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Interactive comment on "The response of supraglacial debris to elevated, high frequencyGPR: Volumetric scatter and interfacial dielectric contrastsinterpreted from field and experimental studies" *by* Alexandra Giese et al.

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General comments: This paper asks whether 'airborne' ground-penetrating radar (GPR) can be used as a means of quantifying supraglacial debris thickness. The authors collected a large amount of GPR data on a debris-covered glacier in Nepal, as well as on a sort of artificial debris-covered glacier in a 'laboratory'. In addition, they made extensive manual pit measurements of debris thickness on the glacier. They found no clear ice surface reflection below debris from which to estimate debris thickness in the field-based GPR data and suggest that this is because the ice and debris

had similar dielectric constants during the survey period. However, they found that they could estimate debris thickness from volumetric backscatter in the GPR data with some success compared to the manual measurements, using a statistical approach, instead.

The research question is a good one because debris thickness is a strong control on the surface energy and mass balance of debris-covered glaciers, and because making ground-based measurements is very difficult. The data collection will have been hard work, having been carried out at high altitude and in a remote part of Nepal, and the dataset that was collected is potentially a valuable resource for the modelling community. The analysis of the dataset, which was possibly more difficult than the authors had originally hoped it would be, is honest, thorough and appropriate. The work is novel in the sense that it focusses on the potential for airborne application (achieved by mounting the GPR on a plastic box above the debris surface), and in its development of the above-mentioned statistical approach to determining debris thickness from volumetric backscatter. The development of the volumetric backscatter method is a useful one, and is the primary contribution this paper makes to the field, as well as a good starting point for any planned or future studies of debris thickness by airborne GPR. It seems likely that the method would always have to be used in conjunction with some ground-based measurements, for calibration, which is a downside and, although 'estimated' debris thicknesses are broadly similar to 'measured' debris thicknesses, I expect that if the two were plotted against each other there would be a lot of scatter. However, the idea is still attractive, especially given the recent proliferation of UAV-use in glacier research, and the difficult nature of the problem. The paper is generally well-written and easy to read, although a few things could be clarified and some of the figures need axis labels and clearer numbering.

I have three major issues that should be addressed before publication (as follows), as well as a number of more specific comments and some technical corrections.

(1) The dielectric constant that was used to estimate debris thickness in the field was determined through laboratory experiments. Even though the laboratory debris was

chosen to have broadly similar mineralogy, grain size etc. to the field debris, the two will inevitably have had slightly different dielectric properties. This is an important point because the choice of dielectric constant will have affected the threshold derived in the volumetric backscatter method, and therefore the estimated debris thicknesses. I don't think the analysis needs to be done again, because optimising the threshold against the pit measurements will have compensated for such a difference, but this should be stated more clearly in section 3.3. (2) I am not convinced that the pine shavings used in the lab are a good analogue for ice. The dielectric contrast is considerably greater between the debris and the pine than between the debris and the ice. I suppose the point is that if there is no clear reflection at the interface between the debris and the pine, where there is a relatively strong dielectric contrast, it should be expected that there is no clear reflection between debris and ice, where there is a relatively weak contrast? If this is the case, I think this could be explained more clearly. (3) On p18, in Table 3, the standard deviations are larger than the mean, suggesting a non-normal distribution if debris thickness is always positive. Median debris thicknesses and interquartile range might be more appropriate here.

Specific comments: P1, L2. The first paragraph of the introduction could do with re-structuring. The first sentence is about water supply, the second, third and fourth about debris-covered glaciers, the fifth back to water supply, then the sixth to climate change. Maybe the water supply and climate change sentences could go together instead.

P3, L10. I don't see why the frequency affects the area that can be covered using GPR.

P3, L12. Remove 'implying a layer of solid granite or very dense debris'. Any number of sediment or debris layers with a dielectric constant of 6.46 are possible. Therefore a dielectric constant of 6.46 does not imply a layer of solid granite or very dense debris.

P4, Figure 1. Would be good to have the transects labelled and the caption updated accordingly.

P5, Table 1 caption. Why did you add 1 cm? This seems quite arbitrary. Please explain

and include the explanation in section 2.2 main text, rather than in table caption.

P7, L26. Sentence beginning 'We collected…' seems like it would fit better in section 2.2 as it is more about data collection than results.

P9, Figure 5. Needs axis labels and clearer numbers.

P10, Figure 6. Needs axis labels and clearer numbers.

P11, Figure 7. Needs axis labels and clearer numbers.

P16, L3. This is the first mention of the porosity measurements. Should be mentioned in section 2.2 as well.

P17, L5. McCarthy et al (2017) discussed the possibility that the strength of the ice surface reflection in their GPR data was variable due to variable dielectric contrast. It seems likely that they could often see an ice surface reflection in their GPR data because the ice was often melting during their study period. I would suggest that this is the key difference between the two studies.

P17, L25. Suggest 'Assuming the small reflections in the profiles are englacial debris, englacial debris is more concentrated…'. There is no proof that these reflections are englacial debris, so some caution is required.

P18, L1. There must be a thickness limitation unless the debris cover is completely lossless. Possibly it is better to say there is no thickness limitation within the range of debris thicknesses that is likely to be encountered in a supraglacial setting.

P19, L12. I am not sure of the meaning of the sentence beginning 'Future work…'. This should be clarified.

P29, Figure B1. Y-axis limits are too wide to see any detail near the debris-ice interface. Suggest 0 – 4 m would be sufficient.

P30, Figure B2. Y-axis limits are too wide to see any detail near the debris-ice interface.

Suggest 0 – 4 m would be sufficient.

Technical corrections: P2, L26. Sentence beginning ‘Because debris thickness…’ needs to be rearranged, otherwise ‘its thickness’ – ‘it’ meaning ‘debris thickness’ – reads ‘debris thickness thickness’.

P3, L21. Remove ‘yet’.

P23, L31. Suggest ‘to the southeast’. ‘Southeasterly’ suggests flow from the southeast, as e.g. westerlies are winds blowing from the west.

P4, L9. Suggest ‘longitudinal to ice-flow direction’.

P4, L12. By ‘collecting more thickness data’, do you mean making pit measurements? Please clarify.

P7, L29. ‘Spectra’ is plural, yet we have ‘is shown in Figure 7’.

P10, Figure 6. Text on figure suggests volume scatter and direct coupling both begin at 1.9 ns, yet these two lines are separated by at least a nanosecond in time. Possibly one is a typo?

P11, L3. ‘compared the scatter behaviour’.

P16, L5. Remove ‘personal’.

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