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Interactive comment on "Comparison of a coupled snow thermodynamic and radiative transfer model with in-situ active microwave signatures of snow-covered smooth first-year sea ice" *by* M. C. Fuller et al.

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Thank you for your revision of our work.

It has improved the content and clarity. We have also attached a zipped file which includes a word.docx copy of your original review and our response, and JPEG and PNG versions of revisions to improve the clarity and lines of the figures.

Interactive comment on "Comparison of a coupled snow thermodynamic and radiative transfer model with in-situ active microwave signatures of snow-covered smooth first-

year sea ice" by M. C. Fuller et al.

Anonymous Referee #2 Received and published: 25 August 2015

The manuscript presents the coupling of a multi-layer physical snow model (SNTHERM) driven by NARR observations and an active microwave radiative transfer model (MSIB) to simulate the backscatter signal over first-year sea ice. The study first present a validation of the NARR output relevant to SNTHERM with a comparison with a set of in-situ measurements. The SNTHERM's simulated snow properties pertinent for MSIB are then validated with in-situ snow measurements. Finally, the simulated backscatters from the coupled SNTHERM/MSIB are compared with in-situ scatterometer measurements.

The study is valuable as it explores the development of a processing chain to simulate backscatter from reanalysis over sea ice. However, the introduction and the method sections need some clarification and restructuration. Also, at my sense, because the backscatter simulation is the central topic of the study, the analysis of the backscatter simulations is incomplete. Hence, I recommend publication in The Cryosphere following some major revisions as outlined in the following report.

1. p.3295-Line.8-9: The term "controlled" is inadequate in the sentence.

1. AUTHORS: The wording has been changed. "Snow albedo is influenced by grain size, which is both affected by, and effects, radiant exchanges."

2. p.3295-Line.9-15: It is not clear if these 2 sentences make reference to snow on sea ice or snow in general.

2. AUTHORS: We have clarified these sentences: "The distribution and character of snow cover over sea ice is highly variable both spatially and temporally. . ."

3. In the introduction, it is not clear why and how radiative transfer is important. Few sentences introduce assimilation (p.3295-Line.2528; p.3296-Line.12-15) , but it remain vague and dispersed. The introduction would benefit of clearer description of assimila-

tion approaches (see Reichle et al., 2008). Also, in an assimilation scheme, what snow geophysical properties could be potentially inverted from radar?

3. AUTHORS: We envision that this methodology would undergo further development and optimization, and eventually be used in data assimilation using a forward model, in which case geophysical inversion from SAR is not a priority. This work is intended as a first-step in order to identify shortcomings in the "simplest-case" system, which will reveal areas for further development and optimization in future work. Hence, we have characterized this work in the Introduction as a smaller part, or first-step, within the greater context of fully developed assimilation systems.

4. The link to Environment Canada site is not relevant.

4. AUTHORS: This link has been removed.

5. In the introduction, the litterature cited is mostly based on passive work. What about active radiative transfer modeling? Is there any other active radiative transfer model? Is there any study using active radiative transfer model on land?

5. AUTHORS: The microwave emission model of layered snowpacks (MEMLS) and Dense media radiative transfer theory (DMRT) are both able to function in either passive emission or active backscatter modes. Recent study by Proksch et al. (2015) compares MEMLS simulated backscatter to SnowScat observation. This work has been cited and added to the reference list. The MSIB model was chosen as it has been validated with both surface- and satellite-based backscatter data over first-year sea ice under varied conditions.

Proksch, M., Matzler, C., Wiesmann, A., Lemmetyinen, J., Schwank, M., Lowe, H., Schneebeli M.: MEMLS3&a: Microwave emission model of layered snowpacks adapted to include backscattering, Geoscientific Model Development Discussions, 8, 2605-2652, 2015.

6. p.3297-L.9-14: You should keep the sentence more general: Langlois et al., 2009

only use NARR to drive snow models; Langois et al., (2012) use SNOWPACK and MEMLS. Kohn and Royer, 2010 use SNTHERM and HUT.

6. AUTHORS: We have re-worded this section as per your suggestions. It now reads: "Previous work has considered the use of NARR variables to compare snow models over land (eg. Langlois et al, 2009), and the simulation of passive microwave emission (MEMLS) from physical snow models (SNOWPACK) driven by NARR data over land (eg. Wiesmann et al, 2000; Langlois et al, 2012). NARR variables were used to drive SNTHERM and subsequently the HUT emission model for soil temperature estimation (eg. Kohn and Royer, 2010), and for dowelling microwave emission estimation over land (eg. Roy et al, 2012; Montpetit et al, 2013). Willmes et al. (2014) employed European Re-Analysis data to drive SNTHERM and subsequently MEMLS for simulation of passive microwave emission of snow and sea ice."

7. p.3297-L.14: "microwave" downwelling atmospheric emission (not that the method was developped in Roy et al., 2012).

7. AUTHORS: We have noted this and added Roy et al., 2012 as a citation and to the reference list.

8. Most of the elements in the 2 last paragraphs of the introduction should be put in the method section.

8. AUTHORS: This suggestion was also made by Reviewer 1 and the SNTHERM and MISB paragraphs have been moved to the appropriate places in the methods section.

9. P.3299.L.16-17: I think the use of the term "operational scenario for simulation of C-band backscatter" is ambigious. Operational use of radiative transfer model sould lead to assimilation approach?

9. AUTHORS: We have revised that sentence. It now reads: "4) What are the implications of the use of the SNTHERM89.rev4 thermodynamic model in an operational approach for a radiative transfer simulation of C-band backscatter over first-year sea

ice?"

10. Sect. 2.2.1 : This section is confusing. It is not clear which station is where (land or sea ice) and what it measures. A table could also help to better understand. Informations on the 13 January to 23 March 2010 (p.3303-L.24) should be given in this section.

10. AUTHORS: REVIEWER 1 also noted this. The paragraph has been revised for clarity. It now reads: "The in-situ meteorological instruments were located on sea ice 500 m adjacent to the snow sample sites and measured relative humidity (RH), sampled every 10 minutes and averaged to hourly data. Environment Canada's 'Churchill A' station (N58.733, W 094.050) is on land approximately 20 km from the study site and measured air temperature. The NOAA NCEP NARR data was downloaded for the 32 km grid containing the sample site. This data included reanalysis of air temperature, RH, wind speed, longwave and shortwave incoming and outgoing radiation, and precipitation amount. The NARR grid data were resampled from 3 hour to hourly data using a linear interpolation and contains a roughly even split of land and bay."

11. Sect. 2.2.2: Even if the dataset is described in Fuller et al. (2014), some more descritpion should be given to help the reader. For example, it is never explained what the 3 samples refer to exactly?

11. AUTHORS: We have now included an explanation of what the snow samples are intended to represent. The text now reads: "The snow samples are referred to as Sample 1, Sample 2 and Sample 3, and were selected to represent the observed variation of snow geophysical character. These provide a basis for a comparison of observed and simulated backscatter for a modeled snow and sea ice layering analysis, which is condusted in Fuller et al. (2014). The geophysical properties of these Samples 1, 2, and 3 are compared to those provided by SNTHERM when forced by NARR data (Section 3.2 and its associated figures)."

12. Initial conditions: it is not clear how was set all the initial conditions of SNTHERM?

Is any spin-up was done?

12. AUTHORS: The initial conditions are described in the text (Pg 3301 Lines24 and 25; Pg. 3302 Lines 1-3) as SNTHERM A and SNTHERM B. The information is also presented in Table 2. No spin up was done as the field site initial condition was smooth first-year sea ice with no snow.

13. p.3302.L.6-7 : Sentence incomplete?

13. AUTHORS: The sentence has been clarified. It now reads: "The hourly meteorological state variables used include 2 m air temperature, 2 m relative humidity, 10 m wind speed, incoming and outgoing shortwave radiation and incoming longwave radiation, and precipitation amount."

14. One of the major weakness of the results is the fact that there are stations inland, and stations on sea ice, and the NARR pixel is mixed. Also, NARR information is compared with land station, but for sea ice application? The effect of the mixed NARR pixel on the validation is not well described. These limits should be more clearly answered in the manuscript. Why not choosing a "pure sea-ice" pixel close to the sea ice station and a "pure land pixel" for inland station?

14. AUTHORS: Operationally, for this location, a mixed NARR pixel would have to be used. We have acknowledged this in the paper. The text now reads: "Operationally, in order to match the location of snow geophysical sampling, the observed backscatter, and the state variables required to drive SNTHERM, we employed a NARR grid spanning sea ice and snow covered land. The effects of the grid encompassing the transition zone may be a source of error."

15. p.3303-L.6-9: NARR clearly underestimates the diurnal temperature variation between 22 to 29. What could be the impact of that (lower gradient in the snowpack?)?

15. AUTHORS: We agree and have noted that this may contribute to the overestimation of the temperature by the SNTHERM model. The text now reads: "Additionally, NARR

data underestimates the observed diurnal temperature variation, which potentially results in overestimation or bias observed in SNTHERM simulated snow temperature (Section 3.2)."

16. p.3304.L.17-19: It is not necessarely the case if no meteorological station close to the site is assimilated.

16. AUTHORS: We agree and have acknowledged this as a potential source of error in the text. It now reads: "This may partially explain the low correlation of relative humidity, but is not necessarily related to the NARR predicted 2 m air temperature, 10 m wind speed, or precipitation, as these are assimilated from surface observations (Mesinger, et al., 2006). However, as there are no meterological stations close to our study site, this may remain a source of error."

17. All figure : the fontsize must be increased.

17. AUTHORS: The font size meets the specifications of the TCD production team.

18. p.3305-L.26-27: It is not clear in the figure if the snow temperature get above 0_C (add a line at the melting point in the Fig.9 left). Or the model can have snowmelt even if the snow temperature is below 0_C?

18. AUTHORS: The 0_C line has been added to Figure 9.

19. Fig.10 : how is the dielectric permittivity is calculated (which model?)? Is it part of the MSIB model? This figure could be in the MSIB evaluation section? How is the dielectric permittivity is measured and at which frequency (generally the instruments measure the permittivity at lower frequency than C-band)?

19. AUTHORS: An explanation of the calculation for the dielectric permittivity has been added to the MSIB methods section. It now reads: "The permittivity εÊź and dielectric loss εÊźÊź for brine-wetted snow are calculated using: 1) the dry snow permittivity as a function of snow density (Geldsetzer et al., 2009); 2) the temperature- and frequency-dependent permittivity and dielectric loss of brine (Stogryn and Desargant, 1985); and

3) a mixture model based on the brine volume and saturation within the snow (Geldsetzer et al., 2009). The snow brine volume is a function of the snow density, temperature and salinity, and is estimated via the relative densities of brine and pure ice, and the sea ice brine volume for a given temperature and salinity (Drinkwater & Crocker, 1983; Geldsetzer et al., 2009).

20. P.3306-L.7-9: But in this case, SNTHERM does not take into account the brine wicking anyway. It should be mentionned.

20. AUTHORS: It is true that SNTHERM does not take into account brine wicking, and this is noted throughout the text. However, the brine volume inputs to the MSIB model, taken with temperatures from SNTHERM simulations, will affect dielectric calculations in the MISB simulations.

21. Sect. 3.3: It is hard to tell how good the simualtion results are. What other studies obtained for snow on land? But the most imporant point is to evalaute at what point the simulation precision is relevant for assimialtion application.

21. AUTHORS: At this stage we are identifying the shortcomings in the system in order to identify areas for further development and optimization in future work. The goal of this work is to see what, in the simplest case, these source of error are. The goal of this work is not to establish the precise accuracy needed for assimilation, as this will be addressed in future work.

22. Fig. 6 left: The figure is not very clear.

22. AUTHORS: We have brought forward and thickened the lines and dots in the Figure 6 to improve clarity.

Minor :

- SNTHERM89.rev4 is not specifically defined in the abstract. AUTHORS: SNTHERM89.rev4 has now been specified in the Abstract.

- P.3296-L.8 : “to” or “for”? AUTHORS: This has been corrected to “for” in the text.

- P.3301.L.11 : “if” or “and”? AUTHORS: This sentence reads correctly. It is similar to an “if” “then” statement.

- Figures : change RËĘ2 for R2 AUTHORS: This has been changed in the figures.

References :

Reichle, R.: Data assimilation methods in the Earth sciences, Adv. Water Resour., 31, 1411–1418, 2008.

AUTHORS: Reichle, 2008 has been cited and added to the reference list.

-Langlois, A., Royer, A., Derksen, C., Montpetit, B., Dupont, F., and Goita, K.: Coupling the snow thermodynamic model SNOWPACK with the microwave emission model of layered snowpacks for subarctic and arctic snow water equivalent retrievals, Water Ressour. Res., 48, W12524, doi:10.1029/2012WR012133, 2012.

AUTHORS: Langlois et al. 2012 has been cited and added to the reference list.

-A. Roy, A. Royer, J.-P.Wigneron, A. Langlois, J. Bergeron, and P. Cliche, “A simple parameterization for a boreal forest radiative transfer model at microwave frequencies,” Remote Sens. Environ., vol. 124, pp. 371–383, Sep. 2012. Interactive comment on The Cryosphere Discuss., 9, 3293, 2015. C1494

AUTHORS: Roy et al. 2012 has been cited and added to the reference list.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/9/C1736/2015/tcd-9-C1736-2015-supplement.zip

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Interactive comment on The Cryosphere Discuss., 9, 3293, 2015.