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The Cryosphere Discussions

Interactive comment on "The microwave emissivity variability of snow covered first-year sea ice from late winter to early summer: a model study" *by* S. Willmes et al.

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We want to thank referee #1 very much for a detailed review and very valuable comments to our manuscript. Referring to your concerns and comments we will argue on each of the mentioned points in the following:

1. Snow initialization.

The use of a uniform snowpack at all locations is important to allow a comparison of the net atmospheric influence within regions and hemispheres, for this reason we also neglect snowfall and precipitation. In SNTHERM, the number of initial layers is the same at any position, while layer thickness adjusts itself during simulation and layers

can disappear such that a decrease in snow height is possible (the snowpack is vertically uniform only in the beginning, see new suggested Figure 3, below). It might in fact be reasonable to characterize the initial snow profile for winter with 4-5 layers only, however, we want to allow for the formation of thin layers within the profile which will certainly impact MEMLS simulations differently as if properties were averaged within layers of a thickness larger than 1 cm. Our approach represents an experimental study where we assume initial snow conditions at the start of simulations and quantify the impact of seasonal snow metamorphism in the absence of accumulation. With this setup we focus on emissivity variations in areas with high ice concentrations as described by Andersen et al. (2007). The obtained results contribute to a better understanding of the uncertainty and variability of sea-ice concentration and snow-depth retrievals in regions of high sea-ice concentrations. (Andersen et al., 2007; Markus et al., 2006; Comiso et al., 1997; Cavalieri, 1994).

2. Coupling of models.

As you suggested, we would like to add an additional figure (Fig. 3) that addresses a) an exemplary evolution of the snow pack properties (density, temperature and grain size) for two locations in the Arctic and Antarctic, respectively and b) a comparison between SSM/I and modeled TB together with associated sea-ice concentrations. Moreover we changed Figure 2 such that now the frequency distributions of modeled and observed PR/GR and TB data are shown. As far as the scaling factor is concerned we would like to add the following statements and references to our revised version: "In doing so, a value of 0.12 was obtained for F. The use of a correlation length correction scheme for microwave modeling has recently also been demonstrated by previous studies. Wiesmann et al. (2000) obtained best results for the combination of SNTHERM and MEMLS when pex was calculated by scaling d0 with a value of 0.16. Durand et al. (2008) applied a linear relationship between pex and the natural logarithm of the maximum grain diameter, while Langlois et al. (2012) and Montpetit et al. (2013) used an approach similar to equation 1, while they include an additional factor of 2/3 according to Mätzler (2002) and obtained scaling coefficients of 0.1 and 1.3, respectively. In general, the calculation of correlation lengths and choice of correction factors depends on the applied model combinations."

The new Figure 2 is described as follows:

Figure 2 a and b show the PR and GR ratios obtained from simulated brightness temperatures for the Arctic and Antarctic, respectively. In addition, the figures show PR and GR ratios from observed brightness temperatures extracted from the daily polar gridded satellite data sets for all regions where the sea-ice concentration exceeds 90%. As expected, the simulated data are closely aligned with the 100% sea-ice concentration lines (white dotted, Cavalieri et al., 1984, 1994). However, PR and GR ratios show a larger range of variability and scatter in the Antarctic than in the Arctic, both in observations and simulations. In general, the simulated data cover a narrower range of PR/GR ratios than observed data. This is mostly due to the fact that the model results (point-scale) represent 100% sea ice concentration, whereas observed data have been extracted for sea-ice concentration >90%, and therefore are affected by emissivity variations arising from different open water fractions, surface heterogeneity and sea-ice drift. Since the simulated data represent a sea-ice concentration of 100% the presented PR/GR variability arises exclusively from changes in the snowpack. The last month of simulations (Arctic: June, Antarctic: December) is highlighted by red dots to indicate the effect of beginning melt processes. In June in the Arctic, there is a pronounced cluster of melt signals with GR values close to zero. In the Antarctic there is less change of PR and GR ratios at the beginning of summer, i.e. in December. The frequency distributions of simulated and observed PR and GR values in the bottom of Figure 2a and b indicate a small bias between observed and simulated data, and narrower distributions with less variability of the simulated data. Although the simulated values are within a realistic range of observed PR and GR, the simulations indicate on average higher PR (Arctic: +0.005; Antarctic: +0.002) and lower GR (Arctic: -0.005; Antarctic: -0.014). Possible reasons for these differences were introduced above. No-

table is also a large contribution of simulated GR values close to zero especially in the Arctic, which is not found in the observed data. These GR values are caused by melting snow and result only from data in the last month of simulations (Arctic: June). We suggest that due to different open water fractions, surface heterogeneity and a lower temporal resolution this signal contribution is smoothed in the observed data. As demonstrated by the graphs, the hemispheric differences that are found in the satellite data, i.e. the frequency distribution of PR is flatter and low GR values are less frequent in the Antarctic than in the Arctic, are also present in the simulated data. Figures 2c and d show associated brightness temperatures and their frequency distributions. Modal values of observations and simulations are similar, and the distributions of simulated brightness temperatures are narrower as for the PR and GR ratios. However, in addition, simulated 19V and 37V brightness temperatures show an additional peak at high temperatures of 273 K.. In both hemispheres, Tb values of 273 K are reached in the simulations when the snow starts to melt. This behaviour is not clearly seen in the observed Tb which is probably due to the melt signal being smoothed by different open water fractions and surface heterogeneity within the sensor footprint.

The new Figure 3 is described as follows:

The SNTHERM snow pack evolution for two locations in the Arctic and Antarctic is presented in Figure 3a and 3b, respectively. The two profiles are characteristic of the general hemispheric differences in snow pack evolution described by Nicolaus et al. (2006). In the Arctic, melting does not occur before mid June and is followed by a rapid thinning and disappearance of the snow while density changes in the pre-melt period are only small and grain sizes increase predominantly from the bottom. In contrast, in the Antarctic, the first melt event occurs already in July and is followed by multiple freeze-thaw cycles, which cause a layering of the snow, together with increasing densities and increasing grain sizes also in the upper layers. Time series of associated simulated and observed 19H, 19H, 37H and 37V brightness temperatures are shown in Figure 3c, d together with the coincidentally retrieved sea-ice concentration at the respective grid points. The simulated data are very smooth in comparison to satellite Tb, while occasionally simulated larger peaks and excursions are also found in the observed Tb, however, superimposed to a substantially larger background variability. Especially when the snow is dry, the observed Tb variability is likely a consequence of other temporal changes of ice and snow properties at the respective grid points, e.g. due to variations in roughness, age and salinity of thin ice (e.g. Eppler et al., 1992). The largest differences between simulations and observations are found for Arctic PR values which is mainly due to the fact that the simulations overestimate 19V by approximately 5 K on average which could be an effect of the snow depth of 30 cm being overestimated in this location.

3. /4. Figure 2 / model uncertainty.

To ensure that our model results are within the realistic ranges of observed data, we chose to plot them in PR/GR feature space in Figure 2. As stated correctly, the modeled data cover a more narrow range than observed TB, but here we have to keep in mind that modeled data (point-scale) represent 100% sea ice concentration, whereas observed data include also emissivity variations arising from different open water fractions, surface heterogeneity, ice types, drift, etc. To provide additional confidence, we changed Figure 2 as you suggested to show additionally frequency distributions of modeled and observed TB data. The use of a bias or RMSE of our modeled TB is not meaningful. The sources for a deviation of modeled and SSM/I observed TB data here include ERA ambiguities (no detailed met data available) and snowpack initialization (see above). An SSM/I grid point that we could compare to our modeled TB is first subject to ice drift and thus includes an undetermined TB variability due to changing surface compositions (heterogeneity) and second includes open water (sea-ice concentration 90-100%), which certainly impacts the observed TB (for 85 GHz SSMI TB will also be influenced by atm. water vapor). We justify the use of the combined SNTHERM-MEMLS modeling approach instead by referring to the studies of Wiesmann et al. (2000) and Tonboe (2010) and state here explicitly that our approach

represents an experimental study with an identical snow pack and for 100% sea-ice concentration only. With this setup however, we focus on emissivity variations at areas with high ice concentrations as described by Andersen et al. (2007). This means that instead of simulating accurate snow packs and associated TB data, we here elaborate on the translation of atmospheric forcing into emissivity variations for an experimental snow pack and determine its regional and hemispheric characteristics. Hence, instead of providing an RSME, we present time series on observed TB and modeled TB for two points in a new Figure 3 (see below) and discuss differences in context with the evolution of sea-ice concentrations and potential other sources of deviation. We recognize that the presented modeling approach might appear ambiguous in terms of TB accuracy, but in comparison to e.g. Montpetit et al. (2013), Brucker et al. (2011), this study does not intend to fully reproduce a measured TB evolution with the model output. As such, for the reasons itemized we do not aim at an accurate point-to-point agreement between simulations and observations. It is instead our focus to quantify the net regional effect of atmospherically driven snow metamorphism in the absence of accumulation. In our understanding, this approach and the obtained emissivity variations reveal what we call the “background emissivity variation” which we propose as a minimum emissivity variation that has to be considered for regions with high-ice concentrations in a seasonal and regional context. With this our study builds upon the conclusion of Andersen et. al (2007) saying that especially at high sea-ice concentrations, accuracy suffers from emissivity variations in the snowpack. We include this discussion in a revised version to put more emphasis on the experimental character of our approach and the relevance of ambiguities.

P5718, l.3: We now specifically show the last month of simulations in red (Figure 2, see below) and refer to this in the text.

5. phase related processes

Ablation of snow and surface sea ice is dominated by a strong albedo-melt feedback in the Arctic. As a result most of the mass is lost toward the ocean and evaporation (sublimation) is comparably small. In contrast, on Antarctic sea ice, sublimation is much stronger and thus the mass loss to the atmosphere is larger than to the ocean. Reasons for this are mostly a result of stronger surface cooling through upward fluxes. However, we do not include this explanation into this manuscript, since this statement directly refers to the given reference of Nicolaus et al (2006). We use evaporation instead of sublimation to better highlight the mass transfer to the atmosphere.

6. Penetration depths

...were calculated by accumulating layer transmissivities and determining the depth at which only 1/e of the signal contributes to the emitted signal at the surface. The slight reductions in penetration depth during months 1 to 4 arise from the presence of early melt events that cause a decrease in penetration depth on both frequencies. We suggest to extend the respective text by the following sentence: We calculated the penetration depth by accumulating layer transmissivities and determining the depth at which a fraction of 1/e of the signal contributes to the emitted signal at the surface. Maximum values were constrained to the maximum snow depth of 30 cm (snow penetration depth). To clarify the description of what is being shown in Figure 6 we add the following: The mean monthly microwave snow penetration depth is lower in the Arctic than in the Antarctic during month 6 (12.5 cm vs. 20 cm). At 37 GHz the penetration depth in the Arctic starts to deviate from the Antarctic already during month 5 (May/November) with a value of 17 cm (Antarctic: 19 cm) and 10 cm (Antarctic: 17 cm) in month 6 (June/December). The rate at which the penetration depth decreases throughout the season is smaller for 19 GHz than for 37 GHz. This points out the stronger sensitivity of Tb values at 37 GHz to atmospheric variability and associated changes in the vertical snow profile. In the pre-melt period, the bulk snow density increases on average faster in the Antarctic

7. Trends

Yes, these trends were calculated for the 2000-2009 period. We recognize that this

period is rather short for the computation of trends, however, we would prefer to include this finding anyway since it addresses the context of an increased frequencies of early melt onset dates as e.g. described in Markus et al. (2009) and the trends that we describe here could provide new insights in this context, although the short time period in fact requires careful argumentation. Hence, we suggested to expand the manuscript as follows: Although we recognize that the 10 years period is rather short for a trend analysis we chose to present these trends as shifts in seasonal transitions have been reported by e.g. Markus et al. (2009).

8. Impact on sea-ice concentration

We agree with the referee that a full retrieval sensitivity study is needed, but that requires different associated problems to be solved beforehand which are not subject of this paper. E.g. thermodynamic models that are capable of simulating variations in sea-ice freeboard, associated flooding and draining. Moreover, information on local ocean salinities and sea-ice thickness would be an asset, and the scale gap between satellite and point-scale data remains an issue after all. As we state in the text, what we present is experimental study to quantify the atmospherically induced “background emissivity variability” that gives insight into the minimum variability that needs to be considered. To provide path for further elaborations on this we suggest to include a supplementary table (Table S1a / S1b, see supplement) that includes monthly emissivity variations for regions and frequencies/polarizations. We agree that the conclusions stating that the emissivity data can be directly used to asses sea-ice concentration accuracies is somewhat misleading and appears high provided that we do not directly investigate the impact on sea-ice concentration. Therefore we suggest to rephrase this conclusions as follows: The obtained emissivity data characterize the background emissivity variability of snow-covered first-year sea ice due to atmospheric forcing and contribute to a better understanding of sea-ice concentration and snow-depth product accuracies at high sea-ice concentrations. The results need to be interpreted in the context of assumptions and simplifications.

Editorial Comments:

P5712, l. 21: This is changed according to your suggestion

P5713, l. 3: We replaced “detailed” by “additional”

P5713, l. 21: This paragraph is changed now.

P5713, l. 29: We changed the sentence to “For example, Cavalieri et al. (1990), Comiso et al. (1997) have described how layered snow and the associated presence of ice crusts and lenses cause a low sea-ice concentration bias....”.

P5714, l. 9: The entire paragraph is changed to state more explicitly what is being done (see revised version in supplement).

P5718, l. 27: Done.

P5720, l. 4: Done.

Figure 6c: We think that the label is correct?

P5722, l. 7: We here address gap layers in Antarctic sea ice as described e.g. by Ackley et al. (2008) and add this reference in the text.

Suggested additional references:

Ackley, S. F., Lewis, M. J., Fritsen, C. H. and Hongjie, X.: Internal melting in Antarctic sea ice: Development of “gap layers”, Geophys. Res. Lett., 35, L11502, doi:10.1029/2008GL033644, 2008.

Brucker, L., Royer, A., Picard, G., Langlois, A. and Fily, M.: Hourly simulations of seasonal snow microwave brightness temperature using coupled snow evolution-emission models in Quebec, Canada, Rem. Sens. Environ., vol. 115, pp. 1966-1977, 2011.

Durand. M., Kim, E. and Margulis, S.: Quantifying uncertainty in modeling snow microwave radiance for a mountain snowpack at the point-scale, including stratigraphic effects, IEEE T. Geosci. Remote, 46(6), 1753-1767, 2008.

Montpetit, B., Royer, A., Roy, A., Langlois, A. and Derksen, C.: Snow Microwave Emission Modeling of Ice Lenses Within a Snowpack Using the Microwave Emission Model for Layered Snowpacks, IEEE T. Geosci. Remote, 51(9) 4705-4717, 2013.

Wiesmann, A., Fierz, C. and Mätzler, C.: Simulation of microwave emission from physically modeled snowpacks, Ann. Glaciol., 31(1),397-401, 2000.

Parkinson, C. L., and Cavalieri, D. J.: Arctic sea ice variability and trends, 1979–2006, J. Geophy. Res., 113, C7, doi:10. 1029/2007JC004558, 2008.

Cavalieri, D. J., and Parkinson, C. L.: Antarctic sea ice variability and trends, 1979–2006, J. Geophy. Res., 113, C7, doi:10. 1029/2007JC004558, 2008.

Stroeve, J. C., Serreze, M. C., Holland, M. M., Kay, J. E., Maslanik, J., and Barrett, A.P.: The Arctic’s rapidly shrinking sea ice cover: A research synthesis. Clim. Change, doi:10.1007/s10584-011-0101-1, 2012.

Eisenman, I., Meier, W. N., and Norris, J. R.: A spurious jump in the satellite record: is Antarctic sea ice really expanding?, The Cryosphere Discuss., 8, 273-288, doi:10.5194/tcd-8-273-2014, 2014.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/7/C3319/2014/tcd-7-C3319-2014-supplement.pdf

Interactive comment on The Cryosphere Discuss., 7, 5711, 2013.

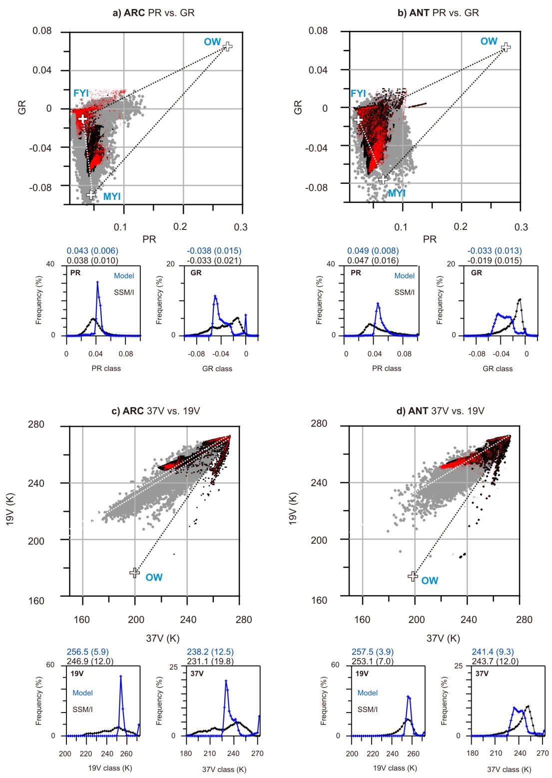

Fig. 1. Figure 2 (modified)

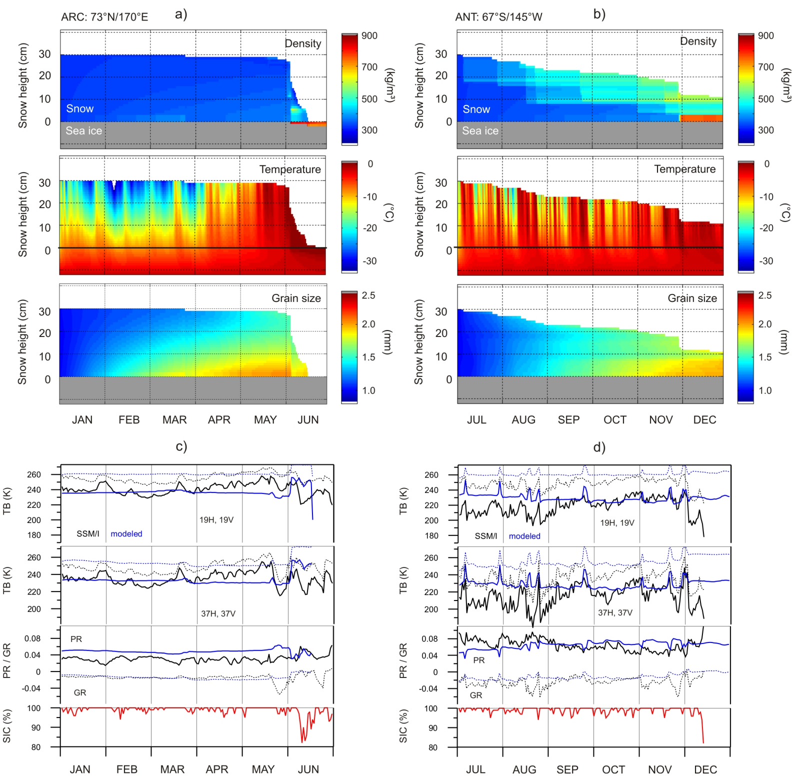

Fig. 2. Figure 3 (new)