Reply to Referee 1:

This manuscript describes ground-based passive microwave radiometer measurements over a winter season, and uses a physical snowpack model to provide snow inputs to a snow emission model. The radiometer measurements are relatively unique, and the ability to couple physical snow and snow emission models is important in the context of satellite retrievals and land surface modeling applications. As outlined below, however, the manuscript fails to deliver on the promising experiment setup:

We would like to thank you for very helpful comments contributed to the improvement of our paper. Please see detailed replies below to each of your suggestions and how we modified this manuscript to address your comments.

1. The Introduction does not present any clearly stated objectives or hypothesis to test. This results in a very descriptive paper with little quantitative analysis.

We have revised the introduction and conclusion sections to clarify that the main scientific contribution of the work presented here is the season-length time series of multi-wavelength microwave observations of a snowpack through its formation, aging, and melting, which is expected to be augmented in future work by the addition of more in situ snow property data. Also, added figure and discussion with entire time series of simulated brightness temperature (suggested by Anonymous Referee #2).

We mention that not measuring the snow properties is a weakness of the current work, but this is being addressed in the next stage of the experiment. Meanwhile, the inferred evolution of the snow grain size is not purely subjective, as it is physically consistent with the meteorological and snow temperature and depth observations and with SNTHERM simulations forced by observed meteorology.

2. There are numerous cases of conceptually incorrect statements regarding snow metamorphism and the microwave emission/scattering properties of terrestrial snow, and there is confusion regarding melt metamorphism versus temperature gradient metamorphism.

Examples include: -Page 8107 line 19: "Further, as a time progress smaller grains locked together to form bigger grains." Is this referring to melt metamorphism? 'Locked together' is a strange word choice.

We revised the manuscript with help of native speakers, and simplified various sentences and removed sentences which are convoluted.

-Page 8107 lien 25: Do you really think soil properties 'dominate' winter season microwave emission? If so, how could we use these measurements to look at snow?

Here we meant to say “soil temperature”. We observed that the measured and simulated soil surface temperature (and temperature at 5 and 10 cm below surface) varies from ~268 K in the month of January to 273 K in the month of March. This change in temperature drives dry snow to wet snow transitions, which eventually affect the microwave emission. We revised the sentence accordingly.

-Page 8112 line 16: “The diurnal variation of brightness temperature during the snow accumulation phase was smaller due to slow snow metamorphism compared to the later winter period.” The diurnal variation in Tb is likely due to temperature and snow wetness processes not grain metamorphism.

We agree with you that the diurnal variation in Tb is likely due to temperature and snow wetness processes, not grain metamorphism. We revised the sentence.

-Page 8113 line 15: “The increase of the brightness temperature at 89GHz immediately after the snowfall event is due to the greater microwave scattering of the fresh snow as compared to soil or aged snow.” Greater microwave scatter related to increased Tb?

We agree that greater microwave scatter is not physically related to increasing Tb. However, we observed increasing Tb after every snowfall event. We currently don’t have an explanation for this observed increase in Tb after snowfall. Therefore, we will be citing this as an observation, which will be investigated more fully in the next stage of the field experiment.

- Page 8114 line 18: “Snow metamorphism, which transforms smaller grains into larger grains, is slow when below freezing temperatures persist.” What about temperature gradient metamorphism? Prolonged cold temperatures drive this process:

We agree with you that prolonged cold temperature drive the metamorphism process. However, in this paper we broadly divided the season into 3 phases and discussed snow metamorphism patterns in terms of these phases. In the first phase, the snowpack temperature gradient is mostly stable during day and night time, which slows down the snow metamorphism process compared to third phase where a warmer surface and larger snowpack temperature gradient were observed.

3. Details are missing on some aspects of the radiometer measurements. Given the beam width, incidence angle, and height, what are the dimensions of the measurement footprint? How was the radiometric stability of the instruments evaluated during the course of the measurements? Was there any calibration drift? If so, how was this corrected? Was there any post-processing of the measurements?

The details of radiometer characteristics including beam width, incidence angle, height, footprint size are now provided in Section 2.

Both radiometers were calibrated using two blackbody targets of different and carefully known temperatures before and after the winter season to check calibration drift. The targets are provided by Radiometric, and include an ambient temperature target and patented liquid nitrogen (LN) target in polystyrene insulating containers for this purpose. The radiometers are to take observations into these targets, and adjust the corresponding parameters in the Configuration File instruction set so that the radiometer reads the blackbody target temperature correctly. A Toughbook laptop connected to radiometer receiver, receives the dual polarized brightness temperature values along with several hardware related values.

4. There are some critical gaps in the field measurements. How were the grain size and density measurements made? Were grain size and density really only measured on a single day (10 March 2011) as stated on page 8111 line 6? If so, this means all the statements throughout the manuscript on the impact of grain size and density on brightness temperature are speculative and not quantitative. A lot of descriptive statements lack any evidence from snow measurements. For example: -page 8113 line 1 "The reduction of TB in 89GHz band at both vertical and horizontal polarization was primarily associated with the change in surface temperature accompanied with the change in snow grain size." -page 8113 line 20 "This reduction is apparently related to changes in the snowpack properties particularly to the increase of the grain size." Were any grain size measurements made during these periods? If so, they must be presented quantitatively to avoid speculative statements like these.

We understand that not directly measuring the snow properties (grain size and density) is a weakness of the current work, but that this is being addressed in the next stage of the experiment. We added (Fig 8) validation of grain size and density measured on single day, which shows very good correlation. Further, we also found good correlation between observed and SNTHERM simulated snow thickness/depth as shown in Fig 7.

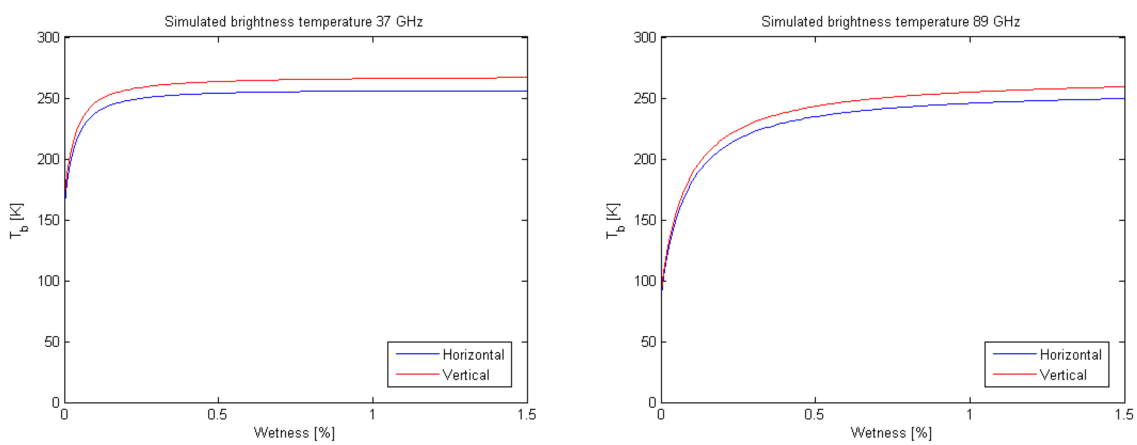
Meanwhile, the inferred evolution of the snow grain size is not purely subjective, as it is physically consistent with the observed snowpack temperature and snow depth with simulated from SNTHERM. To convey this more clearly, we rewrote the above mentioned sentences.

5. An additional section is needed on the implementation of SNTHERM and HUT. Coupling physical snow models with snow emission models is not a trivial task, and many research groups are currently addressing this issue. It is difficult to take physical snow model output (for example, grain size) and feed it directly into a snow emission model, so more details are needed here. It also appears that the SNTHERM simulations, with the exception of temperature, were not validated at all with observations. In addition to temperature, HUT requires grain size, SWE, and density inputs. If these were taken straight from the SNTHERM simulations with no validation how do you know these values were reasonable? How can uncertainty in the Tb simulations be attributed to the model inputs versus the model parameterizations? HUT also requires surface roughness and surface dielectric inputs. How were these determined?

We now provide more detail. In general, the simulations are intended as an initial check of the ability of current models to capture the main patterns seen, and this function is served here even though some of the inputs were estimated rather than directly measured.

6. The strong 37V response to ice layers (section 4.1.3) is not consistent with previous studies and warrants further attention. I would check: Rees, A., J. Lemmetyinen, C. Derksen, J. Pulliainen, and M. English. 2010. Observed and modelled effects of ice lens formation on passive microwave brightness temperatures over snow covered tundra. Remote Sensing of Environment. 114: 116-126. Lemmetyinen, J., J. Pulliainen, A. Rees, A. Kontu, Y. Qiu, and C. Derksen. 2010. Multiple layer adaptation of the HUT snow emission model: comparison with experimental data. IEEE Transactions on Geoscience and Remote Sensing. 48: 2781-2794.

The strong 37V response to in section 4.1.3 (Melting and Refreezing), is not only due to ice layers but to snow wetness condition. Moreover, during this phase, the snowpack temperature is close to 272K, which is major factor in strong 37V response. Please see figure below for sensitivity of brightness temperature at 37 and 89 GHz to snow wetness using HUT model.



7. I suggest re-thinking the snow categories in Section 4.2. The 'aged snow' category in particular should include some consideration of grain shape, i.e. rounded versus faceted, or some consideration of the layered nature of snowpacks which typically contain both old and new snow layers.

Thank you for suggestions. Since, we didn't measure the snowpack grain size and shape (except 1 field visit) on the field, we cannot make more nuanced classification of the aged snow at this point. However, for analyzing data from the next winter season we will definitely consider this suggestion.

8. Figure 4: I was struck by the lack of response of the 37 GHz measurements to snow depth, even when the snowpack was close to 40 cm and relatively cold. This is quite unexpected. Is there any explanation for this?

The Tb 37H is shown to have dropped slowly after snowfall of 15cm (snow depth 17.5 cm) on DOY 20, going from 252K to 231K on DOY 37. It is further reduced after a snowfall of 15 cm (total snow depth = 38 cm) on DOY 37 to 180K on DOY 57. 37V is less responsive than 37H to the change in snow depth and drops to 208K on DOY 57.

9. Figure 8: A lot of temporal averaging was performed before comparing the simulations and observations. What does a statistical analysis of more instantaneous measurements and simulations look like?

We added an additional figure of hourly simulated brightness temperature from HUT model.

Editorial Comments

The manuscript requires a thorough edit for many minor grammatical/word choice errors. Remove all mention of non-metric units (i.e. inches).

We revised the manuscript and removed the grammatical errors. Also removed all non-metric units mentioned in the manuscript.

Page 8108 line 19: "Previous snow field experiments (Chang et al., 1981; Elder et al.,2009; Hewison and English, 1999; Langlois et al., 2007; Macelloni et al., 2005) that have used microwave radiometers to study snowpack microwave emission properties." Not a complete sentence.

The sentence is revised and completed.

Section 3.2: details on the data logger are not necessary.

The details of data loggers were removed.

Section 4.1 and throughout the manuscript: the term 'subfreezing' is not typical. Are you referring to processes in the snowpack or the top soil layer?

We are referring to processes in the snowpack.