Ocean Science Discussions

Ocean Sci. Discuss., author comment AC1
https://doi.org/10.5194/os-2021-60-AC1, 2021


# Reply on RC1

Matthew Clark et al.

Author comment on "Weakening and warming of the European Slope Current since the late 1990s attributed to basin-scale density changes" by Matthew Clark et al., Ocean Sci. Discuss., https://doi.org/10.5194/os-2021-60-AC1, 2021

We would like to thank reviewer 1, Hjálmar Hátún, for the detailed comments on this work as provided in "https://doi.org/10.5194/os-2021-60/RC1". We will now respond to each comment in turn, with *Hátún's original comments presented in italics*.

Firstly, we consider Hátún's comments on sea surface height (SSH):

*The discussion on eastward flows in the North Atlantic Current has a long history (which the present study does not appear to acknowledge). Already in 2002, Pingree (2002) linked this to the meridional gradient in sea surface height (SSH), as revealed by satellite altimetry. He discussed increased SSH gradient/transport during NAO+ years (e.g. 1994-1995 and 1999-2000). He (and a large volume of following literature) has associated such interannual changes to the NAO index and variability in the wind stress curl field over the NE Atlantic.*

*After this, SSH data (observed and simulated) have been utilized by myself and many others, to discuss this dynamics in a broad and longer context (Hátún and Chafik, 2018, and reference therein). For example is the calculation of the so-called gyre index closely linked to variability mentioned by Pingree (2002), and likely to your eastward transport records based on hydrography. Your analysis on these transports is interesting, and does provide new information/knowledge. Just try to better weave it into the existing volume of knowledge. This includes paying more attention to the interannual fluctuations that you present (Figure 6 and 7). Your study is clearly motivated by identifying drivers behind ecosystem fluctuations along the European continental slope (ECS). We have previously linked these pulses to many ecological aspects in the NE Atlantic (e.g. Hátún et al., 2017, 2016; Jacobsen et al., 2019), and a growing body of evidence shows that this type of variability does also characterize the ECS (Pätsch et al., 2020). You have the evidence, utilize it better.*

Hátún is correct in saying we have overlooked SSH gradients as a driver for eastward flow in the North Atlantic. We have also not related our results to the North Atlantic Oscillation (NAO) index, which in hindsight would have been appropriate. We will incorporate SSH studies into the introduction and background materials, as well as attempting to relate our main findings to SSH changes (accessible via GODAS 'sshg' files). We will relate our findings back to the NAO index as well.

Our study is indeed motivated by identifying drivers behind ecosystem fluctuations along the slope and shelf seas. We thank Hátún for drawing our attention to the studies referenced above. We propose to relate our observed hydrographic changes and calculated particle trajectories to the gyre index: this may prove to be a valuable link. We will also introduce a new SSH decadal mean anomaly figure in the style of Figs 2-4, for direct comparison to observations already in the literature. Additionally, we'll include an estimation of monthly eastward barotropic (SSH-related) transport across the same region as our GODAS estimates (30 °W, 45 – 60 °N), for the time period 1980 – 2019.

We note the fact that the NAO and poleward flow is out of phase:

*Garcia-Soto et al. (2002) and Pingree (2002) discuss the conditions along the ECS in relation to the relatively narrow slope currents from the south (Bay of Biscay). This topic should be better handled in your work. For example does Pingree (2002) claim that the North Atlantic Current strength and the mentioned poleward flow are out of phase. Weak NAC (aka NAO-) is related to stronger flow of warm and saline waters from Spanish waters – also referred to as Navidad events/years (Garcia-soto, 2002). This seems to be at odd with your perspective (although I follow your argument that NAC waters are being continuously recruited to the slope, north of the Porcupine Bank). This aspect must be better handled.*

We agree that the NAO needs to be better handled within our manuscript. This will be done through a more thorough discussion of our results in this context, relating back to the papers highlighted above as well as additional relevant material.

The more specific suggested figure alterations are, for the most part, wholly appropriate and justified comments. We will comment on each figure (or figure grouping) individually:

*I will below suggest some more specific changes to your work. If you are will to roughly follow this path, I can provide a more detailed review during the next round.*

*Fig. 1 does nice illustrate the entrainment of water to the boundary north of Ireland, and no northward bound boundary current south of the Porcupine Bank. Your particle tracking figures, however, suggest near-slope patterns further south. Would velocity quiver maps on a shallower level maybe reveal any influx from the Bay of Biscay?*

We are cautious about providing quiver maps at shallower levels. The literature suggests the core of the Slope Current to be approximately 200 – 300m deep (Porter et al, 2018), hence our chosen GODAS depth level of 245m. This will be justified more strongly within the manuscript. The message we were trying to convey was the seasonal and interannual variability of the Slope Current. We are happy to test shallower depth levels and reassess the best level(s) to display here.

*Figs. 2-4: You can state the association between T and S, and the tight linkage between T and SSH in the text, and only show the density field (Fig. 4). The T-S-density relations are well known between oceanographers, and the T and S figures are not strictly needed. And as suggested below, provide a better figure, which includes a relevant geographic domain, and averages over relevant periods.*

Removing Figs. 2 (S) and 3 (T) is a sensible suggestion. We will improve the description of the T and S relationship in the text after removing them, particularly in the discussion. An overview of the entire study area can be provided in an updated version of Fig. 1.

*I would also include altimetry data here. It would (i) validate the chosen in situ hydrography data product, (ii) produce and independent east ward transport record, and (iii) enable you to put your analysis in much better context – and link to the existing literature.*

SSH data, from GODAS, will be plotted in the style of Figs 2-4. Please see the previous comments on SSH. We will then link any observations back to the existing literature throughout the discussion.

*I would only show the GODAS-based Hovmöller diagram in Fig. 5. You say that there is mutual agreement between the GODAS-based and the EN4-based. I think there are large differences between them (although basic major feature are comparable). You also describe some limitations with the EN4 dataset (pages 10 and 11). And my impression of the hydrographic signal at ~60°N (which is based on many years of experience and many data sources), is that the GODAS product probably is more reliable for you purpose. Suggestion, skip EN4. It would enable you to produce a clearer figure, and convey a clearer message.*

EN4 will be removed in this figure and other figures for better clarity of our findings. Whist both GODAS and EN4 have their limitations, we agree that GODAS is the more appropriate and reliable dataset.

*I would merge Figures 6 and 7 into one two-panel figure with the GODAS-based time series. It is reassuring that the EN4-based series show similar variability, and this could be mentioned with words/correlations.*

Current Figs. 6 and 7 will be merged to form a 2-panel plot of GODAS-derived eastward volume transport: a- geostrophic, b- total. The EN4 transports will still be mentioned within our discussion of results.

*It is good to see the transport change in T-S space (Fig. 8). You could, however, zoom in on a narrower TS window, which would enable a better/clearer figure. The TS-transport figure based on ORCA12 (Fig. 9) is actually very different from the GODAS-based figure (Fig. 8). GODAS shows a major decrease around 5-6°C, 35.0 (which must be close to Subpolar Mode Water), which is not reproduce by the ORCA model. Suggestion: Stick to GODAS – skip Fig. 9.*

We will remove ORCA12 from this figure and amend the TS window to reflect that: T in range 5 – 18 °C, S in range 34 – 36 PSU. We will still refer back to the differences between GODAS and ORCA12 within the discussion, to create context with our necessary use of the ORCA12 simulation for calculating the particle trajectories that are central to the variable pathway/provenance analysis in Sect. 3.3.

*Fig. 10. Yes the transports are much larger at the northern section (admixture of NAC-derived water, right?), and there is a somewhat worrisome decline in this transport (in line 255, you mention an almost-steady northward transport of 2 Sv after 1995, while I see a continuing decline, also after 1995). While I guess that you already have tested this thoroughly, are you still confident that you capture the entire slope current, with this model extraction? If yes, which current is then presently feeding the Faroe-Shetland Channel?*

Our current Fig. 10 will be repurposed to better reflect the changes in northward transport along the shelf edge. We now propose to present 4 northward transport time series: at 51, 54, 56, 58 °N, or alternatively a Hovmuller plot showing northward depth integrated transports over time for the shelf edge 50 – 58 °N. We will test these and decide on a best course of action. Replotting will better reflect the release locations for the particle tracking experiments later in the manuscript. The calculations will be done in the CDFTools package, proving a more accurate estimation of volume transport through the ORCA12 meshgrid.

*The results from you particle tracking analyses are nice. Keep.*

*I hope that I have been too frank. I really hope that your work will become a part of the literature, because it is needed. If you (and the editor) think that my suggestions are too drastic, I would be ok with being revoked as an editor. Otherwise, I look forward to read a reworked version J*

*Figures (I wrote this, before the text above. You can maybe use it as guidance)*

Many of Hátún's additional comments on the figures are formatting improvements to better utilise the plotting space, or to avoid repetition in the figures and captions. For instance:

*Figure 1: Remove the header "Velocity quiver at 245 m" from each panel, and this common information in the caption. Remove the y-axis information on the right panels, and the x-axis information/labels in the upper panels, enlarge each panel, which removes too much void space between them.*

We fully agree with this recommendation, and this change will be implemented in full for the reworked version of the manuscript.

There are a lot of additional comments about figures 2-4:

*Figures 2-4: Remove " S/T/density decadal mean anomaly, and "205 m" from each title. This information is already in the caption.*

The figure titles will be amended and simplified, according to this suggestion.

*You lose out in insight and smear out valuable signal, by strictly averaging over these decades. For example, the 1990s was is contrasting period, with dense waters until the mid-1990s, and much warmer/lighter waters after. The average over these contrasting states is not so meaningful. I am aware of our wish to stay objective, but you have explainable reasons for selecting contrasting periods (e.g. early 1990s and early 2000s), in order to portray spatial hydrographic structures over the North Atlantic. Also pay attention to the (short term) interannual signal (mentioned above).*

We agree with this point. We will replot Figs 2-4, with means pre 1997 and post 1997, which will bring them in line with the T-S plots shown in Figs 8 and 9. This will enable a better comparison between the "warm" and "cold" periods/states as observed in previous literature and indeed our own results. SSH will also be plotted here (see previous comments on SSH) in the same style.

*Add some selected isobaths (e.g. 1000m, 2000 m and 3000 m) to these plots. In order to discuss these patterns against previously published key patterns in the North Atlantic (e.g. the spatial sea surface height mode, which is associated with the gyre index), you might what to include a broader meridional window (e.g. 35-65°N, although you only calculate transports over the 45-60°N latitudinal range). Maybe use a bit narrower color ranges, in order to emphasize the obtained patterns.*

Isobaths will be added to current figures 2-4 (including the replacement SSH plot). We will select narrower colour bar ranges as suggested. We will plot for 35 – 65 °N, and annotate the figures with the profile used in our calculation of transport at 30 °W, 45-60°N.

Previously in this response, we agreed to limit the plots to just one showing the density anomaly patterns.

*Figure 5: Maybe use a bit narrower color ranges, in order to emphasize the obtained*

*patterns.*

*The obtained Hovmöller diagrams based on GODAS and EN4 are actually rather dissimilar (mentioned above).*

A narrower colour range will be trialled, most likely in the range ±0.2 kg m-3.

More minor figure amendments were recommended:

*Figure 11-13*
*Just keep the y-axis information on the left panels, and the x-axis info on the upper panels. Enlarge the panels, which would remove the excessive white spaces in these figures.*

*Figure 6:*
*Remove "Geostrophic eastward transport", from the titles. This info is provided in the caption.*

*Figure 7:*
*Remove "total eastward transport", from the titles. This info is provided in the caption.*

We agree with these recommendations and they will be actioned in full for the amended manuscript.

We once again thank Hatun for his detailed comments. We look forward to presenting a revised manuscript and hope that the amendments and additions satisfy your feedback.

Kind regards,

Matt Clark,
Lead Author
on behalf of all authors.