Author's response to comments of reviewer N. J. Kinar

Authors

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Paper Title

Sodankylä manual snow survey program

Thank you for a complete review of the paper. We will answer your comments in the presented order.

We will submit a modified version of the paper after the review period. As suggested by other reviewers, we will modify the paper structure to include presentation of all sites and detailed measurement procedures and description of each instrument. We will add more citations, including references to this special issue. A short comparison with other measurement sites (Weissfluhjoch and Col de Porte) will be added. In addition, some of the measurements described in the paper are now available online. Details for downloading the data will be added to the paper.

We will include more figures and tables to show the data and add more analysis and comparison of data from different sites. However, the aim of this paper is to present the available data and be a reference for anyone who wants to use the Sodankylä snow measurements in their research. The added references to the articles utilizing this data set present the advancements in the understanding of environmental processes.

Specific Comments

1. Few sentences will be added related to the significance of those properties in the global context**.** Analysis related directly to Sodankylä climate is not made but the common properties are applicable also to Sodankylä.

2. A new paragraph introducing papers that use the manual snow data set will be added to the end of introduction.

3. Easily accessible measurement sites on different land cover, terrain, and vegetation types in the premises or the vicinity of the FMI-ARC station were chosen in order to provide easy and quick access to maintenance, electricity, and data transmission (as we also have automatic instruments at the sites), and to be able to carry out frequent manual measurements. Sites represent typical conditions in the land cover types. Temporal and spatial variation of snow conditions were not studied before the selection of the sites. The collected time series have been used to study the temporal variation of snow, and the chosen permanent measurement sites, as well as additional campaign-based measurements around them, have been used to study spatial variation. Citations to papers will be added to this paragraph, as well as in the new paragraph (Comment 2) detailing the research based on the data set. We will also include more detailed descriptions of all the measurement sites.

4. Citations to papers will be added here, as well as in the new paragraph (Comment 2).

5. At the moment we do not know of any pictures about the earliest measurements. We will still try to locate some, as well as some more information about the first measurements. If we locate those documents or information, we will add it to paper.

6. Our aim was to describe the snow depth data set and the variability in snow depth and the length of snow season between different winters in Sodankylä. Together with the 30-year averages (referenced in Section 2) they provide to the reader an understanding of the snow conditions in Sodankylä.

7. When the snow course network was established, the locations of the courses were selected to cover different land cover types all over Finland. The main use for the collected data is river runoff forecasting and regulation, and the courses are located mostly in major watersheds. Individual measurement spots of each course are selected with regular interval (typically every 50 m). Geostatistics was not used to aid in the selection of the locations, and as the network has now been operating for decades, there is no need to relocate the courses. If the network would be established today, definitely geostatistics could be a useful tool. We will add more details about snow course locations and their selection to the paper.

8. The original planning of the course locations was done based on a general information about the land cover, terrain and vegetation to include the typical land covers of the area. However, individual measurement sites are classified by the person doing the measurements on the field. The measurement sites are marked and do not change, so this classification is done once when a course is established, and then only if the land cover changes (e.g. forest is cleared). We will add a short description of the classification to the paper.

9. Data of first snow courses are only in paper form in Helsinki in FMI archives. The exact date of the first measurement in Sodankylä is currently unknown. Digitizing work of the paper log sheets is ongoing.

The Sodankylä snow course is always sampled in the middle of the month (before 1991 only in January and March); in addition there are measurements also in the beginning of month (1991-1996, 2009-2014). We will modify the text to highlight the fact that the course is always measured in the middle of the month. Changes in timing are related to the change of the responsible operator (before 1991 FMI and after 1991 SYKE). The additional measurements in 2009-2014 were related to a measurement campaign. Therefore, there is no lack of observations in middle of the month.

10. Our point here was that by keeping a distance between the pits the changes in snow structure due to digging of previous pits and air temperature changes do not affect the snow in the new pit location. Thus the snow structure is not disturbed by previous measurements, and the time series of snow pit data are comparable. Topography of all the sampling locations is flat; however, the vegetation, albeit only a few centimeters of lichen and heather at the forest site, and mostly below water/ice at the bog site, will introduce spatial differences in snow. This is unavoidable in destructive snow sampling, but the sites were selected to minimize the special variability. However, on Lake Orajärvi the snow is quite heterogenic: wind-driven dunes, snow mobile tracks and water on ice are quite common. This is one of the reasons why we ended the snow on ice measurements, as it was very difficult to get a representative measurement of the snow conditions. We will clarify the text in the paper.

11. Description of our camera setup, as well as of all the other instruments used in the measurements, will be added to the text. Basically the method is the visual estimation described by Fierz et al. (2009), but it is applied to the photographs of the grains on a grid. We will also add detailed measurement protocols of all instruments and include references when available.

12. The equations used in deriving the density and liquid water from the dielectric measurement assume that the surrounding material is homogeneous. There are two frequent cases, where this assumption is not valid: 1) at the surface and bottom of the snowpack close to air, ground or vegetation, and 2) if there is air around the rods (from the user moving the rods too much especially in very fluffy surface snow or large depth hoar crystals, which fall off easily). Moreover, snow compacts (density increases) when the rods are inserted into snowpack. Despite this, our comparisons with bulk snow density measurements show that the density measured with our snow fork is on average 0.04 g/cm^3 lower than density from the sampler. This might be a calibration issue. In addition, the frequency measurement accuracy of the snow fork is not enough to determine very low moisture contents (less than ~1 %).

We will add detailed descriptions of all the instruments and measurements with their error sources.

13. Dimensions of the two samplers are 10 cm x 10 cm x 5 cm (total height for the rectangular sampler, maximum height for the wedge one). If used to sample snow every 5 cm, as we did, there is certainly a difference between densities from the wedge and rectangular samplers arising from the fact that snow is not homogeneous. Both of the samplers are 5 cm high, but when the rectangular sampler gives an average density for the sampled snow, the wedge-shaped one gives a weighted average: most of the sampled snow is from the bottom of the sampled layer. Thus the newer, self-made rectangular sampler is better, but the difference between the samplers depends on snow homogeneity. In addition, snow doesn't escape so easily from the rectangular sampler, which reduces measurement error. More details about the samplers and their differences will be added to the paper.

14. Exact time for thermal equalization depends on air temperature and snow temperature profile: larger temperature differences require longer time. After first cooling the thermometer in air, it takes a few minutes to reach thermal equalization in snow. In practice the temperature is measured alongside grain sizes and densities, and thermometer is left in the snow until the reading does not change. We will add detailed measurement protocols of all the instruments to the paper.

15. Our snow sampler is the Finnish one (described first by Melander and Korhonen, 1923) made out of black plastic tube. We have not compared it to other SWE samplers, because we do not have e.g. ESC30 sampler available. Diameter of the SWE tube is 100 mm, resulting in a cross-section area of 78.54 cm^2. There is a lid with a handle in one end of the tube. A small flat shovel is slid below the tube and used to seal the bottom of the tube when the snow sample is extracted. The maximum measurable SD for the tube is 70 cm and maximum volume is then 5500 cm^3. If there is more than 70 cm snow, several samples are taken on top of each other and weighted separately. This is one error source. Vegetation on the ground and within the snow is another error source; however, this can be minimized by the selection of the measurement site. However, vegetation and ground surface clearly affect the accuracy with which all the snow and only the snow (i.e. no vegetation or soil) can be sampled. Systematic error of the tube and scale can be minimized by frequent calibration measurements of standardized weights. We will add detailed descriptions of all the instruments to the text, especially of those not commercially available.

16. Three measurements are enough for averaging, because they characterize only the pit (~1 m in diameter). Ground and topography are flat in snow pit sites, and standard deviation of the three measurements is typically below 2 cm.

17. There are no wind speed or blowing snow mass flux measurements at the IOA. However, we do have measurements at 18 m (well above the trees) close to IOA, and at 1.5 m height from a forest opening similar to IOA. These measurements show very low wind speeds (ten-year (2006-2015) mean value at 18 m height is 2.22 m/s +/- 1.26 m/s, two-year (2014-2015) mean value of measurements from mid-September to mid-May each year at 1.5 m height is 1.17 m/s +/- 0.56 m/s). We will add more detailed descriptions of the FMI-ARC site and its climatology.

18. We will add manufacturer names and citations for all the instruments.

19. Citation to Corine Land Cover 2000 data added.

20. Wind redistributes snow and levels the snowpack surface. SD at the bog site is typically lower than in IOA. Together with the different temperature gradient in snow due to ice and water (instead of soil) below snowpack, this results in differing grain metamorphism compared to IOA. More details about wind effects will be added to the paper.

21. Snow on lake ice is affected by wind, different temperature gradient (compared to measurement sites on ground), water on ice, and the timing of changes in air temperature vs. snow fall (if air gets cold before any heavy snowfall, the ice gets thick quickly, but heavy snowfall on thin ice slows down ice formation). All of these affect the structure and density of snow on ice and the differences in snowpack between the various measurement sites.

22. The aim of this section was to provide a quick look of the available data for an interested user. However, we will rewrite the Example data section to include more details of the differences in snow at the measurement sites.

23. We will add more detailed measurement protocols and detailed descriptions of the instruments, including citations.

Technical Corrections

Manufacturers and sensor types will be added to text. We will also add descriptions of all the not commercially available instruments.

Figure 1: We will add a larger map showing the location of Sodankylä and include the projections. Corine Land Cover 2000 data, aggregated to five general classes, is on the background. Details of the land cover classification will be added.

Figure 3: Standard deviation (std) for mean is presented. Data is averaged from operational daily snow depth observations (section 3.2) which are made only at Sounding station. Therefore, snow measurement sites (IOA, bog, and Lake Orajärvi) are not included.

Figure 5: This snow pit presents typical properties of snowpack during mid-winter. However, this figure will be removed and replaced with the time series of spatial variability of some snowpack properties, as other reviewer suggested.

Figure 6: Differences in snow depth and ice thickness between the years are mostly due to differences in timing of changes in air temperature vs. snow fall (see 21). Therefore this data set alone can not be used to detect any trends in snow depth and ice thickness. However, we will add more analysis of the presented data. This figure will be replaced with a table, as other reviewer suggested.

References:

Fierz, C., Armstrong, R.L., Durand, Y., Etchevers, P., Greene, E., McClung, D.M., Nishimura, K., Satyawali, P.K. and Sokratov, S.A.: The International Classification for Seasonal Snow on the Ground, IHP-VII Technical Documents in Hydrology N°83, IACS Contribution N°1, UNESCO-IHP, Paris, 2009.

Melander, G. and Korhonen, V. V.: Uusi lumentiheysmittari (Novel snow density meter), Suomalainen tiedeakatemia (Finnish Academy of Science and Letters), Esitelmät ja pöytäkirjat (Presentations and proceedings) 1922, ed. G. Komppa, 39-42, Suomalainen tiedeakatemia (Finnish Academy of Science and Letters), Helsinki, 1923.