Monitoring Firn and Wet Snow on Mountain Glaciers: Polarization and Orbit Effects

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1. Introduction

- Mountain glaciers are sensitive to climate variability and can be of great importance for downstream residents due to their hydrological significance.
- Snow line is defined as the transient boundary between wet snow and ice on a glacier, which is related to the annual glacier mass balance; the firn line is the boundary between glacier ice and old firn from many previous years, which are related to multi-year glacier mass balance. it is important to discriminate wet snow and firn zones.
- Images are often used to monitor glaciers based on the backscattering coefficient, but the influence of satellite orbit and polarization when collecting images for wide regions have not been well considered.
- We aim to explore the the effect of polarization and orbit when monitoring wet snow and firn.

2. Study Area and Data

2.1.Study Area

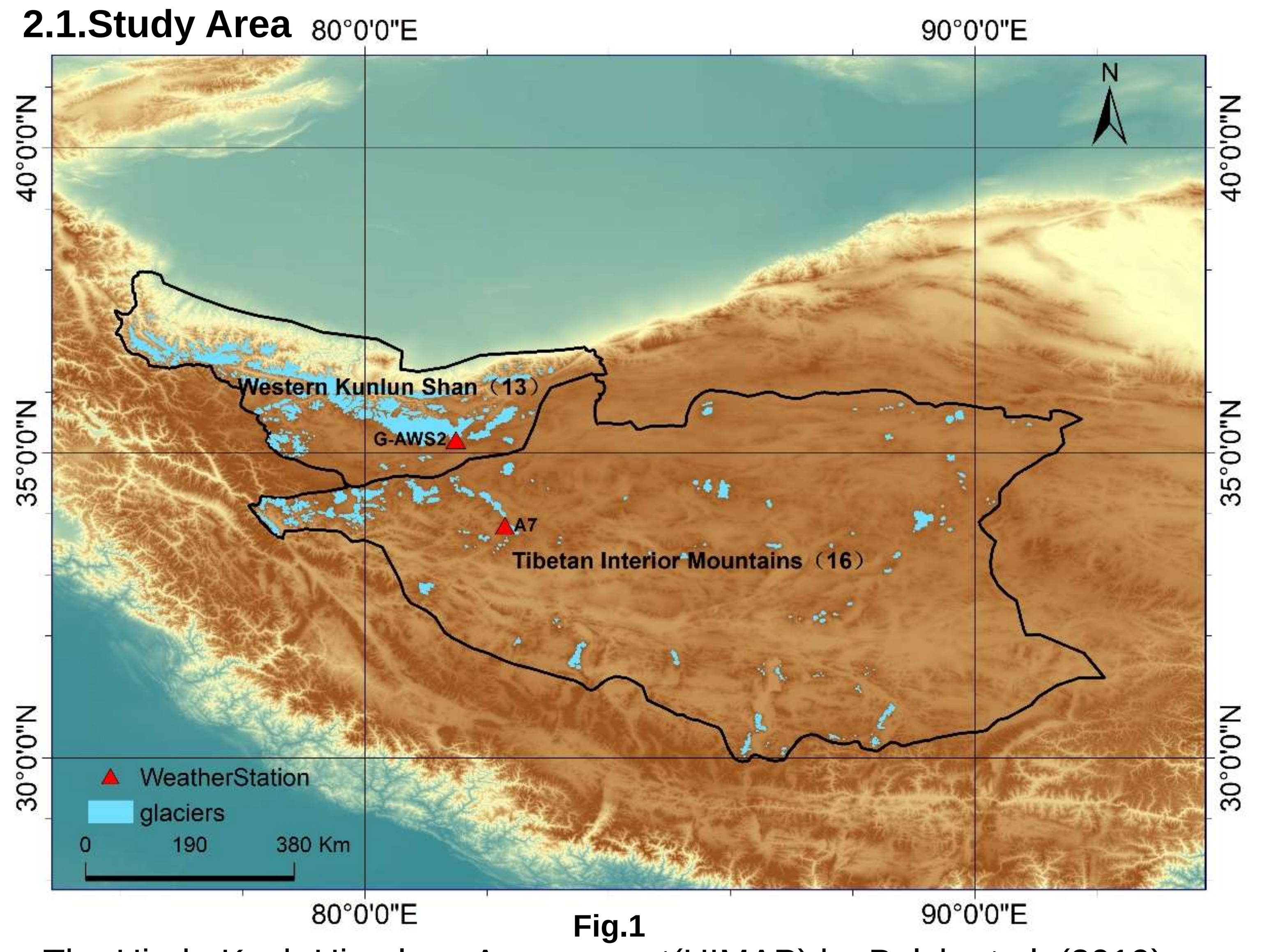

Fig.1

The Hindu Kush Himalaya Assessment(HIMAP) by Bolch et al. (2019) , divides 22 glacial zones in the High Asia region, of which the study areas are subset of West Kunlun Shan(WKS) and Tibetan Interior Mountains(TIM).

2.2.Data

We used C-band SAR images from **Sentinel-1A and 1B satellites**, facilitated by Google Earth Engine(GEE). And we obtained temperature data(Fig.2 Fig.3) from the automatic weather station **GAWS2**(**altitude of 6005m in WKS)** and the**A7(altitude of 6013m in TIM**).

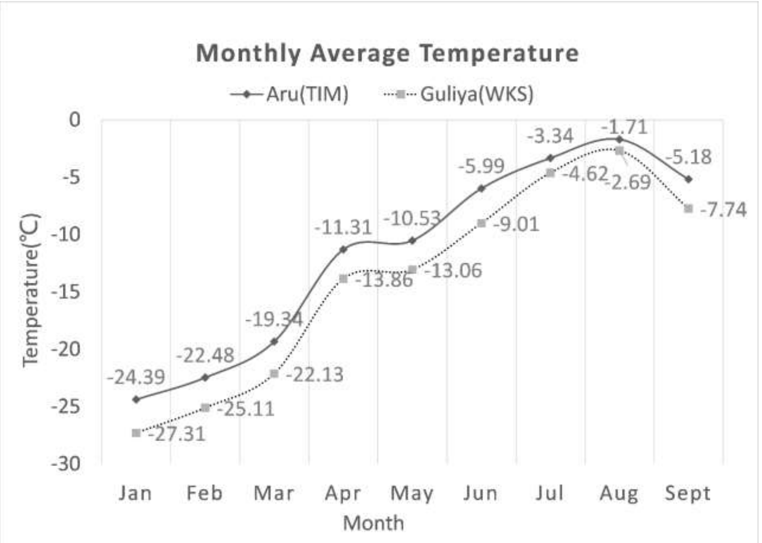

Fig.2

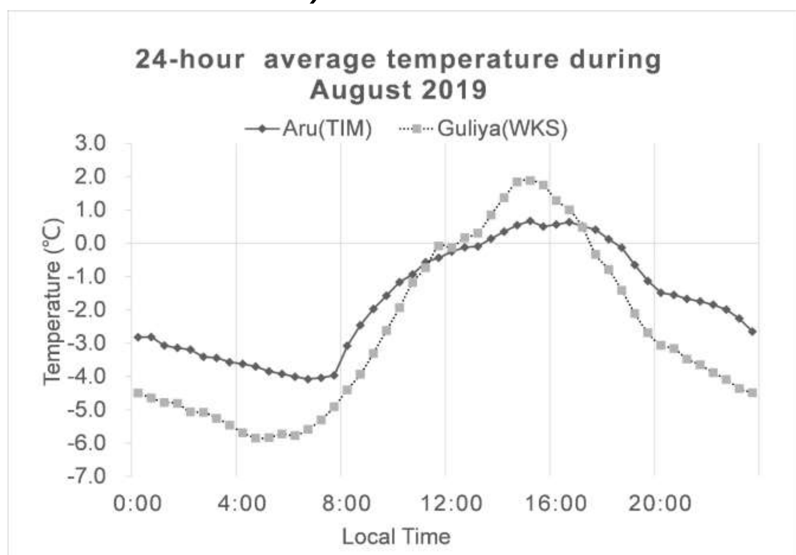

Fig.3

3. Method

Upon acquiring the images from GEE, our initial action involved utilizing the normalized difference snow index (NDSI) to remove debris. Subsequently, a median filter was applied to merge them into a single composite. Following this, terrain correction was carried out. Having completed these preprocessing tasks, we conducted the maximum likelihood classification(MLC) and subsequently analyzed the classification outcomes(Fig.4).

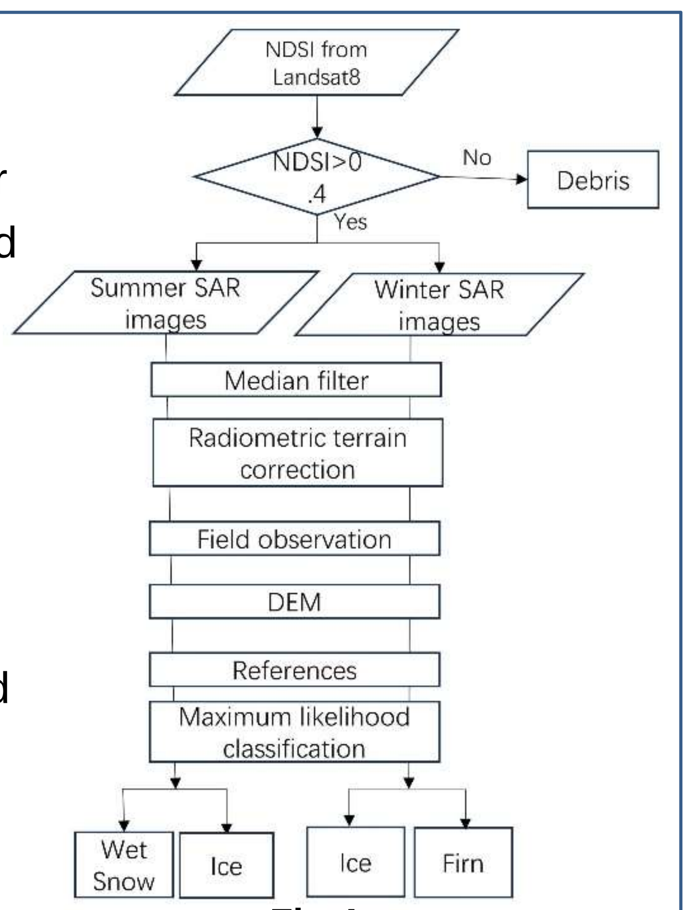

Fig.4

4.Result and Discussion

4.1. Maximum Likelihood Classification and The Effect of Polarization

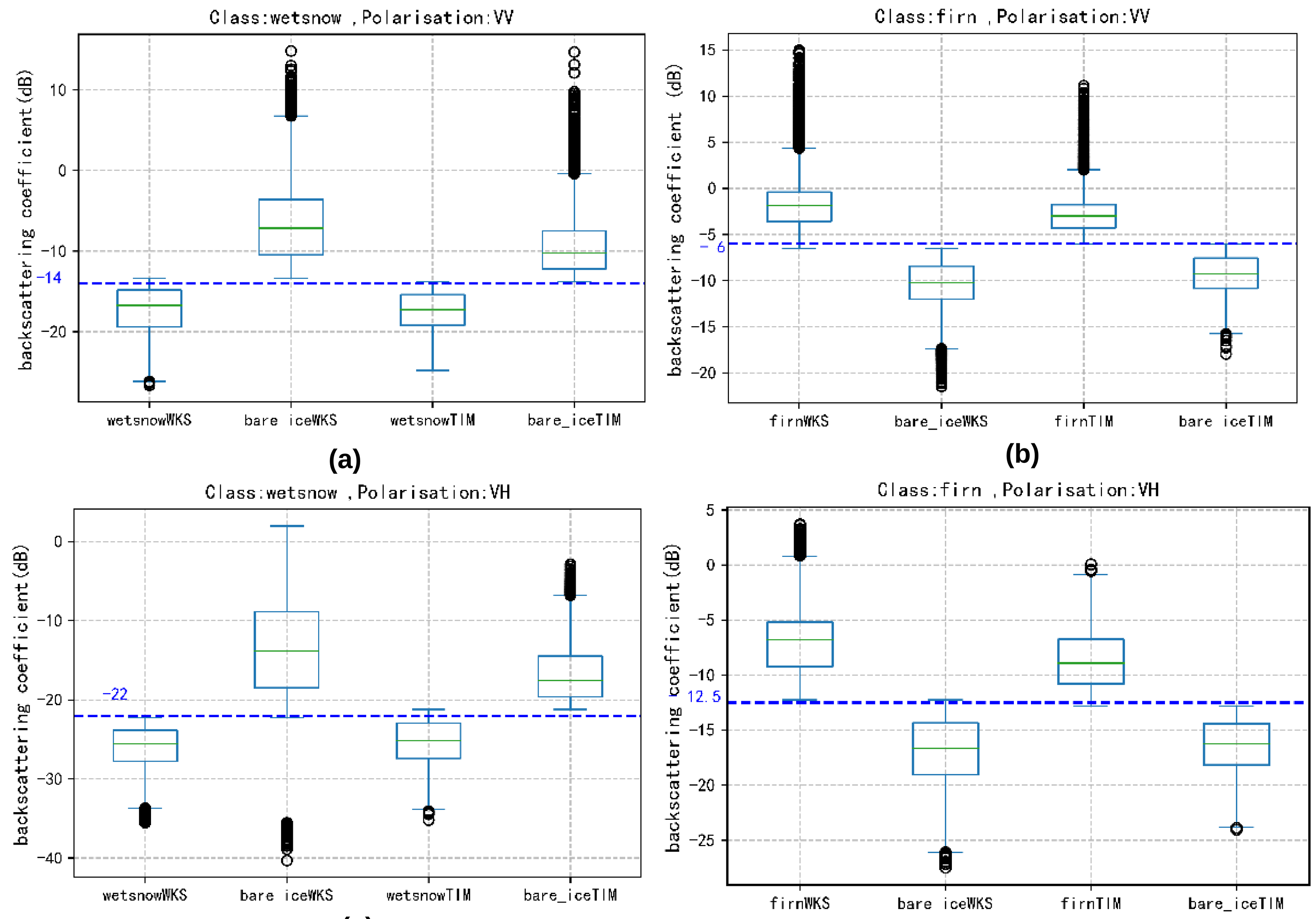

Fig.5

- There is a distinct threshold between wet snow and ice, firn and bare ice regions. Under the co-polarization （**VV**)the value is **-14 dB for wet snow**(Fig.5a) and **-6 dB for firn** (Fig.5c). Under the cross-polarization(**VH**)the value is **-22 dB for wet snow** (Fig.5c) **and -12.5 dB for firn** (Fig.5d).
- Using these thresholds to calculate the ratio of wet snow and firn (**Table I**). the difference between the wet snow and firn ratios for the different polarizations **is very small(no more than 2%)**, except for the firn ratio in WKS.

Table I Wet Snow/Firn Ratio with Different Polarizations

Area	WKS		TIM	
Polarization	VV	VH	VV	VH
Wet Snow Ratio	30.94%	29.24%	47.83%	51.45%
Firn Ratio	73.41%	70.89%	60.94%	61.70%

4.2. Variation of Summer Wet Snow and Winter Firn in Combination with Orbits

- The **wet snow** ratio of **the ascending is higher than that of the descending orbit and the averaged**. In July and August, the wet snow proportion of the ascending is over **15%** higher than that of the other two orbits (Fig.6a, Fig. 6b).
- The percentage of firn in winter **does not show much variation between different years** in the two regions . It agrees well with previous studies which showed that the glaciers in the WKS were slightly positive and glaciers in TIM were slightly negative in the past decades (Bhattacharya et al., 2021).
- It is found that **the time of ascending is almost the highest temperature of the day** base on the temperature in two areas in summer (Fig.3). It can be inferred that the influence of the orbit when monitoring wet snow is mainly due to the temperature difference at the acquisitions time.

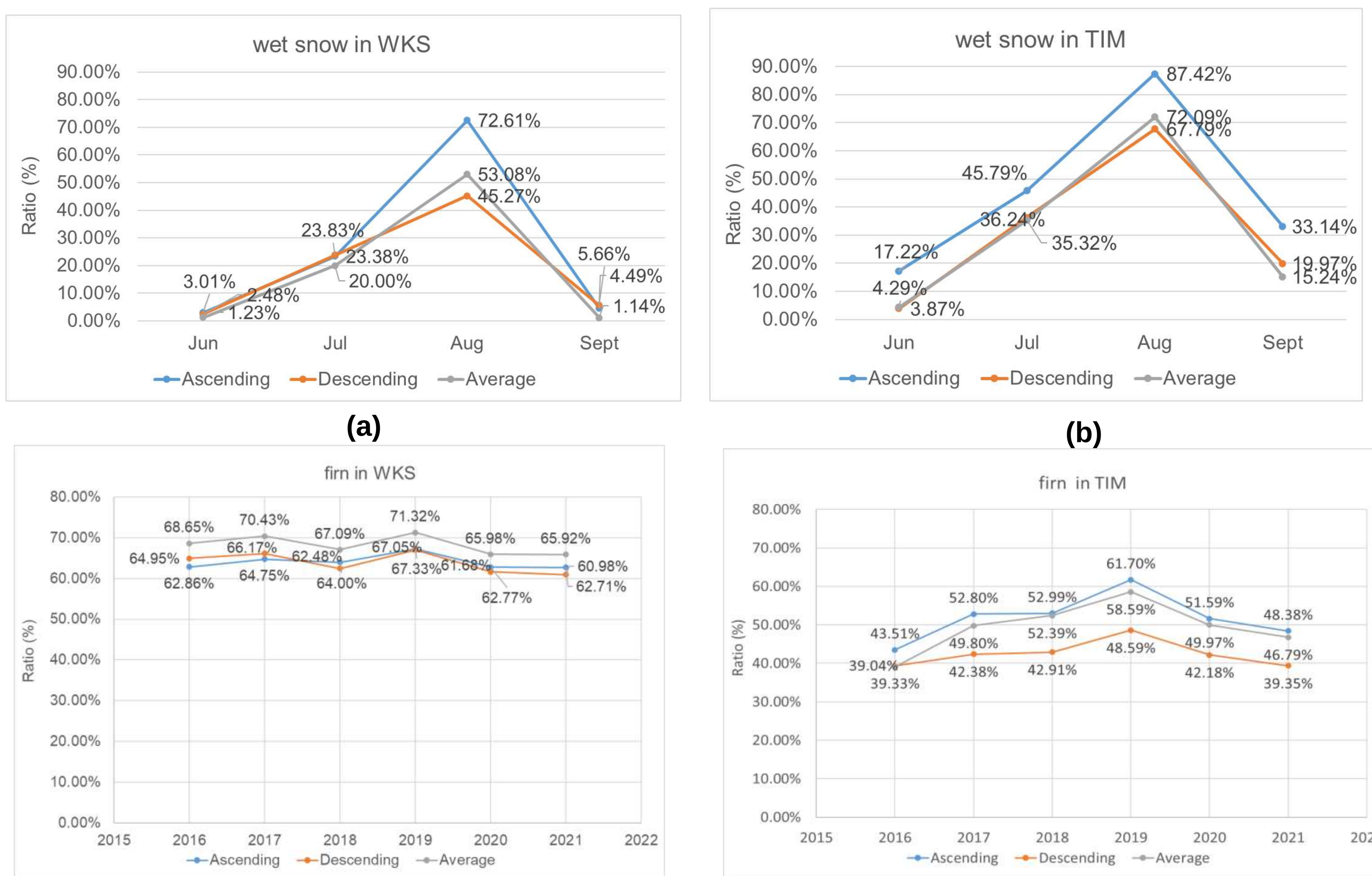

Fig.6

5. Conclusions

- There is a clear threshold for the backscattering coefficient in the glacier area after using the MLC, and using this threshold allows monitoring of both wet snow and firn.
- Images from ascending and descending may differ greatly in summer for wet snow detection. This effect can be related to the orbit and therefore the different acquisition time and different air temperature in the morning and afternoon .
- Orbital produce greater identification differences than polarization.

6. References

[1] Bolch, Tobias, et al. "Status and change of the cryosphere in the extended Hindu Kush Himalaya region." The Hindu Kush Himalaya assessment: Mountains, climate change, sustainability and people (2019): 209-255.

[2] Bhattacharya, Atanu, et al. "High Mountain Asian glacier response to climate revealed by multi-temporal satellite observations since the 1960s." Nature communications 12.1 (2021): 4133.

7. Acknowledge

This work was by the Dragon 5 programme (400059344/21/I-NB) supported by ESA and NRSCC/MOST.