

## **Cloud effects on the surface energy and mass balance of Brewster Glacier, New Zealand**

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### **Summary:**

A study of the impact of cloud cover on the surface energy and mass balance for an in situ station on Brewster Glacier, New Zealand was conducted. Used measurements of atmospheric variables, fluxes, snow depth and density, in conjunction with a surface mass balance model to study the effects of clouds. They conduct a model sensitivity study to examine how clouds affect the sensitivity of SMB to air temperature. They find that for this location, clouds dramatically affect the SEB, and enhance the frequency, and to a lesser extent the magnitude of melting, primarily by changing the direction of net longwave radiation at the surface. A sensitivity study suggests that under cloudy conditions, SMB is more sensitive to fluctuations in temperature. The authors argue that the importance of clouds and atmospheric moisture should be recognized when studying glacier climate interactions.

### **General Comments:**

This study is well written and I think that the conclusions are scientifically sound. The authors sometimes do not explain some statements carefully, and as a result, the results section is sometimes difficult to understand. I think that the study points to an important factor that is sometimes overlooked and should be considered, and therefore is new and relevant research. Therefore I believe the study should be published after the revisions suggested below, which are minor in the sense that they are related to the presentation of the material.

Some general points are:

1. The authors do not define what they mean by the “snowfall-albedo feedback” or “accumulation-albedo feedback”, which is not necessarily a positive feedback. This should be clarified below (see specific comments).
2. The authors should comment further on the potential of the methods used to distinguish between cloudy and non-cloudy conditions to impact the results.
3. In general some statements, particularly with regard to interpretation of results are unclear, as mentioned below.

### **Specific Comments**

1. **P. 976, Lines 13-14:** The impact of precipitation on the surface-albedo feedback depends on whether the precipitation falls as rain or snow. Snow would induce a negative feedback, while rain would contribute to the positive feedback.
2. **P. 977, Lines 5-6:** I am not sure what the authors mean by the “strong positive feedback between accumulation and surface albedo”. Warmer conditions can lead to increased precipitation, which increases surface albedo if the precipitation falls as snow, reducing the energy available at the surface for melting and grain size metamorphism. This is a negative feedback. (e.g. Box et al., 2012). However, a transition from snowfall to rainfall can lead to a positive feedback. Please clarify here and throughout the paper.

Box, J.E., Fettweis, X., Stroeve, J.C., Tedesco, M., Hall, D. K., and Steffen, K.: Greenland ice sheet albedo feedback: thermodynamics and atmospheric drivers, *The Cryosphere*, 6, 821-839, doi: 10.5194/tc-6-821-2012, 2012.

3. **P. 977, Line 15:** I am not sure I agree that the effect of clouds is “far more pervasive”. Perhaps the authors mean to say that clouds have a strong effect on *variations* in the SEB? What timescales are being considered here? I would argue that all of the factors mentioned by the authors are important, and may be more or less important depending on the location or timescale being examined (e.g. surface albedo variations may be most important for the seasonal SEB variability, while clouds may dominate day-to-day or hour-to-hour variability. The authors also mention differences in the SEB for different glaciers in the Discussion section.) I think the authors should not diminish the importance of other factors, which does not diminish the importance of clouds to the SEB.
4. **P. 979, Line 2:** Please include the years covered during the 22 month period.
5. **P. 979, Line 9:** Please indicate what the dataset is a hybrid of.
6. **P. 980, Line 19:** Clarify whether the bias introduced by the instrumentation is  $-0.7^{\circ}\text{C}$ , or whether the correction to the original dataset is  $-0.7^{\circ}\text{C}$ .
7. **P. 980, Lines 8-15:** Can the authors provide further discussion of errors that may be associated with this method, and validation of the emissivity model? Can the authors be certain that the changes in LW radiation are indeed associated with clouds, and not other factors, such as atmospheric water vapor content?
8. **P. 981, Lines 22-24:** This sentence is unclear. Are the effects of evaporation and condensation on surface meltwater accounted for in the model?
9. **P. 982, Lines 9-13:** Can the dates covered by SMB<sub>mr</sub> and SMB<sub>pr</sub> be reiterated here? Also, specify where the inputs to SMB<sub>pr</sub> parameterizations come from for clarity.
10. **P. 982, Line 18:** How is upward heat flux at the bottom of the subsurface model determined?
11. **P. 984, Line 10:** What were the values used?
12. **P. 984, Lines 15-16:** Why didn't the authors use the period 1 May to 24 October 2011? It seems that this would allow for a more continuous period of measurements.
13. **P. 985, Line 5:** How would this be a positive feedback? Does the increased albedo lead to more snowfall?
14. **P. 985, Lines 10-12:** This sentence should be moved to the previous paragraph, as it is describing another modification to the albedo scheme. It is not entirely clear, but I think this modification has also been applied in the generation of the modeled timeseries in Fig. 2a.
15. **P. 985, Line 21:** Table 6 is mentioned before Tables 4-5. Perhaps the authors can refer to the results section rather than Table 6, move Table 6, or simply mention the parameters that were changed here.
16. **P. 985, Line 26:** Change “multiplying” to “multiplying half-hourly  $\Delta\text{SMB}$ ” for clarity.
17. **P. 986, Line 8:** Figure 2b is mentioned after Figure 3. I think Fig. 2b needs to be mentioned sooner, perhaps when albedo is discussed, or a separate figure that follows Fig. 3 should be created.
18. **P. 986, Lines 10-11:** This sentence is unclear. What is meant by “winter accumulations”, the total amount of accumulation during winter months? Please clarify.
19. **P. 988, Line 15:** The sentence makes it sound as if changes in  $e_a$  are caused by increases in  $T_s$ . Perhaps change “associated with” to “accompanied by”.

20. **P. 989, Line 14:** Suggest changing “similar source of energy as  $R_{net}$ ” to “producing an amount of incoming energy comparable to that of  $R_{net}$ ”.
21. **P. 989, Lines 20-21:** This sentence is unclear. Isn't the higher level of melting during cloudy conditions a consequence of differences in the energy budget, rather than a cause? Or are the authors trying to say that if there weren't melting, the energy available for melting would be even larger? Please clarify.
22. **P. 990, Lines 4-5:** Do the authors mean “ $LW_{net}$  and  $QS$ ” rather than “ $LW_{net}$  and  $QC$ ”? Perhaps change “diverged strongly with cloudiness” to “changed dramatically during cloudy conditions” for clarity.
23. **P. 990, Line 9:** Change “large” to “large sensitivity of”
24. **P. 990, Line 10:** Can the authors briefly reiterate the meaning of  $\Delta SMB$  here and in Table 7? Is this the average per year value over the two-year sensitivity period?
25. **P. 990, Lines 9-22:** I think it would be helpful to reiterate here that the magnitude of perturbations is determined but the estimated errors for the input variables.
26. **P. 990, Lines 9-22, Table 7:** I believe that  $\Delta SMB$  is the difference between the + and – perturbation runs. This is not entirely clear from this section, and from Table 7. Please clarify this here and in the caption to Table 7. Also, while the left column of Table 7, always shows +/- values, this section discusses the effect of “increases” and “decreases”. I think the authors mean an increase from the negative to the positive perturbation, and vice versa; but it appears as if the impact of positive vs. negative perturbations is being examined. Please clarify in the text and caption.
27. **P. 991, Lines 15-17:** Can this calculation be explained in a bit more detail?
28. **P. 991, Line 25:** Change “on the  $\Delta SMB$  to  $T_a$ ” to “on the relationship between  $\Delta SMB$  and  $T_a$ ” or something similar.
29. **P. 991, Line 28:** “accounting for 50%”. Since the sentence begins with “In absolute terms”, the absolute amount should be mentioned here, rather the percentage. The percentage values are also interesting, and could still be included. Alternately, the sentence could begin with “In relative terms”.
30. **P. 992, Lines 9-10:** Change “ $\Delta SMB$  in clear-sky conditions showed a long period of minimal  $\Delta SMB$  from May...” to “During May through October (inclusive)  $\Delta SMB$  during clear sky conditions was minimal.”
31. **P. 992, Line 14:** What is meant by “perturbing  $T_{r/s}$  with  $T_a$ ”? This is unclear.
32. **P. 992, Lines 16-24:** I'm not sure that Figure 9 supports the assertions being made here. An annual plot of  $\Delta SMB$  (direct) as a fraction of  $\Delta SMB$  (full) would reveal whether this argument is supported by the graph. Also it is not clear how changes in snowfall during cloudy conditions affect the change in  $SMB$ ; is this due to a switch from snow to rain? Please clarify, and include the additional plot if possible.
33. **P. 993, Line 3:** Please clarify “The strong divergence of  $SEB$  with cloud condition”, perhaps changing the phrase to “The large difference in  $SEB$  terms between clear and cloudy conditions...”
34. **P. 994, Line 11:** Change “high sensitivity of  $SMB$ ” to “high sensitivity of  $SMB$  to  $T_a$ ”.
35. **P. 994, Line 13:** Suggest changing “overcast conditions which” to “overcast conditions which this study suggests”, as it is not clear whether different conditions in the Alps would produce different effects.
36. **P. 994, Lines 25-26:** Can the authors be sure of this, given that this study only covers one location? Perhaps change “appears to have been” to “may have been”.

37. **P. 997, Line 11:** I think the authors mean changes from snowfall to rainfall. Please clarify.
38. **Table 8, Caption:** Perhaps “sum” should be changed to “cumulative sum” for clarity.
39. **Figure 3:** Can the authors include the 1:1 line as in Fig. 4, for clarity?

**Technical Corrections:**

1. **P. 977, Line 25:** Change “properties” to “properties,”
2. **P. 981, Line 23:** Change “surface temperature” to “surface”
3. **P. 983, Line 23:** Do the authors mean “evolution” rather than “evaluation”?
4. **P. 985, Line 9:** Change “responsible for decreased” to “responsible for reducing” for clarity.
5. **P. 989, Line 27:** Change “experienced” to “experienced during”.
6. **P. 991, Line 1:** Change “snow fall” to “snowfall”.
7. **P. 991, Line 24:** Change “cloud” to “clouds”.
8. **P. 992, Line 19:** Change “SMB” to “ $\Delta$ SMB”.
9. **P. 998, Line 28:** This reference should be updated as the article has been published online.