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The impact of atmospheric and oceanic circulations on the Greenland Sea ice concentration
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The revised version of the manuscript is a substantial improvement on the original submission. For the most part I think that my concerns have been well addressed, but I still have some comments regarding the TOPAZ- EN4 comparison and the upper-ocean stratification in the western Greenland Sea that I hope the authors will take into consideration.

Authors' reply:

The authors thank the reviewer for appreciating the modifications made in the revised version. The concerns mentioned here are addressed below:

Specific comments:

Hovmöller plots of SST and SSS and time series of potential temperature, salinity, and stratification from the western Greenland Sea region are shown in Figs. 3 and 4. The data are taken from the TOPAZ reanalysis and from the EN4 objective analysis from the period 1991 to 2017. The authors note that the temporal evolution of these parameters appears to be well represented in TOPAZ, but that there are some differences such as the magnitude of the stratification and the location of the polar front separating the cold, fresh polar waters along Greenland from the warmer, saltier Arctic waters in the Greenland Sea. My concern is that there are hardly observations from the western Greenland Sea region chosen for this comparison (consider, for example, Fig. 2a in Brakstad et al., 2019). It appears that EN4 will relax to climatology when there are no observations (Good et al., 2013). The western Greenland Sea is an exceptionally data-sparse region, so I am very sceptical that these two figures provide much information about how well TOPAZ represents the hydrographic conditions in this region. I suggested instead that TOPAZ is evaluated against observations in the central Greenland Sea and that Latarius and Quadfasel (2016) or Brakstad et al. (2019) would be good points of comparison. In my opinion that would be a more sensible evaluation of TOPAZ.

We have followed the suggestions provided by the reviewer. We found TOPAZ4 doesn't perform well in the central GS in terms long term trend, particularly in the deeper levels. This is probably due to the fact that TOPAZ has been initialized with too warm in deep waters of this area (Xie et al., 2017). Please find the comparison below (Figure 1), where EN4 reproduces the deep warming as found in Latarius & Quadfasel (2016) observations. But the TOPAZ4 reanalysis seems to recover from a too warm initial condition at depths of 400m-1600m. The warm bias is however not visible in the upper 100 meters of the water column, which is where our analysis is focusing.

In addition, we note that the processes at play are taking place further in the south-western Greenland Sea, where the model quality appears to be fair in comparison with climatology and also with other reanalysis (ORAS5). Note that in other areas in the Nordic Seas, fore.gFram Strait or Svinøy sections also TOPAZ4 performs reasonably well (Chatterjee et al., 2018), although with local biases. Further the oceanic processes explained here are in the south-western Greenland Sea and its impact on sea ice variability therein is consistent with the satellite sea ice observations. Since our major focus area is the south-western Greenland Sea, we think that it is more meaningful to compare TOPAZ4 with the limited existing data sources there (where the different processes are explained and their impact on sea ice is found to be consistent), than comparing in a different region, particularly when it is known that the performance of TOPAZ4 may vary regionally (Sakov et al., 2012, Xie et al., 2017).

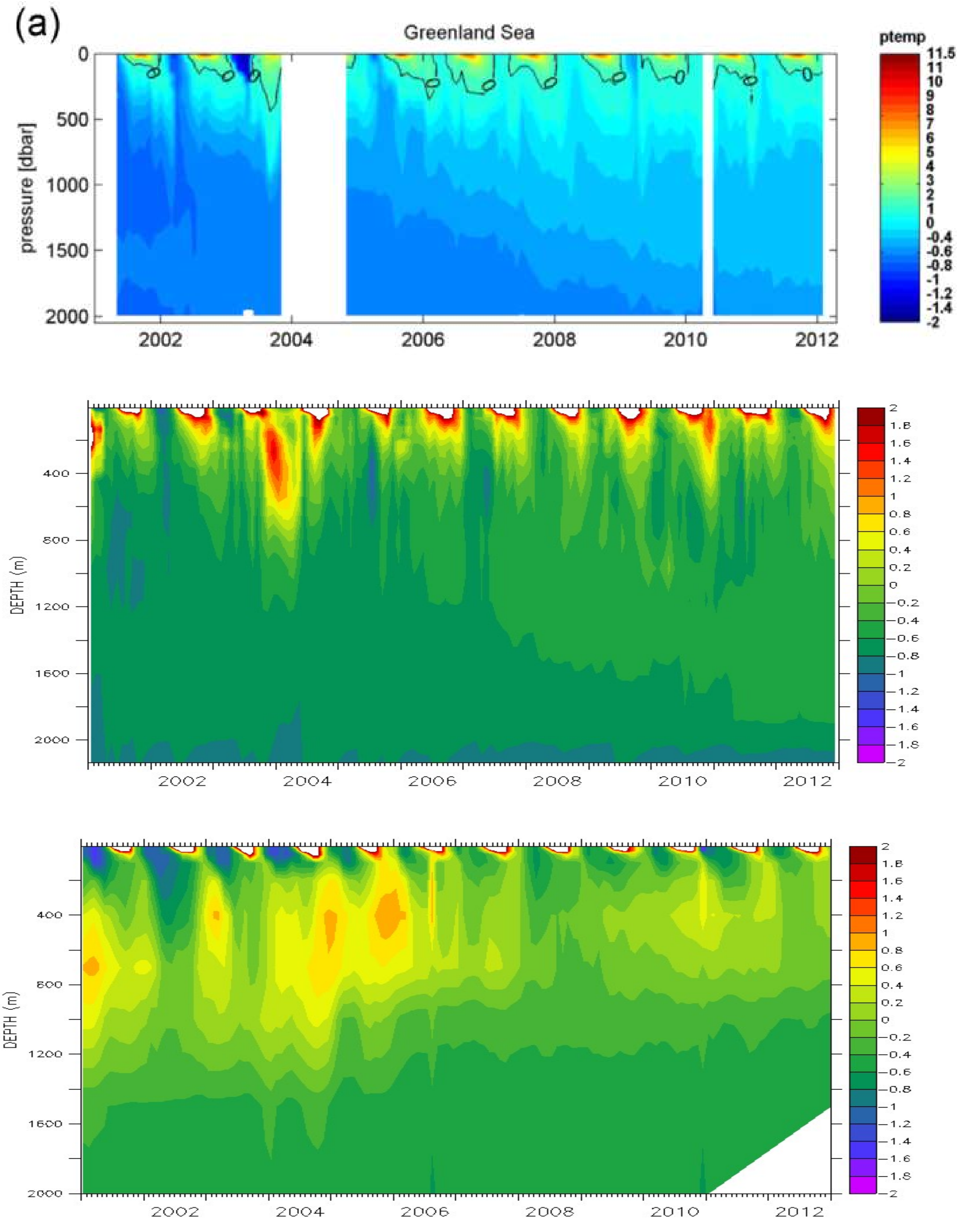


*Figure 1: Potential Temperature in Greenland Sea gyre (top) from Latarius and Quadfasel (2016) (middle) EN4 (c) TOPAZ4.*

We thank the reviewer for raising the issue and we do feel that it needs to be addressed in the main text. Accordingly, we have added the following lines in the discussion (line 296-301 ):

*It should be noted that the complex subsurface processes and their interactions with the large scale circulation are often difficult to capture in the reanalysis, particularly with sporadic subsurface observations in both time and space. For example, while the surface variables are well captured in TOPAZ4, the reanalysis is too warm in the GS below 300 m as observed in Xie et. al, 2017 (their Figure 9). Of particular interest in this study, the south-western GS, is a particularly sparse region in observational data. Increased long-term observations from these areas would help improving the reanalysis datasets and better understand the complex atmosphere-ocean interactions and their impact on the sea ice variability of this region.*

I have some concerns about the upper ocean buoyancy frequency (Fig. 9a) in the western Greenland Sea. The western Greenland Sea region that you have defined is a region of complex hydrography. It includes the Greenland shelf, which is dominated by polar surface water, the shelf break and upper slope where the EGC transports Atlantic-origin water at intermediate depth, and the interior Greenland Sea where Arctic-origin water is formed (e.g. Håvik et al., 2017; Renfrew et al., 2019). I don’t think that a spatial average across this region is very meaningful. The Greenland shelf is highly stratified, while offshore of the polar front the stratification is far weaker and deep convection is possible. In my opinion stratification averaged across this region is not a robust measure of vertical mixing of Atlantic-origin water or of the strength of the Greenland Sea Gyre.

We agree that the hydrography changes in this region within small horizontal extent and that makes the spatial average over the region bit ambiguous. Thank you for raising this issue! We checked it further and the below analysis shows that it does not affect the main message of the study.

The main purpose of showing the stratification is to highlight that indeed there is weakening of stratification in this region and that causes the Atlantic waters to mix vertically, which is further supported by Fig 9b and c.

It is this process, which we are attempting to attribute to the sea ice variability of this whole region and associate with the Gyre circulation. One would expect, and also as evident in the figure below, the extent/magnitude of the impact of Gyre circulation on the sea ice concentration (through stratification changes) depends on the complex hydrography of the region as rightly mentioned by the reviewer. For example, it can be noticed that during strong/weak gyre circulation years (negative/positive values), the spatial pattern of the satellite observed sea ice concentrations closely follows the stratification pattern. The impact on sea ice is larger in the eastern side with less stratified waters and it is smaller in the highly stratified Greenland coast waters as can be expected. Nonetheless, the main point is that the process is valid for both types of hydrography, only the magnitude of the implication of the process differs.

We have kept the text identical for the sake of brevity.

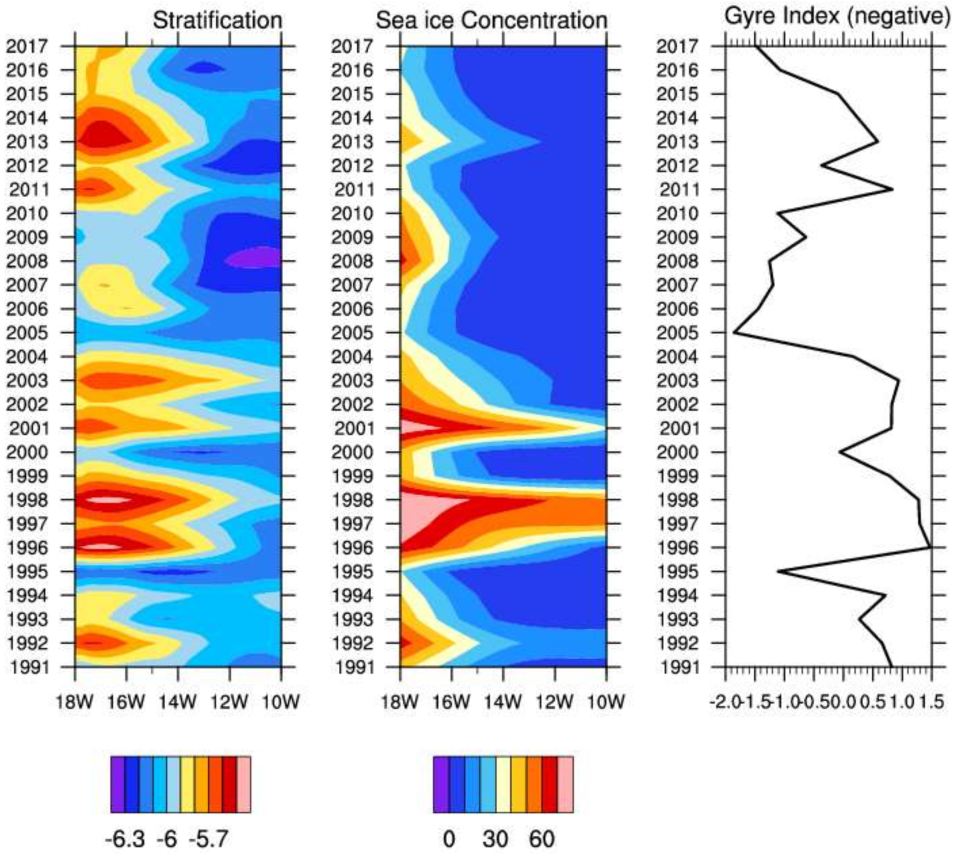


Figure 2: Logarithm of squared Brunt-Väisälä Frequency (left) , Sea ice concentration (middle) and Gyre Index (right) during the DJF.

Line 26:
The importance of the Greenland Sea to the AMOC is still overstated. While recent results of Huang et al.(2020) indicate that the Greenland Sea is an important source of the densest overflow waters from the Nordic Seas in the present climate and Chafik and Rossby (2019) demonstrate that the overflows from the Nordic Seas are key to the lower limb of the Atlantic Meridional Overturning Circulation, none of the references cited in the paper (or any other papers that I am aware of) demonstrate that the strength of the overturning circulation partly depends on the amount of freshwater in the Greenland Sea.

We have modified the text following the suggestion as below (Line 26-27):

*The freshwaters in the GS plays an important part for Nordic Seas overflow (Huang et al., 2020), which constitutes the lower limb of the Atlantic meridional overturning circulation (Chafik and Rossby 2019).*

Line 42:
This sentence is unclear. Ice free conditions, or at least partially ice free conditions, are required for deep convection to occur. According to Moore et al. (2015) the reduced depth of convection in the central Greenland Sea is not because it is ice free - that is a prerequisite for deep convection. It is

instead caused by the retreat of the ice edge, and the region of strongest ocean-to-atmosphere fluxes which is tied to the ice edge, toward Greenland such that heat loss from the central Greenland Sea is reduced.

We agree that the sentence is confusing. The sentence is removed in the revised version.

Lines 53-55:

I counted 6 different acronyms on these three lines. Are all of these really necessary? The readability of the text would improve if the number of acronyms were reduced.

We have reduced few acronyms as below (Line # 52-55) :

*Selyuzhenok et al. (2020) also argued that consistent positive North Atlantic Oscillation (NAO) forcing in recent decades have led to warmer AW in the Nordic Seas and resulted in a declining sea ice volume trend. However, the response of Nordic Seas circulation to the atmospheric forcing and the mechanism through which it can influence the SIC in GS is not studied in detail.*

Line 57:

The subpolar North Atlantic is generally considered the subpolar gyre south of the Greenland-Scotland Ridge, not the Nordic Seas.

Modified as: (Line 57-58)

*The Greenland Sea Gyre (GSG) is a prominent large-scale feature of the Nordic Seas circulation and can be identified as a cyclonic circulation in the central GS basin (Fig. 1).*

Line 147:

The region outlined in Fig. 2 is in the very southwestern part of the Greenland Sea (the Iceland Sea is more or less immediately to the south of this region). As such, I think referring to it as southwestern Greenland Sea rather than western Greenland Sea would be more appropriate.

In the revised manuscript the region is addressed as southwestern Greenland Sea.

Line 219:
The term "temperature advection" should be defined also in the text, not only in the caption of Fig. 8.

Defined (line # 218)

Line 246:
How often is this pattern, which resembles the NAO but has centers of action shifted toward the north, realized?

The shift of NAO centre of action has been identified in many studies earlier (e.g Zhang et al., 2008, Moore et al., 2013). The shift is more prominent from late 1990s as observed in the figure from Zhang et al., 2008.

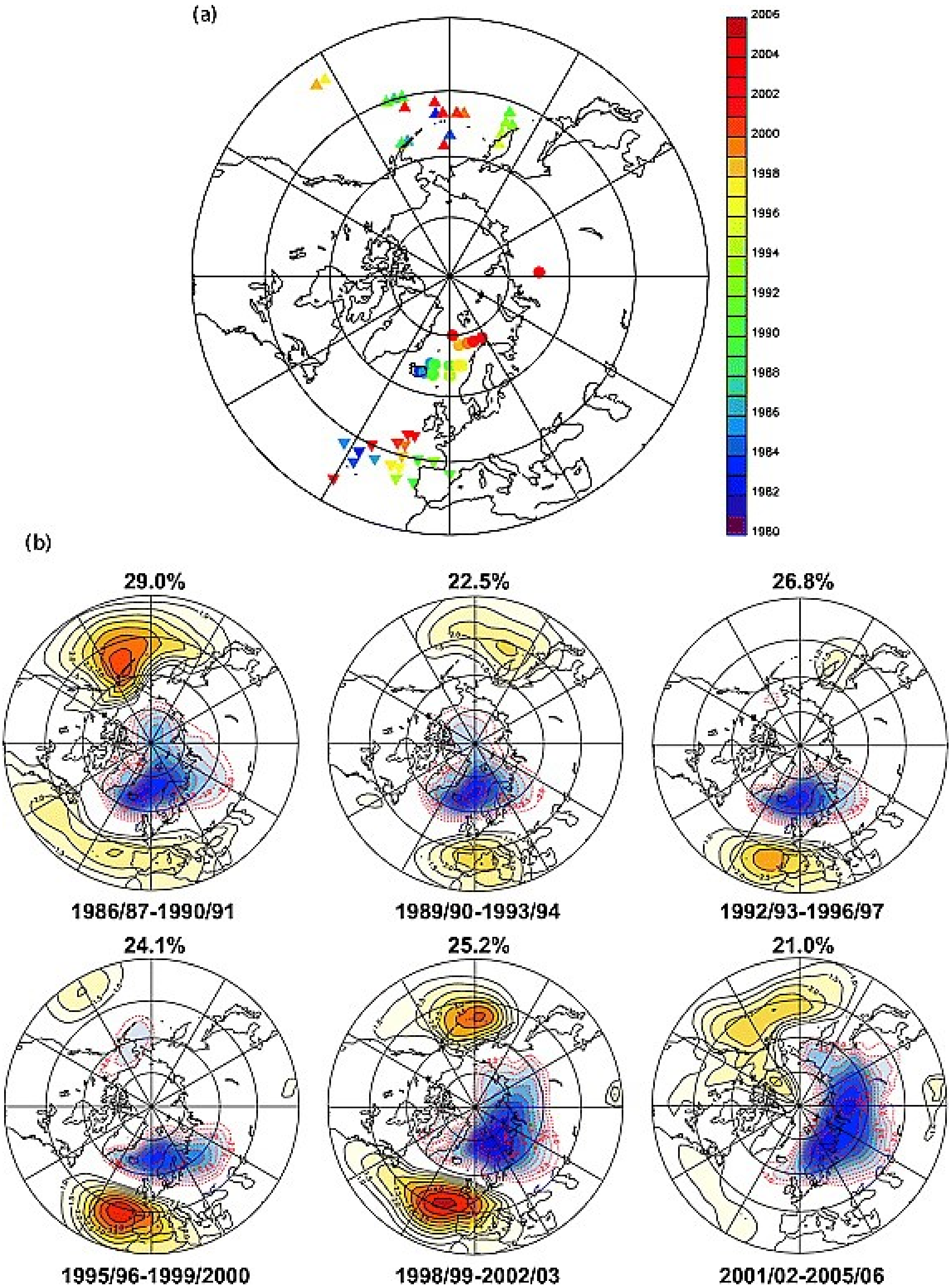


*Figure 3: (a) Positions of the centers of action and (b) the first EOF/PC spatial patterns in the recent representative time windows. The circles and triangles represent positions of the centers of action for each time window centered in the year shown in the color bar over the Arctic, North Atlantic, and North Pacific. From Zhang et al., 2008:*

Figure 1:
The thick black line marking the 3000 m isobath is not clearly visible.

Modified

Figure 3:
It would be good to specify in the caption that monthly values are considered.

Mentioned

Figure 10:
Ekman is misspelled in box A2.

Corrected