Answer to reviewer #2:

We thank very much Referee #2 for the insightful and extensive comments which helped us very much to improve our paper. We here first answer the three major questions raised in the review: 1. What does SMOS measure, the modal or mean ice thickness? 2. What kind of ice thicknesses are retrieved with Algorithm II and II*? 3. Which algorithm should be used to be compared with MODIS derived ice thickness?

Answer 1: (added at the beginning of section 5 in the revised paper)

“The limitations of SMOS measurements are twofold: 1. SMOS has a large spatial resolution (about 35 km at nadir view) and thus SMOS signal comes from diverse ice types and even open water within the resolution. It is difficult to decide what kind of ice thickness SMOS really measures since the ice thickness distribution within the spatial resolution is not well known. 2. Under cold Arctic conditions the maximum retrievable ice thickness from SMOS is about 50 cm, and varies depending on the ice temperature and ice salinity. SMOS-derived ice thickness depends on the thin ice part in the ice thickness distribution within the spatial resolution while the contribution of the thicker ice part can not be quantified due to the limited penetration depth. Thus, the overall mean thickness for a mixture of thin and thick ice can only be estimated in a statistical sense when the thickness distribution function is known.”

Answer 2: (added at the end of section 5 in the revised paper)

“The implementation of a lognormal function in Algorithm II* is an approximation of the ice thickness distribution within the SMOS spatial resolution. This is an attemption to correct the underestimation of ice thickness caused by the plane ice layer assumption in Algorithm II. However, there are uncertainties concerning the ice thickness distribution function and the determination of logsigma, which was derived from IceBridge data mainly over multi-year ice regions. The validity of this lognormal function in thin ice areas remains to be investigated. Under the assumption that ice thicknesses within SMOS spatial resolution follow a lognormal distribution, the SMOS ice thickness retrieved from Algorithm II approximates the modal ice thickness of the lognormal distribution, and the ice thickness retrieved from Algorithm II* approximates the mean ice thickness.”

Answer 3: (added at the end of section 8.1)
"We use SMOS Algorithm II for the comparison with ice thicknesses derived from MODIS thermal measurements because both represent the modal (level) ice thickness of undeformed ice."

In the following we address the detailed comments given in the supplement document of the review according to page and line numbers.

P5735 The Title is changed to "SMOS derived thin sea ice thickness ..."
P5736
line 5: We added "up to 50 cm" after "sea ice thickness"
line 23: "The altimeter" is changed to "These early radar altimeter"
P5737
line 3: "100 km" is changed to "25-100 km"
line 14: The upper thickness range for the radiometer derived thickness is correct, it is 10-20 cm according to the studies referred to in the text.
Line 22: Sea ice emissivity (i.e. emission, and thus brightness temperature) depends on the dielectric contrast, i.e. Fresnel transmissivity coefficient, between sea ice and air. We added "(i.e. brightness temperatures)" after "further ice emission".
P5738
line 6: "The footprint varies" is changed to "The spatial resolution varies".
Line 10: "IceSat" is corrected to "ICESat".
P5740
line 22: It is true that JRA-25 covers the period from 1979 to 2004. However, JRA-25 is transitioned to JCDAS, which takes over JRA-25 after 2005 on a real time basis using the same assimilation system (Onogi et al., 2007). This additional information was added in the revised paper.
P5741
line 5: We added a reference (Kerr et al., 2001).

line 7: “latitude” is added before “85°”. We added “The southern boundary of the north polar region is defined as latitude 50° for the sea ice thickness retrieval.”

line 10: We added a reference (Camps et al., 2005).

line 11: We changed “footprint” to “spatial resolution”.

line 16: We changed “The SMOS L1C data are given on the Discrete Global Grid (DGG) system. The DGGs are fixed Earth grid coordinates of the ISEA 49 hexagonal grid centers which have a spatial distance of 15 km (Indra, 2010).” to “The SMOS L1C data are geolocated in an equal-area Discrete Global Grid (DGG) system called ISEA 4H9, i.e. Icosahedral Snyder Equal Area projection with aperture 4, resolution 9 and shape of cells as hexagon (Pinori et al., 2008). ISEA 4H9 provides a uniform inter-cell distance of 15 km”.

line 18: We first gather all the brightness temperature measurements at each pixel for one day and then make a daily average.

P5742

line 17: We corrected it in the figure.

line 26: We changed “pixels” to “DGG grid points”.

line 27: It is true that by averaging all the measurements we partly smooth out the geophysical and temporal variability. This information was added in the revised paper.

P5743

line 1: We added a link (https://nsidc.org/data/polar_stereo/ps_grids.html).

line 11: Explained above.

line 24: The SSS climatology covers the time period of 2002-2009. This information was added in the revised paper.

P5744

line 3: We changed “up to the Bering Strait” to “with the Bering Strait as the boundary”

line 6: We added a reference for ETOPO2 (Smith and Sandwell, 1997).

line 7: The 8km resolution model starts on 1 Jan 1948.

line 8: We added two references for WOA09 (Locarnini et al., 2010; Antonov et al., 2010).

line 12: We changed “At the open northern (Bering Strait) and southern (33S)” to “At the open boundaries” line 20: We added a reference for PHC (Steele et al., 2001).

line 23: Compared with Fig.4, the PHC reveals less variability.

line 24: The period is given above.

line 26: We added “Annually averaged river run-off based on the Fekete et al. (1999) dataset is introduced as a virtual salt flux, which is summed at certain coastal grid points (at approximately the river mouths) to the freshwater forcing, namely to the precipitation (from the NCEP reanalysis) minus evaporation (computed in the model)”.

P5745

line 1: We emphasize with this sentence that since the SSS directly influences the ice salinity, it is necessary to use SSS weekly climatology instead of keeping SSS as constant. We rewrote this sentence to make it clear.

line 9 and line 26: We added “The upper limit for accurate MODIS based ice thickness is 35-50 cm, but we show anyway in the thickness chart a larger thickness range. MODIS ice thicknesses larger than 50 cm show areas of thick ice without accurate thickness estimate.”

P5746

line 15: The effect of a snow layer on the L-band emission is twofold. One is the thermodynamic effect on the bulk ice temperature, the other one is the effect on the emissivity. The first factor is considered in our study by including a snow layer in the thermodynamic model. However, the second factor can not be investigated with the three-layer (air-ice-water) emission model based on the model developed by Menashi et al. (1993) since we can not add a snow layer in this model. We agree that the radiative contribution of a snow layer to the overall brightness temperature could be one of the major uncertainties in our retrieval, which we can not quantify right now. The effect of a snow layer on thick ice (compared to the penetration depth) has been investigated in Maaß et al. (2013b) with a multi-layer emission model that includes a snow layer. According to the model used in that study, whether or not the ice snow-covered has a higher impact on the brightness temperature of thin ice than the thickness of the snow cover. However, an inter-comparison and validation of the different models for thin ice has not been done yet. A future ice thickness retrieval may benefit from including precipitation data, in order to classify snow-covered and bare sea ice, respectively. We added in the conclusion P5765 line 9 “The quantification of the effect and uncertainty caused by a snow layer is considered as future work.” Instead of “The model does not include a snow layer.” we used following sentences in the revised paper. “The model does not allow for adding a snow layer. A snow layer has a twofold effect on the L-band emission. One is the thermodynamic insulation effect, which will be discussed in the following section, the other is the radiative contribution to the overall brightness temperature. To consider the second effect an elaborate inter-comparison with a multi-layer emission model, which includes a snow layer (e.g. Maaß et al. (2013b)) would be necessary.”

P5747

line 13: We changed “and can therefore be applied to ...” to “therefore we can calculate ice salinity based on the Arctic-wide SSS climatology.”

P5749

line 2-3 and line 12-14: We added the definition of T_s : “T_s is the snow surface temperature. In case of bare ice this is the ice surface temperature.” T_s is calculated with leastsquare method for each d_{ice} under thermal equilibrium assumption. We added in line 15 “The snow thickness h_s is calculated with d_{ice} according to the relationship given in Doronin (1971) (see section 2.4).”

line 16: This sentence is rewritten as “As an approximation we first calculate k_i with $0.5(T_s + T_w)$ instead of $0.5(T_{si} + T_w)$. Here we neglect the difference between T_s and T_{si} . This makes a minimal change in k_i.”

P5751

line 14: The TB over 100 % ice covered area changes from 105 K (for very thin ice) to 250 K (for very thick ice). The ice thickness increases fast in the freezing period, e.g. from October to December. 220 K is a good approximation of the mean TB over thin ice covered areas.

line 22-25: We rewrote these two sentences as “There are mostly more than 100 TB measurements at each grid point in the Arctic region per day. By averaging the measurements we on the one hand reduce the measurement uncertainty, on the other hand smooth out the temporal and spatial variation. We describe the variability of TB by dividing the standard deviation of TB with the square root of the number of measurements during one day at each grid point. This

is mostly less than 0.5 K in the Arctic, except for the strongly RFI affected regions."
line 26: We added "and the uncertainty caused by the missing physics."
P5752
line 17: For less saline ice we can retrieve much thicker ice, that is, d_{max} is considerably higher than for saline ice. However, the retrieval is also very sensitive to ice salinity. Accordingly the uncertainty of the retrieved ice thickness due to the ice salinity is also high.
P5753
line 3: "The inherent skewness of the thickness distribution results in a considerable underestimation..." is changed to "SMOS-derived ice thickness depends on the thin ice part in the ice thickness distribution within the spatial resolution. This leads to a considerable underestimation..."
line 16: Under the assumption of a lognormal ice thickness distribution, the logmean μ is calculated using leastsquare method comparing with the observed brightness temperature.
line 25: It is true that logsigma depends on the region and the sea ice types. More studies are needed concerning the variability of this parameter over thin ice. Please refer to the main answer Nr. 1.
P5754
line 12: We are aware that the constant logsigma may not be valid for the entire Arctic region. Furthermore, this method may especially cause errors in regions where the ice thickness distribution does not follow a lognormal distribution. More investigation will be carried out in the future based on more observation data.
line 18: Changed to "decreasing temperature."
P5755
We added two references (Kaleschke et al. (2001); Spreen et al. (2008))
P5756
line 27: The modeled SSS shows strong seasonal and inter-annual variability in the Lena Delta which is consistent to the observations.
P5757
line 6 and line 10: The correlation is almost the same with PIOMAS and TOPAZ. Instead of

“PIOMAS” we used “model outputs” in both sentences.

line 14: We added a reference(Kaleschke et al. (2013)).

line 26: The SMOS ice thickness along the 200 km flight track is quite homogeneous with a standard deviation of 1 cm. That is the reason why we only compared the mean value. This information was added in the revised paper.

P5758

line 3: The standard deviation is removed from the figure.

line 5: The ice thickness measured by EM-Bird is total ice thickness (ice thickness + snow thickness). No snow thickness estimation was made.

P5759:

line 4-7: We compared ice thicknesses from Algorithm I, II, and II* (blue, black, and red solid lines in the upper panels of Fig. 11-13) with model outputs and EM-Bird data. The model outputs can not be considered as validation data, only as inter-comparison. We rewrote this paragraph: “The comparison between Algorithm I and II shows that by taking into account the variability of ice temperature and ice salinity the Arctic-wide ice thickness distribution gets more realistic. However, the underestimation of ice thickness caused by the one plane layer assumption is still a shortcoming of Algorithm II. This problem is partly solved in Algorithm II* by implementing a lognormal ice thickness distribution function, which is a first approximation of the inhomogeneity of natural ice. The inter-comparison with model outputs shows a considerable advantage of Algorithm II*, which produces ice thickness values close to the model outputs at least in the freezing up period. Furthermore, good agreement is found between Algorithm II* and EM-Bird validation data in the Laptev Sea. Therefore, Algorithm II* is used to retrieve ice thickness from SMOS data operationally.”

P5760

line 2: “NSIDC grid resolution” is changed to “SMOS ice thickness grid resolution of 12.5 km”.

line 10: This item is handled in the main answers No. 1 and No. 3.

line15: “averaged” is changed to “modal”.

P5761

line 1: Snow (or ice in case of bare ice) surface temperature T_s derived during SMOS ice thickness retrieval is compared with snow (or ice) surface temperature T_s estimated from MODIS data.

line 7: We included the pixels with lower ice concentrations because these pixels are also included in our SMOS sea ice thickness product.

line 20: All variable names are added in the revised paper.

line 22: "at the ice temperature as low as -10° C" is changed to "under cold conditions."

P5763

line 10: Minimum is correct. If the saturation ratio reaches 100 %, what we retrieve is the minimum of the actual ice thickness, which is at the same time the maximum retrievable ice thickness.

line 14: "due to ice deformation" is deleted.

line 20: A more extended discussion is done in the main answer No. 1.

line 26: "and indicates a possible shortcoming of our retrieval method" is deleted.

P5764

line 4: It is true that the difference between Algorithm II and II* is greater than the difference between Algorithm I and II. However, considering that the correction factor between plane layer ice thickness and inhomogeneous layer ice thickness is on average about 2, any change in the plane layer ice thickness would result in twice as much of a change in Algorithm II*. We will try to improve both steps in the future.

Fig.2. Caption: The caption is changed as follows: "The RFI-induced data loss in the Arctic from 2010 to 2012. The data loss is defined as the ratio between the number of RFI contaminated measurements and the number of total measurements. Much less data loss can be observed in 2012 especially in the Canadian Arctic Archipelago compared with the map of 2010."

Fig. 3. V+H is corrected to 0.5(V+H)

Fig. 5. different d_{max} is marked in the plot.

Fig. 10. 1,1 unity line was added. We added in the caption "The thin black line is the 1,1 unity

line.”.
Fig. 11. The ice surface temperature mentioned in the y-axis is the snow (or ice in case of bare ice) surface temperature T_s. It is not the snow-ice interface temperature T_{si}. The bulk ice temperature T_{ice} is correlated with T_s , and T_s is one of the parameters we provide in the SMOS ice thickness data set. Therefore, we plotted T_s instead of T_{ice}. We added “middle panel” after “ice concentration” in the captions of Fig. 11, 12 and 13.
Fig. 16. and Fig. 18. In the caption we changed “averaged” to “modal”
Fig. 20. In the caption we changed “the 30 days” to “selected 30 days between 2009 and 2011”

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