Biogeosciences Discuss., 4, S2114–S2119, 2007
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Biogeosciences Discussions

Interactive comment on "Variability in air-sea O_2 and CO_2 fluxes and its impact on atmospheric potential oxygen (APO) and the partitioning of land and ocean carbon sinks" *by* C. D. Nevison et al.

C. D. Nevison et al.

Received and published: 7 December 2007

Response to Referee #2:

1) We have tried to explain this better by rewriting the paragraph to read, Oxygen and carbon fluxes are also closely coupled during fossil fuel combustion, but with a slightly larger O2:CO2 molar ratio of ˜ 1.4. As a result, fossil fuel combustion exerts a small influence on APO, since it yields changes in oxygen and carbon that cancel out mostly but not completely in Equation 1.

2) Thank you for catching this typo. The correct Equation is: d(APO)/dt = beta*gamma

((abio-af)Ffuel - abio Focean) + Zeff (4)

3) We agree and have removed the sentence about predicting future levels of CO2.

4) We have rewritten this paragraph to simply list 3 reasons for the decoupling of oceanic O2 and CO2 fluxes: Early applications of the vector method assumed that the atmosphere-ocean system for O2 was still essentially in equilibrium and thus that the net annual mean air-sea flux of O2 was approximately zero [Keeling et al., 1993; 1996]. This assumption was closely related to the reasons for the decoupling of oceanic O2 and CO2 fluxes. First, O2 is far less soluble than CO2, with only 1% of the O2 in the ocean-atmosphere system partitioning into the ocean compared to 98% for CO2. Second, the buffering effect of carbonate chemistry in seawater increases the air-sea CO2 equilibration time scale by an order of magnitude relative to that of O2. Third, fossil fuel combustion and deforestation have raised atmospheric CO2 significantly, by ˜35% relative to preindustrial levels, thus providing the geochemical driving force for net global oceanic CO2 uptake. In contrast, these processes have reduced atmospheric O2/N2 by only ˜240 per meg, or less than 0.03% of the total O2 burden, since atmospheric monitoring of O2/N2 began in the late 1980s [MK06].

5) We have rewritten this section to read, First, the magnitude of FO2thermal was scaled down by a factor of 0.7 to account for incomplete thermal equilibration of O2. Second, the flux was delayed for half a month to account for non-instantaneous air-sea equilibration.

6) We have included Table 1, which summarizes the different O2, N2 and CO2 surface fluxes run in MATCH, along with the length of the simulations. Table 1 also lists which of these O2, N2 and CO2 tracers are used to calculate the different APO tracers presented in the results. Table 1 includes code letters and numbers which are assigned to each run and cited throughout the text and figure captions to clarify which run is being referred to. We have also added more introductory material in the text before presenting Figures 10-12 and put labels on the (now 4) panels in Figure 10 (see also

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our response to Reviewer 3), which should help to address the concern that the results section is dense.

7) The physics of the NCAR model have not changed substantially from the model of Doney and Hecht, 2002 (cited in the Naegler et al., 2007 APO paper) to the model used here. We believe that the change in the biogeochemistry algorithm, f rom OCMIP to process-based, is the much more important change that explains the improved agreement with the observed seasonal cycle in APO.

8) We have rewritten this paragraph and included the following definition: The concept of seasonal rectification was first defined in atmospheric CO2 studies [Denning et al., 1995], and involves a covariation between seasonal variability in transport and surface fluxes that can yield regional non-zero annual mean atmospheric tracer concentrations, even when the annual mean surface flux of the tracer is zero.

9) The results don t conform well to a combination set-up/summary table, because Figures 10-12 present different manipulations of the same runs with the WHOI model. In other words, there is not a specific result associated with each MATCH simulation. We hope that the additional text describing Figure 10 (see response to 6) will clarify this issue.

10) We have changed the gray scale from the RGB weightings [0.7 0.7 0.7] to a darker shade of gray [0.5 0.5 0.5]. This change affects figures 1,2,4,5,10,11, and 12.

11) and 12) We made these changes to the figure captions.

13) We have tried to clarify the Figure 6 caption by rewriting as: Interannual variability in WHOI/MATCH APO at the stations a) to l) defined in Figure 1. Model APO is calculated from monthly mean output using Equation 5. The seasonal cycle is removed with a 13-month weighted running average and interannual variability in per meg year-1 is calculated as the time derivative of the deseasonalized time series.

Response to Referee #3:

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To respond to some of Referee #3 s comments, we refer to our responses to Referee #2, who had a number of overlapping comments.

Section 1: see response 1) for Referee 2.

Section 2: see response 6) and 9) for Referee 2.

Section 3.1 a) We have given some examples of studies that neglected oceanic CO2 when computing APO: [e.g., GK01; Blaine, 2005]

Section 3.1 b) The discussion of reinforcing thermal and biology/circulation effects on O2 fluxes refers to somewhat different issues in the Introduction and in Section 3.1. We have tried to be more precise about this by including an example of reinforcing seasonal effects in the second paragraph of Section 3.1: In general thermal and biological O2 fluxes tend to reinforce each other over the seasonal cycle; e.g., in fall/winter, thermal ingassing occurs due to the increased solubility of cooling surface waters, while biological uptake occurs as deep waters depleted in O2 by biological decomposition are ventilated during the breakdown of the seasonal thermocline [Keeling et al., 1993]. This discussion comes up in the context of trying to explain why the WHOI model might reproduce the observed APO seasonal cycle better than the Garcia-Keeling climatology. The Introduction discussion refers more to long-term O2 outgassing from the ocean associated with climate change. The studies cited in the section have found that the ocean is losing more O2 than one would estimate based on solubility alone, suggesting reinforcing effects from biology and circulation. These reinforcing feedbacks are fairly complex, involving such things as increased ocean stratification and changes in surface nutrient utilization and carbon export, and generally beyond the scope of this study. We prefer to refer the reader to other papers that have explored this topic in depth rather than emphasizing it in the Introduction.

Section 3.1 c) We have rewritten as, MATCH runs with the annual mean O2 flux climatology capture the equatorial bulge relatively well (Figure 5c,f). There are no seasonal rectifier effects in the annual climatology runs, since the O2 fluxes are uniform through-

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out the year and thus do not covary with transport.

Section 3.3, figure 6: We have tried to explain why the observations aren t shown by rewriting as, Interannual variability in APO is a topic that observation-based studies have begun to address only recently. Based on what is known so far, interannual variability in WHOI/MATCH APO appears to have the same amplitude range (ś 5 to 10 per meg year-1) as observations [Bender et al., 2005; R. Keeling, personal comm.] (Figure 6). Since interannual APO data are not yet publicly available at many of the stations in Figure 6, we felt it would not be appropriate for our model-based paper to try to interpret these data before they have been published by the observational groups.

Section 3.4: We have added the following text before presenting figure 10 to introduce the overall concept, Although our ultimate goal is to examine the uncertainty in the method associated with O2 outgassing, we first examine how well the method performs when the exact Zeff is used in Equations 2 and 4. In these first tests, any discrepancies between the estimated and true Fland and Focean terms must be introduced by atmospheric transport and sampling constraints. We also added some text at the beginning of the Figure 10 caption, Figure 10. Summary of calculations testing the sensitivity of Fland and Focean, estimated by solving Equations 4 and 2 using WHOI/MATCH tracers, to different spatial sampling strategies, time spans, land CO2 tracers, and inclusion/omission of the O2 outgassing term Zeff.

Section 4. We have added to the end of Section 3.2, para. 1: The fact that the WHOI model predicts O2 uptake over the mid to high latitude oceans (not shown), similar to the Gruber et al. [2001] climatology, confirms that the atmospheric transport model, rather than the ocean model, is responsible for the positive APO values in Figure 3b around 45-60ž latitude. We are confident about this statement, since we originally had included some flux APO panels in Figure 3, in which APO was estimated directly from ocean fluxes with a variant of Equation 5 based on the moles of N2 and O2 released in each grid cell divided by the total moles of air in that grid. The flux APO figures looked similar for WHOI and the annual climatology, with negative APO over the mid

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to high latitude oceans. We did not include these figures in the final paper because we decided that the concept of flux APO would take up too much space to explain and might be confusing to many readers.

Figures 3 and 5: We made these changes to the figure captions

Figure 10: We have added text to the bottom of each panel describing what it shows. We have also eliminated panels e) and f), since their message is illustrated more thoroughly in Figure 12.

Figure 11: We have included gray in the line descriptions.

Interactive comment on Biogeosciences Discuss., 4, 2877, 2007.