Reply to reviewer 1

We would like to thank the reviewers for their constructive comments on our manuscript. Both reviewers are concerned about the novelty of the methods employed and the results obtained in this study. We therefore have to acknowledge that we were unable to explain the purpose of our study and to highlight the novelty of our results. Before addressing the reviewer's specific comments in detail, we will therefore briefly mention the goals and the novelty of this work:

As mentioned in the introduction the three goals of this study were:

i) Modelling the annual mass balances of eight Scandinavian glaciers with long annual mass balance series using a suite of statistical models using seasonally averaged climate data as input variables. These models enable us to compare the relative importance of accumulation-season precipitation and ablation-season temperature on annual mass balances of glaciers.

ii) Assessing temporal changes of relative importance of accumulation-season precipitation and ablation-season temperature. These temporal changes are then compared to large-scale oceanic and atmospheric modes, such as the Atlantic Multidecadal Oscillation (AMO) and the North Atlantic Oscillation (NAO).

iii) In a last step we compare the climate sensitivities of ablation-season temperature and accumulation-season precipitation of statistical models to results from other modelling approaches, namely temperature index models and physically based models. We then used the mass balance models and climate projections for the years 2050 and 2100 to predict average annual mass balances for these years.

The reviewers are very concerned about point iii). The projections were only a side product of this work, and as the reviewers point out a rather poor one. We therefore removed this part of the manuscript. As the reviewers point out, the glaciers studied in this study have all been studied previously, most of them with more sophisticated models.
These studies have focused on two aspects of glacier mass balances:
i) Many studies have focused on sensitivities of mass balances to changes in temperature and precipitation, i.e. on expected changes of net balances for given changes in temperature (in °C or K) and precipitation (in % of a reference level).
The different units of temperature and precipitation make a direct comparison of the climate sensitivities in term of relative importance difficult. For instance 1 K and 10% of the precipitation of a reference period do most probably not cover the same proportion of the range of precipitation and temperature data.
Considering data from Bergen for the period 1962 – 2010, the standard deviation (sd) of temperature from May to September (T MJJAS) is 0.856 °C. 1°C is then 1.16*sd(T MJJAS). The average monthly precipitation from October to April (P ONDJFMA) is 200 mm, the standard deviation is 52 mm. 1.16 * sd(P ONDJFMA) is then 61 mm which corresponds to a precipitation change of 30%. In this case, climate sensitivity to a 1°C change similar to a 30% precipitation change is indicative of equal relative importance of T MJJAS and P ONDJFMA. The standard deviation of summer temperature and winter precipitation is different for each station and for each point of a gridded data set.

In this study, we therefore want to estimate the relative importance of summer temperature and winter precipitation, most importantly these relative importances are directly comparable, which is not the case for climate sensitivities.

ii) Some studies have focused on the relative importance of summer (Bs) and winter balance (Bw) for the annual balance (Ba) (e.g. Nesje et al. 2000, Andreassen et al. 2005, Mernild et al. 2014). Nesje et al. (2000) used the correlation between Bs and Ba and Bw and Ba as estimators of relative importance, whereas Andreassen et al. (2005) used the more direct measures of ratios of standard deviations of Bs and Ba (sBs/sBa) and Bw and BA (sBw/sBa).

In this study, we use a combination of these two approaches: We want to estimate the relative importance of climate variables (summer temperature and winter precipitation) for the annual balance. Additionally, we are interested in changes of relative importance of summer temperature and winter precipitation for the annual mass balance, and we test if the relative importances change when only considering years characterised by certain states of climate indexes.

In this study, we propose a statistical framework in which we are able to automatically/ objectively assign relative importance to variations in summer temperature and variations in winter precipitation. Standardising all variables involved in a linear model (as outlined on page 389) enables the calculation of relative importance of summer temperature and winter precipitation for net balances. Most importantly these relative influences are then comparable. I.e. a higher absolute value of the relative importance of summer temperature (the standardized partial regression coefficient to use some jargon) than of winter precipitation means that summer temperature is more important.

We are interested in the relative importance of summer temperature and winter precipitation for the entire measurement period, but we are also interested in changes of the relative importance of summer temperature and winter precipitation through time. Therefore, we estimate the relative importance of summer temperature and winter precipitation in 25-year moving windows (changed from 30-year windows in the original manuscript).

As there is one main pattern of oceanic variability, the AMO and one main pattern of atmospheric variability, the NAO, over the North Atlantic, we are interested to see if there are changes in relative importance of summer temperature and winter precipitation for the net balance for the two states of the AMO and the two states of the NAO. In addition to 25-year running windows, we therefore estimated relative importance of summer temperature and winter precipitation in phases where we expect above and below normal summer temperature (as expressed by the AMO) and in phases where we expect above and below normal winter precipitation (as expressed by the NAO).

The results of the analyses in moving windows and the estimation of relative importance of summer temperature and winter precipitation for different states of the NAO and the AMO are the main novelty of this study. These results demonstrate changes of relative importance of summer temperature and winter precipitation depending on the calibration period, and their association with large scale oceanic and atmospheric patterns.

To our knowledge, such a thorough assessment of relative importance of summer temperature and winter precipitation on net balances has never been presented for Scandinavian glaciers before. Hence, we belief that the results presented in this study are indeed novel and interesting from a climatological viewpoint.

These results are especially interesting for palaeoclimatological studies, where at maximum seasonal precipitation and temperature, or possibly only one of them is available. This study cautions against the assumption of a constant relative importance of winter precipitation and summer temperature for net balances and against the use of mass balance reconstructions for reconstructing the NAO-index.

In comparison to methods used by Nesje et al. (2000) and Andreassen et al (2005) we only need annual mass balance, and not winter and summer balance to estimate relative importance of summer temperature and winter precipitation.

We rewrote large portions of the manuscript to improve the explanations of methods used and to emphasise the points made above. We also changed some analyses as follows:
We also replaced the analysis shown in Fig 3 (correlations of winter and summer balance with net balance) with a direct measure of the relative importance of winter (Bw) and summer (Bs) balance on the annual balance (Ba). Like Andreassen et al. (2005) we used the ratios of the standard deviations of winter balance (sBw) and annual balance (sBa) and summer balance (sBs) and net balance (sBn) and compared the entire measurement period with the two states of the NAO and if possible the two states of the AMO.
We also modified most of the figures according to the reviewers' suggestions.

Reply to reviewer 1:

Page 384, line 23: What about summer accumulation and winter melting? Throughout the entire paper the authors only talk about winter accumulation and summer ablation. Of course, these components are the most relevant ones, but for maritime glaciers considerable snow fall amounts can also occur during summer in the higher regions, and the glacier tongues can experience melting over the winter season. These problems are not discussed at all.

The influence of summer snow-fall and winter melt are indeed not accounted for with the methods used in this study. The reviewer points out that these are minor effects compared to winter snow-fall and summer melt, and suggests that winter melt and summer accumulation are particularly important for maritime glaciers. Still, mass balances of maritime glaciers are very well modelled by the statistical models and models explain more of the variance of net balance for maritime glaciers than for continental glaciers. This clearly shows that winter melt and summer accumulation are (currently) not a major problem for modelled mass balances.
We added a short discussion related to this problem.

Page 385, line 21: This sentence appears to be circular to me – or maybe too complicated to get its essence. It occurs in similar form several times in the paper.

The sentence reads 'When modelling the joint influence of ablation-season temperature and accumulation-season precipitation on annual mass balance, statistical models allow for assessing the individual influence of ablation-season temperature and accumulation season precipitation on annual mass balance.'

This formulation was unclear and was changed to: When modelling the joint influence of summer temperature and winter precipitation on annual mass balance, statistical models enable us to compare the relative importance of summer temperature and winter precipitation on the annual mass balance.

Page 386, line 13: The uncertainty in the mass balance data is not addressed. At least for some of the maritime glaciers, there is an indication that the glaciologically derived mass balances are significantly *more positive than mass balance based on long-term geodetic surveys. As the mass balance data are the backbone of the study, more effort could be invested to discuss the uncertainty in the input data and potential effects on the results.*

The uncertainty in the mass balance measurements is estimated to between 0.2 and 0.4 mwe per year (Andreassen et al. 2005). The effect of the uncertainties is determined by their nature. If the mass balance measurements are mainly biased, then the estimates of the relative importance of summer temperature and winter precipitation will change (if the measurements are biased in the way described by reviewer 1, then the relative importance of temperature will increase). If the uncertainties are mainly random, then they are affecting our models in a random way, i.e. estimates of relative importance may change either way, and variance explained will change as well.

On the one hand, the unexpected changes of relative importance of winter and summer balance for net balance as function of NAO-index for Aalfotbreen and Engabreen (decreased relative importance of winter balance for years with above median NAO-Index) might suggest problems with the mass balance data, on the other hand, arguing: as we do not get the expected results the data we used is poor is a very dangerous line of argument.

We also added a paragraph discussing possible uncertainties.

Page 392, line 25: What is the objective of analysing positive and negative AMO phases separately? I.e. what do the authors want to find out?

We hope that we could answer this question in the general part of this response. We are mainly interested in the relative importance of winter precipitation and summer temperature for the net balance. We suspect that the AMO has an influence on this relative importance, as the AMO expresses changes in sea-surface temperatures. That is why we tested the differences between models including years with exclusively AMO + and exclusively AMO-, respectively.

Section 2.2.6.: The first paragraph should rather be in the data section

This entire section was removed.

Page 387, line 15: Here and elsewhere. Why not simply "winter" balance and "summer" balance? The use of "ablation-season mass balance" etc is relatively complicated and sometimes awkward.

As suggested by reviewer 1, we now use winter and summer instead of accumulation season and ablation season

Figure 3: What is on the y-axis? The label is tiny. Better use text. Furthermore, I found the point cloud not very intuitive. When printed in black-white the information is almost impossible to extract. Also the

experiments are difficult to understand from the caption. It might also be reasonable to reduce the number of experiments shown.

We improved the readability following the reviewer's suggestion. We kept the number of experiments constant as we compare correlations for the entire measurement period and for years with above and below median NAO-index.

- Figure 4: add (a), (b) etc to the panels. What is on the x- and y-axis? It would bemuch more intuitive when writing "Summer temperature" and "winter precipitation" –

The labels of the y-axis are indeed unclear, these are the smooth terms of the additive model.

Figure 5: add (a), (b) etc. Shouldn't this figure be flipped by 90 degrees?

Yes, this figure was arranged in this way by the editorial team.

- Figure 6: I really have troubles with this figure. The labels are tiny! Furthermore, even after re-reading the text, the figure is difficult to understand. The approach of evaluation, the presentation of the results and their interpretation (text) should be improved.

In Fig. 6, the changes of relative importance of summer temperature and winter precipitation through time are indicated. Hence, this is one of the main figures of this manuscript. We tried to improve the explanation of this figure.

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