Response to Reviewer 2

This work provides an active and passive simulation study for the East Antarctica using SMRT model. Simulations are done for a wide range of frequency channels from 5.2 to 89GHz. The authors want to draw an analogy between the ice moons and this particular region of Antarctica and looks like the authors want to claim that this region would be a good example for the study of icy moons.

From my personal perspective, some major points need to added to the paper and some concerns need to be resolved before the paper can be published.

We thank the reviewer for a thorough reading of our manuscript, and for constructive suggestions.

Here are some general comments for the paper:

1. In the abstract, the authors need to provide some conclusions that they obtained from this study and also need to provide the "up-shot" (how would this study contribute to a "larger picture" and would help answer a problem).

The larger picture is provided in the abstract which states that (i) the model well reproduces Antarctica data especially showing the need for an upper thin ice layer (ii) it helps explain the passive and active microwave observations of icy moons, but more work is to be done to interpret the very large backscattering signatures.

We added a sentence to the abstract to make it clearer:

"**More work is still to be done to fully reproduce the microwave signatures of icy surfaces in the solar system.**"

2. If the goal of the paper is to show that the Region of Interest (ROI) in the East Antarctica is a good analogy for icy moons, the active and passive data signature, and the measurement set-up for the icy moons needs to be presented and the features of the icy moons and ROI needs to be discussed. In such a way, the analogy could be drawn. Currently, the discussions are not sufficient.

One of the goals of the paper is to test whether the Antarctica ice sheet could serve as a good analog for the surfaces of Saturn's icy moons based on their measured active and passive microwave signatures. This question is valid because these surfaces share a common composition (dominated by water ice) and a potential common structure as the surfaces of icy moons are thought to be covered by a snow-like material originating from the E-ring (itself fed by Enceladus' geysers). This is explained in details in section 2.

Regarding the measurement set up for the icy moons, it is presented in length in Le Gall et al. (2023) as referenced in the Introduction section of the paper. It is out of the scope of this paper to repeat the (very long) description of the acquisition and reduction of this dataset.

To make it clearer on the origin of the icy moon data we added a sentence in the introduction:

"**The microwave data obtained on icy moons has been detailed in Le Gall et al. (2023)**"

3. Since the paper is majorly doing simulation to match up the observations, if parameters from icy moons can reproduce the measurements over ROI, this can also imply an analogy.

We are not sure to understand the reviewer's question/suggestion. One of the main goals of the paper was to test the Antarctica ice sheet as a potential analog for icy moons, not the other way around. The microwave observations of the Antarctica ice sheet are well reproduced by the model without having to invoke other parameters.

Detail comments are the following:

1. Resolution. As indicated by the sensor parameters, the scatterometers and radiometers are having different resolutions (ASCAT, Qscat 25km, AMSR2 based on frequency). In this work, the authors project the different data sets into uniform 12.5km grids. In such a way, the near by data pixels would be highly correlated and would not provide extra information for pixels within the resolution of a given data set. Such a interpolation would ignore the heterogeneity within a large resolution and may mistakenly use the coarse, larger area averaged measurement to represent the measurement for a smaller area. I believe a better way is to aggregate the high resolution data into low resolution such that different data sets can have the same averaging effect over the measured area. Can the authors provide some discussion on this?

The objective of this study is to provide a physical interpretation of multi-frequency passive and active microwave observations using reasonable geophysical parameters. While we acknowledge that observations from nearby pixels are likely spatially correlated for each observation type, this study does not attempt to explicitly exploit the spatial structure of the data.
When merging datasets with differing spatial resolutions, trade-offs are inevitable. As the reviewer suggested, one approach is to average the higher-resolution observations to match the lower-resolution dataset, specifically, the spatial resolution of the 6 GHz passive microwave channels. In this study, we chose to grid all observations to a common resolution of 12.5 km, which is close to the resolution of the 36 GHz AMSR2 channel. The goal is not to achieve a perfect match to each individual observation, but rather to ensure a consistent and physically reasonable interpretation across frequencies and observation modes. **The spatial resolutions of the different observations have been added in Table 1.**
Using a coarser grid (e.g., matching the 6 GHz resolution) would not alter the conclusions of the study. It would primarily smooth out some of the stronger scattering signatures observed at higher frequencies, at 36 and 89 GHz.

2. If my memory serves me correctly, L3 data from AMSR is already grided. That data set might be better? Only a suggestion.

In this study we use the L1R from AMSR2, at each native spatial resolution and at swath level as specified in section 2.1 in the paper. We do not make use of the L3 data from AMSR.

3. The way of data averaging is not clear to me. How is the measured data averaged to a data point in each frequency?

This has been clarified in the text: **'For each observation type, the swath data are projected over a 12.5 km grid using the EASE-grid 2.0 Southern hemisphere grid projection (Brodzik et al., 2012, 2014). All pixels falling within a given grid point are averaged over a full year of data, for each instrument and observation conditions (frequency, polarization, incidence angle, and mode).'**

4. In matching the data, active part looks fine to me, but the passive part doesn't look satisfactory. The observables from radiometers are brightness temperatures, emissivity values are derived values. Radiometers are very accurate, usually the errors are within 3K, assuming a physical temperature of 270K, this corresponds to an error in emissivity around 0.011. I would suggest the authors show the comparison in terms of brightness temperature. In such a way, the forward simulation would show a difference of 10K or more. Match up can be improved.

For passive microwave observations, we agree that the analysis could have been conducted directly using Tbs. However, emissivities were used in this study for two main reasons: 1) most studies on icy moons present results in terms of emissivity rather than Tbs, and 2) our team has extensive experience working with emissivity over snow- and ice-covered surfaces on Earth.
The relationship between emissivity and brightness temperature has been clarified in the manuscript, in section 2.1.
'Note that at a frequency where the atmosphere is transparent, the radiative transfer equation reduces to $T_B = e \times T$, and a difference of 0.01 in emissivity e with a snow / ice temperature of T = 270 K results in a change of 3 K in T_B.'

It is important to note that achieving agreement within 10 K across all passive microwave channels from 6 to 89 GHz and for both polarizations is already highly challenging. Even at a single frequency and polarization, significant discrepancies are common. For example, Burgard et al. (The Cryosphere, 2020) reported differences exceeding 10 K at 6 GHz V polarization over sea ice, despite multiple model adjustments. See below.

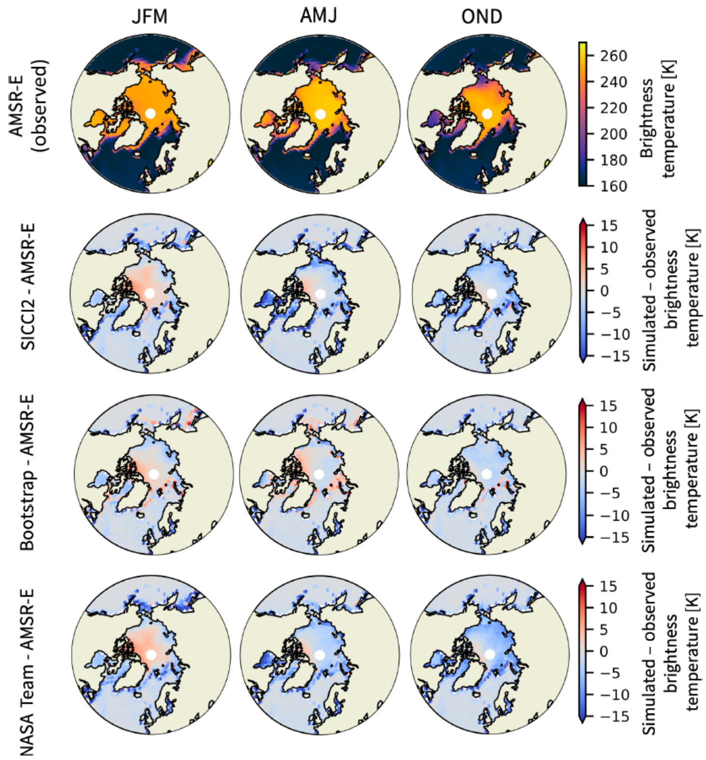

Figure 4. Observed brightness temperatures by AMSR-E (top row). Differences between brightness temperatures simulated with ARC3O from MPI-ESM output assimilated with SICCI2 (second row), Bootstrap (third row), and NASA Team (bottom row) sea ice concentration and observed brightness temperatures. The columns stand for the three cold seasons: JFM, AMJ, and OND. Summer (JAS) is discussed in Sect. 4.4.

At ECMWF, Hirahara et al. (Remote Sensing, 2020) performed simulations of Tbs over continental snow and compared them to AMSR2 observations from 6 to 89 GHz. The discrepancies observed were substantial, particularly for horizontal polarization, and increased significantly with frequency, both in terms of bias and standard deviation (see the red curves below).

These findings highlight the considerable challenge of achieving good agreement between simulated and observed passive microwave signals under frozen surface conditions, especially across a broad range of frequencies and polarizations. In this context, the level of agreement achieved in our study can be considered very acceptable.

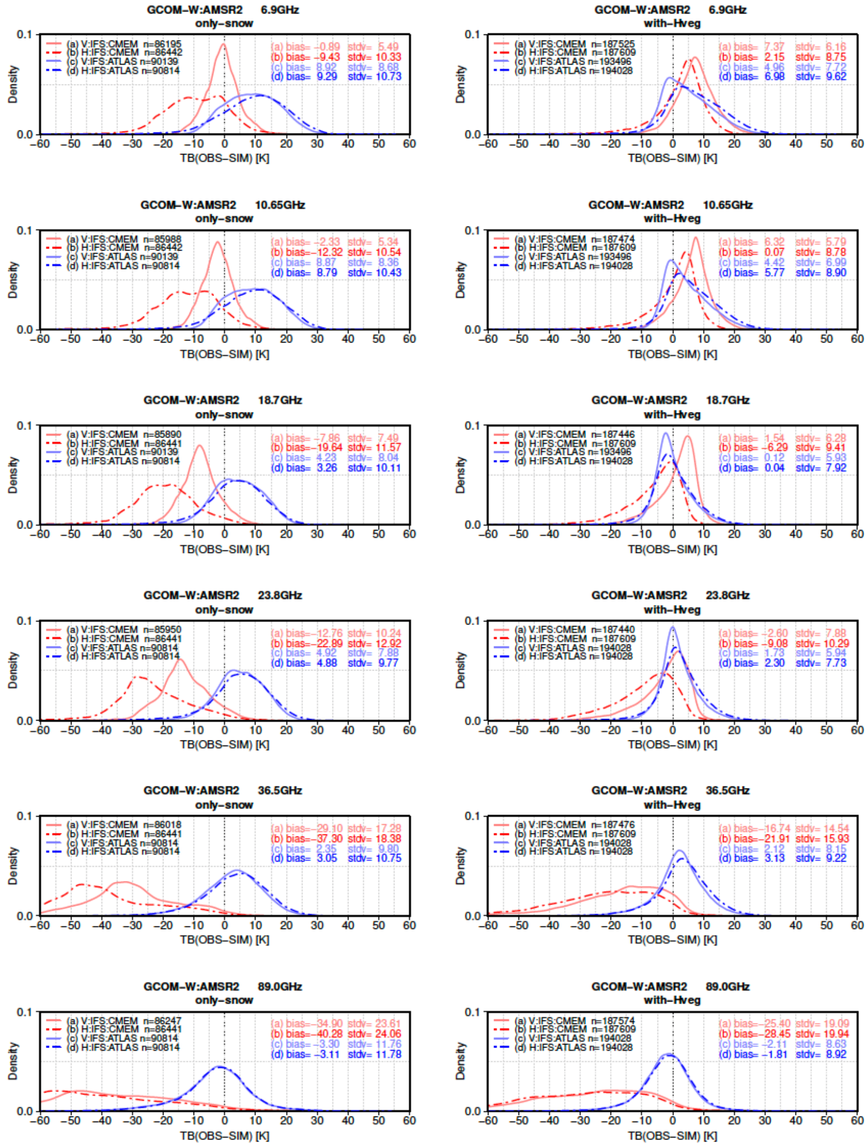

Figure 13. Kernel density estimation of AMSR2 first guess departure (O−B) in K, for January 2019, for IFS:ATLAS (blue) and IFS:CMEM (red), at V (solid lines) and H (dotted lines), for snow-covered (excluding glacier and ice shelves) area without (left) and with (right) high vegetation, for the six AMSR2 frequencies from 6.9 GHz (top) to 89 GHz (bottom).