Response to Reviewer:
Recurring Northward Flow Events in the East Greenland Current: A New Pathway for Atlantic Heat into the Arctic

MS No.: egusphere-2026-2955

Rebecca McPherson, Wilken-Jon von Appen, Laura de Steur, Luise Becker, Monica Ionita, Thomas Krumpen, Gunnar Spreen, and Finn Ole Heukamp

The original comments are presented in the order provided and in bold, and the responses from the authors are underneath the corresponding comment. The amendments to the manuscript itself are in italics.

We thank the Reviewer for their careful and insightful review of this manuscript. Their comments have prompted us to strengthen several aspects of the analysis and presentation, and we are grateful for the thoughtful suggestions,

Major comments

title "... into the Arctic" I suggest to write "Arctic Ocean" instead, as "the Arctic" is generally badly defined and may be understood as "north of the polar circle".

The title has been changed for clarity. Furthermore, we have replaced 'the Arctic' with 'the Arctic Ocean' in all instances where the oceanic basin is specifically intended.

Fig. 2 and 4 You are using potential temperature and Absolute Salinity? Please, either stick to the EOS-80 standard and use potential temperature together with practical salinity, or (recommended) use the TEOS-10 standard and switch to Conservative Temperature and Absolute Salinity. Please make sure to be consistent throughout the paper.

We thank the Reviewer for flagging this inconsistency. We have revised the manuscript to adopt the TEOS-10 standard throughout, replacing potential temperature with Conservative Temperature and ensuring Absolute Salinity is accompanied by its unit (g kg^{-1}) wherever numerical values are quoted. Figure axes and captions have been updated accordingly.

If you are actually showing Absolute Salinity in Fig. 2b, it does have a unit (gkg). What about a slightly non-linear color scale in salinity to clearly show the salinity structure (or simply using twice as many color levels)?

The unit has been added to the axis label and the number of colour levels has been increased.

l. 205 and all following occurrences I am slightly struggling with the word "local" in this context. To me, it implies a horizontal limitation in space, not a vertical one. I don't have a great suggestion either, but what do you think about "partial" instead?

This is a good suggestion by the Reviewer. We agree that *'local'* is ambiguous in this context and have replaced it with *'depth-limited'* throughout the manuscript as it more precisely conveys that these events involve northward flow at only some of the measured depths rather than through the full water column, with the focus on the vertical limitation.

l. 207 "local events are typically subsurface intensified" This is very easy to believe, but you are never explicitly showing how strong this subsurface intensification is. Could you show a typical velocity profile (with standard deviation, similar to what you did in Fig 8 for sea ice) during local events, deep events, and compare it to normal conditions? Maybe even highlight profiles for 2019 and 2025 events in particular. This could be a figure for the appendix if you don't want to add it to the main manuscript, but I would be very interested in seeing these profiles - even if they only contain three depths.

To directly address the reviewer's point regarding the vertical structure of these events, the additional figure suggested is below (Figure R1). This includes the mean 'background' profile, the mean of all depth-limited (previously 'local') and deep events, and then the 2019 and 2025 events specifically, including the standard deviation.

The mean velocity profiles confirm that deep events are strongly northward at all three mooring depths (50, 250, and 500 m), with comparable magnitudes (~0.06–0.10 m s^{-1}), consistent with a quasi-barotropic structure. Depth-limited events, by contrast, generally show a modest northward anomaly at 50 m that weakens and reverses at 250 m, confirming that these are surface-intensified and distinct from the deep events. The normal background state is southward at all depths, as expected for the EGC. This figure has been added to Figure 3 (the new Fig. 3a), and the vertical structure of the flow events is referred to in the manuscript in section 3.1:

…These depth-limited events are typically surface intensified, with a northward velocity anomaly at 50 m that weakens and reverses at depth (Fig. 3a), and over 80% of them lasted fewer than 5 days….

…Deep-reaching northward events (i.e., when the flow at all three measured depths is northwards; v > 0 m s^{-1}) show comparable northward velocities across all three mooring depths (Fig. 3a)...

…Both events exhibit a vertically coherent northward velocity structure across all three mooring depths, with the 2025 event showing stronger northward flow at all depths relative to 2019 (Fig. 3a)...

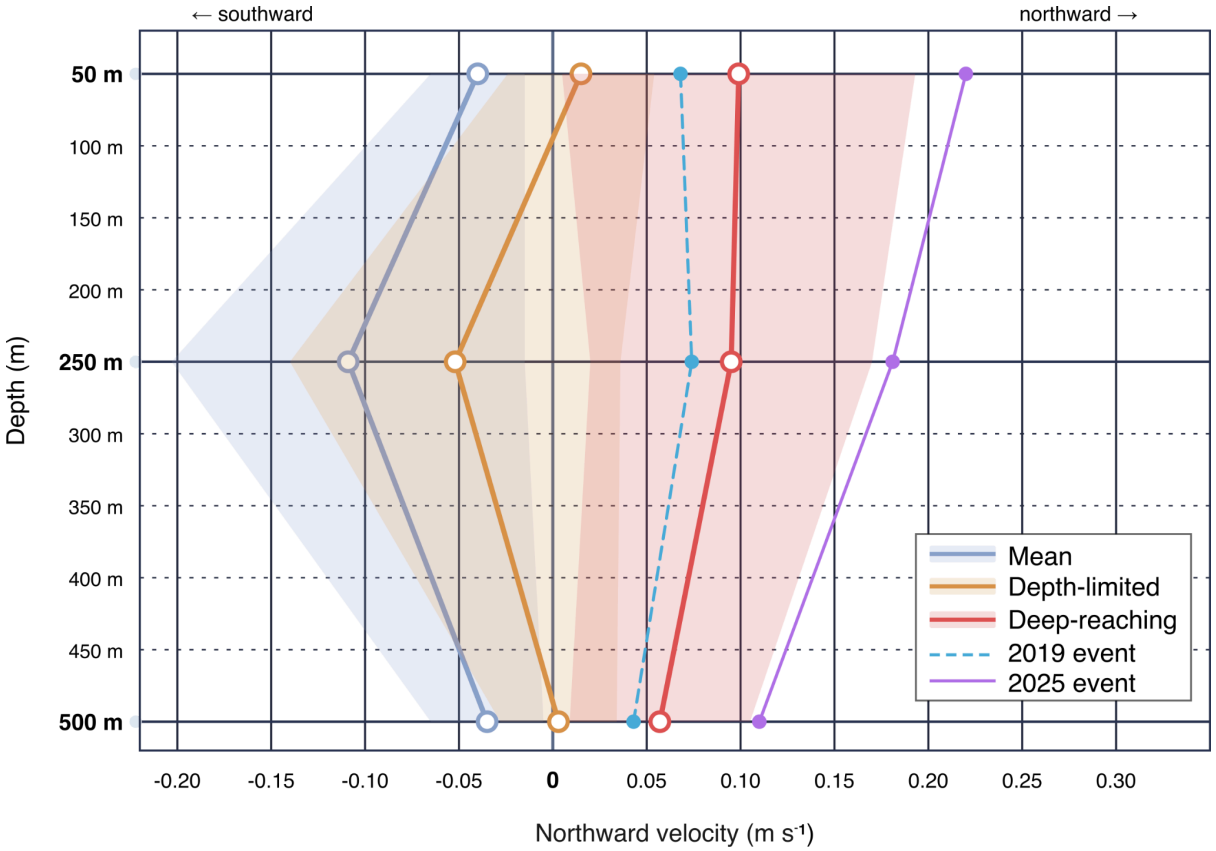


Figure R1 (new Figure 3a). Mean velocity profiles by flow regime. Daily-mean northward velocity (m s^{-1}) at 50, 250, and 500 m depth at the 79°N mooring. Profiles connect observations at 50, 250, and 500 m. Shading shows ± 1 standard deviation across all days in each category. Northward (positive) velocities indicate anomalous poleward flow against the mean southward EGC.

Fig. 3
This figure is already very informative, but some ideas here to improve:

We thank the reviewer for these constructive suggestions which have substantially improved the figure. We address each point in turn.

• In a), you are explicitly showing the velocities of the 2019 and 2025 events. This is good to get an order of magnitude, but it is difficult to know for somebody who hasn't worked with that data whether this is a lot stronger than shorter events or just at the upper end of the distribution. Could you add smaller dots for the other deep events of shorter duration?

We have replaced the original panel (a) that was the seasonal velocity histogram with a 2D pcolor histogram showing the full distribution of daily upper-500 m mean velocities by month (new Fig. 3b). This more effectively conveys how the 2019 and 2025 events deviate from the typical velocity distribution in May, and from the record as a whole.

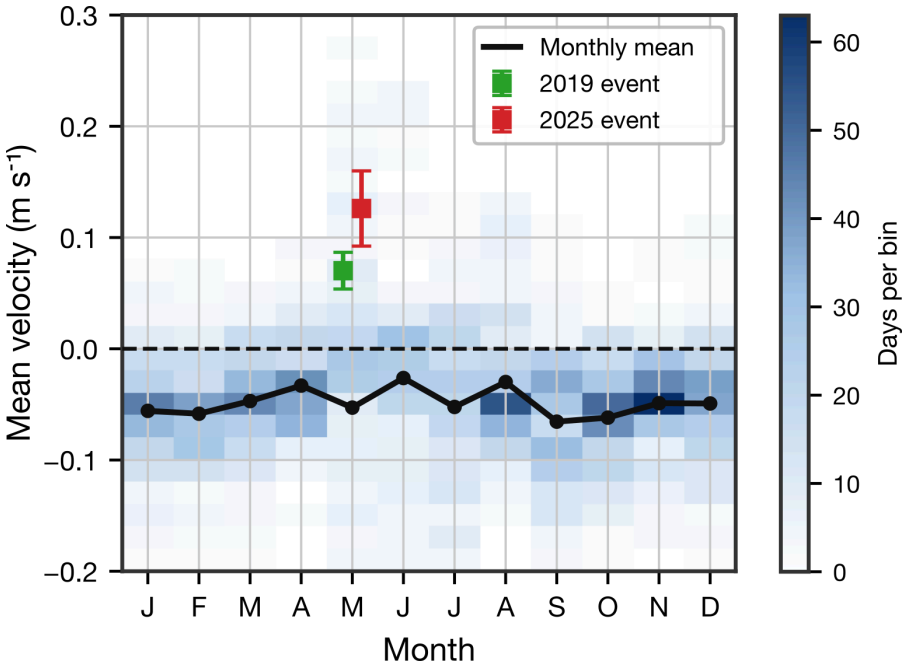


Figure R2; Seasonal cycle of upper- 500 m mean north-south velocity components, shown as a 2D histogram of daily values binned by month and velocity colour scale. The black line shows the monthly mean, excluding the 2019 and 2025 May deep events; green and red squares mark the mean velocity during those events respectively, with whiskers showing ±1 standard deviation across depth levels.

• When reading these paragraphs, I start to wonder how much of the seasonal bias is due to the seasonal shift of the mean velocity rather than any external drivers such as eddies. The distribution here may help again. In a), you are indicating variability in each month by the standard deviation. Would it be possible to show the speed distribution as a violin diagram for each month instead? Or would this just overload the figure?

We concluded that a violin diagram would overload the figure without adding sufficient insight beyond what the new seasonal pcolor histogram (new Fig. 3b) already provides. Instead, we computed whether the seasonal bias in event occurrence reflects the seasonal shift in mean velocity using the Spearman rank correlation between climatological monthly mean velocity and the percentage of days occupied by northward events (see response to the final point below).

• could you add more gridlines on the y-axis? Then it would be easier to compare mean values across months.

Additional y-axis gridlines have been added to all panels.

• if you show the vertical profiles of velocity, this comment becomes redundant. Alternatively you could use several shades of orange/red to indicate at which of the instrument depths the "local" events were identified and stack the counts on top of each other in b).

We have added mean velocity profiles by flow regime as a new panel (new Fig. 3a), which directly addresses the vertical structure of depth-limited vs. deep events.

• Looking at 3c): curiously, there are quite many deep events registered in December, which seems to have a mean velocity comparable to March - when no deep events were registered! Stacking the total occupation time of all events on top of each other though, they may be comparable? I agree with you that events are statistically more likely to happen when the mean speed is weaker. It would be quite straight forward to show such a correlation by plotting climatological v-component against instantaneous v-component maybe as a fourth panel of Figure 3? Color coding by local vs deep and highlighting the 2019 and 2025 events would shed even more light on the statistical nature of the anomalous northwards events.

This is an interesting suggestion. To test whether northward events preferentially occur during months with weaker mean southward flow, we computed the Spearman rank correlation between the climatological monthly mean velocity and the percentage of days occupied by northward events in each month (Figure R3 below). The correlation is strong and statistically significant for all events combined ($\rho = 0.83$, $p < 0.001$) and for depth-limited events individually ($\rho = 0.66$, $p = 0.02$), with a consistent but weaker signal for deep events ($\rho = 0.53$, $p = 0.08$), likely reflecting their lower frequency (35 events vs. 141 depth-limited events). This confirms that northward events are more likely to occur, as well as occupy more days, when the mean EGC flow is weakest, consistent with the reviewer's hypothesis.

The December deep events noted by the reviewer are entirely consistent with this pattern: the December climatological mean (-0.049 m s^{-1}) is virtually identical to March (-0.047 m s^{-1}), suggesting comparable background conditions in both months. We have added a sentence to the results to reflect this finding:

Northward events occurred preferentially during months with a weaker mean southward flow, with the percentage of days occupied by events correlating strongly with the climatological monthly mean velocity (Spearman $\rho = 0.83$, $p < 0.001$).

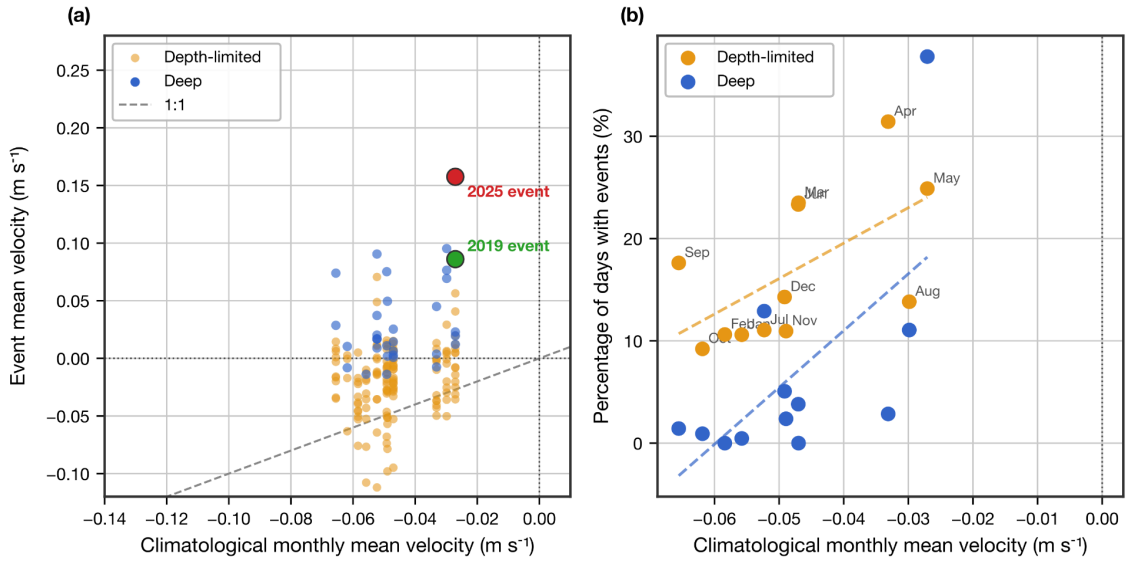


Figure R3. Relationship between climatological monthly mean northward velocity and the occurrence of northward flow events at the 79°N mooring (2018–2025). (a) Mean velocity during each individual depth-limited (orange) and deep (blue) northward event plotted against the climatological monthly mean velocity for the month in which the event occurred. The 2019 and 2025 May deep events are highlighted separately. The dashed line shows the 1:1 reference (event mean = climatological mean). (b) Percentage of days per month occupied by depth-limited and deep events as a function of climatological monthly mean velocity, with linear fits (dashed lines). Spearman rank correlations are shown inset. Climatological monthly means exclude the 2019 and 2025 May deep events.

l. 290 "The May 2019 and 2025 northward flow events were also associated with changes in the hydrographic structure" "hydrographic properties". You just spent half a paragraph telling the reader that the hydrographic structure (the layering of water masses) was maintained during the events

Amended.

(l. 251-259). I interpret the TS diagram such that the general structure is still consistent (the three distinct water masses are still present), just that the actual properties of the different water masses shifted towards higher salinities and temperatures, particularly in the AAW. One may even go as far as seeing a mixing line between AW and AAW properties during both events (this could be picked up in the discussion).

We agree that the T-S diagram shows the three-layer water mass structure is maintained during both events in the sense that PSW, AW, and AAW remain identifiable, but that the properties within the AW/AAW depth range shift substantially toward warmer and saltier values, particularly at depths normally dominated by AAW. The language in Section 3.2 has been clarified to make this distinction explicit. The observation about the mixing line is also interesting. The T-S properties during both events do trace a path between the AW and AAW end members on the T-S diagram (Fig. 4), consistent with active mixing between these two

water masses during the northward flow events, and we have added a sentence to Section 3.2 making this interpretation explicit in the text.

This had been added to Section 3.2 of the manuscript:

Whilst the three-layer water mass structure remained identifiable during both events, the properties within the Atlantic-origin water layer shifted substantially toward warmer and saltier values, particularly at depths normally dominated by AAW. The T-S properties during both events lie between the AW and AAW end members on the T-S diagram (Fig. 4), consistent with active mixing between these two water masses during the northward flow events in addition to the displacement of AAW by the intruding AW.

In the Discussion in Section 6.1, this has been added:

The T-S properties during both events lying between the AW and AAW end members on the T-S diagram (Fig. 4) are consistent with this interpretation, suggesting that the upwelling and enhanced vertical shear associated with the wind-forced reorganisation drove active mixing between the intruding AW and the AAW normally present at these depths.

l. 366-368 “Under this assumption, subsurface AW at 250m could have been advected approximately 250 km northward during the 2019 event, [...], and over 750 km during the 2025 event [...].”

It is not clear what this comment refers to. The current sentence is in line with the reviewers comment:

Under this assumption, subsurface AW at 250m could have been advected approximately 250km northward during the 2019 event, reaching ~81°N, and over 750km during the 2025 event, potentially reaching ~86°N.

If this water is flowing so far north, it also needs to return somehow, which should be visible in TS properties in the EGC, right? Could one, based on the temperature and salinity development after the events, conclude how long it takes to get back to normal and based on that derive an estimate for how far north the water actually got before it returned - or whether it left the EGC sideways, indicating that the reversal of the EGC was rather local in the end (now meaning “confined to the mooring location”)?

This is an interesting suggestion. In principle, the post-event T-S recovery time could constrain the return pathway if the water parcel retained its T-S signature during its northward and southward transit. However, we believe that this calculation could be unreliable as the northward-advected AW mixes with surrounding water masses during its transit — including mixing with AAW as evidenced by the T-S mixing signature discussed in Section 3.2 — its T-S properties will be progressively modified, making it impossible to identify the same water parcel upon its return at the mooring location. Furthermore, the broader Arctic Ocean circulation, including the Transpolar Drift, may act on the water mass independently of the EGC dynamics, potentially diverting it from a simple northward-then-southward trajectory along the slope which would return over the mooring

location. As discussed in Section 5.3, the slow return of T-S properties to climatological values over approximately 3 months following the 2019 event also cannot be unambiguously attributed to return flow of the advected water parcel versus sustained enhanced AW recirculation from the WSC — both these processes would produce a similar T-S signal at a single mooring location.

A reliable estimate of how far north the water actually travelled before returning would require either Lagrangian float observations or a mooring array spanning multiple latitudes north of 79°N to track the water parcel directly, and remains an important objective for future observational studies.

Minor comments

Make sure that spacing between number and unit is consistent and according to SI standards (250m and 250km).

We have revised the manuscript to ensure spacing between numbers and units follows SI standards.

Fig. 5 caption “lasted over 5 days” do you mean “lasted for at least 5 days”? or “lasted for exactly 5 days”? Based on the figure, it looks as if all these events that lasted for longer than 5 days did actually last for more than 20 days. Is that correct? If that is the case, what would cause such a gap between 5 and 20 days? In Fig. 3b, you show that there are some deep events lasting up to 14 days at least, but they don’t seem to be part of this figure?

We believe that the confusion arises from the colorbar scales differing between panels (a) and (b) despite the same colour. Panel (a) covers 8 events with a duration range of 5–11 days whilst panel (b) covers the much longer durations of the 2019 and 2025 events, up to 50 days. We have clarified the caption and ensured the colorbar labels in panel (a) are sufficiently clear to avoid this misreading. The caption has also been updated to read 'lasting for at least 5 days' rather than 'lasted over 5 days' to remove the original ambiguity the reviewer identified.

Figure 5. Progressive vector diagram of the velocities from (a) all the deep-reaching northward events than lasted for at least 5 days (excluding 2019 and 2025), and (b) the 2019 (outlined) and 2025 events at 50 m (circles), 250 m (triangles), and 500 m (squares). Note the axis scales and colourbars differ between the two panels reflecting the order-of-magnitude difference in northward displacement between the shorter events in (a) and the prolonged 2019 and 2025 events in (b).

l. 421-434 I believe that you refer to Fig. A5 when you mention the 8 deep-reaching events registered by the FSAOO dataset - but you are not referring to the figure. In fact, you are not referring to Fig. A5 at all anywhere in this manuscript. Please add a reference or remove the Figure if it is not needed.

A reference to Fig. A5 has been added in the relevant passage.

Fig. 8 As you are discussing the impact of anomalously warm water on sea ice, it would be good to see the actual potential of the ocean to melt any ice. You could, e.g. add a second panel on top (or bottom) that shows available heat divided by latent heat for melting over time or as a cumulative quantity: Q = ρ cP (T50m − Tfreeze)/Lmelt

We thank the reviewer for this interesting suggestion but conclude that it is not feasible with the current dataset as our 79°N mooring provides point measurements at fixed depths and therefore lacks the horizontal extent needed to compute a heat transport or integrated melt potential. Without knowing the vertical temperature structure between the surface and 50 m, which is precisely the layer most relevant for sea ice melt, introduces very large and poorly constrained uncertainties.

The FSAOO mooring array, which does provide horizontal coverage, would in principle be better suited to this calculation however, the key challenge is the choice of reference temperature T_freeze: defining an appropriate reference temperature against which to measure “available heat” is a point of considerable discussion and debate in the oceanographic community, with different choices leading to substantially different estimates of melt potential.

l. 602 “the July 2004 sea ice area was also among the lowest values in the record”. From Fig. 8 it is not clear which year is 2004. I do like the figure as it is and think that more colors would make it overwhelming, but I wonder whether it is possible to establish a stronger link between events of anomalous northward flow and anomalously low sea ice? The expected time lag makes a correlation difficult and I don’t want you to add a full lagged-correlation analysis. I don’t know if that is feasible, but could you for example calculate a kind of index that represents the strength (normalized duration * velocity during event * depth range impacted) of the events and color the lines by that?
Fig. A3 I assume that “normalised velocities” somehow makes the velocities at the different depths comparable even when they are orders of magnitude apart. But what exactly is it normalised by? And what for? It is not specified anywhere. Since this is an appendix figure, you may just like to add a sentence in the figure caption. What is the value of this Figure compared to Fig. A1? Could you combine them/just choose one?

Good point. Figure A3 has been removed and the vertical red lines that showed the deep northward events have been moved to Figure A1.

l. 24 “... is identified all strong deep northward flow events” → “... is identified during/before all strong deep northward flow events”

Amended

l. 57 “into the Arctic” → “into the Arctic Ocean”

Amended

l. 75 “increase in the salinity stratification of the PW due to freshening of the upper layer and increased presence of AW has occurred” → “increase in the salinity stratification of the PW due to freshening of the upper layer and increased presence of AW below has occurred”

Amended.

Fig. 2 caption (and elsewhere in the manuscript) I noticed that you are slightly inconsistent with type setting of units. Here, e.g.: kgm−3 vs ms-1. Other inconsistent occurrences are, e.g., l. 198 vs l. 199. I suggest to stick to the raised power notation (ms−1) throughout the manuscript and to stick to the SI standards for spacing between numbers, units and unit prefixes (see, e.g. https://www.nist.gov/pml/owm/writing-si-metric-system-units or https://physics.nist.gov/cuu/Units/checklist.html). I can warmly recommend the siunitx package for handling units…

We have revised the manuscript to use raised power notation consistently throughout (e.g., m s^{-1}) and have ensured spacing between numbers and units follows SI standards as defined in the useful links the Reviewer included.

Fig. 2c label for colorbar should be “Northward velocity (ms−1)” (not “Northwards”) to be consistent with the figure caption.

Amended

l. 223 “occurring in over 10% days” → “occurring in over 10% of days”

Amended.

l. 255 for better reading flow, I like to exchange “>” with “larger than” in the text.

Amended in the text when referencing the AW definition (i.e., *AW core with temperatures greater than 2°C*), but kept when defining the northward flow events (i.e., $v > 0$ ms^{-1})

l. 295 “mean of 34.1 and 33.5” if you are using Absolute Salinity (as you do in your figures), these numbers deserve their unit gkg !

Amended

Fig. 5 Sorry for being picky, the ever-lasting discussion about colors. The colorbars in this figure are not particularly color-blind friendly and neither perceptually uniform. I like diverging colorbars, but in this case a linear one may be more appropriate. You could continue using cmcocean, for a change I can recommend these colorbars: https://www.fabiocrameri.ch/colourmaps/, and if you want to stick to a rainbow-type of colormap, maybe try out these ones: https://colorcet.com/gallery.html#linear

We feel that the blue-to-red progression is intuitive here, as the bright, highly contrasting colours clearly identify the temporal evolution of the different events which is lost with a

perceptually linear colormap (we plotted a number of different options from the Crameri toolbox), and have therefore retained the original colormap in Figure 5.

l. 313 “In the two weeks preceding both events, salinities and temperatures were generally typical of the mean properties for the EGC at each depth, though near-surface salinities in 2019 were slightly higher” Point the reader to Fig. 4.

Amended

l. 408 “in the EGCs structure” → “in the EGC’s structure”

Amended

l. 542 Chapter 4 is titled: “Possible Drivers of Anomalous Northward Flow”. 4.3 is discussing a consequence of anomalous northward flow rather than a driver. I suggest to either make this chapter 5, or to rephrase the title of chapter 4.

Good point. Section 4.3 has been made Section 5.

l. 620 “than previously been described” → “than have previously been described”

Amended

Fig. 9b
• Can you increase the vertical gap between “SSH gradient anomaly” and “Offshore shift and slowing of the EGC core”

• Make the arrow indicating upwelling of AW in the same color as the AW bubble

• make the figure labels (a,b) bold to distinguish from text in figure Fig. A1 panel labels (a,b) are missing in the figure. Maybe number panels with a) and b) instead of (a) and (b), such that one can easily distinguish between a reference to a panel a) and a statement in parentheses (u) in the caption?

We have revised Fig. 9 as suggested: the vertical spacing between labels has been increased, the upwelling arrow now matches the colour of the AW body, and panel labels have been made bold for clarity.

Fig. A3 caption “events in red” → “events highlighted in red”

Amended.

Fig. A5 I assume that the gray lines are marking the same periods that are highlighted red in Fig. A3. Could you choose the same color coding for both Figures?

Supplementary Figure 3 has been removed entirely, following the Reviewer’s earlier suggestion by combining it with Supplementary Figure 1. The grey vertical lines that mark

the timing of the deep northward events in Supplementary Figure 5 have been marked in Supplementary Figure 1 in the same colour for continuity.

Fig. A6 caption Another very picky comment: “velocity” is a vectorial quantity, while “speed” would be a scalar. e.g., l. 644 “northward velocities [...] southwards velocities” I know it technically doesn’t matter, but as a reader I would prefer if the authors decided whether they want to stick to “...ward” or “...wards”. You use a very variable language - which is refreshing to read, but some basic consistency will make it easier to focus on the even more refreshing content :) I personally prefer the version without s, but that is a totally subjective opinion.

We have standardised the manuscript to use 'northward' and 'southward' throughout, removing the inconsistent use of 'northwards' and 'southwards'. Furthermore, the caption of Fig. A6 has been corrected to use 'speed' instead of ‘velocity’.