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Interactive comment on "Impact of debris cover on glacier ablation and atmosphere-glacier feedbacks in the Karakoram" *by* E. Collier et al.

Anonymous Referee #3

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General comments

The interactive surface-atmosphere modelling applied in this paper is state of the art and the utility of the approach to understanding glacier mass balance and response to climate has been demonstrated by earlier publications. The context and problem to be addressed are explained very nicely in the introductory sections. This is the first study I knows of to model glacier mass balance at a regional scale in such physical detail and generates several interesting and novel results, particularly in terms of the impact of debris cover compared with bare ice glaciers. It is apparent that knowledge of necessary data input fields, such as debris thickness, thermal and moisture content properties, is a limitation on model performance, and the paper should help focus attention on understanding these important properties and processes.

The paper is extremely well written and the figures and tables very well presented on the whole. I only have a few discussion points the authors might want to consider and some suggested minor corrections.

Specific comments

Section 2.3.

The parameterisation as debris thickness, d, as a function of length with a gradient of 0.75 cm km-1 generates 'thick' debris, but only on extremely long glaciers, e.g. the maximum thickness on a 20 km glacier would be just 15 cm. I think this value is unrealistically low as there is evidence from Himalaya, e.g. Rounce and McKinney, 2014; TC 8, 1317-1329, and elsewhere, e.g. Mihalcea et al., 2008, Cold Regions Science and Technology, 52, 341-354 of 30 cm + thickness debris being extensive on much shorter glaciers. Hence, the debris thickness gradient is probably steeper on shorter glaciers leading to an underestimate of d on many glaciers in the study. However, the authors are probably correct that most of the 'energy balance impact' of debris occurs in the first 20 cm or so in addition to acknowledging this likely underestimation, this point is really a consideration for future work.

Section 3.3

2273, 4-5, the presence of debris results in >800 additional melt hours compared with bare ice. On p 2275 you discuss a very interesting feedback via energy emission to the lower layers of the atmosphere from sun-warmed debris resulting in higher air temperatures and hence increased melt rates. Is an additional explanation the fact that debris surface temperature can exceed 0 deg. C, resulting in conduction of energy to the ice, even when air temperature is <0.

2273, 5-7. Surely, it isn't only during 'melt hours' that DEB Qs flux to the atmosphere is greater than CLN as implied here. Debris could still be a lot warmer than the air and supply heat to the atmosphere when temperatures are below zero.

There isn't much discussion of latent heat flux in Section 3.3. An interesting observation in figure 10b is the slightly increased precipitation for the DEB runs at highest elevations, particularly >7 km. Why? Is this due to additional moisture input from debris, or from enhanced convection?

Section 4

2274, 23-27. "Accounting for vapour fluxes increases the net loss by 3.7% compared with CLN and comprises 8.7% of the total negative mass flux in DEB" How can net loss (assuming this means mass loss) be greater than for CLN when earlier in the paragraph the opposite conclusion is drawn (i.e. debris cover reduces glacier mass loss by 7% over the whole basin and by >2.5 m w.e. at lowest elevations). Is the mass loss from ice which melts and subsequently evaporates counted twice?: once in the melting of ice and second when it evaporates. This ignores the fact that most meltwater from clean ice melt runs off so it isn't a consistent comparison between DEB and CLN.

Discussion

The model results are highly dependent upon assumptions of: a) debris thickness and other debris thermal properties distributions and b) moisture conditions within debris layers and their distribution. In a) a small adjustment to the parameterised gradient of debris thickness change along glaciers has a dramatic impact on debris mass balance and presumably QS to the atmosphere. In b) the finding that debris cover results in a minor increase in QL compared to clean ice could be dependent on necessary assumptions about moisture distribution within debris. As the authors note in their previous paper (Collier et al., 2014) the simple reservoir parameterization applied in the CMB model underestimates the surface-atmosphere vapour pressure gradient. In addition to the conclusion regarding the importance of determining debris thickness fields in the final paragraph of the paper, the authors should also emphasise the need to improve understanding of moisture fluxes between debris and the atmosphere.

Minor corrections

2270, 18-20, why are only 55% of debris-covered pixels exposed. I would have thought this would be close to 100% during the summer ablation period. Later in the same paragraph, a minimum figure of 15% is given for the Karakoram as a whole. Again, why so low? The fact that 2004 was probably a particularly snowy year becomes apparent later, but it would be helpful to point this out here.

2275, 1, 'thicker' than what?

Figure 2 (c) does not show debris thickness as stated in the caption, but it could do so if the x-axis label was changed from km to cm.

Table 4 and Figure 6– Subsurface melt is 3 x greater (and half the surface melt value) for DEB compared with CLN. Does 'subsurface' in this case mean sub-debris? In which case, please use different terms to distinguish subsurface melt in ice due to penetrating shortwave and sub-debris (or debris-ice interface) melt. Otherwise, explain the physical process leading to so much sub-ice-surface melt beneath a debris layer.

Interactive comment on The Cryosphere Discuss., 9, 2259, 2015.