We thank Reviewer #2 for their constructive comments. We have listed their comments in bold below and our responses in normal formatting.

Reviewer #2

My main concern is that the results are likely tied to the circulation model applied. As shown by Duteil et al. (2013; Biogeosciences, 10, 7723–7738, doi:10.5194/bg-10-7723-2013) the transport matrices from the MITgcm seem to suffer from far too large outcrop areas of dense waters in the Southern Ocean (their Fig. 2), indicating that the model circulation does not represent the real ocean in that region very well. Also, because of the very coarse resolution, this model might not represent the physical dynamics in the eastern equatorial Pacific very well. However, in the present study these two regions - the subantarctic regions and equatorial upwelling - have a large influence on CO2 (Fig. 3 and 5). Thus, whereas this study provides important and interesting information for other global model studies that apply similar circulations (as noted in Discussion and Conclusions), I think that a few sentences on this are necessary to caution readers not familiar with the advantages and disadvantages of global circulation models. (To illustrate or investigate this point further, one could, e.g., look at the density distribution or mixed layer depths of the model.)

We have added a plot of density outcrops from the annual mean model output and World Ocean Atlas 13 climatological observations (see Figure 1), a comparison of the volume of water ventilated from each region in the model with the data-constrained estimates from Khatiwala *et al.,* (2012) (Table 1), and a plot of ideal mean age (Figure 2) to the Supplementary Material to demonstrate this caveat.

As the reviewer highlights, the modelled Subantarctic regions are a larger source of water for the ocean interior than observed (Figure 1, Table 1). Additionally, the equatorial regions contribute a much smaller volumetric fraction than observed (Table 1). An alternative approach could be to use the data-constrained ECCO circulation but this comes with a much higher computational cost due to higher resolution and higher number of non-zeros in the sparse matrices, limiting the feasibility of the sensitivity analysis. The MITgcm circulation, as noted by the reviewer, has been widely applied. Therefore, we have kept the MITgcm circulation and have added a substantial discussion in the manuscript referring to the new supplementary figures that discusses the circulation as a caveat to the findings:

"Our results are dependent on the use of transport matrices derived from one global circulation model. Whilst this model has been widely applied to study biogeochemistry previously, it is subject to a number of caveats. The ocean model predicts significantly larger outcrops of dense water in the Southern Ocean compared to observations (see Figure S4; Duteil et al., 2013) leading to deep-water formation occurring at latitudes around 50S (Figure S5). The volumetric fraction of water in the ocean interior derived from the Subantarctic is also higher (26%) compared with data-constrained estimates (18%: Khatiwala et al., 2012). As such, the sensitivity estimates for the Subantarctic may be over-estimated. This is also consistent with the higher sensitivity compared to the basin-scale analysis of Kwon et al., (2009) who found that the Southern Ocean (>40S contributed 22% of the global CO_2 sensitivity, compared with 36% in this study (>38S, Table 1). However, our results have key similarities, including absolute and relative magnitudes of regional preformed PO_4 export, to other studies using alternative steady-state circulation states (DeVries et al, 2012; Pasquier and Holzer 2016). As such, our results should be broadly reproducible with other models."

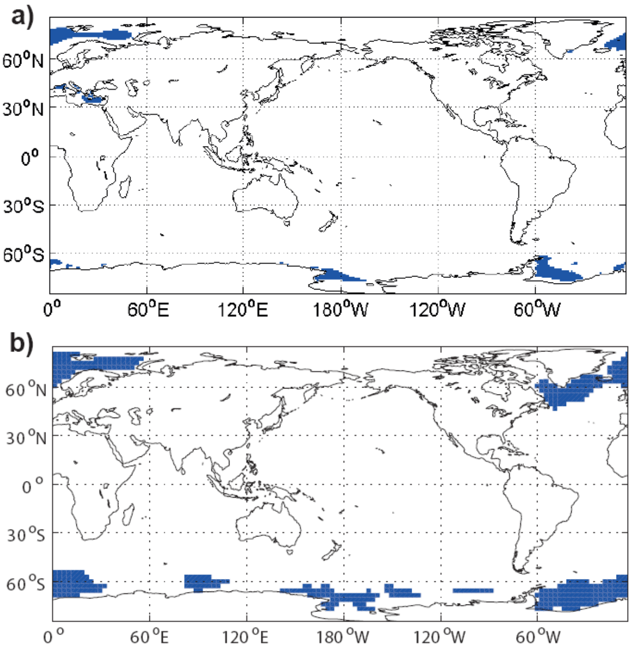

Figure 1: Regions where density is greater than 1027.5 kg m^{-3} calculated using the Gibbs SeaWater toolbox (McDougall & Barker 2011) with annual-mean temperature and salinity from (a) World Ocean Atlas 18 and (b) MITgcm output.

Figure 2. Meridional cross section of ideal age in the Pacific (224°W).

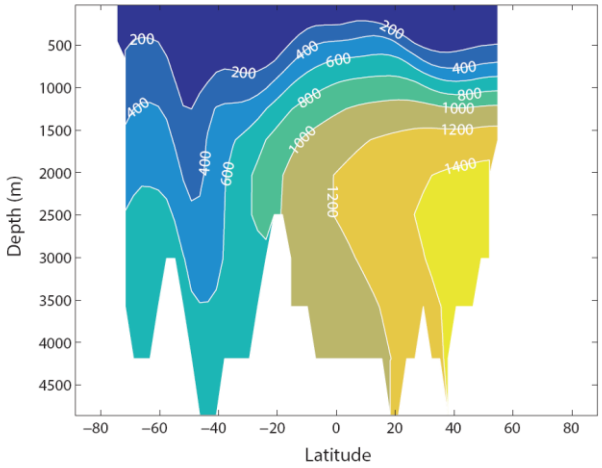

Table 1. Global ocean volumetric fraction (%) for different source regions from a data-constrained estimate (Khatiwala *et al.,* 2012) and from this study.

Region	**Khatiwala2012 (%)**	**This Study (%)**
Antarctic	39	28.7
Subantarctic	18	26.1
North Atlantic	26	35
Tropical	4.5	0.86
Subtropics	8.1	4.5
NPacific	4	4.5

There seems to be a strong sensitivity of CO2 to changes in b in the constant-export scheme (Fig 3), and also a clear relationship to export (Fig 4a). In contrast, normalized (by what?) preformed phosphate seems to be more sensitive in the nutrient restoring scenario (Fig 5 vs Fig S3), and no relationship seems to exist between CO2 sensitivity and export (Fig 4b). I think these contrasting patterns for both model types deserve a bit more discussion. Perhaps some section plots of, e.g., density across the Pacific and Atlantic (see above) could aid the disussion about the effects of circulation vs. export type ("biogeochemistry"). If the circulation model is anywhere near the real world, some insight regarding the "connectivity" of different regions might perhaps be gained from the data-constrained analysis of water fractions presented by Khatiwala et al. (2012; Earth and Planetary Science Letters, 325–326, 116–125)

In response to this and other reviewer comments, we have replotted Figure 5 in a format which is hopefully more accessible, and that allows for the inclusion of panels for both the fixed and restoring export ensembles (see Figure 3 here). The new plot highlights that the sensitivity estimates are broadly similar across both the nutrient-restoring and constant-export schemes but that preformed PO_4 appears more sensitive to local changes in b (boxes on the diagonal) in the nutrient-restoring scheme. We have added text in the Results to note this difference. We have also included the following equation in the manuscript text to describe the normalisation:

$$\overline{P_{pre}^{region}} = \frac{\overline{P_{pre}^{region}} - \min(\overline{P_{pre}^{region}})}{\max\left(\overline{P_{pre}^{region}}\right) - \min(\overline{P_{pre}^{region}})}$$

We have addressed the comments on circulation in the response to the previous comment.

In terms of the relationship between sensitivity and export production, the distribution of regions within the nutrient-restoring panel is very similar to the constant-export panel despite a much weaker relationship. We have added text to the Results to demonstrate the weaker relationship between export production and sensitivity for the nutrient-restoring scheme:

"Similarly, we find a general positive correlation between sensitivity and regional export production ($r=0.79$, $p<0.01$ for constant export, $r=0.47$, $p=0.07$ for restoring uptake), as measured by the mean annual average export production across the 200 ensemble runs (Fig 4). The correlation is much weaker with nutrient restoring uptake compared to the constant-export production."

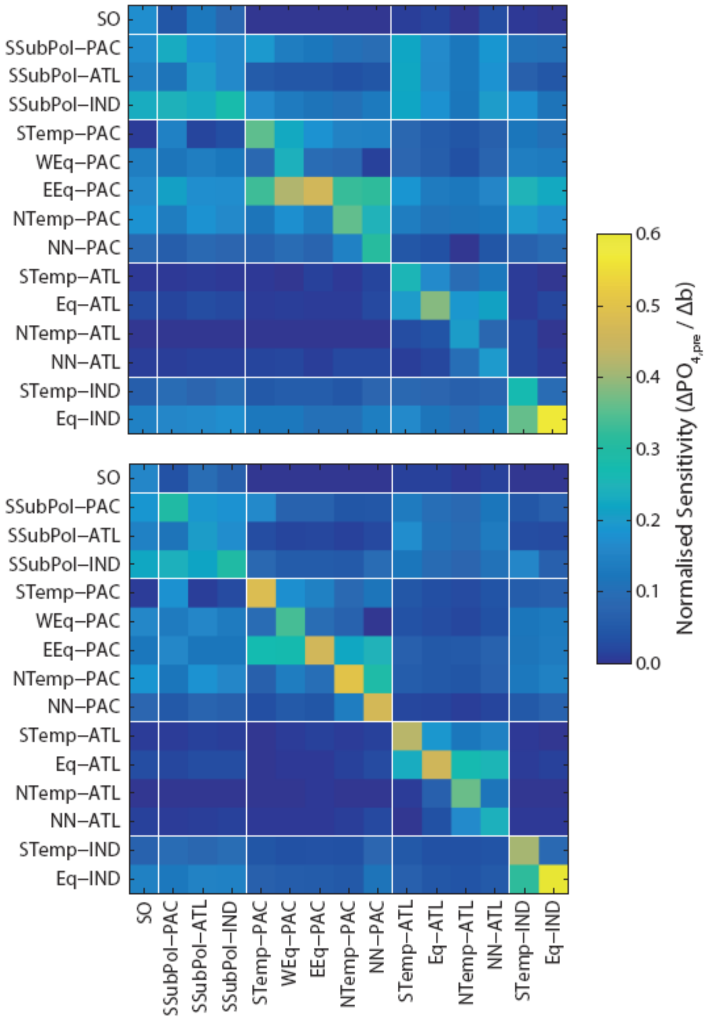

Figure 3. Sensitivity of steady-state normalised mean preformed $[PO_4]$ exported from each region. The preformed $[PO_4]$ from each region is expressed as a function of b using linear regression. Preformed $[PO_4]$ is normalised to the range of values from each region within the ensemble to account for large differences in preformed $[PO_4]$ between regions. The regression coefficients are arranged such that each row shows the impact of changing b in that region on preformed $[PO_4]$ across other regions. Results from the constant-export and nutrient-restoring schemes are shown in the top and bottom panels respectively.

p 3, line 15: "MITgcm" sounds like technical slang to me - is there a better word for it?

The text has been changed to: "*MIT general ocean circulation model (MITgcm)*"

Section 2.3: At first, I had difficulties understanding the experimental design; I would suggest to indicate more clearly that the "reference" experiments were carried out over a discrete set of

globally uniform "b" values (how many?), and to distinguish this more clearly from the LHS experiments for the regional variation

We have updated the text with headings to separate the description of the control run, global and regional sensitivity runs. We have also clarified the number of globally uniform b values tested.

Eqn. 2 and Table 1: The connection between beta_0 and beta_k of Eqn 2 and Table 1 is not clear to me: are beta in the table beta_k of equation 2? Is beta_0 constant?

We have added the subscripts to the betas in Table 1 and have added a reference to eqn. 2 in the Table caption.

p 5, line 11: "we fit linear regression models" - I suggest to refer here again to Eqn 2.

Done.

p 5, line 28-29: "However, the relative sensitivity ranked across regions remains similar, as shown by expressing b_k as a percentage (Table 1)." - relative to what?

This has been reworded to "…as shown by expressing each β_k as a percentage of $\sum_k \beta_k$ (Table 1)."

Table 1: Please explain clearly what is shown in this Table: are beta the beta_k of Eqn 2? What does beta(%) mean - normalised by area? Are the two rightmost columns for the constant export experiments?

We have added the subscripts to the betas in Table 1 and have added a reference to eqn. 2 in the Table caption. We have also added annotation and text to the caption to explicitly state that the beta(%) is relative to the sum of the regression coefficients.

p 6 line 4 "positive"

Fixed.

p 6 second paragraph: is there a difference between "export production" and "export productivity"?

Fixed. Export production is now used throughout.

p 6, line 20 "is normalised" - by what?

The text has been updated to explicitly describe the normalising (see also equation above)

p 7 line 3: "sensitivity"

Fixed.

p 11, line 5: "κ"

Fixed.

p 11, line 20: "function"

Fixed.

p 19, caption: "relects"?

Fixed to "reflects".