Reviewer #1:

General:

I appreciate the additional analysis and modification the authors have made and thank for the detailed explanations and clarification as response to my questions and suggestions. The article has been substantially improved, and to me the manuscript is almost ready for publication. I have only a very few minor comments:

We appreciate the reviewer's thoughtful feedback and efforts in improving this manuscript. We have addressed the minor comments and incorporated the suggested revisions, highlighting the changes in bold while keeping the original text in italic for reference.

We have revised the manuscript and included a marked-up version, where removed text is shown in red and new text in blue. For your convenience, we have also updated the line numbers and new figure numbers to align with the marked-up version.

1. My old comment 6/ new Figure 13 with respect to improvements of trends: Thank you for showing the CDFs for the temperature trends in the three regions. Maybe I do not understand this, but I do not really see why you would judge from these figure that the trends are showing an improvement in ECE3L compared to ECE3? I see a reduced spread in the trends across the members in ECE3L compared to ECE3. While it could be possible that the reduced sea ice bias in ECE3L leads to a reduced and potentially more realistic spread in the trend across members, we do not know if that is really an improvement because we do not know how large the spread in reality would be if we would have an 'ensemble of realities'. I do not think that we can judge from the fact that more ensemble members are closer to the observed trend that this is more realistic. Maybe the reality itself was not a central value but an outlier?

We acknowledge with the reviewer that Fig. 13 (now is Fig. 12) shows better alignment in trend with the observation that is the only realisation. We replace the term 'improvement' with more neutral wording in Section 5.1, which discusses how sea ice evolution influences Arctic warming. We made minor adjustments in the abstract and conclusion.

Abstract: Notably, ECE3L ***shows closer*** *alignment with observational data and refines the declining sea ice volume trend overestima****tion*** *in ECE3, reducing* ***overestimated*** *ensemble variability* ***caused by excessive sea ice. This, in turn, amplifies sea ice*** *sensitivity to Arctic warming, particularly in the marginal ice zone. These findings* ***emphasize*** *the importance of* ***accurately*** *representing surface heat flux through sea ice leads, which plays a critical role in capturing the influence of atmospheric stability on sea ice dynamics and regional Arctic amplification.*

L344: This study provides valuable insights for Arctic climate modelling. By incorporating a modulating factor for surface sensible heat flux over sea ice to ***account for*** *processes over leads, the EC-Earth3 model shows* ***closer agreement with observed*** *Arctic sea ice extent and volume, particularly under colder climate conditions. This adjustment* ***mitigates*** *a known bias in earlier simulations.*

*L351: The **parameterisation introduced** in this study supports these insights, **emphasizing the need to represent** finer-scale ocean-sea ice-atmosphere coupling processes.*

*L361: The temperature trend maps for 1980–2014 (Fig. **12**a-c) **show** that ECE3L **more closely aligns with observed trends along the ice edge in the North Atlantic sector of the Arctic compared to ECE3, which** overestimates the warming trend in the Barents Sea**, while underestimating it in** the Greenland and Labrador seas. Additionally, ECE3L **represents** the warming trend **in** the East Siberian Sea, unlike ECE3, which consistently underestimates the trend in the **Pacific sector of the** Arctic.*

*L367: The cumulative distribution function (CDF) analysis in Fig. 13d-f emphasizes regional differences in ensemble performance, with ECE3L **exhibiting** reduced variability and a **central tendency that aligns more closely with observations than** ECE3. This **results in more consistent representation of** warming trends across the Greenland-Iceland-Norwegian Seas (GIN), the Barents and Kara Seas (BAKA), and the broader Arctic. Consequently, ECE3L **achieves closer alignment with observed** local amplification ratios (the ratio of local warming to global mean warming; Rantanen et al., 2022), **leading to more confined** estimates of Arctic amplification.*

*L444: ECE3L **shows reduced ensemble variability**, **leading to enhanced sea ice** sensitivity to Arctic warming and **providing more constrained** estimates of Arctic amplification.*

2. My old comment 7: Sorry to insist a bit on this point: Why should any coupled model reproduce the large observed ice decrease between 2000 and 2012? The observed reduction was clearly due to a combination of decreasing trend and ('negative') internal variability, similar as the missing trend after 2012 is also a combination of negative trend and ('positive') variability. It would be different if CMIP6 models would not at all be able to simulate sea ice reduction periods of the observed magnitude but I do not think this is the case.

We agree that the decadal variability may have played an important role in the observed declining trend between 2000 and 2012. Our intention was to highlight the risk that, while the multi-model mean can capture periods of rapid sea ice loss, models with excessive sea ice volume may alter their sensitivity to external forcing. We have revised it

L30: "*The CMIP6 multi-model mean captures the observed **decline in Arctic sea ice in general, while substantial variability exists both among different models and among ensemble members of the same model (Lee et al., 2023), highlighting internal variability as a key source of uncertainty in decadal trends (Dörr et al., 2023). A major challenge lies in ice thickness representation—models with thicker ice tend to exhibit a faster decline** in sea ice volume **than those with thinner ice, increasing uncertainty in reproducing the overall rate of decline (Lee et al., 2023; Massonnet et al., 2018). Ice thickness also influences** feedback mechanisms, such as the ice-albedo effect**, where thinner ice and earlier melt expose open water, accelerating warming (Bhatt et al., 2014). Additionally, missing processes like surface heat flux over leads — open water areas within sea ice cover, which mediate ocean-atmosphere heat exchange in winter, can amplify local warming (Esau, 2007; Marcq and Weiss, 2012). These factors***

contribute to uncertainties in modelling Arctic warming, projecting *future sea ice evolution,* ***and climate impacts (Wunderling et al., 2020)****.”*

3. Line 9: the spatial pattern is similar between cold and transient run but the amplitude is different, right? To clarify this, I would suggest to write “spatial patterns of the mean sea ice changes in …” instead of “spatial changes”. I would suggest the same change in the conclusions.
I am still surprised that your 1985-control run is hardly warming and sea ice volume even slightly increasing after initializing from year 1985 of the transient historical run. Normally, you would assume that net radiation is not in balance in a transient run and you would see some warming thereafter. However, also in your 2015-year control run, no additional warming seems to happen, and I agree that your results suggest that this seems not to be an artifact of internal variability.
The revised phrase in blue with the original in black and italic:
Abstract: L9
"*The* ***spatial patterns of mean*** *sea ice* ***changes*** *in the transient climate closely resemble those observed in the cold-climate experiment*."

Conclusion: L438
"*The spatial* ***patterns of mean sea ice changes*** *from 1980 to 2014 in ECE3L closely mirror those simulated using 1985-forcing (cold-climate)*."

4. Line 13: replace “overestimated” with “overestimation” ?
Done.

5. Line 66: Both in the title and in the first line of section 2.1. If you mention “relationship”, I would expect a “relationship between A and B”, but you are only mentioning one thing (in the title) and nothing (in the first sentence).
Thank you for the suggestion. We revised accordingly:
L74 Title: "*2.1 Empirical relationship* ***between*** *surface heat flux amplification A_{lead}* ***and*** *sea ice leads*"
L75: "*An empirical parameterisation, introduced by Davy and Gao (2019) for the NorESM model, defines* ***the relationship between surface sensible heat flux (SSHF) amplification and sea ice leads****.*"

References:
Bhatt, U. S. et al. Implications of Arctic sea ice decline for the Earth system, Annual Review of Environment and Resources, 39, 57–89 (2014).

Davy, R. and Gao, Y. Improved key process in representing Arctic warming (D3.5), https://doi.org/10.5281/zenodo.3559470 (2019).

Deser, C. et al. The seasonal atmospheric response to projected Arctic sea ice loss in the late twenty-first century, J. Climate, 23, 333–351 (2010).

Docquier & Koenigk. Observation-based selection of climate models projects Arctic ice-free summers around 2035. Commun. Earth Environ., 2, 144 (2021).

Doescher, R. & the EC-Earth Consortium. The EC-Earth3 Earth System Model for the Climate Model Inter-comparison Project 6, Geosci. Model Dev., 15, 2973–3020 (2022).

Dörr, J. S. et al. Forced and internal components of observed Arctic sea-ice changes, The Cryosphere, 17, 4133–4153 (2023).

Esau, I. Amplification of turbulent exchange over wide Arctic leads: Large-eddy simulation study, J. Geophys. Res., 112 (2007).

Keen, A. et al. An inter-comparison of the mass budget of the Arctic sea ice in CMIP6 models, The Cryosphere, 15, 951–982 (2021).

Lee, Y. J. et al. Assessment of the Pan-Arctic accelerated rate of sea ice decline in CMIP6 historical simulations, J. Climate, 36, 6069–6089 (2023).

Marcq, S. and Weiss, J.: Influence of sea ice lead-width distribution on turbulent heat transfer between the ocean and the atmosphere, The Cryosphere, 6, 143–156 (2012).

Massonnet, F. et al. Arctic sea-ice change tied to its mean state through thermodynamic processes, Nat. Clim. Change, 8, 599–603 (2018).

Notz and SIMIP Community. Arctic sea ice in CMIP6. Geophys Res Lett 47, e2019GL086749 (2020).

Wunderling, N. et al. Global warming due to loss of large ice masses and Arctic summer sea ice, Nat. Commun., 11, 5177 (2020).

Reviewer #2:

The authors responded to the different points raised by the reviewers in a satisfactory manner... with a few exceptions. I still have some remaining points that require discussions which pushes me to still upheld any decision to accept the paper at this stage:

We appreciate the reviewer's feedback on this manuscript. We have addressed the comments point by point and incorporated the suggested revisions, highlighting the changes in bold while keeping the original text in italic for reference.

Additionally, we have provided a marked-up version of the manuscript, where deleted text is shown in red and new text in blue. To ensure clarity, we have updated the line numbers and figure numbers accordingly to align with this version.

1. implementation for the heat flux exchange: the authors in their response explicitly state that the modulation of SSHF is non-conservative. However, the language used is not totally clear to me. Just to make sure that we mean the same thing: the ocean over open leads of relative area A feels a flux F so that A.F is the total flux for that entire grid cell (assuming zero flux under sea ice) but the atmosphere receives a.A.F, i.e., where a is the additional modulation flux? Understandably, this non-conservative aspect worries me since it is not physical. Is there a particular reason for not conserving the flux exchange between the two earth components? [Maybe the authors need to rephrase the sentence on Line 124: "This means the ocean is not more prone to freezing, as the same amount of heat loss to the atmosphere » as the subordinate (second part) is missing a verb.] If my interpretation is correct, it would mean that the sea ice thickness and cover is reduced in winter because the amplified flux warms the atmosphere which feeds back to the sea ice as a warmer boundary condition. However, this precludes any interaction with the ocean which, on the other hand, should be cooler (due to the amplified flux lost to the atmosphere) and would form more ice. Hopefully, this is just a communication issue.

Thank you for your comment. The non-conservative phrasing in the original text resulted from a misinterpretation, as the role of the coupler was overlooked. The coupled ECE3 framework operates in the following order:

1) The atmosphere computes all fluxes (including SSHF) using bulk formulas.
2) The ocean/sea ice components receive these fluxes directly via OASIS3-MCT, meaning the same flux (e.g. $A \cdot F$) is used consistently across components (Döscher et al.2022, Table 3 in Section 2.2).
3) In ECE3L, Alead modifies the atmospheric sensible heat flux (e.g., amplifying it to $a \cdot A \cdot F$), the adjusted fluxes warm the atmospheric surface, which may enhance ice melting in the winter. Since the ocean model does not compute the flux independently but instead receives it from the atmosphere via the coupler, the process remains conservative in principle.

The previous description was misleading because we emphasized that the ocean fluxes calculated from bulk formulas with no changes. Then the implementation of Alead emphasized a "one-way" modification to the atmosphere model, which was true only for our atmosphere-only experiment.

However, in the coupled experiments, the OASIS-MCT coupler ensures that the ocean receives the fluxes as determined by the atmosphere. The input files to the coupler, providing the ocean surface state variables (incl. sea surface temperature, sea ice concentration, sea ice temperature) to the atmosphere for computing surface fluxes, and remapped those fluxes to the ocean/sea ice model grid via the coupler. Importantly, the coupling time step between the atmospheric, ocean, and sea ice components is synchronized at 2700s (Table 2 of Döscher et al. 2022), meaning that the fluxes exchanged between these components remain dynamically consistent.

L129: We have revised the text by clarifying the role of OASIS3-MCT. "*In ECE3L,* ***all surface fluxes are computed in the atmosphere using state variables from the ocean-atmosphere interface and then remapped to the ocean and sea ice components via the OASIS3-MCT coupler (Doescher et al., 2022).*** *The modulating factor, Alead,* ***influences only the sensible heat flux in the surface atmosphere by either*** *"amplify**ing*** ***or*** *damp**ing it*** *over leads****, depending on atmospheric stability****. This adjustment can increase up to 1.2, enhancing surface heat exchange over sea ice where SIC* ***exceed****s 70%, particularly during winter. Conversely****,*** *in summer,* ***the factor*** *decreases from 1 to 0.9, leading to* ***a reduction in surface heat exchange and producing*** *the opposite effect on the surface atmosphere (see Fig. S1 and Section 3.2).*"

We agree with your interpretation: While amplified winter heat loss (Alead) enhances localized basal freezing, the model also captures central Arctic thinning due to a warmer atmospheric boundary layer. Since thinner ice is more vulnerable to melting, this results in reduced ice extent along the ice edge, despite the modulation factor being restricted to the central pack. However, we have decided to remove this aspect, as basal freezing is outside the scope of our study.

2. The second concern is the reduced spread of the ECE3L transient run. The authors did show in their response and revised manuscript that the reduced variability (e.g. new Figure 13d-c), is not due to the peculiarities of the initialization from two perturbed members since the AMOC (arguably the largest source of internal variability in the system) spread is recovered after a short initial spinup. The authors conclude that the reduced spread is beneficial as it reduces the error relative to the available datasets. However, I don't think the source of the reduced spread/variability is discussed. I personally speculate that the modulation factor acts as a negative feedback mechanism, warming the atmosphere in cold climates and cooling it in warm climates, thus reducing the intrinsic variability of the Arctic climate. This, of course, relates partly to my concern about unphysical flux exchanges in the previous point.

Thank you for the suggestion. We argue that the role of negative feedback is not evident in this context. As shown in Fig. 2, *the interannual variability in ECE3L closely aligns with that of ECE3 across all months in both ExpCold and ExpWarm. This indicates that the parameterization does not alter the system's internal variability.* We have added this to L226-228.

In transient simulations, the smaller model variability in ECE3L is accompanied by substantial reductions in overestimated sea ice area and volume prior to 1990 (L292–300). This suggests that the narrower spread resulted from improved sea ice representation in simulations (prior to 1990) with excessive sea ice, without significant changes to other simulations or periods.

We propose addition discussion in the next paragraph (L301) as follows:

In this sensitivity study, the parameterisation amplifies winter heat loss to reduce ice thickness and dampens summer heat uptake to delay melt, potentially addressing seasonal biases such as excessive winter ice thickness and premature summer melting, which would otherwise shift the annual minimum from September to August (Döscher et al., 2022; Keen et al., 2021). In ECE3, Alead is most effective in colder conditions with excessive sea ice, where greater sea ice coverage and atmospheric stability contribute to large model variability before 1990 (Fig. 7). However, *as the Arctic warms****, its influence weakens due to reduced*** *winter stratification* ***and continued summer sea ice retreat*** *(Deser et al., 2010).* ***Consequently, its impact on mitigating summer sea ice bias remains limited. Thus, the smaller spread in ECE3L is a direct***

result of bias reduction in sea ice representation rather than an artificial constraint on variability."

3. Another point related to the reduced spread is the impact on the scores. The authors state regularly that they favor their ECE3L setup which has a smaller spread and better scores, seemingly implying that spread is "bad". This is of course quite a simplification since it all depends of the dispersive nature of the climate run. For instance, the authors have not demonstrated that the default run is too dispersive in the Arctic, just that the mean ensemble is a bit off relative to the observations. Moreover, please check Section 3 of Peterson et al. (2022) for an explanation why the scores are automatically improved due to a reduced spread. Please elaborate.

Thank you for the suggestion. We acknowledge the reviewer's concern regarding the interpretation of ensemble spread and its impact on scores. Our intent is not to imply that a reduced spread is inherently superior or that spread is "bad." Rather, the reduced spread in ECE3L results from addressing excessive sea ice through the parameterisation, which examines the impact of missing heat flux representation over leads in ECE3.

Regarding "the default run is too dispersive in the Arctic," Figures 6 and 7 demonstrate that ECE3 persistently overestimates Arctic sea ice area and volume, with observations often aligning with the lower bound of the ensemble spread. This suggests that the wide spread reflects systematic biases rather than an appropriate representation of natural variability.

The reduced spread in ECE3L arises from addressing excessive sea ice in colder conditions before 1990, which shifts the ensemble mean closer to observations. While Peterson et al. (2022) note that reduced spread can improve scores, our focus is not on tuning for better scores but on understanding how heat flux representation affects Arctic climate simulations. The narrower spread reflects the effects of this sensitivity experiment, not deliberate tuning.

We add the following to section 5.1 in L374: "*Constraining ensemble variability, which may incidentally improve certain forecast scores (Peterson et al., 2022), is not our objective. Instead, we aim to assess how the missing representation of heat flux over leads influences Arctic climate simulations. The narrower spread in ECE3L arises from the modulating effect of Alead on surface heat exchange, rather than from deliberate tuning. This underscores the sensitivity of sea ice states to subgrid-scale heat flux processes, highlighting the need for further investigation.*"

4. The results shown in Figure S3c are worrying me: they show that, in September, the modulation is thickening the ice in the Pacific marginal sea sector and decreasing in the central Arctic to the point where the former regions are thicker than the latter, in particular North of the CAA and Greenland where we typically expect to find the thickest ice. I fear here that the flux modulation is reducing too much the melt in the marginal ice zones. Please elaborate.

Thank you for your observation. However, the pattern you noted—thicker ice in the Pacific marginal sea sector and thinner ice north of the CAA and Greenland—is a known bias in EC-Earth3 historical ensembles, as documented in Doescher et al. (2022, Fig. 13): "

1) *In September, the Arctic sea ice is clearly too thick in the model, with a bias of up to 2 m compared to PIOMAS.*
2) *In March, EC-Earth3 overestimated sea ice thickness in the central Arctic but underestimated it in the Bering and Kara Seas.*
3) *PIOMAS appears to overestimate thin ice thickness and underestimate thick ice, partly explaining the higher modeled thickness in the central Arctic.*"

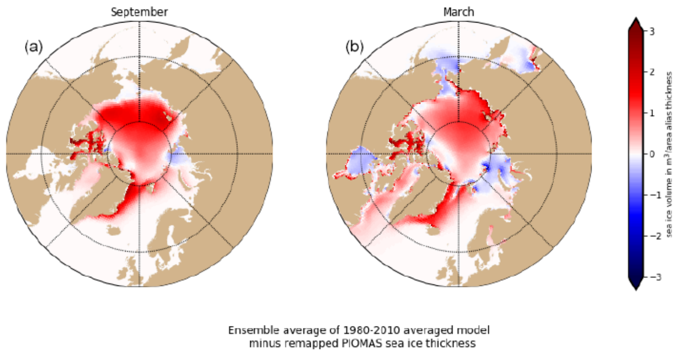


Figure 13 of Doescher et al. (2022). "*Difference in Arctic sea ice thickness between the ensemble mean of EC-Earth3 and PIOMAS in September (a) and March (b), averaged over 1980–2010.*"

We include ECE3 (e) below in addition to Fig. S3c, d for ExpWarm. The thicker ice in the Pacific marginal seas compared to north of Greenland is present in both ECE3L and ECE3L (Fig. S3c,e). The difference between ECE3L and ECE3 (Fig.S3d) indicates that ECE3L either reduces or slightly increases ice thickness in the Pacific marginal sea sector while slightly increasing it north of the CAA and Greenland. We argue that the modulating factor does not directly cause reduced ice melting in the Pacific marginal ice sea sector, because the parameterisation is confined to the central Arctic, where SIC > 70%, as shown in Fig. 1 and Fig. S1.

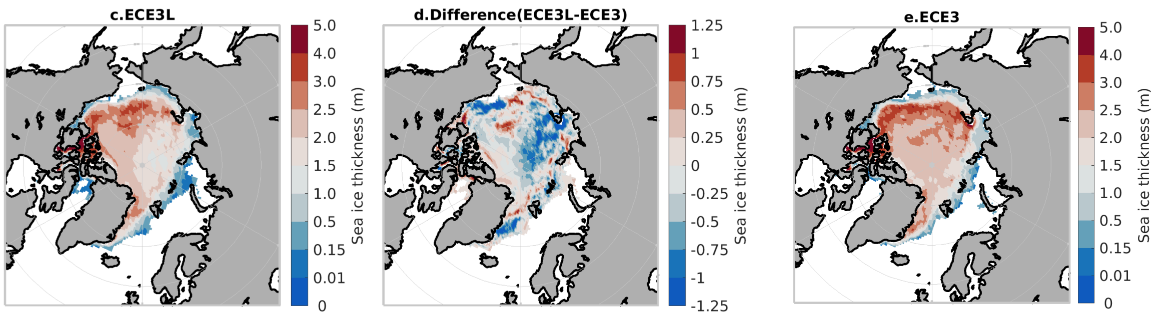


Figure S3. Late summer (September) Arctic sea ice thickness under constant forcing: for ExpWarm (c) ECE3L, (d) Difference (ECE3L-ECE3), and (e) ECE3.

To improve clarity, we revise L249: "*In Arctic summer (Alead<1),* ***sea ice thinning patterns*** *remain consistent with* ***winter*** *(Fig. S3),* ***indicating the dominant role of winter amplification. The thicker ice in the Pacific marginal seas compared to north of Greenland is present in both ECE3 and ECE3L and results from a known EC-Earth3 bias (Doescher et al., 2022), not the modulation effect (Fig. S3d), which applies only in the central Arctic (Fig. 1).*** "

Other minor points:

5. Line 58: "introducing the modulate factor to a coupled climate model", "implementing the modulation factor into a coupled climate model" instead?

Done (Now in L66).

6. Line 80 and more: I fear that there is now a text duplication between the appendix and the main body.

Thank you for your feedback. Considering the length of the main text, we have simplified Section 2.1 and included a cross-reference to Appendix A in L106: "*A full derivation of this* *parameterisation, including governing equations and parameter choices, is provided in Appendix A.*" We also removed the redundant introductory sentences from Appendix A.

7. Line 86: I don't think that the variable theta in Greek symbol has been introduced at this stage. In fact, I see it declared at line 94 instead.

Thank you for pointing this out. We have revised the text to introduce θ at its first mention (in L100).

8. Sorry, I don't understand Line 214-215. Maybe it is meant as a relation between thickness and impact of the modulation? Would a scatterplot help then?

Thank you for pointing this out. We add a scatterplot to Fig. S2d, and revise the two last sentences to improve clarity in L222: "*In ExpCold, **the modulation of heat fluxes in ECE3L consistently reduces SIA and SIV after the spin-up, leading to thinner ice compared to ECE3. In ExpWarm, however, ECE3L exhibits both increases and decreases in sea ice with minimal impact on overall thickness** (see full time series in Fig. S2).*"

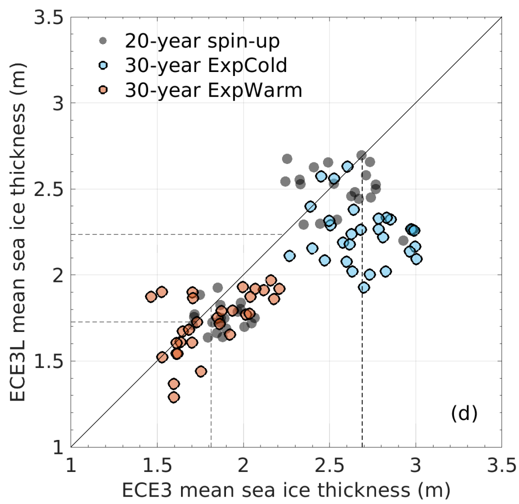


Fig.S2 (d) Scatter plot comparing the 30-year mean sea ice thickness (SIV/SIA, in meters) between ECE3 and ECE3L simulations. The diagonal line represents a 1:1 ratio, where points above indicate thicker ice in ECE3L and points below indicate thinner ice. Colors differentiate between the 30-year ExpCold (blue) and ExpWarm (red) periods, while the 20-year spin-up phase is shown in gray. Dashed lines indicate 30-year means for each dataset.

9. Line 225: beware that expression like eastern/western Arctic are country centric (maybe North-American in your case?). Better use the Atlantic/Pacific sectors as done later.

L237: *In ExpCold (**Fig. 3b**), it reaches a maximum of -1 m in the central Arctic, **particularly in the region from north of Greenland to the Beaufort Sea**. **In ExpWarm (Fig.3d), the largest reduction** (-0.5 m) **shifts to the central Arctic, north of the Laptev and East Siberian Seas.***

10. Since I see the Supplement figures being cited often, I believe this could justify their inclusion in the main manuscript. The authors should decide what other figures to drop to limit the total number of figures. Role of the supplement: maybe the editor could enlight me since this minor point was already raised?

Thank you for your suggestion. However, we prefer to maintain the current structure, with the main manuscript focusing on key experimental results and the supplementary material providing supporting details.

For example, Figure S1 illustrates the modulation factor in ExpCold and ExpWarm, based on lapse rate and sea ice concentration from previous atmosphere-only (AGCM) simulations using CMIP6 historical forcing and surface boundary conditions from the UK Met Office Hadley Centre SST and SIC dataset (1/4-degree, Version 2.2.0.0).

Figures S3 and S4 present summer results, where the modulation effect is minimal due to the factor being below 1, sea ice extent retreat (SIC > 70%), and warm air advection from lower latitudes.

Figure S6 is omitted from the main manuscript as the spatial patterns of mean sea ice concentration changes in the transient climate remain consistent with those observed in the ExpCold (Figs. 4a,b for March & Figs. S4a,b for September).

After careful evaluation, we think including these figures in the main manuscript would not provide additional insights to readers. We appreciate your feedback and welcome any further guidance from the editor regarding the role of the supplementary material.

11. Line 295-296: I assume you mean that the Alead < 1 in summer. You could be more explicit about it.

Thank you for your comment. In the context, the statement in Lines 295-296 (now in Lines 316-318) is not related to Alead <1 in summer, as it pertains only to ECE3 when comparing mean SIT between ExpCold and the transient climate.

This statement was originally in response to Reviewer #1's previous minor comment 5, which questioned why the impact of modulated heat flux is smaller in the transient run despite similar mean climate states in ExpCold and the transient climate.

For reference, we quoted our previous response here:

1) ECE3's mean SIT in March is slightly higher in the central Arctic for ExpCold than in the transient run (Figs. 4b & 5b), with minimal differences in summer (Figs. 4d & 5d).
2) The smaller reduction in sea ice during the transient run leads to thicker ice remaining in ECE3L (Fig. 10a).

These points directly support the statement in Lines 318-319, explaining why ice is generally thicker in ECE3L under the transient-climate due to the diminished effect of heat flux amplification on ice thinning compared to ExpCold.

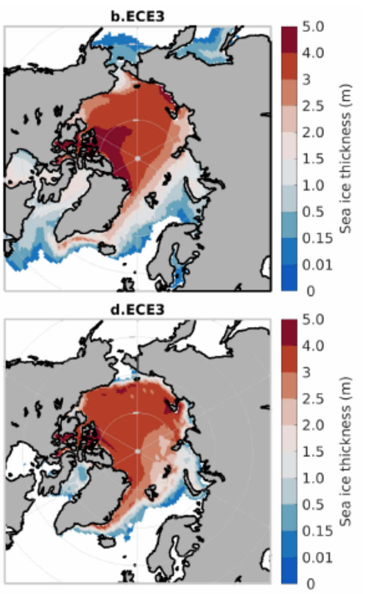


Fig.4b,d

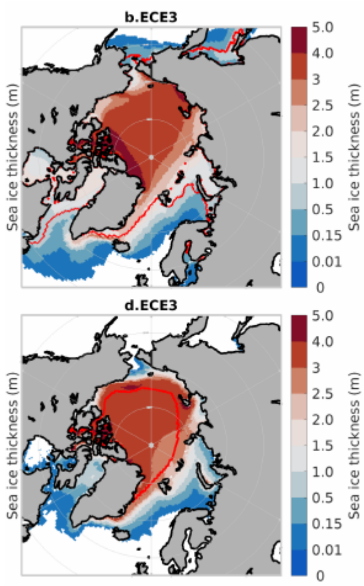


Fig.5b,d

Figure 4. ECE3 30-year mean sea ice thickness in March (b) and September (d) for the cold-climate experiments. Figure 5. As Fig.4, but showing the 35-year mean for the transient-climate experiments.

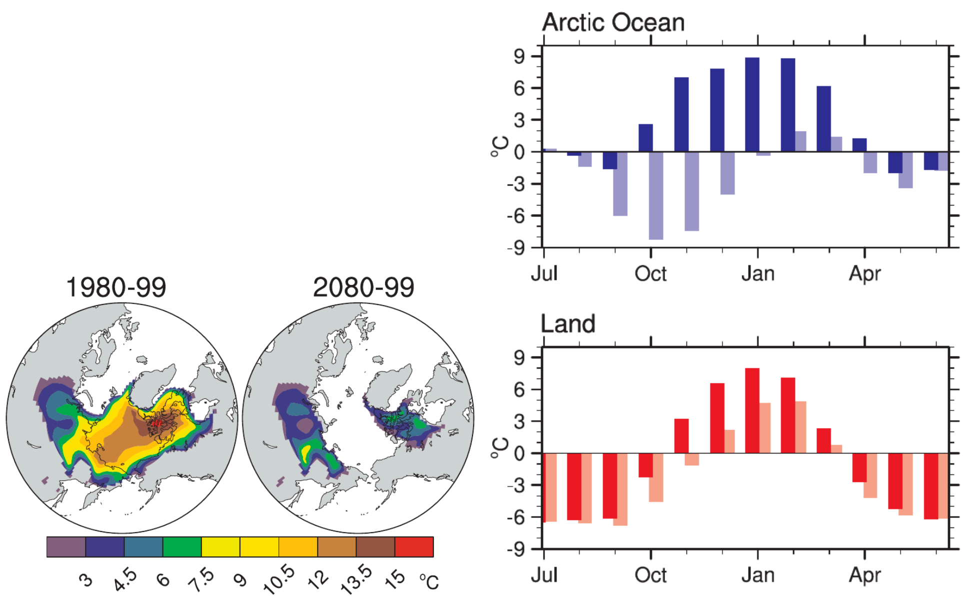
12. L364: “model-form » not sure what the expression means

Thank you for your comment. By 'model-form uncertainty,' we refer to uncertainties arising from the structural assumptions and parameterizations used in models. We now replace “model-form uncertainty” with “*structural uncertainties in models*” (L394).

13. Not sure that Fig.1 is that useful. I fear also that the sign of the temperature difference is reversed between panel a and b-c.

The sign of the temperature difference in Fig. 1 aligns with Deser et al. (2010), which we followed to illustrate the temperature inversion over Arctic sea ice. The temperature difference (T850 - T100) is typically positive in winter, indicating a strong inversion where cold air near the surface suppresses vertical mixing, leading to a highly stratified atmosphere. Unlike the open ocean, sea ice limits heat exchange between the ocean and atmosphere, preventing warm oceanic influence from mixing upwards. This reinforces surface cooling and sustains the inversion.

In Fig.1, the comparison between ExpCold (dark blue) and ExpWarm (light gray) highlights the weakened inversion in ExpWarm, demonstrating the reduced role of sea ice in maintaining the inversion.



In Deser et al (2010) “*Left: Fig 7. Geographical distributions of the strength of the December low-level inversion (T850hPa-T1000hPa) during 1980–99 and 2080–99. Right: FIG. 8. Seasonal cycles of T850hPa-T1000hPa during 1980–99 (dark colors) and 2080–99 (light colors) over the (top) Arctic Ocean (blue) and (bottom) high-latitude continents (red).”*

14. Paired t-test or two-sided t-test?

It is a two-sided t-test. We clarify it throughout the text (L220, Captions of Figs. 2,5,6,8,11).

15. Fig.6 is of less interest to me, could be a candidate for exclusion if space is an issue.

Thank you for the suggestion. We remove Fig.6 as well as Lines 264-266.

16. Sep minimum is not recovered by the new scheme as noted by Rev #1, should be noted as part of the limitation, along with my concern in point 1.

This is addressed in response to the major comment 2. We also briefly discussed it in Section 5.2 Advances and limitations (L413): "*Moreover, the new scheme does not fully recover the observed September minimum, underscoring persistent challenges in simulating late-summer sea ice loss. This limitation stems from its focus on atmosphere-ice heat flux modification, without directly addressing ocean-ice dynamics, which are crucial for accurately capturing summer retreat (Docquier and Koenigk, 2021).*"

17. Caption of Fig. 10: "The areas with SIC≥70% in ECE3L is compassed by red lines.": I think you mean "both ECE3 and ECE3L are encompassed" here.

Yes, we have added "*in both ECE3 and ECE3L are*" the captions for clarity.

18. Fig A.1a: not sure why the climate model would show any variation with lead size! [this was not in the Esau paper]

The black line was not in the Esau paper, therefore, we removed it from Fig. A.1a. This black line represented a 2D turbulence structure, contrasting with the 3D turbulence parameterisation described in Esau (2007). It was used to illustrate general turbulence parameterisation in climate models (Davy and Gao, 2019); however, since it was not explicitly mentioned in the description here, we decided to remove it to avoid confusion.

Additionally, the red solid line has been changed to a red dashed line to improve accessibility for readers with color vision deficiencies.

19. Caption of Figure S1: "Factor modulated to turbulent heat fluxes" do you mean "Figure S1. Factor modulating the turbulent heat fluxes »?

Yes, we have revised the caption accordingly for clarity.

Reference:

Deser, C. et al. The seasonal atmospheric response to projected Arctic sea ice loss in the late twenty-first century, J. Climate, 23, 333–351 (2010).

Docquier & Koenigk. Observation-based selection of climate models projects Arctic ice-free summers around 2035. Commun. Earth Environ., 2, 144 (2021).

Doescher, R., Acosta, M., Alessandri, A., and the EC-Earth Consortium: The EC-Earth3 Earth System Model for the Climate Model Intercomparison Project 6, Geosci. Model Dev., 15, 2973–3020 (2022).

Peterson, K. A. et al. Understanding sources of Northern Hemisphere uncertainty and forecast error in a medium-range coupled ensemble sea-ice prediction system. Quarterly Journal of the Royal Meteorological Society, 148 (747), 2877-2902 (2022).