Interactive comment on:

"Modulation of the North Atlantic Deoxygenation by The Slowdown of the Nutrient Stream"

by F. Tagklis, T. Ito, A. Bracco

*Texts in black are the original comments by the reviewers, which is followed by our responses in blue coloured text.

Anonymous Referee #2:

The study presents an analysis of phosphate, dissolved oxygen, temperature, apparent oxygen and velocity changes in the upper ocean for the northern hemisphere from 4 different CMIP5 Earth system model projections. A plausible narrative is presented as to how changes in the dissolved oxygen in the northern basins are controlled in terms of overturning and temperature changes. There is a clear asymmetry between the North Atlantic and North Pacific with a weakening of the meridional overturning in the former basin. Taking that view forward, the narrative is engaging in terms of discussing the likely changes in terms of a weakening of the western boundary currents and the associated nutrient stream. However, the study is lacking in providing supporting quantitative analysis to endorse the above interpretations as to how the dissolved oxygen and nutrient distributions are controlled. There are no estimates of the nitrate flux carried by the western boundary currents and no estimates of nitrate transports along sections running across the basin. There is no real proof that either the nutrient transport change or the temperature changes are controlling the dissolved oxygen changes. Thus, a very plausible set of interpretations are presented that need to be made more quantitative and so become more robust and convincing.

I recommend that the authors address the following points:

1. What is the northward transport of nutrients in the nutrient stream and by how much has that weakened?

2. The nutrient stream is providing a redistribution of nutrients, but it is unclear whether the changes in this redistribution is confined within the subtropical gyre/subpolar gyre of the North Atlantic?

3. Alternatively, the changes in the overturning drives a weakening in the change in nutrient transport across the equator from the South to the North Atlantic.

For points 2 & 3, see Palter and Lozier (2008) supporting a more confined basin view and Sarmiento et al. (2004) and Williams et al. (2006) supporting a cross basin view. Both processes could be occurring to different extents.

While I agree with the view that the horizontal transport and redistribution of nutrients is probably key to the response, there needs to be mention of the implied changes in the vertical transfer of nutrients and oxygen within the basins.

A minor point, there are a lot of abbreviations that could be removed to make the text more readable.

In summary, the manuscript presents an engaging view of how the nutrients and dissolved oxygen distributions are controlled in the Earth system model projections. However, the authors need to provide more quantitative evidence to support their interpretations, rather than rely on changes in property maps.

We appreciate reviewer's comments. We have tried to address and clarify the suggested points as indicated below. In doing so, we had to consider key limitations in the variables that are available in the CMIP5 catalogue and the frequency at which they were saved.

Regarding points 1, 2, and 3:

We discuss in the introduction of the manuscript the role of the nutrient streams in biogeochemical cycling and their contribution towards maintaining basin scale productivity at the mid- and high-latitudes over interannual and longer timescales (Letscher et al., 2016; Palter and Lozier, 2008; Palter et al., 2005; Williams and Follows, 1998; Williams et al., 2011; Williams et al., 2006).

Focusing only on centennial-scale changes, we observed a common pattern among the models suggesting a plausible mechanism of the ocean resisting to the deoxygenation as a result of changes in the large-scale ocean circulation. As indicated by the reviewer, the study is lacking a more quantitative analysis of the fluxes and advective transport. The calculation of advective fluxes and budget analysis require monthly model output. Unfortunately, nutrient and oxygen data are typically saved at such frequency only at the surface in the CMIP5 catalogue and as annual averages at all other depths. So it is impossible to perform these analyses realiably for this manuscript. We added a sentence in this regard in the Conclusions of the paper.

Attempting to address the reviewer's comment on the nutrient transport changes, we looked for an additional quantitative analyses in our assessment. In figure S1 we constructed an index of phosphate concentration in the upper 0-700m in a box area covering the extent of the western boundary currents. We then calculated the correlation coefficient of such index with the apparent oxygen utilization, also averaged over the 0-700m layer. The boxes used to construct the indices are different for the two basins but the same among the models. The time series extend over the historical period 1870-2005. The correlation map provides supportive evidence of the linearly correlated behavior between the western boundary currents, phosphate (nutrients) and AOU concentrations.

**Further supporting evidence is provided in figure S3 where we present the regression coefficients of the current speed for the period (1870-2005) onto the upper ocean (0-700m) phosphate index defined in the box indicated in each basin (box PO4). The phosphate index lags 2-years the current speed timeseries.

To prove the role of temperature on oxygen changes we could provide the centennial changes of the O2 saturation which is inversely proportional to the temperature changes, but we decided to exclude this figure as repetitive. Indeed it does not provide more information than the ΔT maps as shown below in Figures S5,S6.

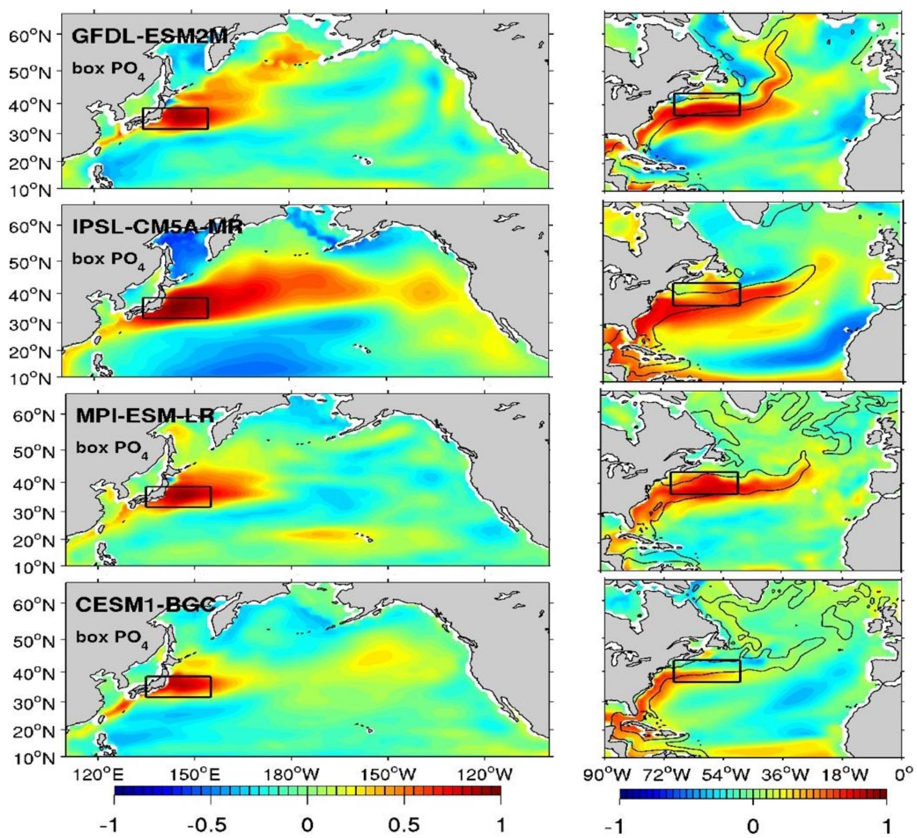

Figure S1: Regression coefficients of the apparent oxygen utilization (AOU), for the period (1870-2005) esmHistorical annual mean output onto the upper ocean (0-700m) phosphate index defined in the box indicated in each basin (box PO4). The contour represents 0-700 meters and 1987-2005 averaged current speed greater than 0.05 m/s and reflects the Western Boundary and North Atlantic Current pathway.

Atlantic Ocean Box: Lon: [69 49] West, Lat: [36.5 43.5] North

Pacific Ocean Box: Lon: [135 155] East, Lat: [31.5 38.5] North

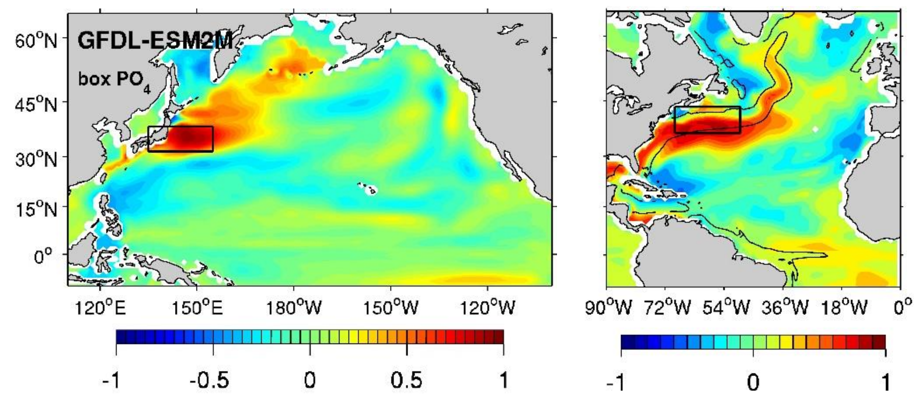

Figure S3: (As in figure S1)Regression coefficients of the apparent oxygen utilization (AOU), for the period (1870-2005) esmHistorical annual mean output onto the upper ocean (0-700m) phosphate index defined in the box indicated in each basin (box PO4). The contour represents 0-700 meters and 1987-2005 averaged current speed greater than 0.05 m/s and reflects the Western Boundary and North Atlantic Current pathway.

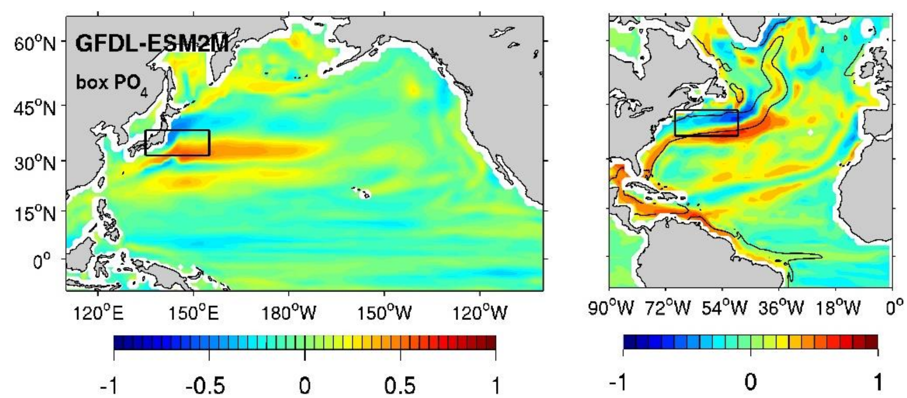

Figure S4: Regression coefficients of the current speed for the period (1870-2005) esmHistorical annual mean output onto the upper ocean (0-700m) phosphate index defined in the box indicated in each basin (box PO4). **The phosphate index lags 2-years the CS timeseries.** The contour represents 0-700 meters and 1987-2005 averaged current speed greater than 0.05 m/s and reflects the Western Boundary and North Atlantic Current pathway.

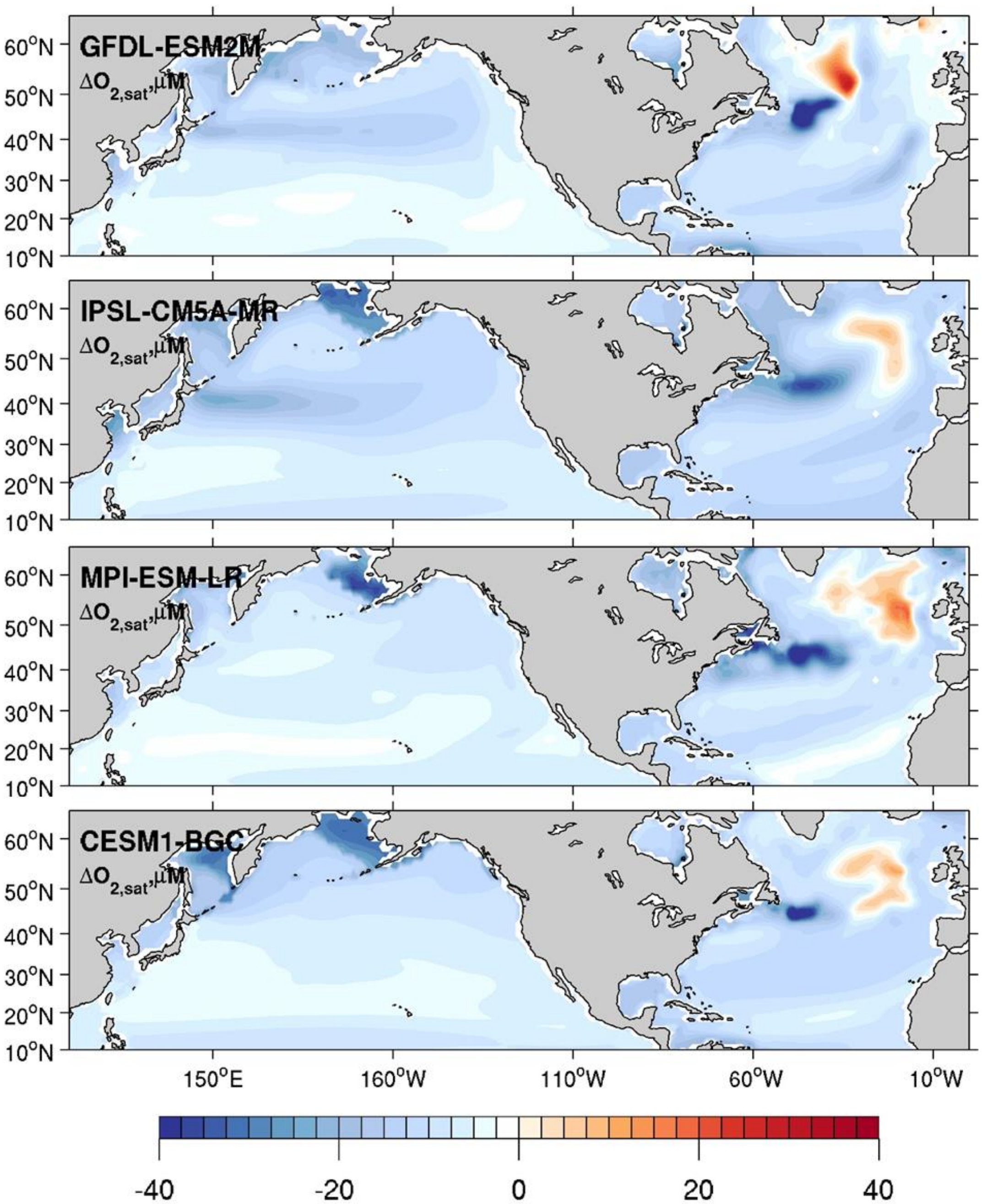

Figure S5: Centennial change of oxygen saturation calculated as the difference in 30-year averages between (2070-2100) and (1970-2000). All plotted values are 0-700 m depth averages.

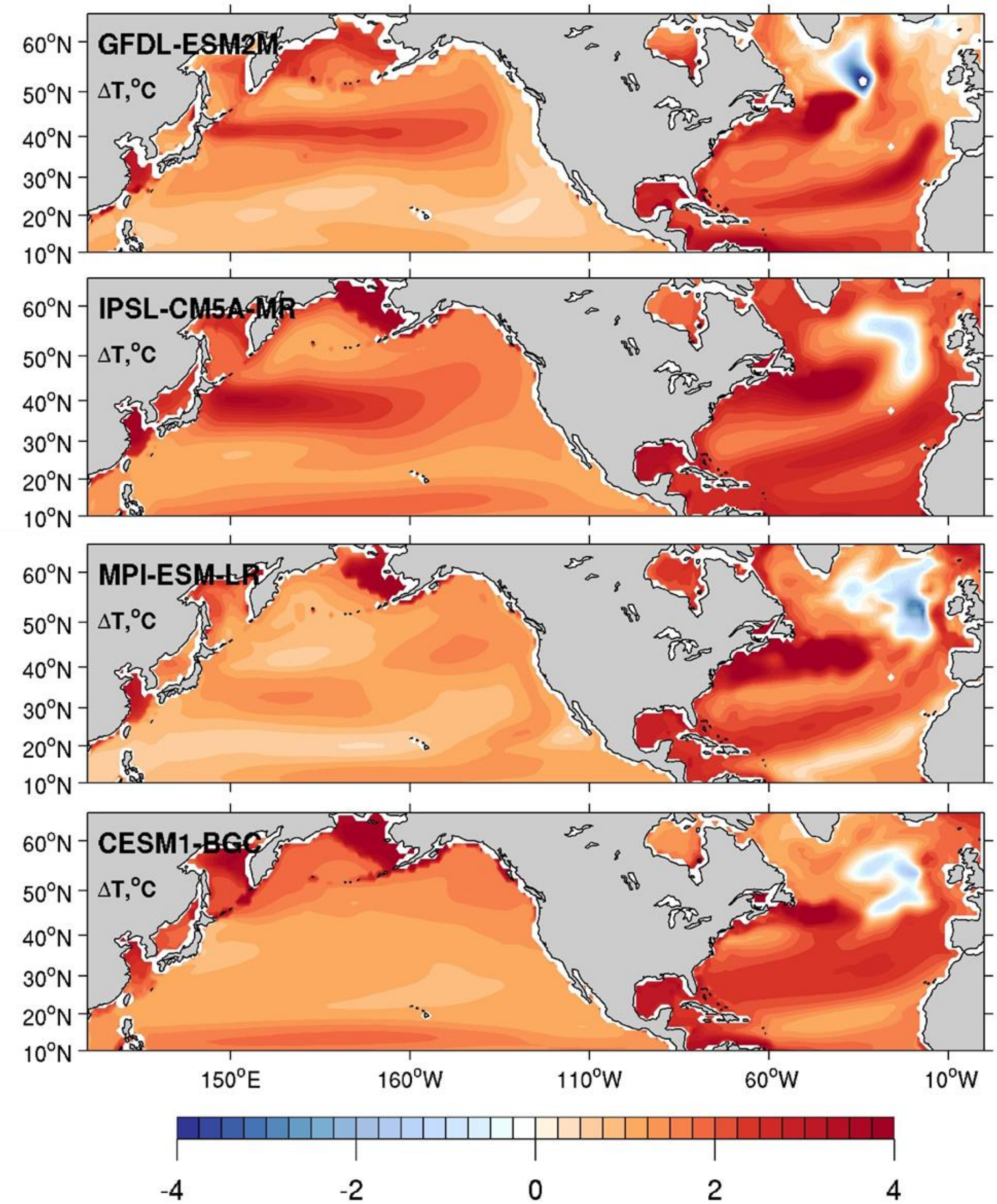

Figure S6: Centennial change of T calculated as the difference in 30-year averages between (2070-2100) and (1970-2000). All plotted values are 0-700 m depth averages.

References

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