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The Cryosphere Discussions

Interactive comment on "Comparison of the meteorology and surface energy balance at Storbreen and Midtdalsbreen, two glaciers in southern Norway" *by* R. H. Giesen et al.

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We would like to thank the two anonymous referees and M. Pelto for their positive reactions on the manuscript and suggestions for further improvement. Below is our response to all comments.

Referee 1:

\- *Turbulent fluxes*
As noted by the Referee and mentioned on p881, line 15, the reason for using the measurements from the upper mast level in the turbulent flux calculations is the almost continuous record for this level. The sensors at the lower level were buried by snow in several winters, leading to significant data gaps. Moreover, these sensors sometimes

disfunctioned after the snow had disappeared, likely caused by water in the spring snowpack.
We agree with the Referee that the upper level may be above the wind maximum in katabatic flows and that this could affect the turbulent fluxes computed for such situations. Although it was not mentioned explicitly in the paper, we thoroughly compared the measurements at the two levels (when available) and investigated differences in the turbulent fluxes calculated from these measurements. The height of the wind maximum cannot be established from measurements at only two levels, but katabatic flows with a wind maximum below the upper level are found to occur on both glaciers. This observation has been added in the revised manuscript. To obtain good agreement between the turbulent fluxes calculated from measurements at the two levels, we impose a limit of one-third flux reduction on the stability correction, which works well on both glaciers. This was mentioned shortly in the paper (p885, lines 17-20), but has now been extended.
Near-neutral conditions occur seldom on Storbreen, but for these days derived z_{0v} values were compared with values for Midtdalsbreen and were found to be in the same magnitude range. This was not mentioned in the paper, but has now been included.
A snow depth record, constructed from the surface height measurements and checked with computed albedo, is used to determine whether the surface is snow or ice and hence which value for z_{0v} should be applied. This explanation has been added.

- *Table 3*
Values of mean air temperature and wind speed are included in Table 3, when reported in the individual studies. Humidity was less often reported and in some cases either relative or absolute humidity was given, leaving only a few studies to compare. Hence, humidity is not included. A sentence was added expressing that no simple dependencies between variables in the listed studies could be found.

- *Specific comments*
p875, line 7 : The annual mass balance turnover is an area-averaged value; definition

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is rewritten.
p875, line 10: Ålfotbreen and Gråsubreen are included in Fig. 1. These are not values for a station, but glacier mean values.
p877, line 13 : Long-term mass balance measurements are available for Storbreen, but the mass balance on Midtdalsbreen was only measured in two years, this is not enough to estimate the ELA. The 0°C isotherm has not been determined, but the difference in air temperature gives an idea of the effect of temperature differences on H_{sen}.
p878, lines 18-23 : The exact tilt of the masts is not known, but the tilt could be estimated from tilt angles measured during visits combined with data from a tilt sensor in the mast, which did not function properly. The tilt effect on reflected solar radiation is small for the observed tilt angles; because of the uncertainty in the tilt angle no correction was applied. This has been added in the revised manuscript.
p882, line 3 : The sum H_{sen}+H_{lat} is meant indeed, this has been changed in the text. The reported percentages are larger in summer, but not much, as the summer values already determine H_{sen}+H_{lat} for the largest part. We only intend to give a rough estimate of the turbulent flux sensitivity to z_{0v} and the stability correction here, for a detailed analysis we refer to Giesen et al. (2008).
Section 3.3.2 : As noted on p882, lines 15-17, the model does not keep track of the changing depth of the snowpack, the snow depth is prescribed from the sonic ranger measurements. The (varying) density of the snowpack is not known, hence it is difficult to translate snow depth changes to mass changes.
p883, lines 12-19 : The periods of the data gaps were excluded from the calculation of r, as explained on p883, lines 18-19.
Fig. 8 : We chose to show a sequence of only two years, because 2004 and 2005 have a data gap in one of the records and 2006 is not complete. This has been added in the section.
Table 2, Section 4.9 : Winter accumulation at the AWS sites is difficult to compare, as only surface height changes are monitored, which can result from snow accumulation,

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wind drift, sublimation/rime and snow melt. Because the density profile of the snow-pack is not known, the associated mass changes cannot be determined accurately. The best comparison of winter accumulation at the two sites can be made with Figure 11a. In summer, most precipitation falls as rain on the two glaciers, as shown by the albedo records (Fig. 8), only occasionally a snowfall event occurs. A comment on this has been added in Section 4.4. The amount of rain is not known, it is not measured by the AWSs. Precipitation is only measured at Finsevatn, not at Sognefjellhytta, this was stated erroneously and has been corrected. In general, precipitation in Norway displays large spatial and topographic gradients and climate information cannot be based on a comparison of single stations. The precipitation regime for the areas around Storbreen and Midtdalsbreen can best be derived from Figure 1. A reference to this figure has been added in Section 4.9.
Fig. 12 : An explanation for the larger diurnal cycle in air temperature outside the glaciers on clear-sky days, has been added.
Conclusion : The paragraph has been extended with a sentence describing the albedo feedback mechanism.

Referee 3:

1. We acknowledge that values for the ELA and AAR for the two glaciers would be helpful in the comparison between the two glaciers. However, while Storbreen has an extensive mass balance record, mass balance on Midtdalsbreen has only been measured in 2000 and 2001. A longer mass balance record is available for Rembesdalsskåka, another outlet glacier of Hardangerjøkulen, but this glacier has a different orientation and hence the mass balance profile could be different. The period with simultaneous measurements is too short to establish a relation between the mass balance on the two outlet glaciers. We are therefore not able to provide values for the ELA and AAR of Midtdalsbreen for the measurement period.
2. It is tentative to draw conclusions about the climatic setting of the two glaciers

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from the AWS measurements. However, measurements are only obtained in the glacier near-surface boundary-layer, not in the free atmosphere. Differences observed between the glaciers could either result from a different climatic setting or from local effects (e.g., topography, boundary-layer structure, surface processes). The humidity of the air near the glacier surface will follow humidity changes in the free atmosphere, but is also influenced by surface processes as melt and sublimation. Hence, it is difficult to directly couple humidity and cloud coverage. Because we find high correlations between meteorological variables at the two glaciers, including shortwave and longwave radiation, the climate forcing has to be similar for the two glaciers and differences in cloudiness are likely local effects. These comments have been added in the sections about humidity and cloudiness.
3. It is certainly interesting to investigate the relation between observed differences on the two glaciers and synoptic weather patterns. As the Referee acknowledges, this is beyond the scope of the current paper, but we will consider this topic for future research on the data set.
4. We have estimated the accuracy of the daily and annual mean values of the meteorological variables and the energy fluxes, as these averages are mainly shown in the paper. The values have been included in Table 2. Section 5.1 has been extended with additional comments on the variables with the largest errors and implications for the energy balance calculations.

All technical points have been addressed in the revised manuscript. Below we comment on the remaining corrections/suggestions.

c) The paragraph about the turbulent flux calculations has been extended with a comparison between upper and lower level measurements. We comment on the occurrence of a wind speed maximum below the upper level, which leads to the underestimated fluxes with the upper level measurements.
h) The section has been extended with a more elaborate reasoning why lower

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incoming solar radiation on Storbreen in summer can only be caused by higher cloud coverage.
q) The locations of Storbreen and Midtdalsbreen have been added in Figure 1, to make the comparison of the climatic setting easier. Figure 2 has been kept as it illustrates the distribution of glaciers in southern Norway and the relative position of Storbreen and Midtdalsbreen with respect to the other glaciers.

M. Pelto:

- *Ablation*
We have included additional information on ablation in several ways in the paper. The fraction of melt for the entire period was not mentioned yet and has now been added in Section 4.8. M. Pelto suggested to include a figure or table with ablation for specific days with R_{net} or H_{sen}/H_{lat} dominant, but this cannot be done because H_{sen}/H_{lat} dominant days occur seldom and only in spring and autumn. Instead, we have added a figure showing the seasonal cycle in the absolute contribution of the energy fluxes to melt, to supplement Figure 10 which shows the relative contributions. Using the information provided by this figure, Section 4.8 was extended. In Section 4.9, we included the dates between which the surface becomes snow-free at the two sites. Other details of ablation at the two sites are described in Andreassen et al. (2008) and Giesen et al. (2008), e.g. the differences in ablation between cloudy (windy) and clear-sky (katabatic) days were already analysed by Giesen et al. (2008).

- *Specific comments*
p882, line 6 : The validity of the subsurface heat flux is discussed in Section 4.7.
p883, line 24 : The mean value for the lapse rate during melt has been added.
p884, line 15 : Specific humidity during melt is listed in Table 2, reference included.
p885, lines 5-15 : This detailed analysis of wind observations is provided because it is mainly the wind characteristics that are different at the two AWS sites. All other parameters show similar fluctuations, generally only the absolute values differ.

p887, line 10 : The seasonal cycle of the turbulent fluxes for cloudy (windy) and clear-sky (katabatic) conditions on Midtdalsbreen has been investigated by Giesen et al. (2008). In the current paper we focus on the differences and similarities between the AWS records from Storbreen and Midtdalsbreen.
Figure 3 : Pictures of the two glaciers with the location of the AWSs marked, have been added in the figure. Figure 9: A third panel column in Figure 9 is not feasible, because the panels would become too small to see the details. Instead, an additional figure has been added that illustrates the differences in the seasonal contribution of the energy fluxes in a more general way.

References:

Andreassen, L. M., M. R. van den Broeke, R. H. Giesen, and J. Oerlemans (2008), A 5 year record of surface energy and mass balance from the ablation zone of Storbreen, Norway, J. Glaciol., 54, 245–258.
Giesen, R. H., M. R. van den Broeke, J. Oerlemans, and L. M. Andreassen (2008), 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, D21111, doi:10.1029/2008JD010390.

Interactive comment on The Cryosphere Discuss., 2, 873, 2008.