

Interactive comment on “Continuous and self-consistent CO₂ and climate records over the past 20 Myrs” by R. S. W. van de Wal et al.

Anonymous Referee #3

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This manuscript attempts to model atmospheric CO₂ concentrations from the Zachos et al. (2001) benthic $\delta^{18}\text{O}$ curve, a series of 1-D ice sheet models and four parameters relating bottom water temperature, atmospheric temperatures and CO₂. Reduced complexity models, such as this one, have a role in trying to understand processes and reduce highly complex systems down to their fundamentals. For all such models, it is important they are formulated in such a way to retain enough information or predictive ability to be able to accurately reproduce all the essentials of the system. To show this they need to reproduce known independent data, i.e. data not used in the calibration of the model. While this work is undoubtedly interesting and I'm sure that there is much to be learnt from these simulations, the efficacy of the model formulation and assumptions to accurately reproduce climate and CO₂ over the last 20 million years is questionable, particularly with the lack of testing against relevant independent data.

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Probably the most problematic feature of the model is the amount of information that is required for the reconstruction of 20 million years of climate history and atmospheric CO₂. Essentially the only information driving the model is the benthic $\delta^{18}\text{O}$ curve. For this to be a sufficient proxy for the whole climate system and atmospheric CO₂ levels requires a number of assumptions, including that the partitioning of heat in the climate system is fixed, that all temperature change over the last 20 million years is coupled to atmospheric CO₂, that the ice sheet only responds to surface air temperature, that all the other factors affecting $\delta^{18}\text{O}$ (ocean circulation, ocean gateways, salinity, isotope fractionation etc.) are unchanged and that any climate change is globally coherent. Each of these assumptions can be relatively easily disproved, for example see Dowsett et al. (2010), Lunt et al. (2009), Schoof (2007), Spero et al. (1997) and Raymo et al. (2006) respectively. The problems of such assumptions are best illustrated by the middle Miocene (14 million years ago). Although this was a period of particular warmth and significant ice sheet retreat, no-one proposes that the Antarctic ice sheet returned to a pre-glacial state as in the Eocene. However, middle Miocene $\delta^{18}\text{O}$ values were similar to those found in the Eocene and hence this model shows an almost total collapse of the Antarctic ice sheet and a return to a pre-glacial climate.

Testing the results of this model is a particular problem, as the use of Pleistocene glacial-interglacial contrasts and the Eocene-Oligocene transition to calibrate the model leaves only the much less well-known Oligocene and Neogene for model evaluation. However, the predictions of the model for the Pliocene and Miocene do not seem to match existing knowledge of the climate and ice sheet in these periods, e.g. Dowsett et al. (2010), Denton et al. (1984) and Talarico and Sandroni (2009). Furthermore some of the implications of the equations derived for this model require the authors to be absolutely sure of the model efficacy. From their equations 4 and 5 it is easy to see that the sensitivity of palaeoclimate temperatures to a doubling of CO₂ (\sim Earth System Sensitivity) is 27°C for the Northern Hemisphere and (from the authors reply to D. Rapp we see) this corresponds to 11°C for the globe. This is almost double the next highest estimate of Earth System Sensitivity from data and models (Hansen

et al., 2008; Pagani et al., 2009; Lunt et al., 2009).

Any paper that is going to suggest alternative Cenozoic climate history and suggest much larger values than generally held for the sensitivity of the Earth System to increases in atmospheric CO₂, definitely needs to be well evaluated and tested and currently this paper does not achieve this. The model presented here seems too simple to reproduce CO₂ and climate over the last 20 million years. Either this paper needs to be reframed as an interesting sensitivity study or the authors need to provide much more justification for their results. As an absolute minimum the authors would have to do the following:

- justify the use of Pleistocene relations between bottom-water temperature, Northern Hemisphere temperature, Southern Hemisphere temperature and CO₂ for periods with hugely different boundary conditions (e.g. no large-scale Northern Hemisphere glaciation, open seaways in Panama and Tethys etc.).
- assess from a purely data perspective the assumption that these relations are constant over geological time.
- assess the model predictions of temperature, sea level and CO₂ against the available independent data, i.e. not Pleistocene or Eocene-Oligocene transition.
- explain why this analysis of ice core CO₂ records produces such a different relationship to that found by Hansen et al. (2008), who showed a longer term or Earth System sensitivity of 6°C (not 11°C).
- much greater analysis of the relationship between temperature and CO₂, including the following:
 - improved analysis of ice core CO₂ record, including showing scatter and uncertainty in temperature relationship.
 - justification of linear relationships for proxy CO₂ records when some seem to show a break in gradients, little relationship etc.

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- why records that show very different development over the last 5 million years seem to have the same CO₂-temperature relationships.
- how ice core record can rule out stomatal records, when there is no overlap either in time or CO₂ concentrations.
- discussion of the implications of the formulation of the model and the retrodictions of past climate and CO₂.

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