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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.

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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 #2 Received and published: 23 April 2020 In manuscript "Can the boundary profiles at 26N be used to extract buoyancy-forced AMOC signals?", Polo et al. examined vertical profile of density in at 26N and its relation to AMOC and to the buoyancy forcing subpolar North Atlantic, in both forced and couple models. Their results suggest that depth structure and the lagged covariances between west and east boundaries at 26N may provide useful information for detecting density anomalies of high latitude origin in more complex model and observations, although time filtering and longer time series are required. The paper is well-organized and well-written over all, but I do have a couple of con-

cerns regarding the realism of the 1 degree model and how fast the density signal transferring from subpolar to subtropical North Atlantic and some clarification and/or discussion are needed.

Title: Spell out AMOC.

Response: The title has been changed.

Line 7: "The temporal variability of the Atlantic meridional overturning circulation (AMOC) is driven : : :"

Response: The sentence has been changed

L135: Given the central relevance to the topic, it is required to include a simple comparison of the T/S/density profiles between model and RAPID for, let's say, a five-year period 2005-2009, to see characteristically how similar/difference they are. And this should be in the paper, not in the supplementary, I understand that profile of density gradient is shown in supplementary, which is fine. Why focus on density gradient there?

Response: As the referee has suggested, we have added the new Fig. 1, which shows the comparison of the temperature, salinity and density profiles at the boundaries between RAPID and CTRL experiments for the period 2005-2009. The figure is commented in the manuscript (from line 138).

Vertical density gradients could be important for the boundary waves phase speed, so we will maintain Fig. S1, which also shows the standard deviation of the density profiles.

L149: Here I think the modeled standard deviation for monthly mean AMOC need to be listed too for comparison with the RAPID value (4.4 Sv).

Response: The standard deviation, after removing the linear trend, using the monthly mean timeseries for NEMO1 is 2.28 and 1.92 Sv for CTRL and BUOY respectively. RAPID reaches double this level (4.4 Sv). This information is now added (from line

153). Additionally, the seasonality of the standard deviation is shown in Fig. S2.

L215: Should Fig. 1a be Fig. 1c?

Response: The reference to Fig. 1a was right. The correlation scores in old Fig. 2c are the correlations between timeseries in old Fig. 2c and timeseries in old Fig. 1a.

L299: The speeds in the forced models are consistent with the lag found between boundaries, but more importantly, are these speeds realistic? It needs some discussions regarding how fast the density signal transfers. A speed of 0.3-0.4 m/s seems really fast to me (until I saw 2m/s later in GC2 experiment), what does this speed represent? Do we have observational/theoretical supports?

Response: There are works showing the density propagation along western boundary (at deeper levels) from variations of the AMOC (i.e. Kohl, 2005; Hodson and Sutton, 2012; Zhang, 2010). Hodson and Sutton (2012), although they show spatial patterns of the adjustment, they do not specifically give a phase speed of boundary propagation. However, they showed how the speed of the adjustment is sensitive to model resolution, they found that higher resolution model represents better the propagations at tropical latitudes. Zhang (2010) found different regimes along the latitudinal wave path. From 34N to the equator, she found a propagation coherent with Kelvin wave phase speed.

Johnson and Marshall (2002) have theorised the surface response to an AMOC change through the wave propagation. Other studies have found Kelvin wave propagation from observations and models in the equatorial Atlantic. From linear theory, Atlantic equatorial Kelvin wave speed for first, second and third baroclinic modes are around 2.5, 1.3 and 0.8 m/s respectively (Katz, 1997; França et al., 2003; Illig et al., 2004; Polo et al., 2008). In particular, from sea surface height, Polo et al., (2008) found Kelvin-like waves along the equatorial Atlantic and poleward along the African coast traveling at 1.6m/s, as mixed first and second baroclinic modes. We had reviewed the adjustment of the AMOC on different model simulation in the introduction section 1, and now we

have added more in section 4 (from line 390).

The subpolar density exhibits a significant variability in the last several decades, why we do not see similar variability in the south.

Response: Density over the subpolar gyre is highly variable in comparison with lower latitudes. We assume that part of the energy is lost as it travels southward. The Labrador Sea is a major source of density variations on the western boundary at depth in many models (Hodson and Sutton, 2012, Polo et al 2014). The propagation in figure hovmuller is quasi-non-dispersive until the equator (around track point 100).

L314 and later in this section: 2004-2010 should be 2004-2009

Response: it is now corrected.

L325: It seems to me an overstatement that the model and observations are very similar here. Not only the PC differ significantly for the first half of the time series, but also the model EOF pattern exhibit much lower magnitude. Also, is the length of the record the only key factor that leads to the difference between BUOY and CTRL (and RAPID)? Although Figure 1b with longer record does show a significant correlation between CTRL and BUOY (in AMOC), the similarity is mainly due to the decadal variability during 1970s-1990s, for which I am not sure if there is any observational support. The similarity/difference between the two experiments display significant time-dependence.

Response: In general, variability in the observations is greater than in the model (see previous comparison of AMOC standard deviations). This is also true in density profiles (see Fig. 1 and Fig. S1 RAPID has more variance at both boundaries at nearly all levels. This is especially important for NEMO1, the low-resolution model does not resolve part of the density variability.

Decadal variability in the AMOC is also supported by the reanalysis products (Wang et al 2010). The similarity of CTRL and BUOY operates at lower frequencies (decadal) not at interannual, which is dominated by the wind (see also Polo et al 2014). This is also true for the comparison we made with RAPID, with only a short record we cannot extract buoyancy-forced signal from the CTRL experiment (new Fig. 9). We have made an effort to explain better this part in the manuscript (from line 332).

L372: The phase speed in GC2 is faster than in the forced simulations by a factor of 5-7 and clearly need some explanations. How robust are the model results, especially, to different model resolution?

Response: There are factors that potentially can influence propagation (and hence the phase speed) of boundary waves in numerical models. i) Model resolution; the along-shore phase speed of a Kelvin wave falls rapidly as grid spacing increases beyond the Rossby radius (Hsieh et al (1983)). Using 2 coupled models, with Arakawa-B grid, Hodson and Sutton (2012) showed that the MOC adjustment proceeds more rapidly in the higher resolution model due the increased speed of western boundary waves. Although in our study, NEMO1 model uses an Arakawa-C grid, it is expected to show difference in higher resolutions versions. ii) Lateral viscosity; increased values of viscosity reduce the along-shore phase speed of coastal Kelvin waves (Davey et al., 1983)). iii) Orientation of the coastal boundary relative to the ocean grid: the along-shore Kelvin wave speed falls as the angle of the coastline to the underlying grid increases (Schwab and Beletsky, 1998). iv) ocean stratification along the path wave.

Additionally, in our study, GC2 is a more complex model since it is a coupled model in comparison with ocean-only NEMO1, which potentially influence the propagation. Hodson and Sutton (2012) found in coupled model evidence of extratropical atmosphere response and a weak negative feedback on deep density anomalies in the Labrador Sea. We think that both, resolution and complexity are explaining the differences in the phase speed along boundaries shown in the hovmuller plots (new Figures 7 and 11). However, specific sensitive experiments should be designed and performed in order to properly understand these factors. This is now discussed more in section 7 (from line 480).

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