Review response on

"From snow accumulation to snow depth distributions by quantifying meteoric ice fractions in the Weddell Sea" by Stefanie Arndt et al.

Anonymous Referee #2

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This study aimed to try to understand some of the complex snow processes that occur on Antarctic sea ice such as snow-ice formation and super imposed ice in order to improve snow models and also satellite measurements of sea ice volume. They used multiple Snow Buoys and insitu core data from multiple ship campaigns over the years in the Weddell Sea. The snow buoys tell the amount of snow accumulations and melting that occurs throughout the year, and the cores give the amount of snow ice and super imposed ice. A 1-d sea ice model and a more sophisticated snow model (SNOWPAK) are used to model the amount of snow, and super imposed ice and ice formation that is taking place at the buoy locations as they drift throughout th4e Weddell Sea. They found that the snow models were not the best at producing the amount of snow and ice compared to observations, which is likely caused by missing processes that are taking place within the ice. They also determined that more snow/ice formation is occurring in the western weddell sea and at lower latitudes.

While this paper was well written and easy to follow, I wish there were more details on the individual models and processes there in. What ways could the models improve to improve the snow-ice and super imposed ice estimates? How do the models produce the snow-ice?

More details like this could improve the paper. What would happen if you change the densities and salinities of the snow and ice in the models, will the snow depth be more similar to the buoy snow depths? More details like this would help.

Otherwise, I really enjoyed this study, and I think It makes a great addition to our understanding of the Antarctic snowpack.

We sincerely appreciate the constructive input provided by the reviewer for enhancing our manuscript. Also, we are delighted to hear that they enjoyed reading it. To address the highlighted lack of detail in describing the two model approaches, we have substantially revised both subsections, as detailed below.

In addition to both reviews, we conducted a re-assessment of all SNOWPACK model results due to the following reason: Upon re-evaluating the model code for running the SNOWPACK simulations, we identified an error in writing out the ERA5 reanalysis data to a format suitable for the SNOWPACK model. In an earlier version, the surface fluxes were provided in 6-hour intervals, requiring division by 6 to align with the hourly input data. However, in the current version of retrieved ERA5 data, all parameters, including surface fluxes, were available in hourly steps. Despite this, they were still divided by 6 when producing the meteorological input for the model. This error has been rectified, and all simulations were re-run using the corrected meteorological forcing data.

2.3 One-dimensional thermodynamic sea ice model

A simple one-dimensional thermodynamic ice growth model based on the number of freezing degree days (Thorndike, 1992), as used in Arndt et al. (2021), is applied to estimate the evolution of the thermodynamic sea ice growth at the bottom of the ice and the resulting ice freeboard. For the latter, a simplified assumption is made that a calculated negative freeboard causes potential flooding of the snow/ice interface and subsequent snow-to-ice conversion, i.e., snow ice formation, both taking place in the same time step. Previous studies by Wever et al. (2021) have demonstrated that such an assumption tends to overestimate actual flooding and snow ice formation on a floe-scale, primarily due to the significant spatial heterogeneity of snow and ice thickness. To address and assess this limitation, the results of the model runs are evaluated alongside in-situ observations (refer to section 2.5).

Model runs are initialized with the measured initial sea ice thickness during buoy deployment. The atmospheric forcing of the model, i.e., surface temperature and heat fluxes, is based on ERA5 reanalysis data (Copernicus Climate Change Service, 2017), which were extracted for the nearest-neighbor grid points of the daily buoy positions.

Reported values for ocean heat fluxes in the Weddell Sea vary, ranging from 2-7 Wm^2 (Lytle and Ackley, 1996; Robertson et al., 1995) in the western part to well above 20 Wm^2 (McPhee et al., 1999) in the central part. Considering that the buoys primarily drift in the inner pack ice, the ocean heat flux for the simulations in this study is set toward the lower end of the range, prescribed with a constant flux of 3 Wm^2.

For snow density and thermal conductivity regionally adjusted parameters, following Arndt (2022), are utilized. Specifically, snow densities of 340 kg m^{-3} and 264 kg m^{-3}, along with snow thermal conductivities of 0.28 $Wm^{-1}K^{-1}$ and 0.17 $Wm^{-1}K^{-1}$ for perennial and seasonal sea ice, respectively, are applied. Further details regarding the model setup can be accessed in the appendix of Arndt et al. (2021).

2.4 Multi-layer snow model SNOWPACK

To estimate the amount of both snow ice and superimposed ice formed during the buoys' lifetime, we use the multi-layer snow cover model SNOWPACK. In the one-dimensional SNOWPACK model, snow microstructure is represented in detail and liquid water flow and refreezing processes are taken into account (Bartelt and Lehning, 2002; Lehning et al., 2002a; Lehning et al., 2002b; Wever et al., 2015; Wever et al., 2016). SNOWPACK was originally developed to represent physical processes in the snow cover in alpine regions, but has been adapted and applied to sea ice environments recently (Wever et al., 2021; Wever et al., 2020).

For our simulations, we initialize the model with the initial snow and ice thicknesses as measured during buoy deployment. The initial snow and ice temperature profile is determined from the ERA5 surface temperature and a water temperature of 271.35 K, assuming that the snow and ice column is in thermal equilibrium. For the remaining properties, we follow the approach of Wever et al. (2021): For the snow layers, we assume an initial density of 275 kg m^{-3}, corresponding to a volumetric ice content of 0.3 m3 m^{-3} and a volumetric air content of 0.7 m3 m^{-3}, and set the grain radius to 0.15 mm, the bond radius to 0.09 mm and sphericity and dendricity to 0. For the ice layers above sea level, we assume the volumetric ice and air content to be 0.95 m^3 m^{-3} and 0.05 m^3 m^{-3}, respectively. Ice layers below sea level are assumed to contain also a fraction of water, calculated from the layers' temperature and an assumed bulk salinity of 1.75 g kg^{-1}.

Following the approach of Wever et al. (2021), we use the Richards equation, combined with the transport equation for salinity to solve liquid water and brine distributions. For two out of the 36 Snow Buoys (2017S49 and 2019S88) the simulations are aborted due to numerical instability and we use a more simple bucket-type approach instead of the Richards equation. In contrast to Wever et al. (2021), we choose an atmospheric stability following Holtslag and De Bruin (1988), as in the SNOWPACK model documentation this was changed to be the new default setting (the effect on the snow depth is minor). Like in the simple thermodynamic sea ice model described above, the ocean heat flux is set to a constant value of 3 Wm^{-2} and the atmospheric forcing is based on ERA5 reanalysis data, specifically surface heat fluxes, humidity, and surface wind.

Here, we present snow-height-driven simulations, which means that the SNOWPACK simulations are forced to closely follow the snow height evolution as measured by the Snow Buoy. While snow accumulation as indicated in the Snow Buoy datasets will lead to an instant increase in the SNOWPACK simulation (like a precipitation event), sudden reductions in snow height will only be incorporated within the scope of the model physics. Wind-induced transport of snow is neglected. The simulated snow densities are used to distinguish between snow (density ≤ 600 kg m^{-3}), superimposed ice (600 kg m^{-3} < density < 918 kg m^{-3}) and snow ice (density ≥ 918 kg m^{-3}).