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Discussions

Interactive comment on "Can the boundary profiles at 26N be used to extract buoyancy-forced AMOC signals?" *by* Irene Polo et al.

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Interactive comment on "Can the boundary profiles at 26N be used to extract buoyancy-forced AMOC signals?" by Irene Polo et al. Anonymous Referee #1 Received and published: 22 April 2020 This paper addresses a significant question and presents interesting results which should be published. There are though some important details that need to be addressed in the presentation of the results before the work can be published. The main result is that, in the model simulations, the variance of density variations on the boundary is, like the AMOC, dominated by the wind on inter annual timescales and only on decadal timescales does the buoyancy forced signal emerge from the "noise" of the wind forced variability. This is not too surprising and the paper could be strengthened by more emphasis on the structure of the variations associated

with wind and buoyancy forcing, which has been less studied in previous work. Below are some specific points to consider:

1. More often than not the axes in figures are not labelled and/or units are not given. This is a fundamental requirement.

Response: Thank you for the comment. We have carefully checked the figures and the plots are now correctly labelled with units.

2. In the introduction (l95) it is stated that section 7 "describes the limitations of the interpretations, as well as possible applications e.g. in data assimilation", but there is no mention of assimilation in section 7.

Response: We have removed the sentence from the introduction.

3. Table 1. Its stated that all correlations are significant if greater than 0.3, but doesn't the significance of correlation depend upon number of independent data and hence whether the time series are filtered or not?

Response: Thank you for this comment. We have calculated the significance with a t-test now with the number degrees of freedom. In table 1 and 2, we have highlighted the significant correlations with a star. The full table of p-values with corresponding effective number degrees of freedom for a two-sided t-test is detailed for the referee below:

p-value (number of effective degrees of freedom) Nf / 1yrF r(PC1-WB, AMOC) r(PC1-EB, AMOC) r(PC1-EB,PC1-WB) BUOY 0.63/0.63 (10/10) 0.75/0.75 (7/7) 0.67/0.67 (9/9) CTRL 0.2/0.38 (103/26) 0.20/0.37(241/29) 0.25/0.48 (64/17)

4. Figure 1b. I would like to see the time series of WIND shown too, without that it is not clear how much variability there is in wind on longer timescales.

Response: We have added the AMOC timeseries for the WIND experiment in new Fig. 2, to compare variability at long timescales, filtered with 1year running mean. The

WIND experiments show variability with a peak in 5 years-period in comparison with BUOY and CTRL which has 10 years-period.

5. Figure 1a,b Was the same standardisation applied to each time series? Probably better not to standardise then it would be obvious to the reader what is being compared.

Response: Yes, the timeseries are standardised (for each experiment with respect to their own seasonal standard deviation), in order to compare the variability. Otherwise the comparison could be not fair due to, in part, the different model drifts in each experiment (Megann et al 2014). We have added panels to the Fig. S2 for this clarification. In Fig. S2a it can be appreciated that BUOY experiment has a strongly positive trend compared with CTRL and WIND. Fig. S2b shows the seasonal cycle of the interannual variability. The standard deviation (in Sv) for the 3 experiments is very different; In particularly there is a strong seasonal dependence for CTRL and WIND, but relatively little change through the year for the BUOY experiment. Therefore, we think it is better to compare the normalised anomalies.

6. Notation in the figures is sometimes inconsistent. E.g. “AMOCg” and “1PC” in Figure 1 , but “AMOC” and “PC1” elsewhere. Also abbreviations identifying filtered and unfiltered data vary.

Response: AMOC and PC1 are now consistently used through the manuscript, and in the figures. We also use Nf (for no filtered) and 1yrF (for 1year filtered).

7. Calculation of EOFs (l228) Figure 3c,d show EOFs calculated using data below 800m, so how are these extended up to the surface as seen in the Figures? Some more information is needed in the methods. And are these EOFs for annual or monthly data? 8. The EOFs presented in this paper are dimensional. This is useful, but they are not always calculated this way (sometimes they are normalised) so the text need to make clear what methodology is used here. And it is particularly important to show units on axes to avoid confusion! I presume the variance of the PCs is standardised?

Response: We have better clarified now in the methods Section how PCs are calculated (from line 172). PCs are calculated from monthly density data. The PCs for below 800m (PC-f800) are calculated using only the information from 800m downwards. The PC corresponds to standardised anomalies. However, the EOF pattern is represented as the regression of density anomalies onto the PC-f800. Therefore, the resulting EOFs can have a density signal shallower than 800m. Furthermore, EOFs have density units (density anomalies per 1 standard deviation of the PC).

9. The results of different truncations in Figure 4 suggest anomalies propagate at different speeds at different depths. This would imply that there is no direct correspondence between the EOFs and the modes of boundary waves. This should be discussed.

Response: Thank you for the comment. The correspondence of PCs and boundary wave modes is not direct.

The boundary EOFs are not stationary with time and latitude. Figure 4 shows that the teleconnection between density signals at WB and EB occurs very quickly at 800m-1100m (around 8 months as a fast response) however, at deeper levels for EB, the signal is delayed. There is a possible vertical propagation of the density anomaly at the WB from upper levels (400m) to 2700m.

Different lags in old Fig. 4 could be reflecting different propagation speeds along the equator (Hovmuller diagrams at different depths suggest that the phase speed changes at the equator, not shown here). Whereas the propagation along either the WB or the EB are reasonable to represent similar boundary waves, with coherent combined EOF vertical mode, albeit different modes on WB and EB.

10. Discussion of Figure 8 should highlight how low the variability is in run BUOY over this period.

Response: the AMOC in the BUOY experiment has a peak variability at 10 years (figure 1 in Polo et al., 2014). Similarly, the variability of the zonal density gradient also has a

very low frequency in the BUOY experiment (figure 2 in Polo et al 2014). Additionally, it is shown that EB density variability contains higher frequencies in comparison with WB density variability in BUOY (see new Fig. 3c, d).

Considering the short period analysed in Fig. 8 (2004-2009), the BUOY experiment shows a decrease and increase of AMOC at 26N (it is also seen in new Fig. 2 at the end of the period). This trends in AMOC are associated with density variability at WB (red line in new Fig. 3c). Therefore, we agree with the referee about the WB low-frequency density signals in BUOY experiment for long (1958-2009) and short (2004-2009) periods.

However, RAPID shows a decline from 2007 up to 2010, more similar to CTRL and WIND timeseries (new Fig. 9). As a conclusion, RAPID at 2004-2009 period is only representing wind-forced signal. We have tried to make it clear in Section 5 (from line 334).

11. To what extent does the length of the model run affect the results in Figure 9? The run is only about 60 year long so I suspect that for the longer time periods the reduction in the inter-quartile range is a reflection of the length of the model run, rather than the uncertainty of the correlation.

Response: The referee is right. As the period is longer with more years, we have fewer independent periods and therefore less variance in the sample distribution (i.e. the box-plot is smaller). However, the interpretation of old Fig. 9 is still valid. Motivated by old Fig. 8, we realized that for short periods, it was difficult to discriminate buoyancy-forced signals in CTRL (and RAPID). Old Fig. 9 extends this idea using samples of the total model period. Old Fig. 9 (new Fig. 10) suggests that for long periods the correspondence of PC1-WB CTRL and PC1-WB BUOY is straightforward (correlation is high and thus the WB density profile is mainly buoyancy-forced signal).

Other minor comments: l15 “a propagation speed leading to” is unnecessary

Response: We have removed that part in the sentence.

l16 Abstract - what does maxima refer to?

Response: The sentence has been changed to “The timing of the density anomalies appearing at the eastern and western boundaries at 26N reveals $\sim$2-3 years lags between boundaries at the deeper levels (2600-3000m)”. (line 15)

l67 Despite many model studies (insert ‘model’)

Response: We have inserted the word in the sentence.

Fig 9 “extension of the ” is not needed. Often the captions are not as well written as the text.

Response: We have rewritten the caption for figure 9 and also we have checked all the figure captions.

l261 More variance of what?

Response: We have rewritten the sentence to be clearer. The first EOF explains part of the density variance.

l459 What does “simultaneously” refer to?

Response: We have removed the word in the sentence.

l460 “It is worth notice that “ Also rephrase to making meaning clear “ : : : that, due to : : : , time filtering is : : :”

Response: The sentence has been rephrased as follows: “It is worth noticing that, due to noise from high frequency wind-forcing, time filtering is needed to see a clear signal in GC2.”

l470 “but it is not that obvious for the EB” not clear what this is referring to.

Response: The sentence has been rephrased as follows: “. . . but the propagation up

the EB is less clear.”.

l476 Which PC1 NEMO (Control, WIND or BUOY? and evaluated over what time period?

Response: “The temporal variability in RAPID WB density modes suggests that wind forcing is still dominating at these short timescales.”

l490 1st conclusion - expand what “characteristic signatures “ means.

Response: The first conclusion is that we have found density vertical profiles linked to AMOC. Then we explained the characteristics in the following conclusions.

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