

Response to the reviewers comments

RC2: 'Comment on tc-2021-370', Anonymous Referee #2

General comments

Authors report on the surge behaviour of three glaciers in the same valley discussing differences in timing, extent and progression of the surges. For this purpose, they use a comprehensive dataset comprising different optical and radar satellites to map glacier advance, flow velocities and elevation changes.

The paper is well written with high quality figures and it also gives a good overview on the literature about glacier surges.

There is only one aspect that should be elaborated more carefully: In addition to the analysis of the surge behaviour of the investigated glaciers, authors compare results from different sensors in order to discuss their suitability for similar studies. This intercomparison has to be done in a more quantitative way. Statements like "average differences are insignificant" or "agree very well" are not enough in this context and error measures should be given (see specific comments).

I suggest to accept the manuscript after minor revisions.

--- Thank you very much for the careful reading and constructive comments! We will add some quantitative numbers to the various dataset inter-comparisons we have performed.

Specific comments

line 212 Could you please briefly state what kind of DEM datasets?

--- It just means here that the HMA DEM is a composite of datasets predominantly acquired at different times within 2015 that cover our study region. All studied glacier tongues are predominantly based on data from 2015 (eight scenes from Feb-Aug. 2015, two scenes from October 2015 over parts of accumulation areas), complemented with four scenes from 2009-2011 in the very East of South/North Chongtar accumulation areas, and a thin stripe from 2009 covering parts of the South Chongtar/Sarpo Laggo glacier tongues. They have all been derived from the same very high-resolution sensors (WorldView 2/3, GeoEye 1) as described by Shean et al. (2016). We can obtain the acquisitions dates from the image footprints, but we do not know by which technique the datasets have been merged where footprints overlap. We have specified the DEM origin within the text and added detailed information about the contributing datasets to Fig. S12.

line 507 "some surface lowering": How much?

--- It is about 10-15 m (added).

line 562 Which area was used to calculate the volume loss of Sarpo Laggo Glacier? In Fig. 11 a) and b) there is volume gain visible in the part of the glacier that is not covered in Fig. 11 c and d.

--- Yes, agreed. We have only calculated the loss part of the volume change (marked in Fig. S5) as we were interested in how this loss compares to the total gain of all other (much smaller) glaciers. Indeed, there is quite some elevation gain higher up on Sarpo Laggo (also visible in Fig. S13f), also for some of the upper tributary glaciers. This is why we have written 'the (uncompensated) volume loss', meaning we have neglected here the volume gain part.

Section 5.6 Uncertainties should be placed before 5.5 Sensor intercomparison. As a result, the differences between the sensors can be quantitatively compared to the determined uncertainties.

--- Yes, this is possible and has been changed. A comparison of sensor differences with uncertainties has been added.

line 572 Give error measures and compare with the sensor uncertainties derived in 5.6.

--- Done.

line 597 “agree very well”: Compare it quantitatively with the stable terrain accuracies (Table S3).

--- Done.

line 630 MAD: Table S2 only lists mean and std. Either explain how you derive std from MAD or adjust text and table. Check all numbers cited in 5.6.2 accordingly.

--- MAD values have been added.

line 667 Explain why “maximum flow velocities in summer” are atypical.

--- They are not atypical for ‘usual’ glaciers as the higher lubrication by meltwater reaching the bed causes more basal sliding and thus higher velocities. However, they are atypical for this specific surge mechanism (controlled by changes in basal hydrology) as the switch from an efficient to an unefficient basal drainage system usually only occurs during winter. We have now added a related explanation.

line 740 Can you comment on the influence of crevassing on the volume determination? Are the crevasses resolved by the DEMs? Does the DEM of the crevassed surface represent a mean elevation or is it more like an envelope curve?

--- As shown by the DEM hillshades in Fig. S1, the HMA DEM and the SPOT DEM from 2020 both see crevasses, at least the upper part of the big ones: The crevasses/bulges on South Chongtar around 3 973 000 N / 620 500 E measure ca. 50 m across and are clearly resolved by the higher-resolution DEM, but averaged out by the 30 m-DEMs Fig. S6f, shows profiles across the down-wasting Sarppo Lago tongue before arrival of the South Chongtar surge bulge, i.e., surface features are very similar for a year or more. It indicates that the SPOT2020 DEM resolves larger surface structures (ca. 50 m across at 3978 km N) nearly as well as ICESat-2, albeit some of the depth is lost, but ignores smaller crevasses (ca. 10 m across at 3,977 km N), and in that case they are treated like an envelope curve. In the same panel, it can be seen that the 30 m SPOT2015 DEM represents an average of the surface captured by the 5 m HMA DEM. In conclusion, the DEMs present a mean elevation of the surface and only the largest crevasses might have been considered for the volume change. The uncertainty in the resulting volume change is thus likely mostly impacted by the uncertainties of the DEMs and the influence of crevassing is small.

line 770 basically identical: But they are from different seasons and Fig. S12 shows the differences. I suggest to give median and MAD to quantify this statement.

--- Median elevation differences off glacier (see Table S3) are -0.11 m (compared to minimum / maximum differences of -51 and +423 m found at artifacts), which we think can be named ‘basically identical’. From the difference image in Fig. S12 we would not conclude that seasonal changes can be seen over glacier surfaces (apart from the advancing North Chongtar terminus), but there may be some influence from contributing DEM data in some parts. We clarified this in the text and added further details to the caption of Fig. S12.

line 858 Was Sentinel-1 used in Section 5.1 or only in the animation? Sentinel-1 images are not listed in Table S1.

--- *We originally had the intention using Sentinel-1 to derive velocity fields, but after this didn't work we only did a few tests shown in Fig. S4. The scene pair is thus not listed in Table S2 but only in L295 (with some typos). The animation in the Supplement is just for illustration purposes.*

Technical corrections

line 27 same region: I'd narrow it down to the same valley, even.

--- *As a valley can be very long, this would not be more restrictive. We have now written 'small region'.*

line 43 Is it ICESat-2 ATL03?

--- *Yes, indeed. Thank you for spotting!*

line 102 by Hugonnet et al. (2021): Please make it clearer that this is an external dataset.

--- *Done.*

line 107 35.94°N

--- *Done.*

line 139 At their historically recorded maximum extent

--- *Done.*

line 181 Sentinel-1 is not included in table S1.

--- *This is because Sentienl-1 has not been used to derive geometric changes.*

line 295 Correct date format.

--- *Done.*

line 299 Which standard processing steps? If these are listed in the following passage, use a colon (:) at the end of this phrase.

--- *Done.*

line 305 "We also excluded data voids": Seems clear. How could you alternatively include voids?

--- *Fully agreed, this is a bit misleading and has been rewritten.*

line 438 Replace "afterwards" with "further down".

--- *Done.*

line 450 Fig. 7a confirms this observation:

--- *Done.*

line 451 "(up to 0.2 m d⁻¹)": Two lines above the maximum is 0.4 m/d.

--- *Agreed. We include up to 0.4 m/d for the pre-surge phase and would argue that afterwards the surge took off.*

line 472 Replace "3 km" with "km 3" like in line 474

--- *Done. We were not sure if this is grammatically possible at all.*

line 474 What do you mean with "maximum velocities near km 15 changed only slowly over the entire glacier length"? Do you refer to the location km 15 or the entire length?

--- *Agreed, this is confusing. We have now written: 'maximum velocities are found near km 15 and decreased only slowly at this location and over large parts of the glacier length (back to km 6) at about the same rate.'*

line 475 Replace "10 km" with "km 10".

--- *Done.*

lines 590, 592, 597: Specify subfigure in Fig. S6 (see comment on S6 below).

--- *Done, thank you for spotting.*

line 643 median elevation differences to the reference DEM "on bedrock"

--- *Done.*

line 670 Replace "implies" with "imply".

--- *Done.*

line 708 "location of the maximum away from the centre": Do you mean centre line?

--- *Yes, changed.*

line 764 strictly or strict?

--- *Strict sounds better, changed.*

line 799 short-term variation

--- *Done.*

line 834 in the same valley?

--- *As above, we have no written small region.*

line 836 Also give the duration of the active phase in comparison to North Chongtar.

--- *Done for both.*

Table 3, line 1150 numbers

--- *Done.*

Figure 1 Add map grid

--- *We added a coordinate cross with its latitude and longitude listed in the caption.*

In some figures (e.g. Fig. 6, 7) colours are hard to distinguish. Please check whether you could use colours that are better distinguishable.

--- *Agreed, in particular for Fig. 6 it is a bit difficult. For Fig. 7a/b we think it is still possible as there is a clear increasing / decreasing pattern that can be linked to the temporal evolution. As this is a colour palette for colour blind people that we wanted to keep. The revised version of the figures (6a, 6b and 7a) include different symbols to better distinguish the colors.*

Figure 9 State direction of cross profile. West to east?

--- *It is SW to NE (added).*

line 1219 with respect to

--- *Done.*

Supplemental Material

Table S1: Add Sentinel-1.

--- Not done (as it Sentinel-1 has not been used for delineating glacier extents or determination of frontal advance rates).

Table S3: Why are some lines in italics? I suggest to add NMAD.

Statistics in regular font are accuracy measures from differences with regard to the HMA DEM (co-registration base). Those in italic font are statistics for other computed DEM differences, i.e. not with regard to the HMA DEM and thus not “official” accuracy measures, but may be of interest nevertheless. An explanation has been added to the table caption. We computed the NMAD and added the values to the table and text.

Fig. S1: Check dates, resolutions and dataset names as they are inconsistent with Table 2. Subfigure d) Use the same clipping as in a)-c).

--- These are subsets of the original DEMs, i.e. at their native resolution. For this reason spatial resolution is different from the resampled DEMs used to calculate elevation changes. The clipping has been adjusted for panel d.

Fig. S5, line 60: What are "biased accumulation areas"?

--- Changed to ‘... to remove no data or accumulation areas biased by artifacts.’

Fig. S6: Consider numbering all panels as subfigures. It makes it easier to refer to a specific panel in the text.

--- Done.

line 66 2 February 2019: Does not coincide with date on map. Shouldn't it be December?

--- Yes, December is correct. Thanks for spotting.

Fig. S7: clockwise? The main paper has the usual order from left to right (e.g. Fig. 5). Please adjust.

--- Yes, the clockwise here is on purpose.

Fig. S13: Dates (and order of dates) do not coincide with the ones in the figure for a) to d).

--- Yes, agreed. This has been adjusted.