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Decreasing albedo led to mass loss in the Western Nyainqentanglha Mountains during the past 20 years

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INTRODUCTION

Glacier albedo determines the net shortwave radiation and therefore affect glacier energy and mass balance (Zhang et al., 2016). Glaciers in the Western Nyainqentanglha Mountains (WNM) are one of the most important fresh water resources for the people around Lhasa, however, the relationship between albedo and mass balance is still unclear due to absence of high spatial resolution and accurate glacier products. In this study, we firstly optimized the procedure to retrieve glacier mass balance for Chinese high resolution stereo images (ZY-3/TLA) uniquely provided by the Dragon Program, then analyzed its change in the WNM during 2000-2017. Secondly, we improved albedo retrieval method for Sentinel 2/MSI, Landsat 8/OLI and MODIS data, and then analyzed long term variability of albedo in the WNM. Finally, explored their relationships based on these two results.

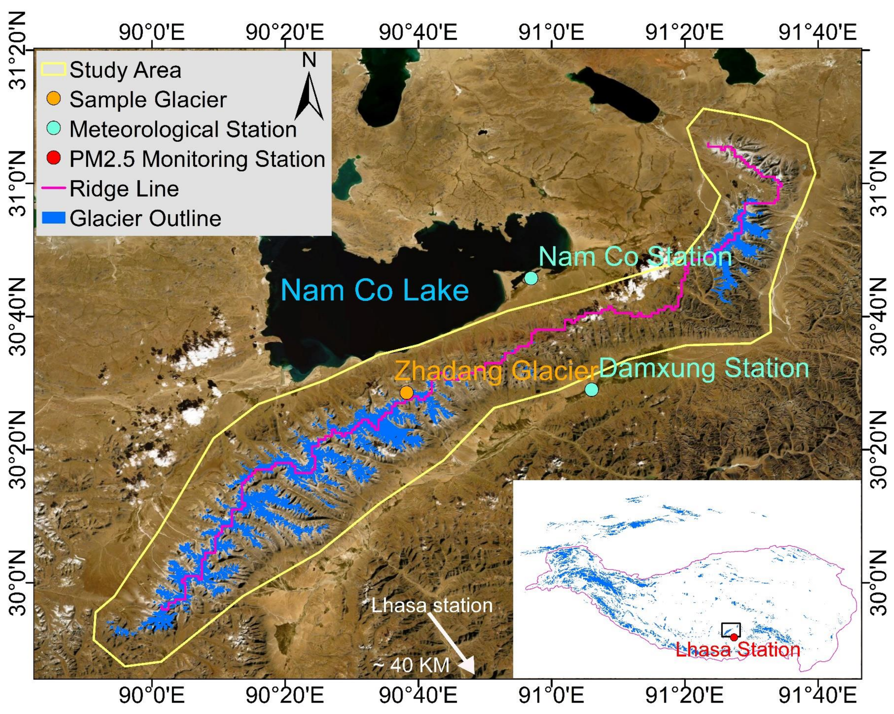

Figure.1 Location of Western Nyainqentanglha Mountain (WNM)

METHOD

The method includes three parts:

1) High resolution glacier elevation change data: we optimized the procedure to extract a Digital Elevation Model (DEM) from Chinese satellite ZY-3 TLA stereo images and estimated the geodetic mass balance in the WNM using ZY-3 DEMs and the C-band Shuttle Radar Topography Mission(SRTM) DEM in 2000-2017 (Ren et al., 2020);

2) Improvement of glacier albedo retrieval method: we improved retrieval method by a new anisotropy correction model for glacier snow and ice, applicable to visible, near-infrared and shortwave-infrared wavelengths using airborne datasets of Bidirectional Reflectance Distribution Function (BRDF). Accordingly, we then retrieved albedo from L5/TM, Landsat 8 Operational Land Imager (L8/OLI) and Moderate Resolution Imaging Spectroradiometer (MODIS) imagery, and evaluated these results with field measurements collected on eight glaciers (Ren et al., 2021).

3) Retrieved MODIS glacier albedo: Using retrieval method mentioned above, we generated half-monthly, monthly, seasonal and annual albedo products by MODIS data and analyzed their spatiotemporal variability in WNM during 2001-2020.

RESULTS

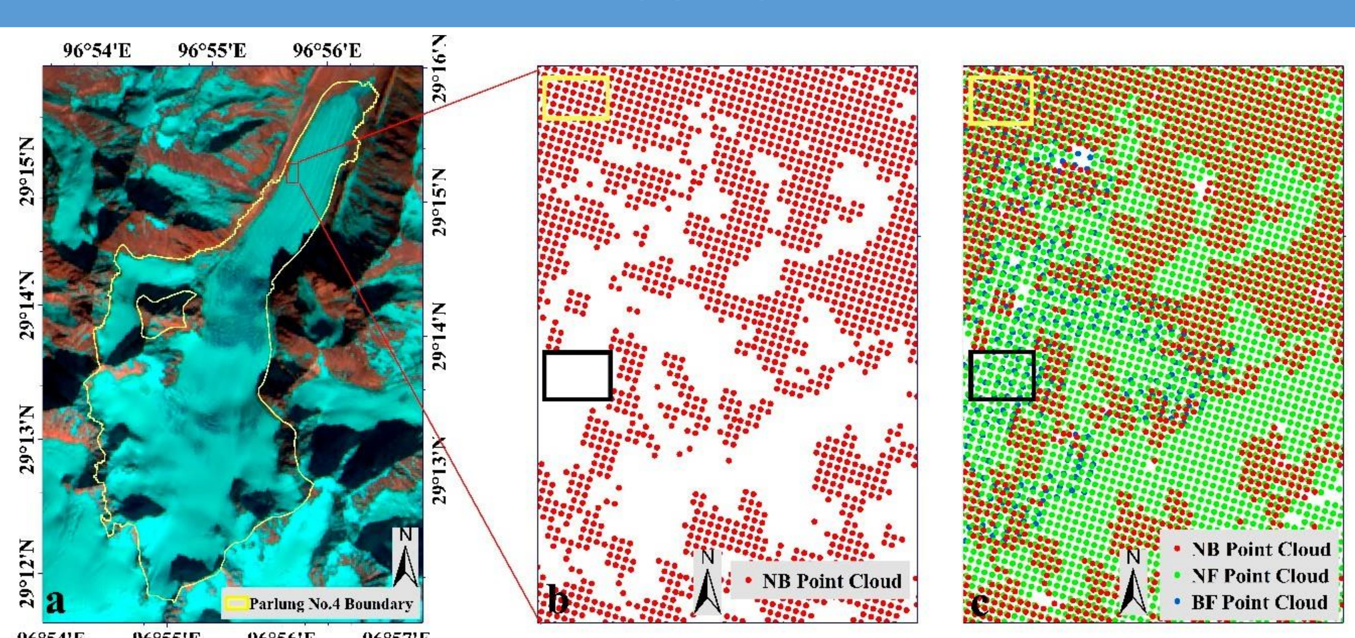

Figure 2. The point cloud of the Parlung No.4 Glacier (a) derived by ZY-3 TLA data. The point cloud generated with the one pair combination (b) and with fusing three pairs combinations (c).

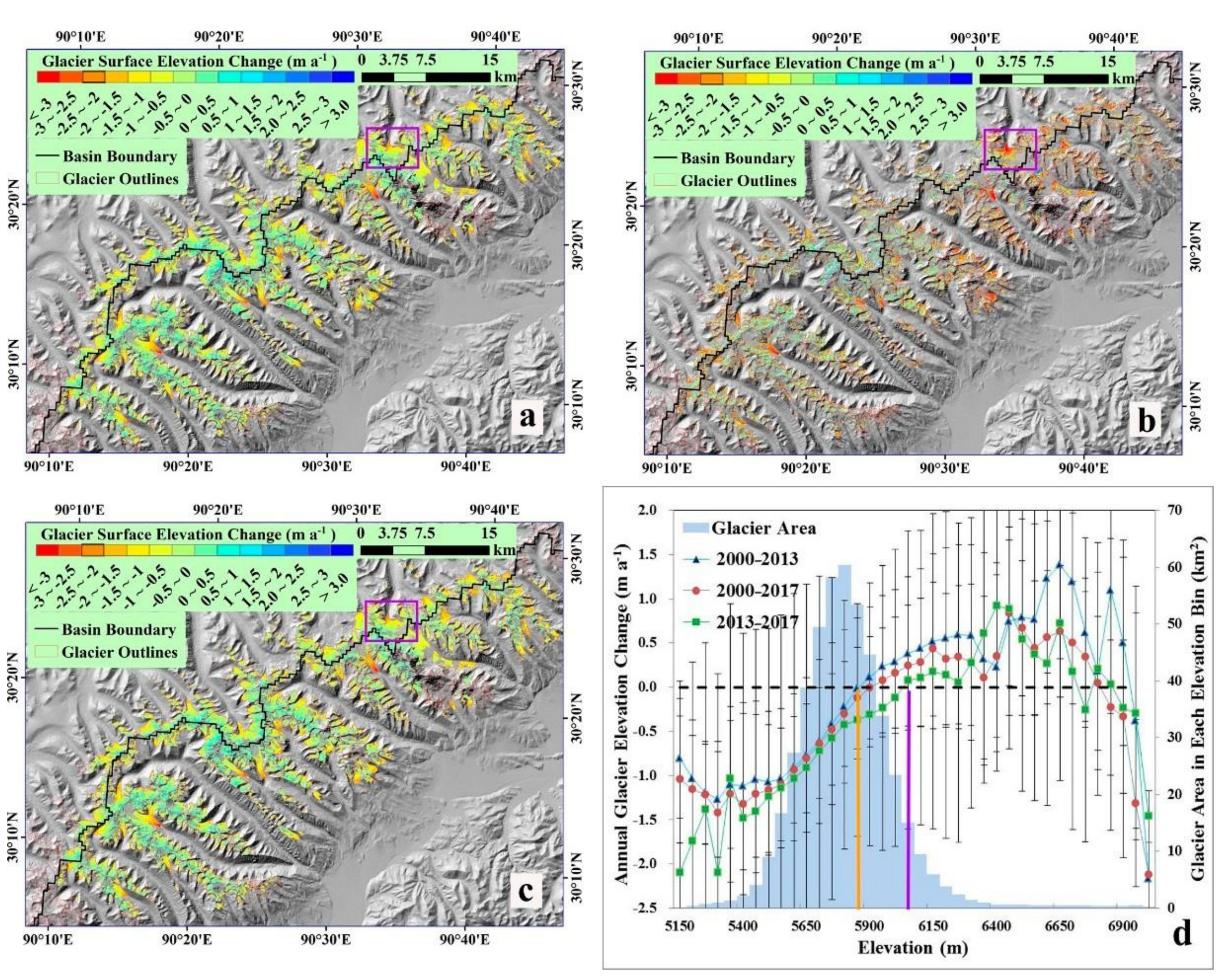

Figure 3. Annual glacier elevation changes estimated by ZY-3 and SRTM DEM in the WNM.
(a): 2000–2013; (b): 2013–2017; (c): 2000–2017; (d): Annual glacier elevation change versus elevation

With our new stereo procedure, ZY-3 TLA data can significantly increase point cloud density and decrease invalid data on the glacier surface map to generate a high resolution (5 m) glacier mass balance map (Fig. 2). This can provide detailed information towards better understanding of glacier change. With generated map, we found that glacier mass balance in the WNM was negative in 2000–2017, and experienced faster mass loss in recent years (2013–2017) (Fig. 3).

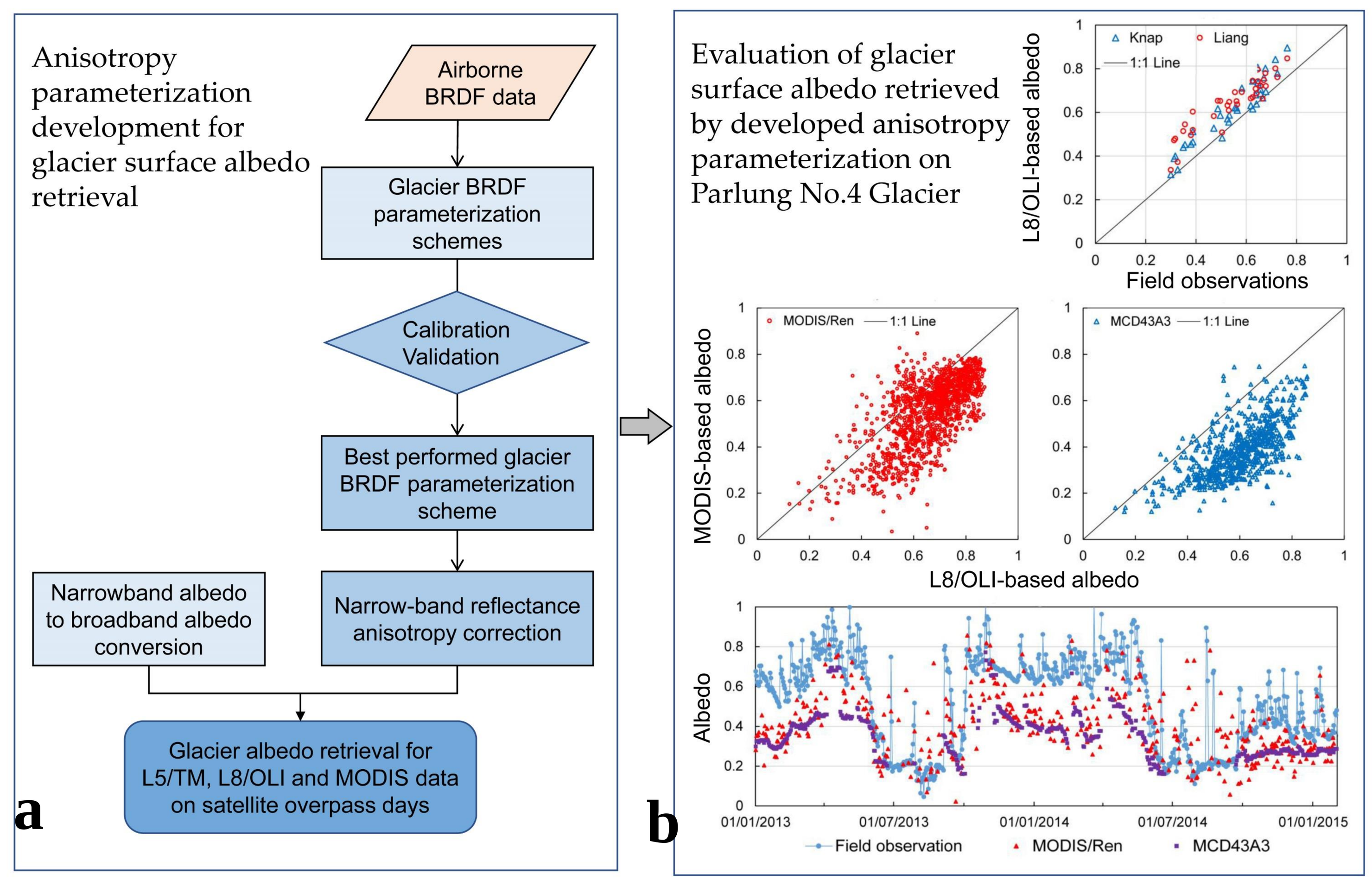

Fig. 4 . Anisotropy parameterization development for glacier surface albedo retrieval (a) and evaluation of glacier albedo on Parlung No.4 Glacier (b).

Fig. 4 shows that our developed model: (1) can accurately estimate anisotropic factors of re-flectance for snow and ice surfaces; (2) generally performs better than prior approaches for L8/OLI albedo retrieval but is not appropriate for L5/TM; (3) generally retrieves MODIS albedo better than the MODIS standard albedo product (MCD43A3) in both absolute values and glacier albedo temporal evolution, i.e., exhibiting both fewer gaps and better agreement with field observations.

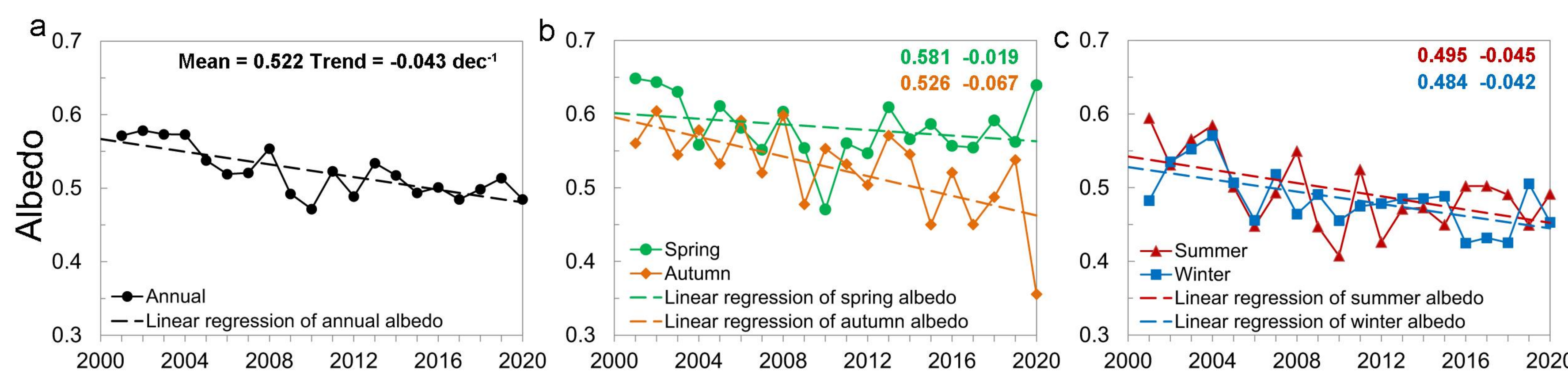

Figure 5. Time series of regional albedo for (a) annual and (b and c) four seasons in the WNM of the Tibetan Plateau during 2001–2020.

Fig. 5 shows that the glacier albedo experienced large inter-annual fluctuations, with the mean albedo being 0.552±0.002 and a clear decreasing trend of $0.04431 \pm 2.2 \times 10^{-4}$ dec^{-1} in the WNM. The differences in seasonal albedo are large. First of all, the spring and autumn albedos are higher due to longer snow retention in these two seasons. Secondly, all seasonal albedos decreased during the last 20 years (Fig. 3 and Table 2) but at different rates. Spring albedo showed the slowest decreasing rate, indicating an early start of the ablation season, while autumn albedo experienced the fastest reduction, indicating a delayed end of the ablation season.

CONCLUSIONS

These results demonstrate that the glacier in the WNM experienced a significant mass loss after 2000, especially in the recent years. At the same time, glacier albedo showed a clear decreasing trend, indicating more net shortwave radiation absorbed by the glaciers. This good consistence between albedo and mass balance shows decreasing albedo played a key role in glacier change in the WNM, however, further quantitative analysis of this relationships is needed.

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