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Discussions

Interactive comment on "The role of electrical conductivity in radarwave reflection" *by* Slawek M. Tulaczyk and Neil T. Foley

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Thank you for your review of our manuscript and for your numerous helpful specific suggestions. I do have a few clarifying points and a few questions:

(1) FIGURE 3 - I am somewhat perplexed by your criticism that our Figure 3 looks like a figure that can be found online. This figure is in the manuscript just to graphically illustrate the physical setup that we are discussing (i.e., two media with different EM properties separated by a flat interface with an incident EM wave reflecting from, and transmitting through, this interface). Anybody who talks about EM wave reflection from a flat interface separating two homogeneous, isotropic media will draft a similar figure. There is not really much room, or need, here for creativity. Our figure is just a slightly

modified version of a figure in Stratton. Can you be more specific as to what would constitute a more acceptable figure? If you prefer that we modify the figure that you found online, instead of using the one we have in the manuscript right now, we can sure do that.

(2) EQUATIONS 7a THROUGH 11 - We are not hiding the fact that some of the equations in the manuscript come straight out of Stratton's book. In fact, wherever we did take an equation straight from the book, we provided a reference to the page and equation number. Contrary to your assertion, out of the equations called out in your review (Equations 7ab, 8, 9, 10, 11), only some come directly from Stratton's book. 7a does but 7b is obtained by us from 7a by setting the magnetic permeability to be the same for both media and by writing out the propagation constants in terms of the attenuation factor and the phase constant. Maybe somewhere in Stratton's book there is an equation that is exactly the same but we got 7b from 7a. If you can provide a page number and an equation number where you found 7b in Stratton's book, I'll be happy to cite it. Similarly, we did not copy equation 8 from Stratton's book. We did take the absolute value of the complex reflection coefficient to obtain this equation. As with equation 7b, if you can provide a page number and an equation number where you found 8 in Stratton's book, I'll be happy to cite it. I could not find this form of the equation in the book but may have missed it. We quote the book pages and equation numbers were we found 9 and 10. The point about deriving equation 11 is to demonstrate that one can obtain the commonly used version of the radar reflection coefficient from equation 8. If equation 8 would not simplify to 11 under the low-loss assumption, this would cast doubt on the validity of equation 8. We show equation 11 as a reassurance that the more complete version of the radar reflection coefficient shown in equation 8 does simplify to the commonly used form (e.g., Peters et al., 2005 and many others) when the reflection is assumed to take place from a boundary between two perfect dielectrics. So, the very point of deriving equation 11 is to show that 11 has the widely used form, not to claim that we have re-invented the wheel. I will change the discussion of equation 11 to make this clearer.

(3) THIS HAS BEEN DONE BY PETERS ET AL. 2005 - Our manuscript provides an approachable formulation for the radar reflectivity that does not require users to deal with complex and imaginary numbers. Anybody with an Excel spreadsheet or rudimentary coding skills can use our work to quickly get at the dependence of glacier bed reflectivity on permittivity and electrical conductivity/resistivity. Effective communication of quantitative concepts is as important as the concepts themselves. It is not a coincidence that radioglaciologists prefer to interpret bed reflectivity in terms of relative permittivity and wetness, it is simply because they are avoiding having to deal with the complex math concepts involved in the past formulations that included electrical conductivity through the obscure concept of loss tangent. By now there are many decades of published geophysical measurements of subsurface electrical conductivity/resistivity using a variety of techniques. These values can be used by radioglaciologists. Loss tangent is a much more abstract, and less frequently used, concept in geophysics. In this manuscript we remove barriers to considering electrical resistivity in interpretations of radar bed reflectivity. We also provide graphical illustration of the dependence of radar reflectivity on electrical conductivity (our figure 4). I am pretty familiar with dozens of papers in the radioglaciology literature and I do not recall that anybody before has produced a figure even similar to ours. Contrast our figure 4 with the figure 3 in Oswald and Gogineni (2008) where bed reflectivity is simply plotted as a single line expressing the assumed one-to-one relationship between bed reflectivity and relative permittivity (i.e., bed wetness). In our manuscript we carefully consider the criteria under which one is, or is not, justified to ignore electrical conductivity of subglacial materials (the low-loss and high-loss conditions). We also point out that many geologic materials, particularly clay-bearing rocks and sediments, have high enough electrical conductivity for their conductivity to matter in determining the radar reflection coefficient. Our manuscript points out that high conductivity subglacial materials (e.g., clays, brines, conductive minerals), can produce some of the brightest radar reflections (>90% amplitude reflection), which are brighter than the maximum reflection of ca. 67% amplitude reflection from ice-water interface in the high-loss assumption.

I have seen many examples, in literature and during conference presentations, of radioglaciologists claiming that ice on top of water bodies (e.g., subglacial lakes) should produce the strongest radar reflection. We point out that a patch of wet clay-bearing sediments can be brighter than a subglacial lake with fresh meltwater. We also point out in our manuscript that the dependence of radar reflectivity on electrical conductivity can actually be useful in practical applications. For instance, under the common, low-loss assumption there should be no difference in radar reflection from ice overlying a freshwater lake versus a high salinity, briny lake. However, when electrical conductivity is taken into account, the radar reflectivity of the latter can be as much as 30% higher than that of the former. I have recently had a discussion with a couple of experienced Europa researchers and they were surprised to find out that a future radar mission to Europa may be able to provide constraints on the salinity of Europa's ocean, due to the sensitivity of radar reflectivity to electrical conductivity. This is because they, just as most of the terrestrial radioglaciology community, were under the assumption that only contrasts in relative permittivity matter in determining the strength of radar reflection from an ice-water interface. Given all of the above, I contend that what we write about is a much more complete treatment of the role of electrical conductivity in bed reflection strength than what is presented in Peters et al. (2005). We clearly make contributions that have not been made by others before. Relative permittivity is, in general, not the sole control on radar reflectivity of glacier beds. Anybody using a version of our Equation 11 when interpreting radar bed reflection strengths is simply making a convenient, but not universally applicable, simplifying assumption that has been made so many times that many in the community think that it is based on a universal law of physics.

We will follow your specific suggestions for improving the manuscript (e.g., considering linear frequencies higher than 100 MHz.)

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