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Can ice cliffs explain the "debris-cover anomaly"? New insights from Changri Nup Glacier, Nepal

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Motivations

Ice cliffs are **major contributors** to debris-covered glacier mass loss [Buri et al., 2016] and exhibit **highly variable** temporal changes [e.g. Thompson et al., 2016; Watson et al., 2017]. Our goal is to quantify the **total contribution** of ice cliff retreat to the tongue net ablation of Changri Nup glacier and of other debris-covered glaciers of the Everest region between **Nov. 2015, Nov. 2016 and Nov. 2017**.

Study area

Datasets

- **Terrestrial photogrammetry** — < 5 cm — 10 000 m²
- **UAV** — 20 cm — 10 km²
- **Pléiades DEM** — 2 m — 150 km²

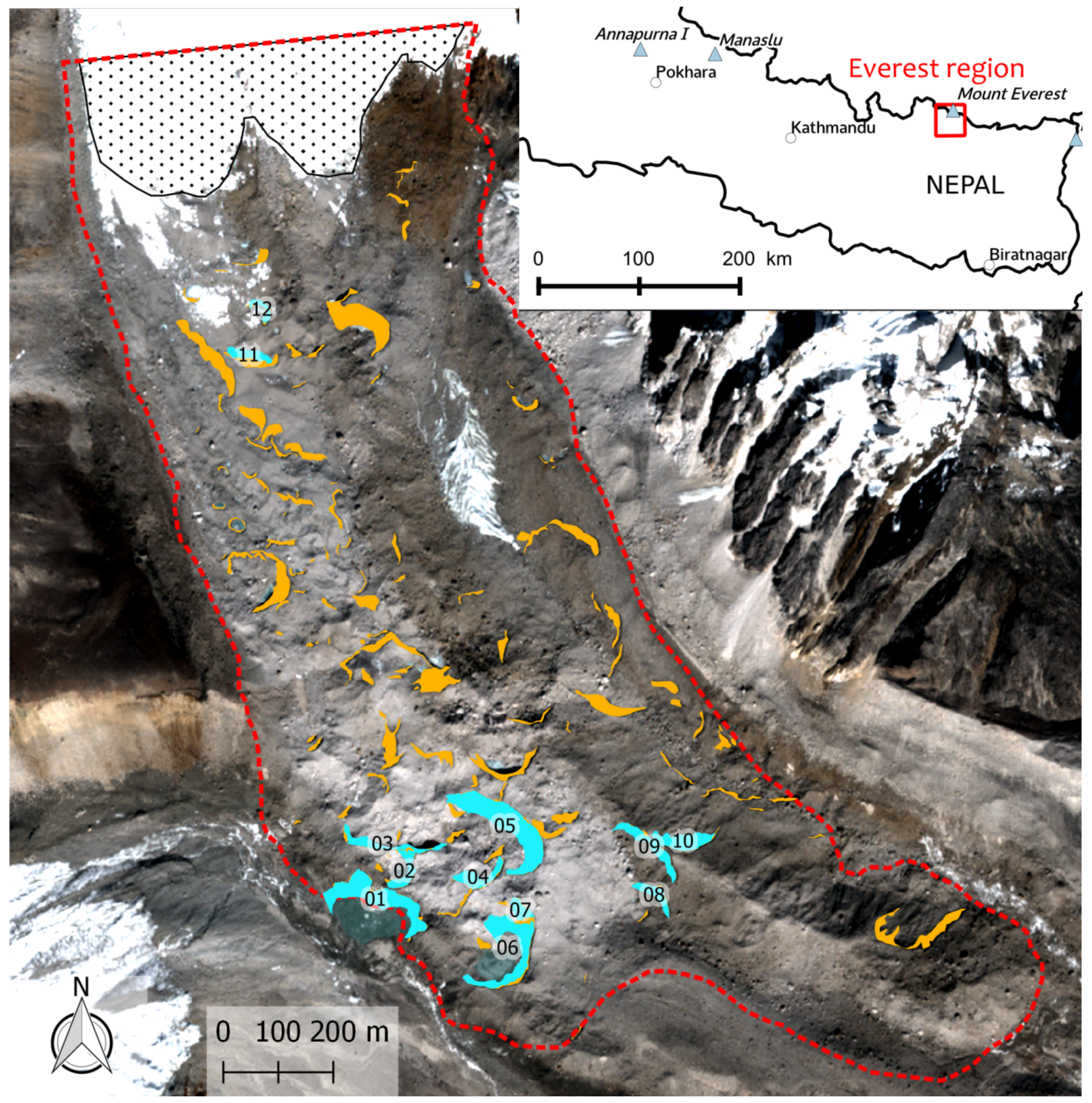


Fig. Map of the study area. The light blue shapes are the twelve cliffs surveyed with the terrestrial photogrammetry and the orange shapes are all the other cliffs of the tongue. The background image is the Pléiades images of November 2016 (copyright:CNES 2016, Distribution Airbus D&S).

Glacier flow correction: the importance of the emergence velocity

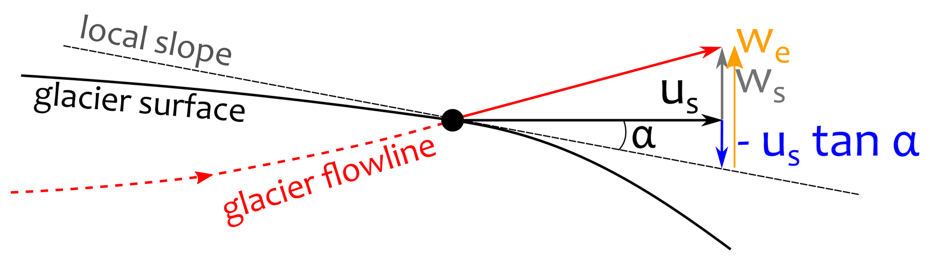


Fig. 3D displacement of the glacier surface

Using a **flux-gate approach**, it is possible to calculate the mean glaicer tongue **emergence velocity** (0.33 m/yr). The surface horizontal velocity (up to ~12 m/yr) was measured with Pléiades images correlation.

We assumed spatially constant emergence velocity and applied a glacier flow correction to each datapoint of the point clouds.

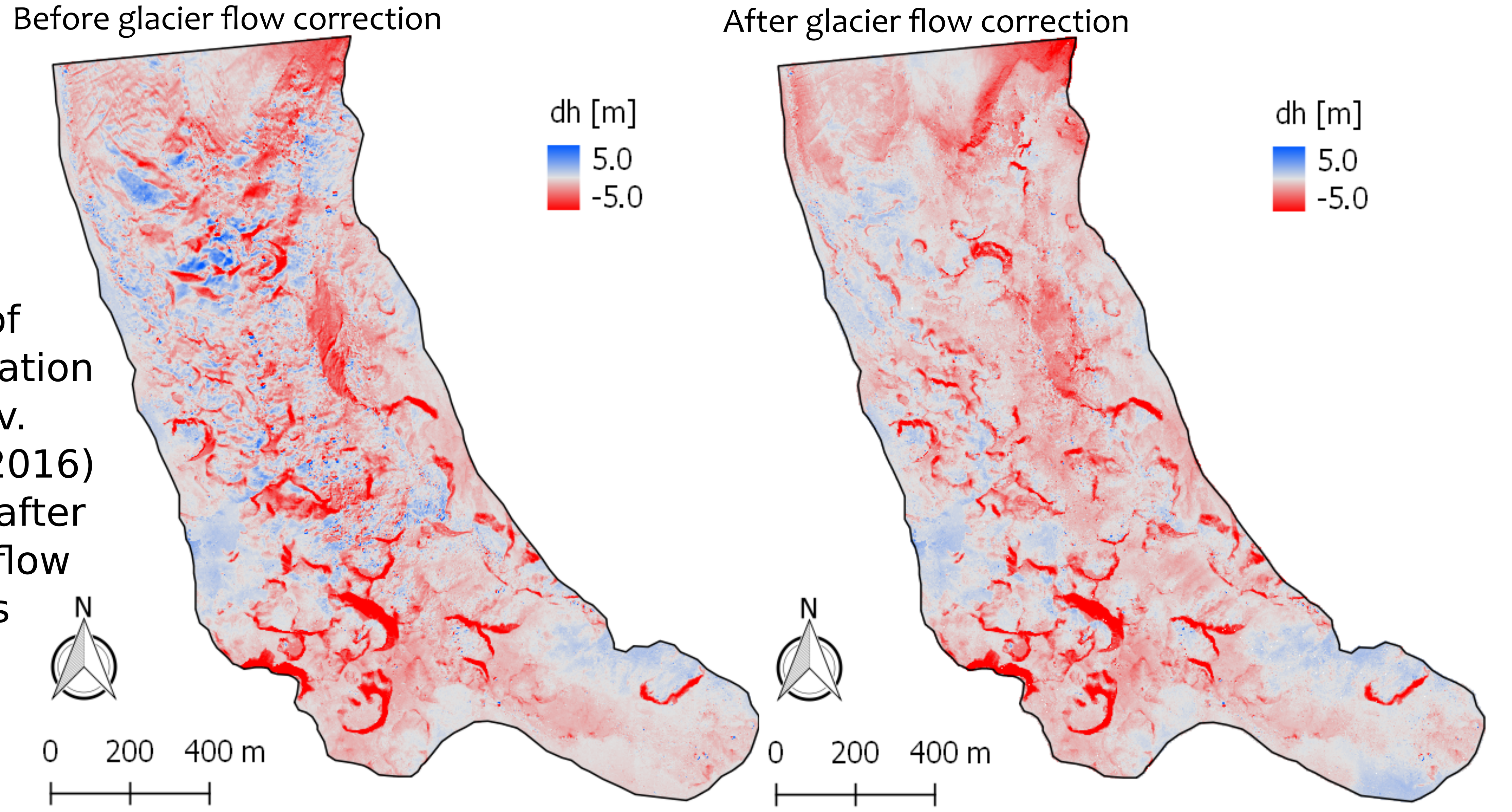


Fig. maps of glacier elevation change (Nov. 2015-Nov. 2016) before and after the glacier flow correction is applied

Total contribution of ice-cliff backwasting

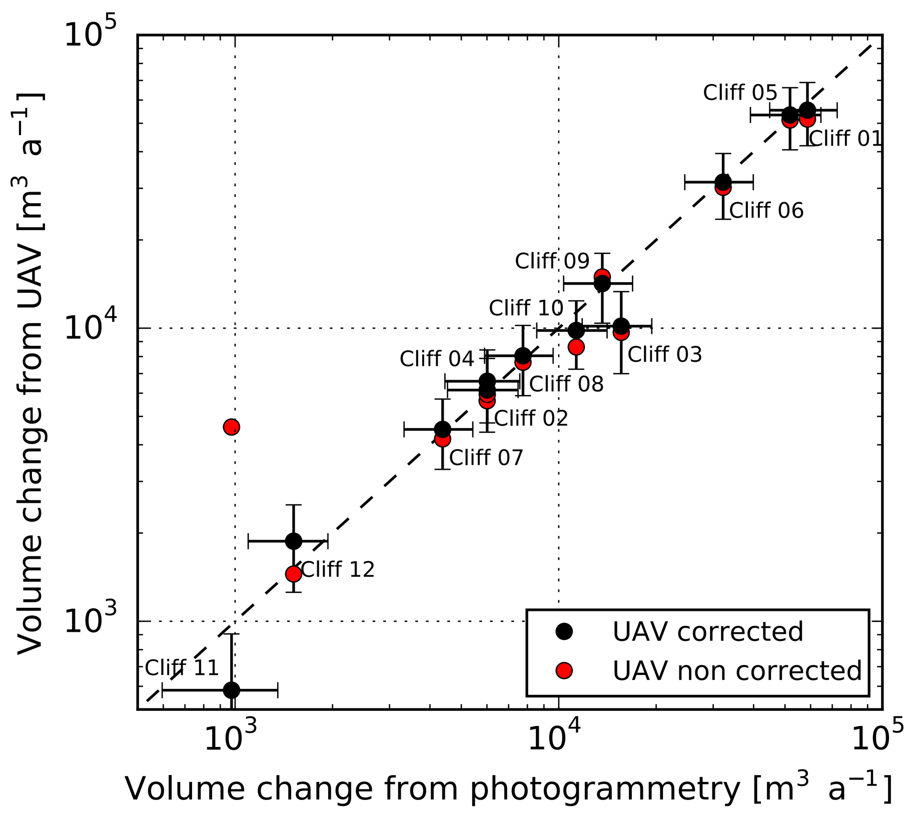


Fig. comparison between volume loss estimated from the terrestrial photogrammetry and the UAV data for the twelve field surveyed cliffs

We **validated** the volume loss calculation obtained from UAV DEMs with the volume loss calculated from the terrestrial photogrammetry [Brun et al., 2016]. For the period November 2015 to November 2016 and Novemebr 2016 to November 2017, ice cliffs contributed to **23 +/- 5 % of the total tongue net ablation**, even though they occupied only 7-8 % of its surface. The mean ablation rate for the ice-cliffs is **3 times higher** than the mean glacier tongue ablation rate. This study provides the first estimate of ice-cliff volume loss at the scale of a glacier tongue based on UAV and Pléiades DEMs (and field monitoring for the ice thickness).

Ice cliffs and the "debris-cover anomaly"

Vincent et al. (2016) showed that the ablation was reduced on the debris-covered tongue of Changri Nup Glacier, compared with a neighboring debris-free tongue. We calculated that the cliffs should occupy 75 % of the tongue surface to achieve the same ablation rate than a debris-free tongue, under similar conditions. Similar thinning rates between debris-free and debris-covered tongues are likely due to the fact that the combination of reduced emergence velocities and lower ablation over debris cover tongues coincidently sum up to similar thinning rates as debris-free glaciers.

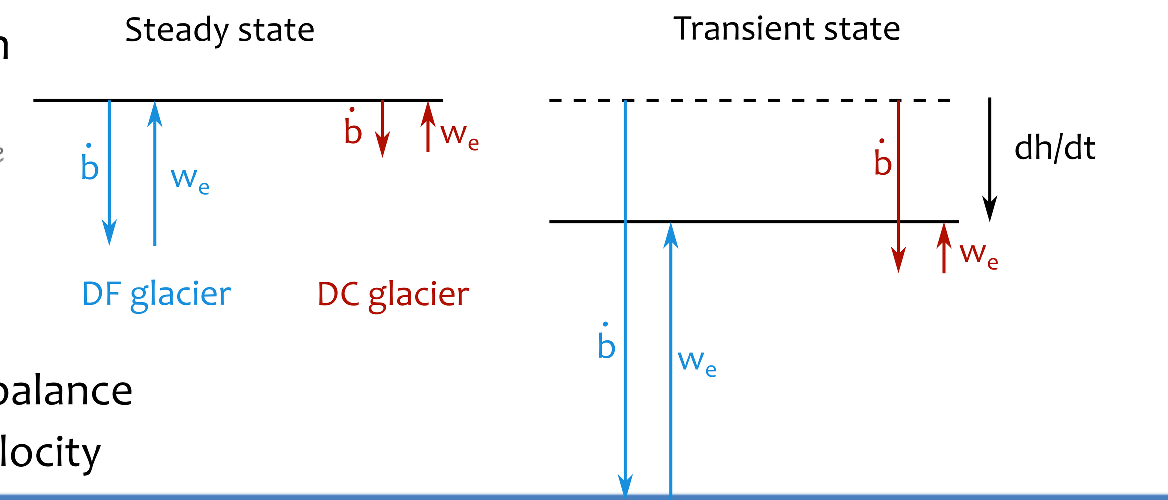
Continuity equation

$$\frac{\overline{\partial h}}{\partial t} = -\frac{1}{\rho}\dot{b} + w_e$$

$\frac{\overline{\partial h}}{\partial t}$ thinning rate

$\dot{b}$ surface mass balance

w_e emergence velocity



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