

Reviewer 2:

We want to thank the reviewer for the time spent on the text and for the spotting of errors and unfortunate formulations, and for the many suggestions on how to improve the manuscript.

Major Comments:

The major comments raised by the reviewer are all, except the last, related to the structure of the manuscript and it is perhaps best to first consider the last point, what is the purpose of this review.

Our intension was, and is, to give a comprehensive discussion of the Arctic Mediterranean that describes the processes and the water mass transformations in the different parts of the area and how these parts are connected by the circulation of the different waters. The manuscript should also highlight how our knowledge of the geography and our understanding of the physical oceanography of the Arctic Mediterranean have evolved over time.

Our aim is to provide an integrated view of the Arctic Mediterranean in contrast to a manuscript consisting of a mere collection of standalone sections, which the reviewer recommends. We will consider the suggested reorganizations of the text and if we find they will improve the narrative, we will make changes accordingly.

In the present rewrite we finally decided to follow our original narrative and the initial structure of the manuscript has been kept.

We have mainly referenced to original and to older publications to provide a sense of the historical developments to the readers. We are aware of the sparseness of references to recent studies, and we appreciate the reviewer's suggestions of articles that should be referred to and could correct this bias. We shall do our best to incorporate these studies in the text.

In the rewrite several new references have been added, not just the one recommended by the reviewer. However, mainly those suggested by the reviewer have been discussed in some detail.

We are, however, rather reluctant to describe how the present study differs from other existing reviews and also from some of our own earlier work. We consider that all reviews have their own values and think it is impertinent to quickly summarize their content in a few sentences, and will rather concentrate on making the present review informative and readable.

We have stayed with this view and the statement above still holds.

With respect to the last major point, “Indigenous peoples’ knowledge”, we must confess that we have nothing to contribute, and we will not address this major point.

Minor comments:

L 92: The two gyres meant are the cyclonic gyre extending from the Nordic Seas into the Barents Sea and the Eurasian Basin and the anticyclonic gyre in the Amerasian Basin centered at the Beaufort Sea. The latter is the only large-scale anticyclonic gyre in the Arctic Mediterranean.

L 102: The sentence has been clarified to: “This is perhaps the area where the effects of a warming climate on the water column have been the strongest.”

L 139-140: Figure 3 in the Fritz’s article on solar radiation in Compendium of Meteorology (1951), showing the energy input at the top of the atmosphere as function of latitude and time of the year, indicates that the energy input in summer is larger at the North pole than at the Equator.

L 187-188: This sentence has been expanded to: “a convoluted channel connecting the upper layer of the stratified and stagnant North Pacific to the convectively ventilated North Atlantic.”

L 656-669: The Bering Strait inflow is now described in more detail and more as well as more recent references have been added.

L 666: The heat transported into the Arctic Ocean through Bering Strait derives from the local seasonal heating in the Bering Sea and is not transported by the ocean from lower latitudes.

L 716-717: The sentence will be rewritten as: “Sea water with salinity $S > 24.7$, by contrast, is densest at its freezing point and the water column has to be convectively cooled to freezing temperature down to the bottom, or down to a density gradient caused by the presence of a deep, more saline, and denser water mass, before sea ice can form.”

Section 7.1: The Dörr et al. paper will be included. We appreciate the authors’ constructive use of T-S diagrams.

The paper is discussed in section 9 on Fram Strait.

L 930-931: The formation of the upper melt water layer in two different locations is discussed. Sea ice melting on colder water (in the Barents Sea) creates a more saline melt water layer than sea ice melting on warmer water (north of Svalbard).

L 970: This refers to waters in juxtaposition, and is changed to: “the intrusions penetrate across the front into the opposite water masses only as long as an unstable density distribution of the driving component remains.”

Figure 9: The data are from two expeditions with RV Polarstern, one in 2007 and the other in 2011. Maps showing the station position will be added and the final sentence clarified.

L 1082: The increase of both temperature and salinity in the bottom layer indicates that the boundary plume, initially at the freezing point, has entrained warm Atlantic water during its descent. Part of the initial brine enriched salinity excess, however, still remains.

L 1154-1155: The sentence has been expanded to: “The East Siberian Sea, in contrast to the Laptev Sea, receives a considerable amount of sea ice from the central basins and acts more as an ice sink than an ice source for the inner Arctic Ocean.

L 1162-1166: More results related to ice thickness from satellite observations have been added in the revised text.

L 1171-1172: A discussion of the Sumata et al. (2024) paper has been included in the revision.

The ice cover in the East Siberian Sea has diminished drastically in recent years and has now changed to seasonal from being present almost the year around. This is but one indication of the changes taking place in the Arctic Ocean ice cover. The decline in sea ice extent has since the beginning of the satellite observations in the 1970s been followed almost in real time, but information about sea ice thickness is more difficult to obtain. Not until upward-looking sonar observations were made from the submarine USS Pargo in 1993 could sea ice thickness measurements be compared with those made about 30 years earlier. The thickness of the Arctic Ocean ice cover had decreased by 40%, from an average thickness of about 3 m to 1.8 m (Rothrock et al., 1999).

The thickness reduction continued and accelerated in the following decades (Kwok et al., 2009) and a major shift in the sea ice distribution was observed. The earlier dominance of

thick and deformed multiyear ice changed in to a stronger presence of thinner first year ice (Kwok et al., 2009; Sumata et al., 2023). This shift appears to have taken place in the first decade of this century (Kwok et al., 2009) and Sumata et al. (2023) relate the change to the strong sea ice export events that occurred in 2005 and 2007. Once the main storage of multiyear ice had been removed the drift speed of the sea ice increased and its residence time decreased, which prevents the buildup of a large volume of multiyear ice in the Arctic Ocean.

The effects of these changes were clearly demonstrated by the ship *Tara*, which in 2008 within the EU-DAMOCLES (Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies) program repeated the drifts of *Fram* and *G.Sedov* in only 18 months compared to 3 years for the earlier drifts, showing that thinner ice moves more quickly than the thick ice cover in the past. The reduction in ice cover thickness and extent the does not appear to have significantly changed the sea ice export to the Nordic Seas through Fram Strait (Spreen et al., 2009

L 1205-1209: The speculation of a possible Sverdrup balance in the Beaufort Gyre is presented in context of Yang et al. (2015).

With more freshwater accumulated in the Beaufort Gyre the stability increases and the upper layer becomes isolated from the bathymetry. The balance between the input of vorticity at the surface and its removal by bottom stress, as proposed by Nøst and Isachsen (2003), might then disappear and another balance is needed. The possibility of a Sverdrup balance has usually been discarded because of the small β at high latitudes. Yang et al. (2015) examined the situation for a circular basin in high latitudes. They found that in the case of no boundaries the effects of the difference in β between latitudes was less pronounced compared to the case when a western boundary was artificially introduced. They concluded that the vorticity input from the anticyclonic wind stress curl would in the gyre be balanced by the time mean divergence of the eddy vorticity flux and along the western boundary by a frictional torque.

No solid western boundary is, however, present near the Beaufort Gyre, but there is a northward flowing boundary current that is fed both from the east and from the west, the Transpolar drift. The Beaufort Gyre is a unique feature in the world ocean. It is forced by anticyclonic winds, creating the density stratification and the gyre circulation. There should be an, albeit weak, southward Sverdrup transport, which could continue south through the Canadian Arctic Archipelago but also could partly feed an inertial current flowing northward on the western side of the gyre. The increase in planetary vorticity would then be balanced by an increase in negative relative vorticity in the boundary current. The flow would intensify as long as f increases, but when the highest latitude is reached, f starts to decrease and the boundary current begins to diverge, reducing its relative vorticity. This is different from mid latitudes, where a purely inertial boundary current cannot exist because the boundary current must shed its relative vorticity, when it leaves the boundary, which only can take place by friction (Vallis, 2017).

L 1287-1290: A discussion of the possibility that a combination of earlier, more saline boundary convection and geothermal heat input from below could generate the observed temperature and salinity structures in the deeper layers has been included, and the reference to Arroyo and Timmermans (2026) has been added.

L 1393: This has been corrected.

L 1404-1409: The discussion of the transports through Fram Strait is expanded and more and more recent references to inverse methods are included, Tsubouchi et al. (2012, 2018), Brown et al. (2025), Bacon et al. (2022).

The discussion above is largely ad hoc and relies strongly on subjective reasoning. However, the inverse modeling of the exchanges between the Arctic Ocean and the world ocean

has greatly improved as more observations from the different gateways have become available. Tsubouchi et al (2012) estimated the transports through all four passages (Davis Strait, Fram Strait, Barents Sea and Bering Strait) for August 2005 when all gateways were monitored and found an oceanic heat flux into the Arctic Ocean of 154 ± 44 TW and a freshwater export from the Arctic Ocean of 155 ± 65 mSv relative to the mean temperature $1.01^\circ\text{C} \pm 0.16^\circ\text{C}$ and the mean salinity 34.67 ± 0.02 on the total cross section. Since all passages were monitored the total heat and freshwater transports are here independent of reference temperature and salinity. However, the heat and freshwater transports through the individual straits may occasionally appear somewhat odd. The largest freshwater export takes place through Fram Strait but primarily as import of saline Atlantic water in the West Spitsbergen Current, not as export of low salinity water in the East Greenland Current.

To estimate the water transformations taking place in the Arctic Ocean Tsubouchi et al. (2012, 2018), Brown et al. (2025) and Bacon et al. (2022) computed the in- and outflows in different density intervals, and the resulting imbalances have to be balanced by mixing across the density surfaces within the Arctic Ocean. The computations reveal that the density interval encompassing the Atlantic water is not balanced and of the inflowing 6.0 Sv only 3.2 Sv return in the same density interval as modified Atlantic water. 1.0 Sv has become diluted by freshwater and returns as less dense upper layer water, while 1.8 Sv have been transformed into denser water and return as intermediate and deep waters (e.g., Bacon et al. 2022). The formation of upper layer water is mainly due to sea ice melting north of Svalbard and the creation of denser water takes place by atmospheric cooling largely in the open water area in the southern Barents Sea.

The observations at the gateways thus reveal transformations of the waters within the Arctic Ocean, processes that are not considered in the circulation model by Nøst and Isachsen (2003). These results above, however, are based mainly on observations, but Dörr et al. (2026) showed that the output from a global NEMO ocean hindcast simulation can describe many of the active processes and how they transform the waters entering the Arctic Ocean. The model was

forced with atmospheric and runoff data from the DRAKKAR forcing set and was run from 1958 to 2015 and the outputs from 1979 to 2015 were examined. The computed net in- and outflows through the different passages are close to those observed, there are net outflows through Davis Strait (1.8 Sv) and through Fram Strait (3.0 Sv) and inflows over the Barents Sea (3.5 Sv) and through Bering Strait (1.3 Sv).

The focus is on water mass transformations and the circulation is described both in density space, showing the transformation of inflowing water into denser and less dense waters, similar to the approach used by Brown et al. (2025). However, the transformations are also shown in TS space, following the approach introduced by Gösta Walin (1982). The model results in similar water mass transformations as those deduced from observations in the Arctic Ocean and discussed earlier in the sections above. One significant difference, however, was that about 3 Sv of Atlantic water were transformed into denser water (Dörr et al. 2026), almost twice the transformation estimated by Brown et al. (2025 and Bacon et al. (2022)). The main area of this transformation was located to the southern Barents Sea.

Figure 15: The RV Hudson station (1982) is located at 75°02'N 005°11'W and the RV Valdivia station (1993) at 74°00'N 004°20'W.

L 1769-1773: The overflow in Denmark Strait is discussed in more detail, including reference to von Appen et al. (2017).

The overflow in Denmark Strait is strong and varies on time scales of a few days (two to five days) The strong overflow events were noticed by Worthington (1969) as the first direct current meter arrays was recovered. These strong overflow events had periods slightly less than a week. However, later observations (Van Appen et al., 2017) have shown that two different kinds of strong overflow events are present. The boluses are related to overflow events where the thickness the overflow plume increases drastically, the temperature of the boluses decreases, but

no significant increase in the overflow velocity is observed. The second overflow anomaly Van Appen et al. (2017) denoted as pulses. The pulses show an increase the overflow velocity but the thickness of the overflow layer decreases. The temperature reduction is less ($-0.1\text{ }^{\circ}\text{C}$) than that observed for the boluses ($-0.4\text{ }^{\circ}\text{C}$) and the more rapid flow in the pulses compensates for the thinner overflow plume and the overflow strength is about the same for the boluses and the pulses.

The difference of height of the overflow plumes first suggests a supercritical flow for the boluses and a subcritical flow for the pulses, but nature is most likely more devious than this. The flow is rotating and the thickening of the boluses is associated with cyclonic rotation and the thinning of the pulses relates to anticyclonic rotation. The most interesting question is, however, if the boluses and pulses are associated with different water masses. The almost similar temperature of the overflow water in the two cases suggests that the main sources are in the central gyres, not in the East Greenland Current, perhaps the Greenland Sea rather than the Iceland Sea.

Figure 19 The southernmost section is shown

L 1858: This is an unfortunate formulation. What is meant is that the northward flowing North Irminger Current comes at the sill in almost direct contact with southward flowing overflow water, and if the main mixing takes place here, a mixing ratio of Irminger Current water to overflow plume water of one to four would be sufficient to explain the temperature increase of about one degree in the overflow plume observed in the deep Irminger Sea. This is much less than if the entrainment takes place during the descent down the slope into the Irminger Sea. The Denmark Strait overflow plume would then comprise more original overflow water and less entrainment, perhaps only 25%. This is clarified in the rewrite.

L 1999-2004: Thanks for these corrections. Equation 5, the transport in the upper layer, should read:

$$M_A + F = \frac{3g\beta(S_2 - S_1)H_1^2}{2f}$$

and Equation 6, the thickness of freshwater m in the upper layer becomes:

$$m = \frac{(S_2 - S_1)}{S_2} H_1$$

The salinity of the upper layer can be written as:

$$S_1 = \frac{M_2 S_2}{(M_2 + F)}$$

Introducing this in the expression for the outflow gives

$$(M_2 + F) = \left(\frac{3g\beta F S_2}{2f} \right)^{\frac{1}{2}} H_1$$

and m becomes:

$$m = \frac{S_2(M_2 + F) - (M_2 S_2)}{S_2(M_2 + F)} H_1 = \frac{F H_1}{(M_2 + F)} = \left(\frac{2fF}{3g\beta S_2} \right)^{\frac{1}{2}}$$

The derivation is from Rudels (2010).

Figure 23: Figure 23 is removed and the text is expanded somewhat.

L 2186: “normalized” will be inserted. We are aware of different NAO definitions but prefer this simpler definition.

Figure 25: Figure 25 is removed.

A new summary figure, Figure 24, has been added.

Typos etc.: All typos have been corrected. In figure 1 we left YM in the figure and made the change YP to YM in the caption. It was simpler that way. We acknowledge the reviewer of such a thorough editorial eye.