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Stratification and mixed layer depth around Iceland, characterization and inter-annual variability

by A. Ruiz-Angulo, E. Portela, C. de Marez, A. Macrander, S. R. Ólafsdóttir, T. Meunier, S. Jónsson, and M. D. Pérez-Hernández

In this manuscript, the rich hydrographic data set collected through long-term monitoring efforts is used to characterize stratification and mixed-layer properties around Iceland. Three distinct regions are identified, characterized as α-, β-, or transition-oceans based on whether temperature or salinity dominates stratification, and implications for water mass transformation are discussed. Straddling the Greenland-Scotland Ridge, Iceland is situated at a key location for the overturning circulation in the Atlantic Ocean, particularly as regards the supply of dense water masses to its lower limb. I think this is an interesting and timely contribution to improve our understanding of the unique importance of Icelandic waters, but I have some concerns about the determination of mixed-layer depths, water mass definitions, and the one-dimensional mixed-layer model simulations that I hope the authors will address.

Major comments:

Your method for determining mixed-layer depths, with an adjusted density criterion, is commonly used. Verifying the outcome of the routine by visual inspection is a good way to ensure that the results are realistic. However, I think that you also need to document this, or at least be more specific about what the mixed layer depth you arrive at represents. Is it the surface mixed layer that is currently in direct contact with the atmosphere or the deepest weakly-stratified layer formed the same winter that may better represent the depth that convection has reached? In the subpolar North Atlantic and the Nordic Seas stacked mixed layers are prevalent and automatic routines are generally not very adept at identifying the depth of wintertime convection (Pickart *et al.*, 2002; Våge *et al.*, 2015; Brakstad *et al.*, 2019). I encourage the authors to consider additional verification of the mixed-layer depths and expand the discussion about the limitations of the routine and what the outcome actually represents.

More details about the PWP model (Price *et al.*, 1986) should be included in sections 2 (Data and methods) and 4 (MLD driving mechanisms from a 1D model). In particular, I miss information about how the model functions, about the initial conditions and forcing time series, and about the integration period and time step used for the simulations. I am sceptical about some of the results from the simulations, in particular the substantial impact of freshwater forcing on stations FX9 and ST5. Freshwater fluxes are usually of lesser importance for the mixed-layer development and tend to restratify the mixed layer (i.e., have a stabilizing influence) (e.g., Brakstad *et al.*, 2019), yet on these two stations they appear to cause a mixed-layer deepening of more than 300 m, which would require substantial evaporation in a region where precipitation generally dominates. At these two stations, wind-mixing is also surprisingly deep. Please confirm that the model simulates the mixed-layer development correctly and expand the discussion about these surprising results.

I am not fully convinced that these water mass definitions (Figure 2, Table 2), dating back to Rudels *et al.* (2005) and primarily focused on polar conditions, have high fidelity around Iceland today. For example, the 0°C isotherm no longer provides accurate distinction between Atlantic- and Arctic-origin water masses (Våge *et al.*, 2022). Perhaps these definitions should be updated or adapted for current conditions around Iceland? It matters when these definitions, without additional evidence, are used to determine the origins of different water masses. For example, are you confident that the dominant water masses near the surface at SI8 are of polar origin (line 172)? At times, the cold, fresh profiles in Figures 2c and 2d are unmistakably polar (compare to Figures 11c and 12c in Rudels *et al.*, 2005), but while there may be some trace of polar water at SI8 the rest of the time I am not convinced that it is the predominant surface water mass. The same applies to the Atlantic-origin water at the same station (line 173). This could be more recently-formed intermediate water in the Iceland Sea that may be warmer than 0°C (Våge *et al.*, 2022). A closer inspection of each profile, to verify that it displays the intermediate temperature- and salinity maxima characteristic of Atlantic-origin water (Mauritzen, 1996), would likely be necessary for unambiguous identification.

General comments:

The paragraph on Atlantification of the Arctic Ocean in the introduction (line 63) appears unmotivated and its purpose is not immediately clear. The transition into an α-ocean north of Iceland is later ascribed to Atlantification, though Atlantification is more generally considered where Atlantic properties displace Polar properties in the Arctic Ocean. If applicable north of Iceland, I think you need to start making a stronger case for the relevance of Atlantification already in the introduction and follow that up in the discussion (e.g., line 373).

Why did you limit the data set to include observations only to 2019 (line 105)? The MFRI monitoring program is ongoing, so more recent data should be available. You document interesting signals toward the end of the record (Figure 5) that could be further examined.

Did you consider including other stations than the deepest on each transect in the analysis? At least some of the transects have several stations offshore of the shelf break. Perhaps for one transect in each hydrographic region, it would be very interesting to know if the other deep stations corroborate the results – that would make your conclusions more robust.

While LB8 may be representative for a β-ocean regime, located in the middle of Denmark Strait it is also characterized by substantial high-frequency variability (von Appen *et al.*, 2014; Lin *et al.*, 2020). Perhaps KG6 would be a better choice for investigating interannual to decadal variability in mixed-layer properties in this region?

I think the text would be more clear if the past tense was consistently used for past events (e.g., line 248). At least, avoid switching between past and present tenses within the same paragraph.

The NAO primarily represents atmospheric variability on time scales shorter than the ocean may fully adjust. Variability in circulation and mixed-layer depth/properties may be expected (e.g., Yashayaev, 2007), but to a lesser extent wholesale changes throughout the water column, hence line 257 could be phrased more conservatively.

If the mean mixed-layer depth at SI6 is less than 100 m (Figure 4), how can anomalies in mixed-layer depth exceed 100 m in both positive and negative directions (Figure 5b, e)?

For the statistical analyses (Figures 5 and 6), please provide the values for the correlations and trends reported in the text as well as their uncertainties. That would help make the analysis more quantitative and robust.

Please provide some information about the gridding or averaging used for the data set that you calculate the spice frequency shown in Figure 8 from.

Detailed comments:

Line 16:
Dense-water formation is generally considered a necessary condition for a global overturning circulation rather than a driving mechanism (e.g., Kuhlbrodt *et al.*, 2007).

Line 24:
Contributions should be in plural.

Line 40:
As a proper name, ridge must be capitalized in the Greenland-Iceland-Scotland Ridge.

Line 44:
The Faroe Islands would be more appropriate than just Faroe.

Line 52:
Regarding the transformation of AW into AtOW, it is unclear what is meant by “along the Norwegian Current western intrusions”. Presumably that water mass transformation occurs along the Norwegian Current, which is a main mode of water mass transformation that is otherwise not mentioned here (e.g., Mauritzen, 1996; Huang *et al.*, 2023).

Line 56:
Very likely heat loss is important also for water mass transformation east of Greenland, but wind forcing and sea-ice retreat are necessary for preconditioning this region before convection can occur.

Lines 60:
Do you mean from the Arctic Ocean? The Arctic, by itself, is ill-defined and has multiple interpretations. The reference to Arctic as north and northwest of Iceland (line 91) does not help clarifying.

Line 64:
The word “extent” is used twice in the same sentence.

Line 71:
Please be more specific, under what conditions does wind forcing enhance turbulent mixing that deepens the mixed layer? The following sentence does not add clarification regarding the impact of wind forcing, even though it alludes to an example of this process.

Line 79:
The definite article in front of 40% should be removed.

Line 82:
It would be good to be more specific about what kind of mixing you refer to, perhaps diapycnal mixing or convection?

Line 170:
There should be a comma after southwest of Iceland.

Line 185:
A reference to Jónsson and Valdimarsson (2012) would be appropriate here.

Line 214:
What do you mean by “hydrographic onset”?

Line 226:
The sentence starting with “Therefore, ...” is unclear and should be rephrased.

Line 228:
It should be: “... the potential **for** deep convection ...”

Line 241:
The paragraph starting on this line is repetitive and could be written more concisely.

Line 256:
The Feucher et al. (2022) paper is missing from the reference list.

Line 278:
Please specify what the anomalies are computed from. Are they anomalies relative to the record-long mean at each station?

Line 286:
The term aliasing has a specific meaning in time series analysis, where high-frequency variability appears as a lower-frequency signal due to inadequate sampling. It is not clear that the term was used appropriately in this sentence.

Line 289:
The reference to Polyakov *et al.* (2017) is not appropriate here, they did not consider the mixed layers around Iceland or the NIIC in their study.

Line 295:
Mixed layers in summer are shallow primarily because the buoyancy forcing abates in spring and becomes largely positive in summer, episodic wind and wave mixing (also reduced in summer) ensure that there is a mixed layer. This is a main reason why stratification is higher in summer than in winter. Please rephrase.

Line 311:
Do you mean SI8 rather than LB8, if you refer to the region north of Iceland?

Line 312:
Wind-stress, by itself, will not cause convection - for that you need buoyancy forcing. This process would more appropriately be referred to as wind-mixing.

Line 350:
There is at least a preposition missing near the end of this sentence.

Line 356:
The surface water masses of the EGC would have a strong Polar (not Arctic) influence.

Line 375:
An increasingly temperature-dominated stratification may in principle lead to deeper convection, but reduced atmospheric forcing and shallower, less dense mixed layers (Moore *et al.*, 2015; Våge *et al.*, 2022) strongly suggest that the Iceland Sea is not likely to become an important source to the NIJ.

Line 390:
The warming trend of 2°C, was that over the entire record length? When reporting a trend, please also provide a time reference.

Figure 5:
It would have been illuminating to see panels of mixed-layer density anomalies as well.

Figure 6:
I think it would be advantageous to use the same color scale for all panels, even if that means that some colors occasionally will saturate, to facilitate direct comparison between stations.

Figure 6, caption:
It should be: “... all stations except **LB8** and KG6...”

Figure 7:
Please also show the total mixed-layer depth resulting from the combination of all driving mechanisms. Do they add linearly? While the observations stem from February and not end of winter when the mixed-layers are deepest, it appears that some of the simulated MLDs will be substantially deeper. In the text, individual panels are referred to by letters, but these letters are not visible on the figure.

Table 1:
KG6 and HB6 are not located in the Greenland Sea. Referring to this region as Blosseville Basin or western Iceland Sea would be more appropriate.

Table 2:
Some of the less than/greater than signs are in the wrong direction and contradict Figure 2 (e.g., SW temperature, warm PSW density, and AtOW density).

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