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Interactive comment on "Laboratory, field, mast-borne and airborne spectral reflectance measurements of boreal landscape during spring" *by* Henna-Reetta Hannula et al.

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GENERAL COMMENTS:

1) General comments from the referee

In this paper, the authors introduce and describe detailed spectral reflectance data for some types of snow, forest canopy, snow-on-canopy, snow-free patches, etc obtained from laboratory, field, mast-borne, and airborne optical measurement systems. The study areas are mainly located in the Arctic region of Finland. The main purpose of the data acquisition is to provide basic information for the development of new and

improved optical snow mapping methods for boreal forested area using satellite data. This kind of remote sensing study is very important recently, because seasonal snow physical conditions, which would affect water resources around the area for example, are rapidly changing due to the ongoing global warming. This reviewer found the data acquisition methods and procedures described in this paper are solid, and presented data are reliable in my opinion. Overall, this paper is detailed, well written, and structured; however, this reviewer suggests the following points to be considered before the publication.

Please note that page and line numbers are denoted by "P" and "L", respectively.

2) Author's response on general comments by the referee

We thank the anonymous referee #2 for the professional and constructive comments allowing us to further improve our manuscript. Please find below the point-by-point answers for each individual comment.

SPECIFIC COMMENTS (MAJOR)

1) Major comment from the referee

P. 16, L. 262: How about showing the standard deviations mentioned here in this paper? I think this information, which show accuracy of the data, is very important.

2) Author's response and 3) changes in manuscript

Yes, we will add the observed standard deviations to Figure 5. In case of pine/spruce spectra the standard deviation describes the measurement accuracy as the deviation is defined within the consequent measurement acquisitions averaged for one reflectance spectrum. In Fig. 5c the mean reflectance of several snow samples sampled from the same snow types and measured with same view-illumination geometry are presented. In this case the standard deviation describes the reflectance deviation between different snow samples collected and measured from the same snow type. Thus, the latter standard deviation does not describe the accuracy of the measurements but overall deviation in the snow type's reflectance. The latter was not clear in the text nor in the figure caption and we will clarify this in the revised manuscript.

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1) Major comment from the referee

P. 16, L. 276: What do the authors think about the effects of the tripod on the measured reflectance data? Please discuss briefly here.

2) Author's response and 3) changes in manuscript

The effect of the tripod on the measured reflectance was very small. To avoid direct shading of the target by the tripod and measurement equipment, the tripod was placed towards the sun. The measured target area did not include the tripod legs. Nevertheless, the tripod with the extended arm obscured a part of the diffuse skylight illuminating the target. This effect has not been quantified nor corrected in our measurements and we will add this note to the revised manuscript.

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1) Major comment from the referee

P. 20, L. 346 _ 347: Please explain more in detail about the resampling procedure (about the choice of a weighting function, etc).

2) Author's response and 3) changes in manuscript

In the resampling procedure the wavelengths corresponding to MODIS band 4 (545-565 nm) were chosen and weighted averages were calculated by using the relative spectral response function (RSR) provided by the data provider. We will add a more detailed description.

SPECIFIC COMMENTS (MINOR)

1) Minor comment from the referee

P. 1, L. 16: For the location of Sodankylä Arctic Space Centre, please indicate altitude of the site together with the Lat Lon information.

2) Author's response and 3) changes in manuscript

We will add the altitude (179 m) in the revised manuscript.

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1) Minor comment from the referee

P. 2, L. 33: Maybe, citing the latest version of the SWIPA report (AMAP, 2017) instead of the previous report (AMAP, 2011) would be better here.

2) Author's response and 3) changes in manuscript

Thank you for the remark. We will change the citation to the latest version.

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1) Minor comment from the referee

P. 2, L. 46: It is better to explain the definition of "spectral endmembers" here especially for non-specialist readers.

2) Author's response and 3) changes in manuscript

Often a satellite image pixel contains several surface types, e.g. both snow-covered areas and snow-free areas during spring snow melting period. The observed reflectance value of that pixel is thus a mixture of reflective properties of the surfaces present within the pixel area (or even the surfaces in the adjacent pixels). Spectral endmember is referring to 'pure' reflectance spectra of a distinct surface type such as distinct type of snow or tree species. Assuming, that the reflectance value of a pixel is linear/nonlinear combination of the spectral signatures of the endmembers (i.e. surface types) present within the pixel, the snow cover area can be retrieved by using inverse model based or spectral unmixing methods. The success of the characterization of the spectral behavior of the endmembers affects the amount of error and uncertainty in the final snow cover retrievals. We will add a short explanation to the manuscript.

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1) Minor comment from the referee

P. 2, L. 50 _ 51: Please consider citing the papers by Aoki et al. (2000), Carmagnola et al, (2014), and Tanikawa et al. (2014).

2) Author's response and 3) changes in manuscript

Thank you. We will consider each of these papers.

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1) Minor comment from the referee

P. 3, L. 72: What do the authors mean by "samples"?

2) Author's response and 3) changes in manuscript

In this case "samples" is referring to the individual spectral acquisitions collected and averaged for one measurement spectrum. However, the use of "sample" has not been clear nor consistent in the manuscript and we will clarify this in the revised version.

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1) Minor comment from the referee

P. 3, L. 95 _ 97: Please indicate spectral resolutions of these data here.

2) Author's response and 3) changes in manuscript

We will add the spectral resolutions.

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1) Minor comment from the referee

P. 4, L. 111: What is fjell?

2) Author's response and 3) changes in manuscript

Fjell should have actually been fell and the word is referring to high and barren arctic hills typical for Scandinavian uplands. They can reach altitudes over 500 m and are usually dome shaped with little vegetation cover. We will an explanation of "arctic hill" (or similar) to be more descriptive.

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1) Minor comment from the referee

P. 5, L. 131: What do the authors mean by "upper atmosphere's perspective"?

2) Author's response and 3) changes in manuscript

Sodankylä is located above the Arctic Circle and as stated by Kangas et al. (2016), the region can be classified as continental sub-Arctic or boreal taiga climate by Köppen classification. However, with regard to stratospheric meteorology, Sodankylä can be classified as an Arctic site, which is often located beneath the middle or the edge of the stratospheric polar vortex. However, we will remove this expression from the revised manuscript as it is not clear.

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1) Minor comment from the referee

P. 6, L. 134: For snow classification, it is better to refer the international snow classification (Fierz et al., 2009).

2) Author's response and 3) changes in manuscript

Referee #1 also pointed out the limitations of the cited snow classification systems in respect of the snow type in Sodankylä. As the international snow classification from Fierz et al. (2009) is rather concentrating on snow classification of snow physical properties than classification from the climatic point of view (which was the point in our manuscript) we will leave out the cited references and rather rely on our own expertise to describe the snow in the Sodankylä region as suggested by the referee #1.

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1) Minor comment from the referee

P. 6, L. 148: Please detail more about the white reference standard used in this study (e.g., manufacturer, location of the manufacturer, and type).

2) Author's response and 3) changes in manuscript

We will add a more detailed description of the reference standard used in the study. The standard was a white Spectralon reference plate (12.7 cm, Labsphere, USA) made of packed sintered polytetrafluoroethylene (PTFE) powder.

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1) Minor comment from the referee

P. 9, L. 211 _ 213: Maybe, referring to photos in Figures 4 and 6 here would be very helpful for readers.

2) Author's response and 3) changes in manuscript

We will refer to the figures as suggested.

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1) Minor comment from the referee

P. 10, Table. 1: I think there is a higher-resolution version of ASD Field Spec Pro. Do the authors think using a standard version of Field Spec Pro is enough for the purpose of this study (the purpose of the data is summarized well in the second paragraph of the Introduction section)?

2) Author's response and 3) changes in manuscript

The standard version of ASD Field Spec Pro (also used in this study) has a spectral resolution of 3 nm @ 700 nm and 10-12 nm @ 1400/2100 nm. The spectral sampling is 1.4 nm (350-1000 nm) and 1.1 nm (1001-2500 nm). The high-resolution version of ASD Field Spec has the same spectral resolution (3 nm) in the VIS-NIR range but resolution of 6-8 nm (depending on model) at longer wavelengths. The spectral sampling interval is the same. As most of the optical satellite instruments have band widths of 10 nm at narrowest in VIS region and 20+ nm in VIS-SWIR region we consider that the resolution of the standard version of Field spec Pro is enough for the purpose of this study. However, we acknowledge the development of hyperspectral imaging (both onboard satellites and for in-situ field studies) and thus understand that while the spectral resolution of this data record remains to be sufficient for the current purpose of the study (mostly related to optical snow cover mapping) it may not be sufficient for other purposes or for the next generation satellite sensors with higher spectral resolutions.

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1) Minor comment from the referee

P. 10, Table. 1: This reviewer is interested in how the authors determined the distances from the sensors to targets especially for the Lab and Portable cases. Please explain.

2) Author's response and 3) changes in manuscript

In case of snow samples measured in the laboratory a panel with known height was placed on top of the snow sample holder. The snow sample holder, in turn, was placed on an adjustable table. The table height was adjusted so that the distance between the tip of the measurement head and the panel (+ panel height) was 25 cm. In the case of the pine and spruce twigs measured in the laboratory the distance was approximately 25 cm when measured between the uppermost limit of twigs and the measurement head. In the field, the distance between the measurement head and the target (snow surface/ground) were measured with a ruler.

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1) Minor comment from the referee

P. 11, Table 2 (The following comment is related to the previous comment for "P. 3, L. 72"): If I understand the meaning of "samples" correctly, I would like to know why the numbers of samples per target in Table 2 vary from date to date. I would make the instead number the same throughout the study period when I do this kind of measurements.

2) Author's response and 3) changes in manuscript

The datasets have partially been collected within different projects/campaigns and thus the number of samples (i.e. the number of consequent spectra collected and averaged to represent one target spectrum) is not constant throughout the data record. The number of samples chosen in each case is supposed to be the best decision for those measurement conditions and for those targets. For the snow measurements in laboratory when newly precipitated snow was measured in 2015 the number of spectra per sample were reduced from previous years as this kind of snow is very sensitive to metamorphism; it was noticed that the number of consequent measurement acquisitions collected during previous experiments was not the most optimal for other types of snow and thus this number was changed.

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1) Minor comment from the referee

P. 19, L. 317: Are "hours 10, 12, and 14" in local time?

2) Author's response and 3) changes in manuscript

The hours are in UTC time. We will indicate this in the revised version.

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1) Minor comment from the referee

P. 22, Figure 10a: Please mention where the sensor is attached in the helicopter.

2) Author's response and 3) changes in manuscript

The AISA sensor was attached in a box mounted on the bottom of the helicopter. In the bottom of the box was a hole for the sensor and the instrument foreoptics unit was set to look at nadir (0âŮę) direction. We will add this to the figure caption.

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1) Minor comment from the referee

P. 24, L. 419 and Table 3: Please consider adding "geometric" before "snow grain size" to indicate explicitly the "snow grain size" is not an optical one.

2) Author's response and 3) changes in manuscript

We will add "geometric" to the text and to the Table 3 to indicate that the grain size is referring to the 'traditional' snow grain size.

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1) Minor comment from the referee

P. 24, Table 3: For air temperature, cloud cover, snow depth, snow patchiness, snow temperature, soil surface temperature, and snow water content, please indicate the types of sensors (as well as manufacturer and location of the manufacturer) used to measure these properties. Regarding IceCube and Snow Fork, please indicate manufacturers and their locations. Also, please explain how the authors measured impurities in snow [%]?

2) Author's response and 3) changes in manuscript

We will add the sensors and manufacturers where necessary. The snow patchiness was visually estimated by the measurer when observing the surrounding area. Also cloud cover was estimated only visually. The manufacturers and their locations for IceCube and Snow Fork will also be added. The mark for amount of impurities in snow (%) was a mistake and only whether there was forest litter visible in the snow surface have been indicated with a number. We will also correct this in the revised manuscript.

TECHNICAL CORRECTIONS

1) Technical correction from the referee

P. 8, L. 207: "Analytical Spectral Devices" -> "ASD"; already defined.

2) Author's response and 3) changes in manuscript

Thank you. We will correct this.

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1) Technical correction from the referee

P. 15, Figure 5: Consider rephrasing "Wet snow with littered surface" to "Wet snow with forest litters".

2) Author's response and 3) changes in manuscript

We will rephrase the legend as suggested.

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1) Technical correction from the referee

P. 16, L. 266: "Jr" -> "JR"

2) Author's response and 3) changes in manuscript

Will be corrected.

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1) Technical correction from the referee

Sections 4 and 5 should be merged, then, please consider add some subsections.

2) Author's response and 3) changes in manuscript

Thank you. We will merge these sections and add some subsections.

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1) Technical correction from the referee

P. 25, Equation (3): "L_{sN}" -> "L_{sN} (nlambda)"

2) Author's response and 3) changes in manuscript

'(lambda)' will be added.

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1) Technical correction from the referee

P. 25, L. 453: "L_{s1} and L_{s2}" should be "L_{sN}"?

2) Author's response and 3) changes in manuscript

We will change this in the revised manuscript.

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