Author response to the Referee Comments by Anonymous Reviewer 1 on the manuscript:

Conservation of heat and mass in P-SKRIPS version 1: the coupled atmosphere-ice-ocean model of The Ross Sea

Alena Malyarenko, Alexandra Gossart, Rui Sun, and Mario Krapp

submitted to Geoscientific Model Developments (https://doi.org/10.5194/egusphere-2022-1135)

We thank the Reviewer for spotting all the typos and inconsistencies of our manuscript and are pleased with their positive and constructive comments. Please find the response to each of the comments below. The reviewer's comments are displayed in **bold text**, replies are shown in normal text, text from the original manuscript is shown in blue, and proposed changes to the manuscript are shown in red.

The authors have submitted a much improved manuscript, and I believe it to be suitable for publication after addressing the very minor comments below:

Line 29: "due to the remoteness of and harsh conditions prevailing in the Antarctic."

Thank you, we will add 'of'.

due to the remoteness and harsh conditions prevailing in the Antarctic.

due to the remoteness of and harsh conditions prevailing in the Antarctic.

Line 33: "Warmer global-mean surface temperartures lead to..."

Thank you, we will add 'global'.

Warmer mean surface temperatures lead to

Warmer global mean surface temperatures lead to

Line 37-53: The acronyms "ESM" and "GCM" are used interchangeably here. In general for the context here they are the same thing, but I would suggest sticking with one to avoid confusion.

Yes, it is indeed quite confusing for the reader. We will change all the acronyms to 'ESMs' and will add a line specifying that by ESMs we also mean GCMs.

Earth System Models (ESMs) and Global Circulation Models (GCMs) present an alternative to explore the past, present and future state of Antarctica and the Southern Ocean. Studies using GCMs or ESMs have highlighted the importance of atmosphere-ocean-sea ice interactions in the representation of polar systems, especially for estimating the evolution of Antarctica in a future, warmer setting (e.g. Goosse et al., 2018). Warmer mean surface temperatures lead to increased basal melting of ice shelves (Naughten et al., 2021). In addition, warmer ocean water masses in cavities can be induced by increased surface stress due to thinning of the sea ice (Hellmer et al., 2012) and increased incoming radiation causing surface melting. The latter can lead to ice shelf fragilisation and potential collapse (DeConto and Pollard, 2016).

ESMs that are part of the Coupled Model Intercomparison Project (CMIP) experiments, generally have coupled global ocean, atmosphere, land and sea ice models (Meehl et al., 1997). However, the global atmosphere and ocean models that make up ESMs are not optimized for polar areas (e.g. Azaneu et al., 2014) and polar versions of these models are developed to represent processes specific to these regions. In addition, the spatial resolution of ESMs is rather coarse, which prevents them from representing local or regional-scale processes. For example, Smith et al. (2021) raises the fact that accumulation and melt at the ice-ocean-atmosphere interface have refined spatial patterns that can not be represented in GCMs. And this leads to static ice boundaries and heavy parametrization of these processes, limiting the inclusion of refined ice sheet or ice shelf cavity models into GCMs. Therefore, ice-ocean and ice-atmosphere interactions are usually not accurately representend into GCMs. In addition, the parametrization of processes occurring at higher resolution in GCMs physics limits them in the representation of local scale and regional features (e.g., the orography and associated local processes of the Antarctic Peninsula, Bozkurt et al., 2021), indicating that the global physics of GCMs are not optimised for polar areas (Agosta et al., 2015; Bozkurt et al., 2021), leading to various performances in the Arctic and Antarctic.

Earth System Models and Global Circulation Models (ESMs and GCMs respectively, for simplicity we will refer to both as ESMs hereafter) present an alternative to explore the past, present and future state of Antarctica and the Southern Ocean. Studies using ESMs have highlighted the importance of atmosphere-ocean-sea ice interactions in the representation of polar systems, especially for estimating the evolution of Antarctica in a future, warmer setting (e.g. Goosse et al., 2018). Warmer global mean surface temperatures lead to increased basal melting of ice shelves (Naughten et al., 2021). In addition, warmer ocean water masses in cavities can be induced by increased surface stress due to thinning of the sea ice (Hellmer et al., 2012) and increased incoming radiation causing surface melting. The latter can lead to ice shelf fragilisation and potential collapse (DeConto and Pollard, 2016).

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Also, Hines and Bromwich (2008) is an odd choice of citation here (Line 39). This paragraph is talking about how global models are not optimized for polar regions, but the citation is for a paper presenting results from a polar-optimized regional model (PWRF). Would suggest finding a better reference for this statement or removing

We thank you for this remark and will remove the citation.

are not optimized for polar areas (e.g. Hines et al., 2008; Azaneu et al., 2014) and polar versions of these models are developed to represent processes specific to these regions.

are not optimized for polar areas (e.g. Azaneu et al., 2014) and polar versions of these models are developed to represent processes specific to these regions.

Line 61: "However, fully-coupled ocean-atmosphere-sea ice (and ice sheet) models are rare for any of the..."

Thank you, we will add 'models'.

However, fully coupled ocean-atmosphere-sea ice (and ice sheets) are rare for any of the regional models

However, fully coupled ocean-atmosphere-sea ice (and ice sheets) models are rare for any of the regional models

Line 83: Here and in other places there are parentheses around the year for references already in parentheses. I suspect this will be caught in copy-editing though.

We thank you for spotting this and will edit all the citations accordingly.

Line 102: "... are extracted from the BEDMAP-2 product (Fretwell et al., 2013)."

Thank you, we will add 'the'.

The model bathymetry, ice shelf draft, and grounding line are extracted from BEDMAP-2 product

The model bathymetry, ice shelf draft, and grounding line are extracted from the BEDMAP-2 product

Line 118: dissociates -> distinguishes

Thank you, we will change 'dissociates' by 'distinguishes'.

and dissociates between bare ground, land ice (glaciers) and sea ice.

and distinguishes between bare ground, land ice (glaciers) and sea ice.

Line 121: "...and has a refined snow water equivalent reproduction (closer to reality)." I appreciate that the authors have revised this sentence, however my question was really about what IS reality here? What observational product is the model being compared to to make this assessment?

The new version of the Noah-MP model has been tested against direct measurements of snow depth, SWE, snow surface albedo and snow skin temperature. These were taken at the Sleeper River Watershed (Vermont, USA) and Col de Porte in the French

Alps. This is described in Niu et al., 2011 and Figure 5.b) shows an improvement of SWE between the older version of Noah, and the new one for the Sleeper River Watershed. Figures 6 and 7 illustrate the improvement for SWE and snow depth at Col de Porte.

Niu, G.-Y., et al. (2011), The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements, J. Geophys. Res., 116, D12109, doi:10.1029/2010JD015139.

We will add a short sentence describing this as follows:

The land component of PWRF is the community Noah land surface model with multi-parameterization options (Noah-MP, Niu et al., 2011) and distinguishes between bare ground, land ice (glaciers) and sea ice. The latest version includes a three-layer snow model (Yang et al., 2003). It improves the representation of surface fluxes, surface meltwater production, percolation and retention/refreezing in the snow layers and surface runoff, and has a refined snow water equivalent reproduction (closer to reality) with an improved diurnal cycle of the snow skin temperature.

The land component of PWRF is the community Noah land surface model with multi-parameterization options (Noah-MP, Niu et al., 2011) and distinguishes between bare ground, land ice (glaciers) and sea ice. The latest version includes a three-layer snow model (Yang et al., 2003) and has been shown to perform well against observations at Col de Porte (French Alps) and Sleeper River Watershed (Vermont, USA) (Niu et al., 2011): It improves the representation of surface fluxes, surface meltwater production, percolation and retention/refreezing in the snow layers and surface runoff, and has a refined snow water equivalent reproduction (closer to reality) with an improved diurnal cycle of the snow skin temperature.

Line 124: 61 model levels -> 61 vertical levels

Thank you, we will change 'model levels' by 'vertical levels'.

It has 210 x 240 grid cells and 61 model levels.

It has 210 x 240 grid cells and 61 vertical levels.

Line 149: "The experiments were set with the aim of testing the model skill...". Similar to my first round of comments, you are not really testing model skill. That is, you are not evaluating the model's ability to reproduce observations or another model. Would suggest rephrasing to "...with the aim of comparing various model configurations for different sea ice cover conditions (winter vs summer)."

Thank you for this comment, we will adopt your suggestion.

The experiments were set up with the aim of testing the model skill for different sea ice cover conditions (winter versus summer).

The experiments were set up with the aim of comparing various model configurations for different sea ice cover conditions (winter vs summer)

Line 151: "cast study" -> "case study"

We will change 'cast study' for 'case study'.

our cast study including the conservation of heat and mass,

our case study including the conservation of heat and mass,

Line 197: “This standard import way” -> “This standard import method”

Thank you, we will change ’way’ for ’method’.

This standard import way (used in SKRIPS)

This standard import method (used in SKRIPS)

Line 334-335: “...the components are added individually and the time step non conveective precipitation term is ignored.”

I think the words “time step” are not needed here? So I think this should be “...the components are added individually and the non-convective precipitation term is ignored.”

This is the name of the variable as is defined in PWRF, but we will remove ’time step’ for better readability.

In the P-SKRIPS, the components are added individually and the time step non convective precipitation term is ignored.

In the P-SKRIPS, the components are added individually and the non convective precipitation term is ignored.

Line 362: P-SRIPS -> P-SKRIPS

Thank you for spotting this typo, we will replace ’P-SRIPS’ by ’P-SKRIPS’

In P-SRIPS, the snow cover

In P-SKRIPS, the snow cover

Line 398-399: Would suggest changing to “The energy imbalance of up to 922 W m-2 due to non-conservation of energy in the previous Skripps-KAUST version of the model likely affects the heat content ...” or similar.

Thank you for this comment, we will rephrase the sentence accordingly.

The non-conservation of up to 922 W m^{-2} is likely affecting the heat content of the atmosphere and deep convection of the ocean.

The energy imbalance of up to 922 W m^{-2} due to non-conservation of energy in the previous Skripps-KAUST version of the model likely affects the heat content of the atmosphere and deep convection of the ocean.

I would also like to note that I am pleased to see that a solution has hopefully been come to for the issue of code availability.

Thank you, we are also pleased that we could find an agreement with the editor!

Author response to the Referee Comments by Dr Guillaume Boutin on the manuscript:

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We thank the Reviewer Dr Guillaume Boutin for his review of our manuscript and are pleased with his positive comments. Please find the response to each of the comment below. The reviewer's comment is displayed in **bold text**, the reply is shown in normal text, the text from the original manuscript is shown in blue, and proposed change to the manuscript is shown in red.

Small typo: L322: 1.1013–> I believe you mean 1.10^13.

Yes, thank you for spotting this typo.

The ocean receives a larger amount of latent heat in the SKRIPS simulation with an almost constant bias of 1.1013 W

The ocean receives a larger amount of latent heat in the SKRIPS simulation with an almost constant bias of $1.10^{13} W$.