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 thorough and constructive review of this manuscript. The comments have led to significant improvements in the clarity and scientific rigour of the paper, and we are grateful for the time taken to provide such detailed feedback. We address each comment in turn below.

General comments

To test your hypothesis that episodes of anomalous southerly winds cause the reversals, I suggest that you identify all cases in the ERA5 reanalysis from the 1997-2019 period characterized by persistent southerly winds in Fram Strait of sufficient duration and strength, and then use the mooring data to determine whether each of those events did indeed cause a flow reversal. If that is the case, it would substantially strengthen your hypothesis. If not, at least it would demonstrate that southerly winds alone are not sufficient to cause the flow reversals. That would also have implications for the hypothesized increased frequency of such events (section 5.3). Are southerly winds in Fram Strait, presumably a necessary condition for flow reversals, becoming more prevalent?

We thank the reviewer for this suggestion and agree that looking at all wind events, and not only at those that happened to coincide with the reversals we observed, is the right way to test our idea.

To identify the wind events, we used daily ERA5 10-m winds for 1971–2025 and averaged the north–south wind component over Fram Strait and the northeast Greenland margin (76–81°N, 15°W–5°E). Because the wind here normally blows from the north, we looked at southerly events in two ways: periods when the wind actually turned and blew from the south, and periods when it was much more southerly than usual for the time of year (more than one standard deviation above the 1971–2000 daily mean). In both cases the condition had to last at least five days. We chose five days because this roughly separates the short, eddy-related reversals in our mooring record from the longer ones. We also tried three, seven and ten days, and a smaller area covering only the shelf and slope (77–81°N, 12–2°W). These choices change the number of events, but not our conclusions (Table R1).

Table R1. Number of southerly wind events in ERA5 (1997–2025) for the two definitions, two areas and four minimum lengths. "Wind from the south": daily mean north–south wind > 0. "Unusually southerly": more than one standard deviation above the 1971–2000 daily mean. A 79°N event counts as matched if a wind event occurred between 30 days before its onset and its end; an FSAOO event if a wind event occurred in the event month or the month before.

Area	Type of event	Minimum length	Events 1997–2025	Per year	79°N events matched	FSAOO events matched
Fram Strait	Wind from the south	3 days	442	15.2	2 of 2	7 of 8
Fram Strait	Wind from the south	5 days	261	9.0	2 of 2	6 of 8
Fram Strait	Wind from the south	7 days	168	5.8	2 of 2	5 of 8
Fram Strait	Wind from the south	10 days	71	2.4	0 of 2	3 of 8
Fram Strait	Unusually southerly	3 days	241	8.3	2 of 2	6 of 8
Fram Strait	Unusually southerly	5 days	95	3.3	2 of 2	4 of 8
Fram Strait	Unusually southerly	7 days	56	1.9	2 of 2	2 of 8
Fram Strait	Unusually southerly	10 days	13	0.4	0 of 2	0 of 8
Shelf and slope	Wind from the south	3 days	475	16.4	2 of 2	8 of 8
Shelf and slope	Wind from the south	5 days	270	9.3	2 of 2	5 of 8
Shelf and slope	Wind from the south	7 days	168	5.8	2 of 2	3 of 8
Shelf and slope	Wind from the south	10 days	80	2.8	1 of 2	2 of 8
Shelf and slope	Unusually southerly	3 days	226	7.8	2 of 2	6 of 8
Shelf and slope	Unusually southerly	5 days	90	3.1	2 of 2	3 of 8
Shelf and slope	Unusually southerly	7 days	49	1.7	2 of 2	0 of 8
Shelf and slope	Unusually southerly	10 days	6	0.2	0 of 2	0 of 8

Southerly wind events turn out to be quite common in Fram Strait (Fig. R1). Between 1997 and 2019 the wind blew from the south for at least five days on 213 occasions, roughly nine times a year, and was unusually southerly for at least five days 76 times, about three times a year. Many of the events happen in summer, when the usual northerly winds are weak.

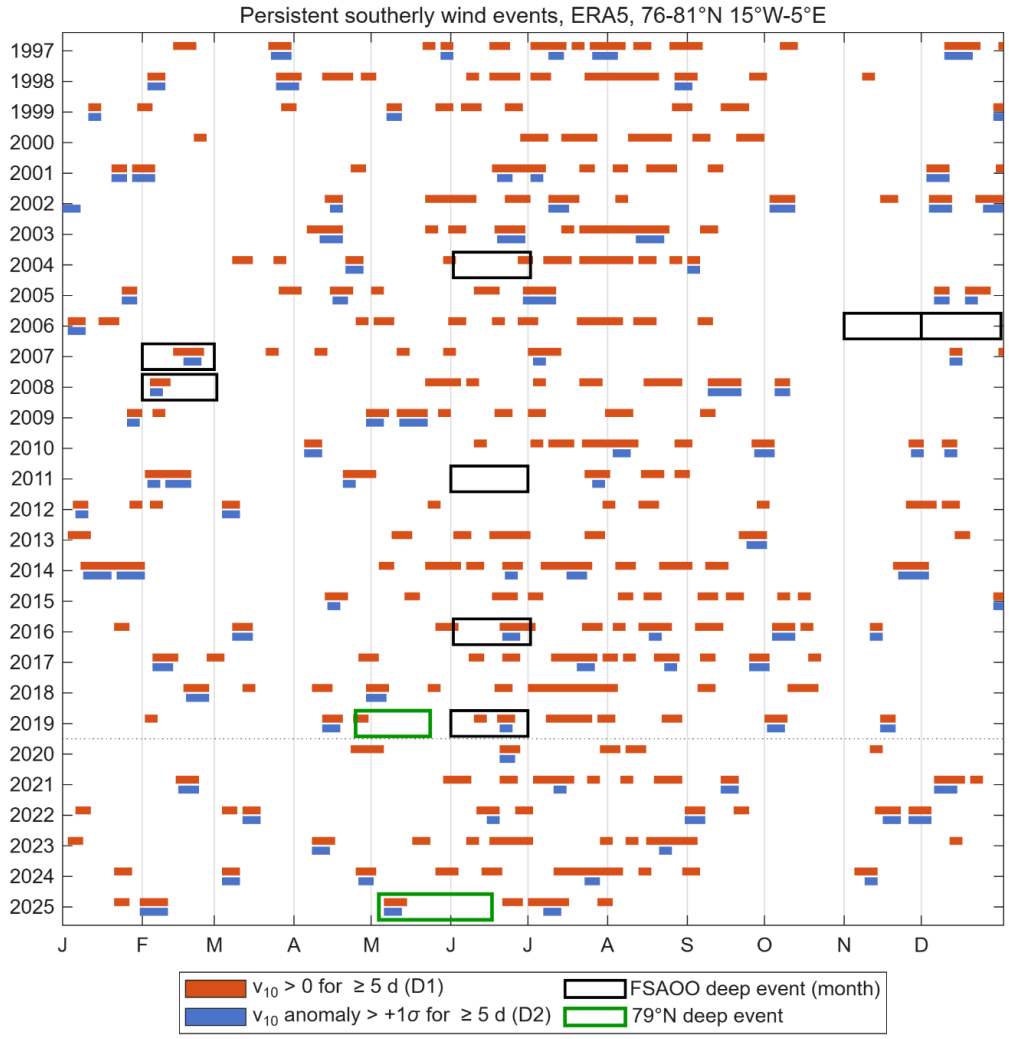


Figure R1. Southerly wind events in Fram Strait (76–81°N, 15°W–5°E) lasting at least five days, 1997–2025, one row per year. Orange: wind from the south; blue: unusually southerly wind. Black frames: months with deep northward flow events in the FSAOO record at 78°50'N; green frames: the two deep events at the 79°N mooring.

The two long events at the 79°N mooring fit our hypothesis well (Figs. R2 and R3). In April 2019, a strong high over Scandinavia and a low southwest of Greenland drove southerly winds through Fram Strait for about two weeks. The northward flow at the mooring began on 25 April, about a week after the strongest winds (12–18 April). During the event itself the wind had already turned back to northerly, which supports our interpretation that the ocean keeps responding for some time after the forcing has stopped. In May 2025, a deep low over Greenland and a high over the British Isles produced the strongest southerly wind episode of that spring (6–12 May, with daily winds of up to 12 m s^{-1}), right at the start of the northward flow on 4 May.

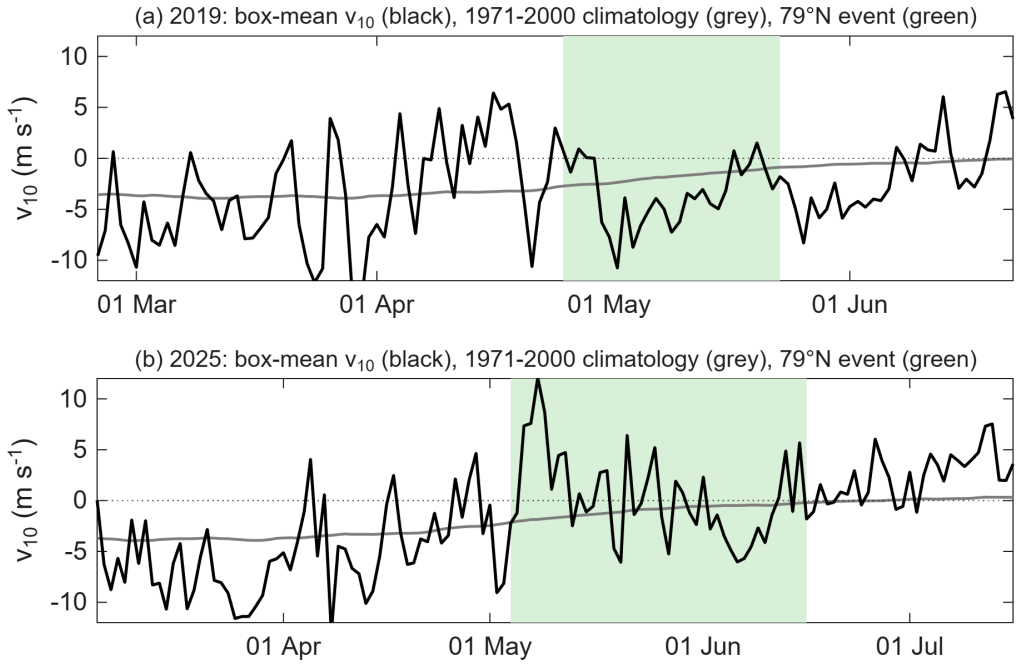


Figure R2. Daily north–south wind averaged over Fram Strait (black; positive = from the south) and its 1971–2000 average for the same day (grey), around the 2019 (a) and 2025 (b) events at the 79°N mooring (green shading).

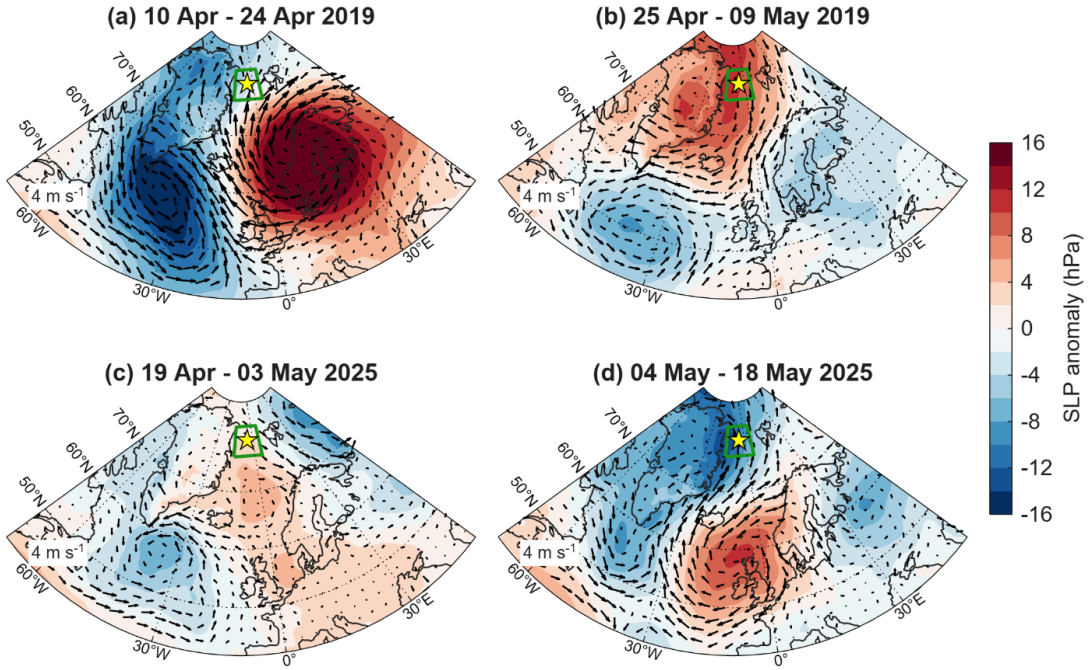


Figure R3. Sea-level pressure (colours) and 10-m wind (arrows) anomalies for the 15 days before the start (a, c) and the first 15 days (b, d) of the 2019 (top) and 2025 (bottom) events at the 79°N mooring. Anomalies are relative to the 1971–2000 daily average. Green box: area used for the wind events; star: mooring position.

The longer FSAOO record gives a less clear picture. Only four of the eight deep events at 78°50′N had an unusually southerly wind episode in the same month or the month before, and we found no such episode at all around November–December 2006. Seen the other

way round, most of the southerly wind events between 2003 and 2019 were not followed by a deep northward event in the FSAOO record. We should add that the FSAOO data are monthly means, which would hide reversals that last only a week or two, so this comparison is not a strict test.

The daily record from the 79°N mooring (2018–2025) allows a cleaner check. Table R2 lists the 25 unusually southerly wind events in that period, together with what the mooring recorded.

Table R2. Unusually southerly wind events in Fram Strait during the 79°N mooring period (2018–2025), with the response at the mooring. Wind: mean north–south wind during the event (positive = from the south) and its mean anomaly in standard deviations (σ). Deep flow: northward at all three depths; local flow: northward at one or two depths.

Start	End	Days	Wind (m s^{-1})	Anomaly (σ)	Deep flow at 79°N	Local flow at 79°N
2018-02-18	2018-02-26	9	7.75	1.91	[ ]	[ ]
2018-04-29	2018-05-06	8	4.98	1.56	[ ]	[ ]
2019-04-12	2019-04-18	7	3.50	1.33	[Y]	[Y]
2019-06-20	2019-06-24	5	5.20	1.42	[Y]	[Y]
2019-10-02	2019-10-08	7	5.05	1.64	[Y]	[Y]
2019-11-15	2019-11-20	6	5.84	1.81	[Y]	[Y]
2020-06-19	2020-06-24	6	3.57	0.98	[ ]	[Y]
2021-02-15	2021-02-22	8	5.96	1.61	[ ]	[ ]
2021-07-11	2021-07-15	5	5.87	1.58	[ ]	[Y]
2021-09-14	2021-09-20	7	5.23	1.58	[ ]	[Y]
2021-12-06	2021-12-14	9	3.91	1.43	[ ]	[Y]
2022-03-12	2022-03-18	7	7.03	1.85	[ ]	[Y]
2022-06-15	2022-06-19	5	5.09	1.41	[ ]	[ ]
2022-08-31	2022-09-07	8	4.41	1.30	[ ]	[ ]
2022-11-16	2022-11-22	7	2.53	1.20	[ ]	[ ]
2022-11-26	2022-12-04	9	3.71	1.44	[ ]	[ ]
2023-04-08	2023-04-14	7	4.01	1.44	[ ]	[ ]
2023-08-21	2023-08-25	5	4.53	1.17	[ ]	[ ]

2024-03-03	2024-03-09	7	4.89	1.43	[ ]	[ ]
2024-04-25	2024-04-30	6	4.54	1.47	[ ]	[ ]
2024-07-22	2024-07-27	6	5.78	1.46	[ ]	[ ]
2024-11-08	2024-11-12	5	1.38	1.03	[ ]	[Y]
2025-01-31	2025-02-10	11	5.79	1.63	[ ]	[Y]
2025-05-06	2025-05-12	7	6.57	1.88	[Y]	[Y]
2025-07-07	2025-07-13	7	5.05	1.36	[ ]	[ ]

Strong and persistent southerly winds seem to be needed for the long, deep-reaching events we describe, but they are not enough on their own: many wind episodes of similar strength and length did not produce a deep reversal. Other conditions must therefore also play a role (for example how long and over how large an area the wind blows, the strength of the Atlantic Water recirculation and of the background East Greenland Current, and the stratification and sea-ice cover, which control how much of the wind's momentum reaches the ocean).

We have added this analysis to the Supplementary Materials (specifically Figures R1 and R3) and rewritten Sections. 4.2 and 5.1 so that we now present the wind as an important trigger of the events rather than as their only cause. We are grateful to the reviewer for this suggestion, which has led to a more balanced and, we believe, more convincing discussion.

In section 4.2, we have added:

To test whether southerly wind forcing is a consistent precondition for deep northward flow events, all episodes of anomalous southerly winds over Fram Strait and the northeast Greenland margin were identified in ERA5 between 1997 and 2025 (Supplementary Figure 5). Southerly wind episodes lasting at least five days were relatively common, occurring approximately nine times per year. Both the 2019 and 2025 events were preceded by southerly winds (Supplementary Figure 6). For the 2019 event, the strongest southerly winds occurred approximately one week before the event onset on 25 April, consistent with the adjustment timescale of the boundary current system, and the wind had already weakened by the time the oceanic event was fully established, supporting the interpretation that the ocean retains its adjustment beyond the period of active wind forcing. For the 2025 event, the strongest southerly wind episode of that spring (6–12 May, daily winds up to 12 m s^{-1}) coincided with the event onset on 4 May and is consistent with the greater intensity and longer duration of the northward oceanic flow observed relative to other events in the record (Figs. 2a,b). However, most southerly wind episodes in the record were not followed by a deep northward flow event at the mooring location. Sustained anomalous southerly winds therefore appear to be a necessary, but not sufficient, condition for maintaining deep northward flow events indefinitely. Other factors are discussed in Section 5.1.

In the Discussion, we have added:

The ERA5 wind analysis (Supplementary Figure 5) demonstrates that whilst anomalous southerly winds are a necessary condition for deep northward flow events, they are not sufficient on their own. Many wind episodes of comparable strength and duration in the 1997–2025 record were not followed by a deep reversal, suggesting that other factors modulate the oceanic response. These likely include the spatial extent and persistence of the wind forcing, the strength of AW recirculation from the WSC, the background velocity of the EGC, and the upper ocean stratification and sea ice cover — all of which influence how efficiently wind momentum is transferred to the ocean and how readily the boundary current reorganises. Identifying the combination of conditions that distinguishes triggering from non-triggering wind episodes remains an important objective for future observational and modelling studies.

If 8 deep-reaching events were identified in the Fram Strait Outflow Observatory, perhaps a composite analysis of all events centred around the peak of the event +/-1 month before and after, both in the oceanic velocity and temperature fields as well as the atmospheric pressure and wind fields, could shed more light on the typical development of events and how they form?

We thank the reviewer for this suggestion and have carried out the composite analysis for the atmosphere.

One practical point first. The FSAOO velocity and temperature fields are monthly means, so we do not know on which day each event peaked. We therefore centered the composites on the event month rather than on the peak. For the atmosphere, because ERA5 is available daily, we made two versions: one with monthly means (the event month and the month before) and one with 15-day averages from about six weeks before to six weeks after the middle of the event month. Since four events occurred in summer and four in winter, we worked with anomalies from the 1971–2000 average for the same time of year. To check whether the patterns are more than chance, we compared them with several thousand composites built from the same calendar dates in randomly chosen years.

The clearest signal appears in the month before the events (Fig. R4a, Table R3). Pressure was higher than normal over Greenland and the central Arctic and lower over Scandinavia and the Norwegian Sea, and the winds through Fram Strait were more northerly than usual. This was the case in all eight events. The daily composites show that this happens mainly two to four weeks before the middle of the event month (Figs. R5b and R6).

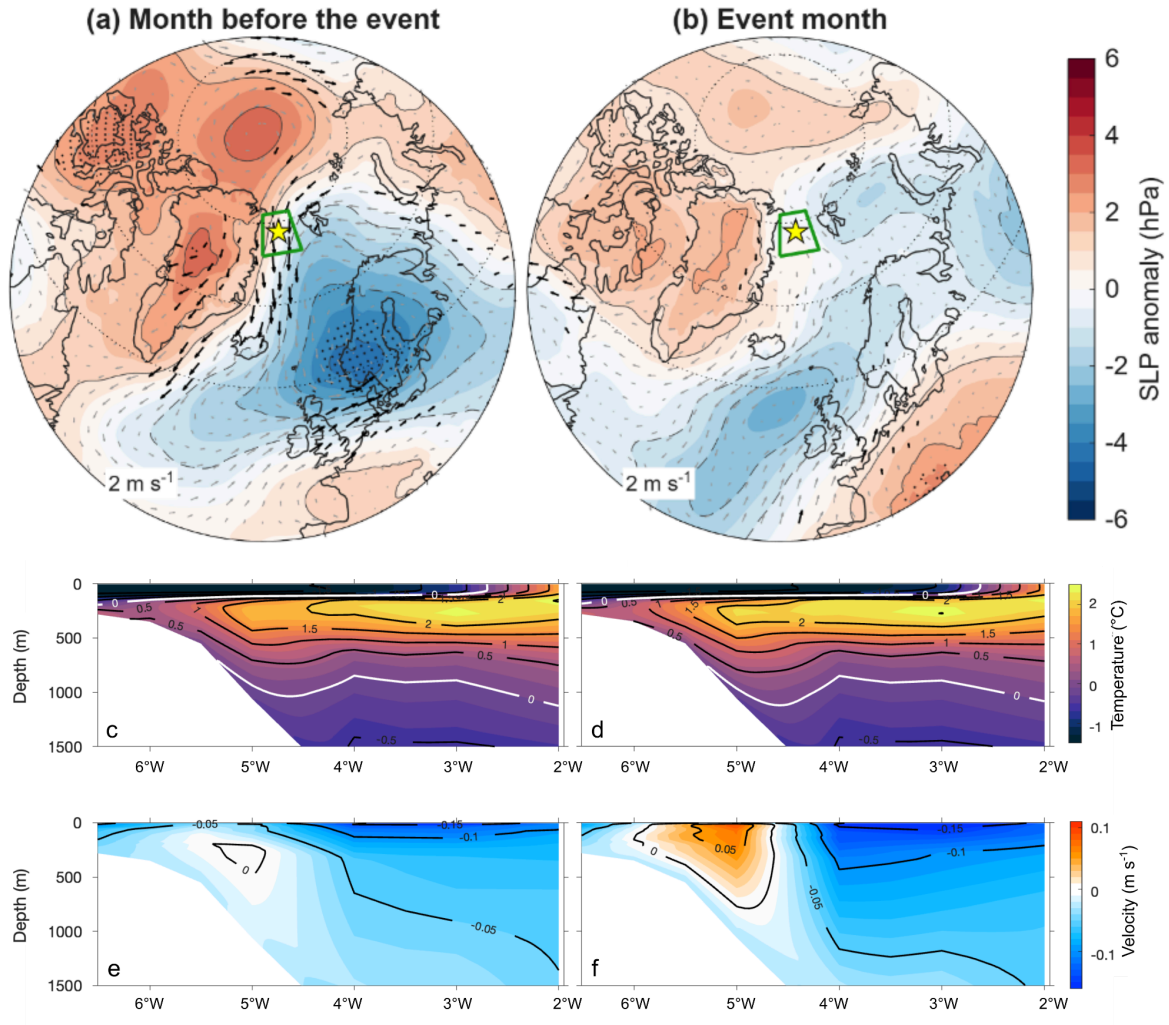


Figure R4 (new Figure 8 in the manuscript). Composite analysis of the eight deep-reaching northward flow events identified in the FSAOO mooring record (2003–2019; Supplementary Figure 4). (a, b) Mean sea-level pressure (colours, hPa) and 10 m wind (arrows) anomalies relative to the 1971–2000 climatology for (a) the month preceding each event and (b) the event month. Dots and bold arrows indicate significant anomalies ($p < 0.05$ based on 5000 random composites). The green box marks the Fram Strait region; the star marks the FSAOO mooring position. (c, d) Composite conservative temperature and (e, f) northward velocity sections at 78°50'N for (c e) the month preceding each event and (d, f) the event month. The white contour marks the 0°C isotherm in (c, d).

Table R3. Anomaly of the monthly mean north–south wind over Fram Strait (76–81°N, 15°W–5°E) in the month before and in the month of each FSAOO event. Positive values mean more southerly than the 1971–2000 average, negative values more northerly.

FSAOO event	Month before (m s^{-1})	Month before (std. dev.)	Event month (m s^{-1})	Event month (std. dev.)
2004-06	-2.49	-2.15	-1.51	-1.16
2006-11	-1.39	-0.86	-1.55	-0.68

2006-12	-1.55	-0.68	0.12	0.05
2007-02	-3.72	-1.51	1.60	0.79
2008-02	-1.32	-0.53	0.28	0.14
2011-06	-0.82	-0.71	-1.60	-1.23
2016-06	-1.32	-1.14	0.87	0.67
2019-06	-2.92	-2.52	-0.91	-0.70
Mean	−1.94	−1.26	−0.34	−0.26

In the event month itself the composite is weak and not significant (Figs. R4b and R5c,d). The wind was more southerly than usual in only four of the eight events, and the individual events differ a lot from each other (Fig. R6). After the event month, a deep low tends to develop over the Norwegian Sea (Fig. R5e), but this comes too late to have caused the events.

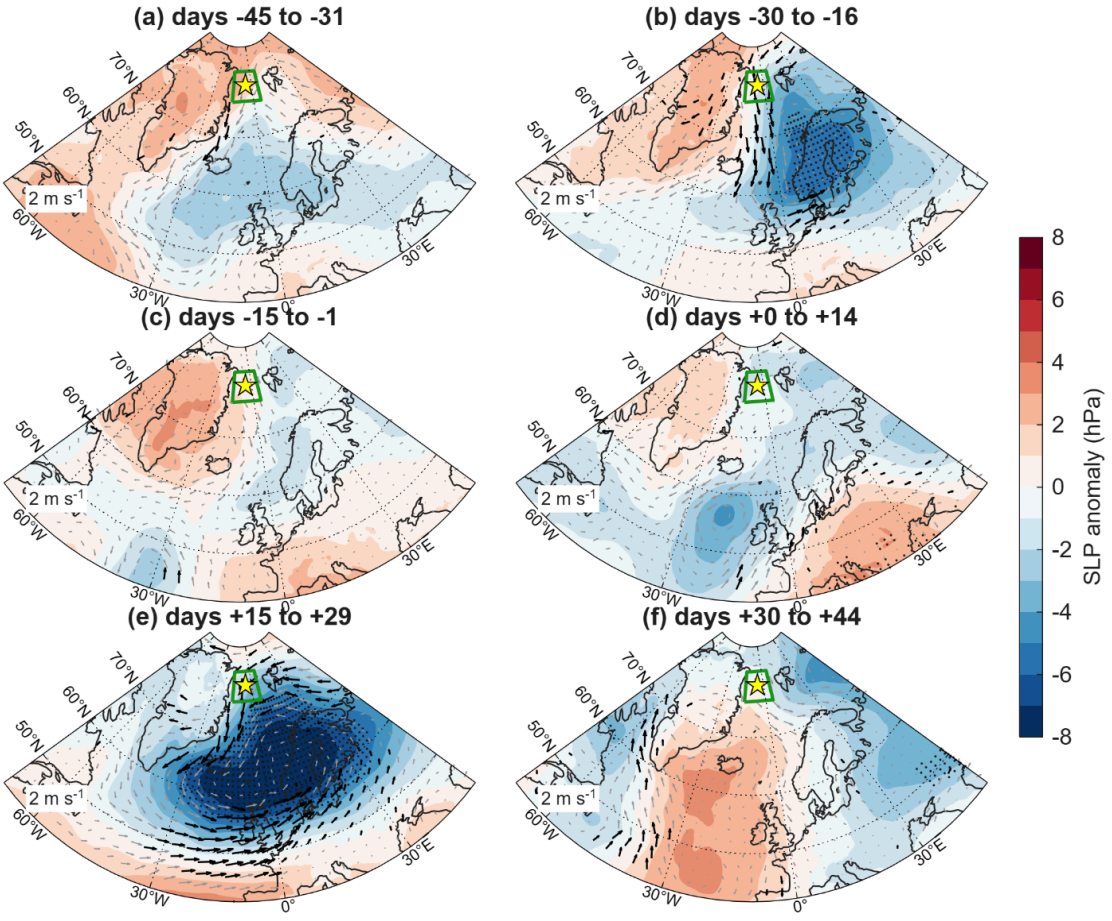


Figure R5. As Fig. R4, but from daily data, averaged over 15-day periods around the eight FSAOO events. Day 0 is the 15th of the event month, so the event month covers roughly days −14 to +15. Significance is based on 2000 random composites.

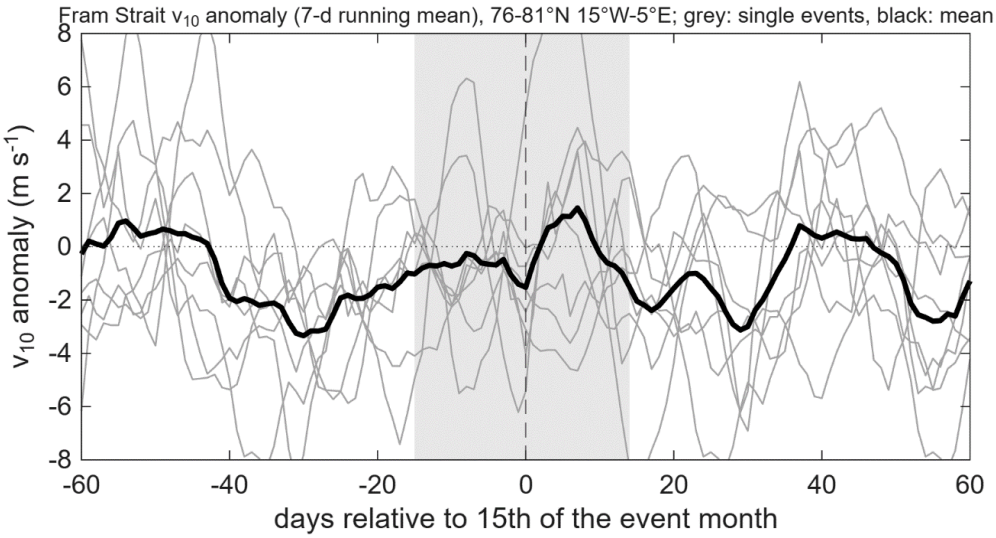


Figure R6. Daily north–south wind anomaly over Fram Strait (7-day running mean; positive = more southerly than usual) for each of the eight FSAOO events (grey) and their average (black). Grey shading: about the event month.

So, unlike the two well-documented events at 79°N in 2019 and 2025, the FSAOO events do not share one typical atmospheric development. We see two main reasons. First, with monthly ocean data we cannot line the events up on their peak, so a southerly wind episode lasting one or two weeks gets smoothed out in the composite. Second, the events may not all have the same cause (e.g., the consistently northerly winds in the month before could mean that the current relaxes after a period of strong southward wind stress, but we cannot test this with the data we have).

The composite ocean sections at the FSAOO array (78°50'N) for the event month and the month before each event (Figure R4) illustrate this contrast clearly. The temperature structure is broadly similar in both periods, with subsurface warm Atlantic Water (> 2°C) found further west, onto the continental shelf edge during the events (Fig. R4c,d). However, the velocity field differs markedly: during the event month a pronounced northward flow signal is present at the shelf edge (between 5–6°W), surface-intensified at approximately 0.08 m s^{-1}, whereas the month before shows predominantly southward flow across the full section with no northward signal (Fig. R4 e,f). This confirms that the thermal pre-conditioning of the water column precedes the flow reversal, and that the northward velocity anomaly is driven dynamically — consistent with the wind-forced reorganisation proposed in Section 5.1 — rather than being a passive consequence of changing water mass properties.

This has been added to Section 4.2 with reference to the new composite map figure of SLP/winds and ocean conditions, the new Figure 8 (Figure R4).

The extended FSAOO record at 78°50'N allows the atmospheric context of deep-reaching northward flow events to be examined over a longer period. A composite of SLP and wind anomalies centred on the eight deep-reaching events reveals that the clearest and most consistent atmospheric signal occurs in the month preceding each event: anomalously northerly winds over Fram Strait were present in all eight cases in the month before each event, whilst the event-month composite is weaker and statistically significant in only four of the eight cases (Fig. 8a,b). We interpret this as likely a temporal aliasing effect: the FSAOO

velocity and temperature fields are monthly means, so a southerly wind anomaly lasting one to two weeks which would be sufficient to force a sub-monthly flow reversal would be substantially attenuated in the composite.

The composite ocean sections at the FSAOO show that during the month preceding the events, warm Atlantic Water is already elevated onto the continental shelf (Fig. 8c) with the temperature structure shows the 0°C isotherm rising over the continental slope, but the velocity field remains predominantly southward across the full section (Fig. 8e). During the event month, AW is found further onshore at the continental shelf edge (Fig. 8d), and a pronounced northward velocity signal emerges at the shelf edge (5 – 6°W), surface-intensified and extending to at least 500 m depth (Fig. 8f). The contrast between the two periods indicates that the northward flow is driven dynamically rather than being a passive consequence of changing water mass properties.

In Section 6.1, we have added:

The composites of sea-level pressure and near-surface winds centred on the 8 deep-reaching events at 78°50'N show a stronger and more spatially coherent southerly wind anomaly in the month preceding the event than during the event month itself (Fig. 8a, b). This is consistent with a geostrophic adjustment timescale of weeks — the boundary current reorganisation that produces the observed northward flow develops over timescales longer than any individual wind episode, such that sustained or repeated southerly forcing in the weeks prior may be a necessary precondition. The corresponding ocean composites confirm this temporal lag: the event-month section shows clear northward flow (~0.08 m/s) and anomalously warm AW on the shelf (Fig. 8 d,f), whilst the month-before composite shows a similar thermal structure but entirely southward velocity (Fig. 8 c, e), demonstrating that the flow reversal is dynamically forced and not a passive response to water mass changes. Identifying the full combination of atmospheric and oceanic conditions that distinguishes 'triggering' from non-triggering wind episodes remains an important objective for future observational and modelling studies.

And in the Conclusions:

Notably, the atmospheric signal is stronger in the month preceding the events than during the event month itself — consistent with a geostrophic adjustment lag of order weeks between the wind forcing and the full oceanic response — whilst the ocean composites confirm that the northward flow is dynamically forced rather than driven by water mass changes alone.

Based on the progressive vector diagram and the assumption that the velocity recorded at the mooring location was constant for the duration of the event, a distance of 750 km farther north, nearly reaching 86◦N, was estimated (section 3.3 and discussion). The assumption of constant speed is discussed, but there's also an implicit assumption that the direction is constant. I think you should also clarify whether you think the flow of Atlantic Water would continue northward into the central Arctic Ocean, which would entail crossing lines of constant f/H (Nøst and Isachsen, 2003), or follow the Greenland slope around the northern end of Greenland.

The pathway for the Atlantic Water north of Fram Strait may also have implications for the impact of the flow reversals. Do the moored records indicate that a similar amount of AW returns when the circulation reverts back to its long-term mean state following an event, which may not be unlikely if the AW remains along the Greenland slope. Or does most of the AW that flowed into the Arctic Ocean not return, which may imply substantial diversion of AW into the central Arctic Ocean?

This is an interesting question about the fate of the northward-advected AW and has important implications for how much heat is permanently injected into the Arctic versus temporarily displaced and returned.

Examining the daily temperature and salinity records at 250m in the weeks and months following the 2019 event reveals a notably slow return to climatological values. Temperatures at 250m remained well above the climatological seasonal cycle — staying near 2.5 °C compared to the climatological decline from approximately 1.8 °C in June toward 1.0 °C by September — until approximately September 2019, roughly 3 months after the event ended on 23 May (Review Figure 1). Salinities similarly remained elevated above 35.1 g kg^{-1} until August, well above the climatological seasonal mean. This slow return to background conditions is consistent with either a gradual return flow of the northward-advected AW along the Greenland slope — suggesting the water remained topographically trapped rather than being diverted into the central Arctic Ocean — or a sustained enhancement of AW recirculation from the WSC following the event, or a combination of both.

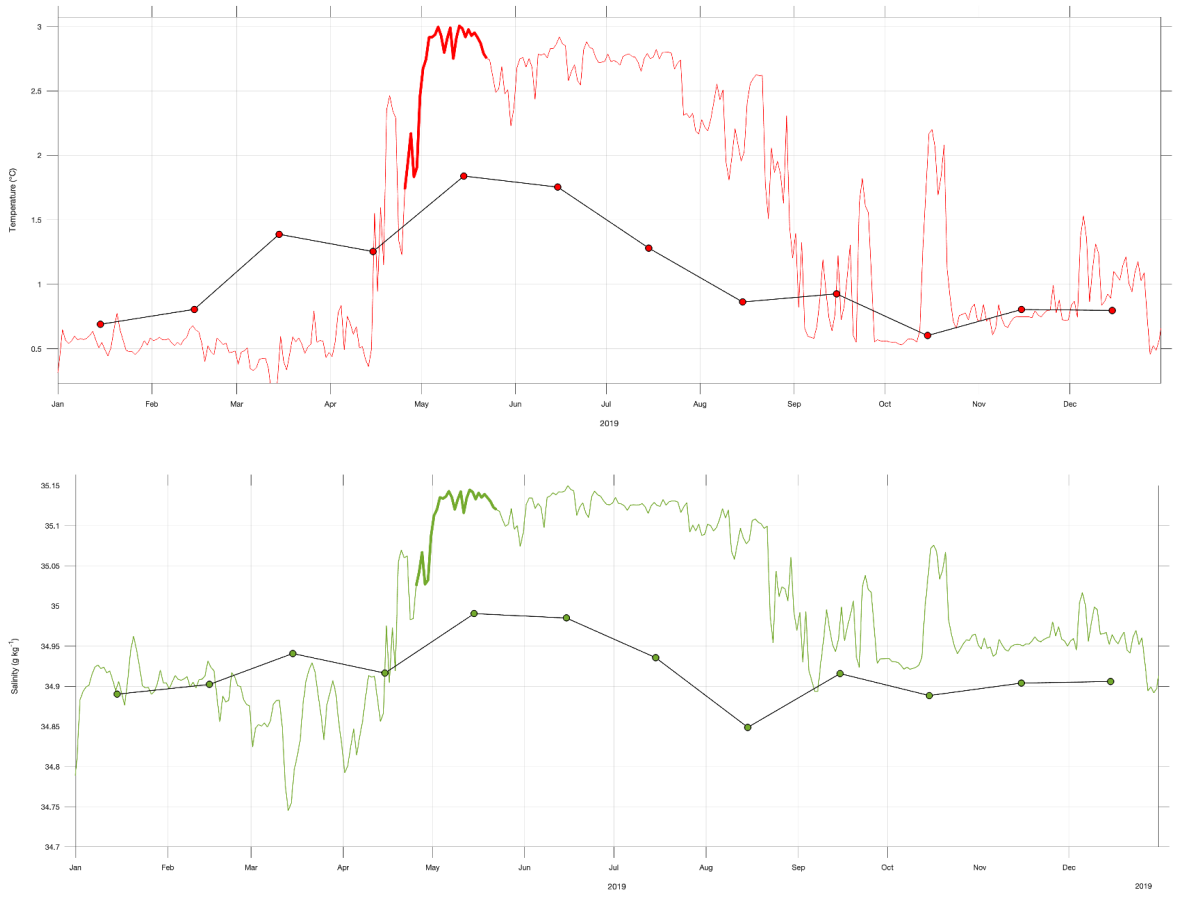
A single mooring at 79°N cannot distinguish between these interpretations, as both would produce a similar temperature and salinity signal at the mooring location. The monthly mean resolution of the FSAOO array at 78°50'N is also insufficient to resolve the post-event evolution on the relevant timescale. Definitively resolving the pathway and fate of the northward-advected AW would require Lagrangian observations or a mooring array spanning multiple latitudes north of 79°N, and represents an important objective for future observational studies. This observation has been added to Section 3.2 which reads:

Following the end of the 2019 event in late May, temperatures and salinities at 250m remained substantially above the climatological seasonal mean until approximately September 2019 — approximately 3 months after the event ended. Temperatures remained near 2.5°C while the climatological mean declined from approximately 1.8°C toward 1.0°C over the same period, and salinities remained above 35.1 g kg^{-1} while climatological values decreased. This slow return to background hydrographic conditions suggests either a gradual return flow of AW along the slope or a sustained enhancement of AW recirculation following the event, though the available single-point observations cannot distinguish between these possibilities.

We have also added a note to Section 5.3 acknowledging this observation and its implications.

Whether this northward-advected AW continued into the central Arctic Ocean or remained topographically steered along the Greenland continental slope is an open question. The slow

return of temperature and salinity at 250m to climatological values following the 2019 event — persisting for approximately 3 months after the event ended — suggest that the anomalous AW was not immediately advected from the region, and is consistent with a gradual return flow along the slope rather than rapid diversion into the central Arctic Ocean interior. However, a single mooring at 79°N cannot distinguish between return flow of the advected water parcel and a sustained enhancement of background AW recirculation following the event, and the ultimate fate of the northward-advected AW remains an open question that warrants targeted future observational and modelling studies.



Review Figure 1. Timeseries of (top) temperature and (bottom) salinity at 250m for the year 2019 with the mean seasonal cycle imposed on top as circles. The bold portion of the timeseries shows the hydrographic properties during the 2019 event. The daily timeseries has been low-passed filtered with a 7-day cutoff.

While it is true that the flow reversal events provide new understanding of the variability of the EGC, I think care should be taken not to overstate these results. Figure 6 and line 785 demonstrate that there is still a net southward transport in the EGC, even during reversal events. It may be more correct to state that they add nuance to the "conventional picture of the EGC as a persistent, year-round southward boundary current" rather than upending this picture. You may not have stated it so bluntly, but it is how I interpret that passage.

This is a well-judged observation and we agree that the northward flow events add nuance to rather than overturn the conventional picture of the EGC as a persistent southward boundary current. As the reviewer notes, Fig. 6 and the mooring record clearly demonstrate that net southward transport is maintained in the EGC even during reversal events — the northward flow is confined to the inner slope inshore of the displaced southward EGC core rather than representing a wholesale reversal of the boundary current. We have revised the relevant passages in both the Results and Discussion to reflect this more carefully, emphasising that these events represent episodic and spatially confined departures from the dominant southward flow rather than a fundamental reorganisation of the EGC system.

In Results section 4.3, an addition now reads:

Farther offshore toward the central Fram Strait, the EGC continued to flow southward. A surface-intensified southward flow at 2°W was maintained and slightly intensified relative to the mean, consistent with an offshore shift of the boundary current rather than a wholesale reversal of the EGC system.

At the end of the opening paragraph of the Discussion, we have added:

Whilst the EGC maintains net southward transport even during these events — with the southward core displaced offshore rather than eliminated — the episodic development of northward flow on the upper continental slope represents a mode of variability that has not previously been documented at this location.

The proposed forcing mechanism (section 5.1) appears to be a standard coastal upwelling scenario (e.g., Pickart et al., 2009; H°avik and V°age, 2018; Pacini and Pickart, 2023). It is not very clear from the discussion what distinguishes your proposed forcing mechanism from coastal upwelling, if anything.

We agree that the proposed forcing mechanism is consistent with the classical wind-driven coastal upwelling framework, and we have revised the text to make this explicit.

A sentence has been added at the opening of Section 5.1 acknowledging this:

Building on the atmospheric observations in Section 4.2, it is proposed that deep northward flow events are driven by anomalous northward wind along the East Greenland continental margin, which then reorganises the boundary current system through two complementary oceanic responses. The proposed forcing mechanism is consistent with the classical wind-driven coastal upwelling framework described for the East Greenland shelf (Pickart et al., 2009; Håvik and Våge, 2018; Pacini and Pickart, 2023), here applied to the reorganisation of the boundary current system under sustained anomalous northward wind forcing. What distinguishes the events documented here is not the underlying dynamics but their sustained duration over periods of weeks rather than days, resulting in a sufficient forcing to drive a wholesale lateral reorganisation of the boundary current and produce net northward flow at the shelf-break — with the resulting northward advection of Atlantic-origin water representing a mode of Arctic heat input not previously documented in this region.

Within the framework of the Thermodynamic Equation of SeaWater 2010 (TEOS-10), the preferred thermodynamic pair would be Absolute Salinity and Conservative Temperature (e.g., Figures 2 and 4). I suppose that Absolute Salinity and potential temperature can be considered together, but in that case this combination should be justified. Please also note that Absolute Salinity has the unit g/kg (e.g., paragraph starting on line 290), unlike practical salinity, Absolute Salinity is not unitless.

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.

Detailed comments

Line 24: There is a preposition missing near the end of this line.

The sentence has been amended to read:

A persistent sea-level pressure dipole with anomalous northward winds along the East Greenland margin is identified during all strong deep northward flow events.

Line 130: Please elaborate why the 79◦N mooring has been maintained given that NPI's Fram Strait Outflow Observatory is located only 18 km farther south.

The AWI-maintained mooring has been continued as it contains multiple biogeochemical sensors (e.g., sediment traps, RAS) in addition to the hydrographic instruments, which NPI does not measure in their Fram Strait Outflow Observatory. It is kept at 79°N to be at the same latitude as the mooring array in the eastern Fram Strait, measuring the West Spitsbergen Current (e.g., von Appen et al., 2016; McPherson et al., 2026).

Line 161: Perhaps events should be defined by northward velocities significantly greater than 0 m/s, not just greater than 0 m/s, where measurement, statistical, and other uncertainties are taken into account?

We acknowledge that defining events by velocities strictly greater than 0 m s^{-1} could in principle include noise-driven fluctuations. However, we believe our current definition is robust as all velocity data were daily averaged prior to event identification — from hourly or 2-hourly sampling — which substantially reduces the influence of measurement noise and short-period variability on the detected signal. A velocity persistently above 0 m s^{-1} in the daily averaged record therefore represents a genuine oceanographic signal rather than instrumental noise. This is described in the methods:

All measurements from the 79°N mooring were daily averaged to a common time series.

Second, barotropic events — which form the focus of this study — require all three instrument depths to simultaneously record northward flow, making it highly unlikely that residual noise alone would generate a false positive across three independent measurements. The instrument accuracy of the Aanderaa Seaguard and RCM11 current

meters (approximately 0.01 m s^{-1}) is also well below the mean velocities of even the weakest events identified. For baroclinic events, where only one depth is required to show northward flow, the threshold is more sensitive to residual noise, and we acknowledge this as a limitation.

Line 223: There is a preposition missing from this line.
Amended.

Line 396: It looks like the most pronounced temperature difference between the long-term May mean and the 2019 event was offshore of the flow reversal. In fact, the temperature field (Figure 6a, c) looks very similar at the location of the reversal. If that's generally the case, would such events rather entail Arctic Atlantic Water sloshing back and forth through Fram Strait than a poleward transport of Atlantic Water?

The most pronounced temperature difference between the long-term May mean (Fig 6a) and May 2019 (Fig 6c) is indeed offshore of the flow reversal location as the Reviewer notes, around 3°W–4°W, where the warm AW core is deeper and more intense during the event, consistent with the offshore displacement of the southward EGC core carrying warm water eastward. However, the temperature field at the shelf-break reversal location (5°W–6°W) is also slightly warmer in May 2019 than the long-term mean, albeit less, consistent with upwelling of slightly warmer subsurface water to shallower depths at the shelf-break as part of the wind-forced reorganisation described in Section 5.1.

The Reviewer's AAW sloshing interpretation is physically plausible, particularly at the FSAOO where AAW dominates the shelf-break under normal conditions. However, at the 79°N mooring, the T-S record at 250m during both events shows temperatures of 2.7–2.8°C (compared to a climatological mean of 1.1°C), which plot clearly in the AW field on the T-S diagram (Fig. 4) rather than the AAW field. This demonstrates that AW, not just AAW, was present at depth during the northward flow events at this location. The T-S properties during both events suggests a mixture of AW transport and AW-AAW mixing rather than pure sloshing of unchanged water masses.

Line 447: What do you mean by Arctic outflow in the context of lateral density gradients? It appears to be something else than the front between AW and PW.

Arctic outflow was used as a general definition here when more specifically it is Arctic Atlantic Water (AAW), meaning water of Atlantic origin that has previously circulated through the Arctic Ocean (see Rudels, 2002). The sentence has been amended to reflect this:

Eddies are generated primarily by baroclinic instability of the strong lateral density gradients between warm, salty AW and cold, fresh PW and AAW.

Line 453: I think a reference detailing how eddies from the eastern Fram Strait interact with the EGC should be included here.

An appropriate reference has been added and the sentence now reads:

While westward-propagating eddies from the eastern strait occasionally interact with the EGC where high values of eddy kinetic energy are found (Wekerle et al., 2020), they do not generally constitute a sustained eddy field at the shelf-break.

Line 457: Could you please clarify how you estimate the diameter of eddies, by considering the product of the northward velocity and the duration of the event, if the northward flows had been generated by eddies? Presumably, this would not apply to the case of semi-stationary eddies.

The methodology for estimating eddy diameter is described in the manuscript in Section 4.1. We acknowledge the reviewer's point that this assumption does not apply to semi-stationary eddies however, we note that a semi-stationary eddy centred over the mooring for the full duration of the event would need to be at least as large as the estimated diameter — and likely larger — since it would need to encompass the mooring location throughout its entire residence time rather than simply passing through it. A semi-stationary eddy of ~175–393 km diameter remaining centred over a fixed mooring location for 29–35 days is even less consistent with the observed eddy size distribution in Fram Strait, where over 90% of eddies have radii below 10 km (Wekerle et al., 2020), than a travelling eddy of equivalent size.

Line 485: "Farther south" would be more correct than further south.
Amended.

Lines 504-507: I suggest consistently using the past tense to describe past events, as was done in the rest of this paragraph.
Amended.

Lines 583 and elsewhere: I would write "Arctic Ocean". The Arctic, by itself, is ill-defined and has multiple interpretations.
We have replaced 'the Arctic' with 'the Arctic Ocean' in all instances where the oceanic basin is specifically intended.

Line 620: It should be: "...boundary current system than have previously been described..."
Amended

Figure 1: Please include in the caption a definition of all acronyms introduced in this figure.
The caption now reads:

Red arrows indicate the northwards flow of warm, saline AW of the Norwegian Atlantic Slope Current (NwASC) and Norwegian Atlantic Front Current (NwAFC) from the northern North Atlantic to the Barents Sea Opening and in the West Spitsbergen Current (WSC) in Fram Strait and its westward recirculation. The blue arrow indicates the surface Polar Water and underlying Arctic Atlantic Water, constituting the Arctic Outflow, which feeds the southward flowing East Greenland Current (EGC).

Figure 2c: Have the vmADCP velocities shown in this figure been de-tided using a tidal model? If not, how strong are the tidal currents at this location?

The VMADCP velocities shown in Figure 2c were not de-tided. Typical tidal currents at this location are approximately 0.05 m s^{-1} (Baumann et al., 2020). Figure 2c represents a snapshot collected over a relatively short transit across the section, meaning that tidal phase will vary across the section and tidal signals will not be spatially coherent. The anomalous northward flow signal at the shelf-break reaches up to 0.4 m s^{-1} and the southward EGC core exceeds 0.4 m s^{-1}, both substantially larger than the typical tidal amplitude. We therefore consider that tidal contamination does not materially affect the interpretation of the velocity structure shown in Figure 2c, though we acknowledge it as a source of uncertainty in the absolute velocity values. The mooring-based velocity timeseries, which form the primary basis for the event characterisation and statistical analysis in this study, were daily averaged prior to analysis, which effectively removes tidal variability

Baumann, T. M., Polyakov, I. V., Padman, L., Danielson, S., Fer, I., Janout, M., Williams, W., & Pnyushkov, A. V. (2020). Arctic tidal current atlas. Scientific Data, 7(1), 275. https://doi.org/10.1038/s41597-020-00578-z

Figure 6: Please mark the locations of the moorings.
The data is from a gridded product to which gap-filling and interpolation have been applied across the array (see Karpouzoglou et al., 2021) and where the mooring positions are described in detail. Adding mooring location markers could mislead readers into interpreting the interpolated fields as point measurements.

Figure A1: Perhaps consider showing a wind rose plot rather than time series in Figure A1. Such a figure would be easier to digest than time series of both u and v as well as providing additional statistical information.

The purpose of Figure A1 is to show the temporal evolution of the along- and cross-slope velocity components at all three mooring depths. This allows the reader to assess the raw observational record, identify individual northward flow events, and evaluate the depth coherence of the signal over time. A wind rose plot would collapse this temporal information into a directional frequency distribution. We have therefore retained the time series format, which we consider the most transparent presentation of the underlying data.