Dear reviewer,

We thank you for the constructive comments on the earlier version of the manuscript. We have revised our manuscript following the comments and our response is as follows.

Reviewer 1:

The manuscript "Impact of atmospheric forcing uncertainties on Arctic and Antarctic sea ice simulation in CMIP6 OMIP" by Lin et al. 2022 presents a study, that addresses the impact of different atmospheric forcing on the CMIP6 Ocean Model Intercomparison Project (OMIP). The paper focuses on the simulated sea ice condition by three OMIP models that provide sea ice tendencies for a complete analysis of the results.

The study is well structured and organized. It addresses the newest model versions of model intercomparison project, the CMIP6. Methods and data are appropriate, and the results are clearly presented and described (text and figures). The referencing is good. The paper presents a useful report of the model experiments with different forcing datasets, but could profit from more ambitious interpretation of the physical processing behind the results, and evaluation of the atmospheric results against reference datasets.

Thanks for your time and positive evaluation.

Here I suggest three main points that the authors could consider to further improve the manuscript:

- Comparison of the forcing datasets (COREII and JRA55-do)
    - You could compare the surface energy fluxes and the near surface wind speeds of the two input datasets. This would allow to say how directly the differences in the input data are transferred to the model results

Answer: Thanks for your suggestion. The surface air temperature, specific humidity, downward shortwave and longwave radiation fluxes during melting months, and wind speed during freezing months in COREII and JRA55-do are shown in Fig. 1 below. These months are shown because in general the ice concentration simulations are improved from OMIP1 to OMIP2 in summer due to surface heat flux changes and in winter due to the wind stress changes. More information can be found in Figs. 1 to 4, A1 to A4 of our manuscript. Compared to COREII, the downward shortwave radiation flux and specific humidity in JRA5-do in the central Arctic Ocean and the coastal region of the western Weddell Sea (Figs. 1g, h, q, r) are lower, the downward shortwave radiation flux in the Canadian Arctic Archipelago (CAA) and central Weddell Sea (CWS) regions and the air temperature in the CAA region are larger (Figs. 1h, r, f), and the surface wind speed on Antarctic sea ice in the inner part of the exterior region from 70° to 180°E is weaker (Figs. 1t). These differences in the atmospheric forcing are transferred to the modeled surface fluxes and contribute to the improved ice concentration simulation in those regions. Compared to OMIP1 simulations, the downward shortwave radiation flux and latent heat flux in OMIP2 in the central Arctic Ocean and the coastal region of the western Weddell Sea are lower, the downward shortwave radiation flux in the CAA and CWS regions and the sensible heat flux in the CAA region are larger, and the surface wind stress on Antarctic sea ice in the inner part of the exterior region from 70° to 180°E is weaker (Figs. 4, 5, A4, A5, A6 in the previous manuscript).

Action: We have added Fig. 1 below to the revised manuscript as a new Fig. 6 and added the explanation before on how the differences in the atmospheric forcings are transferred to the model results in the main text.

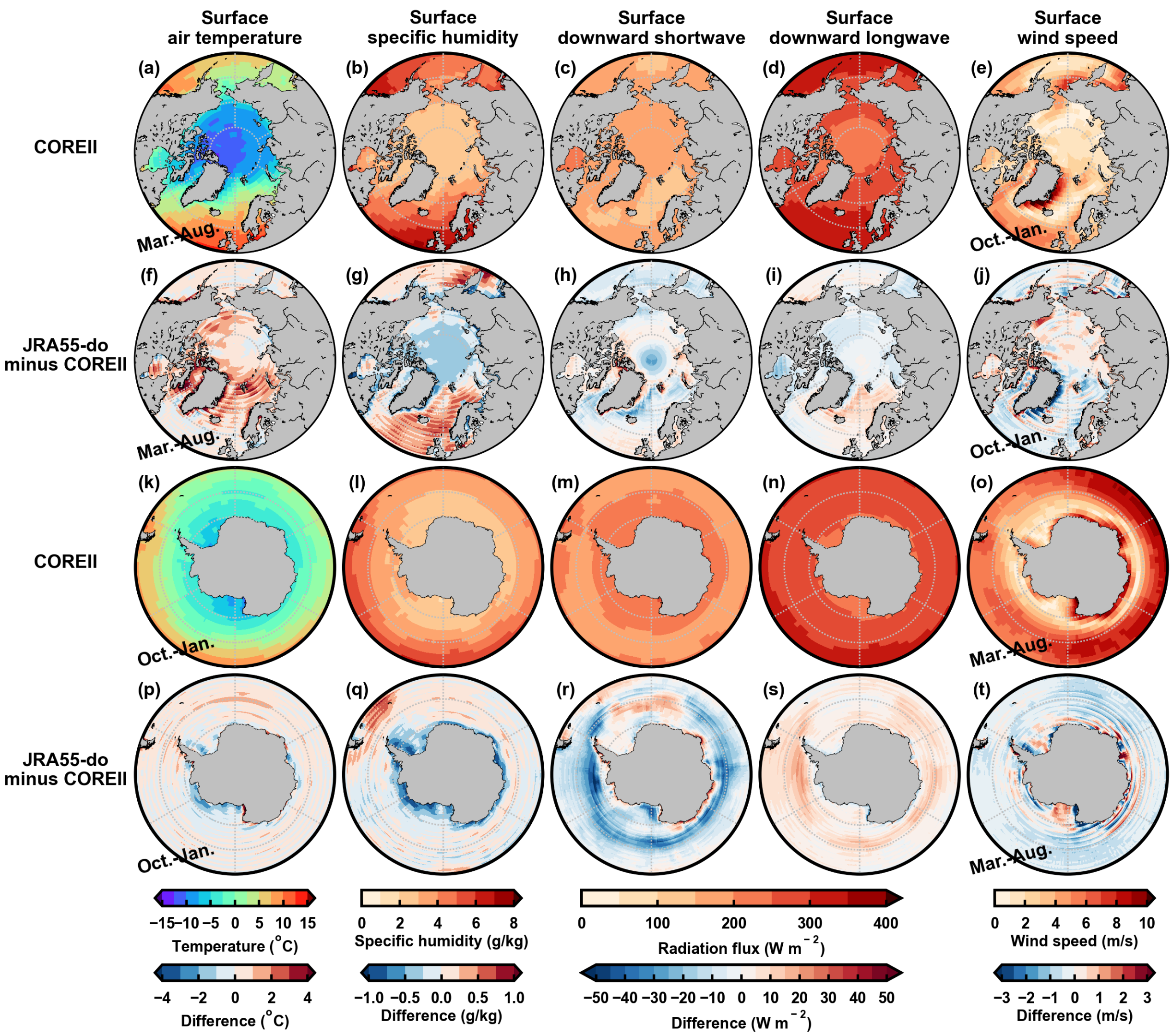

Figure 1. 1980-2007 March-August mean Arctic and October-January mean Antarctic surface air temperature (first column) and specific humidity (second column), downward shortwave (third column) and longwave radiation fluxes (fourth column), as well as October-January mean Arctic and March-August mean Antarctic surface wind speed (fifth column). The first and third rows correspond to COREII, and the second and fourth rows are differences between JRA55-do and COREII.

- More focus on the evaluation and interpretation of the energy balance terms
    - Are the model results realistic, are OMIP2 results better that OMIP1? You could compare the modeled fluxes against literature values or reference data. I understand that finding a good reference dataset for polar energy fluxes is hard. Still, it would be possible to compare the fluxes against reanalyses (eg. ERA5, JRA55 or NCEP-CFSR) to get an idea of the possible biases. Another approach would be to compare each model against the multimodel mean (mean of CMCC-CM2-SR5, MRI-ESM2-0 and NorESM2-LM), assuming that the multimodel mean is better than each individual model.

Answer: We compared the simulated surface fluxes to ERA5 reanalysis data. The multi-model mean includes each model result, so comparing a model to it is not relevant if we want to study the skill. The 12-hourly ERA5 data of sea ice concentration, surface sensible, latent, net shortwave and longwave radiation fluxes, northward and eastward surface stresses on Earth surface from 1980 to 2007 are used to calculate the surface fluxes on sea ice. The net surface heat fluxes during melting months and the surface stress during freezing months (Fig. 2), as well as surface sensible, latent heat fluxes, net shortwave and longwave radiation fluxes during melting months (Fig. 3) from ERA5 and the differences between NorESM2-LM/C and ERA5, and between NorESM2-LM/J and NorESM2-LM/C are shown below.

As introduced in section 3.1.2, compared to NorESM2-LM/C simulations, the downward net surface heat fluxes during melting months in NorESM2-LM/J are smaller in the central Arctic Ocean and over the coastal regions of the western Weddell Sea, and larger in the CAA and CWS regions. The changed downward net surface heat flux changes in NorESM2-LM/J compared to NorESM2-LM/C contribute to the improved September ice concentration simulation in those regions. It can be observed in Figs. 2a to h that the downward net surface heat flux in NorESM2-LM/J in these regions is close to the ERA5 reanalysis data. The contributions from the surface sensible, latent heat fluxes and the net shortwave and longwave radiations to the improvements are explained in section 3.1.2. These surface fluxes in NorESM2-LM/J in these regions are close to the ERA5 reanalysis data (Fig. 3).

Compared to NorESM2-LM/C simulations, the decreased surface wind stress in NorESM2-LM/J in the inner part of the exterior region from 70° to 180°E (Fig. 2p) slows down the ice motion and improve the modeled September ice concentration in the exterior region from 70° to 180°E. The surface wind stress in NorESM2-LM/J in these regions is close to the ERA5 reanalysis data (Figs. 2m to p).

Even though the NorESM2-LM/J simulations are close to ERA5 reanalysis data in some regions, we found that there are large surface flux differences between model outputs and ERA5 data. It is very hard to qualify surface energy balance fluxes and observational uncertainties are large. Graham et al. (2019) evaluated six atmospheric reanalyses over Arctic sea ice from winter to early summer and found that the surface heat fluxes bias in reanalyses are large in general, in particular turbulent fluxes, for instance.

Compared to OMIP1, the OMIP2 simulations on surface fluxes can be considered better because the JRA55-do atmospheric forcing is relatively new and with higher temporal and horizontal resolution compared to CORE-II, as detailed in Tsujino et al. (2018).

Action: We prefer not to include ERA5 data in the revised paper due to the large uncertainties in the surface fluxes. However, we indeed have added these contents in the discussion part.

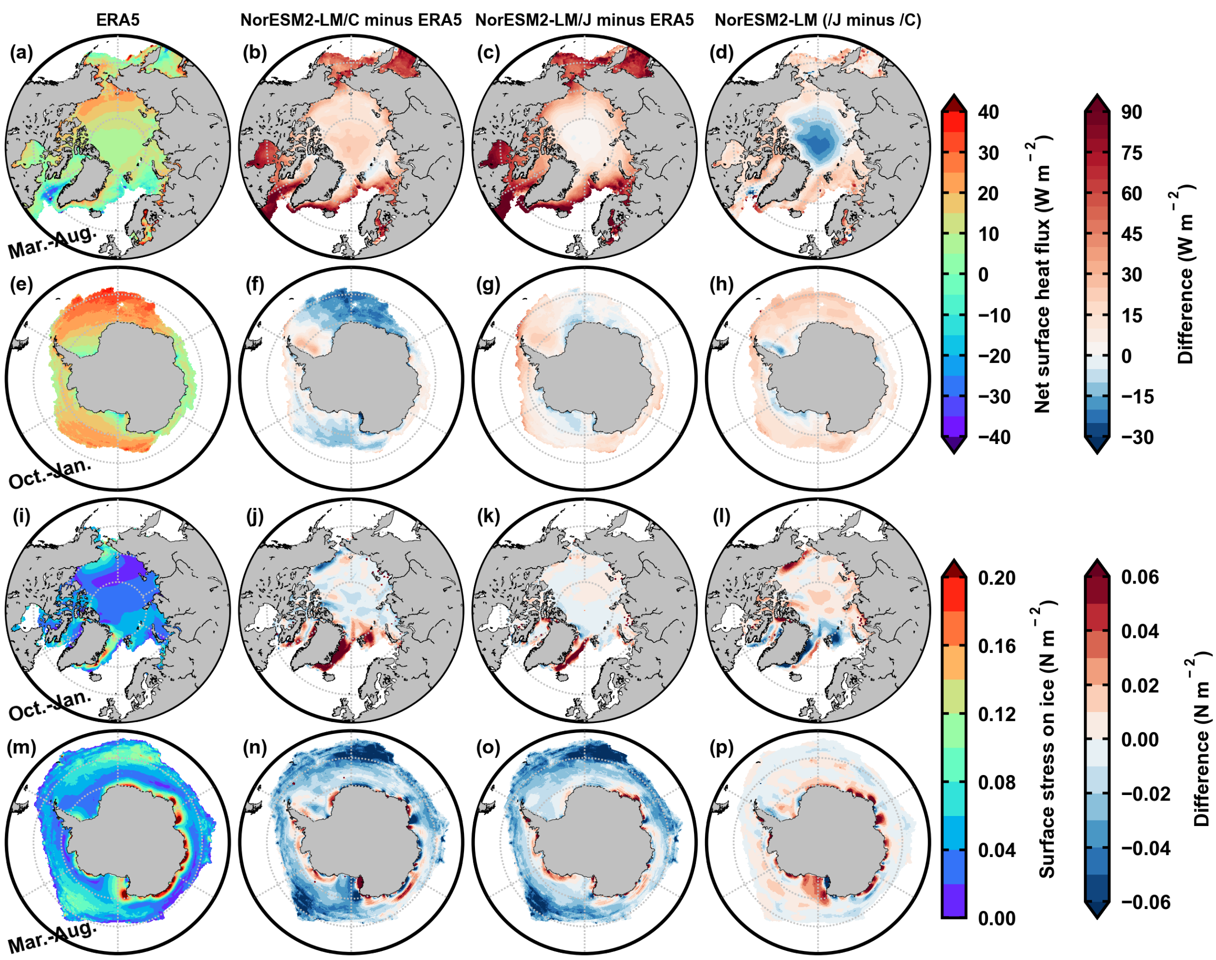

Figure 2. 1980-2007 March-August mean Arctic net surface heat flux (a to d) and Antarctic surface stress (m to p), and October-January mean Antarctic net surface heat flux (e to h) and Arctic surface stress (i to l). The positive values indicate a surface flux downward. The first column corresponds to ERA5 data and the second to fourth columns are differences between NorESM2-LM/C and ERA5, between NorESM2-LM/J and ERA5, and between NorESM2-LM/J and NorESM2-LM/C, respectively.

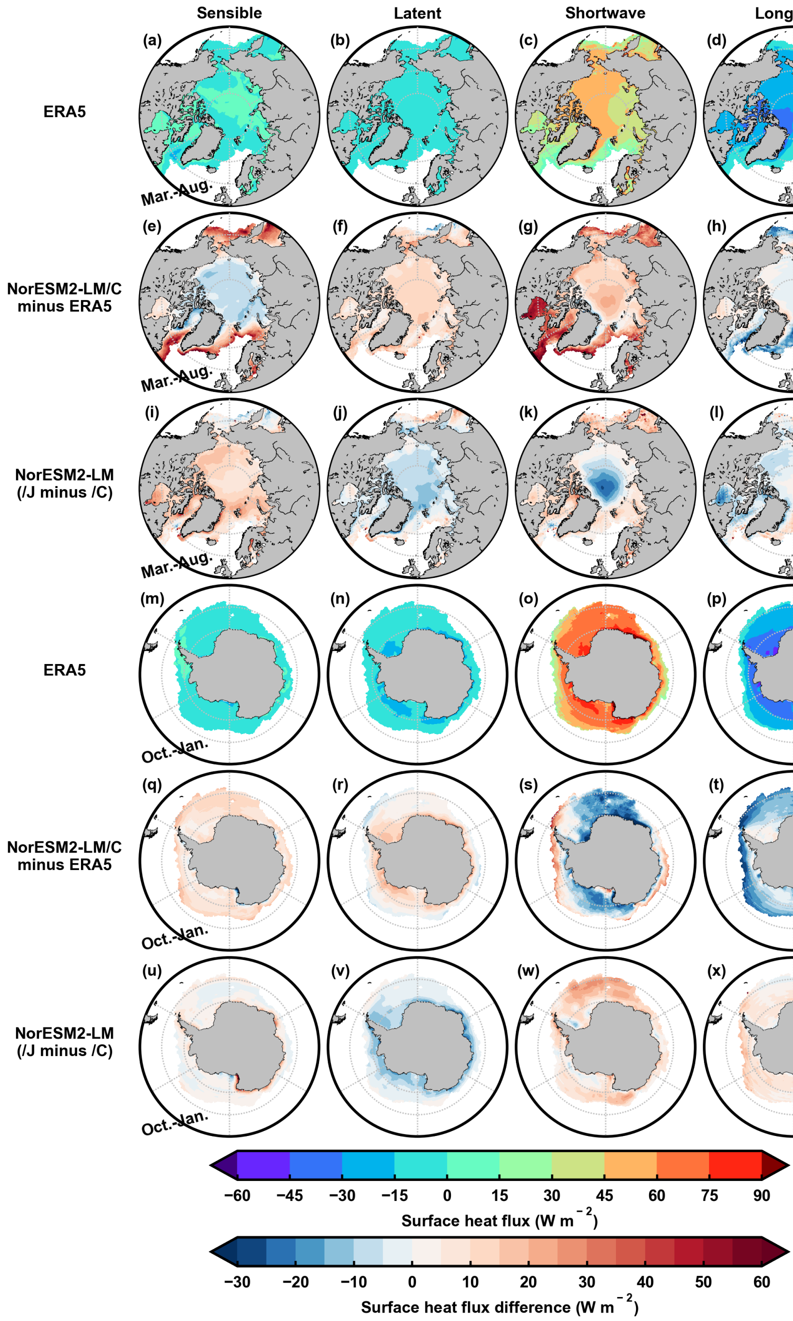

Figure 3. 1980-2007 March-August mean Arctic (a to l) and October-January mean Antarctic (m to x) surface sensible (first column) and latent heat fluxes (second column), net shortwave (third column) and longwave radiation fluxes (fourth column). The positive values indicate a heat flux downward. The first and fourth rows correspond to ERA5 data, and the second and fifth rows are differences between NorESM2-LM/C and ERA5, and the third and sixth rows are differences between NorESM2-LM/J and NorESM2-LM/C.

- Evaluation of the sea ice thickness
  - There are substantial biases in the sea ice thickness. Can you comment them in any way? Is the reference data reliable (see also my comment for Page 17, lines 399-400), can the limitations in model physics make the ice too thick, what in the forcing data or initial conditions could cause the ice to be too thick?

Answer: The ice thickness observations during 2003-2007 are restricted to a few months per year in both Envisat and ICESat datasets. The Envisat data includes ice thickness from November to April for the Arctic with coverage up to 81.5°N and May to October for the Antarctic from 2003. The ICESat data includes 13 measurement campaigns for the Arctic and 11 for the Antarctic during 2003–2007, and these campaign periods are limited to the months of February–March, March–April, May–June, and October–November, with each campaign lasting roughly 33 d. The comparisons between individual models and the two observational references are thus restricted to these months when data are available.

The estimated ICESat sea ice thickness is added in Fig. 4. In general, modeled sea ice thickness is close to sea ice thickness in the ICESat dataset, while modeled ice thickness is too thick in the Arctic and too thin in the Antarctic compared to Envisat data. We average modeled ice thickness limited up to 81.5°N and this affects the ice thickness in the summer months but not from November to April. There is no consistent improvement of the representation of sea ice thickness in both hemispheres by changing the atmospheric forcing from COREII to JRA55-do (Fig. 4). More observations and studies are needed to evaluate the ice thickness bias in models.

Action: We have added ICESat sea ice thickness to the revised manuscript as new Figs. 7 and 8, and added the contents explained before to the main text.

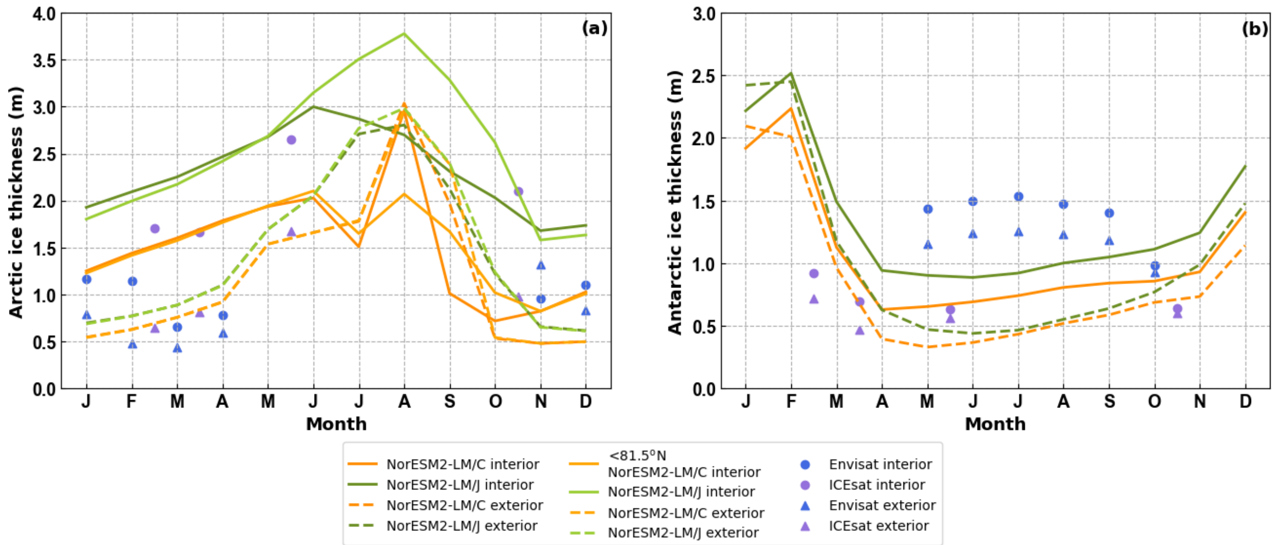

Figure 4. 2003-2007 monthly mean and spatially averaged Arctic (a) and Antarctic (b) ice thickness from Envisat (blue marks), ICESat (purple marks), NorESM2-LM/C (orange) and NorESM2-LM/J (green). The Envisat ice thickness data is provided from November to April and the coverage is limited up to 81.5°N. The measurement campaigns of ICESat ice thickness is for the months of February–March, March–April, May–June, and October–November, with each campaign lasting roughly 33 d. The solid and dashed lines are spatial averages on the regions with ice concentration larger (interior) and smaller (exterior) than 80% in NSIDC-0051, respectively. The light orange and green lines in the Arctic (a) are modeled ice thickness averaged limited up to 81.5°N.

These improvements could make the paper even more relevant to the audience and turn the “clues on how improved atmospheric reanalysis products influence sea ice simulations” to more than just clues. However, even in the current form, the paper points out the aspects where more research is needed, which is also very relevant for the community. All in all, this is a meticulously prepared manuscript, where the expertise of the authors is visible. Thank you for the interesting reading!

Thanks a lot.

I provide some more detailed comments below.

Page 3, Line 87: In this paragraph, you could summarize some main links between the atmospheric circulation and sea ice conditions. You could describe the role of atmospheric circulation and it’s impacts on sea ice on a general level. You could mention that some circulation patters allow heat and moisture transport to the Arctic, while others prohibit it.

Thanks for your suggestion. We have added more details in the revised manuscript. The spatial variability of sea ice concentration and its links with the atmospheric circulation vary with season. The change in the position and strength of the cyclonic or anticyclonic circulation over the sea ice can affect the sea ice motion and freezing/melting (Rigor et al., 2002; Raphael and Hobbs, 2014; Ding et al., 2017). Strong winter wind-driven ice exports in the Eurasian coastal region occur during high North Atlantic Oscillation (NAO) index years, which can contribute to the reduction of summer Arctic sea ice extent observed during the 1980s and 1990s (Hu et al., 2002). In the Antarctic, the decreases of sea ice concentration generally occur in regions of poleward flow and the increases of sea ice concentration occur in regions of equatorward flow (Renwick et al., 2012).

Page 5, Lines 165-166: To help the reader, you could mention that SIC was overestimated in CCA in OMIP1 and that overestimation was reduced in OMIP2.

We have added the information.

Page 8, Table 1: The caption states: “The improvements on ice concentration simulations and the related reasons in summer (bold) and winter (bold italic) are marked”. Bold and italic text is used also for the sea ice concentration tendencies, the surface heat flux, and the surface stress on sea ice. Is this correct, or should the improvements be marked only for the SIC?

Yes, the related sea ice concentration tendencies, the surface heat flux and the surface stress on sea ice are also marked. We have rephrased the sentence.

Page 13, line 319: You wrote "downward net shortwave radiation flux" do you mean the net shortwave or the downward shorwave?

Thanks for pointing this out. It is 'net shortwave radiation flux'. The text has been clarified.

Page 16, Table 2: To me, it would be more intuitive to see the OMIP1 (C) and OMIP2 (J) values instead of C and J-C. Best would be to have all three values (C, J, and J-C), but it's hard to fit them in one table. Also, I would suggest adding the downward longwave and upward longwave radiation, as you did for the shortwave radiation. You will see if the decreased downward shortwave radiation coincides with increased downward longwave radiation. This would suggest an increase in atmospheric moisture/cloudiness between the two experiments.

Thanks for your suggestion. We have modified them to OMIP1 [C] and OMIP2 [J] values. The downward and upward longwave radiation fluxes are added in Table 2 and shown below. The decreased downward shortwave radiation in the Arctic interior region does not coincide with increased downward longwave radiation. The connections between downward shortwave and longwave radiation fluxes are not direct. Both temperature and humidity can affect the downward longwave radiation flux.

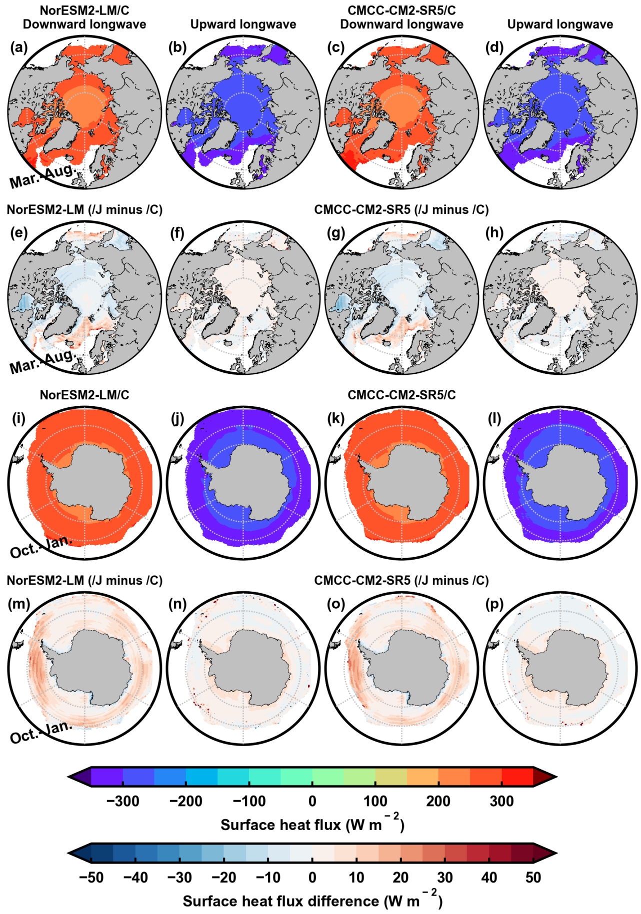

Figure 5. 1980-2007 March-August mean Arctic (a to h) and October-January mean Antarctic (i to p) downward and upward longwave radiation fluxes in NorESM2-LM (first two columns) and CMCC-CM2-SR5 (last two columns). The first and third rows correspond to model/C, and the second and fourth rows are differences between model/J and model/C. The positive values indicate a surface heat flux downward.

Page 17, line 390: Could you add a definition or equation for the MKE?

Yes, we have added the equation of the MKE.

Page 17, lines 399-400: Could you select the modeled sea ice thickness for a domain that matches the Envisat data (< 81.5°N)? This would allow a better comparison between the datasets.

We have added this calculation for a better comparison. This is explained in the response to the third main point before.

Page 17, line 402: Should "ice drift speed" be "ice-motion MKE"?

Thanks for pointing this out. We now use 'ice-motion MKE' in the revised manuscript.

Page 18, Figure 6: The interior-bar in June is all green. I think that the blue and orange bars might be missing/hidden.

We have changed bars to lines in new Figs. 7 and 8 to make it clear.

Page 19, line 434: "drift speeds" or "MKE"?

We have checked this sentence in the full text and modified it.

Page 22, line 515: "More attention needs to be paid to the radiation fluxes and wind stress in the atmospheric reanalysis products." Here you could elaborate on what kind of attention is needed. What are the sources of the current problems, what caused the improvements when passing from CORE-II to JRA55-do etc.

Thanks for your comment. We have explained the reasons for improvements when passing from CORE-II to JRA55-do in the manuscript. Some aspects of the sea ice simulation are not improved by changing the forcing from CORE-II to JRA55-do, such as the winter Arctic ice concentration in the exterior region, summer Antarctic ice concentration in the coastal regions and Antarctic ice drift speed. The bias in surface heat fluxes and surface stress in these regions are large in NorESM-LM/J compared to ERA5 (Fig. 2). Improving Antarctic radiation fluxes, and Arctic and Antarctic winds in the atmospheric reanalysis products can be helpful to reduce the bias. We have added these comments in the discussion section.

Yours sincerely,

Xia Lin, François Massonnet, Thierry Fichefet, Martin Vancoppenolle