Annual to seasonal glacier mass balance in High Mountain Asia from Pléiades stereo images: examples from Muztag Ata (Eastern Pamir) and Western Nyainqentanglha (Tibetan Plateau)

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Introduction

Glaciers are important sources of fresh water in particular for the arid lowlands surrounding High Mountain Asia. In order to better constrain glacio-hydrological models, annual or even better seasonal information about glacier mass changes is highly beneficial. In this study, we test the suitability of very high-resolution Pleiades DEMs to measure glacier-wide mass balance at annual and seasonal scales in two regions of High Mountain Asia (Mustag Ata massif in Eastern Pamir and parts of Western Nyainqentanglha, South-central Tibetan Plateau) where recent estimates have shown contrasting glacier behaviour (Bhattacharya et al., 2021

Objective

- In this study, we aim at providing a recent (2019-2022) glacier geodetic mass balance record of the Muztag Ata and Western Nyainqêntanglha districts at annual to seasonal scale, using 5 Pleiades DEMs over a 3-year period (Fig.1).

- We further aim to compare the geodetic results with ICESAT-2 measurements and a snowline-fed mass balance model.

Figure 1. Location of the study sites in High Mountain Asia. Sources: Holzer et al. (2015), Bolch et al. (2010).

Methods

- Pleiades DEMs with 4 m spatial resolution are build using the NASA Ames Stereo Pipeline (ASP, Shean et al., 2016).
- DEMs are coregistered (Nuth and Kääb, 2011) and subtracted to generate elevation change (*dH*) grids.
- Along- and across-track corrections are applied to remove spatially- dependent biases due to satellite oscillation (Deshamps-Berger et al., 2020) (Fig. 2).

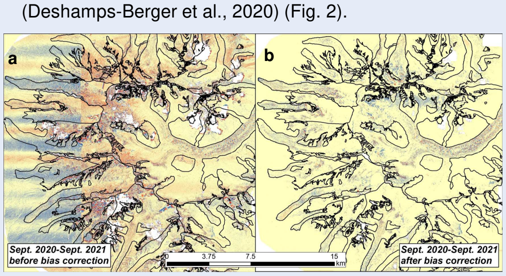

Figure. 2. *dH* maps of Muztag Ata showing the oscillation effect of satellite jitter. **(a)** DEM mosaicing and differencing **before** coregistration leads to diverse jitter effect on different satellite acquisitions (left and right parts of panel **(a)**. Panel **(b)** depicts the dH grids **after** bias-correction and final mosaicing.

- Outliers and data voids are removed and filled, respectively (Fig. 3).
- Snow and Ice masks are generated using image classification techniques and material densities are applied accordingly (Fig. 4) to obtain the glacier-wide mass balance.

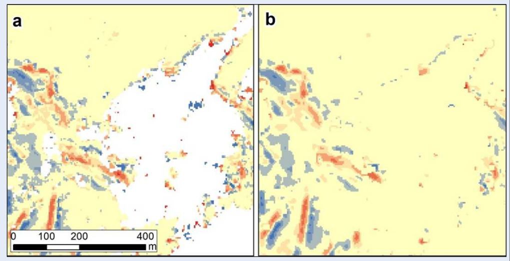

Figure 3. Removal of anomalous cells around data voids and subsequent filling using a 3-pixel buffer **(a)**. Whilst outliers remain, a larger buffer will remove valid cells **(b)**.

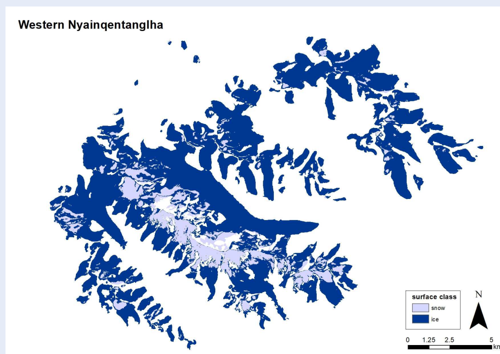

Figure 4. Supervised classification of ice and snow classes for the 11-20-2020 acquisition over Western Nyainqentanlha.

- Finally, uncertainties are calculated using the patch method (Wagnon et al., 2021).

Results

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- Annual mass balance in the Muztag Ata massif between 2019-2020 and 2020-2021 were -0.24 ±0.19 m w.e. a^{-1} and +0.17 ±0.35 m w.e. a^{-1}, respectively.
- On the contrary, annual mass balances in the Western Nyainqentanglha range for similar periods show highly negative conditions (-0.87 ±0.22 m w.e. a^{-1} and -0.52 ±0.11 m w.e. a^{-1}).

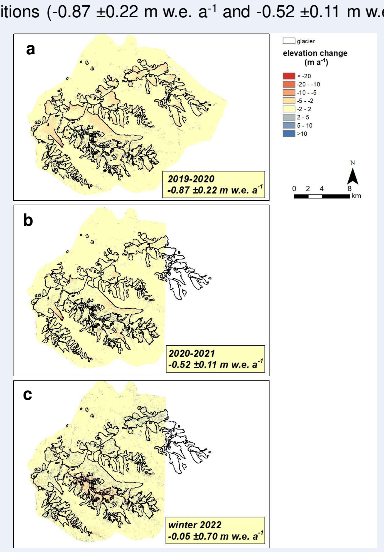

Figure 5. 2019-2022 *dH* maps over the Western Nyainqentanglha range at annual **(a-b)** and seasonal **(c)** scale.

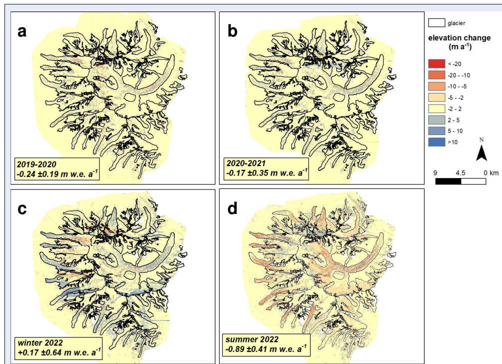

Figure 6. 2019-2022 *dH* maps over Muztag Ata at annual **(a-b)** and seasonal (**c-d**) scale.

Discussion

- In the Western Nyainqentangla range, the 2019-2020 and 2020-2021 mass budgets suggest much higher mass loss rates when compared to the previous six decades.
- With some limitations due to the high uncertainty, the Western Nyainqentanlha winter mass balance estimate (-0.05 ±0.70 m w.e. a^{-1}) does not show any mass recovery.
- The mass balance estimates between 2019 and 2021 for the Muztag Ata massif suggest a greater variability in mass budget than previously acknowledged in the region.
- In addition, the 2022 winter (+0.17 ±0.64 m w.e. a^{-1}) and summer (-0.89 ±0.41 m w.e. a^{-1}) budget provides provisional evidence for a winter accumulation regime, though mass balance uncertainties are high.

Conclusions

- In this study, we have evaluated the capability of very high-resolution Pleiades DEMs to quantify annual and seasonal mass balance in selected sites of High Mountain Asia using the geodetic method.
- Sources of uncertainty include the DEM quality, the ability to consistently map snow and ice areas on glacier surfaces, density assumptions as direct measurements are unavailable.
- Whilst the Pleiades DEMs have proven suitable to quantify both annual and seasonal mass balances, associated uncertainties are high in some cases.
- Further work will focus on using additional data (such as ICESat-2) and methods (such as snowline-derrived mass balance estimates) to reduce the uncertainty

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