The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2019-60-RC3, 2019


The Cryosphere
Discussions
Open Access



# *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.

**Anonymous Referee #3**

Received and published: 24 September 2019

Summary: This study employs new lab experiments into understanding GPR signal properties for sounding glacier debris cover, and presents a new approach to analysing GPR backscatter strength from field surveys as a proxy for debris thickness. I think the lab experiments are particularly useful and I'd like to see them expanded to more thoroughly explore the backscatter signal. I am less convinced by the derivation of debris thickness from the summed backscatter power, as explained below. As such, I suggest further work is needed, and recommend that this manuscript not be accepted but a new manuscript be submitted at a later date.



Printer-friendly version

Discussion paper

Details: Page 3 Line 10: "...low frequencies irrelevant for efficient areal coverage..." There is no reason why the systems used in the cited studies (and much larger systems) could not be deployed by helicopter (I have a helicopter-slung system more than 20 m long for example). "...dragged antennas, an approach that was impossible at our field site..." The surface of Ngozumpa, Lirung and Langtang glaciers are very similar to the pictures of Changri Nup shown here.

Line 26: "frequency relevant to remote systems..." by which you mean drones. See above comment regarding helicopters, which are readily available for charter in the Khumbu. Page 4 Line 11: The frozen ice surface is critical here. By far the largest control on the dielectric contrast in such a setting is the presence or absence of water. It would be much easier to detect the ice-debris interface if you surveyed in dry weather by in thawing conditions (so debris is largely dry but ice surface is wet). This is what McCarthy et al. and Nicholson et al. did.

Page 9 Line 3: "Profiles at 50 ns and 100 ns..." Not sure what this means, please clarify. Line 8 and in general: I don't think the term 'volume scatter' is used correctly. It is normally used to describe the net result of multiple bounces from many discrete, closely-spaced reflectors of similar size to the wavelength, within some medium, which I think is what you have here. In such a case, the interfaces are likely to be air-rock, rock-rock and ice-rock interfaces. I think you're describing it as single-bounce reflections back from individual point scatterers within the debris layer, which is analogous to detecting an aircraft in flight (which clearly is not volume scatter). If it was dominated by single-point scatterers then you'd expect to see hyperbolae in the unstacked radargram (e.g., Figure 5) resulting from the radar moving closer to then further away from the point scatterer, but I don't see these. It's also not clear why the signal would penetrate through the debris above but reflect from these particular buried scatterers. Line 9: "The volumetric backscatter is dramatically stronger than the surface return..." But the surface return is obscured/interfered with by the direct wave, so it is not clear what the surface return strength is from the field data. Indeed, the lab experiments show the surface return at least as strong as the volume scatter (Figure 10).

Page 11 Rock box experiments: these are really nice and I'd like to see more, with the aim of characterising the attenuation and ice-surface detectability. I suggest: Increasing the debris thickness (round trip of 57 cm is thickness of only 28.5 cm, which doesn't capture the potential range of thicknesses in the field). Vary the thickness and measure how the aluminium-base signal strength varies, to characterise attenuation with depth. With the pine base, try wetting the pine (by pouring water in at the base, while keeping the debris largely dry) to simulate a thawing ice surface. Try the above but wetting the debris from above, to simulate rain or snowmelt. Repeat the above with a range of GPR frequencies.

Page 14 Line 14: "…area under the Hilbert transformed curve…" – meaning that the value calculated is the sum of the gain-corrected backscatter power over the chosen time window? This would seem to depend on both the gain function used and on the time-window selected. As the signal attenuates with depth, eventually it reaches the noise floor (i.e., system noise), so if a long time window was chosen for exactly the same profiles, this would add 'power' to the summed magnitude because the this approach would sum up this noise. This would increase the total summed power and so the 38% level would be deeper. This would be a spurious increase, unrelated to the actual debris thickness. Also, I think this approach assumes a linear relationship between summed backscatter power and debris thickness, but the effect of attenuation would mean that this is incorrect. This is because the near-surface returns contribute much more to the sum than the deeper ones, so for example, doubling the debris thickness would not double the summed backscatter power, the increase would be much less than double. I think the sensitivity of the summed power to increasing thickness would follow a decay curve. Clearly the deeper debris should contribute less backscatter because much of the transmitted signal has already been scattered back by the debris above, and so is no longer available. This also means that the variation in the threshold calculated locally (e.g., the 35%, 42%, 43% in Table 3) could mean large variability in thickness, i.e. including another 8% of the summed power could mean including a lot more debris, because the debris at depth contributes little to the total. A further implication of attenuation is that there is certainly a limit to the debris thickness that can be quantified by GPR (page 18, line 1, "...we do not have a thickness limitation.") – above a certain thickness, there is no longer enough signal for backscatter to be detected, and therefore no sensitivity to debris. It is not obvious a priori what this limit is because it depends on the debris properties, but once this is exceeded than all that can be said is that the debris is thicker than this detectability limit. Finally, the 38% threshold is empirical and so does depend on the local properties (of porosity, lithology, grain size distribution, wetness). This means that it may be useful for interpolating thicknesses within a single survey, but is unlikely to be universally applicable (as suggested later).

Line 24: If the debris layer produces 38% of the backscatter, where does the other 62% of backscatter come from? Seems that you've already ruled out significant backscatter from the surface and sub-debris ice.

Page 16 Line 13 and elsewhere: be careful with the use of the word 'coherence' – it has a particular meaning in radar processing, whereas I think you're using it to mean 'detectable and continuous' or similar. Line 29: need to add these porosity uncertainties into the debris-thickness error budget (yellow lines in Figure 8 etc). Page 17 Line 11: by far the greatest influence on ice detectability in at least the McCarthy and Nicholson studies is the wet ice surface. Section 4.3: see above regarding volume scatter versus point scatter.

---

Interactive comment on The Cryosphere Discuss., https://doi.org/10.5194/tc-2019-60, 2019.