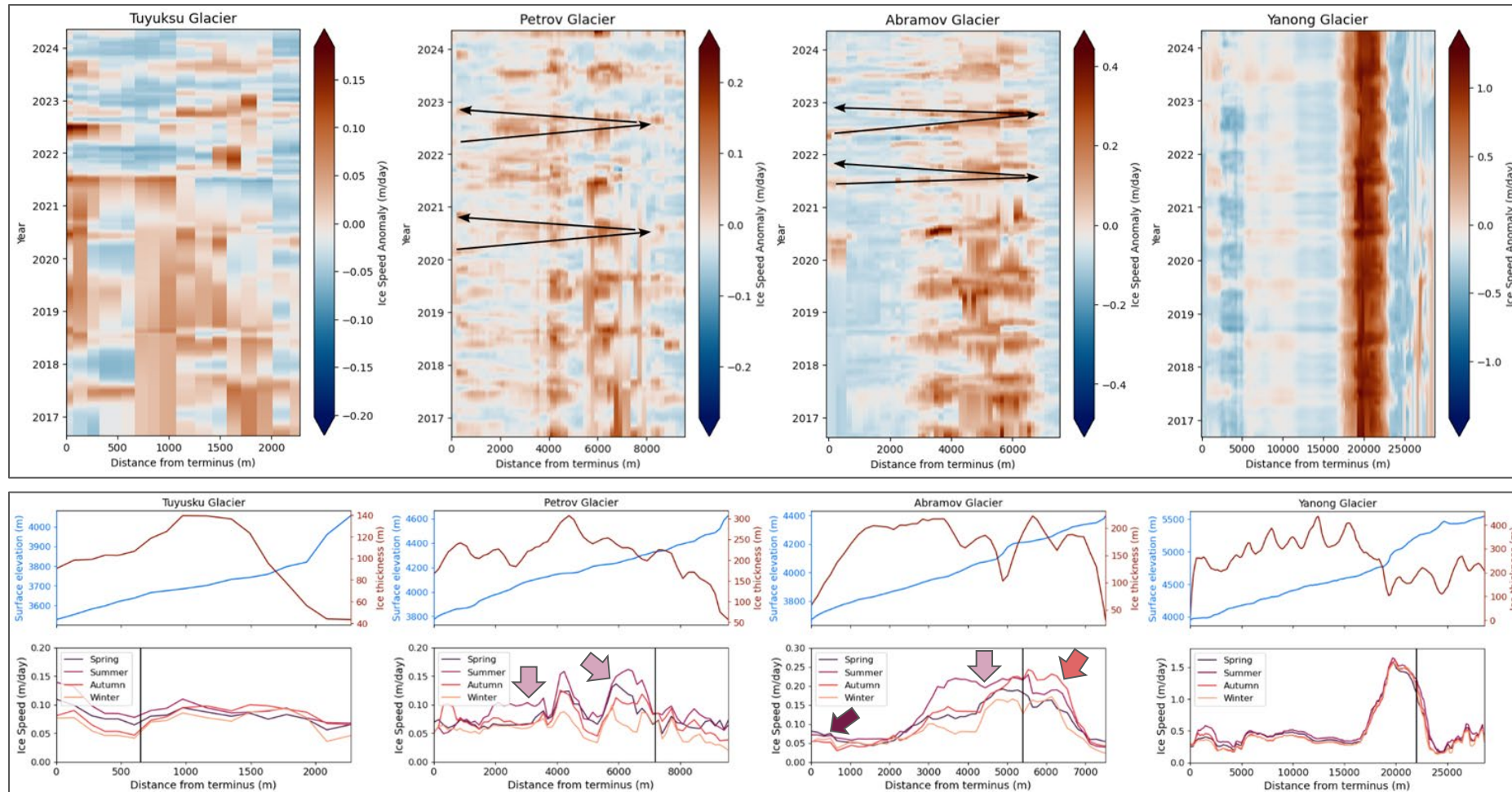


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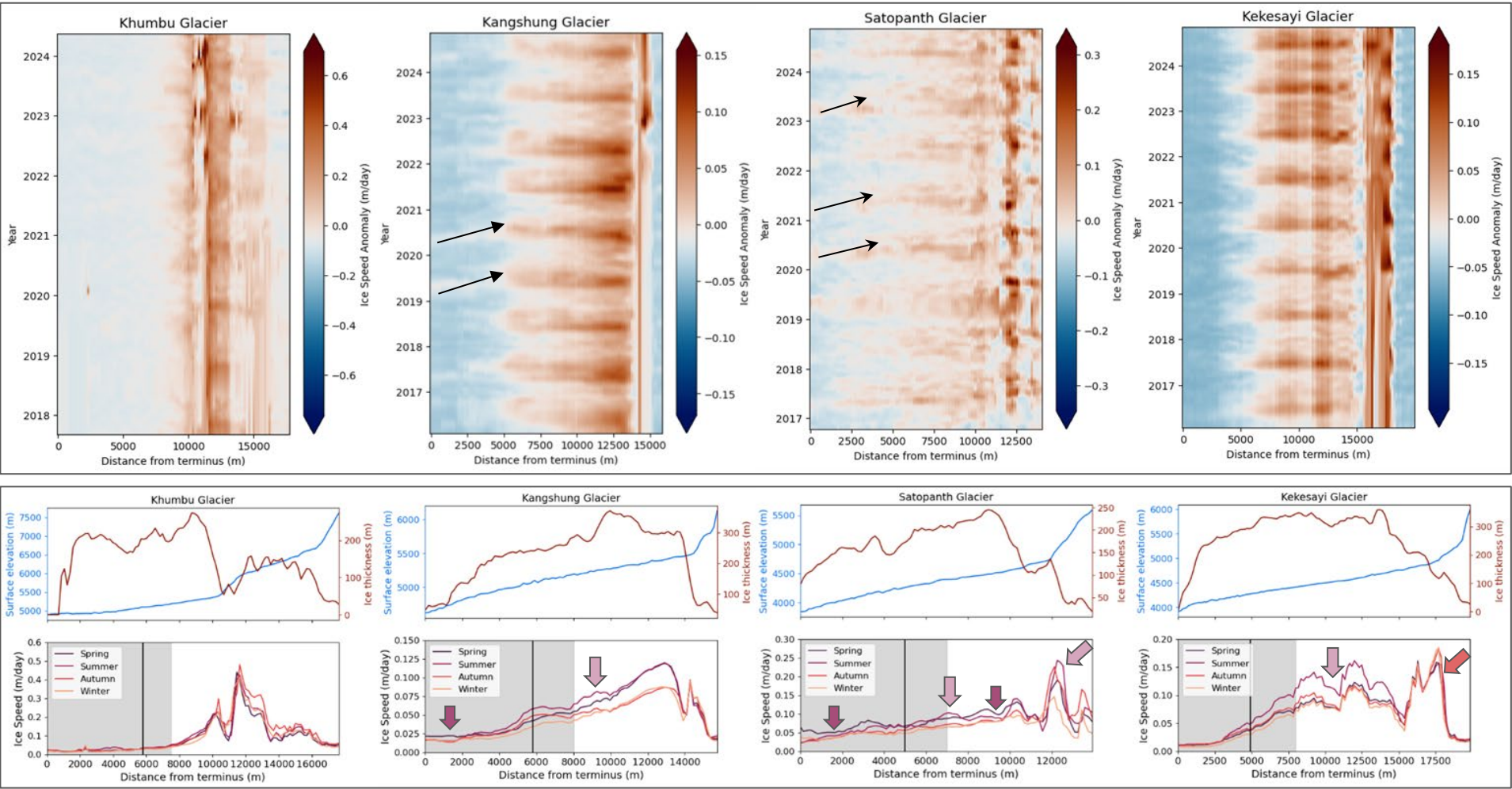
## Debris-free glaciers



# Seasonal flow velocity: from EU sides



## Debris-covered glaciers



# Seasonal flow velocity: from EU sides

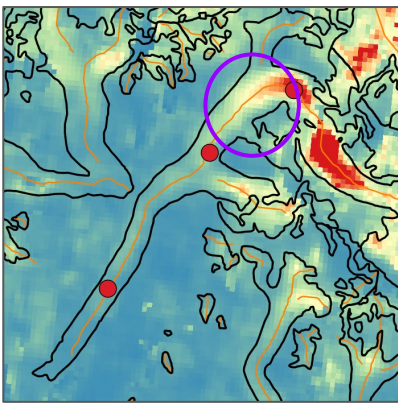


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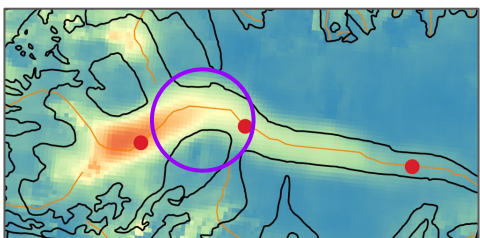
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Khumbu

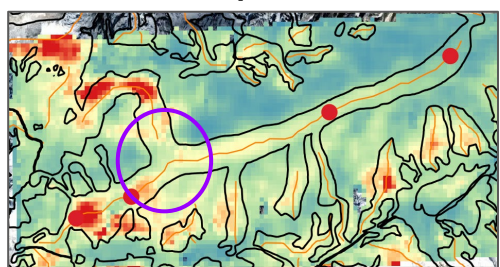


Summer

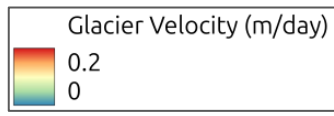
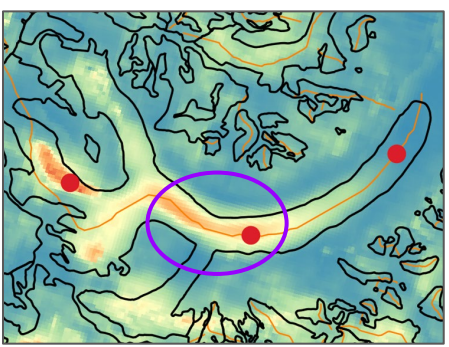
Kangshung



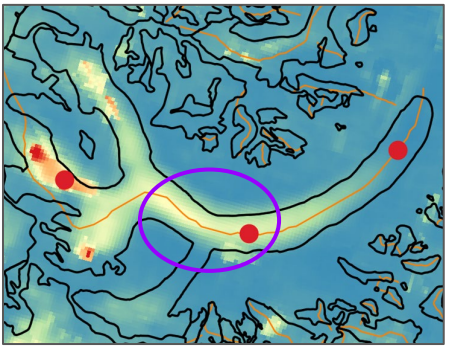
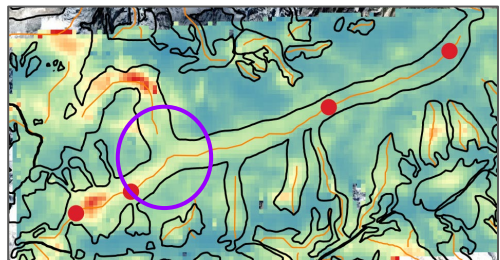
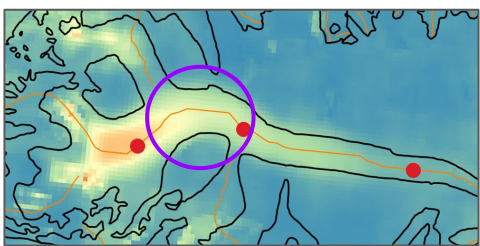
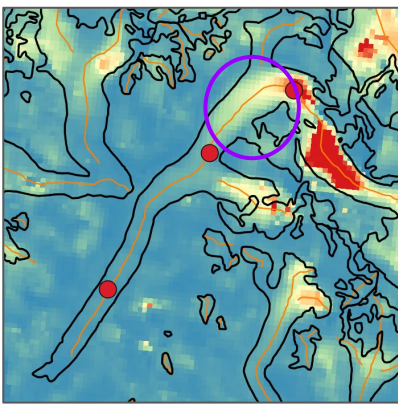
Satopanth



Kekesayi



Winter



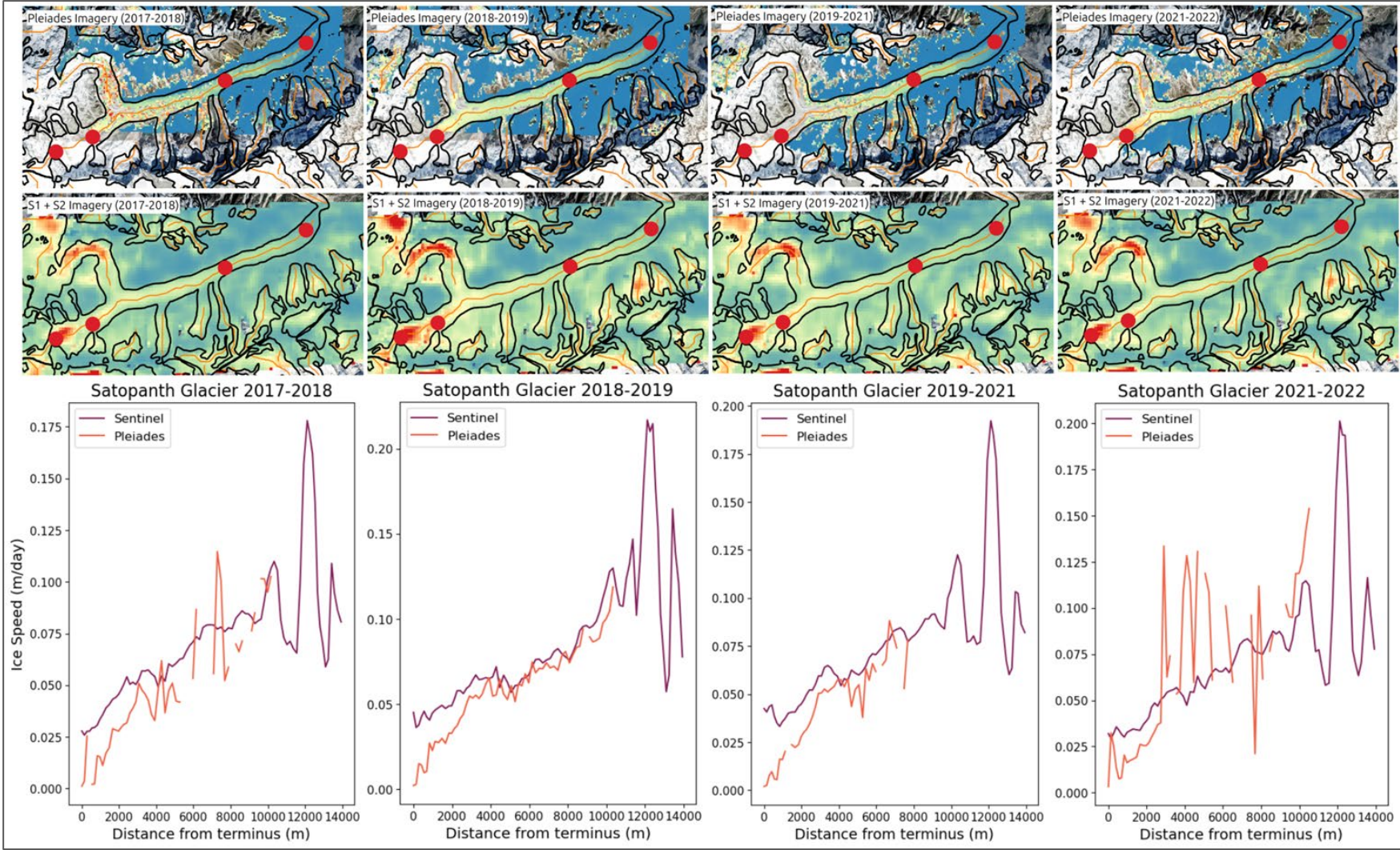
# Seasonal flow velocity: from EU sides



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## Key Findings:

- The **timing of the seasonal velocity variations is similar** for both DCGs and DFGs.
- The **location** of the seasonal velocity variations is **higher up-glacier** for DCGs.
- The **seasonal propagations** of velocities up- or down-glacier are **absent or less clear** for DCGs.
- **Icefalls** likely **alter the seasonal flow response** of both DCGs and DFGs.
- **Summer and winter accumulation type glaciers** exhibit stronger seasonal velocity signals for DCGs and DFGs compared to transitional accumulation type glaciers.
- **Significant relationships** are found between monthly velocities and air temperature.
- **Changes in the subglacial drainage system** are likely driving the seasonal velocity signals and may explain the differences in seasonal flow responses between DCGs and DFGs.



Whether very high-resolution DEMs can measure glacier mass balance at annual and seasonal scales?

0.7m resolution Pleiades imagery were tried for DEM differences

**Table 1.** Acquisition dates (dd-mm-yyyy) of the Pléiades imagery.

| Sector   | Muztagh Ata |            | Western Nyainqêntanglha |                         |
|----------|-------------|------------|-------------------------|-------------------------|
|          | Pléiades    | Sentinel-2 | Pléiades                | Sentinel-2              |
| W        | 11-09-2019  | 13-09-2019 | 11-11-2019              | 11-11-2019              |
| E        | 05-09-2019  | 03-09-2019 | 29-10-2019              | 27-10-2019              |
| W (~ 1)  | 09-09-2020  | 07-09-2020 | 08-10-2020 <sup>a</sup> | 11-10-2020 <sup>a</sup> |
| E (1.05) | 22-09-2020  | 22-09-2020 |                         |                         |
| W (~ 1)  | 08-09-2021  | 07-09-2021 | 30-09-2021 <sup>b</sup> | 06-10-2021              |
| E (~ 1)  | 21-09-2021  | 22-09-2021 |                         |                         |
| E (1)    | 22-09-2021  |            |                         |                         |
| W (0.59) | 10-04-2022  | 10-04-2022 | 18-03-2022              | 20-03-2022 <sup>a</sup> |
| E (0.56) | 17-04-2022  | 15-04-2022 | 19-03-2022              |                         |
| W (0.40) | 31-08-2022  | 02-09-2022 | 07-11-2022              | 05-11-2022              |
| E (0.45) | 27-09-2022  | 27-09-2022 | 01-11-2022              | 31-10-2022              |



## Results of seasonal mass balance in Muztagh Ata

The 2022 winter  
( $0.13 \pm 0.24 \text{ m w.e.}$ )  
and summer  
( $0.35 \pm 0.15 \text{ m w.e.}$ )  
mass budgets in  
Muztagh Ata

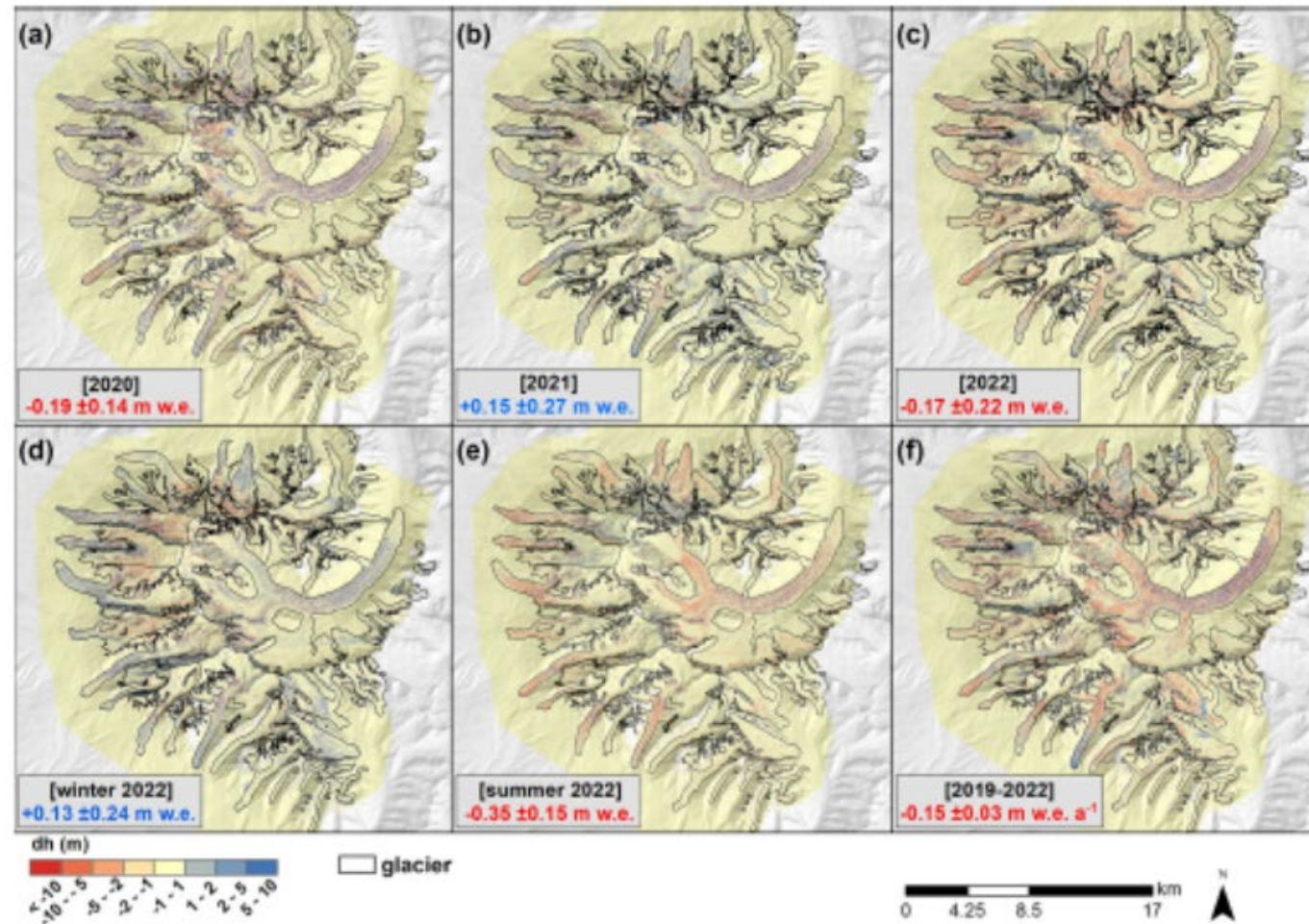


Figure 4. Annual (a, b, c), seasonal (d, e), and multi-annual (f) surface elevation change grids over Muztagh Ata and associated geodetic mass balance estimates.



## Results of seasonal mass balance in Western Nyainqentanglha

Western Nyainqêntanglha  
( $0.03 \pm 0.27$ mw.e. in winter;  
 $0.63 \pm 0.07$ mw.e. in  
summer)

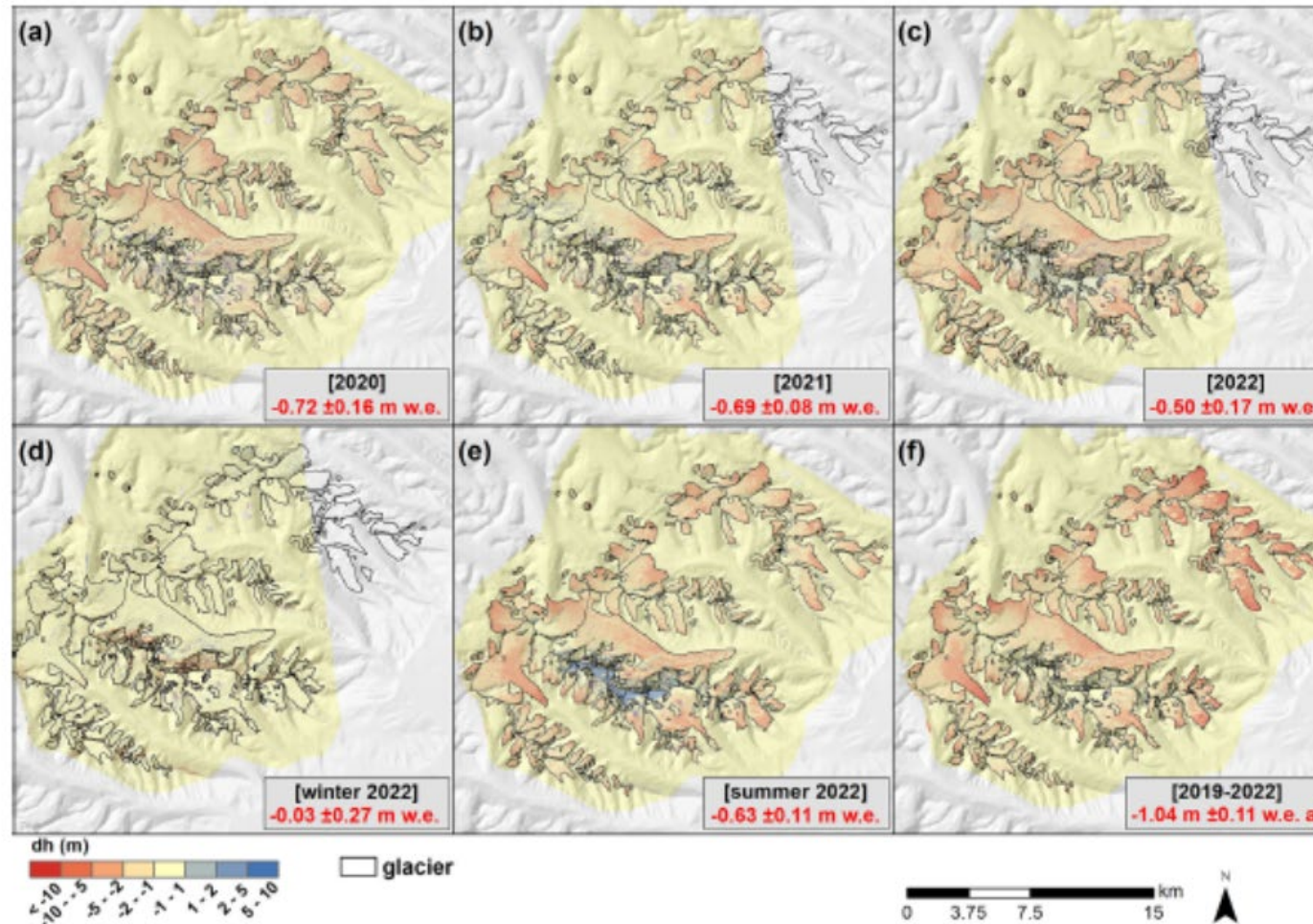


**Figure 6.** Annual (a, b, c), seasonal (d, e), and multi-annual (f) surface elevation change grids over western Nyainqentanglha and associated geodetic mass balance estimates.

# Seasonal mass balance: from EU sides

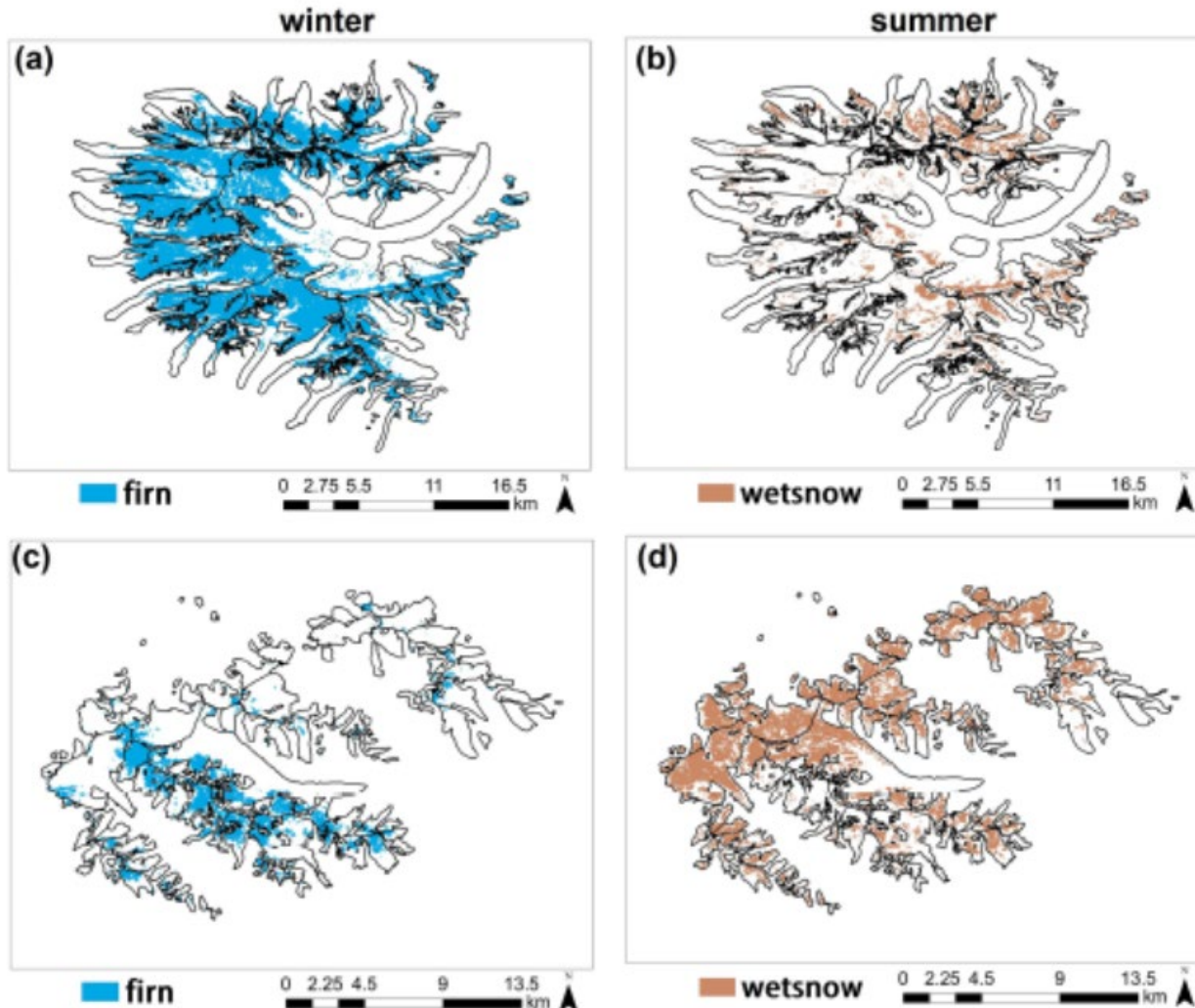


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Results of DEM difference and accumulation pattern from snow cover **agree well** with each other



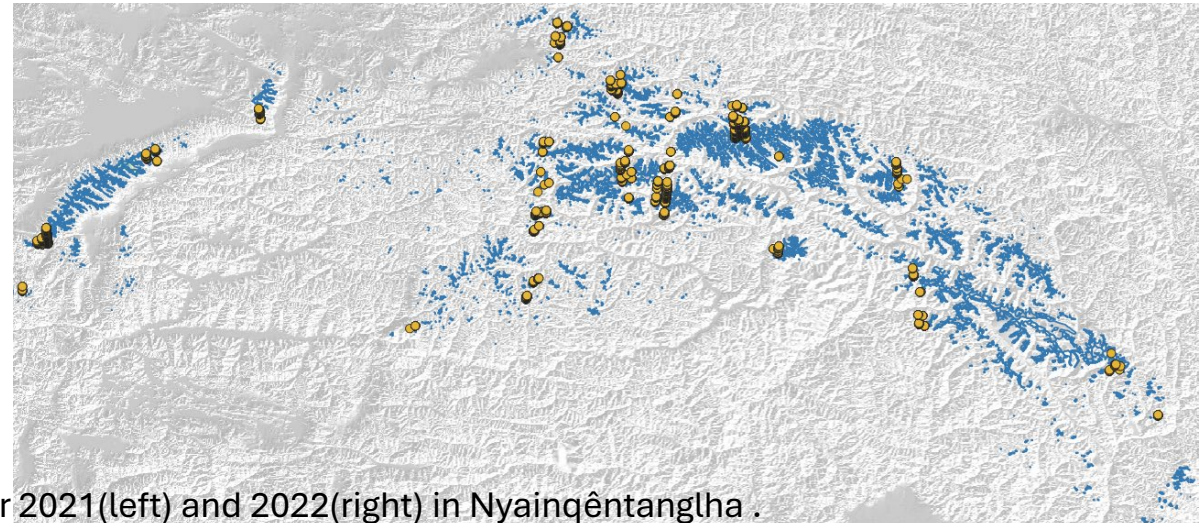
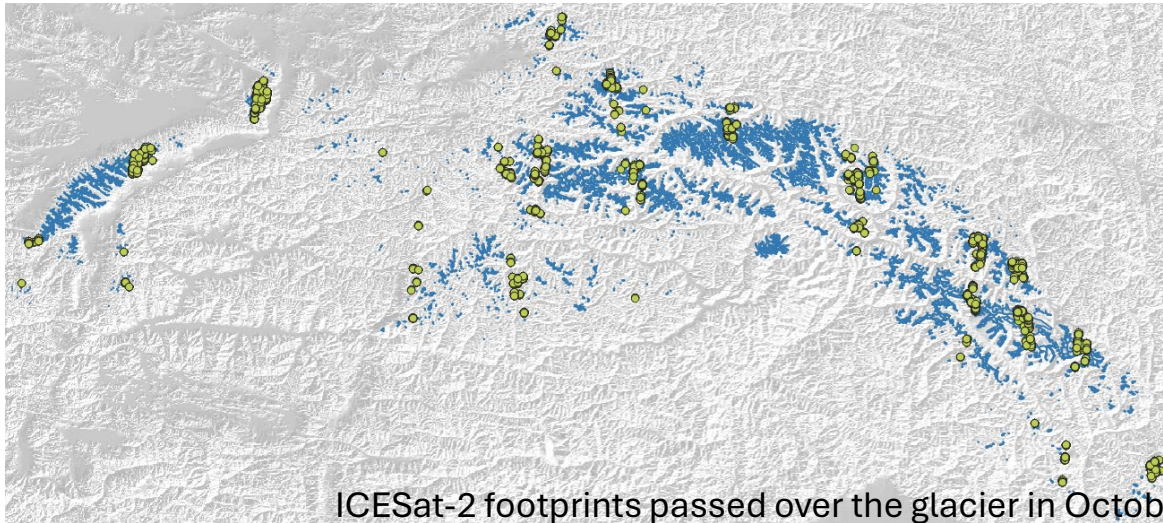
The 2022 winter ( $0.13 \pm 0.24 \text{ mw.e.}$ ) and summer ( $0.35 \pm 0.15 \text{ mw.e.}$ ) mass budgets in Muztagh Ata and western Nyainqêntanglha ( $0.03 \pm 0.27 \text{ mw.e.}$  in winter;  $0.63 \pm 0.07 \text{ mw.e.}$  in summer) suggest **winter- and summer-accumulation-type** regimes, respectively

Good match with accumulation type using wet snow accumulation



## Mountain Glacier Elevation Change from ML Interpolation

- Satellite DEMs provide large coverage but limited spatial and temporal resolution.
- Altimetry (ICESat-2) offers frequent updates and high resolution but with **sparse spatial footprints**.



ICESat-2 footprints passed over the glacier in October 2021(left) and 2022(right) in Nyainqêntanglha .

Our method applies **machine learning interpolation** to estimate full DEMs using ICESat-2 elevation and auxiliary predictors.

### Inputs(X):

**4 topographic factors** (TanDEM, slope, aspect, roughness)  
**21 monthly climate predictors**(**concurrent with ICESat-2 measurements** like 2m temperature, precipitation and so on)

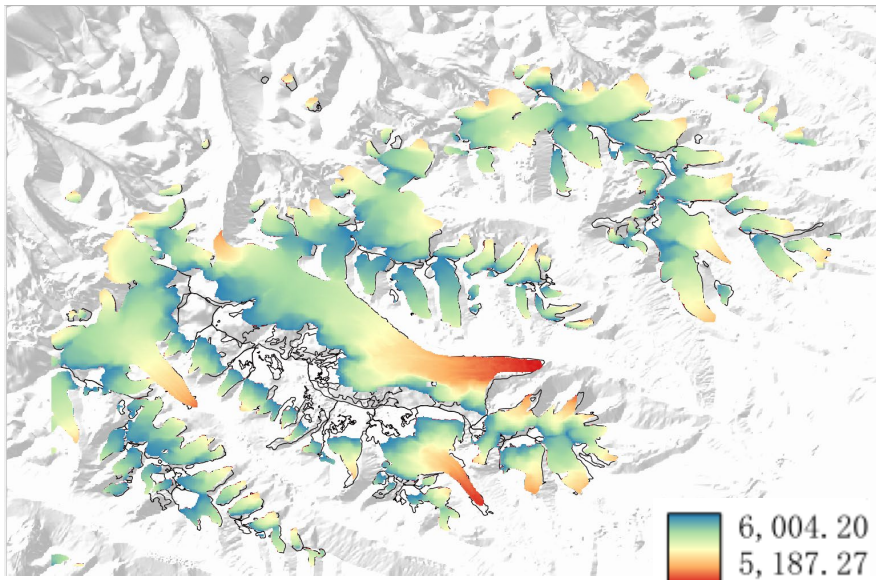
**Output(Y):** **Residual = elevation (ICESat-2) – elevation (TanDEM)**

**Model:** **XGBoost with elevation-informed residual correction**

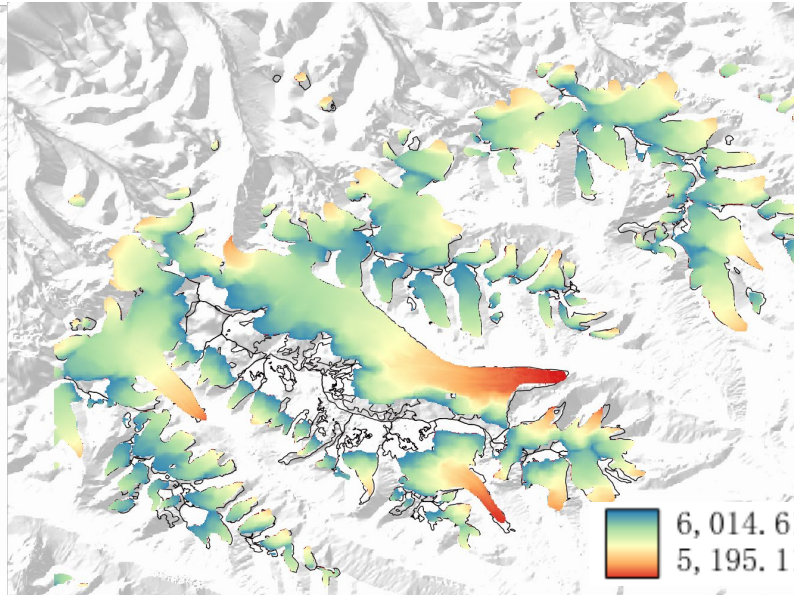


## Preliminary Results:

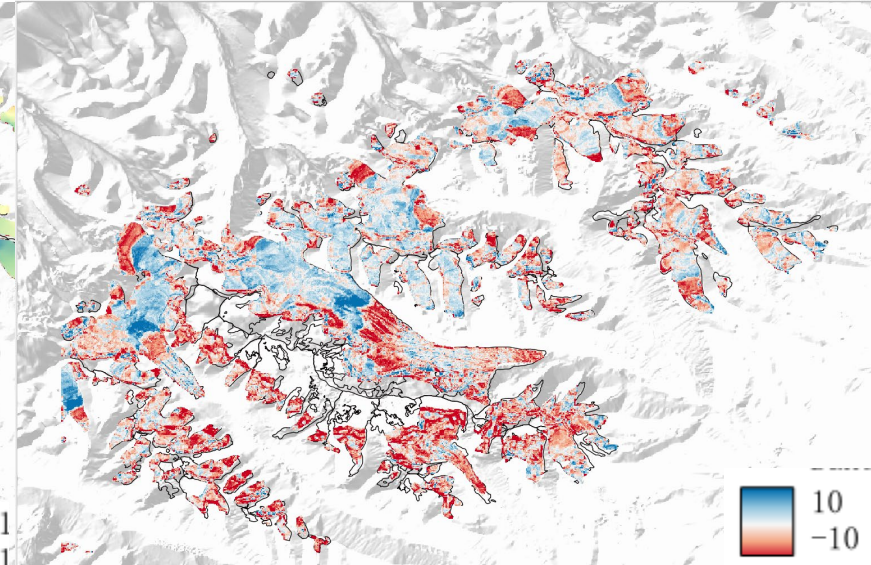
An example of in the Western Nyainqêntanglha



Predicted elevation(10.2022)



Predicted elevation(10.2021)



Annual elevation difference  
based on the predicted  
DEM(2022)



Glacier has been observed with seasonal characteristic

Seasonal accumulation pattern: summer accumulation type thins faster

Seasonal ablation pattern: Daily and monthly state differs greatly

Seasonal flow velocity pattern: Seasonal variety is clear

Seasonal mass balance pattern: Possible for Very high resolution satellite image pairs and ICESAT

What is **connection** between the seasonal factors and **influence** on long-term mass balance is still not well investigated, which is the key for next step.

In the future work we will try to incorporate the seasonal pattern into mass balance model, and use it to predict the fate of glaciers