nature portfolio

https://doi.org/10.1038/s41561-021-00885-z

## Supplementary information

# Ice velocity and thickness of the world's glaciers

In the format provided by the authors and unedited

# Supplementary Information for “Ice velocity and thickness of the world’s glaciers”

Romain Millan[1,2,*], Jérémie Mouginot[1,3], Antoine Rabatel[1], Mathieu Morlighem[3,4]

[1] Université Grenoble Alpes, CNRS, IRD, Grenoble INP, IGE, Grenoble, France
[2] Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark
[3] Department of Earth System Science, University of California Irvine, Irvine, CA
[4] Department of Earth Sciences, Dartmouth College, Hanover, NH, USA

*To whom correspondence should be addressed: romain.millan@univ-grenoble-alpes.fr

## This document contains :

- Figure S1-S13
- Table S1-S3

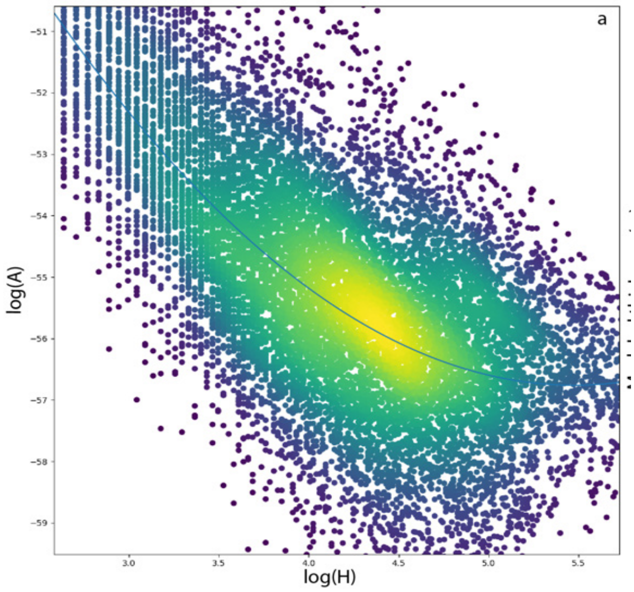


**Figure S1**. **Calibration of the A value in the case of the European Alps using a quadratic fit**.

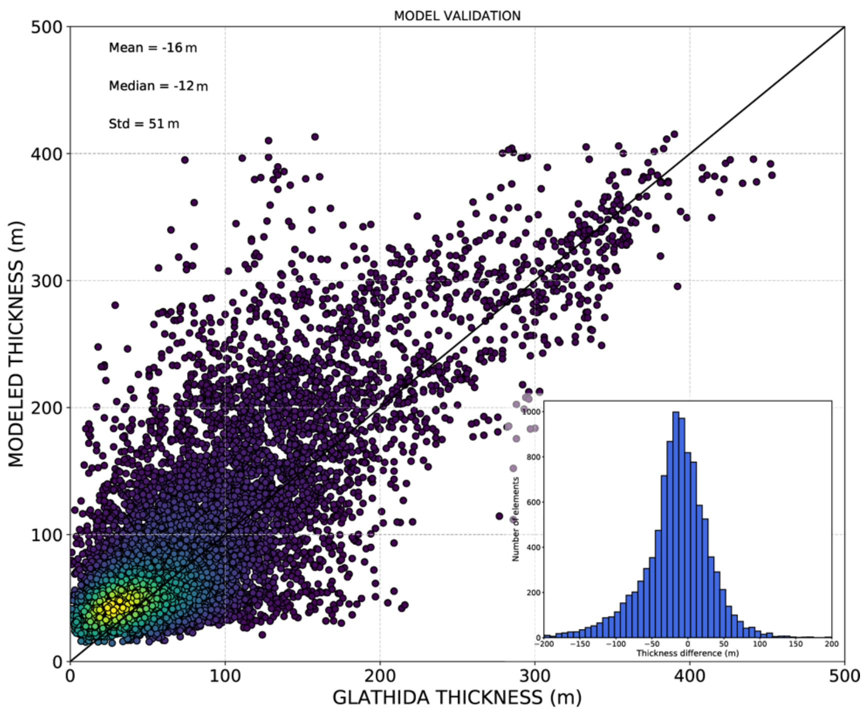


**Figure S2. Validation of the ice thickness model over the European Alps.** The graph represents the modeled vs. observed ice thicknesses that were not used for the calibration. Inset shows the mean, median and standard deviation of the difference between observed and calculated thicknesses in meters.

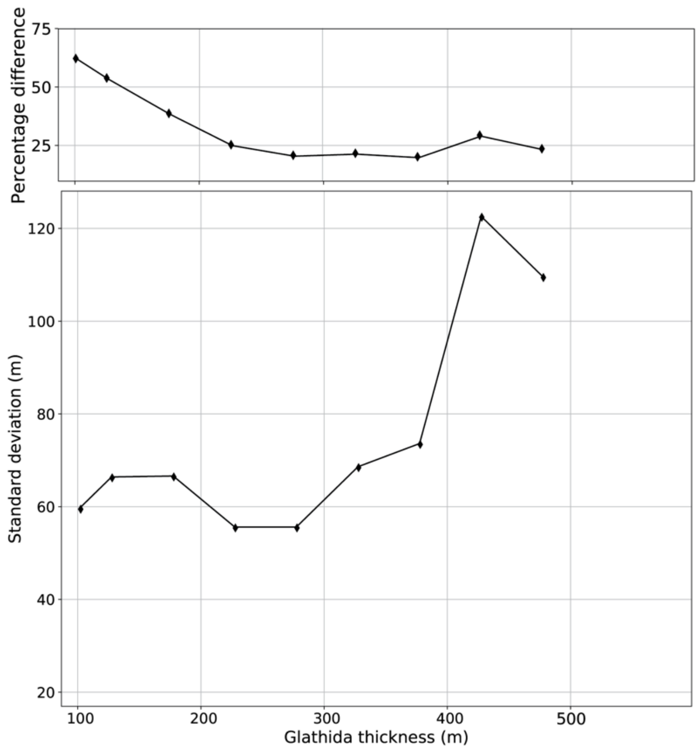


**Figure S3.** Bottom: Standard deviation of the difference between modeled and observed ice thickness for different thickness bins over the European Alps. Top: Error percentage as a function of the observed ice thickness.

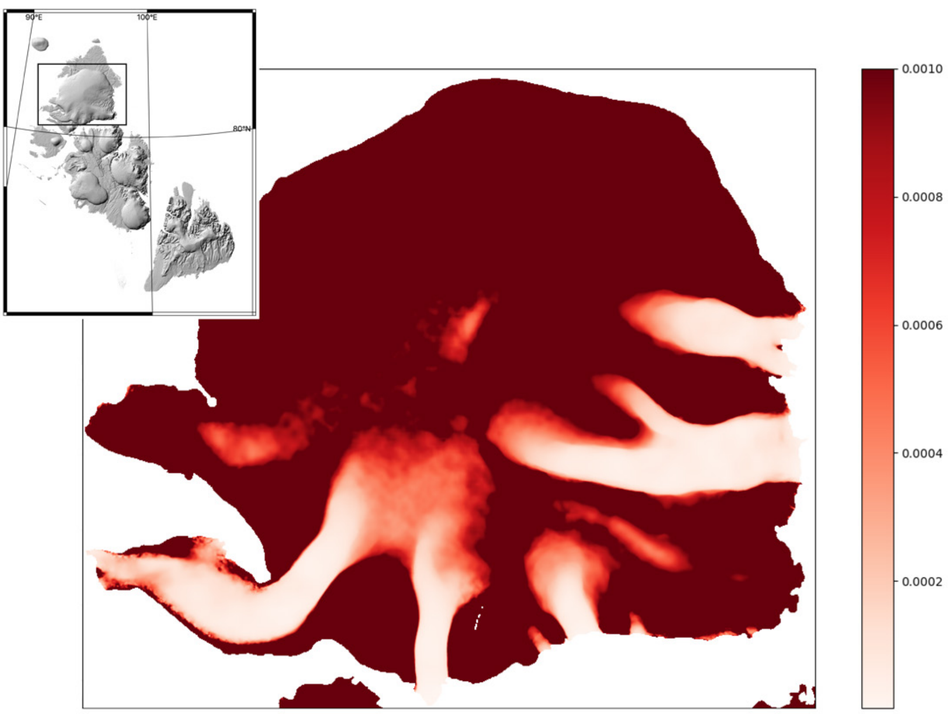

**Figure S4.** Ratio of the slope and surface velocity (units of yr.m$^{-1}$) over Academy of Science ice cap (Russian Arctic), color coded from red to white.

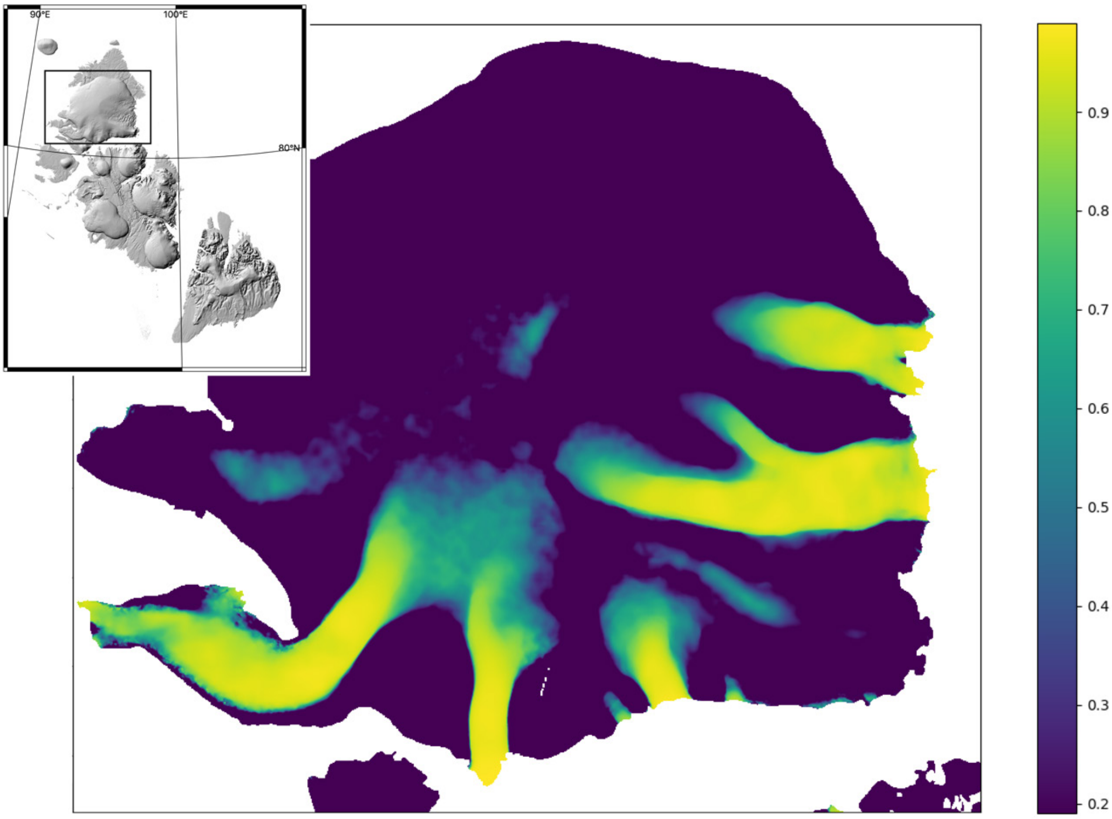


**Figure S5.** Value of the β parameter over Academy of Science ice cap (Russian Arctic), color coded from blue (10% sliding) to yellow (90% sliding).

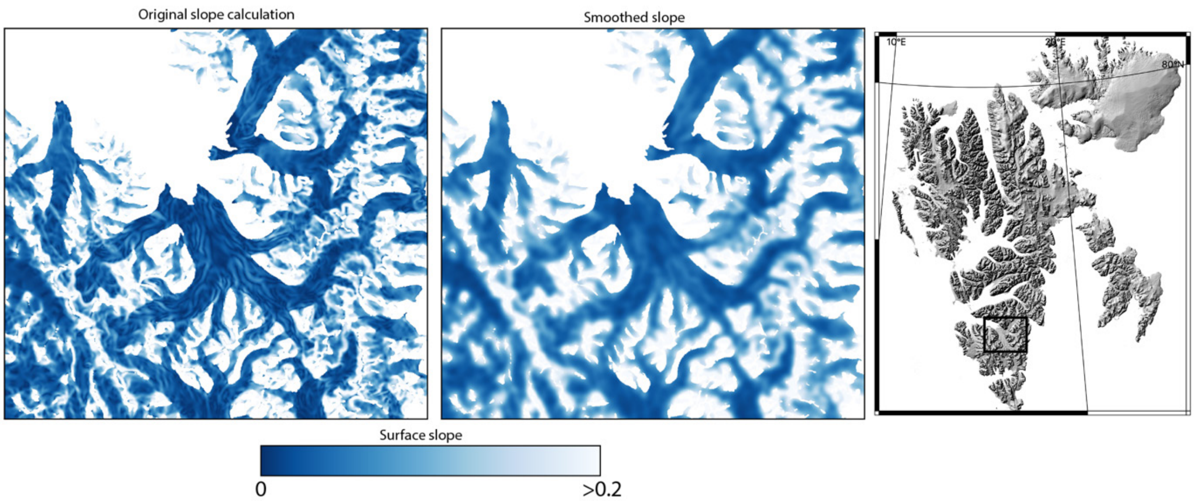


**Figure S6.** Slope calculation over the Svalbard, close to the Nathorstbreen region. Left panel: Original rough slope map. Middle panel: Smoothed slope map. Right panel: inset map showing a shaded version of the TanDEM-X global DEM with a rectangle indicating the location of the slope maps.

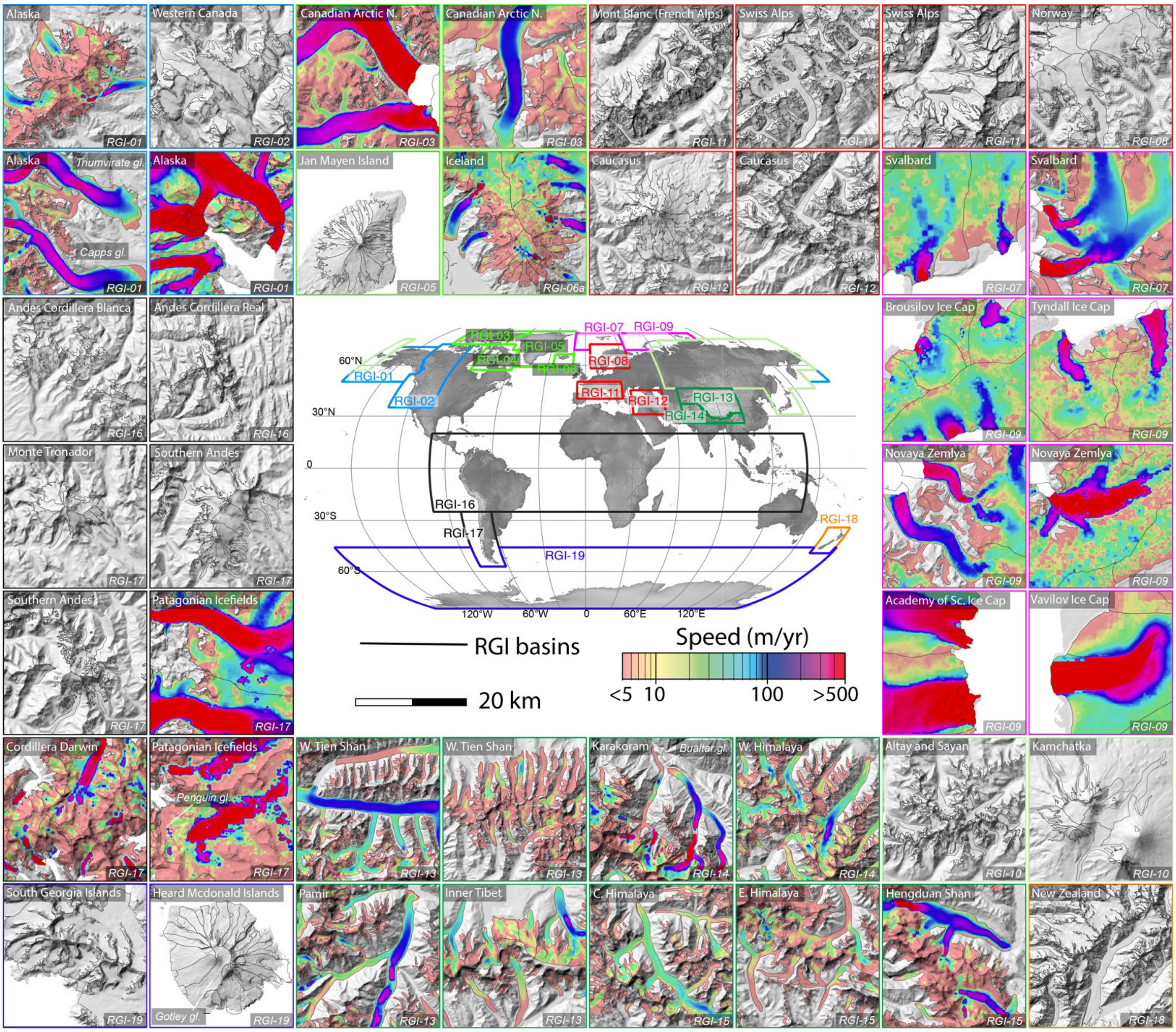


**Figure S7.** NASA's MEaSUREs ITS_LIVE[1] Ice velocity of the world's glaciers (https://its-live.jpl.nasa.gov/). Center world map illustrates the coverage by Randolph Glacier Inventory region [4]. For regions where no mapping exists, we only display the DEM in shaded relief. The 44 panels represent 25x25 km portions of ice velocity for the different RGI regions color coded on a logarithmic scale overlaid on shaded relief. RGI regions have been assigned a specific color that is also used for the frames of the ice velocity panels.

| Differences (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **RGI Region** | **Farinotti 2019** | **Radic et Hock 2010** | **Huss and Farinotti 2012** | **Marzeion 2012** | **Grinsted 2013** | **Radic 2014** | **Consensus Estimate 2019** | **Average of other studies** | **Average difference** |
| 1 and 2 | 0.3 | -31.5 | -6.3 | -37.9 | 6.0 | -31.1 | -4.4 | -23.4 | -18.4 |
| 3 | -6.0 | -66.8 | -22.6 | -36.1 | 7.3 | -52.1 | -10.4 | -43.7 | -28.8 |
| 4 | -14.6 | / | -25.1 | -12.1 | 20.0 | -21.4 | -18.6 | -12.7 | -12.1 |
| 5 | -21.1 | -30.6 | -35.0 | 11.6 | -34.5 | -27.7 | -24.8 | -26.3 | -23.5 |
| 6 | 3.7 | -20.0 | -11.8 | -23.9 | 11.1 | 47.5 | -1.2 | -5.2 | 0.0 |
| 7 | -1.6 | -28.5 | -24.3 | -17.6 | 37.4 | -19.5 | -6.4 | -15.3 | -9.5 |
| 8 | 4.6 | 46.4 | 22.0 | 22.0 | -8.5 | 46.4 | -3.7 | 22.0 | 18.9 |
| 9 | 11.0 | -8.2 | -3.4 | -31.2 | 19.8 | -8.4 | 5.9 | -9.2 | -2.9 |
| 10 | 0.0 | -30.9 | 0.0 | -53.9 | -44.7 | -60.5 | -22.1 | -44.7 | -32.1 |
| 11 | 0.0 | -41.1 | 0.0 | 0.0 | 0.0 | -1.9 | -10.6 | -13.4 | -8.4 |
| 12 | -30.3 | -30.3 | 0.0 | -30.3 | -30.3 | -30.3 | -8.3 | -22.6 | -22.8 |
| 13-14-15 | 40.9 | -20.9 | 3.1 | -15.2 | -34.2 | -23.2 | 33.9 | -19.8 | -4.4 |
| 16 | -8.0 | -77.0 | -38.7 | -69.3 | -38.7 | -69.3 | -27.4 | -64.6 | -49.1 |
| 17 | 15.5 | -24.0 | -7.4 | 20.2 | 30.7 | -9.7 | 10.1 | -2.0 | 4.2 |
| 18 | -9.8 | -9.8 | -9.8 | 0.0 | -39.9 | -9.8 | 1.7 | -18.0 | -11.9 |
| 19 | -20.8 | -38.2 | -1.9 | | 21.7 | -24.4 | -24.6 | -16.4 | -14.9 |
| **Total** | **-7** | **-39** | **-13** | **-26** | **4** | **-30** | **-11** | **-17** | **-17** |

**Table S1.** Percentage difference of this study relative to other global estimations of ice volume[2,2–7]. Average of other studies indicates the average difference outside of the consensus estimate. Average difference includes the consensus estimate. Comparison is based on the sea-level equivalent before correcting for the ice located below sea level. Blue color indicates negative differences, while yellow color indicates positive differences. Column "Farinotti 2019" is based on the Table S2 from their study (same weight for every region), whereas column "Consensus Estimate 2019" is based on the conversion of their volume into sea level equivalent using identical ice density values as the one used in our study.

| RGI | Mean | Median | Std |
|---|---|---|---|
| 1 | -4.0 | 3.0 | 177.0 |
| 2 | 0.5 | -1.25 | 61.5 |
| 3 | 12.0 | 1.0 | 159.0 |
| 4 | -11.0 | 1.0 | 132.5 |
| 5 | 6.8 | 7.7 | 134.0 |
| 6 | 8.0 | 1.0 | 103.0 |
| 7 | -2.0 | 1.0 | 90.0 |
| 8 | 26.0 | 5.5 | 97.5 |
| 9 | -16.0 | 110.0 | 110.0 |
| 10 | 1.0 | 0.0 | 17.0 |
| 11 | -14.0 | -7.0 | 55.0 |
| 12 | 21.0 | 9.0 | 58.0 |
| 13+14+15 | 12.0 | 12.0 | 75.0 |
| 16 | -13.0 | -12.0 | 17.0 |
| 17 | 12 | 5 | 37 |
| 18 | 5 | 6 | 63 |
| 19 | / | / | / |
| **Total** | **2.8** | **8.9** | **86.7** |

**Table S2.** Comparison of our thickness estimates with in-situ ice thickness data from GlaThiDa[8]. For ice thickness statistics in the Antarctic periphery (19) refer to *Morlighem et al.*, 2021.

| Region | Number | Area in $km^2$ (% of the RGI region) | Volume in $km^3$(% of the RGI region) |
|---|---|---|---|
| RGI-1-2 | 4 | 2449 (2) | 536 (3) |
| RGI-3 | 6 | 5024 (5) | 1198 (5) |
| RGI-7 | 14 | 2943 (9) | 1010 (14) |
| RGI-9 | 1 | 354 (1) | 157 (1) |
| RGI-13-15 | 73 | 3991 (3) | 688 (7) |
| **Total** | 98 | 14761 (2) | 3589 (2) |

**Table S3.** Inventory of surging glaciers over the period 2015-2019, and respective area and volume estimation by RGI regions. This inventory is based on surface elevation changes patterns from *Hugonnet et al.*[10].

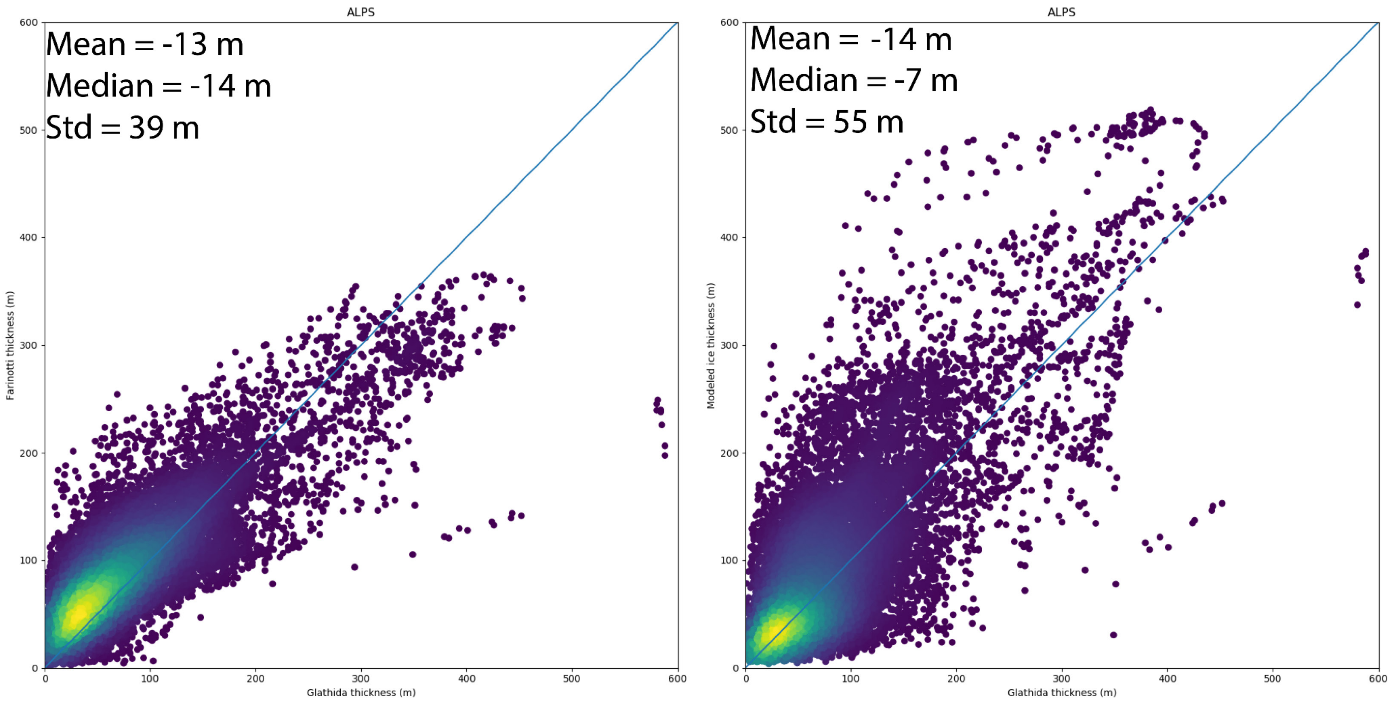


**Figure S8. Comparison of ice thickness estimates with in-situ ice thickness data from GlaThiDa for Farinotti et al[2] (left) and this study (right), over the European Alps.** The inset shows statistics of the difference between observed and modeled ice thickness.

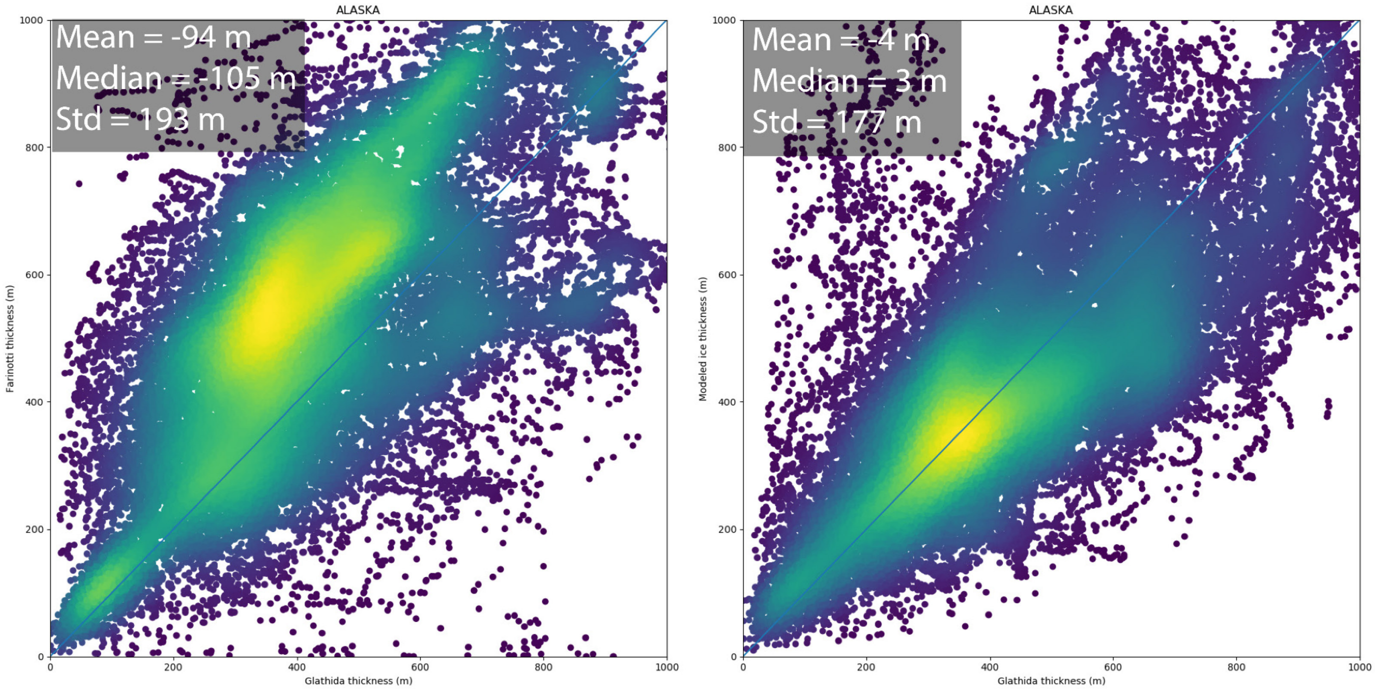


**Figure S9. Comparison of ice thickness estimates with in-situ ice thickness data from GlaThiDa for Farinotti et al[2] (left) and this study (right), over Alaska.** The inset shows statistics of the difference between observed and modeled ice thickness.

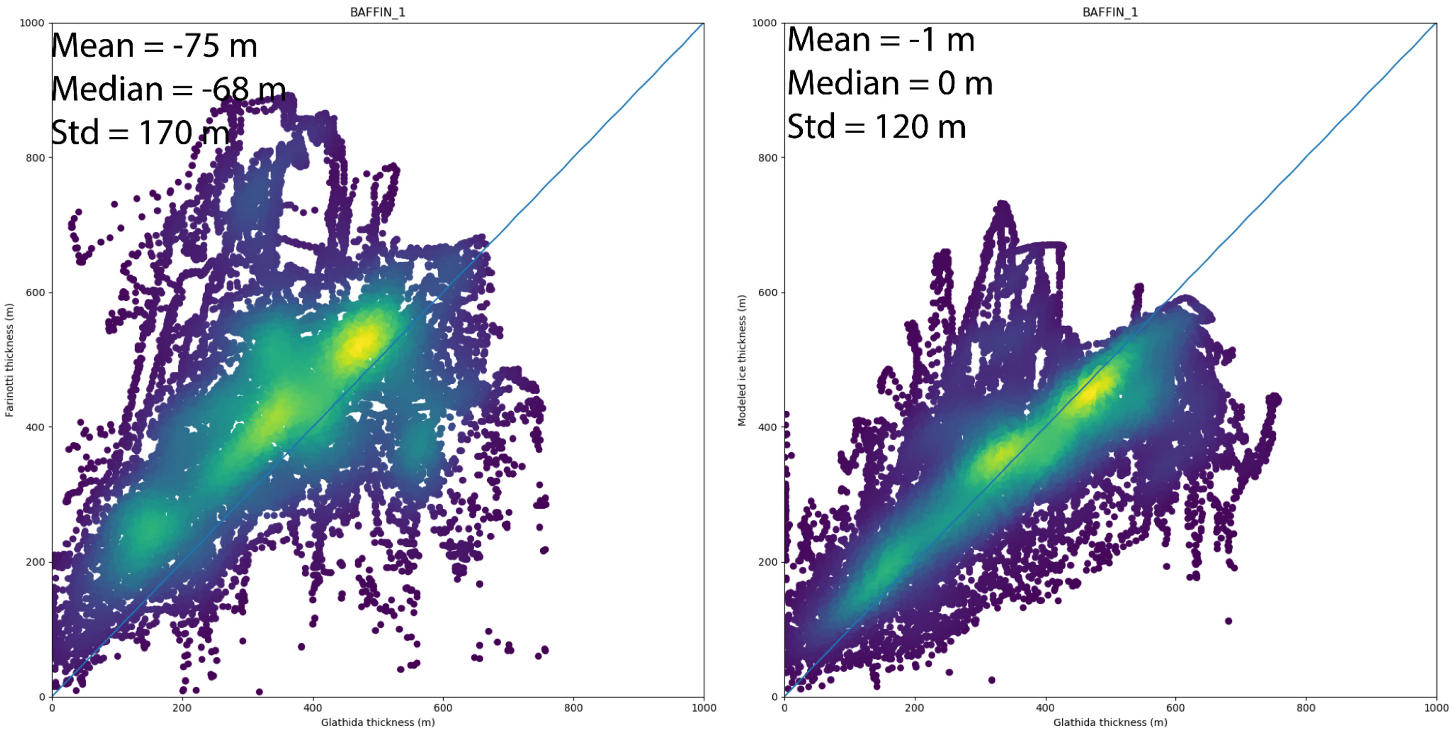


**Figure S10. Comparison of ice thickness estimates with in-situ ice thickness data from GlaThiDa for Farinotti et al[2] (left) and this study (right), over the northern part of Baffin Islands (lat 69°N to 73°N).** The inset shows statistics of the difference between modeled and observed ice thickness.

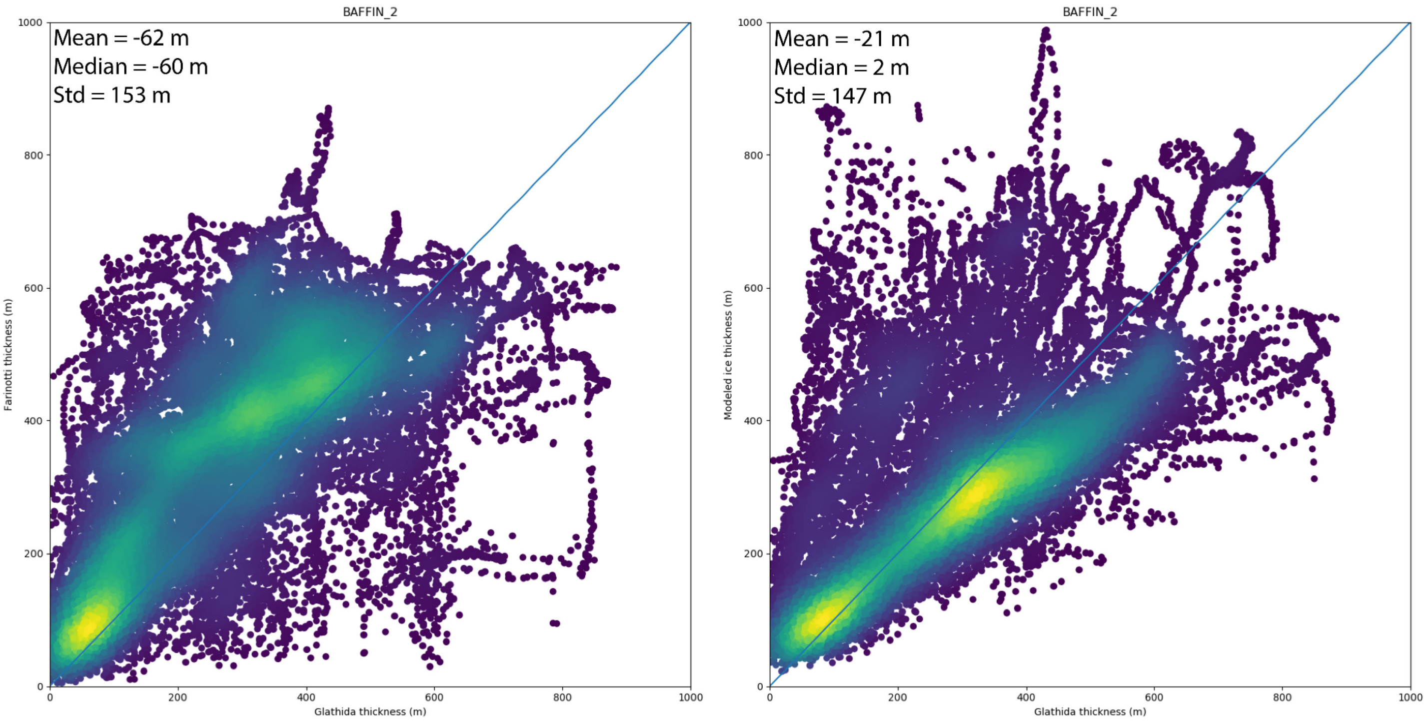


**Figure S11. Comparison of ice thickness estimates with in-situ ice thickness data from GlaThiDa for Farinotti et al[2] (left) and this study (right), over the southern part of Baffin Islands (lat 60°N to 69°N).** The inset shows statistics of the difference between modeled and observed ice thickness.

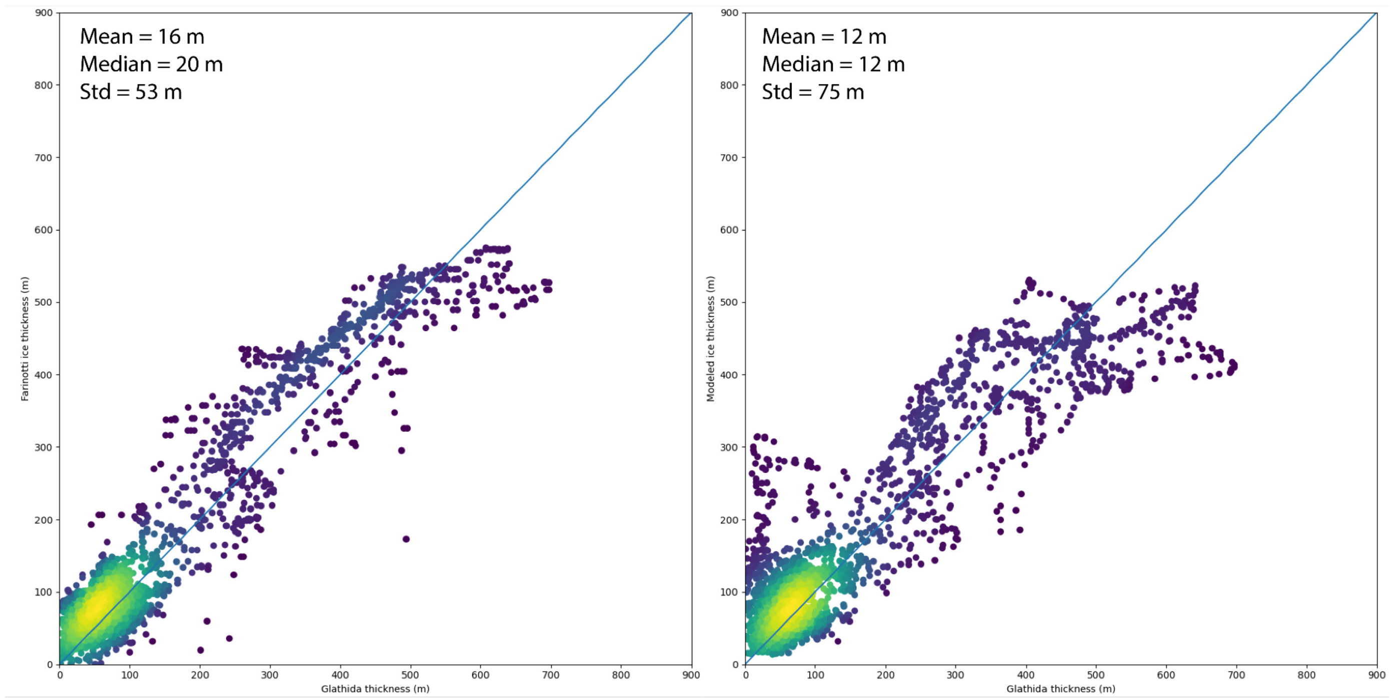


**Figure S12. Comparison of ice thickness estimates with in-situ ice thickness data from GlaThiDa for Farinotti et al[2] (left) and this study (right), over Asia.** The inset shows statistics of the difference between modeled and observed ice thickness.

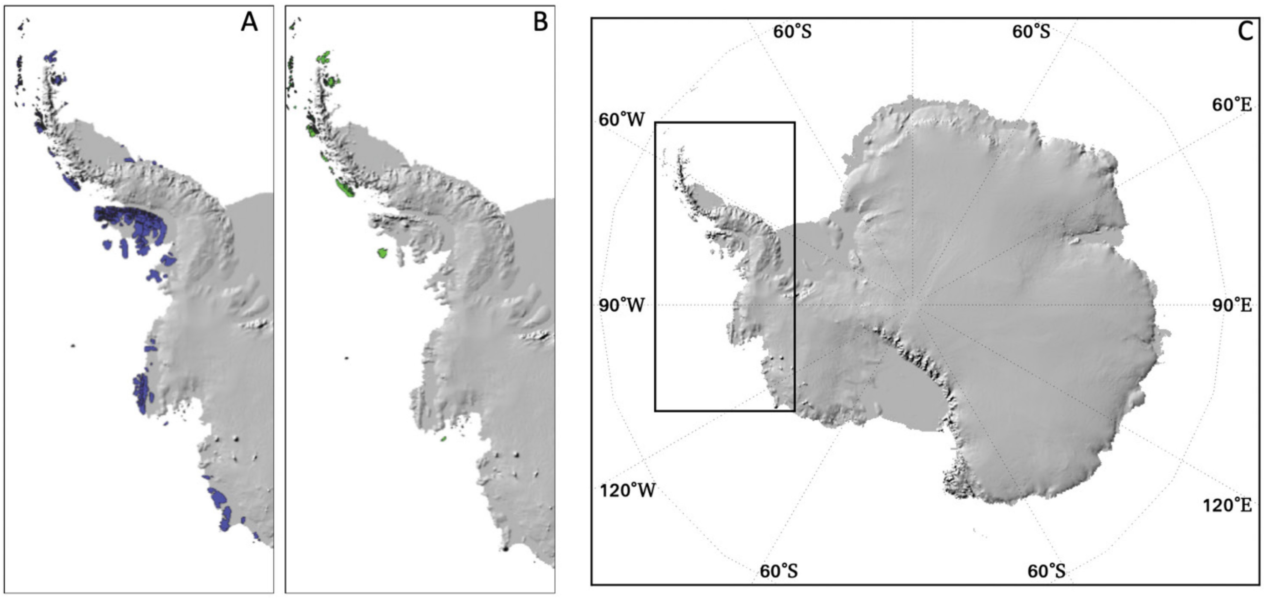


**Figure S13. Antarctic glacier mask used for global volume estimations.** (A) Entire RGI glacier inventory, with glacier basins in blue, (B) Glacier inventory after removing glaciers with a strong level of connectivity, glacier basins in green. (C) Map showing the location where most of the connected glaciers were removed. Background is a shaded version of the DEM from the BedMachine dataset[9].

# References


1. Gardner, A. S., Fahnestock, M. & Scambos, T. ITS_LIVE Regional Glacier and Ice Sheet Surface Velocities. (2020).
2. Farinotti, D. *et al.* A consensus estimate for the ice thickness distribution of all glaciers on Earth. *Nat. Geosci.* **12**, 168–173 (2019).
3. Radić, V. & Hock, R. Regional and global volumes of glaciers derived from statistical upscaling of glacier inventory data. *J. Geophys. Res. Earth Surf.* **115**, (2010).
4. Huss, M. & Farinotti, D. Distributed ice thickness and volume of all glaciers around the globe. *J. Geophys. Res. Earth Surf.* **117**, (2012).
5. Marzeion, B., Jarosch, A. H. & Hofer, M. Past and future sea-level change from the surface mass balance of glaciers. *The Cryosphere* **6**, 1295–1322 (2012).
6. Grinsted, A. An estimate of global glacier volume. *The Cryosphere* **7**, 141–151 (2013).
7. Radić, V. et al. Regional and global projections of twenty-first century glacier mass changes in response to climate scenarios from global climate models. *Clim. Dyn.* **42**, 37–58 (2014).
8. Welty, E. *et al. Worldwide version-controlled database of glacier thickness observations*. https://essd.copernicus.org/preprints/essd-2020-87/ (2020).
9. Morlighem, M. *et al.* Deep glacial troughs and stabilizing ridges unveiled beneath the margins of the Antarctic ice sheet. *Nat. Geosci.* 1–6 (2019) doi:10.1038/s41561-019-0510-8.
10. Hugonnet, R. *et al.* Accelerated global glacier mass loss in the early twenty-first century. *Nature* **592**, 726–731 (2021).