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Interactive comment on "Spatial and Temporal Variation of Bulk Snow Properties in North Boreal and Tundra Environments Based on Extensive Field Measurements" *by* H.-R. Hannula et al.

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General comments:

In this paper the authors describe an intensive in situ measurement program over different land cover types in northern Finland during winter 2011-2012. The measurement campaign was carried out over 5 km transects and included manual (every ∼100 m) and Magnaprobe (every ∼2-10 m) measurements of snow depth (SD), along with manual snow corer measurements (every ∼500 m) of snow water equivalent (SWE). Ancillary information was also collected on snowpack structure. The purpose of this detailed measurement campaign was to provide ground-truth for evaluating ESA Snow SAR airborne acquisitions. The paper describes the data collection process, analyzes

the spatial and temporal variability in snow cover across nine different land cover types, and makes some coclusions about "optimal" sampling strategies for SD measurements based on the spatial autocorrelation structure. There is no doubt the authors have collected a valuable dataset. However, the paper is frustrating read because key concepts (e.g. spatial variability of snow cover) were not discussed at the outset, and the methodology evolves throughout the paper instead of being clearly defined at the outset and linked to specific problems / hypotheses. It is also unclear what new findings are being presented and how the study conclusions relate to previously published work. The authors also make a number of sweeping conclusions about "true" snow cover and "optimal" sampling that are (1) based on a limited sample size, (2) do not take into account the error from the fitted spatial model, and (3) do not take into consideration the spatial scales and uncerainty requirements of users. The paper as it stands requires extensive revisions. However, one option the authors might consider is to remove the spatial analysis component of the paper, and resubmit a much shorter paper that describes the dataset and its importance for the snow research community.

Thank you for the detailed review of the paper. All comments will be now answered. Each comment is followed by the response. The revised version of the paper will be submitted after the author's response for the referee comments have been submitted. We agree that the analysis of the snow spatial variability has been left narrow and the links with previous studies are largely missing. The purpose of the scale analysis was supposed to be made in the special context of the SnowSAR-2 airborne campaign (Di Leo et al., 2015) and this has not been clearly expressed. As suggested by the Referee #1 we will expand the presentation of the data itself and we will compress the scale analysis, retaining only the most significant findings describing the collected snow dataset. The significance of these findings will be explained more elaborately, following suggestions made by the reviewer and will be better explained in the context of the FMI work.

Detailed comments:

1. Introduction: the first two paragraphs are peripheral to the study. The focus of the paper is on measurement uncertainties and scaling issues so you need to plunge into this at the outset. The work of Pomeroy and Gray (1995), the seminal paper by Blöschl (1999), the review paper by Clark et al (2011) and more recent work by McCreight et al (2014), and Trujillo and Lehning (2015) should be consulted to help frame the discussion and framing of the problems being addressed in this paper. You should also look at some of the recent papers appearing in the literature looking at detailed spatial variability in snow cover from airborne or UAS lidar (e.g. Zheng et al. 2016). Some discussion of user needs would also be appropriate in the introduction. For some applications such a runoff monitoring over large basins in non-mountainous terrain, spatially averaged SWE information at 10-25 km scale is probably more than adequate when combined with higher resolution satellite snow cover information in a hydrological modelling framework e.g. Bergeron et al (2014).

The introduction will be rewritten focusing better on the uncertainties and scaling issues as suggested by the Referee#1. The general discussion about the importance of the snow cover information, which is mentioned not to be relevant for the study, will be compressed. The discussion and study objectives will be framed in the context of the ESA SnowSAR-2 airborne acquisitions (Di Leo et al., 2015) with a focus on data description. The in situ dataset was collected to provide ground-truth for the airborne acquisitions, currently offering a 2 m data resolution. However, the snow retrievals (e.g. SWE) sought by the SnowSAR data will not be produced at the native 2m resolution but aggregated up to e.g. 200-500 m. Hence, the analysis of variability of snow properties at scales from several meters and beyond becomes necessary. Keeping this in mind, some discussion about the user needs and scale issues, including the definition of 'scale' and related concepts, in the context of this study and in general, will be added.

2. The terms “optimal” and “true snow conditions” are introduced in lines 81-83 without rigorous definitions or any discussion. In practice, both these terms depend on user requirements.

The “true snow conditions” will be defined as the snow conditions, having distinct pattern of variance and characteristics, at the time of the measurements of this study. However, our only knowledge of these “true” snow conditions is the collected in situ dataset described in this paper, which itself already includes some errors of estimation. As such, the term “apparent snow conditions” suggested and used by Blöschl (1999) will be added to refer to the snow characteristics captured by the in situ dataset. The “optimal” sampling frequency will be defined as a sampling strategy which will capture the variation described by the dataset without significant over- or under-sampling, and which will fulfil the user requirements for the ground-truth data collection for the specific aerial dataset. A rigorous definition of all the terms used, as well as, discussion about the terminology, scale issues, uncertainty issues, and their dependence on the user needs will be added.

3. Study objectives (last para page 4): Given that the objectives listed here have been previously studied by a number of investigators, what is unique about the data collected and the proposed data analysis methods that merit publication in GI? The “aims and scope” of GI on the GI homepage may be helpful in responding to this comment.

The snow in situ measurements described in this study comprise an exceptionally large manually collected dataset of snow conditions in taiga and tundra environments. As mentioned in the review paper of Clark et al. (2011), also recommended by the referee #1, many of the earlier studies with a same count of individual measurements have been automatically collected by using e.g. ground penetrating radar or light detection and ranging (LIDAR) instrument. Also, previous intensive measurement campaigns in northern Scandinavia in a similar kind of environments are limited. As such, the collected dataset is a valuable addition for the snow research community and merits a publication in GI, as the journal features advances in “major national and international field campaigns and observational research programs”. In addition to this, the aims of “uncertainty in measurements” and “calibration and data quality assessment” will be touched, although, will not be the main focus in the revised version of the paper.

4. Data and methods: A figure/schematic showing the different measurement methods and their approximate spatial scales would be helpful background information for this section.

A schematic/table to collectively represent all the different measurement methods and their approximate scales will be added.

5. Second sentence in Section 2.3.1 is difficult to follow. Suggest rewording to "Land cover class was determined based on the GPS coordinates..."

The sentence will be reworded as suggested.

6. Line 149 page 7: Where does the 30% threshold come from?

The 30 % threshold value comes from the Corine2012 (Coordinate information on the environment 2012) land cover dataset which was used to determine a generalized land cover class for each measurement GPS point. In Corine2012 dataset, areas with tree cover density exceeding 30 % are classified as dense forests and areas with tree cover density between 10-30 % are classified as sparse forests. The 10 % and 30 % threshold values follow the definitions of the European Environment Agency (EEA) for a 'forest', and for a 'dense forest', respectively. Information of the EEA forest classification and the technical details of the Corine2012 land cover project, being currently part of the Copernicus/GIO land program, can be found from:

http://www.eea.europa.eu/soer-2015/europe/forests

http://land.copernicus.eu/user-corner/technical-library

7. Line 159 page 7: "... has larger effects on the RS..."

This will be corrected.

8. Lines 188-195 page 8: Please provide the equation, the definition and some discussion of the correlation length as this is a central part of your analysis method. Since this is obtained from curve fitting, the regression error should also be discussed and

presented. It is not entirely clear to me how this statistical property translates to "optimal" sampling e.g. one could fit an autocorrelation function to SWE data collected over 10 or 25 km grid cells and obtain a correlation length corresponding to this scale of information. You don't discuss how rmsd varies with distance but it seems to me this is more important for uncertainty analysis than the spatial autocorrelation i.e. the rmsd may be within operational requirements over a longer distance than suggested by the correlation length. What about interannual and site variability in the length scale? Do you get similar results repeating the measurements in another year and at another location?

The correlation length analysis was done at this scale due to the connection with the SnowSAR-2 campaign. We agree this was not clear and have now emphasized this. The main question we wanted to answer by analysing the correlation length from Magnaprobe measurements (done every $\sim$1-3 m), was to try to estimate how much information will be lost by sampling snow depth with increasing spatial distance (e.g. the original sampling strategy was to measure snow depth only every 100 meters). However, the reviewer is correct that the correlation length alone does not provide a satisfactory answer in this regard. As suggested, we will add an analysis of RMSD with distance.

The equation, the definition, and some discussion of the correlation length, as well as, regression error will be added. As the referee #1 points out, the method or the results are not self-explanatory. The possible variation of the results during different years and different sites will be discussed; however, similar data from other sites or seasons is not available to the authors. It is expected that the absolute values for correlation length vary year and site to site, but the relational differences, e.g. between open and forested areas may hold. In respect of "optimal" sampling, discussion will come back to the definitions also touched in the comment #2.

9. Line 219 page 9: what does "percentual" mean?

The “percentual” refers to %-coverage of each land cover group within the specified 7 km x 10 km area. The word will be replaced with ”%-coverage”.

10. Line 239 page 10: Is the “deviation of snow depth” the standard deviation? I suggest you use consistent terminology to avoid confusion.

“Standard deviation” will be used instead of just “deviation” throughout the paper.

11. Section 3.3 lines 328-333 talks about results but does not give any! The presentation of analysis results throughout the paper needs to be more focussed and concise.

The actual values of the results will be added. In addition, the chapters for the results and the discussion will be reordered as other anonymous referees commented these sections to be interchangeable.

12. Line 389: Is “measurement frequency” the correct term here?

The term “measurement frequency” will be replaced with “measurement spacing” following the definition by Blöschl (1999) where he suggests that measurement scale consists of three parts: spacing, extent, and support.

13. Line 398: I take issue with your conclusion that observing at resolutions higher than Lex does not provide “meaningful statistical information”. The relevance of spatial scale depends on the application and the scales of the processes contributing to variability in the snow or snow-related property of interest. For runoff monitoring, synoptic scale events are important for accumulation and melt and these operate at scales much larger than 5 m! Sub-grid scale variability can also be estimated through distributed snow modelling.

This is right and a more detailed discussion about the scale issues will be added. The results will be discussed specifically in the context of this measurement campaign and its application needs. In addition, it will be discussed, what snow processes might be captured on this scale, and which processes probably work on different scales and would thus, require/be satisfied with denser/sparser measurement spacing.

14. Line 438: What do you mean by “correct” RS information retrieval? This is subjective terminology.

The term of “correct RS information” was meant to refer to the actual snow conditions without the error introduced by the retrieval methods (here, remote sensing). However, as discussed earlier, as the “true” depends on user needs and as such is not good terminology, the sentence will be removed.

15. Line 448: The same comment applies to the “true variation of SD” which is a statistical concept. I suggest you revise this sentence to read “. . . to capture the spatial variation in SD typical of these environments”.

The sentence will be revised as suggested.

16. Lines 449-453: see previous comment in #13. Taking your point to its logical conclusion we should scrap satellites and invest in an army of Lidar-equipped drones for monitoring snow depth :0)

As mentioned previously, the concept of spatial scale will be discussed and the results will be analysed in relation to the user needs of the later SnowSAR aerial data analysis. Indeed, no conclusions, without defining the appropriate scale for the application, can be made.

17. Where is the dataset published? I assumed a journal dedicated to datasets would require the dataset to be published online.

The dataset is now available via the ESA Campaign web page upon registration: https://earth.esa.int/web/guest/campaigns. This information will be updated in the manuscript.

References cited:

Bergeron, J., Royer, A., Turcotte, R. and Roy, A. (2014), Snow cover estimation using blended MODIS and AMSR-E data for improved watershed-scale spring stream-flow simulation in Quebec, Canada. Hydrol. Process., 28: 4626-4639. Doi:10.1002/hyp.10123

Blöschl, G., 1999: Scaling issues in snow hydrology. Hydrological Processes, 13(1415), pp.2149-2175.

Clark, M. P. and Coauthors, 2011: Representing spatial variability of snow water equivalent in hydrologic and land-surface models: A review. Water Resour. Res., 47, doi:10.1029/2011WR010745.http://www.agu.org/pubs/crossref/2011/2011WR010745.shtml (Accessed March 10, 2012)

McCreight, J.L., Slater, A.G., Marshall, H.P., and Rajagopalan, B., 2014: Inference and uncertainty of snow depth spatial distribution at the kilometre scale in the Colorado Rocky Mountains: the effects of sample size, random sampling, predictor quality, and validation procedures, Hydrol. Process., 28, 933-957.

Pomeroy, J.W., and D.M. Gray, 1995: Snowcover – Accumulation, Relocation and Management, National Hydrology Research Institute Science Report No. 7, Saskatoon, Canada, 144 pp.

Trujillo, E. and Lehning, M., 2015: Theoretical analysis of errors when estimating snow distribution through point measurements, The Cryosphere, 9, 1249-1264,doi:10.5194/tc-9-1249-2015.

Zheng et al. 2016: Topographic and vegetation effects on snow accumulation in the southern Sierra Nevada: a statistical summary from lidar data. The Cryosphere, 10, 257-269, 2016 http://www.the-cryosphere.net/10/257/2016/ doi:10.5194/tc-10-257-2016

References added by the authors:

Di Leo D., Coccia, A., and Meta, A., 2015: Technical Assistance for the Development and Deployment of an X-and Ku-band MiniSAR Airborne System (SnowSAR). ESTEC No. 4000106761-CCN1. (https://earth.esa.int/web/guest/campaigns).

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