

## ***Interactive comment on “Biology and air–sea gas exchange controls on the distribution of carbon isotope ratios ( $\delta^{13}\text{C}$ ) in the ocean” by A. Schmittner et al.***

**Anonymous Referee #2**

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The paper discusses the results of a model simulation of the  $\delta^{13}\text{C}$  of dissolved inorganic carbon (DIC) in the ocean. The authors separate the impacts of the biological pump and air-sea gas exchange on the spatial distribution of  $\delta^{13}\text{C}$  by running several model simulations with a range of conditions. They compare the model simulations with  $\delta^{13}\text{C}$  observations.

**Positives-** This model analysis of  $\delta^{13}\text{C}$  is one of the most thorough to date. The authors perform a range of model sensitivity experiments to isolate impacts of the biological pump and gas exchange. They come to some important conclusions. First, that the biological pump exerts dominate control versus gas exchange on the ocean distribution of  $\delta^{13}\text{C}$ . Second, that the non-uniform ocean  $\delta^{13}\text{C}$  decrease resulting from anthropogenic  $\text{CO}_2$  uptake has reduced both surface and depth gradients in  $\delta^{13}\text{C}$  compared to pre-industrial times. Third, the model simulations yield  $\delta^{13}\text{C}$  values that are reasonably close to observations in the surface ocean (after accounting for anthropogenic change) and deep sea which one could interpret as the model having about the right balance between biological pump, gas exchange and circulation characteristics of the ocean. Of particular note, is the discussion of the importance of preformed  $\delta^{13}\text{C}$  (and nutrients, etc.) on the observed spatial variability of  $\delta^{13}\text{C}$  in the ocean, which generally is under appreciated. The results of this study improve our understanding of the factors controlling  $\delta^{13}\text{C}$  distribution in the ocean and thus should improve the use of  $\delta^{13}\text{C}$  as a tracer of the ocean's carbon cycle both in the modern and paleo ocean.

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**Negatives-** Like any modeling based analysis, the results depend on the model formulation. In this case the accuracy of the model's  $\delta^{13}\text{C}$  output depends on the accuracy of the model's ecosystem, gas exchange parameterization and circulation/mixing scheme. The latter factor is not discussed in the paper despite its impact being significant. For example, the impact of gas exchange on surface  $\delta^{13}\text{C}$  depends not only on the gas exchange rate but also the residence time of water in the surface ocean, which in turn depends on the strength of the Ekman and geostrophic transports, upwelling/downwelling rates, mixed layer depth, eddy mixing, etc. Likewise in the deep sea, the  $\delta^{13}\text{C}$  depends not only on in-situ respiration but on deep sea ventilation rates and the relative strength of northern and southern deep water end members (and their preformed  $\delta^{13}\text{C}$ ) which depends on the strength, for example, of the meridional overturning circulation. Unfortunately, one can't easily determine the sensitivity of the model output to changes in circulation strength as one can to changes in the gas exchange rate or biological pump. Furthermore, the model dependence of the  $\delta^{13}\text{C}$  output makes it difficult to determine which  $\delta^{13}\text{C}$  trends are more robust than others and complicates comparisons other model simulations of  $\delta^{13}\text{C}$ .

One of the major conclusions is that the equilibrium effects of air-sea gas exchange “generates meridional ( $\delta^{13}\text{C}$ ) gradients opposing those of biology” (8431) and “the

effect of air-sea gas exchange is to reduce the biologically-imposed  $\delta^{13}\text{C}$  gradients" (8442). This conclusion that gas exchange exerts an effect on  $\delta^{13}\text{C}$  opposite to the biological pump is in part a result of their approach which compares the  $\delta^{13}\text{C}$  output of two model experiments, one with no biology to one with no gas exchange (Fig. 4). However, one could take a different approach and compare the impacts of air-sea gas exchange and the biological pump on the  $\delta^{13}\text{C}$  in the surface ocean currently observed (with the anthropogenic effect) or (estimated) for a pre-industrial ocean. In this case one finds that in the tropical/subtropical surface ocean the observed  $\delta^{13}\text{C}$  is higher than that predicted at equilibrium with the atmospheric  $\delta^{13}\text{C}$  and so the impact of gas exchange (depleting  $\delta^{13}\text{C}$ ) opposes the impact of the biological pump (enriching  $\delta^{13}\text{C}$ ). However, in the subarctic ocean the observed  $\delta^{13}\text{C}$  is lower than that expected at equilibrium with the atmosphere and thus in this region both gas exchange and the biological pump are enriching the  $\delta^{13}\text{C}$ . This approach yields a significantly different take on the roles of gas exchange and biological pump impacting  $\delta^{13}\text{C}$  in the surface ocean with these processes working together in some regions and opposing each other in other regions. It would be worth having the authors discuss this alternate look at the interplay between gas exchange and biological pump in the paper.

I would have liked to see some property-property plots to compare observations and model output. For example,  $\delta^{13}\text{C}$  vs DIC or  $\delta^{13}\text{C}$  vs  $\text{PO}_4$  trends in the surface ocean and deep sea. Are model slopes and scatter similar to observations? How sensitive are the slopes to model parameters (gas exchange rates, biological pump, etc.)? Can these relationships be used to evaluate model performance?

Overall- I like the paper. The authors present a systematic model-based evaluation of the impact of the biological pump and gas exchange on spatial distributions of  $\delta^{13}\text{C}$  in the ocean. Given the increase in  $\delta^{13}\text{C}$  data from WOCE and CLIVAR programs this type of analysis is clearly needed. They conclude that the biological pump dominates the  $\delta^{13}\text{C}$  distribution in the ocean and that the  $\delta^{13}\text{C}$  changes resulting from anthropogenic  $\text{CO}_2$  uptake have significantly altered  $\delta^{13}\text{C}$  gradients from pre-industrial times.

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These are important points. The results are model dependent and thus it's difficult to evaluate the robustness of their conclusions until other models are used to simulate  $\delta^{13}\text{C}$ . In the meantime, the author's analysis has identified some important findings on processes controlling  $\delta^{13}\text{C}$  in the ocean which will help the community utilize  $\delta^{13}\text{C}$  as a tracer of the ocean's carbon cycle in the modern and paleo ocean.

I strongly recommend publishing the paper.

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