The authors would like to thank Estel Cardellach for her comments on the submitted manuscript and believe that by addressing them, as below the study has been improved and is now suitable for publication in The Cryosphere.

Our response consists of the reviewer's comments in black, our responses in red and additions or changes to the text in blue.

Estel Cardellach (Referee)

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The manuscript is well presented, the study expands and improves a previous one by the same author/s. A few minor issues:

- What is the difference between Table 2 and 3? (interpolated error and gridded data, what does it mean?). Could these two concepts be clearly explained in the manuscript?

Interpolated error corresponds to the error associated with individual measurements, whereas gridded error reflects the error in the DEM as a gridded product (lines 123 and 130-134). The authors believe that these two different measurements of error shed light on the effect of the gridding process on the accuracy of the measurements as well as comparing the end product more faithfully with other DEMs. The authors will add the below to the text on line 134 to clarify the purposes of the multiple error calculations.

Addition, line 134

[…]TDS-1 estimates. Both types of error (interpolated and gridded) are considered in order to give a comprehensive view of the sources of error both on point measurements and impact on the finished product. Antarctic […]

- The Introduction reads: "As stated by Slater et al. (2018), DEMs can help in the understanding of ice sheet hydrology through mass balance calculations, grounding line thickness, and delineation of drainage basins. These further improve understanding of ice dynamics and potential sea level rise associated with ice sheets.". Which precision is required for DEMs to serve this purpose? Are biases at ten/s of meter level and RMSE at hundred/s meter level sufficiently good for these purposes? (values in Tables 2 and 3).

The authors do not believe the dataset presented to be adequate in its own right for cryospheric conclusions at present due to the coarse resolution and the uncertainties noted in section 4 of the study. However, a system based on these techniques and designed for the purpose would enable the honing of the technique and improvements in error calculations and, therefore accuracy. A further section has been added to clarify the ways in which a dedicated mission would be expected to improve upon the errors seen here, as well as statements of the magnitude of errors concerned.

Addition, replacing lines 209-216

5. Discussion of Benefits and Limitations of the technique

The primary benefits of this technique result from the low power and mass of the receiver. These mean that a low cost multi-satellite mission is feasible with the potential to increase the spatial and temporal resolution of observations far beyond those in the present study. The use of a technology demonstration mission limits the data available here and were this technique to be exploited using dedicated platforms designed for these measurements, a very large increase in the available data could be expected. For example, the continuous operation of a single sensor would lead to a 300% increase in data as compared to the initial TDS-1 mission. If, in addition, a larger number of reflections were to be tracked at once, this would also multiply the data available, giving a many-fold increase in the spatio-temporal resolution of products. As seen in this study, the higher resolution of the product gives an increase in accuracy, indicating that the footprint of the measurements is not the limiting factor on the resolution of the data product, but the quantity of data available. This results in a compromise necessary to maximise coverage over the area of interest. A dedicated mission would require a full error budget appraisal, accounting for corrections required due to the design of the sensor and the auxiliary measurements necessary to enable these. It is likely, in addition, that a dedicated mission could also collect phase information from the reflected signals in order to greatly improve the accuracy of the height retrievals, as seen in Hu et al. (2017) and Li et al. (2017).

Here we detail sources of error and limitations of this dataset. Due to the unknown physical properties of the surface, the penetration of L-Band into snow and/or ice is a significant unknown. This is primarily due to the wide range of electromagnetic changes snow and ice undergo in terms of varying densities and precipitation regimes as the snow is compacted and the glacial ice formed. Cardellach et al. (2012) measured the penetration of GNSS signals of up to 300 m over dry snow in Antarctica, whilst similar studies at L-Band over glacial ice in Greenland have yielded between 3 m and 120 m of penetration depending on the terrain, (Li et al., 2017; Mätzler, 2001; Rignot et al., 2001). These corrections are not applied to the dataset here due to the unknown characteristics of the surface at the time of the retrieval. An additional factor is the atmospheric uncertainties at high latitudes resulting in ionospheric and tropospheric effects on the signal. These are thought to introduce errors of around 10 m at the equatorial maximum (Hoque and Jakowski, 2012) with errors being smaller at higher latitudes, and thus these are much smaller than the error magnitudes found here (assuming that the comparison DEMs are “truth”, but they too, of course, contribute to the RMS errors).

- Figure 2 and lines 209-212: authors report some relationship between the biases in Figure 2 and topography/terrain slopes. Can they report on potential penetration effects biasing the altimetry over very dry snow –light density of the ice? Cardellach et al., 2012 reported rather deep penetration of GNSS-R signals into Antarctica ice sheet at Dome Concordia. How is this accounted in this study? Only a few sentences are added (page 10, line 209-212), to point that penetration is unknown. However, experimental work with GNSS-R at Concordia Dome (Antarctica) did show large penetration, up to ~250 m under the very dry/light ice conditions of the area (quite typical of most of Antarctica). Rius et al., 2017 did take penetration into account, reducing the actual geometric path traveled by the signal by considering the slower propagation through dry snow. Would the authors consider a refined DEM with penetration issues accounted for?

As above, the addition of section 5 (“Discussion of Benefits and Limitations of the technique”) before the conclusions will clarify the necessary corrections and error calculations that would be expected were a mission to be dedicated to this technique. The unknown nature of the penetration has been clarified, referring to the unknown conditions of the retrieval, rather than the lack of investigation into the propagation of the signal into various ice and snow types. The varying properties of the snow, firn and ice are the principal unknowns in this technique, with modelled penetration values ranging from 8 to 120 m in studies by Rignot et al. (2001) over Greenland’s glacial ice to 250 m or more in Cardellach et al. (2012)’s for dry snow in Antarctica. As the authors are unable to find reliable data on the characteristics of the snow and ice pack over both ice sheets in order to ensure corrections are as accurate as possible, these corrections are not attempted here but such unknowns are recognised and discussed.

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