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The Cryosphere Discussions

Interactive comment on "Response of the ice cap Hardangerjøkulen in southern Norway to the 20th and 21st century climates" *by* R. H. Giesen and J. Oerlemans

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We like to thank the referee for his positive reaction on the manuscript and suggestions for further improvement. Below is our response to all comments.

Climate change scenario
We acknowledge that we use a simplistic future climate scenario, but do not agree with the referee that this is a major drawback of the research presented. The aim of the future volume projection of Hardangerjøkulen was not to present 'true' ice cap changes, but to determine how the ice volume responds to changes in climate that can be expected in the 21st century. Our main questions were how fast an ice cap

of this size in a maritime climate would disappear in different probable future climates and how large the role of feedback processes is. By imposing a simplistic climate representation instead of input data with realistic variability, we could easily compare ice cap responses to different climate projections, the effects of seasonally varying changes and the role of feedback processes. Of course, large decadal-scale variability will be present in the 21st century and may even lead to years with a positive mass balance, but also to years with a much more negative mass balance than obtained with the climate change we prescribe. However, the timing of periods with more positive and negative mass balance is unknown and including this variability therefore does not add additional decadal-scale information for policy makers. As mentioned in the paper, the mass balance sensitivity does not change too much when real meteorological data is replaced by the control climate. Hence, we expect that the ice volume projection obtained with our simple climate will not deviate much from a curve resulting from averaging modelled ice volumes from a large ensemble of more realistic climate projections.

Temperature lapse rate

We chose the temperature lapse rate over the ice cap based on measurements at the two AWSs at 1450 and 1860 m a.s.l. The mean lapse rate calculated from the observations is 6.7 K km^{-1}, with a median value of 7.1 K km^{-1}. A lapse rate of 6.5 K km^{-1} is also reported from other studies in Norway. This information will be added in the revised manuscript. As the AWS at the summit was only operational from May to October, most lapse rate values were actually obtained above a melting surface. An explanation for these high values compared to other glaciers may be that the measurement height is rather high (about 6 m above the surface) and that the near-surface climate at Hardangerjøkulen is dominated by the large-scale circulation, as is demonstrated by the observed wind speed and direction (Giesen et al., 2008). Daily mean air temperatures at the ice cap summit, calculated from the observations from the AWS on Midtdalsbreen agree very well with the measurements, with a mean difference smaller than -0.01^{o}C, a standard deviation of 0.54^{o}C and a linear correlation r=0.99. This good correspondence indicates that we are certainly not underestimating air temperatures near the summit and did not prescribe the high turbulent exchange coefficient to offset cold temperatures.

Day-to-day variability in climate projections
We agree with the referee that neglecting day-to-day variability could influence the energy balance, especially the energy available for melt. Before starting to use the control climate, we therefore carefully investigated whether the model results change notably when using the control climate instead of meteorological records. Much to our own surprise, not any of the characteristics were found to be significantly altered. Because we expected this question to arise with readers as well, the results of these experiments were included in the paper. The energy balance components simulated with the control climate are compared to results with the local meteorological data in Fig. 4, showing that both for the 1961-1990 period as for a 3^{o}C warmer climate, the correspondence is good in all months and melt energy is not underestimated. The control climate may seem to underestimate ablation in Fig. 5c, as noted by the referee. However, as mentioned in the text, the AWS period (2001-2005) was about 1^{o}C warmer than the period included in the control climate, which may explain the difference. The comparison in Fig. 5c was also not intended as solid validation, but to show that the shape of the accumulation and ablation curves is well modelled with the control climate. In Section 5.3 we mention that the annual mass balance modelled with the control climate is equal to the mean value modelled with real meteorological data over the period 1961-1990. Finally, in Section 5.5 we note that the climate sensitivity of the model using either local data or the control climate is not very different.

Error estimate
We acknowledge that a thorough error analysis could improve the confidence of the public in the obtained results. As stated by the referee and was argued in the response to the comments by Referee #1, providing a well founded error estimate would be a laborious task, considering the interdependence of the model parameters and input

data. We will consider applying such a procedure in future work.

Precipitation gradient
Both the vertical and horizontal precipitation gradients are based on measurements. For a discussion of the origin of the parameterizations used, we refer to the response to the comments by Referee #1. The revised manuscript includes a numerical description of the horizontal gradient and a new figure showing the vertical gradient.

Minor comments
All minor comments are addressed in the revised manuscript and the text has been clarified where needed.

Reference
Giesen, R. H., Van den Broeke, M. R., Oerlemans, J. and Andreassen, L. M.: The surface energy balance in the ablation zone of Midtdalsbreen, a glacier in southern Norway: Interannual variability and the effect of clouds, J. Geophys. Res., 113, doi: 10.1029/2008JD010390, 2008.

Interactive comment on The Cryosphere Discuss., 3, 947, 2009.