

Reply to 'RC1: Comment on egusphere-2023-1103' by Referee 1 (Noel Keenlyside)

We are grateful to Dr. Keenlyside for his further comments on the revised manuscript. Our reply is as follows.

Major comments

- *The authors have addressed all but one of my concerns. I still find the description of how sea ice is treated in mode 1 and mode 2 confusing. I think the authors can be easily address this issue with a little rewriting. Below is a summary of my understanding and points of confusion.*
- After reading through the relevant sections several times, I have understood the following for mode 1: The fraction of ice mass is computed using Eq 2a, 2b, A7a from the prescribed sea ice concentration. However, at line 264, it also states that thickness is also prescribed. Thus, the exact setting for mode 1 are ambiguous.*
- The sea ice temperature is computed using equations 7a, 7b, and A6, using the fraction of ice mass. The introduction of an adjustment for sea ice temperature that accounts for the formation/melting of ice is interesting. However, the values in equations A6 are A7a could be a little better justified.*
- I am sorry but it is still not clear to me why including equations A7b – A10 is necessary, and how it helps to explain the formulation in equation A6. Furthermore, it is unclear why you use $S_i < 1$ and $S_i = 1$ rather than $S_i \leq 1$. Doesn't the formulation introduce a discontinuity? And as far as I could tell the values of d_1 and d_2 are not given. The description of the prognostic formulation for the fraction of sea ice mass, then the Appendix "Relationship between sea-ice concentration and thickness" could benefit from reordering to first discuss mode 1, and then discuss mode 2.*

We believe that the confusion originated from the fact that, in the Appendix section "Relationship between sea-ice concentration and thickness" aspects common to mode 1 and mode 2 were discussed first, and then specific aspects of the two operating modes were described. We admit that this approach made it less clear to understand what parts actually applied to the experiments described in the paper.

Therefore, we have rewritten this section following the Reviewer's suggestion, discussing first the formulation applied in Mode 1 (lines 847-872, Eqs. A7 to A9), and then describing the Mode 2 relationship in the last few lines of the Appendix (lines 874-879, Eq. A10). We have also specified the values of d_1 and d_2 in Eq. A7b as requested, and the value of β in Eq. A8. With regard to Eq. A6, we now specify in lines 844-845:

The parameters in Eq. A6 have been empirically chosen is such a way to achieve a realistic annual cycle of sea-ice temperature.

In the main text, at line 264, we have now spelled out clearly how we prescribe sea-ice concentration and thickness in Mode 1, making references to the relevant equations in the Appendix. The new text (lines 263-270) is as follows:

When the sea-ice scheme is run in operating mode 1, only the change in ice temperature is retained, while the ice mass at each time step is derived from time-evolving values of ice concentration (prescribed from ERA5 data) and thickness (estimated from ERA5 ice concentration and surface temperature, see Eqs. A7 to A9 in the Appendix). If instead the ice scheme is run in mode 2 (i.e. with interactive mass), the mass fraction of sea ice f_i at time $t + \delta t$ is set to the value which satisfies the heat content conservation:

$$HC_i^i(t + \delta t) = M_i f_i(t + \delta t) [c_i(T_m^i(t + \delta t) - T_0) - L_f] \quad (8)$$

and an empirical relationship is used to compute values of s_i and d_i at time $t + \delta t$ from the updated value of f_i (see Eq. A10 in the Appendix).

Minor comments

- L34, *several is an understatement. Haven't there been "numerous" studies with SPEEDY.*
"several" changed to "numerous" as suggested.
- L64, *fullstop missing.*
Corrected

Reply to 'RC2: Comment on egosphere-2023-1103' by Referee 2

We are grateful to the referee for their further comments on the revised manuscript. Our reply is as follows.

Minor comments:

- *line 64: dot missing before 'Although'*
Corrected
- *- line 386: atmospheric temperature in the lower troposphere (at 100 hPa) => atmospheric temperature in the lower stratosphere????? (at 100 hPa)*
"lower troposphere" corrected into "lower stratosphere"