Reply to the reviewer 2:

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 2.

Specific comments
P 385. The introduction needs to be rewritten. The authors uses the term physically based mass balance models in contrast to statistical models. They here divide statistical models in i) temperature-index-models and (ii) models that use seasonal and monthly mean T and P. This description in the introduction is a bit unclear and division is not necessarily appropriate for the papers they refer to. There is a whole range of mass balance models from sophisticated energy balance models to simplified temperature-index models and regression models (e.g. see overview by Hock, 2005). Furthermore, mass balance models can be for a point, a profile or they can be spatially distributed, and they may or may not be coupled with a dynamical model. For example an energy balance model can be just for a point, whereas a degree day model can
be coupled to a dynamical model. Moreover, temperature-index models also needs calibration.
C131P 385/386 Aims i-iii. What is the purpose of these aims? In particular iii) seems not to be a good approach based on current knowledge (e.g. a model need to take into account the changes in ablation and accumulation season as well as dynamical changes). Furthermore, why are these years chosen and more importantly, what is the advantage of this approach compared to already published studies?

We tried to address these points in the replies to the reviewers' general comments. But most importantly: we are interested in relative importance of summer temperature and winter precipitation for the annual balance and not in absolute importance (climate sensitivity).
We are interested in changes of relative importance through time and when only considering states of certain climate indexes.

Could here or rather in the introduction mention other data sources, e.g. seNorge.no, reanalysis data etc. In the discussion could be interesting to have a comparison of the results using other data sources. e.g. that mass balance have been modelled for all of Norway using temperature-index models (Engelhardt et al., 2013)

The direct comparison to results by Engelhardt et al. (2013) who used data from senorge.no is extremely difficult. For Nigardsbreen and Storbreen (distance of about 50km) the predicted net balances have a strong negative bias for Storbreen and a strong positive bias for Nigardsbreen. This might be caused by model bias, or by biases in the climate data. We assume these are biases caused by the model and not by the data, as opposite bias on a short distance of 50 km would be very surprising.

We also tested effects of using different station data. For instance, we used climate data from Lom between 20 and 30 km to the north-east of the continental glaciers in southern Norway. Model performance was reduced compared to models using meteo data from Bergen as input. Using data from Sogndal (to the southwest of the three continental glaciers), but much closer than Bergen had no systematic influence on the performance of statistical models (the performance remained unchanged for one glacier, was slightly decreased for one glacier and was slightly increased for one glacier).

Additionally, for our models (except when calculating climate sensitivities), it is only important if there is a linear relation between temperature and precipitation in Bergen and close to the glaciers, as the climate data are standardized.

P 393. Line 9. Are the results then directly comparable when different (the most parsimonious) models are used for each glacier?

In this study, we are first of all interested to compare the relative importance of summer temperature and winter precipitation for the mass balances of individual glaciers. Hence we are not interested to compare the models between glaciers. We are simply interested to see if for individual glaciers, the cost of additional complexity (individual weights for temperature and precipitation, and for additive models, the use of smooths instead of coefficients) is justified by increased variance explained. In this context, it is only important that we always use the same model for one glacier but not between glaciers.

Chapter 3. Line 20->The cumulative mass balance records are not a result of this paper and does not strictly belong here.

This is indeed true, however, not showing the data would make the presentation of results and their discussion extremely difficult.

P 397 Line 5 This is the first time fig 5 is mentioned, but it ends abruptly with a new paragraph, rewrite. Please explain a bit what you mean and what is new here compared to this rather well known results of cumulative balances and mass surpluses for certain periods. Why just AMO and NAO, since there are other indices too that has been studied? The chapter 4 discussion has one subheading for the last ~third of the text, suggest to add 1-2 subheading(s) also for the first part.

In the new manuscript Figs 2, 5 and 6 have been merged. The temporal changes of relative importance of summer temperature and winter precipitation (25-year windows) are now shown together the cumulative mass balances.

Using 25-year running windows, we find changes in relative importance of summer temperature and winter precipitation through time. Results are especially interesting for continental glaciers in southern Norway. For 25-year windows centred before 1978, relative importance of summer temperature and winter precipitation are equal, the relative importance of winter precipitation is higher in the following 25-year windows, and summer temperature gets more important than winter precipitation for 25-year windows centred after 1990.

With the method employed in this study, we are able to directly assign relative importance to summer temperature and winter precipitation in the 25-year moving windows. We are using the same mass balance data as in previous studies, hence we do not expect to find completely different results. For instance we do not expect to find increased relative importance of summer temperature in phases of positive mass balances.

Besides the AMO and the NAO, other indexes for instance the Arctic Oscillation (AO) index could have been used. The NAO and the AO are very similar concepts (Thompson and Wallace, 1998), the NAO-index is traditionally based on pressure measurements of two meteorological stations (on Island and the Azores or Lisbon), whereas the AO is the first PC of the surface level pressure field north of 20N. As NAO and AO are strongly related (Peings and Magnusdottir, 2014, do mention NAO / northern annual model simultaneously) it seems only reasonable to use either the NAO or the AO for comparison with glacier mass balances (as the use of both would be redundant). We decided to use the NAO as the NAO-index is only considering data from the North Atlantic region and not the entire area north of 20N. Additionally, Li et al. (2013) find the NAO to be the dominant mode of atmospheric variability over the North Atlantic.

We now use four subheadings in the results and discussion sections.

P398 Line 18. Incorrect to write that glacier melt started in the early 2000s in Scandinavia. Some of the continental glaciers have in general lost mass throughout since measurements began in 1940s or 1960s, except for the period with transient mass surplus 1989-2005. That glaciers in the alps and Scandinavia correlate differently to the NAO-index is not new, here more references to previously studies should be added, e.g. Marzeion & Nesje (2012) and see also Rasmussen (2007) for more references. P400. Line 9. Might is a weak Word here, it will. Line 24. Here you refer to previous studies, then use present tense. Then you refer to your own results, a bit abrupt, rewrite.

This is indeed true, we meant to say that the transient mass loss after the transient positive mass gain between 1989 and 1995 (not 2005, as stated by the reviewer) started in the early 2000s.

Regarding NAO and the Alps we added references to Marzeion and Nesje (2012) and Six et al. (2001).

P401. Line 4-5. I find this way of using references with your results confusing. Use 'as

shown by' or similar. Conclusion: should be rewritten to focus on the new outcomes of your study.

The conclusions were rewritten.

Table 2. The first sentence is repeated in the next sentence. Giesen is written with one

s.

Figure 1. The mid panel is cut in a strange way. It should be possible to show it in three full panels, using the same orientation and a different location map than the left panel. The source of the P and T data should be given, e.g. seNorge.no? It looks like three maps, not a location map with inserts (they are the same size), thus, rewrite text. Figure 2. This is the same as Fig 5a. As this is not a result by the authors I suggest to remove it here and add the data source to the figure text in 5a.

Figure 3. The first two sentences are nearly identical. Change Bn to Ba as Ba is standard term shortening for annual balance now in common use (Cogley et al., 2011). Bn is usually used as shortening for net balance.

Changed.

Figure 4. could specify the confidence bounds in figure text.

Figure 5. See comment to Figure 2. a)-d) are missing from the figure. c) Jones et al., 1997 are referred to, but data spans to 2010, could add an updated ref or write Jones et al., 1997 with updates.

Was changed.

Figure 6. Very small font compared to other figs.

Font was increased

Figure 7. Annual balance = Ba

Changed.

Figure 8. Not sure if it is worthwhile to show this result due to the limitations of the

model. See previous comments.

This result was removed.

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Nesje A, Lie Ø and Dahl SO (2000) Is the North Atlantic Oscillation reflected in Scandinavian glacier mass balance records? Journal of Quaternary Science 15(6): 587–601.

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