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# Evaluation of snow depth retrievals from ICESat-2 using airborne laser-scanning data

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**Table S1.** Statistics of the co-registration statistics between the external DEMs and the ICESat-2 snow-off DEM.

| Digital Elevation Model (DEM) | Horizontal vector | | Elevation residual | | | | |
|---|---|---|---|---|---|---|---|
| | Easting | Northing | Mean | Median | Mode | NMAD before | NMAD after |
| Airborne lidar (ASO) - 15 m | -0.18 | 0.44 | 1.28 | 0.76 | 0.20 | 1.28 | 1.28 |
| Sat. Photogrammetry (Pléiades) - 15 m | -4.37 | -3.56 | 3.9 | 3.95 | 4.15 | 1.96 | 1.47 |
| Copernicus DEM - 30 m | 0.50 | -2.15 | -1.93 | -1.22 | -0.80 | 2.83 | 2.82 |

**Table S2.** Statistics of the snow depth residuals for different snow-off Digital Elevation Models (DEMs) on 12 March 2019. The *ICESat-2-ASO* product is shown in detail on Figure 3. All residuals are shown in Figure 5 and S4.

| Snow depth product name | Snow-off DEM source | ASO snow depth | NMAD (m) | RMSE (m) | Mean (m) | Median (m) | Number of points |
|---|---|---|---|---|---|---|---|
| IS2-ASO | Airborne lidar (ASO) – 15 m | 15 m | 1.00 | 1.41 | 0.22 | -0.00 | 5449 |
| IS2-Pléiades | Sat. Photogrammetry (Pléiades) – 15 m | 15 m | 1.08 | 2.06 | -0.80 | -0.53 | 1294 |
| IS2-Copernicus | Copernicus DEM – 30 m | 15 m | 3.00 | 5.89 | -1.80 | -0.53 | 5449 |

**Table S3.** Statistics of the co-registration statistics between the Pléiades and Copernicus DEMs to the ASO DEM at15 m. All these DEMs were previously co-registered to the ICESat-2 snow-off points.

| Digital Elevation Model (DEM) | Horizontal vector | | Elevation residual | | | | |
|---|---|---|---|---|---|---|---|
| | Easting | Northing | Mean | Median | Mode | NMAD before | NMAD after |
| Sat. Photogrammetry (Pléiades) – 3 m | -0.55 | -0.44 | 1.56 | 1.29 | 1.15 | 1.15 | 1.11 |
| Copernicus DEM – 30 m | 0.72 | -1.18 | 1.38 | 0.48 | -0.65 | 2.79 | 2.67 |

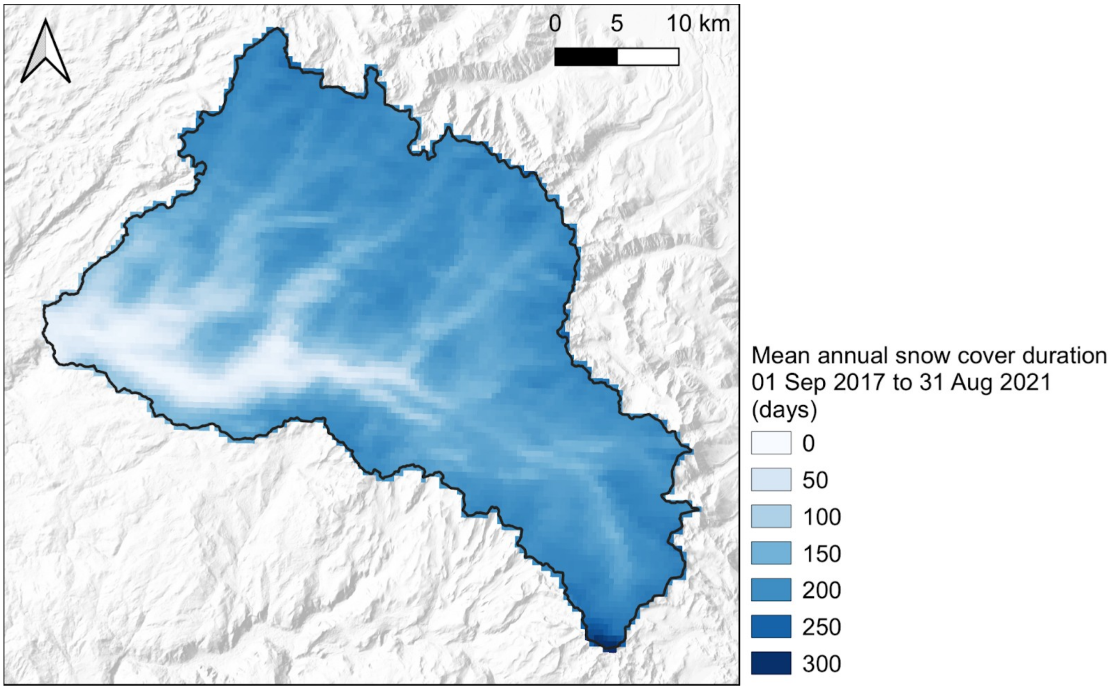


**Figure S1**. Map of the mean annual snow cover duration in the upper Tuolumne basin calculated from a time series of MODIS images (MOD10A1).

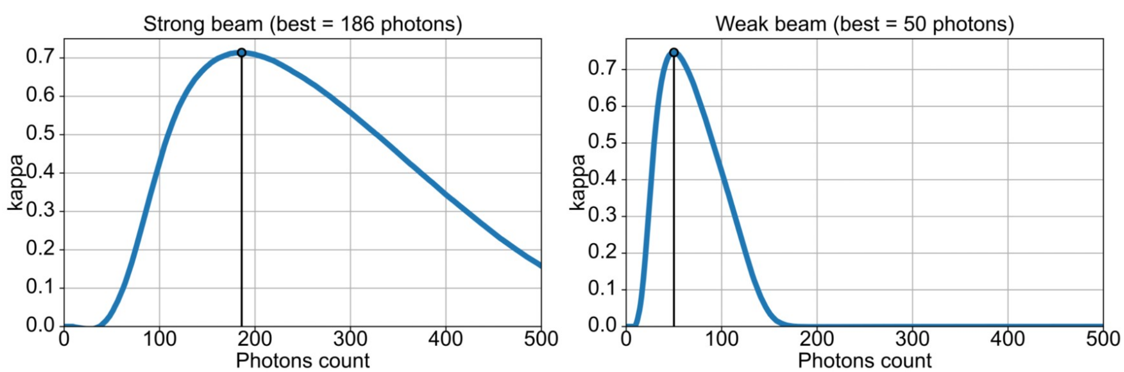


**Figure S2.** Optimization of the kappa index to determine the photon count threshold defining snow-on and snow-off points based on MODIS snow cover area data.

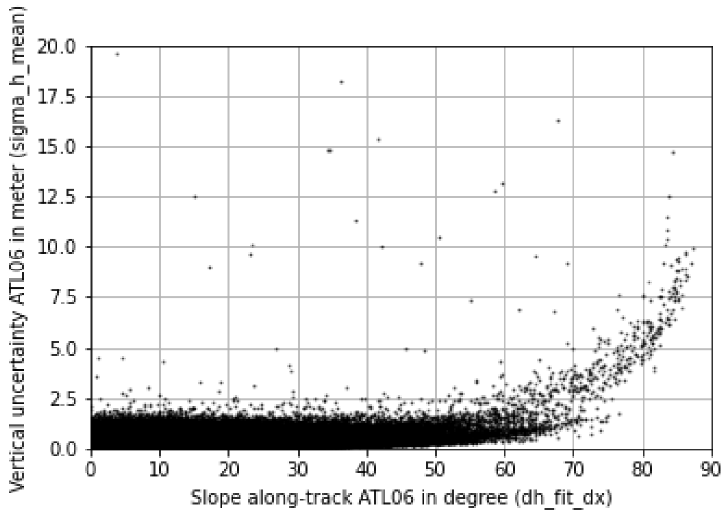


**Figure S3.** Vertical uncertainty of the ATL06 elevation (*sigma_h_mean*) against along-track slope (*dh_fit_dx*). The along-track slope (*dh_fit_dx*) is directly provided in ATL06.

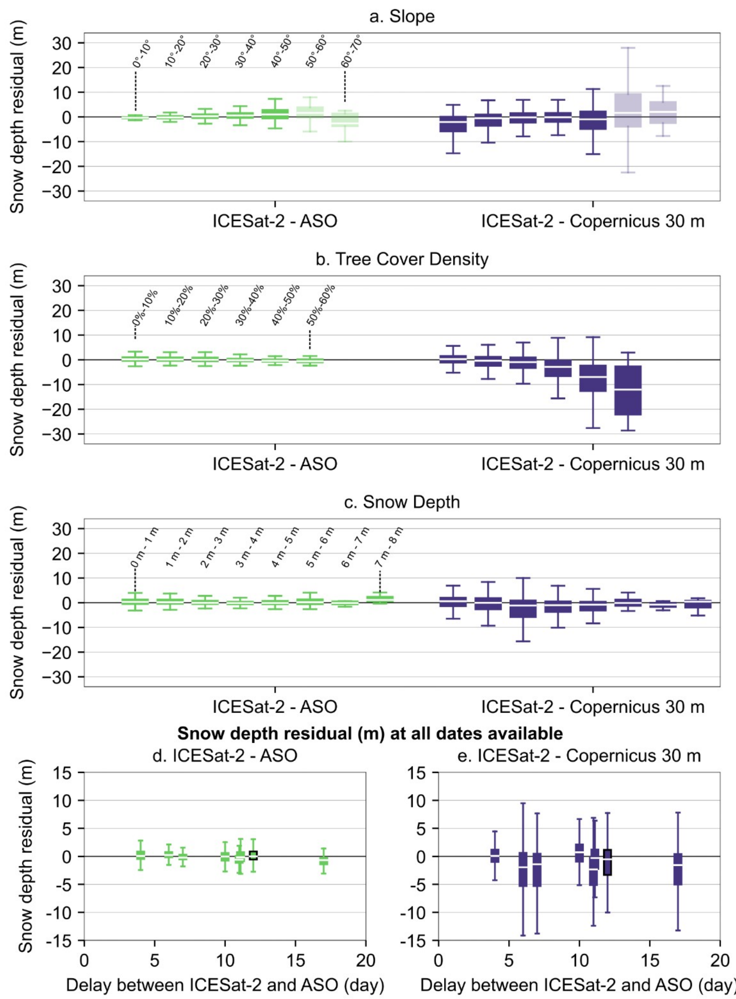


**Figure S4.** Same figure as Figure 5 but with snow depth derived from ICESat-2 and the ASO DEM (green, identical to Fig. 5) and ICESat-2 and the Copernicus DEM (purple). Note the different y-scale compared to Figure 5.

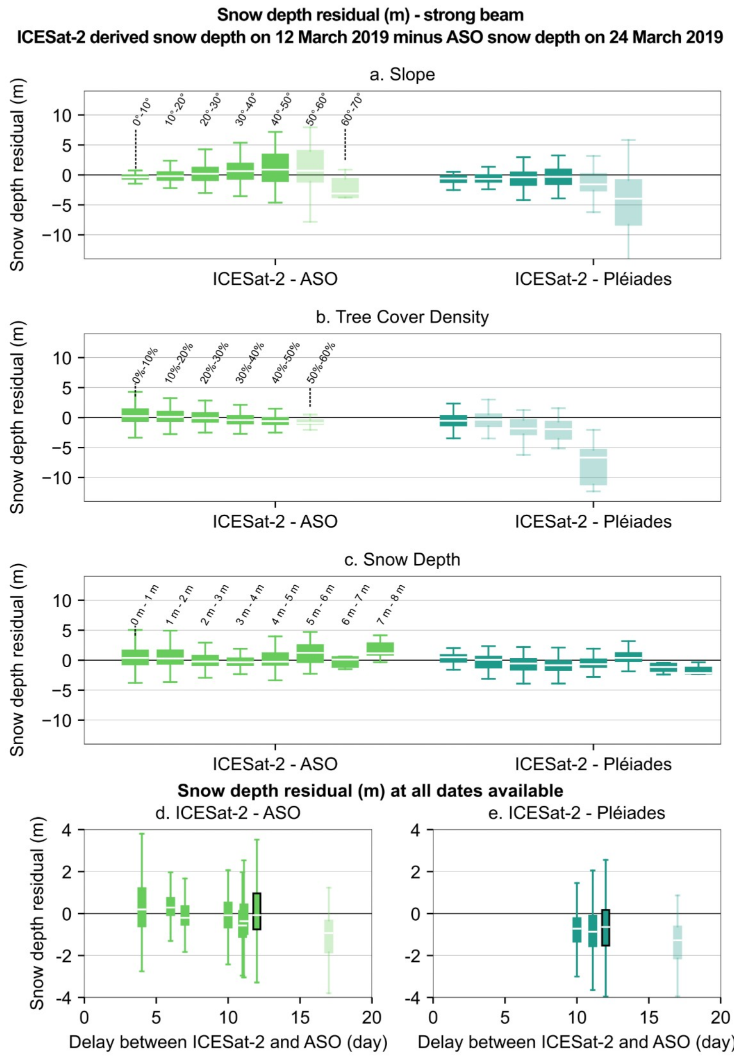


**Figure S5.** Same as Figure 5 but selecting ICESat-2 ATL06 snow-on points of the strong beams only.

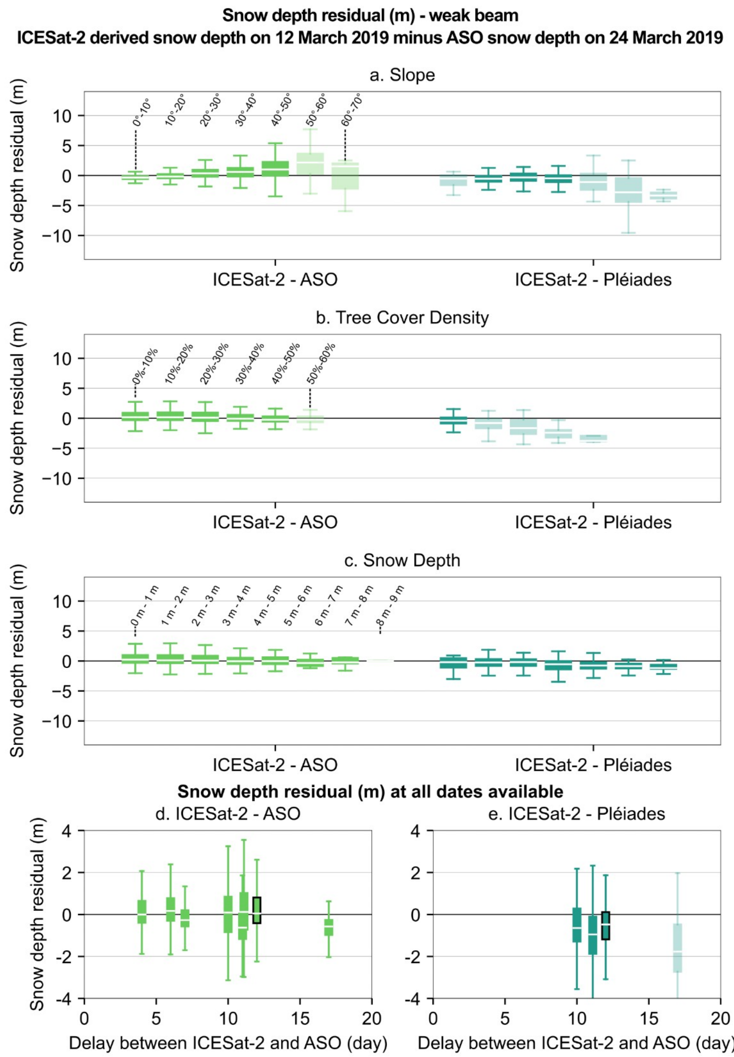


**Figure S6.** Same as Figure 5 but selecting ICESat-2 ATL06 snow-on points of the weak beams only.

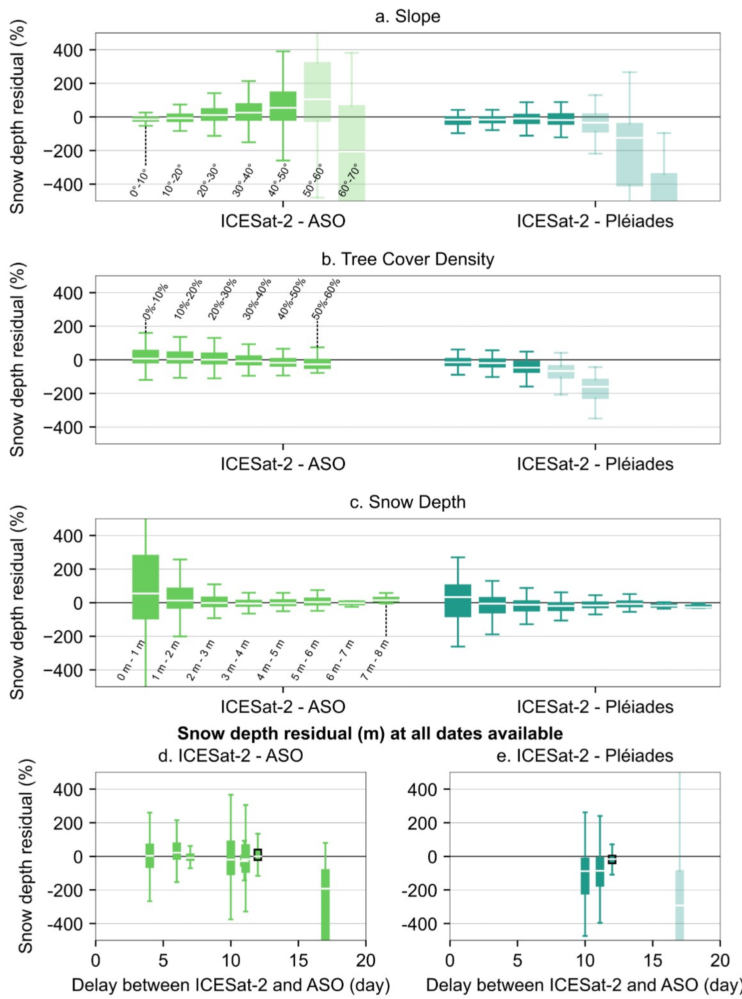


**Figure S7.** Same as Figure 5 but calculating the relative snow depth error (ICESat-2 derived snow depth minus ASO snow depth divided by ASO snow depth) rather than the absolute snow depth error (ICESat-2 derived snow depth minus ASO snow depth).

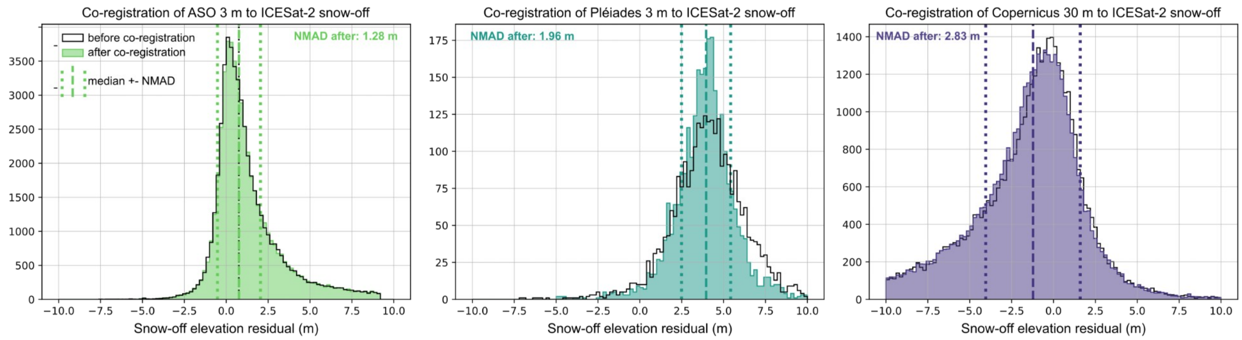


**Figure S8.** Distribution of the snow-off residual (ICESat-2 minus DEM) before (black line) and after coregistration (color) for the ASO DTM (left), the Pléiades DEM (middle) and the Copernicus DEM (right). The vertical lines show the median plus/minus the NMAD after co-registration.

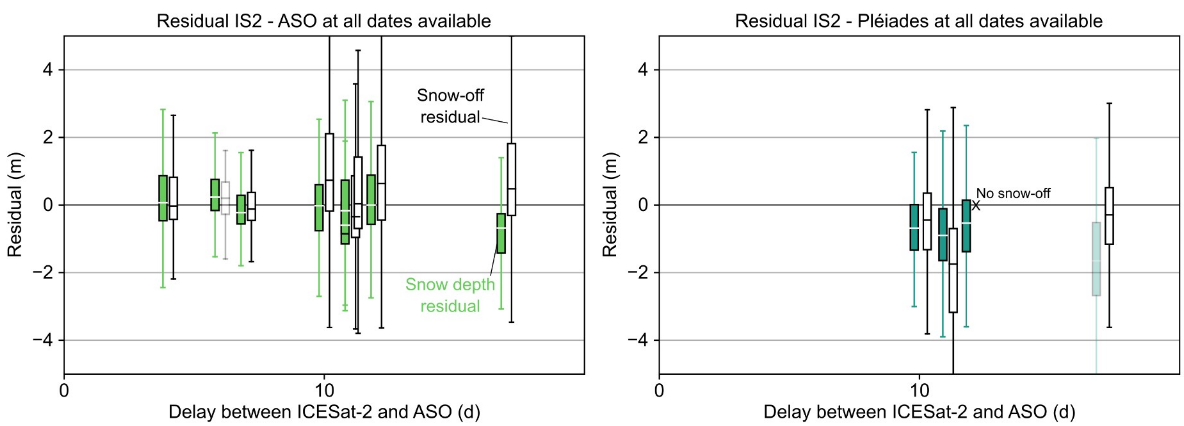


**Figure S9.** Snow depth (colored boxes) and snow-off (white boxes) residuals for ICESat-2 – ASO (left) and ICESat-2 – Pléiades (right). Transparent boxplots show the data where less than 100 points were available.

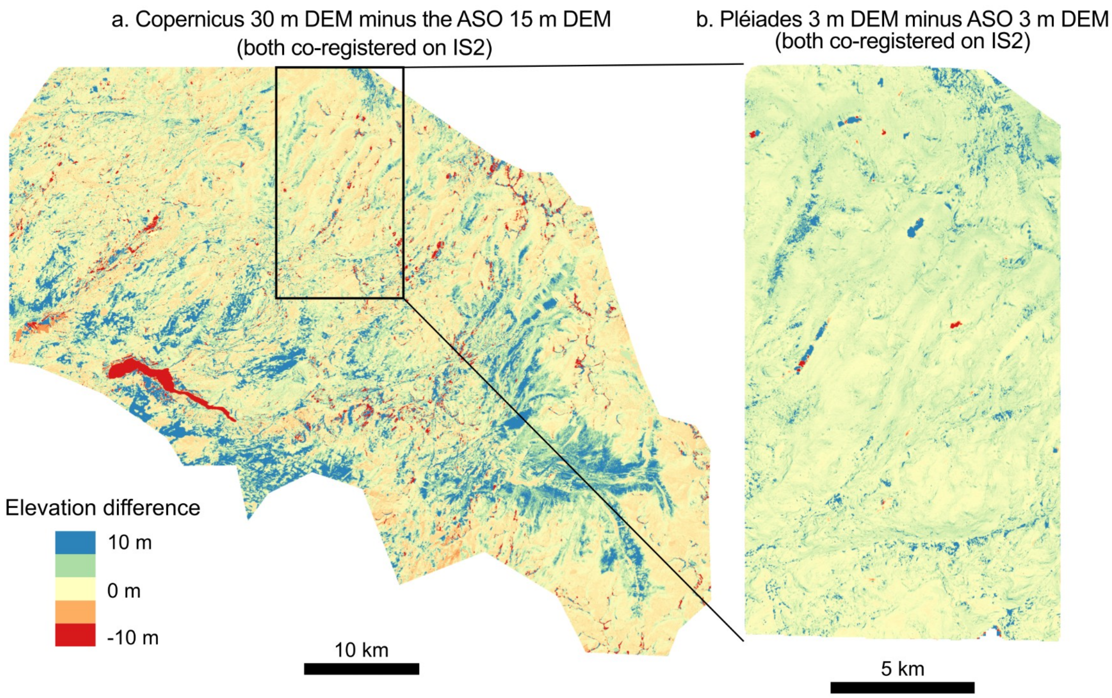


**Figure S10.** Elevation difference of the snow-off DEMs, the difference between the Copernicus 30 DEM and the ASO DEM (a) and the Pléiades DEM and the ASO DEM (b). All DEMs were individually co-registered on the ICESat-2 snow-off points.

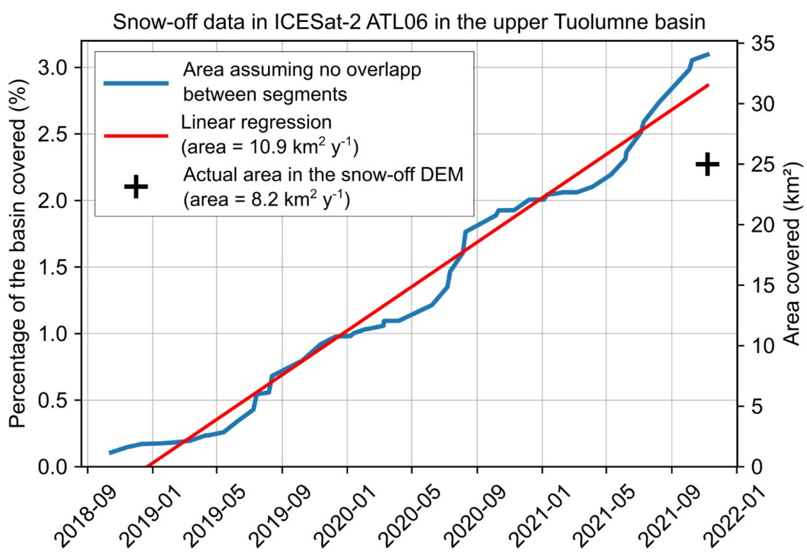


**Figure S11.** Surface without snow available in ATL06 since the start of the acquisition (blue) and the related linear regression (red). Each segment of ATL06 is assumed to cover a square of 15 m by 15 m. Segments are assumed to not overlap which is an acceptable assumption for the first years of acquisitions.