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Ocean Science
Discussions

Interactive comment on "Pending recovery in the strength of the meridional overturning circulation at 26° N" *by* Ben I. Moat et al.

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We thank the reviewers for their time in commenting on this paper. We have prepared a detailed response to reviewers #1 and #2.

The GloSea5 time series has been extended to the end of 2018 by Laura Jackson at the UK Met Office, and is now included in this paper (red line Figure 6a). Laura has also contributed to the analysis in the updated paper so we have included her as a co-author.

Anonymous referee #2

17) However, I have some issues with the central scientific focus of the paper and felt that the general thrust of the argument was often misguided

We thank the reviewer for their detailed comments, and also their support of the RAPID 26N observations. We agree that they are the best available observations of the continuously varying AMOC, and have edited the text to improve this emphasis. However, one of this reviewer's major disagreements with the manuscript was that we tried to put the RAPID observations in the wider North Atlantic context and that this should not have been the focus of the manuscript.

We disagree. The value of RAPID lies not only in giving the best possible estimate of AMOC transport variability at an individual latitude (of great value as a benchmark for numerical models, ocean reanalyses and ocean dynamics investigations), we believe that as the RAPID time series lengthens it is enabling us to begin to address key climate questionsâĂŤthe raison d'etre for AMOC studies. These include detailed analyses of local causes of variability and regional impacts of variability, but also how the subtropical AMOC responds to buoyancy (rather than wind) forcing, what influence the AMOC has on decadal and longer variations in the Atlantic, and what the relationship is between the AMOC at different latitudes. It is clear that we are only beginning to have a long enough record to address these questionsâĂŤand not yet to satisfactorily answer them.

Text has been added in two places: âůŕ Section 2.1, first line: "The 14 years of observations at 26°N represent the most complete and longest records of the directly observed AMOC variability currently available." âůŕ Section 2.1, second paragraph: "The use of boundary moorings which sample at high frequency (hourly) enables high frequency (e.g. tidal and mesoscale) variability to be resolved and not aliased (Kanzow et al., 2009)"

18) I think the GloSea5 data is overused and overly trusted to give a realistic representation of the ocean. The authors attempt to reconcile the results with the 45N time series from Debruyeres et al. (2019), but I think too much respect is paid towards these results which are not of comparable stature

We have added text to clarify that the RAPID observations are the most complete and longest record of AMOC variability, but also that the 45N estimates are the longest available subpolar-area AMOC estimates. While they may be flawed, the covariability between buoyancy forcing and AMOC transport estimates in Desbruyeres et al. (2019) provides some confidence, as does the consistency between the overall findings of Desbruyeres et al. (2019) and the OSNAP programme (Lozier et al., 2019) including that watermass transformation east of Greenland is the major driver of subpolar AMOC transport variability. To provide confidence in GloSea5, Jackson et al., (2019) compared the AMOC at 26N and 50N in a large set of reanalyses and finds agreement in the variability.

Minor Comments 19) Line 27: “Comparing the two latitudes, the AMOC at 26âŮęN is higher than its previous low” this sentence needs to better distinguish spatial and temporal changes. We have replaced:“We have therefore examined the record of transports at 26°N to see whether the AMOC in the subtropical North Atlantic is now recovering from a previously reported low period commencing in 2009. Comparing the two latitudes, the AMOC at 26°N is higher than its previous low.” with “Examining 26N, we find that the AMOC is higher than its previous low, though not yet exceeding its long-term mean.”

20) Line 35: Slightly clumsy sentence, repetition of “on” This has been changed to; “It drives a large net northward transport of heat, with one petawatt (1 PW = 1015 W) released to the atmosphere between 26°N and 70°N, impacting the climate in the North Atlantic region (e.g. Srokosz et al., 2012) on surface temperatures, precipitation and sea level (Delworth and Mann, 2000).”

21) Line 71: “Guided by”. This language ties directly into point 2. RAPID should lead, not follow. We have updated this to: “Based on the RAPID observations and the recent findings at 45°N, we make preliminary investigations into the meridional coherence of the AMOC transport variability between 26°N and 45°N, and the response at 26°N to the impulse forcing in 2013/15.”

22) Line 83: missing “to” This has been corrected.

23) Line 89: The heat and freshwater fluxes are mentioned here but neither shown nor discussed. Perhaps a sentence explaining why? We have added: “Here we focus on the volume transport; updated analyses of the heat and freshwater transports are the subject of a separate study.”

24) Line 95: Are the CTD-Os a subset of the CTDs? No, they are in addition as the CTD-Os and only sample every 4 hours. We have clarified this in the text.

25) Line107: “net the” ‘Net’ has been deleted.

26) Line 109: GloSea5 should be mentioned here. The following has been added in Section 2.3 “We also use data from the GloSea5 global ocean and sea ice reanalysis (Blockley et al 2014, Jackson et al 2016), which uses the NEMO GO5 ocean model with a nominal resolution of 0.25° and with 75 vertical layers (Megann et al 2014). It assimilates in-situ and satellite sea surface temperatures; sub-surface ocean profiles of temperature and salinity; sea ice concentration; and sea level anomalies using the NEMOVAR v13 assimilation scheme (Waters et al, 2015). The experiment is described in more detail in Jackson et al. (2016), with a more in-depth comparison to observations and other ocean reanalyses in Jackson et al (2019).”

27) Line 132: missing “use” This has been corrected.

28) Line 150: Should say “Results” Thank you! This has been corrected.

29) Line 158: why is “anti-correlated” repeated inside the brackets? This has been deleted.

30) Line 158: Clarify: there is no correlation information in the spectral plot. This has been clarified : We replaced: “resulting in a reduction of power at the semi-annual frequency in the AMOC strength relative to the UMO. At periods longer than a year, the AMOC variability is dominated by the UMO transport” with “This anti-correlation is the cause of the reduced power at the semi-annual frequency in the total AMOC relative to

the UMO."

Note that an inference about anti-correlation can be made by comparing spectrum of total AMOC with the spectra of the components. If the total AMOC is less than one of the components then there must be some anticorrelation

31) Line 169: Use the LNADW acronym This has been changed

32) Line 172: "that a reductions" This has been fixed

33) Line 186: This sentence could be improved, just state the maximum and minimum values/times for comparison. This has been rewritten for clarity. "The AMOC transport in the 2017/18 year (17.8 $\pm$ 0.39 Sv) is larger than the recent minimum in 2009/10 (13.5 $\pm$ 0.36 Sv), but this does not represent a return to the high AMOC transport values near the beginning of the observational record (2005/06, 20.9 $\pm$ 0.32 Sv)."

34) Line 210: All this tells us is that GloSea5 is dynamically consistent with itself. It could still be wrong. I assume GloSea5 changes are forced by Lab sea deep convection, which we know many models get wrong, even if it does assimilate observations. This is actually based on observations at 45N and GloSea at 26N. We are using the agreement between GloSea at 26N and RAPID at 26N to provide a view (potentially not correct) of what the longer term variability of the AMOC at 26N may have been, and comparing this against the 45N observations assumingâĂŤbased on their robust agreement with the surface forced overturning in the subpolar gyreâĂŤthat they are a reasonable estimate of the AMOC at this latitude. As RAPID 26N is the only array providing the length and quality of AMOC observations, we will necessarily need to look to other products to investigate meridional connectivityâĂŤat least until the OSNAP observations provide a longer term, high-quality estimate of subpolar overturning.

35) Line 232: You can, but I think this analysis seems uncoupled from the RAPID results. The reviewer is referring to: "we can look more closely at the period of the observations and the longer records of ocean heat content and SSTs to evaluate whether

the observed variations in the Atlantic, as indexed by the AMV, follow the patterns predicted by the numerical simulations." This is an area of significant interest and debate in AMOC/Atlantic communityâĂŤis the AMOC responsible for fluctuations in the AMV? While the observed transport records are short relative to multi-decadal variability, some of the underlying processes (how the heat transport relates to OHC change) are within scope and may lead to mechanistic understanding of whether and how the AMOC influences the AMV.

36) Line 256: Be quantitative. What is the minimum fraction of the mean? We apologise but we do not understand what the reviewer is referring to.

37) Line 266: This is the first mention of the 34.5S array (in the conclusions). We have removed the reference to 34.5S

38) Line 272: Insert "within are analysis framework". We have chosen not to add this phrase in order to be more concise.

39) Line 288: Perhaps substitute "understanding" for "knowledge". This has been changed.

40) Figure 1: Red text on green very hard to read for colour blind people This has been updated to bold black text.

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