

# **The importance of accurate glacier albedo for estimates of surface mass balance on Vatnajökull: Evaluating the surface energy budget in a Regional Climate Model with automatic weather station observations**

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## **Summary:**

The authors present a simulation of mass balance for the Vatnajökull ice cap using the HIRHAM5 regional climate model, with an updated albedo scheme that simulates albedo as a function of snow age and surface temperature. The simulated mass and energy balance are compared with observations from automatic weather stations on the ice cap. There is a fairly good agreement between observed and measured mass and energy balance, with the largest differences being associated with errors in simulated albedo. These errors are associated with inaccuracies in simulating snow cover extent during summer, as well as the lack of a scheme for accounting for impurity deposition in the model.

## **General Comments:**

The paper is well written, well thought out, and scientifically sound. The paper is an important contribution as it focuses on regional climate model simulation of albedo over an ice cap and identifies challenges that can be addressed by future work. I believe the paper should be accepted for publication in the Cryosphere after relatively minor revisions discussed below. The points below are mostly very minor changes.

Some general points are:

1. Since a main focus of the paper is on albedo and how it influences mass balance, some papers discussing the importance of albedo to glacier and ice sheet mass balance and challenges in modeling albedo should be mentioned in the introduction.
2. Though this is not essential, I feel that the methods section could benefit by being reorganized. Since the main focus of the paper is validating the regional model results, the RCM could be described first, followed by the description of observational data, followed by the description of methods of comparison (including AWS point models – section 3.1, validation methods 3.2.2, and elevation-based corrections 3.2.5). This would require some editing to ensure that the text is consistent with the new order.
3. Figure 10 is hardly discussed in section 4.7. There should be more discussion of this figure. In particular, the model – measured differences for the weather station measurements are consistent with the differences shown in Figs. 10 d, e, and f; for example there is a low SMB bias at high elevations and high SMB bias at low elevations. These consistencies should be discussed.
4. Section 4.8 also seems very short. The authors could provide more discussion of how the albedo differences affect SMB, and how this relates to the biases discussed in other parts of the study.

## Specific Comments:

1. **P. 1, Line 14:** Suggest changing “specific mass balance” to “specific surface mass balance” for clarity.
2. **P. 1, Line 16:** Add “through 2014” after “from 1981” to make the time period clear.
3. **P. 1, Lines 16-18:** The second part of the sentence doesn’t fit with the first part, and contradicts it somewhat. I think the point the authors are trying to make here is that the model can provide a reasonable representation of surface mass balance, but that a major source of uncertainty in this representation is the representation of surface albedo and how it evolves. Please clarify.
4. **P. 2, Line 18:** “Good records” is a bit vague. What is good about them?
5. **P. 2, Line 25:** Change “background albedo” to “background bare ice albedo” for clarity.
6. **P. 2, Lines 24-26:** I believe van Angelen et al. (2012) was the first to use this approach. This paper should be cited:  
van Angelen, J. H., Lenaerts, J. T. M., Lhermitte, S., Fettweis X., Kuipers Munneke, P., van den Broeke, M. R., van Meijgaard, and Smeets, C. J. P. P.: Sensitivity of Greenland Ice Sheet surface mass balance to surface albedo parameterization: a study with a regional climate model, *The Cryosphere*, 6, 1175-1186, doi: 10.5194/tc-6-1175-2012, 2012.
7. **P. 3, Line 6:** Note that Brúarjökull and Tungnaárjökull are glaciers that make up part of the Vatnajökull ice cap.
8. **P. 3, Line 25:** How is the summer surface identified?
9. **P. 3, Line 30:** Which MODIS product is used here?
10. **P. 4, Line 5:** add “from AWS measurements” after “The turbulent energy fluxes were calculated” for clarity.
11. **P. 6, Lines 20-21:** How is it known that the new particles are generally washed off? Isn’t it possible that some of the impurities are scavenged at the surface? (e.g. Doherty et al., 2013)  
Doherty, S. J., Grenfell, T. C., Forsström, S., Hegg, D. L., Brandt, R. E., and Warren, S. G.: Observed vertical distribution of black carbon and other insoluble light-absorbing particles in melting snow, *J. Geophys. Res.*, 118, 1-17, doi: 10.1002/jgrd.50235, 2013.
12. **P. 7, Line 31:** I suggest noting here that the correction was applied so that model results could be compared to AWS measurements at AWS locations.
13. **P. 8, Lines 14-15:** This repeats some information from section 3.2.3. Since the corrections made in section 3.2.3 are done for the purpose of validation, perhaps the material from section 3.2.3 can be merged into this section.
14. **P. 8, Line 16:** It is unclear what “components” refers to here.
15. **P. 8, Line 22:** Change “temperature,  $T_{2m}$ ” to “air temperature at 2 m,  $T_{2m}$ ” for clarity.
16. **P. 9, Line 7:** What is the temperature gradient between?
17. **P. 9, Lines 12-14:** Can the author’s elaborate briefly on this? Why are the winds interpolated rather than being calculated within the model?
18. **P. 9, Line 31:** Suggest changing “total LW” to “net LW (incoming-outgoing)” radiation
19. **P. 10, Line 10:** By “generally exposed” do the authors mean “every year”?
20. **P. 10, Line 19:** Since the difficulties in modeling the ELA station have not been elaborated on yet, perhaps the difficulties should be briefly summarized, e.g. “some of the modelling difficulties which affect the ELA station (discussed below), associated with errors in simulating the presence or absence of snow cover...”
21. **P. 11, Line 7:** I believe “underestimating the albedo” should be changed to “overestimating the albedo”.

22. **P. 12, Line 2:** Suggest changing “total energy was estimated” to “total energy balance was estimated”.
23. **P. 13, Line 1:** “the summer surface was reached” is a bit unclear. Are the authors referring to exposure of bare ice at this location?
24. **P. 13, Line 5:** Change “SW radiation” to “net SW radiation” for clarity.
25. **P. 13, Line 8:** Again “net SW radiation” would be clearer.
26. **P. 16, Line 4:** Be more clear about what is underestimated.
27. **P. 16, Line 12:** It is known that the model simulates surface temperatures well, as discussed in the previous paragraph. Perhaps it is better to say that the accuracy of outgoing longwave radiation is consistent with the ability of the model to capture surface temperatures.
28. **P. 16, Lines 15-16:** The better agreement with observations as compared with a fixed albedo, though obvious given the wide spread of observed values, is not mentioned in the results section. If mentioned here, it should also be mentioned in Section 4.3.
29. **P. 16, Lines 30-31:** This sentence is confusing. It makes it seem as if the average modeled mass balance for 1981-2014 is being compared with the average for 1995-2014 from observations. Rather, the model results for 1995-2014 were compared with observations for 1995-2014. Please clarify.
30. **Table 2:** In the caption, the meaning of the parameters in column 1 should be explained, as is done for Table 3.
31. **Figure 1:** The weather station names are not consistent with the names in the text. For example “B-abl” should be “B-AB” to be consistent with the text. Also, in the caption, it should be pointed out that the unlabeled sites in Fig. 1a were not used in the study. Optionally, the symbols could be a different color to emphasize this. Perhaps Brúarjökull and Tungnaárjökull could also be labeled on the map for clarity. The lines on Fig. 1b are not explained. I suppose these connect mass balance sites collected along a transect. Finally, the labels (a) and (b) should be added for the sub-plots.
32. **Figure 10:** (Caption) Add the years of the observational period for clarity.

#### Technical Corrections:

1. **P. 1, Line 3:** Suggest changing “describes the albedo with an exponential decay with time...” to “allows albedo to exponentially decay with time...”
2. **P. 4, Line 1:** Change “lat/lon” to “latitude-longitude coordinates”
3. **P. 5, Line 28:** Change “The found best-fit values were...” to “The best-fit values were found to be...”
4. **P. 5, Line 30:** Change “Refreshment of albedo to the maximum value only occurs...” to “Albedo is only refreshed to the maximum value if..”
5. **P. 6, Line 11:** I believe there is a typo in the equation. Should “ $d^{n+1}$ ” be “ $d^{t+1}$ ”?
6. **P. 6, Line 23:** Change “How much this” to “The extent to which”
7. **P. 7, Line 4:** Change “The model is here run” to “For this study, the model is run”
8. **P. 7, Line 10:** Change “allows a quick and thorough” to “allows for a quick and thorough”
9. **P. 8, Line 5:** Change “like for example that of the albedo” to “including, for example, the albedo parameterization,”
10. **P. 8, Line 31:** Change “with 0.8 K overall” to “by 0.8 K on average”

11. **P. 9, Line 1:** Change “but with less than 0.6 K” to “by less than 0.6 K”; change “it for example” to “for example, it”
12. **P. 9, Line 20:** Change “larger errors-” to “larger errors;”
13. **P. 10, Line 12:** Change “down to 0.03” to “as low as 0.03”; Change “the total overestimation” to “the average overestimation”
14. **P. 10, Line 27:** Change “that low in situ...” to “that a low in situ...”.
15. **P. 11, Line 28:** Change “comparisons statistics” to “comparison statistics”.
16. **P. 12, Lines 10-12:** This sentence is rather long. I suggest splitting it into two sentences.
17. **P. 14, Line 16:** Change “one-third that of the AWS sites...” to “one-third the difference with respect to the AWS sites...”
18. **P. 14, Line 27:** Change “back to 1981” to “extending back to 1981”.
19. **P. 16, Line 6:** Change “comparisons only uses” to “comparisons only use”.
20. **P. 16, Line 12:** Change “there was a larger differences” to “there was a larger difference”.
21. **P. 16, Line 19:** Change “and that the model does not account” to “and the fact that the model does not account”
22. **P. 16, Line 20:** Change “way to include” to “means of capturing”
23. **P. 17, Line 21:** Change “could be including a stochastic...” to “could be to include a stochastic...”
24. **P. 17, Line 31:** Change “with 0.06 m” to “by 0.06 m”.
25. **P. 18, Line 13:** Change “like for example ERA-20C” to “for example, with the ERA20C reanalysis”.
26. **Figure 3:** The axis for Fig. 3b is a bit confusing. I suggest removing the 100, and leaving 0 for all plots.
27. **Figure 4:** suggest adding “from AWS stations” after “fluxes calculated” for clarity.
28. **Figure 6:** The caption seems to be erroneously in italics.
29. **Figure 11:** Change “used AWS” to “AWS stations used in this study”