Review of "Causes of the 2015 North Atlantic cold anomaly in the ECCOv4 state estimates" by Sanders et al.

The manuscript presents an in-depth analysis of a large and cold SST anomaly in 2015 in the eastern North Atlantic subpolar gyre. This signal has been identified previously, and this paper adds to that literature by decomposing the mixed layer heat budget during the cold anomaly. The authors conclude that the majority of the signal is attributable to surface heat fluxes, though horizontal advection and re-emergence from temperature signals below the mixed layer also played a significant role.

I found the paper to be an important addition to the literature. The text was well-written, the logic was clear, and the figures were appropriate. It was clear the authors have put a lot of thought and effort into the submission, which is much appreciated. I have listed a number of important topics the authors should address prior to publication, but none rise to the level of major revisions. I therefore recommend the paper be published pending minor revisions.

1. The authors should clarify in the introduction how this study adds to the results from Grist et al. (2016) and Josey et al. (2018). What is new about these findings compared to those papers?

2. It is still unclear to me what the rationale is for using ECCOv4r3. If there aren't any significant differences then why not use the more recent release? Using a different data product (e.g., EN4) would provide some perspective on the range of values to expect from different reanalyses/state estimates, but using an outdated and updated version of the same product doesn't provide any new information. It also appears the authors abandon r3 half-way through the manuscript (with those figures included in the appendix), so either the authors need to make this case stronger for r3 (probably around line 90) or only conduct the analysis in r4 (my preference).

3. I thought the main utility of ECCO was that it conserved energy/heat! Why don't the seasonal budgets close? It appears the authors try to explain this in the first paragraph of Section 4.5, but this is too late in the manuscript. I recommend this explanation should be moved to the introduction, potentially with more information included because why the heat budgets did not close was still not clear to me… Doesn't the heat budget for each grid cell close? If so, how can the heat budget over multiple grid cells not close?

4. I recommend combining figs 1 and 2 to make comparisons to the observations easier. I also recommend acknowledging a pretty apparent 'NAC' shape in the cold anomalies in Fig. 2c and 2d that is not present in the r3 (Fig. 2a and 2b) or observations (Fig. 1). That suggests that the NAC has shifted southward in r4... is that a correct interpretation? I also think it would be useful to include figures of ECCO SST-HadISST to see how close ECCO SST is to the observations. Similarly, this could be done for MLDs in ECCO and observations.

5. Fig. 3 – Can the mixed layer temperature from EN4 be added to Fig. 3?

6. Fig. 4 – I am a bit surprised that there is a clear signal of re-emergence when you're averaging the MLD over such a large and inhomogeneous region. This is why it would be nice to see a map of MLD in ECCO versus the observations to compare whether ECCO is getting the MLD correct.

7. Line 181 – Can you elaborate on how the cold anomaly drives increased convection? Through preconditioning the stratification below the mixed layer or are you suggesting the fluxes are altered by the ocean temperature anomaly?

8. Fig. 6 (and other time series) – it is hard to see the individual curves over course of 4 years… can you zoom in on the 2014-2016 period?

9. Fig. 7 – What is the difference (if any) between Fig. 7a and Fig. 6a?

10. Fig. 7 – I was also a bit confused by Fig. 7c – it took me a while to understand that the 'bump' in the blue line (vertical temperature gradient at the base of the mixed layer) in winter 2014 is an important signal. Can you do something to highlight that? Otherwise, the most obvious signal for the reader to notice is the anticorrelation between the red and blue curves, but that result is pretty obvious considering the vertical diffusion out of the mixed layer should be proportional to the vertical temperature gradient at the base of the mixed layer.

11. Fig. 8 – Nice schematic! Very clear. Two suggestions: (1) replace "Mixed layer shallows" to "Mixed layer shoals due to seasonal cycle". At first, I wasn't sure if you were still talking about anomalies from the seasonal cycle, so I was confused why the mixed layer would shoal in the spring. And (2) flip the red/blue gradient in the first panel – do you mean to imply cold water will overly warm water or just that the surface waters are cooling relative to the waters near the base of the mixed layer?

12. Fig. 9 – Could you mark the 53°N line that separates the Northern/Southern regions on Fig. 1 and/or Fig. 2?

13. Lines 269-273. While it is interesting that advection plays a larger role in the south, I'm not sure I believe ECCO is best suited to make these comparisons. I would tend to believe the ECCO heat budgets in the northern region more than southern region due to issues resolving the GS/NAC system. In particular, I'm thinking that those 'NAC' shaped anomalies in Fig. 2 that are not apparent in the observations may be playing a disproportionate role in ECCOv4r4 than is present in the real ocean.

14. Fig. 11 – Another really nice plot/schematic, but I was a bit confused by the colors in the background. I thought they corresponded to the mechanisms in the bottom legend. I think they're actually just showing the seasons (is that correct?). I suggest either using a different color scheme or just dashed lines to demarcate the different seasons.

15. Section 4.5 – I suggested above that the first paragraph should go in the introduction, and I think the second paragraph should have its own heading along the lines of "Caveats of ECCO in this region". In addition to this second paragraph, there should also be a list of potential biases in ECCO for this region. The GS/NAC position (especially in the NW Corner region) is the first one that comes to mind, but also the overflows at Greenland Scotland Ridge is another important one. Another one would be that the shelf circulation is not resolved well in ECCO. ECCO is a great tool but there are caveats that go along with working with it, and the text will read better if you acknowledge those caveats up front rather than let the reader ponder their effects on their own.

16. I found that the text overlooked a relatively well-developed literature that has used ECCOv4 in this region: Piecuch et al. (2017), Foukal and Lozier (2018), Tesdal et al. (2019), and Asbjornsen et al. (2020). Including these papers could strengthen the authors case that ECCO is well-suited for this region.

Minor edits:
Lines 14-24 – It was a bit strange to repeat the last sentence in the abstract as the second sentence of the introduction. Can you just remove the sentence from the Introduction?

Line 77 – what is 1 x 1/3-1? I know ECCO's grid size varies with respect to latitude, but this notation is not clear.

Line 195 (and throughout) – It's a bit confusing to cite the numbers in the text as °C/month when they're listed as °C/year in the figure (and sometimes in the text). Can you just use one unit throughout?

Fig. 10f – please remove one of the two legends in this panel (but I'll admit two legends are better than no legends!).

Nick Foukal
Woods Hole Oceanographic Institution

References:

Piecuch, C. G., Ponte, R. M., Little, C. M., Buckley, M. W., and Fukumori, I. (2017). Mechanisms underlying recent decadal changes in subpolar North Atlantic ocean heat content. Journal of Geophysical Research, doi: 10.1002/2017JC012845.

Foukal, N. P., and Lozier, M. S. (2018). Examining the origins of ocean heat content variability in the eastern North Atlantic subpolar gyre. Geophysical Research Letters, doi: 10.1029/2018GL079122.

Tesdal, J. E., Abernathey, R. P., Goes, J. I., Gordon, A. L., and Haine, T. (2018). Salinity trends within the upper layers of the subpolar North Atlantic, Journal of Climate, doi: 10.1175/JCLI-D-17-0532.1

Asbjornsen, H., Arthun, M., Skagseth, O., and Eldevik, T. (2019) Mechanisms of ocean heat anomalies in the Norwegian Sea, Journal of Geophysical Research, doi: 10.1029/2018JC014649.