

Please find below our responses to the reviewer comments and concerns regarding manuscript EGUspHERE-2025-3690 “The observed evolution of Arctic amplification over the past 45 years” submitted to *The Cryosphere*. Our responses are provided in red.

Respectfully,

Mark C. Serreze, and co-authors

REVIEWER #2

Overview: This study provides an update on the evolution of seasonal Arctic amplification (AA) during 1980 to 2024 using output mainly from ERA5. AA is calculated as differences between monthly mean Arctic two-meter air temperature anomalies (both pan-Arctic or individual Arctic gridpoints) and global-average two-meter air temperature anomalies. It should be noted this metric differs from that used in some other studies based on ratios of Arctic-to-global pace of temperature changes. While this manuscript provides no new revelations about Arctic amplification, it is a worthwhile addition as an update through 2024, especially the local amplification anomaly (LLA) metric that helps elucidate “hot spot” regions of AA in connection with sea-ice variability and horizontal advection. I don’t have any major concerns or suggestions, and after addressing numerous minor suggestions/corrections/comments listed below, I recommend the manuscript be published.

We appreciate the great time and effort invested in this review.

Specific comments and suggestions

1. In many instances while reading the text, I found the tense confusing or awkward. Past events and conclusions from past papers were often described with the present tense when it seemed past tense was more appropriate. I request the authors reread the manuscript and decide which tense is indicated and be consistent throughout.

We have made references to past findings more consistent by switching any cases where we had been using present tense to either past tense or past perfect tense. We also added an additional two figure references and switch to more 1st person language when referring to our results. Collectively, we hope these changes improve the readability.

2. Add units to color bars in all plots. Labels on color bars are too small.

This has been done.

3. Line 59: Misplaced parenthesis

Corrected.

4. Figures 1, 2, 3, 4, 8, 9: I suggest removing some longitude labels (maybe every 10 or 20 degrees instead of 5?) to look less cluttered, and please add labels on some latitude lines.

This has been done.

5. Fig. 2: The plot for Sept is duplicated.

The correct plot is in the paper now.

6. 110: “limiting” seems like an odd word to use here. Fluxes are always limited – maybe “reducing” is better?

To make the phrasing less awkward, we change it to *“...reducing energy transfer between the ocean and atmosphere.”*

7. 113: Please add a reference for thinning ice cover.

We have added two studies for this, one based on altimetry (Landy et al., 2022) and the other on moorings (Sumata et al., 2023).

8. 116: Replace “of much of” to “over much of”

Replaced as suggested.

9. 137: Are the units of global anomalies in degrees per decade or per year? Please specify units in Table 1.

The units are simply degrees C since these are discrete anomalies, not trends. The units are now stated in the caption, as well as the reference period being 1981-2010.

10. 139 and 141: Is Arctic defined as poleward of 50 or 60N?

Including the region 50°-60°N in maps was done to provide additional context and comparison to higher mid-latitudes, but all spatially averaged values for “Arctic” are for poleward of 60°N. To make this distinction clearer, we have added the following statement at the end of the first results paragraph (new line 105).

“In this study, the Arctic is defined as areas poleward of 60°N, but maps extend down to 50°N to enable comparisons between changes in the Arctic and the higher middle latitudes.”

11. Table 1, row 3: should be 2000-2009? Row 4 should be 2010-2019. Please specify units in table title.

Units are now specified and the row 3 and row 4 labels are fixed.

12. 145: It would be valuable IMO to point out that AA can also enhance cooling, as presented in Table 1. Usually AA is understood as amplification of warming, but it can go both ways and has in the past.

This is a tricky place to make that statement because we are looking at discrete anomalies relative to the 1981-2010 baseline, not a trend ratio. The temporal temperature trend for this period was still positive (still warming, in other words). Therefore, bringing up the point that AA goes both ways isn't super applicable here. However, the reviewer's point about Arctic amplification being applicable to both warming and cooling trends is apt. To avoid any confusion, then, we added this statement to the interpretation of Table 1.

“Note, since 1980-1989 is (primarily) the first decade of the 1981-2010 baseline period, greater negative anomalies for the Arctic than the globe still indicate amplified warming in the Arctic.”

13. 146: To increase clarity, I suggest beginning this sentence with: “During the decade at the middle of the baseline period...”

The statement is written this way because, mathematically, the reason why 1990-1999 has the smallest anomalies is because it is the middle of a baseline period that contains a roughly linear trend. This should be clearly now based on the edits we made in response

to comments #10 and #11 from Reviewer 2 and comment #9 from Reviewer 1.

14. 157: “now” is confusing and extraneous here.

The word has been deleted.

15. 165: It seems the comma after “values” should be a hyphen?

Yes, indeed. It has been changed.

16. 187: “Regressed” has a specific statistical meaning, so I suggest replacing it with “decreased” for added clarity.

Changed as suggested.

17. 193: Add “period” after 2010-2019

This word has been added.

18. 193-194: “grow” appears twice in grown and growing

The first instance has been replaced with “intensified.”

19. 197: I suggest adding “pan-Arctic” before “AA is somewhat smaller” if that is what is meant.

This has been added.

20. 204: Two “promotings” in this line

The first instance has been replaced with “facilitating”.

21. 227-228: Three “used” in this sentence

We changed the first instance to “applied”. Another edit (based on a comment by reviewer 1), eliminated the second.

22. 233: I believe this should say “latitudes” 75-80N. Why is this latitude range so narrow?

The zonal pattern of AA in SON and DJF is substantially wider.

Yes, that should say “latitudes”, which has been fixed. The 75°-80°N range was selected because it represents the latitude band where the air temperature anomalies are most constantly pronounced across both SON and DJF. Although the zonal pattern of Arctic amplification extends more broadly (from about 70°N to 85°N depending on region and season).

23. 240: Although December anomalies are less vertically extensive, it may be worth noting they are likely to have a bigger impact on fluxes because of larger difference in temperature between the surface and air above.

We thank the reviewer for this thoughtful observation. While Figure 5 shows temperature anomalies rather than absolute temperatures and therefore does not allow a direct assessment of the vertical temperature gradient, we agree that it is valid point and that such anomalies could potentially enhance surface fluxes. We have added a brief statement to acknowledge this potential effect.

“Although these anomalies are less vertically extensive, the stronger near-surface temperature difference between the surface and the air above in December could potentially enhance surface fluxes”.

24. 252: Perhaps note here that summer inversions are elevated? It seems contradictory to say summer inversions are shallower but accompanied by a deep mixed layer.

Summer inversions are now described as often being elevated as well.

25. 256: I'm not sure this will be obvious to readers. Please explain how this plot illustrates variations in stability with latitude. Even better would be a plot of the vertical gradient in theta versus latitude.

To clarify, we have replaced the original sentence with: *"Potential temperature increases with altitude more steeply in the Arctic than at lower latitudes, illustrating its, the stronger the static stability."*

26. 260: The decrease in cloud cover and moisture content from autumn into winter also tends to increase radiative cooling to space.

Our writing here was imprecise. The reviewer is of course right about the radiative cooling being more efficient when less clouds/moisture means less of a greenhouse effect. What we were trying to describe was the Planck and lapse rate feedbacks on the trends, not the mean state. We now reference Figure 5 and rephrased the statement to improve the clarity:

"While pronounced autumn warming does not extend upwards that far (Figure 5), the results nevertheless argue that as amplified warming progresses, cooling to space will become more efficient as a negative feedback on autumn warming."

27. 263: Table 1 illustrates that AA can be negative, so perhaps "progresses" is not appropriate word here. Amplified warming might be clearer.

Changed as suggested.

28. Figs. 7, 8, and 9 captions: add units.

We have added units to all three captions.

29. Figs. 8 and 9: I suggest changing color scales to be just negative for left plots and just positive for right plots to more clearly display spatial variations.

The scale has been changed for the left plot for clarity but kept the same for the right plot given that there are (albeit very small) areas of negative values.

30. 273 and 306: Units are unclear. "Over 1000-850" not clear – I believe it should be K/hPa. K/hPa is not a trend – what is unit of time? There's a typo at ends of these lines: "numbers in for the..."

The captions for Figures 8 and 9 have been revised. The units are now explicit for both the averages and the trends, and the formula for calculating stability (difference in potential temperature divided by difference in pressure) is now expressed mathematically as $(\theta_{850} - \theta_{1000}) / (850 \text{ hPa} - 1000 \text{ hPa})$

31. 282: The word "trend" appears often in these lines – how about changing "downward trends" to "declines"?

Two instances of "downward trends" were switched to "declines" to vary the language.

32. 284: Remove one "October"

The first instance was removed.

33. 285: Are these fluxes turbulent or just sensible? Do you mean upward fluxes have increased?

The flux described here is the conductive flux through the sea ice medium, not an atmospheric turbulent flux. To clarify, we have changed from the plural “conductive heat fluxes” to the singular “conductive heat flux”. We also now make clear that the average conductive flux through sea ice is directed upward in October. Finally, we switch “upwards trends” to “positive trends” to avoid confusion about the meaning of the word “upward”.

34. 290: Ditto.

See previous comment – several tweaks were made to clarify.

35. 296-302: This information is pretty old (2012 paper). Maybe MERRA-2 is better? Please add more up-to-date information if it’s available.

We were able to improve this discussion by citing a more recent reanalysis validation study (Graham et al., 2019) that includes both MERRA-2 and ERA5 (and therefore show the warm bias in the near-surface atmosphere in the winter persists).

36. 315: I think “they” should be “it” to agree with “any process”

Fixed.