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The Cryosphere
Discussions

Interactive comment on "Representative surface snow density on the East Antarctic Plateau" *by* Alexander H. Weinhart et al.

Anonymous Referee #2

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The authors present a suite of highly accurate surface density measurements taken during a traverse in Dronning Maud Land, East Antarctica. These observations have the potential to offer the ice sheet scientific community a unique and very useful dataset to evaluate and improve snow and firn densification models. The authors present principally interesting spatial analysis of the measured snow density, which adds to the presented data. That said, we have significant concerns that should be addressed before publication, namely 1) a more detailed description of density uncertainty quantification, 2) the method used to quantify the impact of density on surface mass balance retrieval, and 3) a more detailed description of observed small scale density variability in the top 1 m presented in Figure 5, as well as its potential drivers and implications for interpretation of satellite altimetry observations. Please find a more detailed descrip-

tion of these suggestions and others broken into major and minor comments below.

Reviewed by: Eric Keenan, Nander Wever, Jan Lenaerts

Major Comments

Section 2.1: This section would benefit from a general discussion of weather and climate conditions in the area, in relation to how they may impact surface density (in terms of variability of yearly accumulation rates, wind speed and temperature). This would help setting the stage for the discussion in section 4.4.

P7,L12: "Breaks and lost snow in the snow profiles haven been corrected." This needs more explanation.

P8,L9-11: "It is generally possible that at the liner top and bottom some snow is lost, but as the exact snow volume is determined with the μCT, we overcome this error source." It's not clear how the microCT can compensate for errors due to lost snow. It's the same liner that's measured by microCT and the scale, so if the snow is lost, both methods should be affected.

P8, L15: "Therefore. . .." I don't see how this sentence follows logically from the previous section.

P8, L19: "spatially independent" Not really clear. Is the measurement setup in Fig. 3 considered spatially independent? I.e., are liners X, A, B, C considered spatially independent? According to the text they are, but those four liners are not really independent.

Section 2.4: This section is difficult to comprehend, and is written very compact. Particularly, please expand on: "This way we use the maximum sample size without an artificially caused bias in the data."

Figure 5: The large variability in observed density, particularly in the top meter, is very interesting and is a very nice inclusion in this paper. Can you please elaborate on what

might cause this (surface topography? winds?) and what this variability means for interpretation of satellite altimetry. In particular, the observed variability is in apparent contrast with the title of this paper "Representative surface snow density...". If surface density is highly variable, is a representative density truly the best approach or should the scientific community make an effort to model this variability? A related comment is that Section 3.5 is really short and only mentions results. It's not clear which conclusions the authors draw from this and how it is important to understand surface density variability.

P11,L1-3 and in the following sections: If the standard deviation for 1m sampling intervals is 5-10 kg/m3, how can the error quantification for the average be only +/- 2 kg/m3?

Figure 8: Observations report a near uniform mean density in the four different subregions. For me, this is a surprising result. How might the different dates the observations were taken affect the measured density, i.e. do you expect a seasonal cycle in surface density. The way this dataset is currently presented, does not take into account this possibility. Additionally, if you are not already planning on doing so, can you please include exact observations date and time in the final dataset publication on Pangaea?

P18,L18: This line mentions natural variability due to antecedent weather conditions. Section 4.2 needs to put the analysis based on climatological trends in perspective to possible year-to-year variability due to antecedent weather conditions. Since accumulation depths in dunes could be up to 30cm, this may impact top 1m density significantly.

Section 4.3: The authors aim to provide the impact of density on the uncertainty in SMB, but they fail to do this correctly. First of all, 3% uncertainty in the firn column does not directly translate to a 3% uncertainty in the overall firn+ice column (since there is much more ice than firn on East Antarctica). Secondly, this calculation pertains to mass, not mass balance (i.e. the change in mass per unit time). Instead, the authors

should think about focusing on the application to altimetry, which needs surface density to convert volume to mass. As most of the elevation changes on East Antarctica measured by altimetry are SMB-driven, the observed elevation change will be associated to the layer of recently accumulated/ablated snow/firn, with an extremely spatially and temporally variable density. Since this (near-)surface density is much more variable than at 1 m, this volume-to-mass conversion is highly uncertain, especially when focusing on small scales such as in this study. The error here is directly proportional to density, i.e. there will be 100% error in mass change if the assumed density is 100% different than it is in reality.

Figure 11: How is surface roughness and sub-grid topography, e.g. using REMA, related to observed density in this figure?

It is recommended to analyze the liners from Kohnen station from different seasons (as mentioned P9,L15/16) to show to what extent there is year-to-year variability.

P21,L5-8: First of all, a primary source of error in modeled snow density by the Ligtenberg et al. (2011) model could as well result from the meteorological driving data for the FDM simulations. Second, the text now seems to imply that more snow redistribution leads to lower densities. However, it has been demonstrated that snow redistribution tends to increase hardness/density (see Sommer at al. 2017, 2018).

We thank the authors for taking the substantial time and effort to collect, describe, and distribute these density observations. That said, we believe these observations would best serve the community if they were also included in a unified and publicly available dataset such as SUMup (Montgomery et. al., 2018).

Minor Comments P1, L11: Underestimations or overestimations.

P1, L25: Density errors can be due to errors in parameterizations or atmospheric forcing.

P2,L3: "Greenland Ice Sheet"

P2,L3-5: Please reformulate. Either “accurate quantification is important” or “The current state and rate are some of the most important quantities . . .”

P2,L11: “Especially in the interior of the ice sheets, the exact surface snow density is a limiting factor in precision.” Please amend why that is, with appropriate references if available.

P2,L23: "Small variability" –> "A small part of variability" I assume.

P3,L1 and L9: "stratigraphic noise" please explain.

P3,L3-6: "In this paper,we present surface snow density data with high precision from a traverse covering over 2000km on the East Antarctic Plateau (EAP). In order to avoid misunderstandings we follow Stenni et al. (2017) using the term EAP for the region higher than 2000m above sea level (asl). The coldest 10m firn temperature is recorded at Plateau Station (Picciotto et al., 51971), which makes the area the best modern analog of glacial firn." Don’t understand this section. Please explain in more detail.

P3, L10 Average local snowpack density.

P4, Fig 1: Please add elevation contour labels.

P6, L20: The sentence “The trench surface was measured. . . ” needs to be placed before P6,L19: “The total height difference between the lowest . . .”

P7, L9 weighted → weighed?

P8, Fig 4: What explains the occasional large difference? Please add linear regression statistics.

P8,L15: "Therefore, to quantify the 1m snowpack density we use L, to investigate smaller intervals we use the 1mμCT(Tab.1)" Since 1mμCT is CT density over 1m, and L the liner density over 1m, how should it be interpreted that 1mμCT can assist in investigating smaller intervals? Or should it read 0.1mμCT.

P8, L17 Snow density profiles?

P9, Section 2.6 Optical leveling needs to be placed before Section 2.2.3., since the optical leveling is already mentioned there.

P9,L17: "Furthermore, a possible effect of the station itself should not be migrated into the other subsets." Please explain what effects are meant here.

P10, Figure description: What is meant by raster?

P12, Table 2: Can you create maps of p_loc and sigma_1m?

P18, L9: Please quantify dune height

P19, L4: What exactly leads you to make this claim. Could density errors be due to errors in atmospheric forcing? Temporal variability in snow density?

Many figures have missing axes. Please correct.

References: please provide doi’s for easy lookup of literature.

References

Montgomery, L., Koenig, L., and Alexander, P.: The SUMup dataset: compiled measurements of surface mass balance components over ice sheets and sea ice with analysis over Greenland, Earth System Science Data, 10, 1959–1985, https://doi.org/10.5194/essd-10-1959-2018, https://www.earth-syst-sci-data.net/10/1959/2018/, 2018

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