Authors’ response to review reports

We would like to thank an anonymous referee and Argha Banerjee for the careful second review and constructive comments that helped to further improve the manuscript essd-2020-272.

We responded to all comments raised by the referees point by point in blue italic font. We thoroughly checked the language of the entire manuscript and made various minor corrections as highlighted in the document in track-change mode. The line numbers refer to the “essd-2020-272-manuscript-version3.pdf” submitted in April 2021.

Changes other than requested by referees

Line 434, Table 2: Values of mean, STD and sum corrected for B_W+B_S, the caption edited:

Table 2: Mass balance (B) measured with the glaciological method, winter balance (B_W), summer balance (B_S), ELA, AAR and mass-balance gradient for Yala Glacier from 2011/12 to 2016/17. The summer balance from 2011/12 and winter balance from 2014/15 (*) have not been reported to the WGMS and are discussed in subsection 5.1.2 Seasonal mass balance.

B year	B (m w.e.)	B_W *(m w.e.)*	B_S *(m w.e.)*	B_W+B_S *(m w.e.)*	ELA (m a.s.l.)	AAR	db/dz (m w.e. (100 m)$^{-1}$)
2011/12	-0.86 ±0.40	0.16	-0.20*	-0.03	5454 ±30	0.28	1.14
2012/13	-0.01 ±0.29	0.36	-0.35	0.01	5380 ±20	0.48	0.99
2013/14	-0.61 ±0.27	0.27	-0.99	-0.73	5431 ±20	0.35	1.18
2014/15	-1.18 ±0.26	0.54*	-1.12	-0.59	5510 ±40	0.13	0.90
2015/16	-0.61 ±0.23	0.19	-0.79	-0.60	5444 ±20	0.31	0.93
2016/17	-1.54 ±0.20	0.20	-1.75	-1.54	5518 ±20	0.12	1.10
Mean	-0.80 ±0.28	0.29	-0.87	*-0.58*	5456	0.28	1.04
STD	0.53	0.14	0.56	*0.56*	52	0.14	0.12
2011–2017	-4.80 ±0.69	1.72	-5.21	*-3.48*			

Line 452, Figure 3 (right) slightly updated: mass-balance years are now also in the format “201x/1y” instead of “201y”, similar to Figure 2.

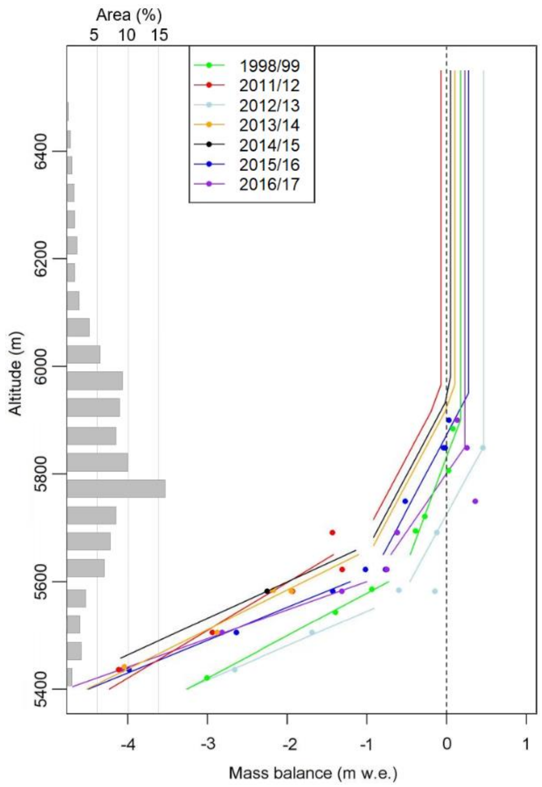


Figure 3: Point mass balance, gradients and hypsography of Rikha Samba Glacier for the mass-balance years 1998/99, and 2011/12 to 2016/17.

Line 577: Figure 11 caption revised: "(Figure adapted from Sugiyama et al., 2013)" deleted. The Figure already uses different data including different base data, a different coordinate system, and different results.

Line 654: Figure 12 has been redesigned and is now shown in colour. We show our own results and data from other sources as declared in the caption. The caption has been revised: "(adapted from Fujita et al. 1998)" has been deleted.

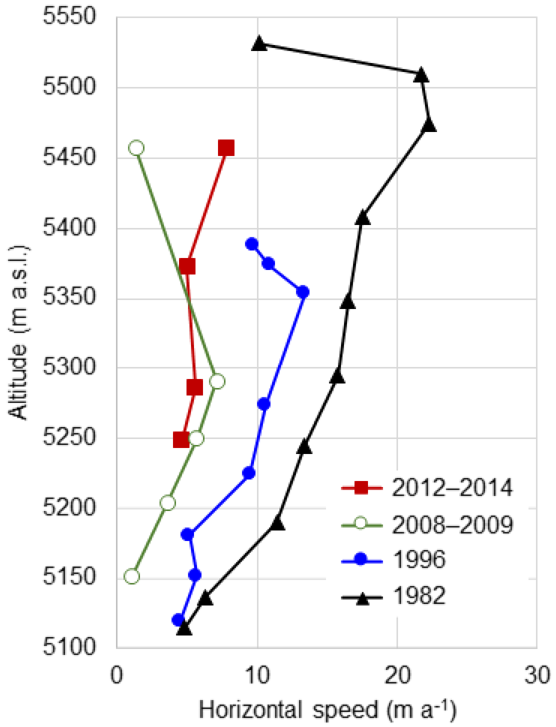
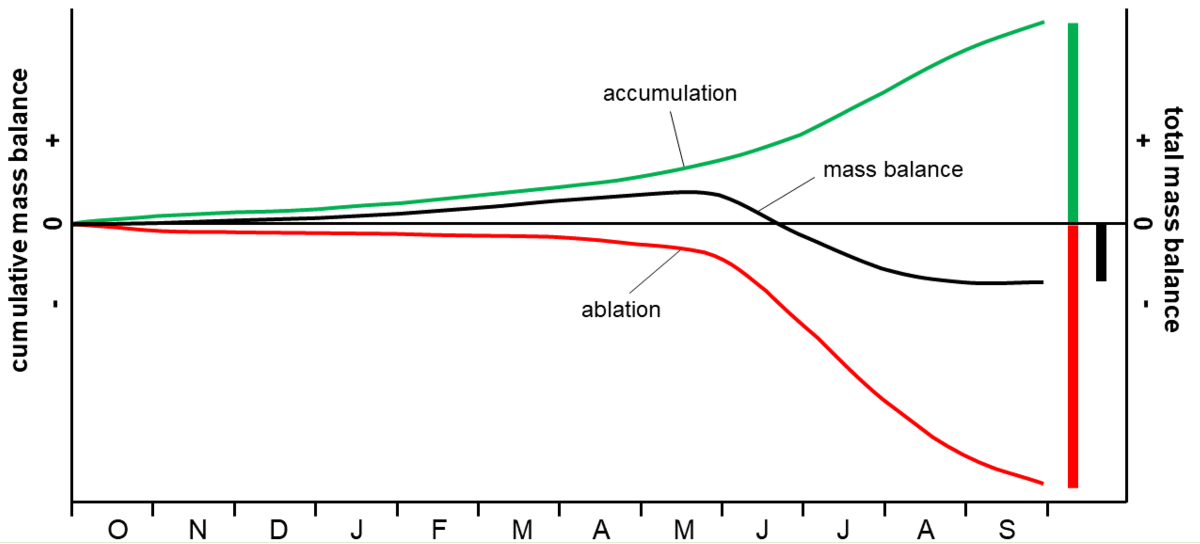


Figure 12: Altitudinal distribution of the surface flow speeds of Yala Glacier, surveyed in 1982 by Ageta et al. (1984), 1996 by Fujita et al. (1998), 2008 to 2009 by Sugiyama et al. (2013) and from 2012 to 2014 in this study.

Supplement: Figure S1 has been further redesigned using a common format. The caption has been revised: "(adapted from Ageta and Higuchi, 1984)" deleted.



Responses to comments of Report #1, by anonymous referee #2

submitted on 12 May 2021

Overall assessment of re-submission:

The authors made a great, if not exceptional, effort to answer the reviewers' questions in great detail, which eventually resulted in a substantial reformulation of large parts of the manuscript incl. changes made to Figures. There is also a largely extended supplementary section. With that, the manuscript is very comprehensive, and I do not see what else needs to be added.

As the underlying data is key for the present paper, I should also mention that the presentation of the data and their availability is now very clearly described in the paper (this point was brought up by both reviewers that assessed the first version of the paper). Another point referred to the extrapolation of the glacier mass balance to higher elevations, which the authors carefully addressed with a dedicated separate section.

Overall, the paper is very comprehensive and it includes really all (or nearly all) aspects that are relevant when assessing glaciological mass balances and especially when implementing a (new) glaciological mass-balance programme. The Introduction offers many references to other studies; it is almost a complete overview on previous (glaciological) work for the particular study region, which is rather long but I think it will also be useful for other studies, too. The following description of the study site and its climate is written very carefully (the sub-section on climate is very comprehensive, but it will be useful for readers who are less familiar with the region). Presentation of results and their discussion are very clear, and there is extensive supplementary material referred to. Finally, I think the new Recommendations section will be very useful, too.

In addition, I also noticed the following points that could be addressed before final publication:

Line 12: you could first list the mass balance and then the length changes, as the main focus of the paper is on (glaciological) mass balance.
Sentences rephrased:

"Here we present the methods and data of the directly measured annual mass balances for the first six mass-balance years for both glaciers <u>from 2011/12 to 2016/17</u>. For Yala Glacier we additionally present the directly measured seasonal mass balance <u>from 2011 to 2017</u>, and the mass balance from 2000 to 2012 <u>obtained</u> with the geodetic method. <u>In additions, we analysed glacier length changes for both glaciers.</u>"

Line 15: It is not quite evident why there are two different observation periods for Yala Glacier (2000-2012 and 2011-2017), which also partly overlap (or maybe do not overlap, because the second period is actually 2011/12-2016/17 (?).
Sentences rephrased: "The <u>directly measured average</u> annual mass-balance rates of Yala <u>and Rikha Samba glaciers</u> are -0.80 ±0.28 m w.e. a^{-1} and -0.39 ±0.32 m w.e. a^{-1}<u>, respectively, from 2011 to 2017</u>. <u>The geodetically measured annual mass-balance rate of Yala Glacier based on digital elevation models from 2000 and 2012 is -0.74 ±0.53 m w.e.</u> The cumulative mass loss for the period 2011 to 2017 for Yala and Rikha Samba glaciers is -4.80 ±0.69 m w.e. and -2.34 ±0.79 m w.e., respectively. <u>The mass loss on Yala Glacier from 2000 to 2012 is -8.92 ±6.33 m w.e.</u>"

Line 18/19: "mass-balance rates" → *corrected*

Line 26: The new FoG database version will be 2021-05 and it should appear very soon on the WGMS doi landing page (you may check here: https://wgms.ch/data_databaseversions/) → *Thank you! Manuscript checked, cited values and references updated*

Line 30: Good and interesting that you refer to the WMO(GCOS) headline indicators. → *Thank you*

Line 32: You could also refer to Gärtner-Roer et al. 2019 (Worldwide assessment of national glacier monitoring and future perspectives, MRD, 39, A1-A11) about the national implementation of the glacier monitoring strategy. *→ Reference added in text and reference list. Thank you.*

Line 45: I would just write "glaciers" and not "clean glaciers". If you want to use the term "clean" in this context, you would have to first explain what you exactly mean.
On the other hand, it would open many other questions., e.g. what about glaciers that are partly debris-covered, and how would this affect the glaciological mass balance. *→ corrected: "clean" deleted*

Line 110: There is a kind of break in here, maybe you could link this last paragraph more to the previous Introduction.
Sentence modified: "In this article we focus on the mass balance and glacier length changes of Yala and Rikha Samba glaciers measured within the framework of the HKH-Cryosphere Monitoring Project."

Line 113/114: Not fully clear; what do you mean with "other supporting data beyond the scope of the WGMS FoG database"?
Sentence and "for" added. The sentences read now: "

At Yala Glacier we measured […]. <u>Additionally, we recorded supporting information such as flow velocity and direction.</u> On Rikha Samba Glacier we assessed […]. The methods are documented for these measurements and data submitted to the WGMS Fluctuations of Glaciers (FoG) database (WGMS, 2021), and <u>for</u> other supporting data beyond the scope of the WGMS FoG database."

Figure 1 is very useful for the broader context, incl. the overview map showing the location of other glaciers with mass-balance measurements.
You could add the date of the glacier outlines (= the same as the satellite image?).

The dates of the glacier outlines have been added in Fig. 1, besides having it mentioned in the caption.

Line 292: Sentence is logically not fully clear, as the DEM is part of the geodetic method (?). Or is it an additional DEM that you are referring to?

Sentence deleted. The information that the DEM2012 was used for the geodetic mass balance calculation is already provided in subsection "3.2 Maps, satellite images and DEMs". In subsection "3.4.1 Point and glacier-wide mass balance", the DEMs are now explicitly specified in Line 322 and the sentence reads now: "The elevations of the <u>DEM2012 for Yala Glacier</u> and <u>the SRTM1 for Rikha Samba Glacier</u> were applied to the regression equations to calculate the glacier-wide mass balance."

Line 320/21: You could explicitly state that Wagnon et al. used this methodology on Mera and Pokhalde glaciers.

"for Mera and Pokalde glaciers" added. The sentence reads now: "The glacier-wide mass balances, the equilibrium-line altitude (ELA) and accumulation-area ratio (AAR) were calculated based on the interpolated mass-balance gradient derived from the point measurements following a similar method used by Wagnon et al. (2013) for Mera and Pokalde glaciers."

Line 535: there is some repetition in this paragraph, when compared to the beginning of this section.

The author didn't find any repetitions. However, in Line 558 the time interval we corrected to "2006 to 2011", instead "2011 to 2016".

Subsection 4.1: 1st paragraph: in situ mass balance both glaciers; 2nd paragraph: seasonal balance Yala Glacier; 3rd paragraph: uncertainties of mass balance; 4th paragraph: densities; 5th paragraph: ELA and AAR; 6th paragraph: mass-balance gradients; 7th paragraph: observations snow; 8th paragraph: geodetic mass balance and cumulative mass balances
Subsection 4.2: 1st paragraph: glacier length changes; 2nd paragraph: glacier flow

Line 604: "Yala Glacier will disappear" *→ corrected, "is" deleted*

Line 663: The conclusions of this discussion (about glacier length, flow, and downwasting) remains a bit elusive: Do you mean that there is a bias in the mass-balance measurements? I read in this paragraph that the detailed topographical analyses (length, flow, downwasting) are useful to better assess the mass-balance measurements. But this could be mentioned more explicitly.

The paragraph has been revised and reads now:

"From 2011 onwards, we observed that concave shapes on Yala Glacier's surface have become more pronounced, and that the glacier surface was downwasting, as observed at other glaciers (Ragettli et al., 2016; Sommer et al. 2020). Both the downwasting and enhanced concave shapes are a consequence of the decreased ice velocities, and indicate changes in the glacier dynamics. The downwasting of Yala Glacier can affect the mass balance and its monitoring in several ways, such as locally enhanced ablation and compromised representativeness of stake measurements. Ablation can be locally enhanced in bowl-shaped areas, where radiation is reflected, resulting in a positive feedback and higher ablation than in the surrounding area (Hock, 2005). Such concave surfaces with transitions to steep slopes became more pronounced, for example, between stakes S1 and S1B and near S5. Usually, stakes represent a characteristic type of glacier area. However, the representativeness of stake measurements is compromised over time when the glacier surface topography changes from an even surface to a very concave surface with steep slopes. The bias induced by reduced stake representativeness should be corrected later with help of complementing geodetic mass-balance analyses for the same timeframe (Zemp et a., 2013)."

Line 695: rather "Fujita and Nuimura (2011) found that…" → *corrected*

Line 746: or: debris-free → *corrected, "clean" replaced with "debris-free"*

Line 817: maybe reformulate this sub-title; the in situ measurements will always remain the same, but the mass balance will be extrapolated to regions without in situ measurements.

The revised title of the subsection is now: "5.6 Extrapolation of mass-balance data to unmeasured areas"

Line 854: Not fully clear: I understood that the glacier-wide mass balance is given for the entire glacier as shown in Figure 1. Hence, there is a quantification for these slopes (as long as they are in the respective glacier area/outline?), but this extrapolation (which nevertheless represents a quantification) may have a certain error. It is also a bit confusing because line 855 says that this error (underestimation of ablation) can be addressed with the geodetic method, which was actually done in the presented study. Or was the applied DEM not sufficient enough (as the following sentence might suggest?).

The paragraph has been rephrased and now reads: "The mass balance of the steep south-west-facing slopes on Yala Glacier could not be measured but have been quantified based on the linear regression equations from the in situ measurements. However, the ablation on steep slopes is possibly underestimated due to the orientation and the steepness of the slopes. This bias can be addressed with geodetic mass-balance analyses using the same time period as for the in situ measurements. The relevance of the steep glacier slopes in terms of area cannot be quantified neither for Yala Glacier, nor the glaciers in Nepal in general with DEMs of 30 m and 90 m resolution, respectively."

Please note, it is a standard to complement glaciological with geodetic mass-balance analyses. It is essential to use data from the same time period (e.g. Zemp et al., 2013 and Wagnon et al., 2020). In our study, the measurement period for the geodetic (2000–2012) and glaciological data (2011–2017) differs, as documented in section "3 Data and Methods", and cannot be used to complement each other.

Also, in the time interval from 2000 to 2012, the annual mass balance on every point on the glacier would have changed every year. From one year to the next, the mass change moved continuously further down on the glacier. Hence, the average annual mass-balance distribution from 2000 to 2012 *in the areas of the ice cliffs and steep slopes does not represent the annual mass-balance distribution for later years. Additionally, the uncertainty is relatively large.*

Geodetic mass-balance analyses can also be used for several applications, taking the purpose, base data (e.g. resolution, time interval) and uncertainties into consideration. One example we give in the discussion section, subsection "5.1.4 Steep slopes and ice cliffs": "To better understand and assess specifically the influence of the steep slopes and ice cliffs of the mass balance, geodetic thickness-change analyses based on ***high-resolution surface elevations for short time intervals*** *could be used, in combination with energy-balance models (Joerg and Zemp, 2014)." Besides this, we write: "Complementing geodetic mass-balance measurements for the same timeframe help to correct the glacier-wide annual mass balances of Yala Glacier for biases such as introduced by steep slopes and ice cliffs (Zemp et al., 2013; Wagnon et al., 2020)."*

Regarding the glaciological and geodetic mass-balance measurements it is important to consider what is actually measured, the role of the measured time interval, ice flow and resolution of DEMs used (see also Cogley et al., 2011). In the Table below a brief overview is provided for the different methods.

	Glaciological mass balance	***Geodetic mass balance***	
		high resolution	***low resolution***
Typical time interval	*Annual, seasonal, monthly*	*Multiannual measurements*	
		Approx. 1–5 years	*Approx. 10 years*
What is measured:	*Mass changes between the glacier surface s_0 and s_1, in the time period between t_0 and t_1, in a relative reference system.* *The measurements are taken in reference to the glacier surface and the used measurement method, e.g. a stake or a snow pit relative to the glacier surface.*	*Mass changes between the glacier surface s_0 and s_1, in the time period between t_0 and t_1, in an absolute reference system.* *The elevations of the glacier surfaces at two different times are measured in an absolute coordinate system.*	
Mass balance:	*Only surface mass balance*	*Surface, internal and basal mass balance*	
Ice flow:	*Ignored*	*Relevant but small*	*Relevant*
Mass balance distribution on glacier:	*On high elevations on glacier: positive balance (or less negative than on low elevations)* *On low elevations on glacier: Negative balance (or less positive than on high elevations)*	*Generally, if time interval is short enough and no extreme events:* *On high elevations on glacier: positive balance (or less negative than on low elevations)* *On low elevations on glacier: Negative balance (or less positive than on low elevations)*	*Generally:* *Depends on past climate/surface mass balance and ice flow. Anywhere on the glacier it can be positive or negative.* *Generally, over very long time intervals, shrinking glaciers have a very negative mass balance in the low elevations of a glacier and less negative mass balances higher up.*

Line 872: "on the following points" → *corrected, "the" added*

Line 1205: Wagnon et al. 2020 is listed twice (it must be an important paper :-))

Corrected. We confirm, it's important. =)

Line 1220: The WGMS (2020a) reference might be replaced with WGMS (2021), because the 2021 database version also includes all data of the 2020 version, and hence you can just refer to the latest database version. (Unless you explicitly want to refer to some data that were in the 2020 database but are not any more or that have changed in the 2021 version; but I think, this (rare) case does not apply here). WGMS (2020b) would then be WGMS (2020).

New FoG database 2021-05 checked, reference and values (Table 6) updated.

Further point that I have noticed:
Usage of three nouns: for mass-balance rate or mass-balance monitoring etc., they are usually written with hyphen (not quite with all occurrences in the text), but other word combinations are written without (e.g. sea level rise).

We checked the manuscript again regarding the hyphenation. Please note, the rules of hyphenation of compound nouns vary. Here, we followed the ESSD grammar guidelines, terminology used by Cogley et al., 2011 (Glossary of mass balance and related terms), common rules found online (e.g. by Cambridge Dictionary, Capstone Editing), and tried to follow the hyphenation rules referee #2 used in earlier comments. We do not have a preference regarding the usage of hyphens.

Responses to comments of Report #2, by Argha Banerjee, referee #1

submitted on 21 May 2021

I congratulate the authors for an excellent revision. In my opinion the manuscript is at a stage where it can be published up to a few minor (but significant) corrections.

These are,

1. It may not be wise to report the winter mass balance data for 2012 and 2015 where there are large uncertainties such that the mass conservation principal was violated. Please see my detailed comments in the annotated manuscript.

In the section results, subsection "4.1 Mass balances, ELA, AAR and gradients", a remark has been added in Table 2 and its caption, as well as in caption of Fig. 4. Additionally, a statement has been added in the result section "4.1 Mass balances, ELA, AAR and gradients" and discussion section "5.1.2 Seasonal mass balance".

Table 2: Mass balance (B) measured with the glaciological method, winter balance (B_W), summer balance (B_S), ELA, AAR and mass-balance gradient for Yala Glacier from 2011/12 to 2016/17. The summer balance from 2011/12 and winter balance from 2014/15 (*) have not been reported to the WGMS and are discussed in subsection 5.1.2 Seasonal mass balance.

B year	B (m w.e.)	B_W (m w.e.)	B_S (m w.e.)	B_W+B_S (m w.e.)	ELA (m a.s.l.)	AAR	db/dz (m w.e. (100 m)$^{-1}$)
2011/12	-0.86 ±0.40	0.16	-0.20*	-0.03	5454 ±30	0.28	1.14
2012/13	-0.01 ±0.29	0.36	-0.35	0.01	5380 ±20	0.48	0.99
2013/14	-0.61 ±0.27	0.27	-0.99	-0.73	5431 ±20	0.35	1.18
2014/15	-1.18 ±0.26	0.54*	-1.12	-0.59	5510 ±40	0.13	0.90
2015/16	-0.61 ±0.23	0.19	-0.79	-0.60	5444 ±20	0.31	0.93
2016/17	-1.54 ±0.20	0.20	-1.75	-1.54	5518 ±20	0.12	1.10
Mean	-0.80 ±0.28	0.29	-0.87	*-0.58*	5456	0.28	1.04
STD	0.53	0.14	0.56	*0.56*	52	0.14	0.12
2011–2017	-4.80 ±0.69	1.72	-5.21	*-3.48*			

The caption of Fig. 4 now reads: "Winter, summer and annual mass balance of Yala Glacier and annual balance of Rikha Samba Glacier, calculated based on the respective gradients. In the mass-balance years 2011/12 and 2014/15, the sum of winter and summer balances differ significantly from the annual balances, likely due to a lack of data in higher elevations. The summer balance from 2011/12 and winter balance from 2014/15 have not been reported to the WGMS."

In the section results, subsection "4.1 Mass balances, ELA, AAR and gradients" the underlined sentence has been added: "The cumulated winter and summer balances largely sum up to the annual balances, except in 2011/12 and 2014/15 when the cumulated winter and summer balances underestimate the annual mass loss by -0.83 m and -0.59 m w.e. These discrepancies are discussed in section 5.1.2 Seasonal mass balance."

In the section discussion, subsection "5.1.2 Seasonal mass balance", the two underlined sentences have been added: "[…] The seasonal mass-balance measurements in June 2015 were taken under precarious conditions, and only stake measurements could be taken up to an elevation of 5217 m a.s.l., resulting in a higher uncertainty for the seasonal mass balances in 2014/15 and a possibly underrepresented accumulation in winter 2014/15. Hence, the winter balance for the mass-balance year 2014/15 has not been reported to the WGMS. […] In autumn 2012, we calculated the least negative summer balance (-0.35 m w.e.), based on only three measurements and likely underestimating ablation. This could explain the underestimated annual mass loss of -0.83 m w.e. in the cumulative seasonal balance *compared to the annual balance of 2011/12. Consequently, the summer balance from the mass-balance year 2011/12 has not been reported to the WGMS."*

Please also note comments and responses below for:

- *Page 15, comments 1, 2*
- *Page 23, comment and responses*

2. Your conclusion about the annual balance on Yala being insensitive to winter balance can be discussed in a bit more detail. Please see my detailed comment in the attached annotated manuscript. Basically you have concluded this based on 4 years of data (if we leave out the two years with large uncertainties) where annual balance stayed mostly negative. The conclusion may not hold in general.

Please note, it is characteristic for summer-accumulation-type glaciers that the biggest mass changes happen in summer. In section 2 we write: "Both glaciers are summer-accumulation-type glaciers (Ageta and Higuchi, 1984), which are characterized by an overlapping main accumulation and ablation season during the monsoon season (Fig. S1). A brief description of summer-accumulation-type glaciers and mass-balance measurements is provided in the Supplement (section S1)."

During the investigation period, the winter balance was positive and the summer balance was negative. Please also see response for comment below, Page 1, Number 4.

3. The manuscript will benefit from a careful copy editing. There are some difficult-to-understand constructions/sentences which could be rephrased. Also, there may be some (minor) claims/statements that are not supported by your data and analysis. I have suggested some corrections, mostly in the abstract, and conclusions sections, to illustrate the point. Similar issues may be there in other parts of the manuscript. Please feel free ignore these suggestions if you feel that they are incorrect or unnecessary.

We checked the language of the manuscript again thoroughly. We highlighted edits in the document in track-change mode and in the responses to the review reports.

At various stages, not only revised sections but the entire manuscript has been edited by senior and junior scientists, as it should be a standard for any submitted manuscript. We are non-native English speakers. Generally, we used British English according to our best knowledge, which naturally varies from English written and used in other countries with English as official language.

Regards,

Argha

Page: 1

In 2011, we established two glacier mass-balance programmes on Yala and Rikha Samba glaciers in the Nepal Himalaya. Here we present the methods and data for glacier length changes and the directly measured annual mass balances for the first six mass-balance years for both glaciers. For Yala Glacier we additionally present the directly measured seasonal mass balance, and the mass balance from 2000 to 2012 analysed with the geodetic method. The annual mass-balance rates of Yala Glacier from 2000 to 2012 and from 2011 to 2017 are -0.74 ±0.53 m and -0.80 ±0.28 m w.e. a^{-1}, and for Rikha Samba Glacier from 2011 to 2017 -0.39 ±0.32 m w.e. a^{-1}. The cumulative mass loss for the period 2011 to 2017 for Yala and Rikha Samba glaciers is -4.80 ±0.69 m w.e. and -2.34 ±0.79 m w.e., respectively. The winter balance of Yala Glacier is positive in every investigated year, but the negative summer balance determines the annual balance. Compared to the regional mean geodetic mass-balances rates in the Nepalese Himalaya, the mean mass-balance rate of Rikha Samba Glacier is in a similar range, and the mean mass-balance rate of Yala Glacier is more negative because of the small and low-lying accumulation area. During the study period, a change of Yala Glacier's surface topography has been observed with glacier thinning and downwasting. Due to the topography, the retreat rates of Rikha Samba Glacier are higher than for Yala Glacier. From 1989 to 2013, Rikha Samba retreated 431 m (-18.0 m a^{-1}), and from 1974 to 2016 Yala Glacier retreated 346 m (-8.2 m a^{-1}). The data of the annual and

Number 1: Author: argha Date: 21/5/21 07:17:07: Comment: period of 2011-2017.

Sentence rephrased: "Here we present the methods and data of the directly measured annual mass balances for the first six mass-balance years for both glaciers from 2011/12 to 2016/17."

Number 2: Author: argha Date: 21/5/21 07:18:31: obtained with → *corrected*

Number 3: Author: argha Date: 21/5/21 07:18:57: Comment: rephrase

Sentence rephrased: "The directly measured average annual mass-balance rates of Yala and Rikha Samba glaciers are -0.80 ±0.28 m w.e. a^{-1} and -0.39 ±0.32 m w.e. a^{-1}, respectively, from 2011 to 2017. The geodetically measured annual mass-balance rate of Yala Glacier based on digital elevation models from 2000 and 2012 is -0.74 ±0.53 m w.e."

Number 4: Author: argha Date: 21/5/21 15:50:41:

You mean annual balance does not depend on winter balance at all? It is confusing as, b_ann =b_w + b_s.

I doubt if one can conclude that based on 4 years of data (let's exclude 2011 and 2015 here - I have explained why in my later comments), when the mass balance values were mostly negative.

Given the above equation, it is clear that b_ann ~ b_w whenever |b_w|>>|b_s|, and b_ann ~ b_s whenever |b_w|<< |b_s|. Since on most of the years with good data on yala glaciers mostly is in the limit |b_s| >> |b_w|, it is obvious that on these years, |b_w| will have a relatively stronger control on b_a.

Please consider the above point, and revise your conclusions as may be necessary.

The sentence in the abstract has been split and rephrased and now reads: "The winter balance of Yala Glacier is positive and the summer balance is negative in every investigated year. The summer balance determines the annual balance."

It is characteristic for summer-accumulation-type glaciers that the biggest mass changes happen in summer. Please also see Supplement, section "S1 A brief description of summer-accumulation-type glaciers and related mass-balance measurements".

Please also note the response for minor comment 2.

Number 5: Author: argha Date: 21/5/21 07:31:07:

may be rephrased as , "The mean balance rate of Rikha... is similar to the regional .... However, the mean ... of Yala ... is realtively more negative ... area."

Typo corrected: "Compared to regional mean geodetic mass-balance rates in the Nepalese Himalaya, the mean mass-balance rate of ...". The first part of the sentence indicates the shifted focus to the comparison with other glaciers and has been kept as it was.

Number 6: Author: argha Date: 21/5/21 15:53:00, Comment: I could not find a corresponding discussion/explanation/conclusion where you establish/justify this claim about topographic control. Maybe I have ust missed it. If not, you may either drop it from the abstract, or add some supporting arguments in the text.

Rephrased: "The retreat rates of Rikha Samba Glacier are higher than for Yala Glacier."

Page: 2

al., 2013), and only few include seasonal measurements (Wagnon et al., 2013; Azam et al., 2016; Sherpa et al., 2017). On a regional scale glacier mass balances have been estimated by remote sensing techniques (e.g. Abdullah et al., 20 Maurer et al., 2019; Gardelle et al., 2013; Vincent et al., 2013; Kääb et al., 2012; Berthier et al., 2007) and modelling (eg, Fujita et al., 2011; Shea et al., 2015a; Tawde et al., 2017). However, due to the remoteness, high altitude topography and logistical challenges there is still a lack of in situ measurements to validate and calibrate such studies. Some studies focused on ablation and runoff on a high spatial and temporal resolution on clean and debris covered glaciers (eg, Litt et al., 2019; Pratap et al., 2019; Pratap et al., 2015; Immerzeel et al., 2014; Fujita and Sakai, 2014), but rarely measured precip on and snow accumulation in high

Number 1 & 3: Author: argha Date: 21/5/21 07:33:54 *→ "e.g." added as suggested*

Number 2: Author: argha Date: 21/5/21 07:34:57: in the region
Omitted because the entire paragraph is about the HKH region.

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Glacier characteristics		
Latitude/ Longitude	28° 14' N, 85° 34' E	28° 50' N, 83° 30' E
Elevation range	5168–5661 m a.s.l.	5416–6515 m a.s.l.

Number Author: argha Date: 21/5/21 07:38:34: Are these values known to 4th significant digits?
→ The elevations are based on the DEMs and have been reported to the WGMS like this

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3 Data and methods

The mass balance of the two glaciers was monitored from 2011 to 2017 with the direct, glaciological method using stakes, snow pits and cores, and for Yala Glacier also with the geodetic method from 2000 to 2012. The frontal variations were evaluated based on satellite images, dGNSS and global positioning system (GPS) data.

3.1 Data collection

The in situ measurements started in autumn 2011, and are conducted twice a year on Yala and annually on Rikha Samba glaciers. On Yala Glacier, the annual/summer balance measurements were taken in November. The winter balance was measured in late April or early May, and in 2015 in early June due to the major earthquake in Nepal on 25 April 2015. On Rikha Samba Glacier, in the first ? years the measurements were carried out in September, which is rather early because still under the influence of the monsoon. In the following years, the measurements were carried out in October or November. Generally, October and November are ideal periods for mass-balance measurements in the central Nepal Himalaya, but coincide with the main festival season in Nepal. The festival season is of great religious importance, lasts for several weeks, and varies every year by weeks. This makes it hard to do plan fieldwork at fixed dates and find people to conduct measurements. The autumn expeditions with ? trainings on Yala Glacier were conducted after the last festival ended to allow ~~training~~ participation from various institutions and universities.

Number 1: Author: argha Date: 21/5/21 07:41:24
I am not sure about your terminology "direct method"? Consider replacing the phrase "direct method" by "glaciological method" everywhere, unless direct method is an established synonym of glaciological method. *→ here "direct" deleted; however, direct method is an established synonym of the glaciological method*

- Number 2: Author: argha Date: 21/5/21 07:42:26 → *here meant is: "…dGNSS (data) and global positioning (GPS) data." Therefore, no comma after dGNSS.*
- Number 3: Author: argha Date: 21/5/21 07:41:48 → *comma added*
- Number 4: Author: argha Date: 21/5/21 07:43:00 → *please note, it is correct to say in English "in the first years", https://www.collinsdictionary.com/dictionary/english/first: e.g. "…the first few flakes of snow."*
- Number 5: Author: argha Date: 21/5/21 07:43:47: 'early' relative to what? → *On Rikha Samba Glacier, in the first years the measurements were carried out in September, which is rather early in the season because it is still under the influence of the monsoon.*
- Number 6: Author: argha Date: 21/5/21 07:44:20: check the sentence → *Sentence rephrased, please see response for Number 5.*
- Number 7: Author: argha Date: 21/5/21 07:45:49 → *"do" instead of "plan"*
- Number 8: Author: argha Date: 21/5/21 07:46:24 → *Sentence rephrased: "In autumn, the expeditions to Yala Glacier were conducted after the last festival ended to allow members from various institutions and universities to participate in the training courses."*

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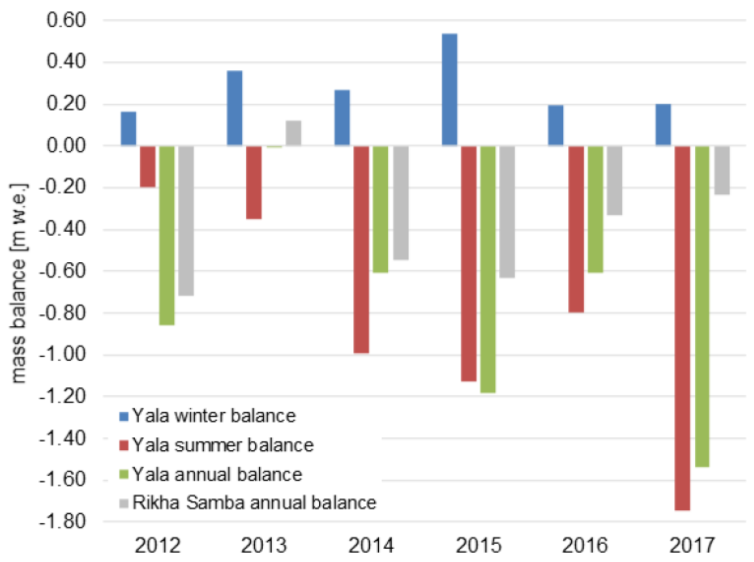

1

2

Figure 4: Winter, summer and annual mass balance of Yala Glacier and annual balance of Rikha Samba Glacier, calculated based on the respective gradients. In the mass-balance years 2011/12 and 2014/15, the sum of winter and summer balances differ significantly from the annual balances, likely due to a lack of data in higher elevations.

- Number 1, 2: Author: argha Date: 21/5/21 16:00:07:

This I find hard to understand. Please rethink and revise.

It simply follows from the definition of mass balance that, if b10 is the net balance between day0 and day1, and b12 is the net balance between day1 and day2, then the net balance between day0 and day 2 is

b02=b01+b02.

or in your case,

b_ann= b_w+b_s

This is a mathemtical relation that follows from mass conservation. I don't see how it can be violated beyond the limit set by the uncertainties in b01 and b12.

You may refer to your own fig S1 to confirm what I am saying above.

In fact, it is clear from your table 2 that only in 2012 and 2015, the above equality was violated signoficantly. I strongly suggest that you revise your data and calculations for these two years, and find out what went wrong.

You must investigate this further, settle the issue and discuss it in detail in the text.

Also, in the method section, please define precisely what is definition of annual, summer, and winter balance (b, bw, bs).

*Please note, the annual and seasonal mass balances have been calculated separately based on linear regression lines from the annual and seasonal direct measurements. This is documented in section "3 Data and methods,", subsection "3.4.1 Point and glacier-wide mass balance": "For Yala Glacier, characteristic gradients for the ablation area were identified, and separately analysed for the annual and seasonal mass balances, with the winter and summer season starting in November and May or June, respectively." (see also Fig. 2). Based on this, it is clear that the annual mass balance (B) must not necessarily be the sum of the winter balance (B_W) and summer balance (B_S). In the caption of Fig. 4 we explicitly state "Winter, summer and annual mass balance of Yala Glacier and annual balance of Rikha Samba Glacier, calculated **based on the respective gradients**."*

The caption of Fig. 4 has been revised and now reads: "Winter, summer and annual mass balance of Yala Glacier and annual balance of Rikha Samba Glacier, calculated based on the respective gradients. In the mass-balance years 2011/12 and 2014/15, the sum of winter and summer balances differ significantly from the annual balances, likely due to a lack of data in higher elevations. <u>The summer balance from 2011/12 and winter balance from 2014/15 have not been reported to the WGMS."</u>

As suggested by referee 2 in the first review report (Line 463), the discrepancies between seasonal and annual balances are now further explained in the discussion section, subsection "5.1.2 Seasonal mass balance".

Please also note comments and responses for:

- *Minor comment 1*
- *Page 23, comment and responses*

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610 **5.1.2 Seasonal mass balance**

On Yala Glacier the negative summer balance determines the annual balance. For every winter season we measured positive mass balances, and during summer only little or no net accumulation in higher elevations (Fig. 2, 4 and Table 2). The slight mass

Author: argha Date: 21/5/21 08:21:55 → *"net" added*

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The effect of the air blasts on the snow cover of Yala Glacier is not known, however, it is possible that snow was blown away and partly sublimated. The air in the valley was filled with dust and it is probable that more dust than usual settled on Yala Glacier, increasing ablation particularly in summer 2015. The seasonal mass-balance measurements in June 2015 were taken under precarious conditions, and only stake measurements could be taken up to an elevation of 5217 m a.s.l., resulting in a higher uncertainty for the seasonal mass balances in 2014/15 and a possibly underrepresented accumulation in winter 2014/15. These circumstances explain the discrepancy in the cumulative seasonal and the annual mass balance by -0.59 m w.e. in the mass-balance year 2014/15 (Fig. 4). In autumn 2012, we calculated the least negative summer balance (-0.35 m w.e.), based on only three measurements and likely underestimating ablation. This could explain the underestimated annual mass loss of -0.83 m w.e. in the cumulative seasonal balance compared to the annual balance of 2011/12. Measurements taken in autumn were generally more reliable because less snow was present on the glacier surface, reducing the uncertainty related to the snow cover. Although Yala Glacier is a summer-accumulation type glacier, most of the accumulation was measured in the winter season because the accumulation area is too small and at a too low elevation to benefit from snowfall during the monsoon months. Together with the overall negative balances it indicates that Yala Glacier is out of balance and shrinking.

Comment: Author: argha Date: 21/5/21 15:58:23

Now that you have indicated that your data during the years 2012 and 2015 may have significantly higher uncertainties, it is clear to me why your (bw+bs) does not equal ba. As I have pointed out earlier, such violation of mass conervation is happenning only on these two years.

Please revise/reconsider all the references/discussions about this apparent violation of conservation. That is due to unavoidable measurement errors/biases on these two years.

In fact, you may not want to report these two winter balance values, since the clearly have large biases.

In section "3 Data and methods" the methodology has been explained. As suggested by referee 2 in the first review report Line 463, the discrepancies between seasonal and annual balances are further explained in the discussion section, subsection "5.1.2 Seasonal mass balance". The two underlined sentences have been added: "[…] The seasonal mass-balance measurements in June 2015 were taken under precarious conditions, and only stake measurements could be taken up to an elevation of 5217 m a.s.l., resulting in a higher uncertainty for the seasonal mass balances in 2014/15 and a possibly underrepresented accumulation in winter 2014/15. Hence, the winter balance for the mass-balance year 2014/15 has not been reported to the WGMS. […] In autumn 2012, we calculated the least negative summer balance (-0.35 m w.e.), based on only three measurements and likely underestimating ablation. This could explain the underestimated annual mass loss of -0.83 m w.e. in the cumulative seasonal balance compared to the annual balance of 2011/12. Consequently, the summer balance from the mass-balance year 2011/12 has not been reported to the WGMS."

Please also note comments and responses for:

- *Minor comment 1*
- *Page 15, comments 1, 2*

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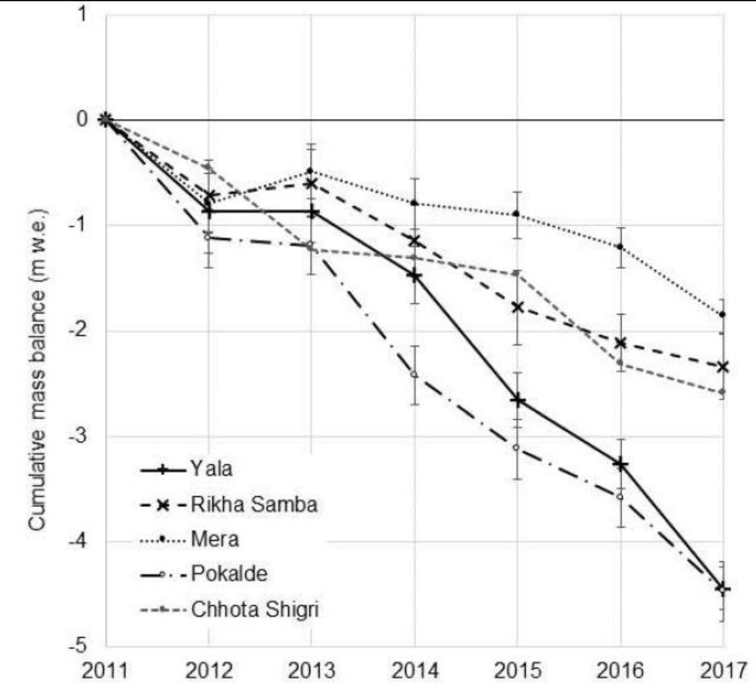
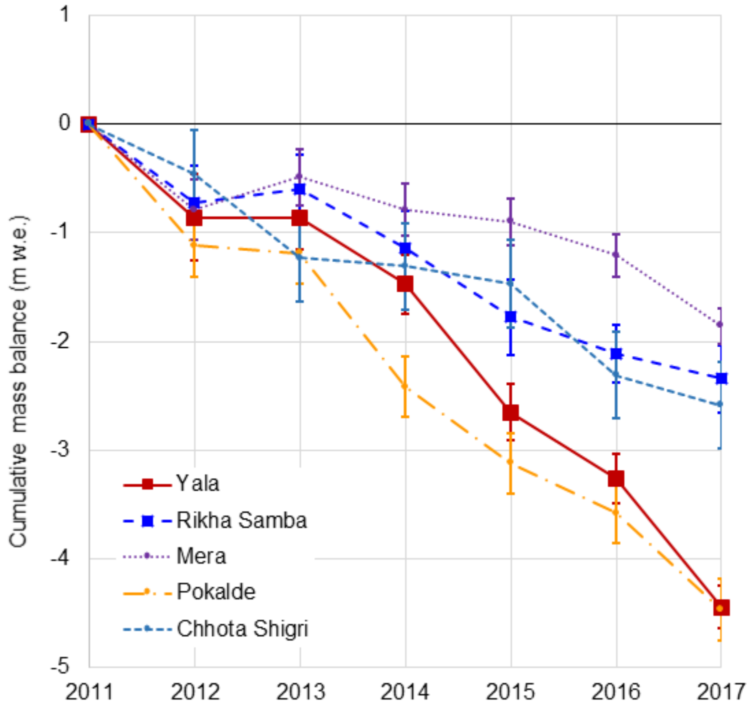


Figure 13: Cumulative mass balances of Yala, Rikha Samba, Mera, Pokalde and Chhota Shigri glaciers. The data for Mera, Pokalde and Chhota Shigri glaciers is from Wagnon et al. (2013), Sherpa et al. (2017), WGMS (2020a), Wagnon et al. (2020) and Mandal et al. (2020).

Number: 1 Author: argha Date: 21/5/21 08:58:20

Could you please use colored symbols for a better readability? *→ Revised, now in colour:*



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6 Conclusions

We measured the in situ mass balance of Yala and Rikha Samba glaciers for the mass-balance years 2011/12 to 2016/17. Additionally, we measured the seasonal in situ mass balance of Yala Glacier, and analysed the corresponding geodetic mass balance from 2000 to 2012. Glacier length changes have been analysed for both glaciers based on field measurements, maps and satellite images. 1

- Both Yala and Rikha Samba glaciers shrank and retreated in the last couple of decades. The geodetic mass balance 2 of Yala Glacier showed a mass loss of -10.5 ~~-10.49~~ ±7.4 ~~±7.41~~ m w. e. from 2000 to 2012, at an annual rate of -0.74 ±0.53 m w.e. a^{-1}. The cumulative in situ mass balances for Yala and Rikha Samba glaciers were -4.80 ±0.69 m w.e. and 2.34 ±0.79 m w.e., and the annual mass-balance rates -0.80 ±0.28 m w.e. a^{-1} and -0.39 ±0.32 m w.e. a^{-1}, respectively. 3 From 4 1974 to 2016, Yala Glacier retreated by 346 m, and from 1989 to 2013 Rikha Samba Glacier retreated 431 m. Under the recent climate it can be expected that Yala Glacier will disappear over time but not Rikha Samba Glacier (Fujita and Nuimura, 2011). 5
- 6 For both the investigated glaciers, the measurements in the ablation area were sufficient to calculate the mass-balance 7 gradients. However, a lack of ~~lacking~~ reliable measurements in the high-elevation areas ~~high-elevations~~ prevented the calculation of accumulation gradients. On one hand, parts of the accumulation areas were not accessible, on the other hand the in situ

Number 1: → *comma added. Please note, the geodetic mass balances are from a different time period and are therefore not corresponding to the in situ measurements.*

Number 2: → *Here, all the results are provided to the second digit.*

Number 3 Author: argha Date: 21/5/21 09:01:15: may be split into two sentences. → *kept as it is*

Number 4: → *Corrected. Both versions are correct.*

Number 5 Author: argha Date: 21/5/21 08:31:02: It may be better to omit results from other studies from the conclusions. Also, an openning sentence before the bullet points start may be added. → *this statement has been added based on a comment from referee 2 (first review, Line 784). The opening sentence "We conclude:" has been added.*

Number 6: → *Here, "both" is used as determiner (Oxford Dictionary for English). It was possible to calculate mass-balance gradients (indefinite: "a" is skipped in plural). However, not all the mass-balance gradients (definite: the) could be calculated, such as in the accumulation area (see following sentence). Hence, the sentence has been kept as it was.*

Number 7: → *Corrected. Both versions are correct.*

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measurements in the accumulation area had higher uncertainties. The related uncertainties can be addressed ~~in future~~ with complementing geodetic mass-balance analyses for the same time interval. 1

- The mass balance of the steep south-west-facing slopes on Yala Glacier could not be quantified, and may result in an underestimated ablation, which can be addressed with geodetic mass-balance analyses. The relevance of the steep glacier slopes in terms of area cannot be quantified either for Yala Glacier, or the glaciers in Nepal in general with DEMs of 30 m and 90 m resolution, respectively. 2 3
- Yala Glacier experienced downwasting, indicated by the observed changes in the ~~changing~~ surface topography between 2011 and 2017 and decreasing ice flow velocities. Over the course of the years, most of the stakes could not be reinstalled at the original coordinates, either because of new crevasses, or significant changes of the surface features at the original site. The downwasting and a small accumulation area at low elevation compromise the long-term monitoring of Yala Glacier. 4 5
- The mean annual mass-balance rate of Yala Glacier is more negative compared to the regional geodetic mass-balance estimates ~~analyses~~. The reasons are ~~is~~ the relatively small area and elevation range of Yala Glacier, and the setting on a relatively low elevation. 6 7

- Number 1: → *"in future" is correct*
- Number 2: → *The sentence has been revised based on a comment from referee 2 and now reads: "The mass balance of the steep south-west-facing slopes on Yala Glacier could not be measured but have been quantified based on the linear regression equations from the in situ measurements. However, the ablation on steep slopes is possibly underestimated due to the orientation and the steepness of the slopes. This bias can be addressed with geodetic mass-balance analyses using the same time period as for the in situ measurements."*
- Number 3: → *"neither … nor" has been used according to the Oxford Dictionary of English*
- Number 4: → *corrected*
- Number 5: → *Modified: "The downwasting and the small accumulation area…".*
- Number 6: → *The regional geodetic mass-balance values are based on various analyses. Hence, "analyses" is correct.*
- Number 7: → *"The reasons are…" corrected.*

Considering the definition of size for glaciers (cf. glacier inventories), the area of Yala Glacier is small. "relatively" is not necessary. Also considering the elevation range of Yala Glacier and glaciers in Nepal in general, the glacier is in fact on a low elevation. "relatively" is not necessary.

"setting" is used according to the definition from the Oxford Dictionary of English: (noun) the place or type of surroundings where something is positioned or where an event takes place.