A review on "Understanding model spread in sea ice volume by attribution of model differences in seasonal ice growth and melt"

The study evaluates the three UK CMIP models performance in reproducing the Arctic sea ice volume seasonal cycle and discusses the inter-model spread using a simple surface energy balance model as a diagnostic tool. The subject of the study is certainly important as the large spread between the coupled climate models concerning the Arctic sea ice volume and extents results in the uncertainty of future climate projections in the Arctic and lower latitudes. Understanding such a spread is crucial for the identification and/or development of more adequate models. A simple approach to explain the model spread is presented by the authors. It consists in using an idealized representation of the sea ice bulk and of the surface energy balance to provide a reference or a framework for the analysis of the more complex model results. It is shown that such an approach can provide some useful estimates of the sensitivity of the net surface heat flux on model variables allowing one to draw important conclusions on the relative role of various factors affecting the seasonal cycle of the sea ice cover. In general, the paper is well written and represents a significant input in the research in this area, and the subject is in the scope of The Cryosphere. The paper can be published after minor revision.

General comments:

1. The authors propose to use a one-dimensional heat balance model. Obviously, in such a box-type or bulk model the sea ice dynamics is neglected. At the same time, we know that the sea ice volume shows significant geographical variability across the Arctic related not only to the variability of the surface heat budget terms, but also associated with the sea ice drift and deformation. Thus, one can expect that changes in the models physics and resolution can affect the sea ice dynamics and it can affect the sea ice volume and contribute to the spread between the models. The authors do not discuss such issues at all. How well do the considered models reproduce the 2D sea ice dynamics? Is there any spread between the models with respect to the sea ice dynamics? Can we expect that different representation of the sea ice dynamics, e.g. amount of the sea ice transport through Fram Strait, can affect the simulated sea ice volume and its annual cycle?
   I understand, that to some extent, averaging over the Arctic ocean solves this problem. However, this should be discussed in more detail. For example, it might be important at which step and how the averaging is done. As far as I understood, the simple model is used at each grid node and then the obtained results are averaged over the Arctic ocean. But at each grid node the advective flux of the sea ice volume is not negligible especially in some regions. Thus, the single-column approach has to be better justified.

2. The authors obviously neglect the heat flux from the ocean to sea ice which is especially important in the Atlantic sector of the Arctic. The authors should discuss the magnitude of this term in relation with the other terms in their simple model.

3. My last comment is related to the applicability of a simple model that the authors use as a diagnostic tool. Obviously, various models can describe the sea ice thermodynamics differently than it is done in such a simple model. The actual sensitivity of the net flux in a particular sea ice model to the model variables can differ from model to model and would also depend on the considered time scale. How large can we expect such differences to be?

Specific comments

Line 193: To summarise, the weaker summer ice melt of the CMIP6 models relative to HadGEM2-ES is driven by a smaller upwelling SW flux from June – August.
It can be the other way round – weaker melt results in a more negative SW flux due to larger sea ice area. How is it possible to identify the cause?

Section 3.3. Variables influencing surface albedo – I suggest to explicitly write the albedo parameterizations used in the models, so that the reader can clearly see what are the variables influencing albedo.

Equations 1 and 2 – variables have to be explained

Lines 220-224: "Despite the substantially higher snow thicknesses in HadGEM3-GC3.1-LL and UKESM1.0-LL, the increase in ice area in the newer models is muted…." It is not easy to follow because there is no reference formula for albedo. How does albedo depend on the snow thickness and ice area? It is not clear

Lines 254-255: It is assumed that the net heat flux is a function of some model variables which are independent of heat flux. But this is not true on the considered time scales. Obviously, albedo and melt pond fraction would depend on the net surface heat flux already on a weekly and monthly time scales. Does it result in a limit of applicability of this assumption?

Equation 3 – superscripts MODEL1 and MODEL2 are not visible.

Line 261: I suggest to write explicitly how the ice volume balance is related to the surface heat flux. I wonder why the ice volume tendency is omitted in the simple model.

Equations 5 and 6 – I suggest different letters for the variable a_melt and the area fractions a_i. Maybe, use capital A for the area fractions, otherwise it is confusing.
Equation 6 – Fsw-net, t is missing
What is the exact definition of a_melt in Section 3 and how is Equation 6 obtained? It is hard to follow.

Line 275: We can use this equation – specify which equation

Obviously, ***Equation 7*** cannot be used for category zero (open water)

Line 351: How is it linearized and what is Bup?

Lines 355-357: First it is stated that Fatmos-ice does not depend on the surface temperature. Next, Fatmos-ice is identified as sum of SW net, LW down and turbulent fluxes. Obviously, turbulent fluxes do depend on surface temperature. It can be argued that LW down also depends on surface temperature on the time scale of the atmospheric boundary layer adjustment (which is not large), because the near-surface air temperature over sea ice is coupled to surface temperature.

Figure 7 and lines 445-450: It should be better explained how the curves in Figure 7 are obtained. Ice melt and ice growth are not described by the model in Section 4. Such terms are simply missing. So it is not clear at all how Figure 7 is obtained.

Line 479: modelled sea ice and growth (??)