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The Cryosphere
Discussions

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Interactive comment

Interactive comment on "Incorporating moisture content in surface energy balance modeling of a debris-covered glacier" *by* Alexandra Giese et al.

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Comment on 'Incorporating moisture content in surface energy balance modeling of a debris-covered glacier' by Giese et al.
In this paper, authors applied ISBA model to debris-covered ice. The model include moisture transport and phase changes in the debris layer. They used observed temperature in the debris layer and melt amount in 2013 as validation. Then, they also carried out sensitivity test for six elements.
But, I think some explanation and discussion are not sufficient in the manuscript. I hope my comment will help to improve your paper.
Thank you, these comments have definitively helped to improve the paper.

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Main comments

1. There is no ‘observed data’ section. Observed glaciological or meteorological data are important to establish model as not only input data (AWS) but also validation (ablation). Even some data are already published, I think authors need to describe what kind of observed data authors have. I recommend to add one section of observation.

The paper structure has been rearranged to include “In Situ Measurements" and “Model Inputs" subsections within Section 2: “Field Site and Data," before the model description (Section 3), including all information from former sections 4.1-4.3.

2. Authors describe in the conclusion ‘Snow is a strong insulator, and any error in simulated occurrence of snowfall will cause error in the surface temperatures and underlying debris temperature profile simulated by ISBA-DEB (e.g. Figure 6).’ In P29 Line24. But, they did not discussed about the snow cover effect in the discussion. Snow cover makes high albedo over the debris, which inhibits ice melting. Snow cover makes no temperature gradient in the debris layer. And meltwater from the snow cover will be important moisture source of debris layer. Therefore, reconstruction of snow cover duration is significant to estimate ablation under the debris. Authors have nice observed data, and simulated data, then they can discuss about the snow cover effect.

This is a valid point, and investigation into the effect of any error in snow cover is an important next step. The complexity of such an undertaking makes it beyond the scope of the paper; however, we have added the following to our Discussion in “Future Directions": “snow is a highly-reflective, strong insulator, and any error in simulated occurrence of snowfall will cause error in not only the surface energy balance and underlying debris temperature profile simulated by ISBA-DEB (e.g. Figures 6, S3) but also in the water mass budget of the debris. An error in snow cover timing or duration affects the net radiation budget and could potentially contribute to the model’s overestimation of sensible heat flux (Section 5.3). In this study, we used precipitation data from Pyramid Research Station and partitioned phase based upon AWS air temperature. The SR50 depth sensor provides additional information: it may indicate *snowfall when there was no recorded precipitation at Pyramid, and it may conversely indicate no solid precipitation when subfreezing temperatures at the Changri Nup AWS coincided with recorded precipitation at Pyramid. Any remaining mismatch after the basic site-specific adjustments performed in this study would propagate error to the calculated ablation. Verifying snow cover duration in the forcing is, therefore, an important undertaking in future research using ISBA-DEB on Changri Nup glacier and should be a priority when collecting data with which to force a debris-covered glacier surface energy and mass balance model–particularly if it includes moisture."*

Specific comments
P3 Table 1 > multiplication should be presented as '×' not '*'.
FIXED.

P4 L9 > I think 'It lies 200 m southeast of' should be southwest. or I misunderstand them?
FIXED.

P4 Fig.1 > There are no description of the location of "West Changri Nup and North Changri Nup glaciers' in the map. So, I cannot detect those locations. Further, location of measurement site of debris temperature are necessary.
FIXED.

P5 L22 'Glacier melt enters the debris at the base, and rain and snowmelt enter the debris at the surface.' > better to add water like 'Glacier melt water, snowmelt water'
FIXED.

P6 Figure 2 > The small letters (Ex. dz varies, n layers) in the left side of this figure can not be read, when the figure has been shrunk.
FIXED.

P7 Figure 3 > I found several ‘Table A1’ in the manuscript. But, there is no table that shown as ‘Table A1’. Revise all ‘Table A1’.
We confirm the presence of Appendix (not Supplement) Table 1. It was on page 31 of the original manuscript.

P8 L7-8 ‘We neglect energy carried by precipitation’ > But, there are arrow of ‘Rain &snowmelt’ in the Figure2. Please explain the detail, how did you treat the penetrated water
We added an explanation for neglecting energy carried by precipitation and added clarity to the figure, which has arrows for the precipitated mass entering the system.
In SURFEX, there is an option to include the energy of rainfall if it is above 0C. Generally, this option is not activated since it cannot currently be used in the coupled (land-atmosphere) configuration because it would require removing this energy from the atmosphere. In other words, it would require keeping track of the temperature of falling precipitation rather than using the current assumption used in most operational and climate models that the rainfall has the same temperature as the air. Thus, we do not use this SURFEX option, but it could be tested in future, decoupled studies.
Concerning meltwater, when the overlying snow melts, meltwater is at 0C in the model (it carries no heat). Note that if meltwater does infiltrate into a layer which is below 0C, then freezing and latent heat release is modeled following Decharme et al. (2016).

P10 L11 ‘τ_α. . . defining the runoff timescale from. . .’ $>$ τ_α is important in this paper.

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Then, I recommend that detail explanation of τ_α are necessary here. For example, *** become larger with increasing τ_α and so on.
We have added a description to the text: "τ_α controls the distribution of moisture, with larger values leading to a concentration of water at the debris-ice boundary and smaller values leading to a more even distribution. All values considered give an increase in water with depth, which is to be expected with the combination of gravity and the fact that debris clasts get finer with depth."

P11 Figure 4 I recommend to change the unit of τ_α in hour rather than in second, because in the text you have discussed the τ_α in hour.
FIXED.

P12 Line 5 I recommend that all meteorological variables are described in the supplement.
We considered this but decided to keep all information about the meteorological data in the main text, given its importance and the comments from reviewer 1.

P12 L13 There are no description about how did you measure the debris temperature and debris density and porosity.
These are added to the enhanced Section 2 "Field Site and Data."

P12 L21 I estimate you used eq.(1) in Wagnon et al.(2009) here. But please draw the equation between -1 to +3 C. The equation has no simple relation. I can't imagine why you have to use the complicate relation. Or you have applied for the temperature range between 0 and +2 C ?
We did, indeed, use the fifth order polynomial between -1 and 3 ^{o}C, as given in Wagnon et al (2009), for the sake of completeness. We agree that it would have been

more logical to apply the equation between 0 and 2 °C only. The relationship between solid precipitation and temperature is complicated in the tails, as the reviewer's plot elucidated. Using a value of one from -1°C - 0°C and zero between 2°C and 3°C would be more straightforward but is highly unlikely to have any impact on simulated glacier melt given how close P is to 1 and 0 in these ranges.

P12 L22 'minor adjustments based on SR50 measurements.' > There is no detail information on the adjustments. I can estimate that measurement of precipitation using Geonor T200B has relatively small error because it can measure weight of precipitation directly. On the other hand SR50 measure only surface elevation change, which is not equal to amount of precipitation. So, why you should adjust using SR50 ?
The SR50 ultrasonic depth gauge indicates whether or not snowfall has taken place at the field site. We use precipitation data from Pyramid and partition phase based upon AWS temperature. However, the SR50 may indicate snowfall when there was none recorded at Pyramid, and it may conversely indicate no solid precipitation when subfreezing temperatures at the West Changri Nup AWS coincided with recorded precipitation at Pyramid. Therefore, it is necessary to perform site-specific adjustments, which we now describe.

P13 Table 2 You should write name of instrument at the 'Instrument' for example Pyranometer for shortwave radiation.
FIXED.

Campbell SR50 can not measure ablation or accumulation directly. It can measure only elevation change, then, you should assume snow or ice density to estimate accumulation or ablation.
We added this distinction in the table caption.

P14 Figure 5c It seems that many point of rainfall have been overlaid by those of snowfall. I think these two data should be shown separately. The label of x-axis should rotate 90 degree. Vertical writing for label of x-axis is easy to detect the exact location.
We separated the plots of rainfall and snowfall and extended the extents of the y-axes to ensure that the x-axis ticks are visible.

There are rainfall, but no snowfall during winter (from Jan 2014 to around March 2014). Is that possible? Please check.
This figure has been FIXED.

P15 L17 '2013 ablation' $>$ There is no information of the observation of 2013 ablation. Location? Duration? Frequency of measurement ? How much is the debris thickness? How did you measure? And the location of ablation measurement were same with that of measurement of debris temperature ?
This information has been clarified in and/or added to the enhanced Section 2 "Field Site and Data."

P15 L18 'using an RMSE calculation to capture the magnitude of temperature.' $>>$ I recommend to write them specifically.
The minimum RMSE, for τ_{α} =30, was 1.99995 which is a shallow minimum given an RMSE range of 1.99995 – 2.08845. The RMSEs for τ_{max} varied even less, with a range of 0.05; accordingly, we did not find a compelling justification to have the value of this parameter differ from the timescale of sandy soil to drain to its field capacity. While the suggestion to include these values in the text is certainly an important one, we decided against highlighting them for fear that they would confuse the majority of readers and detract from the message.

P16 Figure 6 I recommend that daily average data both observation and calculation are plotted in one graph. I cannot compare if those data are shown in different graph. Further, many points are overlapped in Fig. 6, then, daily average are necessary. And I also recommend that scatter plot of the observed and simulated debris temperature are valid to compare and analyze. And how much is the debris thickness? 12.5 cm ?
It is a good idea to include a direct comparison of measured vs. modeled temperatures, and such figures have been added to the Supplement. We have updated the caption of this figure (formerly 6) to emphasize the reason for the figure (i.e. to show why we chose the tuning period we did) and to reiterate the debris thickness.

P16 Figure 6 '(having insufficient snowfall to produce the observed persistent snow-cover)' > It might be possible that model overestimate the melt rate of snow cover. I think reconstruct of duration of snow cover during the melting season is significant (see main comment).
Yes, there could potentially be errors associated with inaccurate reconstruction of snow cover; however, doing snow cover reconstruction and/or an analysis of it is out of the scope of the paper. See our response above concerning the snow cover discussion added to "Future Directions." Additionally, it is indeed true that if any of the simulated incoming components to the energy balance are too large, the model could potentially compensate (equifinality) by heating the surface too much and, thus, overestimating the melt rate of the snow cover. We added a statement that a snow cover simulation error could be responsible for the overestimation of sensible heat flux.

P17 Figure 7 In the explanation, '(a) Temperatures in debris (top 12.5 cm)' I can't understand the 'top 12.5 cm'. This points location of interface between debris and ice? '... below the black line indicates...' > 'below'?
This caption has been rewritten to avoid confusion.

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P17 L3 Figure A2 > Figure 2
FIXED (Figure S2).

P 18 Figure 8 I recommend to describe those data is simulated data.
Clarification added to the figure caption.

P20 Figure 10 There is no calculated data shown in Figure 8 (calculation of moisture integrated model). Why? It seems that the calculated ablation using moisture integrated model (Figure 8) have similar value with 'dry' and 'partially saturated'. And in this section (P20 L1-8), there is no discussion about the difference between three case calculated data and measured data. Measurement value was corresponded with the value of assuming fully saturated, not dry or partially saturated.
Figure 8 is all model output, what we think this reviewer terms "calculated data," and the caption has been updated to reflect that. Figure 8 shows the "partially saturated" case, a point made clear in the caption to the table with which we replaced Figure 10. The "Wet versus Dry Debris" subsection contains an enhanced discussion of the distinction between the three cases and the comparison with measurements.

P21 Figure 11 This is a minute thing, but as for color bar, 'No moisture' are colored by light red. I think the color should be white.
FIXED.

P22 Figure 12 I recommend to add cumulative melt (like Fig. 8).
Our original manuscript stated that "cumulative flux used for melt" was part of figure 12. In the submitted version, we intended to show only latent heat fluxes and have removed the language that remained in the text from a previous revision.

In the last sentence of the explanation, there are 'A greater latent heat flux corresponds to a lower conductive heat flux through...' $>$ There are multiple latent heat fluxes in this system. Please write specifically.
Rewritten as: "Greater latent heat fluxes are balanced with a lower conductive heat flux through the debris into the underlying glacier."

P24 Table 3 '% Change' $>$ What is the change ? Change of ablation ?
Actually, it is melt. Table heading changed to "% Change in Melt."

P28 L12 '75.3 ± 20 cm (2012 – 2013) and 47.1 ± 20 cm (2013 – 2014)' $>$ Here, I have noticed that you have observed data not only 2012 – 2013 but also 2013 – 2014. Why you did not compare observed data and simulated data 2013 – 2014? Because you have tuned parameter 2013 – 2014? But, you have tuned parameter τ_α fitting simulated debris temperature to observed debris temperatures. Not ablation amount. Observed data of ice melt under debris layer are very few, even though those data have large uncertainty.
We converted this to a table with model output from both years and available point mass balance measurements. We erroneously compared model-computed melt to point mass balance in the original submission but have corrected this, along with reporting modeled mass balance components and both stake and SR50 depth gauge measurements.

P29 L23 'more detailed assimilation of the snow rate with the SR50 data.' $>$ Still I don't know the location of the measurement of ablation and debris temperature. Then, my comments might not appropriate. I would like to ask the surface temperature at AWS (SR50 measurement) can be assumed to be same condition with that at ablation measurement site? If you can assume same condition, you can analysis the albedo of AWS using observed SRs downward and upward and weather there is snow cover or

not.
From the available data, we can, indeed, calculate whether there was presence or absence of snow. This is a great point and a methodology that could be employed in future work.

P29 L24 ‘Snow is a strong insulator, and any error in simulated occurrence of snowfall will cause error in the surface temperatures and underlying debris temperature profile simulated by ISBA-DEB (e.g. Figure 6).’ > I recommend to discuss about the snow cover during summer season in the discussion section. Because you have observed data of temperature of debris as shown in Fig.6.
Please see our response above on the scope of the paper and what we added to the Discussion on the subject.

P29 L26 ‘ISBA-DEB may be used to explore past or future changes in sub-debris melt. Reanalysis data, such as that of ERA Interim, provides all variables necessary to drive the model.’ > ERA Interim do not include debris-thickness or particle size of debris, which is important for permeability (thermal conductivity) of debris and also surface roughness, those parameter have high sensitivity in ISBA-DEB model in your result.
The model is driven by meteorological values only, and we have added a list of those exact variables to subsection 2.3 to prevent confusion.

How will you apply the ISBA-DEB model to other debris-covered area? I recommend that you have to better to consider application to other debris covered part.
The model can be applied to debris-covered areas for which debris physical properties (second section of Table A1) and continuous meteorological data (subsection 2.3) are available. We have bolstered the discussion about the applicability and transferability of ISBA-DEB to other debris-covered glaciers and included considerations on scaling the model from the point to glacier scale.

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