

Interactive comment on “Changes in ocean circulation and carbon storage are decoupled from air-sea CO₂ fluxes” by I. Marinov and A. Gnanadesikan

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We thank the reviewers for their encouragement of this work and for their constructive suggestions. Our response is given below.

Reviewer 1 makes four major points:

I.1: Results section is confused and two of the paragraphs don't make a point that contributes to the overall thrust of the paper.

We appreciate the reviewer's confusion and have reorganized the results section to increase the parallelism between the way in which the changes in storage and the

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changes in fluxes are presented. The argument is now set forth as follows.

1. Solubility carbon storage depends on temperature, which decreases in the deep ocean below 2500m and increases above 2500m as the vertical diffusion increases (Fig. 3a)
2. Biological carbon storage is inversely related to the preformed nutrient pool. Increasing the vertical diffusion coefficient increases the preformed nutrient pool and decreases the remineralized nutrient pool by increasing the influence of Antarctic Bottom Water (Fig. 3b).
3. The net impact of vertical diffusion on ocean carbon storage is thus to decrease both the ocean carbon storage associated with the solubility pump (Fig. 3c) and with the biological pump (Fig. 3d).
4. The solubility air-sea CO₂ flux depends on the conversion of warm water to cold water (resulting in ingassing) at high latitudes and the counterbalancing conversion of cold water to warm water (resulting in outgassing) at low latitudes. It therefore scales as the poleward water mass transport times the associated low latitude - high latitude temperature gradient.
5. The biological air-sea CO₂ flux, by contrast, depends on the conversion of remineralized to preformed nutrient in low latitudes (resulting in outgassing) and the counterbalancing conversion of preformed to remineralized nutrient in low-latitudes (resulting in ingassing). It therefore scales as the poleward water mass transport times the low latitude - high latitude gradient in remineralized nutrients (times a Redfield ratio).
6. In the present-day ocean the solubility and biological fluxes work in opposite directions throughout most of the ocean. The solubility flux is bigger and dominates in low latitudes, and the two fluxes are similar in magnitude in high latitudes.
7. Increasing vertical mixing increases the residual mean circulation (Tres in Fig. 2), transporting both more remineralized nutrients and warmer waters poleward. The re-

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sult is that the (significant) increase in poleward transport of biological DIC compensates the increase in equatorward transport of abiotic DIC.

8. Changes in vertical mixing drive significant changes in the individual abiotic and biological CO₂ fluxes. However, the compensation mechanism described above means that the change in the total (abiotic+biological) CO₂ flux is small (this is the point of the paragraph on heat balance- we have now added language that makes this clearer).

9. Changing the lateral mixing coefficient has a smaller impact on fluxes and transports of carbon.

10. The biggest changes are in the Southern Ocean.

As suggested we have deleted the paragraph starting "Because biological and abiotic fluxes..."

I.2: What are the starred lines in Fig. 1D?

The biological pump gradient is due to soft-tissue and carbonate components and is enhanced by the presence of surface CO₂ disequilibrium. (see I.4 below). The starred lines refer only to the soft-tissue (equilibrium, fast gas exchange) component which are associated with nutrients. We have added a sentence to this effect to the first paragraph of the Results and Discussion section.

I.3: Numerous typos

We appreciate the reviewers' willingness to look beyond this and to support the publication of this work. We will try to do better in the final copy.

I.4. Whether the results are significantly changed by gas exchange.

We now reference the Toggweiler et al. (2003a,b) results at two points during the paper. As discussed in these two papers, the impact of CO₂ disequilibrium (i.e., the presence of slow gas exchange) is to make the solubility pump less efficient at storing carbon and the biological pump more efficient, compared to a case in which surface

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gas exchange is infinitely fast.

The magnitude of the impact is relatively small, as can be seen from the difference between the zero lines in Fig 3a and 3c: a more convectively ventilated ocean tends to have slightly less carbon (a weaker solubility pump) than would be expected from the temperature change alone (temperature changes alone give an indication of the strength of the "potential" or "infinitely fast gas exchange" solubility pump).

Similarly, the response of the biological pumps and fluxes to changes in mixing is similar whether the runs have fast gas exchange or slow gas exchange (as described also in Marinov et al. 2008b). This can be seen from the fact that the "fast gas exchange" soft-tissue pump intermodel differences (Fig. 1d starred lines) largely explain the slow gas exchange biological pump intermodel differences (Fig. 1d solid lines).

Thus, while the absolute strengths of the biological and solubility pumps (and of biological and solubility CO₂ fluxes) change slightly with faster gas exchange, the main mechanisms presented in this paper (the described sensitivities to changes in mixing and the decoupling between such changes in mixing and the total CO₂ flux) will still hold with faster gas exchange.

I.5. Wording changes. Other changes.

"are likely a main driver of " has been changed to the more neutral "have been invoked to drive" which we feel is stronger than the rather weak "may play a role in". We don't want to reargue the iron fertilization vs. circulation debate here, but we want to highlight the idea that other investigators do feel that circulation is important.

Other wording changes have been implemented as requested.

We have added 2 missing references.

Finally, we have added for clarity a new Figure (Figure 4) showing the zonally averaged heat flux and heat transport (plotted against latitude). Heat fluxes and heat transport help us understand better the abiotic air-sea CO₂ flux. As mentioned now in the text,

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“The abiotic air-sea CO₂ flux follows to first order the inverse of the heat flux (Keeling et al. 1993), and the abiotic northward transport of carbon follows the inverse of the northward heat transport, as illustrated in Figure 4.”

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