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The Cryosphere
Discussions

Interactive comment on "Uncertainty budget in snow thickness and snow water equivalent estimation using GPR and TDR techniques" *by* Federico Di Paolo et al.

Anonymous Referee #2

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The manuscript "Uncertainty budget in snow thickness and snow water equivalent using GPR and TDR techniques" by Di Paolo et al. presents an approach to quantify uncertainties from radar determinations in snow depth and SWE. The authors compare measured two-way travel times (TWT) with density and snow depth measured conventionally and TDR point observations in snow pits. From inclusion of device specific errors, they assess GPR specific uncertainties. Such an approach is not novel but interesting. Several studies before assessed uncertainties in conversion of TWT to derive SWE and snow depth (Lundberg with several studies and Sundstroem et al. 2012 for instance). Due to several severe misinterpretations and mistakes conducted mainly during fieldwork, I consider this manuscript (MS) not being sufficient for publication in

The Cryosphere. I recommend to reject it. In detail, the following remarks prevent it from publication:

- As major misinterpretation, I consider the comparison of TDR data with bulk densities and bulk wave speeds. You mention several times in the MS that TDR is "the best estimator" for wave velocity (e.g. p14, L4ff). I consider this as being fundamentally wrong. In the presented work you never refer on snowpack stratigraphy. While the presented density measurements and the GPR data are integrated over the whole snowpack, TDR measurements are only valid for a certain point within the pit wall. Techel and Pielmeier (2012) describe the support of the Finnish Snow Fork (a similar measurement device, you used in the field) being at V = 47 cmˆ3 , while the area includes 7.5 x 2 cmˆ2. In consequence, the vertical extent of such a measurement is only +-1.6 cm. So here you compare permittivity determined at a specific depth with bulk conditions for either 30 cm or the whole snowpack (and you assume for homogeneous conditions for 30 cm below your point measurement). Such point measurements are most likely highly influenced by local stratigraphy such as crusts, density differences or as mentioned in the MS the presence of liquid water. However, considering the data presented in Fig. 4 (neglecting the wrong scale in the submitted version) clearly describes discrepancies between TDR and density data. For the case, that liquid water is actually present in the snowpack, your whole conversion scheme has to be revised. It is no longer valid to present an empirical wave speed model not accounting for the volume fraction of water. Summarizing, I disagree with the statement that TDR is your best estimator in three points:

1. you create compaction of the analyzed snow layer while sliding in the instrument (see Techel and Pielmeier (2011) and Kinar and Pomoroy (2015) describing such circumstances) 2. as described above you only measure point conditions vertically with a very limited support and a 30 cm vertical resolution is not adequate to account for bulk conditions (only 10 measurements for a >3 m snowpack; Figure 4). 3. As described by Heilig et al. (2015), TDR measurements to determine permittivity are scattering a lot

and do not represent the assumed accuracy summarized by e.g. Kinar and Pomoroy (2015)

- According to my understanding, you address the wrong uncertainties in your analysis. For the snow density, the uncertainties are not related to the dimensions of the cylinder (which you quantify to +-0.3 mm p7 L12ff). Here you should implement uncertainties in the filling of the cylinder, which is usually the largest component of uncertainty, together with the calibration of the spring scale with which you weigh the sample. Such spring scales usually have an uncertainty related with weight and air temperature. As a third point, I consider the parallax error as being larger than the uncertainty of 0.3 mm in total diameter. None of these points are addressed in your error analysis for density measurements. It is very common in fieldwork that you apply at least two measurements right next to each other to account for such uncertainties.

- I agree with referee #1 that a snow probe with 0.5 m resolution is absolutely inadequate for the analysis you derive. You mention an uncertainty just from depth readings of +-0.14 m. This is somehow very questionable in relation with the presented uncertainties of +-3% in SWE (Table 3). I realized that the uncertainty in snow depth is just one contributing factor for the resulting uncertainties in SWE for GPR data conversion, however, with a snow probe of 0.5 m resolution you just don't present any useful data set for comparison.

- Not a single figure, data set, measure of the prevailing meteorological conditions during data acquisition is presented. Didn't you record snow temperatures, air temperature, moisture or wind during your field acquisitions? Such data would support the current presentation tremendously. Either in terms of understanding how much liquid water may have been present in the snowpack by estimating the energy balance and correspondingly the prevailing melt or how much the pit walls and snow parameters altered during acquisition (no data on sheltered or exposed pit wall either, no data on temporal differences between pit measurements and radar transects).

- Another major point, I criticize, concerns fieldwork as well. You never quantify how "close" radar transects match pit walls. The term "passing close" is not an adequate quantification. Spatial variability in snow depth, density and liquid water content can become very large and might be a much bigger component contributing to uncertainty than indicated in this manuscript.

Other major points that should be addressed in a revised resubmission: - Quite often you reference not the correct publications for respective parameters or methods, e.g. the relative dielectric permittivity of ice given as 3.29 published by Pettinelli et al. (2003) is certainly at the far end of publications. Why didn't you cite Bohleber et al. (2012), who measured such parameters most accurately or any previous well established literature (Hobbs). There are many other publications out introducing GPR for snow depth measurements (e.g. Vickers and Rose (1973) for the first publication describing it and Harper and Bradford (2003) as a more relevant and earlier citation than the ones listed in your MS). It is not a good habit to prefer self citations.

- Koch et al. (2015) conducted a much more in detail comparison of various conversion schemes than just the two you present.

- The initial submission was not carefully revised and checked for errors, typos etc. Apart from the major sloppiness in Figure 4, you do not introduce RMS as abbreviation and several statements are rather unsupported (P2 L17, Kinar and Pomoroy (2015) describe in detail several tubes to measure both parameters at the same time, P3 L13ff, Sundstroem et al. (2012) and Lundberg with several papers presented uncertainty estimates for such issues). Figure 6 has commas as decimal separators.

- You should include a plot or a further description on the field data.

- While you review GPR and field measurements quite excessively (appears to me as a repetition of Kinar and Pomory (2015) for some paragraphs), me as a reader coming from a different perspective, I got no impression about the factor k and what it is referring to and how you can adjust between k=1 or k=2.

Citations, which are not listed in your references but mentioned in my review: Bohleber, Pascal, Norman Wagner, and Olaf Eisen. "Permittivity of ice at radio frequencies: Part I. Coaxial transmission line cell." Cold Regions Science and Technology 82 (2012): 56-67.

Heilig, A., C. Mitterer, L. Schmid, N. Wever, J. Schweizer, H.-P. Marshall, and O. Eisen (2015), Seasonal and diurnal cycles of liquid water in snowâĂŤMeasurements and modeling, J. Geophys. Res. Earth Surf., 120, 2139–2154, doi:10.1002/2015JF003593.

Hobbs, P. V. "Ice physics, 837 pp." (1974).

Koch, F., Prasch, M., Schmid, L., Schweizer, J., & Mauser, W. (2014). Measuring snow liquid water content with low-cost GPS receivers. Sensors, 14(11), 20975-20999.

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