The authors thank the referee #1 for the review and suggestion to our manuscript. We would like to make the following clarifications and responses to the comments.

Comment from the referee:

The authors use laser-based snow freeboard and radar-based snow thickness as well as the sea ice thickness from OIB flights. One problem of the present manuscript arises from the fact that the sea ice thickness in the OIB product was derived using the snow freeboard and the radar-based snow thickness (Kurtz et al., 2013). Therefore, it is not very surprising that the authors find a very high covariance between snow depth, thickness and freeboard because the quantities can not be considered as results from independent measurements. The "verification" in Figure 7 seems to just exemplify this circular reasoning. Additional problems arises from the fact that different snow depth algorithms for OIB exist and that the instrumentation has changed from year to year (Kwok et al., 2017). The dependency of the used data sets and the lack of discussion of the used assumptions cast serious doubts on the validity of the conclusions.

Concerning the judgment by the referee that the verification in the manuscript is "circular reasoning", we would like to point out that the verification is carried out based on the data independent from what used in the retrieval process. **Three clarifications are provided as follows.**

1. Data independency in the covariability analysis. Although the OIB data is used in the analysis, the covariability is carried out between two independently measured parameters: **the total freeboard** measured by airborne topographic mapper (ATM), and **snow depth** measured by ultra-wideband frequency-modulated continuous-wave (FMCW) radar (see Farrell et al., 2012 and related references). Thus the two observations can be considered as independent. Moreover, the covariability analysis is **NOT** carried out between the freeboard (or snow depth) and sea ice thickness, since sea ice thickness is a derived parameter based on the hydrostatic equilibrium relationship. Note that sea ice thickness of OIB is only used in the verification of the retrieved parameters.

2. **Covariability between snow depth and total freeboard is physically sound, and NOT due to that they are not independent.** Considering Equation 1 of the manuscript (isostatic equilibrium model) which relates snow depth, sea ice thickness and the total freeboard, the relationship can be expressed as follows (using the notation in the manuscript):

$$FB_s = \frac{\rho_w - \rho_i}{\rho_w} \cdot h_i + \frac{\rho_w - \rho_s}{\rho_w} \cdot h_s \approx 0.1 \cdot h_i + 0.67 \cdot h_s$$

As indicated by this relationship, if the value of snow depth is considered a random variable, the value of the total freeboard (also a random variable) is clearly correlated with it. Therefore, this covariability is inherent in the physics, NOT due to the data collection process (or OIB in this case). See also Kwok et al., (2011) (subfigure d of figure 10, 11 and 12) for a similar analysis which also provides justification of covariability, but on a different spatial scale of 4 km.

3. **Role of the covariability in the retrieval.** The covariability (between snow depth and total freeboard) is a statistical relationship derived from the OIB data, and the parameters derived from functional fitting (see Section 3.1) using basin-wide observations that are integrated into the retrieval. During the retrieval, the input data include the total freeboard and the L-band TB, and the output data are sea ice thickness and snow depth, while the covariability (in terms of the fitted parameters) serves as a supportive info. The only place where the local information of covariability is used is in the analysis of the sources of the retrieval error in Section 3.2 and Section 4. During the actual retrieval, the local covariability information is NOT available, and Figure 7c and d shows that the corresponding retrieval results are in good consistency with the observed sea ice parameters. Therefore, to summarize the proofs, for the design of the retrieval algorithms and the verification, we does not consider there exists circular reasoning.

Second, concerning the quality of the OIB data especially the snow depth algorithms applied for each year, we make the following explanations of the details of OIB data used in the analysis. In Kwok et al. (2017) (also the reference provided by the referee), five retrieval algorithms (NISDC, GSFC-NK, SLRD, Wavelet, JPL) for snow depth in OIB are discussed. In these five algorithms, both NISDC and GSFC-NK retrievals have lower scatter compared to in situ campaigns and large inter-annual variability compared to the climatological fields. Kurtz et al., (2013a) indicates that IDSI4 product are capable of providing a reliable record of snow depth through independent data comparison. For our analysis and validation, we use IDSI4 dataset in 2009-2013 (Kurtz et al., 2015), which is the existing NSIDC product, and quick-look dataset in 2014–2016, which is based on GSFC-NK algorithm. Data from the quick-look data is used for the campaign which is not accessible since 2014. Quick-look product, which uses modified algorithms to minimize freeboard biases (Kurtz, 2013; Kurtz et al., 2014), takes the consideration of different instrument characteristics of the snow radar. Despite that it is possible that the uncertainties in this product are higher than in IDSI4 product (Kurtz et al., 2013b), we consider the data product as used in the manuscript are optimum in terms of the overall small bias and good consistency with in-situ measurements, for the purpose of the analysis of covariability and the verification of the retrieval algorithm.

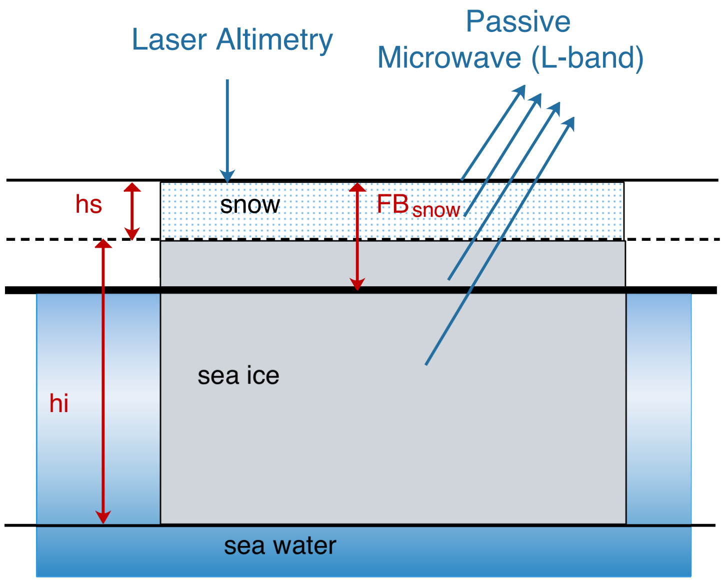
Third, we want to emphasize that the main purpose of the manuscript is the introduction of the retrieval methodology, and the demonstration of its validity through verification with OIB data. Since the “true” values of both snow depth and sea ice thickness are available from OIB, we use the total freeboard measurements (to simulate satellite laser altimetry) and SMOS TB data for the retrieval and verification with the aforementioned “true” or reference values of OIB. Similar practice of using OIB data for verifications to the retrieval algorithm is also common. Take Maaß et al.

(2013) as an example. The snow depth from OIB is used to verify the retrieved snow depth (figure 9 and 10), while the sea ice thickness from OIB is used to guarantee the prerequisite of the retrieval algorithm that the sea ice is thick enough. With respect to the data production with actual satellite data, the covariability that is specific to the resolution of the satellite altimetry should be used (which can be potentially derived from OIB data due to the higher resolution) and compared against other independent data sources for verification, such as other campaigns. We consider this an important direction of future work, which is beyond the length and scope of current work.

Comment from the referee:

Regarding the use of L-band brightness temperatures I found the Figure 1 misleading with emissions arising just from the surface and not from the ice volume or deeper layers. Some crucial model assumptions are not explained in the manuscript, e.g. the parameterization of ice salinity. It seems that a thickness dependent parameterization was used otherwise I can not explain the large sensitivity to ice thickness exceeding 3 meter. All this should be explained and discussed in the manuscript. This is perhaps described in the reference Zhou et al. (accepted) but is not yet available to me.

First, concerning the misleading plot (Figure 1), our original intention is to contrast the altimetry and passive remote sensing techniques. Here we modified the figure to avoid the unnecessary misleading info. The modified figure is shown below.



Modified figure 1. Schematic view of sea ice parameters and active/passive remote sensing of the sea ice cover. The parameters include sea ice thickness (hi), snow depth (hs) and snow freeboard (FBsnow).

Second, concerning the L-band radiation model used for the retrieval, the model is a multi-layer radiation model based on sea ice type-dependent salinity and temperature profile. The model is verified using OIB and SMOS observational datasets. The manuscript documenting the radiation model has been accepted by International

Journal of Remote Sensing (Zhou et al., 2017), but it is not available for public at this moment. Here we would like to quote relevant description of the model and the accompanying figure as below. Please also see Section 2.3 and Figure 3.a (salinity profile) for other supportive information.

> *"In order to explore the sensitivity of the L-band radiation model to the properties of sea ice, we reformulate the model to include multiple layers for sea ice and snow, instead of a single layer adopted by Maass et al. (2013). Specifically, we use a linear vertical temperature prole for the sea ice and snow, based on prescribed thermal conductivity of sea ice and snow, following Untersteiner (1964) and Yu and Rothrock (1996).*
>
> *…-*
>
> *Furthermore, we distinguish the difference in salinity between first-year ice (FYI) and multi-year ice (MYI). For FYI, following Cox and Weeks (1974), a constant salinity prole based on the ice thickness is used to characterize the fact that the salinity has not drained. For MYI, a salinity prole based on observations is used to reflect the effect of brine drainage and flushing during the melt season.*
>
> *…*
>
> *We denote the original model as the single layer radiation model as adopted in Maass et al. (2013), and the improved model as the multi-layer model with ice type dependent vertical temperature and salinity prole. Figure 4.a shows the scatterplot between the original modeled and SMOS observed T_B for 22 Mar 2012, while Figure 4.b is for the improved model. The original modeled T_B tends to cluster around 250K, irrespective of the large range of observed T_B values (y-axis). Clearly, the improved model produces a much better t than that of the original model (0.84 as compared to 0.60 for R^2). The overestimated T_B by the original model for both FYI (triangles) and MYI (circles) are significantly reduced. Figure 4.c (4.d) show the scatterplot for 18 Mar 2014 and 1 Apr 2015 under the original model (the improved model). Again, the simulated T_B is in much better agreement with observations (0.01 as compared to 0.68 for R^2). Taking a close look at Figure 4.b and 4.d, we note that the simulated T_B on 18 Mar 2014 and 1 Apr 2015 is not tightly clustered along the t line as that of 22 Mar 2012, which is also reflected by the relatively lower R^2 in Figure 4.d as compared to Figure 4.b. For these two days, there exist extensive leads as observed by OIB campaigns, which are small in width and not directly distinguishable by L-band observations of SMOS.*
>
> *…"*

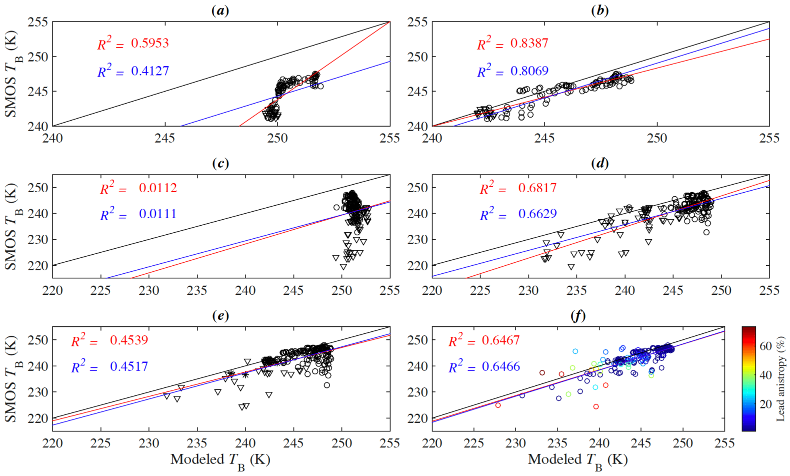


Figure 4. Comparison of modeled and observed T_B for OIB data from representative days. Subfigure *a* to *d* compares the original model and the improved model (with the multi-layer formulation and the vertical salinity and temperature profile). Subfigure *a* (or *c*) and *b* (or *d*) show the evaluation of the original model and the improved model for 22 Mar 2012 with no presence of sea ice leads on the OIB track (or 18 Mar 2014 and 1 Apr 2015 with the OIB tracks covering sea ice leads). The effect of the integration of MODIS lead map is further compared by subfigure *e* (with the improved model but without lead information) and *f* (with lead information). FYI and MYI are marked out by triangles and circles, respectively. Red lines are the least square fit, whilst blue lines are the least square under the constraint that the slope of the fit line is 1. Black lines are 1:1 lines.

We would also like to provide the accepted manuscript (Zhou et al., 2017) to the referee upon request. Furthermore, we want to emphasize the sensitivity for sea ice over 3 meters thick arises from that the retrieval of ice thickness is based on the total freeboard and L-band TB. The referee is kindly directed to Figure 3c, in which the relationship between the L-band TB and sea ice parameters is shown. The retrieval is carried out under a certain total freeboard value (shown by green constant-freeboard lines in the figure), but a certain snow depth. Therefore, even the TB saturates when sea ice is thick under a prescribed snow depth (black lines in Figure 3c), for the proposed algorithm there still exists good retrievability. Section 2.3 (line 26 on page 5) gives a more thorough description on this issue.

Comment from the referee:

Another issue with the manuscript is the overall aim of the method. It is not yet clear what is the main advantage of combining laser altimetry and L-band radiometry? Is the method for the fusion of airborne and satellite data or for to be used for future satellite missions? For the ICESat period there are no L-band radiometer data available. For the ICESat-2 period it is not clear if SMOS and/or SMAP are still in operation. What about the different spatial and temporal samplings and uncertainties? These practical considerations are not yet even mentioned.

First, concerning the advantage of the proposed retrieval algorithm, we would like to further emphasize the status-quo of the retrieval of snow depth and sea ice thickness (see also Section 1, the second and the third paragraph). Current retrieval algorithms mainly focus on a single type of sea ice parameter (such as ice thickness or snow depth), and thus exists large uncertainty due to the lack of knowledge of other parameters. The aim of the proposed algorithm is to retrieve both parameters simultaneously, without simple assumptions such as the snow depth estimations (from climatology or reanalyses) in laser altimetry. The retrieved parameters should be able to serve as better estimations of these parameters and serve potential climatological and operational usage.

Second, concerning the retrieval with simultaneous satellite campaigns, we mainly target at the synergy of observational data between ICESat-2 and SMOS/SMAP. The manuscript provides a basis for the retrieval algorithm design with actual satellite data. ICESat-2 is currently scheduled for launch in 2018 (see https://icesat-2.gsfc.nasa.gov). SMOS and SMAP have been in service since late 2009 and early 2015. Although the designed lifespan of SMOS and SMAP are both 3 years, it is worth noting that SMOS have been providing service for over 7 years. Since it is invaluable for the availability of satellites that co-register the interested regions with complementary capabilities, we would like to express their optimism in the satellite campaigns and determination to make better usage of potential data for the retrieval of sea ice parameters. Additionally, the ongoing Chinese satellite campaign WCOM (Shi et al., 2016) with passive microwave remote sensing (including L-band) capabilities will cover the Arctic region, which serves as another candidate dataset. WCOM is scheduled to launch before 2020. For the co-registration of WCOM and ICESat-2, the combined retrieval can be carried out for the corresponding total freeboard and L-band TB measurements.

Comment from the referee:
P4L7 The resolution of the radiometer depends mainly on the size of the antenna.

According to the comment, the authors have made the correction to the manuscript with respect to the resolution of radiometry.

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