

# Replies to Reviewer Comments

David Wade on behalf of the authors

We would like to extend our gratitude to Jim Kasting and the anonymous reviewers for the time and care they took in reviewing the paper. The comments will be dealt with in turn and changes to the updated manuscript will be described. In all cases, reviewer comments can be identified by the red text and the author reply in the black text. We've provided a tracked changes document for the editor where the new additions (bold black text here) are added in blue and text we have deleted is scored out in red for clarity.

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## Jim Kasting

This paper describes an exhaustive study of the effects of changing pO<sub>2</sub> on Phanerozoic climates. The calculations are carried out with two different state-of-the-art climate models, one of which is an Earth system model that includes coupling between the atmosphere and the biota (forests in particular). This paper responds to a disagreement between the original 3-D climate simulations by Poulsen et al. (2015) and subsequent 1-D simulations by Goldblatt (2016) and Payne et al. (2016) (the latter of which is my own research group). The Poulsen et al. model predicted that higher pO<sub>2</sub> leads to lower surface temperatures; the two 1-D models predicted just the opposite. The new paper basically agrees with the 1-D models, i.e., high pO<sub>2</sub> leads to higher surface temperatures. But the results are more complicated. High pO<sub>2</sub> can actually lead to lower surface temperature when the starting state is a warm climate. In general, the calculations seem to be well done, and the results are well described. I have a few minor comments below. But this paper should be useful in close to its present form. The basic conclusion, which is restated in point 4 below, is that changes in pO<sub>2</sub> are secondary drivers of Phanerozoic climate. The main driver is changes in pCO<sub>2</sub>, and also in solar luminosity, which is not mentioned too many times explicitly but which is implicit in the calculations.

1. (p. 3, l. 2) 'Indeed, there is support for elevated O<sub>2</sub> by carbon isotope measurements (Beerling et al., 2002).'—Elevated O<sub>2</sub> during what time period?

We thank Prof. Kasting and have added the following to clarify: "... isotope measurements **during the Permian** (Berling et al., 2002)."

2. (p. 9, l. 1) 'Proxy data for the Maastrichtian was obtained.'

—Proxy data..were obtained. ('Data' is plural.) This same mistake is found elsewhere.

Thanks for spotting this. We have changed this in the text on P9 line 1, P9 line 3, P24 line 20.

3. (p. 19, l. 18) 'The changes in terrestrial carbon storage are equivalent to 56% of the atmospheric CO<sub>2</sub> content in the Asselian and 16% in the Wuchiapingian which suggests that pO<sub>2</sub> induced Earth system feedbacks could have significant impacts on

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atmospheric pCO<sub>2</sub>.'

–No, I don't buy this argument. Think of the numbers and the relevant time scales. Today, the atmospheric CO<sub>2</sub> reservoir is about 1/60th the size of the dissolved inorganic carbon (DIC) reservoir in the ocean. On long time scales (> 0.5 m.y.), what changes is the total CO<sub>2</sub> content of the combined atmosphere-ocean system. Sequestering 56% of atmospheric CO<sub>2</sub> in forests is a trivial change to this combined reservoir. Forests can only directly affect atmospheric CO<sub>2</sub> if they are chopped down or regrown on very short time scales, less than the time required for the atmosphere and ocean to equilibrate.

We take Prof. Kasting's point here. In our study we neglected to simulate ocean biogeochemistry and as a result there are issues in interpreting the effects of changes in pO<sub>2</sub> on the carbon cycle. In light of this and the other comments from the reviewers we suggest to leave the section on Earth system feedbacks in (section 3.4) but with some modifications to the text. As a result we have modified the text and deleted lines 18 and 19 on P19 and lines 1 and 2 on P 20 and added the following (in bold):

**"Note that while the atmosphere and vegetation are coupled in the physical sense, the carbon cycle is not interactive so determining the impacts of atmospheric pO<sub>2</sub> on the carbon cycle remains an outstanding problem."**

4. (p. 27, l. 11) 'pO<sub>2</sub> therefore remains a secondary contribution to climatic variability in the Phanerozoic but most likely to be important during the Permian.'

–The first part of this statement is essentially what we said in the conclusion section of Payne et al. (2016): 'Given the large uncertainties in past levels of both O<sub>2</sub> and CO<sub>2</sub>, we agree with Berner [2006] that Phanerozoic climate has been driven largely by changes in atmospheric CO<sub>2</sub> and solar luminosity, coupled with changes in continental geography.' So, we are in fundamental agreement on this question.

We thank Prof. Kasting for the comment and have added the following text to clarify this point:

**"pO<sub>2</sub> therefore remains a secondary contribution to climatic variability in the Phanerozoic in agreement with Payne et al. (2016) but most likely to be important during the Permian."**

5. (p. 27, l. 17) 'If pCO<sub>2</sub> and pO<sub>2</sub> are intimately linked such that cooler climates tends to increase pO<sub>2</sub> this would suggest that pO<sub>2</sub> responses have helped to prevent Snowball Earth initiation in the Phanerozoic.'

–Cool! I like this result. The effect of pO<sub>2</sub> on climate is not strong, but it may help to prevent Phanerozoic Snowball Earth events.

Thank you for the comments, we agree this is indeed an interesting result.

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