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The Cryosphere Discussions

Interactive comment on "Surface mass budget and meltwater discharge from the Kangerlussuaq sector of the Greenland ice sheet during record-warm year 2010" *by* D. van As et al.

D. van As et al.

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DVA: Many thanks for the effort you put into this review. You will find that I followed your advice on the additions and edits in the provided pdf document on nearly all accounts. Furthermore, we made numerous additional text edits to make the paper more pleasant to read and easier to understand. See below for a reply to all of your comments posted in the discussion.

JB: Overall Assessment The study that makes a nice set of physical interpretations after a somewhat tedious model description and validation description. By page 14,. "In the lower(or upper) ablation zone", the paper becomes fruitful. It is very nice that

the study makes "Evaluation of the calculations] ... [using three independent methods."

JB: The following key points should be mentioned in abstract and (if not already) conclusions: "we can fully attribute the 2010 melt excess at low elevation to high temperatures" ..."low albedo allowed for higher solar radiation absorption rates, roughly contributing half to the melt increase. During warm episodes in the future we can expect a melt response of at least the same magnitude."

DVA: Yes, this is a good point and I agree. I have updated the abstract and conclusions.

JB: The following major comments appear in "stickies" inserted using Acrobat. I past the comment text here for convenience. Several minor comments and copious text edits (owe me a beer) appear in the .pdf document.)

DVA: Many thanks for the edits - I indeed owe you. I have included nearly all of them in the revised manuscript.

JB: The (usually upwind) proximity of Greenland's largest land mass seems an important factor to consider in discussion of heat sources.

DVA: You are correct. The nearby land mass (there is 160 km separating the ice margin from the Baffin Bay) will have a larger impact on atmospheric heat in this region than in other regions of the ice sheet margin. I have included that the landmass is a potential heat source in section 3.4: surface melt and ablation.

JB: You need to specify which MODIS product you used, MOD34 or MOD10A1?

DVA: Absolutely. I added to the manuscript that we make use of MOD10A1.

JB: I have a clean version of MOD10A1 data I am willing to share. I also share the following text from a manuscript in preparation: "Daily surface albedo retrievals from the MODIS sensor ïňĆown on the Terra platform (the MOD10A1 product; Hall et al. 2006) are available from the National Snow and Ice Data Center (NSIDC). Surface albedo is retrieved for cloud-free pixels using the ïňĄrst seven visible and near-infrared MODIS

bands following the algorithm described by Klein and Stroeve (2002) and Klein (2003). +Hall, D.K., G.A. Riggs, and V.V. Salomonson (2006), updated daily. MODIS/Terra Snow Cover Daily L3 Global 500m Grid V005, April 2000 - October 2010. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media. +Klein, A. G., and Julienne Stroeve. 2002. Development and Validation of a Snow Albedo Algorithm for the MODIS Instrument. Annals of Glaciology 34:45-52. +Klein, A. G., Dorothy K. Hall, and George A. Riggs. 1998. Improving Snow-Cover Mapping in Forests Through the Use of a Canopy ReïňĆectance Model. Hydrologic Processes 12(10-11):1723-1744. "

DVA: Thank you very much for the data offer. We have already been in touch about this and I will gratefully make use of your dataset in upcoming studies. I am looking forward to seeing the paper you are preparing once it is published (or before) for even more details. If you have a title I can refer to in our manuscript I'd be happy to do so. I'm sure you understand that for the present study we will use our own MODIS dataset, on which we spent time comparing and correcting it with AWS measurements, greatly improving the accuracy our surface energy budget calculations. However, we have added the suggested background information to the MODIS description in the methods section based on your comments (also below). The paragraph on MODIS in the current manuscript version reads:

"Surface albedo is a principal input variable, which cannot be interpolated from AWS observations alone due to its inherent spatial heterogeneity. Therefore daily MOD10A1 albedo product from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite (Hall et al., 2006; Klein and Stroeve, 2002) was used. MOD10A1 data were validated using GC-Net AWS data by Stroeve et al. (2006), who reported a root mean square (RMS) error of 0.067 and correlation of 0.79. Issues with the MODIS albedo product over Greenland snow surfaces for large zenith angles were identified by Wang and Zender (2010) (commented on by Schaaf et al., 2011). We applied corrections to remove sensitivity to the solar zenith angle as identified by comparing the MODIS data to the observed albedo at the AWS in the Kangerlussuaq catchment.

We consider our approach a step towards MODIS validation over Greenland bare ice surfaces, but mostly a large improvement in regional melt modelling, since previous studies assumed ice albedo to be spatially and temporally constant."

JB: I recommend you use MOD10A1 because it has the highest temporal resolution.

DVA: Yes, we have done so.

JB: Incorporate the following for MODIS background and validation: + Stroeve, J.C., Box, J.E., Haran, T., 2006: Evaluation of the MODIS (MOD10A1) daily snow albedo product over the Greenland ice sheet, Remote Sensing of Environment, 105(2), 155-171 + Stroeve, J, J.E. Box, A. Nolin, S. Liang, C. Schaaf, F. Gao, 2005: Accuracy assessment of the MODIS 16-day albedo product for snow: comparisons with Greenland in situ measurements, Remote Sensing of the Environment, 94(1), 46-60.

DVA: I have included the Stroeve et al. (2006) reference on the topic of the MOD10A1 albedo product in the methods section.

JB: re: "we can fully attribute the 2010 melt excess at low elevation to high temperatures" ignores the importance of changing albedo and increasing downward longwave. Fettweis (2007) showed that only the increase of the longwave downward ïňĆux explains the recent warming over the Greenland ice sheet and that the decrease of surface albedo ampliïňĄes the impacts of this warming + Fettweis, X. (2007), Reconstruction of the 1979–2006 Greenland ice sheet surface mass balance using the regional climate model MAR, The Cryosphere, 1, 21-40, doi:10.5194/tc-1-21-2007.

DVA: The paragraph in which this is stated discusses the causes of the melt excess in the lower ablation zone in 2010, which are longwave radiation and the turbulent heat fluxes, while net shortwave radiation was not important for the excess. So we do report on the importance of downward longwave radiation, but not on the importance of albedo for melt excess in the lower ablation zone. Your statement is very true for the ice sheet as a whole, but in the lower ablation zone of the Kangerlussuaq region in 2010

the albedo effect drops out of the equation since albedo is low here every summer. I believe that I did not clearly enough state in the original manuscript that I consider an increase in downward longwave radiation also a sign of increased atmospheric temperature, thus allowing us to attribute the excess melt to a warmer atmosphere. In the current version of the paragraph I report more clearly on the correlation between longwave radiation and atmospheric temperature (also by including the Fettweis reference), and on which region of the ice sheet the statement is valid for:

"In the lower ablation zone (below the 1000 m elevation bin) 74% of the excess melt can be attributed to increased net longwave radiation, i.e. larger emission from a warmer (or moister) atmosphere. The remainder of the energy was provided by increased turbulent heat fluxes, also as a result of higher atmospheric temperatures. The high correlation between downward longwave radiation and near-surface temperature over Greenland was shown by e.g. Fettweis (2007). In contrast, net shortwave radiation contributed 2.5 Wm-2 less across the same region. The implication is that the 2010 melt excess in the lower ablation zone can be fully attributed to high temperatures, both near the surface and in the free atmosphere."

JB: Also, Box et al. (2006) note albedo changes in Greenland's changing melt regime. + Box, J.E., D.H. Bromwich, B.A. Veenhuis, L-S Bai, J.C. Stroeve, J.C. Rogers, K. Steffen, T. Haran, S-H Wang, 2006: Greenland ice sheet surface mass balance variability (1988-2004) from calibrated Polar MM5 output, Journal of Climate, Vol. 19(12), 2783–2800.

DVA: Thank you. This is mentioned in the new manuscript version, including the reference.

JB: Suggestions + suggest to connect the red dots in Fig. 2 with solid red line segments.

DVA: I've tried this during the production of the figure, but prefer the figure with yearly temperature given by dots instead of lines (or dots and lines). Although the interannual

variability is clearer with lines, the figure as a whole becomes harder to read.

JB: + avoid using "reïňĆected" or "reïňĆects" to refer to non-radiative concepts

DVA: Ok, no problem.

JB: + downward instead of downwelling; upward instead of upwelling or reïňĆected

DVA: Thanks for the advice. I've replaced all occurrences of down/upwelling, incoming, outgoing and reflected.

Interactive comment on The Cryosphere Discuss., 5, 2319, 2011.