Measurements and modelling of the ice thickness distribution of 4 glaciers in the Tien Shan, Kyrgyzstan

LANDER VAN TRICHT

@LANDER_VT

LANDER.VAN.TRICHT@VUB.BE

LANDER VAN TRICHT

PHILIPPE HUYBRECHTS

JONAS VAN BREEDAM

JOHANNES FÜRST

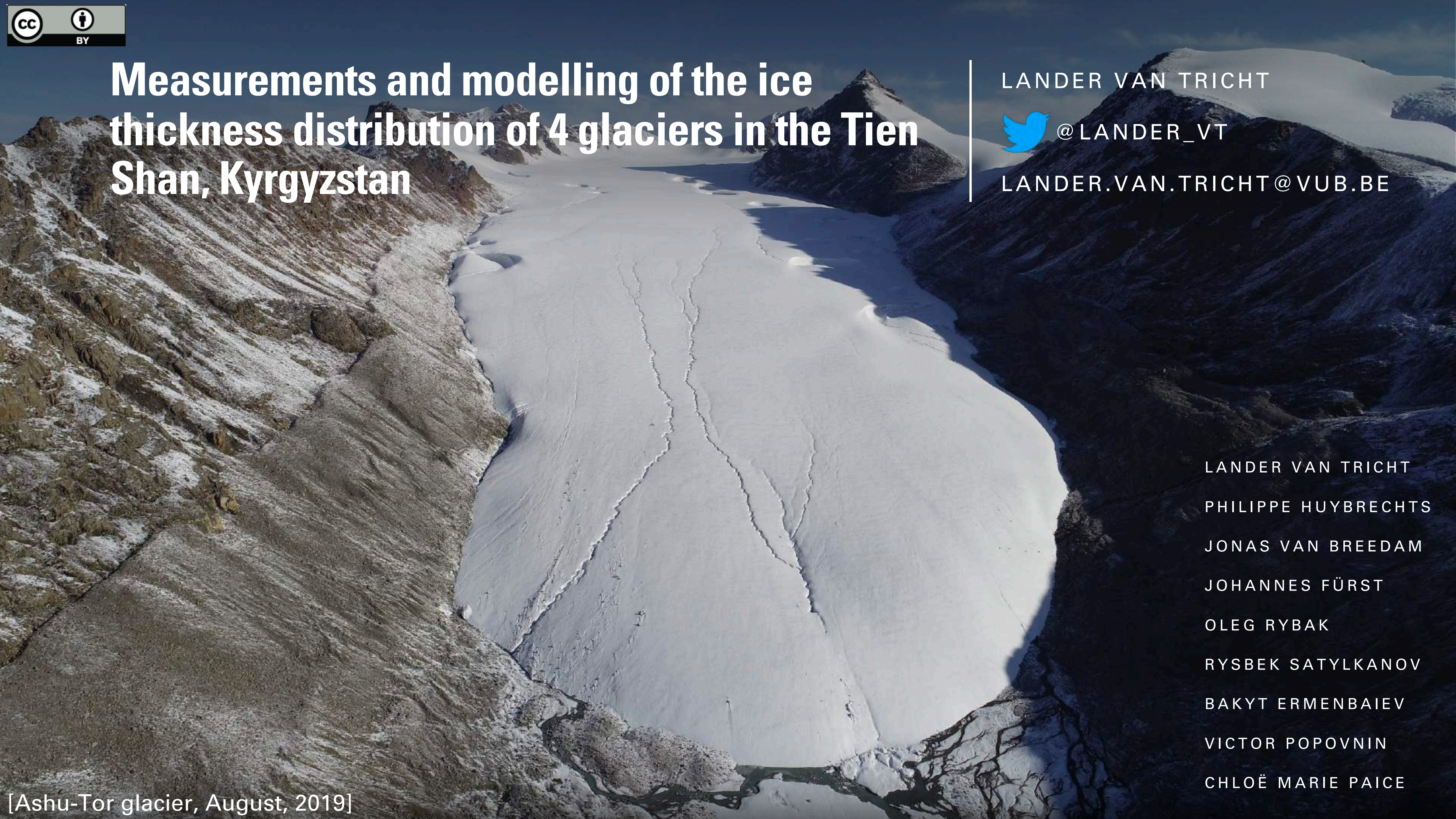
OLEG RYBAK

RYSBEK SATYLKANOV

BAKYT ERMENBAIEV

VICTOR POPOVNIN

CHLOË MARIE PAICE



[Ashu-Tor glacier, August, 2019]

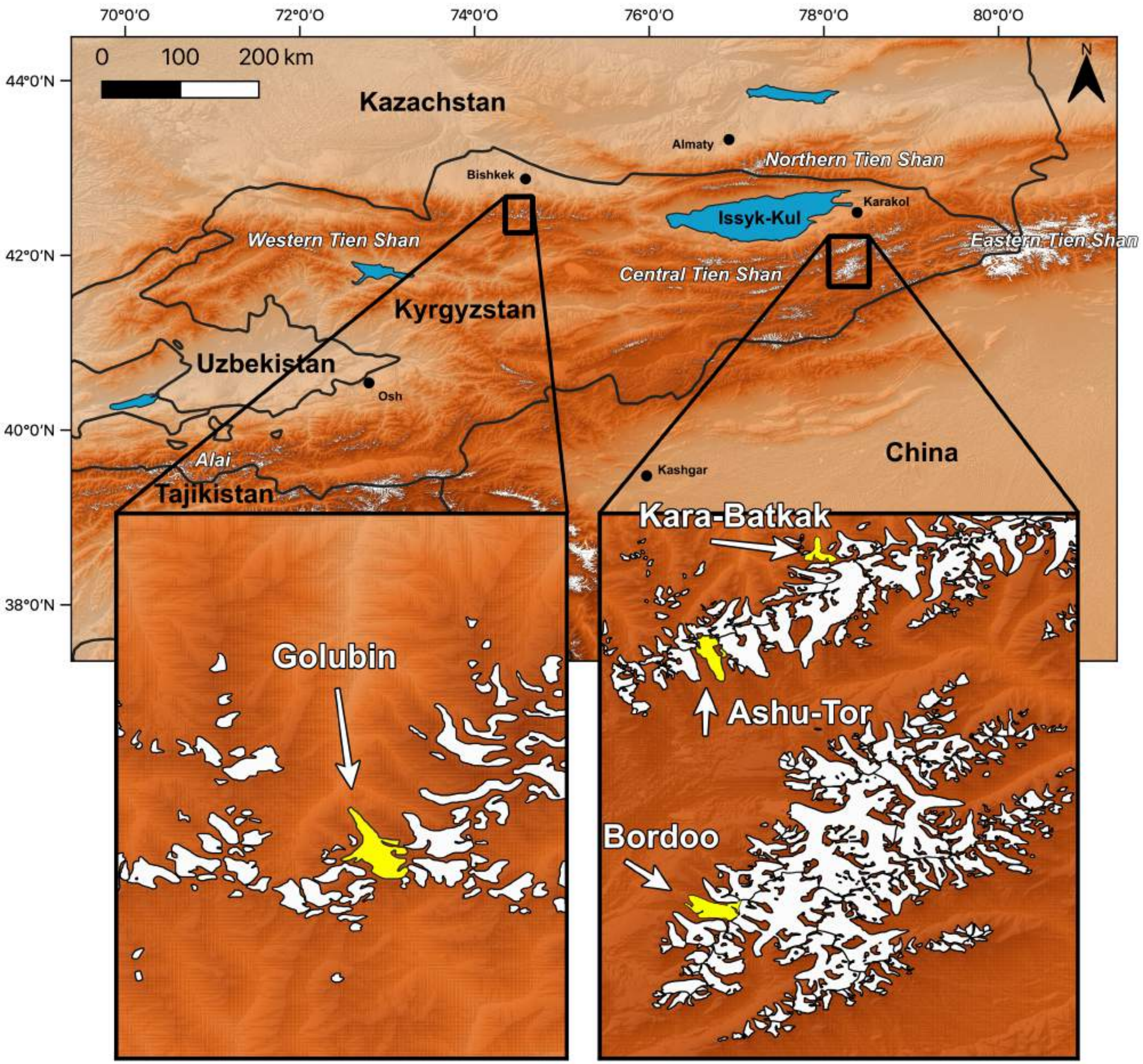
4 glaciers

-> Central Asia

-> Kyrgyzstan

-> Tien Shan

* Kyrgyz Ala-Too
* Terskey Alatoo
* Ak Shyyrak



4 glaciers

Basic characteristics

	Ashu-tor	Bordoo	Golubin	Kara-Batkak
Year of campaign	2019	2016 & 2017	2019	2016 & 2017
Number of profiles	11	22	13	21
RES measurements	284	376	213	206
Area (km^2)	4.76	4.89	4.64	2.27
Altitude range (m)	3895 - 4544	3870 - 4728	3347 - 4288	3350 - 4427
Average slope (%)	0.21	0.36	0.30	0.53
Orientation	SSE	NW	NNW	N

RES measurements (NAROD radar)

Fieldcampaigns in 2016 – 2017 – 2019 - … 2020?

Narod RES system operate at 5 MHz to

* limit amount of attenuation (meltwater)

* sufficiently large penetration depth

Manual selection of reflected wave + Migration algorhitm

-> Error estimate at 8 m $\pm$ 2% of the measured ice thickness

E.g. 100 m ice = 100 $\pm$ 10 m

E.g. 200 m ice = 100 $\pm$ 12 m

Up to date glacier outline

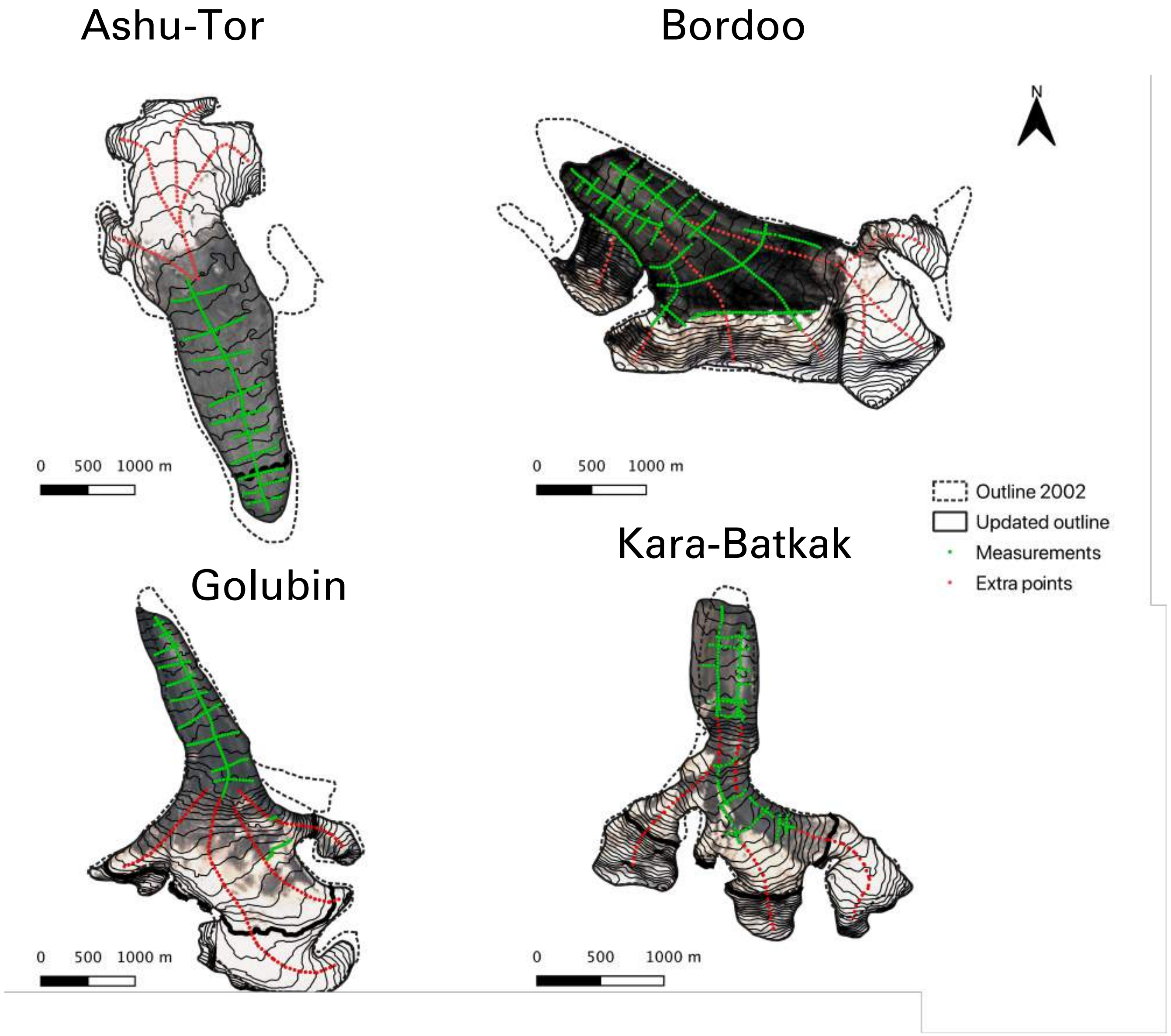
Manual delination based on satellite images (Sentinel) and UAV data. Outlines RGI v6 are adjusted.

Fig:

Green dots are measurements

Red dots are flowline points

Elevation contours for every 20 m. Thick line = 4000 m



Up to date DSM/slope

Start DEM is SRTM void filled (appeared to be the most complete and consistent DEM over the glaciers)

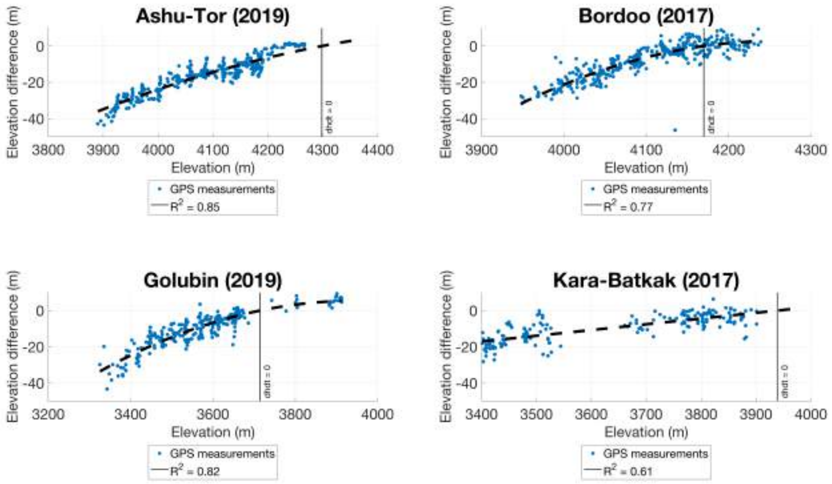
BUT:

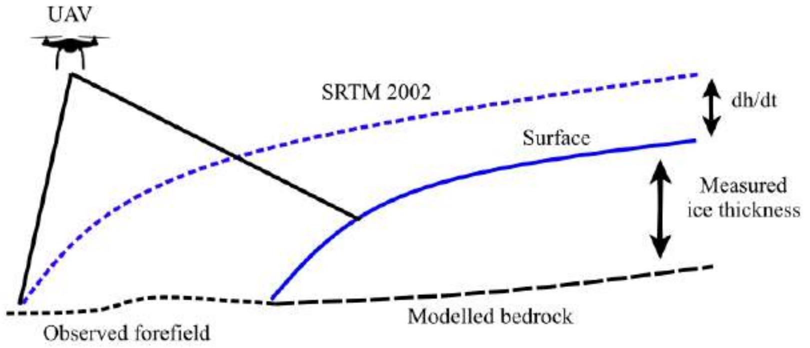
Adjustment of surface elevation based on comparison with

1. > 1000 GPS elevation measurements

2. UAV data (especially at the glacier forefield)

<u>To obtain an up to date DEM</u>





Ice thickess modelling required

Snow cover – crevasses - bad weather:

-> No full coverage of GPR measurements

Ice thickness modelling:

-> 3 different approaches:

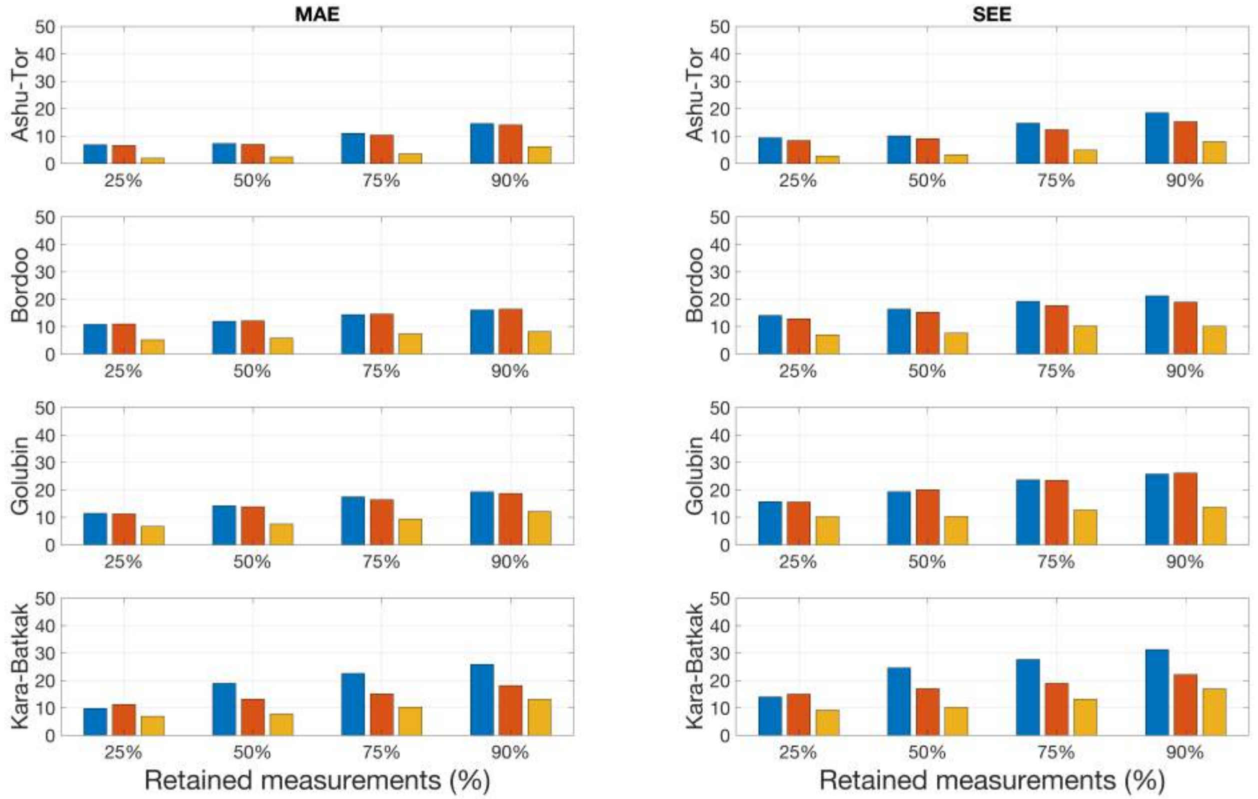
1) Constant yield stress (Linsbauer and others, 2012)
2) Mass flux (Farinotti and others, 2009)
3) Mass flux 2D (Fürst and others, 2017)

Calibrated with measurements (10-25-50-75%)

Validated with measurements (90-75-50-25%)

MAE and SEE are used for the umeasured areas

Model	DEM	Central flowlines	Measurements	SMB gradient	dh/dt
Yield stress model	X	X	X		
Mass flux flowline model	X	X	X	X	X
Mass flux 2D model	X		X	X	X



Blue = yield stress model, Red = Mass flux flowline model, Yellow = Mass flux 2D model

Error estimate

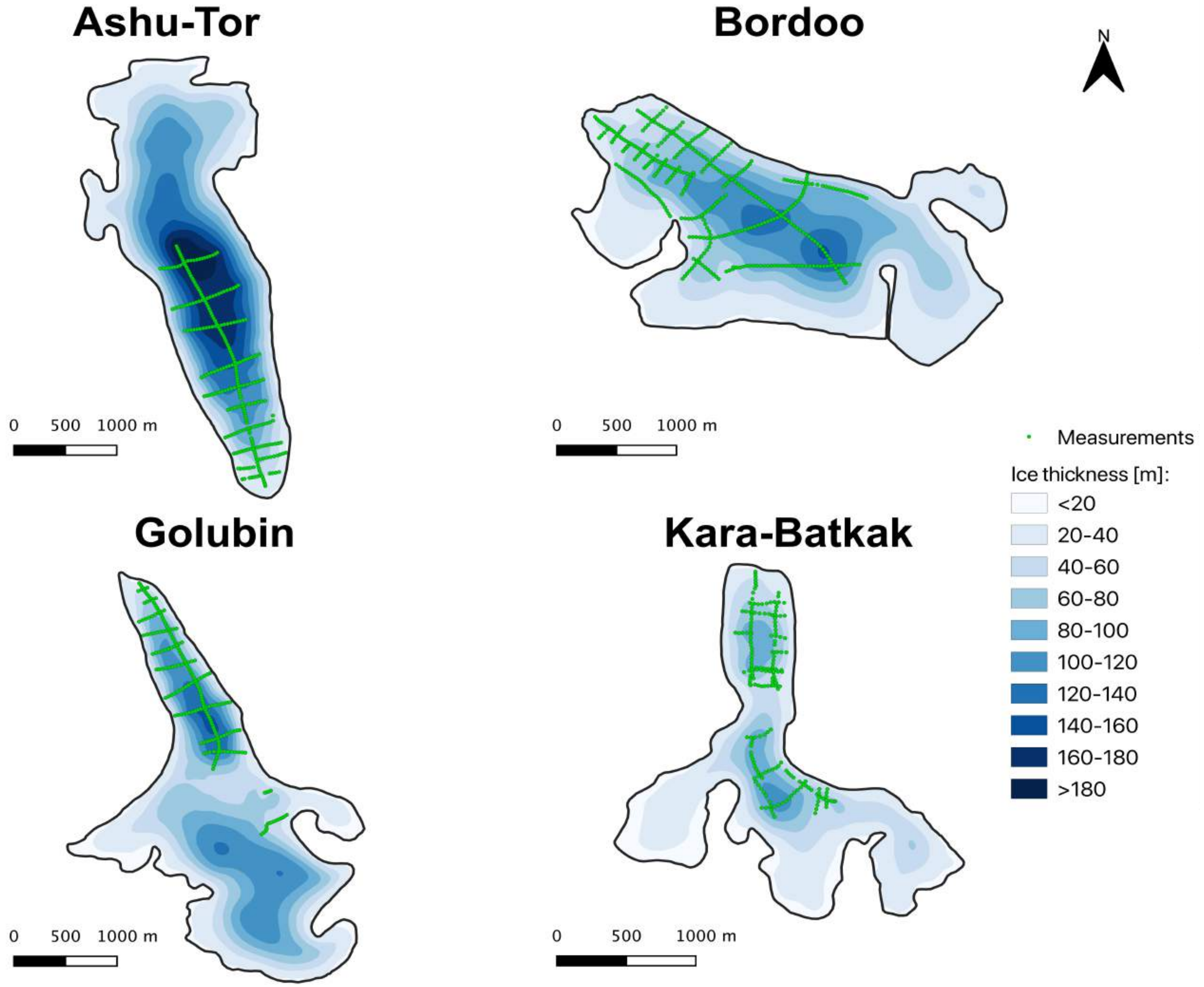
1. Ice thickness measurements: 8m ± 2% of the measured ice thickness

* Timing error (depends on frequency) and radar wave velocity (RWV) error

2. In between ice thickness measurements: assessed using MAE of 50% retained points for calibration

3. In unmeasured areas: assessed using MAE of 90% retained points for calibration and differences between the individual models

contact via: lander.van.tricht@vub.be



Glacier wide ice thickness and volume

1. Attribute weights to every model based on MAE and SEE between measured and modelled ice thicknesses

2. Composition of final ice thickness fields

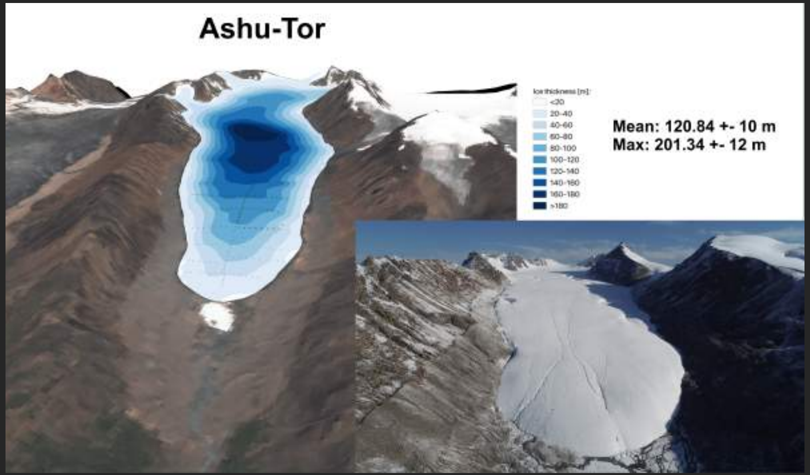
Glacier volumes:

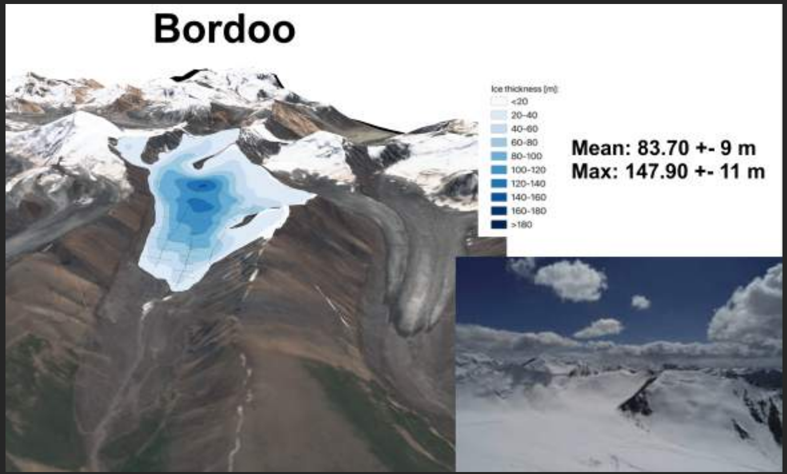
Ashu-Tor: 0.395 $km^3 \pm$ 0.079

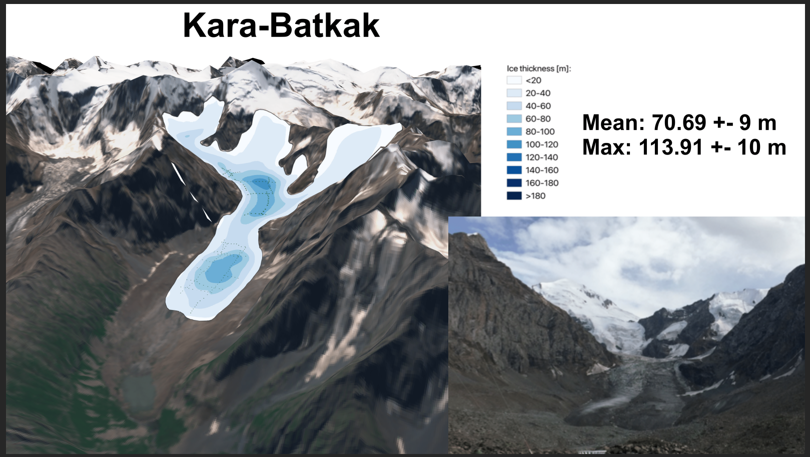
Bordoo: 0.286 $km^3 \pm$ 0.051

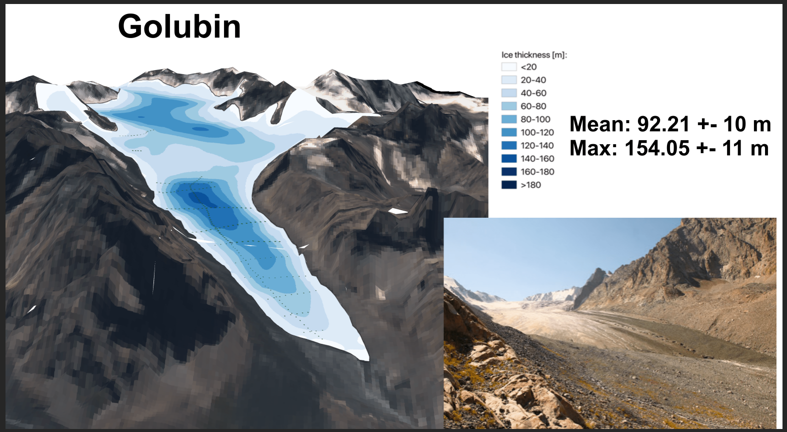
Golubin: 0.295 $km^3 \pm$ 0.062

Kara-Batkak: 0.095 $km^3 \pm$ 0.019







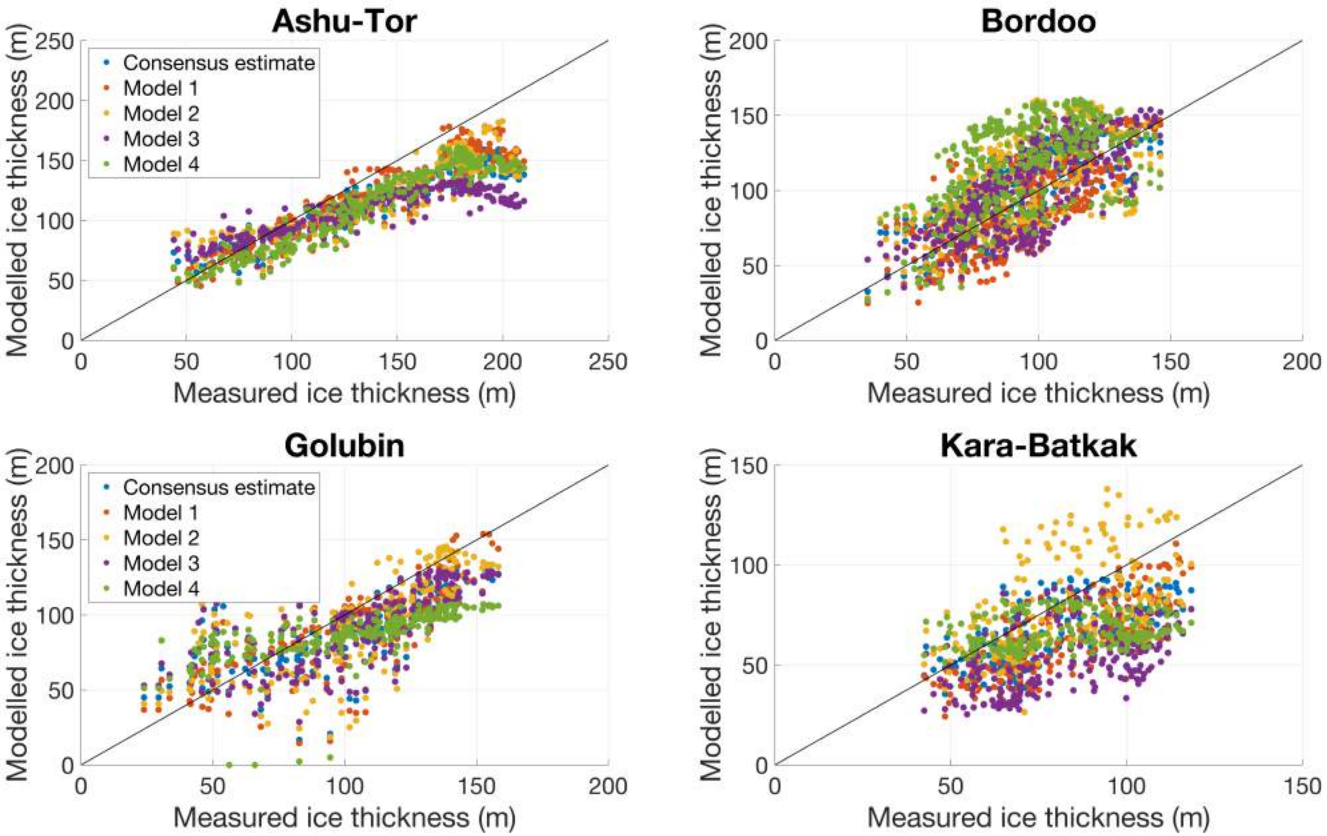


Ice thickness distribution of the selected glaciers within their environment

contact via: lander.van.tricht@vub.be

First comparison with ITMIX dataset and consensus estimate

Consensus estimate (Farinotti and others, 2019)
Model 1 (Huss and Farinotti, 2012)
Model 2 (Frey and others, 2014)
Model 3 (Maussion and others, 2018)
Model 4 (Fürst and others, 2017)



For the selected glaciers:

Model 1 > Consensus estimate > Model 2 > Model 3 > Model 4

contact via: lander.van.tricht@vub.be

References

Farinotti, D., Huss, M., Bauder, A., Funk, M., Truffer, M., (2009): A method to estimate the ice volume and ice-thickness distribution of alpine glaciers. Journal of Glaciology, 55(191), 422-430. doi:10.3189/002214309788816759

Farinotti, D., Huss, M., Fürst, J. J., Landmann, J., Machguth, H., Maussion, F., Pandit, A., (2019): A consensus estimate for the ice thickness distribution of all glaciers on Earth, Nat. Geosci., 12, 168–1973, doi:10.1038/s41561-019-0300-3

Frey, H., Machguth, H., Huss, M., Huggel, C., Bajracharya, S., Bolch, T., Kulkarni, A., Linsbauer, A., Salzmann, N., Stoffel, M., (2014: Estimating the volume of glaciers in the Himalayan and Karakoram region using different methods, The Cryosphere. 8(6), 2313–2333, doi:10.5194/tc-8-2313-2014

Fürst, J. J., Gillet-Chaulet, F., Benham, T. J., Dowdeswell, J. A., Grabiec, M., Navarro, F., Pettersson, R., Moholdt, G., Nuth, C., Sass, B., Aas, K., Fettweis, X., Lang, C., Seehaus, T., and Braun, M., (2017): Application of a two-step approach for mapping ice thickness to various glacier types on Svalbard, The Cryosphere, 11, 2003–2032, doi:10.5194/tc-11-2003-2017

Huss, M., and Farinotti, D., (2012): Distributed ice thickness and volume of all glaciers around the globe. J. Geophys. Res. Earth Surf. 117(F4), n/a-n/a, doi:10.1029/2012JF002523)

Linsbauer, A., Paul, F., Haeberli, W., (2012): Modeling glacier thickness distribution and bed topography over entire mountain ranges with GlabTop: Application of a fast and robust approach. J. Geophys. Res. Earth Surf. 117(F3), doi:10.1029/2011JF002313

Maussion, F., Butenko, A., Eis, J., Fourteau, K., Jarosch, AH., Landmann, J., Oesterle, F., Recinos, B., Rothenpieler, T., Vlug, A., Wild, CT., Marzeion, ., (2018): The Open Global Glacier Model (OGGM) v1.0., Geosci. Model Dev. Discuss., 1–33, doi:10.5194/gmd-2018-9

contact via: lander.van.tricht@vub.be