The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2017-256-AC1, 2018

Interactive comment on "Multi-decadal mass balance series of three Kyrgyz glaciers inferred from transient snowline observations" *by* Martina Barandun et al.

Martina Barandun et al.

martina.barandun@unifr.ch

Received and published: 26 January 2018

Below we respond to all comments by anonymous Reviewer 1. In response to this review, we changed the title of the manuscript and reworked the terminology. Additionally, we justified the independence of mass balances determined with in-situ point measurements with additional model experiments, completed and improved the description and calculation of geodetic mass change when snow-covered high-resolution images are used, and added statements concerning a broader applicability of the snowline approach.

Printer-friendly version

Discussion paper

The responses (normal font style) to the reviewers' comments (displayed in italic font style) are written directly into the reviews . The corresponding revised sentences in the manuscript are given in quotation marks.

We thank the referee for the valuable, constructive and detailed comments which improved the manuscript.

(1) Title of the paper The title of the paper is misleading and needs to be changed. Indeed, in your approach the surface mass balance is modelled with meteorological data and this modelling is constrained by snowline observations during the ablation season. Thus, the title has to mention that the surface mass balance time series are quantified with a model. As it stands, one can have the impression that the surface mass balance is only inferred from snowline observations. I suggest: "Glacier surface mass balance modelling constrained by remote sensing derived snowlines. Application on three kyrgyz glaciers to quantify multi-decadal series". Or "The use of remote sensing derived snowlines to constrain glacier surface mass balance modeling. Application on ..."

We agree that the title did not make reference to the modelling behind the approach, and adjusted it as suggested by the reviewer to “Multi-decadal mass balance series of three Kyrgyz glacier inferred from modelling constrained with repeated snowline observations.”

———

(2) Name of the proposed approach. In the same way, the name you give to the proposed approach (snowline-derived mass balance) is not adequate, and so is the

Printer-friendly version

Discussion paper

abbreviate in the tables and figures (Msnl). For the name of the approach, I propose: Modeled SMB constrained by snowline. And for the abbreviate: Mmod-tsl. TSL stands for Transient Snow Line and must be preferred to SNL.

The name of the method was adjusted to "modelled SMB constrained by snowline observations" and we changed SNL to TSL throughout the entire manuscript. We also use "snowline approach" to refer to the method using a mass balance model constrained by snowline observations.

---

(3) Terminology. "Mass balance", "glacier balance", etc: Be careful with the terminology and follow Cogley and others Glossary of mass balance terminology. For example, use "surface mass balance" instead of "mass balance" or "glacier balance", except when you refer to the geodetic mass balance.

The terminology has been adjusted in the new version of the manuscript and we use surface mass balance wherever it is referred to. However, please note that when the modelled mass balance constrained by snowline observations is compared to geodetic mass balances, we do not refer to the surface mass balance but to a total mass change that includes an estimate of internal / basal mass balance.

---

(4) Glaciological surface mass balance. The used method is not the classical glaciological one. Indeed, a model-based extrapolation is used and optimized to best fit the point measurements. What about the input data for accumulation and ablation (e.g. precipitation and temperature data)? Where do they come from? Are they the same as used in the model constrained by the snowline? If the data are the same, are the methods "constrained by the snowline observations" and "constrained by the point

measurements" strictly independent as they rely on the same meteorological data?

This is an interesting and thoughtful question. Indeed, the same meteorological input is used for both approaches. However, we are convinced that both approaches can be considered as independent out of the following reasons:

The mass balance model used to derive the glaciological series is not regarded as a physical model, but as a statistical tool for obtaining glacier-wide surface mass balances based on field data and is closely tied to the field surveys. It is thus just a way to compute glacier-wide mass balance from stake measurements (such as the profile or the contour method). No model-based temporal extrapolation, e.g. to the hydrological year is involved. Consequentially, the climate data used in the model-based extrapolation of point mass balances permits spatial extrapolation to the entire glacier using physically-based equations and does not affect year-to-year variability which is given by the in-situ measurements. Here, we avoid the use of daily mass balance variability, and refer strictly to the surface mass balance obtained for the measurement dates.

In response to the reviewer's comment we performed a sensitivity test to prove the limited impact of the used meteorological time series on the glacier-wide mass balance computed from in-situ point measurements. We use artificially perturbed air temperature ($\pm 1 \circ$C) and precipitation ($\pm$25%) series. The standard deviation in the inferred glacier-wide surface mass balances is less than 0.01 mm w.e. yr^{-1} for all three glaciers and all years. This indicates that the method used to compute glaciological mass balance from in-situ field data exhibits a very small sensitivity on the actual meteorological data used for driving the mass balance model. The calculated annual glaciological SMB depends thus strongly on the in situ ablation and accumulation measurements and is considered as independent from the snowline approach. We tried to clarify the role of the meteorological data for the glaciological method used here, and added the results of the sensitivity test.

"A model-based spatial extrapolation of point measurements to the entire glacier surface after Huss and others, (2009) was used to retrieve glacier-wide SMB for all years with direct measurements. The model is a combined distributed accumulation (Huss and others, 2008) and temperature index melt model with daily resolution (Hock, 1999) which was automatically optimized to best represent all collected point data from each seasonal/annual survey. The model is considered as a suitable tool to extrapolate the glaciological point measurements to the glacier surface for the measurement periods."

"For a sensitivity experiment we artificially shifted temperature and precipitation series used for the model-based extrapolation by $\pm 1 \circ$C and $\pm$25%, respectively. The resulting glacier-wide SMB indicate a very small sensitivity to the meteorological input data with a Standard Deviation (STD) of <0.01 mm w.e. yr^{-1}. We strictly refer to the annual SMB obtained for the measurement dates that are listed in table 2."

---

(5) High resolution images recorded in November => impact of the snow cover on the derived DEM. Two of the stereo-pairs used to make DEMs and quantify the geodetic mass balance were recorded in November for Abramov and Golubin glaciers, respectively. I had a look at the SPOT catalogue and for Golubin I could find the SPOT7 images from 01/11/2014. Regarding Abramov, the images are not in the catalogue but I assume it is because these have been acquired within the SPIRIT acquisition campaign. Anyway, at least for 2014 and I assume it is the same for 2011, all the more because the SPOT5 images date from late November, the glaciers and surrounding terrains are completely snow covered. This implies several challenges for DEM generation:

- low contrast because of snow brightness

- unknown snow thickness

- impossibility to delineate the glacier outline.

Printer-friendly version

Discussion paper

How these issues have been tackled and what is their impact on the uncertainties? In addition, Table 7 shows that the geodetic mass balances for Abramov (2011-2015) and for Golubin (2006-2014) are less negative that the average annual surface mass balances quantified by your model constrained by the snowline. Can the snow-cover on the images implying a higher surface elevation (of an unknown value!) be a cause of this difference (or at least part of it)?

This is an absolutely justified comment and we are aware that the quality of the two November scenes is not ideal. However, we are convinced to have extracted valuable information from the two images. Low contrast in the upper accumulation area due to fresh snow-cover and shading from steep mountain walls led to data gaps indicated as unmeasured areas on the glacier surface (26% for Abramov and 30% for Golubin, see also Figure 7 for Golubin). We accounted for the unmeasured areas on the glacier surface with a five-fold increase in uncertainty (see Section Uncertainties and Sensitivity). The retrieved information for the remaining glacier area appeared nevertheless reliable.

We agree with the reviewer regarding the issue of the unknown snow thickness. In principle, snow cover introduces a systematic bias into the calculation of geodetic volume change that needs to be accounted for. As it is unknown how deep the snow was on the glacier during the acquisition of the imagery we take a simple but efficient approach and account for the snow coverage by co-registering the digital elevation models using snow-covered stable ground sections. In this way, we approximately correct for the fresh snow on one of the scenes. This has been done for Abramov already in the first version of the submitted manuscript. However, for Golubin the vertical offset correction has now been adapted to systematically include snow-covered stable terrain sections. In addition, we compared the offset inferred using this approach to snow depth measurements at the Automatic Weather Station installed at 3300 m a.s.l. on the 01 of November 2014 and found good agreement. The geodetic mass

Printer-friendly version

Discussion paper

balance was corrected from -0.22 to $-0.30\,\mathrm{m\,w.e.\,yr^{-1}}$. which indeed shows a better agreement between the snowline-constrained model results and the geodetic mass balance for Golubin Glacier.

The outlines have been drawn on snow-free satellite images of other sensors as stated in Section “3.1 Glacier outlines”. We did not include an error related to the delineation of the outlines in our error estimate.

In addition to the above correction, we have added some sentences about snow-cover conditions in the Study Site and Data section of the revised paper and have better described the approach to account for snow cover using the offset correction. Please note that especially for the geodetic mass balance of Golubin Glacier, it was difficult to find appropriate high-resolution images. The estimated uncertainties are considerably higher when snow-covered images were used than for the other geodetic estimates.

“Important snow coverage was present on the SPOT5 image from 2011 for Abramov and on the SPOT7 image from 2014 for Golubin. A fine layer of fresh snow covered parts of the SPOT6 image from 2015 for Glacier No. 354.”

“For this vertical co-registration, only terrain sections with a slope lower than approximately 30° were selected and areas with parallax-matching problems were avoided. Snow-covered areas were included in the offset correction, in order to correct for fresh snow.”

“The geodetic method reveals a total mass balance of $-0.30 \pm 0.42\,\mathrm{m\,w.e.\,yr^{-1}}$ for Golubin Glacier from 8 September 2006 to 1 November 2014 (Fig. 10). The corresponding total modelled mass balance constrained by snowline observations was slightly more negative with $-0.38 \pm 0.35\,\mathrm{m\,w.e.\,yr^{-1}}$ for the same period (Table 8 and Fig. 11).”

Printer-friendly version

Discussion paper

(6) Surface mass balance interannual variability. It is pity that your discussion about the interannual variability of the SMB is short and only dedicated on the annual values. You should have a look on the two terms of the annual surface mass balance, and discuss about their interannual variability. You could see if the interannual variabilities of accumulation and ablation are homogeneous, comparable between the three sites and if the difference you mention regarding the interannual variability of Glacier No. 354 annual SMB is more likely related to a different ablation or accumulation interannual variability.

We agree with the reviewer in general. An analysis of the interannual variability would be very interesting and insightful. However, the data sets available in this study (annual in-situ point mass balance, decadal geodetic mass balance, repeated snowline observations) only allow us to directly constrain annual mass balances. Seasonal and daily mass balances, calculated by the snowline-constrained model are not tied directly to any observations and day-to-day variability depends on partly uncertain meteorological information. Therefore they are subject to larger unknown uncertainties. Furthermore, the calibration of the two parameters DDF_{snow} and C_{prec} are not strictly independent and thus could lead to important under- or overestimations of the two seasonal components of the modelled surface mass balances. This shortcoming of the method is described in Section Discussion and shown in Figure 13b. Unfortunately, at the current stage, we only have a few seasonal in situ measurements for the studied glaciers. A reliable verification of the performance of the snowline approach in terms of the winter and summer surface mass balance is thus not possible. For the above-mentioned reasons we avoid an interpretation of the interannual variability here.

---

(7) Application of the proposed approach. You mention that the approach you propose can be useful to quantify surface mass balance time series for a number of remote glaciers. Although I mostly agree with this statement, I wonder if the approach can

Printer-friendly version

Discussion paper

indeed be applicable for summer accumulation glaciers (like in the tropics, or in monsoon regime regions) or for high latitudes glaciers where superimposed ice can be more important than in Kyrgyzstan. You can probably add some sentences on this point in the conclusion.

We added some sentences on the potential wider applicability of the proposed approach in the Discussion section of our manuscript. However, we are unable to perform a complete assessment of the transferability of our approach to other climate zones in the scope of the present study.

"SMBs inferred from modelling constrained with repeated snowline observations is closely tied to the TSL observations. The method might be able to yield reliable surface mass balance estimates for many glaciers in different climatic regimes, for which the transient snowline is an indicator of the surface mass balance. The relationship between the snowline and the surface mass balance can however be importantly challenged when the position of the transient snowline is blurred by fresh snow or superimposed ice. The applicability of the snowline approach presented here, can thus be critical when the transient snowline on remote sensing data cannot unambiguously be identified. This is mainly a problem for glaciers with a summer accumulation regime due to frequent fresh snow, and glaciers with a high relevance of superimposed ice."

Printer-friendly version

Discussion paper

Specific comments:

Abstract

P1, L5-6: the sentence "A combination of 3 independent [. . .] Golubin and No. 354" needs to be reformulated. Indeed, the methods are not combined to reconstruct the surface mass balance. The methods are compared/cross-validated but not combined. For me, you would have a combination if, for example, your modeled surface mass balance time series had been adjusted with the geodetic method.

Reformulated.

"By cross-validating the results of three independent methods, we reconstructed the mass balance of the three benchmark glaciers, Abramov, Golubin and No. 354 for the past two decades."

P1, L8-9: "satellite optical imagery" instead of "satellite imagery".

Done.

P1, L12, 13 and in the entire paper: should write "yr-1", instead of "a-1". "yr-1" is most common except for IGS journals.

Done.

P1, L15: prefer "unmonitored" to "inaccessible". I do not know about an inaccessible *glacier on Earth."*

Done.

---

1. Introduction

P2, L2: should the IPCC reference be quoted Stoecker and others, 2013?

Referencing has been changed.

P2, L18: remove a comma after "e.g.,"

Done.

---

2. Study site and data

P4, L12-13: this statement is useless if you do not give any quantification.

Quantification has been added.

"For Golubin, the mass loss reported by Bolch, (2015) was -0.28 ± 0.96 m w.e. yr^{-1} from 2000 to 2012, whereas Brun and others (2017) found a mass balance of -0.04 ± 0.19 m w.e. yr^{-1} for the period 2002 to 2013."

P5, L11-12: idem, give a value.

Quantification has been added.

“Mass loss since the mid-1970s was reported by different studies (Pieczonka and others, 2015, Kronenberg and others, 2016, Brun and others, 2017) ranging from about -0.8 to -0.5 m w.e. yr^{-1}.”

P5, L6 and 15: should mention the elevation of the AWS

Done.

Figure 3: for Glacier No. 354, the Quickbird and Pléiades images recorded in 2003 and 2015 respectively have not been used for snowline mapping? If yes, these images should appear in the Figure. If not, why?

The QuickBird image has not been used for snowline mapping because it dates from summer 2003, and the first year to compute was the year 2004. We clarified in the caption and manuscript text.

“Image availability and distribution for snowline mapping. Numbers indicate the total available scenes per year and glacier. Prior to 1998, image coverage is sparse for all three glaciers. For Golubin and for Glacier No. 354, the first summer season for which enough snowline observations could be collected was 2000 and 2004, respectively. Snow-covered high-resolution images have not been used to delineate the snowline and are not shown here.”

Table 1: should write “snowline” instead of SNL. You should also indicate the sensor in brackets for the high resolution images. If I am correct these are SPOT5 and Pléiades for Abramov, ALOS and SPOT7 for Golubin and Quickbird, GeoEye and Pléiades for

No. 354.

Done.

---

3. Methods

See my main comment related to this section (no4), and the one regarding the terminology for the title of this sub-section.

Please refer to the answer given for the main comment No. 4.

P10, L23: the paper by Huintjes and others has not been finally published. I wonder if papers that stayed in discussion and/or were rejected can be quoted. You can probably remove this reference from the text and the ref list, all the more that it is quoted within a list of 5 references starting by e.g.

The reference has been removed.

In Table 2 and in the text (e.g. P11, L7): I recommend using 'Z' instead of 'H' for the elevation criteria. H usually stands for thickness.

Done.

---

4. Uncertainties and model sensitivity

P15, L3-8: you should provide an illustration for the test that uses average daily temperature and precipitation series. In addition, you have to explain the low sensitivity of your model to the input meteorological data. I assume this is because the parameters are adjusted for each year and for each glacier.

An illustration has been added and we have extended our explanation on the low sensitivity of the model to the meteorological input data (see attachement fig. 1)
“These results demonstrate a relatively low sensitivity of our model approach to daily meteorological input data. With the chosen calibration procedure the model parameters DDFsnow and C_{prec} are adjusted to best represent the TSL observations for each year and glacier individually. The modelled SMB are thus closely tied to the snowline observations and exhibit a reduced dependence from meteorological input data.”

Figure 5b: change JAJ by JJA

Done.

---

5. Results
P16, L3-6: you should provide an illustration for the comparison between SCAFs given by the model and the images for all the used images, glacier by glacier.

We added an illustration comparing the observed and modelled SCAF for each glacier (see attachement: fig. 2).

P16, L7-8: the period 1998 to 2016 stands for Abramov Glacier only. You have to *mention the specific periods for each glacier. Golubin starts in 2000 and No. 354 in 2004. In addition "over the two last decades" can be removed from the sentence because the time periods for each glacier will be mentioned.*

Done.

"Annual glacier-wide modelled surface mass balances constrained by snowline observations, calculated for Abramov (1998-2016), for Golubin (2000-2016), and for Glacier No. 354 (2004-2016), located in the Pamir-Alay and the Tien Shan, are predominantly negative (Fig. 8 and Tabel 6)".

P16, L8: you refer to Figure 8, but because figures 6 and 7 have not been quoted yet, this figure should be Figure 6. Anyway, because I suggest adding two more figures, it will probably remain Figure 8, but must appear before the current figures 6 and 7.

Numbering has been corrected.

Table 5: you must indicate in the table itself (not only the caption) on which period the STD is quantified

Done.

P17, L1: should the first close-to-zero SMB period be extended to 2005?

We agree and extended the period to 2005.

P17, L1: "Glacier No. 354, situated in a more continental climate regime, [. . .]". I am a bit skeptical with this statement! All three glaciers are in a continental regime. This glacier being located in the inner range, it might receive less precipitation than the two others. Is it what you mean? See also my main comment related to interannual variability of the SMB (no6).

Indeed, we refer to a strong precipitation gradient from West to East for both the Pamir/Pamir-Alay and the Tien Shan and also a different precipitation distribution. Glaciers in the western part of the Tien Shan receive more winter accumulation whereas glaciers located more in the east are subject to considerable summer accumulation. This corresponds to the general synoptic large-scale meteorological conditions over Central Asia, influenced by the main direction of the zonal flow of the air masses from west to east. According to Balashova and others (1960, Hydrometeorological Publishing House: Leningrad) and Schienmann and others (2008, International Journal of Climatology, vol. 28(3)) also meridional air mass flow can occur. This occurs either in situations when tropical air masses enter from South and south-west or when north-westerly, northerly and sometimes even north-easterly, cold air masses intrude into Central Asia. We specified the statement but do not want go into more detail in the manuscript.

"Glacier No. 354, receiving lower amounts of total annual precipitation than the other two glaciers studied here, shows the weakest interannual variability and has a positive balance only in 2009 (Table 6)."

P17, L4-5: this sentence refers to the years 2006 and 2008 mentioned in the previous sentence? If yes, the two sentences might be separated by a semi-colon not a dot.

Done.

P17, L8-9: same thing here, the two sentences could be separated by a semi-colon not a dot.

Done.

Table 6: you should mention in the caption that the values differ from Table 5 because the glacier-wide annual surface mass balances are not computed over the same number of days. However, the difference is really high for some years, for example 2014 for Golubin Glacier (more than 0.8 m w.e. different!). You could indicate the number of days differing from the quantification given in Table 5.

Instead of indicating the number of differing days, we added a table with the exact survey dates, and changed the statement in the caption to underline the difference to Table 5.

"Annual SMB $B_{\mathrm{sfc(meas)}}$ for the measurement periods (i.e., exact dates of the surveys, Table 2) based on direct glaciological surveys and on the snowline-constrained model for the three glaciers in m w.e yr^{-1}."

Table 7. A dot is missing after 'e' in "m w.e a-1" In addition, regarding Abramov Glacier, why the first period is 2003-2015 and not 2003-2011?

Due to the limited image quality of the SPOT image from November 2011, we considered the mass balance from 2003 to 2015 to be more robust, and decided to show the result for this period instead.

---

6. Discussion

P20, L3: replace “integrating” by “using”

Done.

P21, L6: discuss why the difference is opposite for Glacier No. 354

We discovered an error in the model settings of Glacier No. 354 of the unconstrained model leading to the too positive balance for Glacier No. 354. The error is corrected and we would like to apologize for this mistake. The calculations and figures are now updated (see attachement Fig. 3). Not surprisingly, the mass balance is much more negative for the unconstrained run.

P22, L27: replace “too positive” by “not negative enough”

Done.

P22, L33: change “shows” by “showed”

Done.

P23, L18-20: you indicate that the average glacier-wide annual surface mass balance quantified by Brun and others (2017) shows a stronger mass loss than your study. This is not really exact. The difference is important with your modeling approach, but *the estimate by Brun and others and your geodetic estimate are really close.*

We clarified our statement.

"The average mass balance for Abramov of $-0.38 \pm 0.10\,\mathrm{m\,w.e.\,yr^{-1}}$ (2002-2014) derived by Brun and others, (2017) using multi-temporal ASTER DEMs indicates a stronger mass loss than the results obtained with the snowline approach. We note, however, that the start and end dates of their geodetic mass balance represent a mean over a mosaic of different dates, thus hampering direct comparison. In addition, the differences are still within their error bounds. The results by Brun and others, (2017 are, however, in line with the geodetic mass balance calculated in this study for the period 2003 to 2015 based on high-resolution satellite images."

Interactive comment on The Cryosphere Discuss., https://doi.org/10.5194/tc-2017-256, 2017.

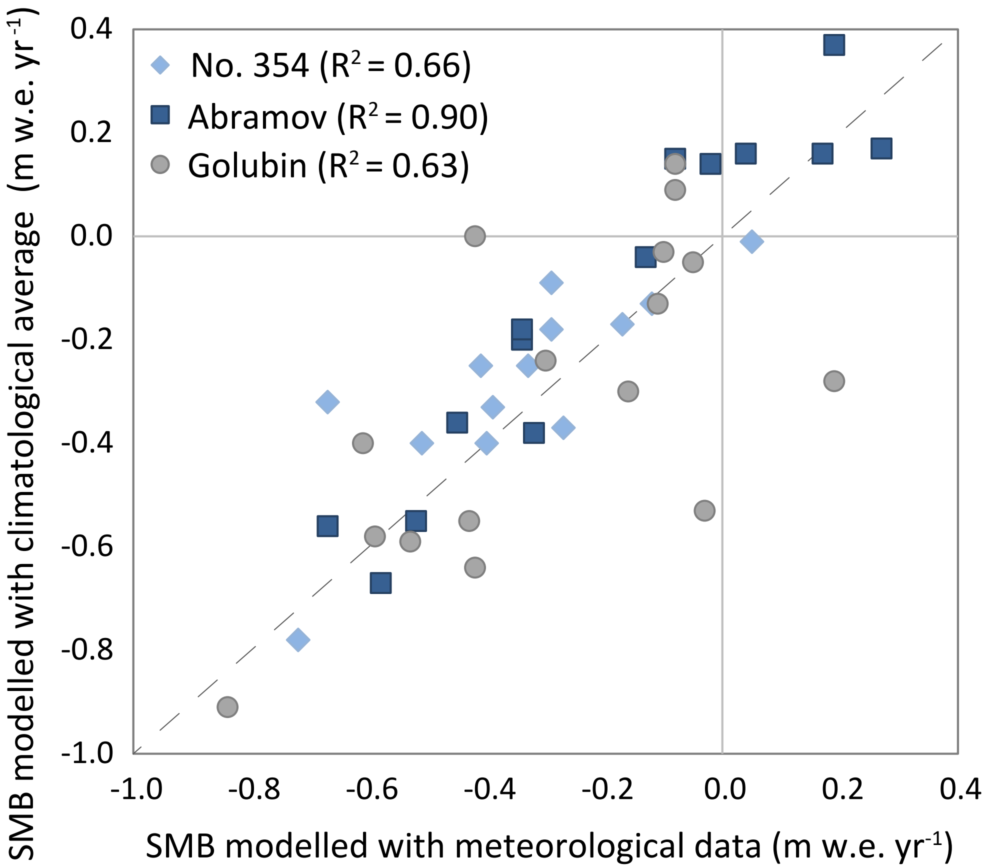

Fig. 1. Comparison between the annual surface mass balance obtained from the snowline-constrained model when using meteorological and climatological average daily data for Abramov (squares), Golubin (diamonds

Printer-friendly version

Discussion paper

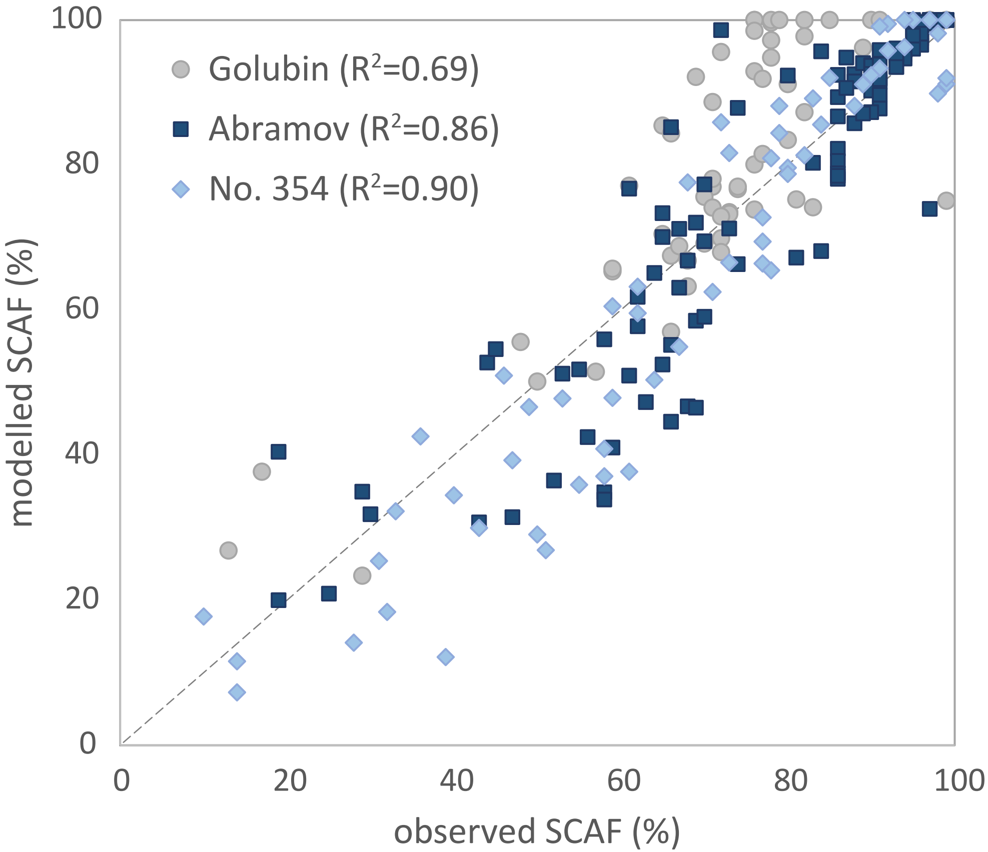

Fig. 2. Comparison between the observed SCAF and the modelled SCAF for for Abramov (squares), Golubin (circles), and Glacier No. 354 (diamonds).

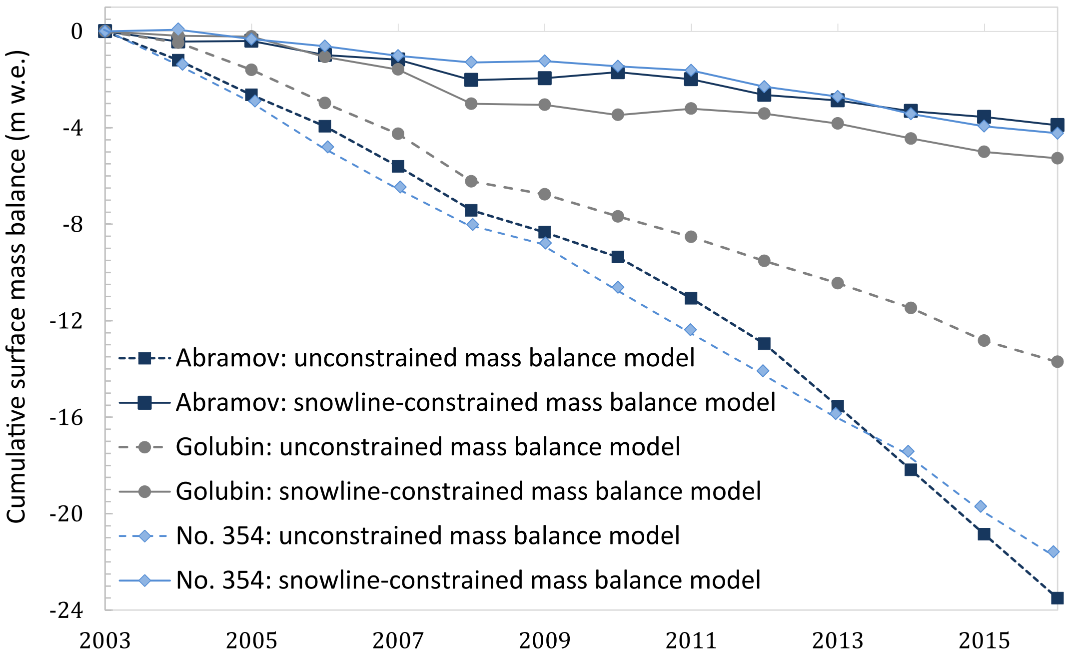

Fig. 3. Comparison of the cumulative surface mass balance derived from unconstrained mass balance modelling to the results obtained from snowline constrained modelling from 2004 to 2016.

Printer-friendly version

Discussion paper