Geosci. Model Dev. Discuss., 4, C539–C543, 2011
www.geosci-model-dev-discuss.net/4/C539/2011/

Geoscientific
Model Development
Discussions

Interactive comment on "LOSCAR: Long-term Ocean-atmosphere-Sediment CArbon cycle Reservoir Model" *by* R. E. Zeebe

G. Shaffer (Referee)

gs@dcess.dk

Received and published: 15 August 2011

1. Introduction

This manuscript by Richard Zeebe provides a description of the architecture and tuning of his Long-term Ocean-atmosphere-Sediment CArbon cycle Reservoir Model (LOSCAR). This fills an important gap by providing the Earth science community with the means to better understand and evaluate recent published LOSCAR applications by Zeebe and co-authors (eg. Zeebe et al. 2008; Zeebe et al., 2009). In addition, this manuscript provides necessary information for possible future use of the LOSCAR model by other modelling groups, including how the model code can be obtained.

The manuscript is unusual in that it presents a detailed model description following

upon a number of published model applications. To address this "cart before the horse" in this review I first consider enhancements and clarifications needed to fully understand the model as it has been used in the applications. I recommend that the model be published in GMD after these points have been addressed. I then present some suggestions on how the architecture and tuning of the model could be improved for future work.

2. Needed enhancements and clarifications

In general the manuscript is well-written and refreshingly brief. However, some aspects need to be addressed:

Model architecture and geometry are summarized in Figures 1 and 2 and in Table 1. Surface box areas and volumes are well defined but there is ambiguity with regard to the areas and volumes of the intermediate and deep boxes. Does the total area of the intermediate and deep boxes equal the total ocean area (by scaling up their % Areas to give a sum of 100%) or does it equal 90% of total area (as the areas of the surface layers above them). Since the height of the intermediate box is specified as 900 m, these different interpretations lead to different intermediate and deep box volumes. To avoid this ambiguity the intermediate and deep box volumes should be included in Table 1.

It is not clear how the Tethys Ocean is connected to the rest of the ocean in the PETM configuration. The text states that the Tethys Ocean has a surface, an intermediate and a deep box but the only circulation or exchange parameter in Table 2 that applies to this ocean is a mixing rate between its intermediate and surface layers. As it stands, matter can only be transported to this ocean via the atmosphere and any matter falling into the deep box of this ocean would just accumulate there. Is this how things work in the LOSCAR model or is there must be something missing in Table 2? This situation is not helped by the fact that the Tethys ocean is obscured in Figure 1 and is omitted ("for clarity") in Figure 2. Aanything missing should be included in Table 2 and I think that the Tethys Ocean should be included in Figure 2 for clarity.

One of the tracers considered in the model is δ13C but important details are missing on how the model treats this tracer. There is no discussion of fractionation during air-sea exchange and during organic carbon and biogenic carbonate production in the ocean surface layers. What fractionation factors were used and how do they depend upon surface layer temperatures and CO2 concentrations? These details and equations for calculating δ13C should be included in Sections 3.2.1, 3.2.2 and 5. Furthermore, 13C is removed from the ocean-atmosphere system as calcium carbonate is buried in the sediment. How is 13C resupplied to the system to maintain a steady state (there is no mention of 13C in the discussion of weathering and volcanic input)?

In a PETM application paper with LOSCAR (Zeebe et. al, 2009), some of the simulations were based on a modified circulation with a contribution of North Pacific Deep Water (NPDW) formation while the Southern Ocean source was reduced relative to its pre-event strength. For completeness in Section 9.2, it would be useful to discuss this and to include the assumed NPDW and SO transports for these simulations (this information was not given in Zeebe et al., 2009).

In Figure 5 and 6 the line definitions in the insets in each of the figures are too small to be read. These figures should be redrafted to address this problem. It would also be useful for comparison with other work to state the total modelled organic and calcium carbonate carbon production (GtC/yr) in both the modern and PETM versions.

3. Possible future improvements

It is somewhat surprising that radiocarbon was not considered in the manuscript. There is a long tradition in ocean modelling of comparing modelled and observed 14C, cast in the form of Δ14C with the help of concurrent 12C and 13C observations. Such comparisons help to calibrate the physical exchange parameters in the simpler models (e.g. Shaffer and Sarmiento, 1995; Munhoven and Francois, 1996) or to validate the circulation and exchange in the more complex models (Matsumoto et al., 2004). Indeed,

Δ14C is very well suited for these tasks since extensive observations are available and time scales of radioactive decay for 14C match those of ocean overturning. The LOSCAR model includes all physical and biogeochemical ingredients for a rigorous treatment of 14C.

As a partial test of the modern day circulation and exchange parameters in the model (Table 2 in the manuscript), I calculated pre-industrial Δ14C (as a physical tracer; Toggweiler et al., 1989) for the model ocean boxes using an assumed atmospheric value of 0‰ṀMy calculations yielded -143, -168 and -206‰ for the deep Atlantic, Indian and Pacific boxes, respectively. This may be compared to approximate data-based averages for these boxes of -105, -180 and -215‰ (Key et al., 2004). Model values are considerably lower than observations for the deep Atlantic and somewhat higher for the deep Pacific. Furthermore, model values for the deep Indian are closer to those of the deep Atlantic than to those of the deep Pacific whereas observations show the opposite.

This mismatch derives from model architecture, specifically, 1. from the use of only one generic high latitude surface box in a multibox model and 2. from a vigorous, deep circulation directly from the Atlantic to the Indian rather than by way of the deep Southern Ocean mixing pot. My calculations yielded -106‰ for Δ14C of the high latitude surface box, situated between estimated, pre-industrial, high latitude surface values of -60‰ and -120‰ for the North Atlantic and Southern Ocean, respectively. Likewise, modelled preformed properties for this box are more reminiscent of the Southern Ocean than the high-latitude North Atlantic. As a consequence, the model overturning circulation carries high values of phosphate, TCO2 and TA into the deep Atlantic, explaining model-data disagreements of these properties there (Fig.4). Good data-model agreement for carbonate ion is still found there since CO32- depends on the TA-TCO2 difference. For future work, it may be a good idea to reconsider LOSCAR model architecture and to use modelled and observed 14C in the tuning process.

4. References

Key, R. M., Kozyr, A., Sabine, C. L., Lee, K., Wanninkhof, R., Bullister, J., Feely, R. A., Millero, F., Mordy, C., and Peng, T.-H.: A global ocean carbon climatology: Results from GLODAP, Global Biogeochem. Cy., 18, GB4031, doi:10.1029/2004GB002247, 2004.

Matsumoto, K. et al. Evaluation of ocean carbon cycle models with data-based metrics, Geophys. Res. Lett., 31, L07303, doi:10.1029/2003GL018970, 2004.

Munhoven, G. and Francois, L. M. Glacial-interglacial variability of atmospheric CO2 due to changing continental silicate rock weathering: A model study, J. Geophys. Res., 101(D16), 21423–21437, 1996.

Shaffer, G. and J.L. Sarmiento, J. L. Biogeochemical cycling in the global ocean: 1. A new analytical model with continuous vertical resolution and high latitude dynamics, J. Geophys. Res., 100(C2), 2659-2672, 1995.

Toggweiler, J. R., Dixon, K. And Bryan, K. Simulations of radiocarbon in a course-resolution world ocean model 1. Steady state prebomb distributions, J. Geophys. Res., 94(C6), 8217-8242, 1989.

Zeebe, R. E., Zachos, J. C., Caldeira, K., and Tyrrell, T.: Oceans: Carbon Emissions and Acidification (in Perspectives), Science, 321, 51–52, doi:10.1126/science.1159124, 2008.

Zeebe, R. E., Zachos, J. C., and Dickens, G. R.: Carbon dioxide forcing alone insufficient to explain Palaeocene-Eocene Thermal Maximum warming, Nat. Geosci., 2, 576–580, doi:10.1038/ngeo578, 2009.

Interactive comment on Geosci. Model Dev. Discuss., 4, 1435, 2011.