**Review for**

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

submitted to: Ocean Sciences
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**Summary of the manuscript:** The authors use long-term velocity and hydrographic observations from several moorings in Fram Strait to analyse the velocity and hydrographic structure of the East Greenland Current (EGC), complemented with CTD data. While the EGC is typically flowing southward, the authors focus on anomalies of northward flow, characterize their frequency and associated hydrographic anomalies, and identify two particularly long-lasting and strong events in 2019 and 2025. Eddies and anomalous northward wind forcing are considered as potential drivers and it is laid out that eddies can explain short-term flow anomalies up to 10 days duration, but that unrealistically large eddies would be necessary to explain anomalies of the prolonged duration of the 2019 and 2025 events. Instead, the anomalous northward flow seems to be a consequence of persistent northward wind-forcing events. Finally, the authors discuss implications of events of northward flow for the sea-ice concentration and conclude that the additional heat associated with upwelling of Atlantic Water during events of anomalous northward flow may accelerate sea-ice melt from below/delay sea-ice formation, but cannot explain alone the abrupt sea-ice loss following the 2025 northward flow event. Instead, the strong wind forcing is probably responsible for both, a reversal of the flow and enhanced sea-ice export from the region under investigation. The authors establish a picture of a less consistent EGC than previously assumed, where strong and long-lasting anomalies are predominantly wind driven.

**Overall statement:**
The manuscript presents important new findings that change our picture of variability in the EGC. This has broad implications for our understanding of heat transport into (and out of) the Arctic Ocean and thus of the impact of Atlantic heat on Arctic sea ice.
The manuscript is in a very developed state and I only have minor comments to improve it further. The figures are well-chosen, clear, containing a lot of information while not being overloaded. The manuscript is well-structured and easy to follow, terminology is used appropriately. The analysis presented is relevant to support the authors' argumentation, and the analysis is well executed.

In the following, I will highlight "*quotes from the manuscript*" in gray, and "*suggestions*" in dark blue. Please treat my comments as pure suggestions, I don't think that any of the suggested changes are strictly necessary to accept for publication.

## Specific 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".

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

**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?

**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.

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

- In a), you are explicitely 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?
- 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?
- could you add more gridlines on the y-axis? Then it would be easier to compare mean values across months.
- 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).
- 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.

**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 (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).

**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 [...].*" If this water is flowing so far north, it also needs to return somehow, which should be visible in TS properties in teh 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")?
Minor comment: make sure that spacing between number and unit is consistent and according to SI standards (250 m and 250 km).

**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?

**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.

**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: $Q = \rho\, c_P\, (T_{50\,\mathrm{m}} - T_{\mathrm{freeze}})/L_{\mathrm{melt}}$

**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 appart. 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?

## Minor Comments

**l. 24** "*... is identified all strong deep northward flow events*" → "*... is identified **during/before** all strong deep northward flow events*"

**l. 57** "*into the Arctic*" → "*into the Arctic Ocean*"

**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*"

**Fig. 2 caption (and elsewhere in the manuscript)** I noticed that you are slightly inconsistent with type setting of units. Here, e.g.: $\mathrm{kg\,m^{-3}}$ vs m s-1. Other inconsistent occurrences are, e.g., l. 198 vs l. 199. I suggest to stick to the raised power notation ($\mathrm{m\,s^{-1}}$) 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...

**Fig. 2c** label for colorbar should be "*Northward velocity* ($\mathrm{m\,s^{-1}}$)" (not "*Northwards*") to be consistent with the figure caption.

**l. 223** "*occurring in over 10 % days*" → "*occurring in over 10 % **of** days*"

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

**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 $\frac{\mathrm{g}}{\mathrm{kg}}$!

**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

**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.

**l. 408** "*in the EGCs structure*" → "*in the EGC**'**s structure*"

**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.

**l. 620** "*than previously been described*" → "*than **have** previously been described*"

**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?

**Fig. A3 caption** "*events in red*" → "*events highlighted in red*"

**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?

**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.