

## ***Interactive comment on “Climate sensitivity and meridional overturning circulation in the late Eocene using GFDL CM2.1” by David K. Hutchinson et al.***

**David K. Hutchinson et al.**

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We thank the reviewer for his/her thoughtful and constructive comments, which have helped to improve the manuscript. We present the reviewer’s comments in black text, and our response in blue text.

### **Summary:**

First of all, I did not read the other online review to this paper prior to writing my own, so this review is completely independent.

This paper aims to explore climate sensitivity and ocean overturning at the Eocene-

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Oligocene, as well as other aspects of the Earth system. It argues that by using more realistic paleogeographies and a relatively high resolution ocean model, it represents an advancement over previous work. In essence, it describes a set of simulation at 3 CO<sub>2</sub> levels for the late Eocene, with 2 different parameterisations of ocean mixing, and includes a model-data comparison. Overall, the paper provides an interesting summary of the basic state and climate sensitivity of this particular model, and is a solid baseline from which additional sensitivity studies can be carried out.

[We thank the reviewer for the overall positive assessment.](#)

### Major comments:

The introduction is a nice overview of some previous modelling work. However, more quantitative information could be presented. This paper focusses mostly on climate sensitivity and overturning, so a summary table of e.g. climate sensitivities and ocean overturning states at different CO<sub>2</sub> levels in previous work would be very informative and provide more motivation and context for the work presented here (especially if the paleogeogs and ocean resolution were included in the same table).

[We have added a table of previous EOT model simulations, include where possible their climate sensitivities, overturning states, and their ocean and atmosphere resolutions.](#)

Section 2 on the model is good, but it appears that several changes have been made (to e.g. the resolution) compared with the published version of the model. As such, it is important to present an assessment of the performance of the model under preindustrial conditions. In addition, at several points in the manuscript comparisons are made with modern, and these are rather meaningless unless they are comparisons with a modern model simulation from the same model.

[We acknowledge that it would be better to compare our model with a control climate model at the same resolution. We are currently developing a new pre-industrial simulation using the same resolution, but this will be a very short run and relatively untested](#)

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at the time of revising the paper. We will in any case try to make this comparison as best we can, based on a short time series.

The spinup plots are useful and interesting, but it would be very useful to see Gregory plots of the three simulations as well, to assess how spun up the simulations are, and the likely equilibration temperature of the simulations.

We have added Gregory plots of the spinup evolution in order to assess the projected equilibrium temperatures.

### Specific Comments:

Abstract: Is the model resolution really greater than previous work? A summarising table of previous simulations would help, see above.

We have added a summary table of previous simulations.

P1, Line 25; P22, line 1: what is meant by “robust” in this context?

We mean robust to CO<sub>2</sub> perturbations, but since that point is already explained in the second half of the sentence, we have removed the word ‘robust’.

P2, Line 14: for a review of the mechanisms see Lear (2016, Science)

This reference has been added, with an extra sentence on the importance of paleogeographic boundary conditions.

P2, line 21: seasonality as well as climate sensitivity was important in the Gasson paper.

This point has been added.

P2, line 22: make it clear whether CO<sub>2</sub> estimates are for just prior to, or just after the EOT.

We have clarified that observations are based on the late Eocene.

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P6, line 10: need to make it clear that although using “realistic” paleotopographies is a step forward compared with some previous studies, there are still uncertainties in these that are not captured in this study.

[We have added further description of the uncertainties in the Baatsen et al \(2016\) reconstruction.](#)

P9, your experiences with model spinup are very interesting and I think warrant inclusion in the conclusions section, and maybe even the abstract.

[A summary of the spinup has been included in the conclusions section as suggested.](#)

P9, line 15: a graph illustrating the fully coupled versus asynchronous spinup procedure (e.g. a graph of time against global mean temperature at a couple of ocean depths) would be very interesting and illuminating. i.e. add non-asynchronous run to Figure 2.

[The synchronous vs asynchronous spinup evolution has been added to Figure 2.](#)

P9, line 23: add another plot which is the evolution of ocean overturning strength in each basin over the model spinup period.

[Evolution of the overturning has been added to the spinup plot.](#)

P9, line 23: Also add another timeseries which is ocean salinity over time in the Arctic (and maybe other ocean basins). It would be interesting to know if this is still decreasing or whether it has reached an equilibrium.

[Evolution of surface salinity in the Arctic basin has been added. We have also included indicative values of Pacific and Atlantic salinity.](#)

P11, line 27; p21, line 19: “La Nina-like mean state” I would avoid this term; it has caused much confusion in the Pliocene community. Instead, just say that in the annual mean the west-east gradient in increased.

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We have removed the “La Niña-like mean state” reference and rephrased as suggested.

P12, line 26: I don't think that the level of confidence in the interpretation of the proxy data justify this statement. I don't think the data really allows us to say which modelled seaice distribution is best (i.e. there is some seaice at 800ppmv).

We have rephrased this statement with reference to other evidence that suggests warm winters in the Eocene (i.e. less prone to sea ice).

P14, line 5: It would be good to note whether these sensitivity studies to mixing scheme were run for exactly the same length of time and had the same spinup process as the 'standard' runs.

They were run for the same time and with the same spinup procedure. This is now added to the text.

P16, line 4 – for the comparison with modern climate sensitivity, is this exactly the same model and same resolution etc?

This did not use the same resolution. We are currently developing a pre-industrial simulation with the same resolution as our Eocene run, but this will be a short run at the time of re-submitting the manuscript.

P16, line 16: “We suggest that the ice-free conditions allow for substantial radiative warming of SST in addition to atmospheric polar amplification.” I don't understand what this means.

We have rephrased this statement. We mainly wanted to mention the two separate effects of radiative forcing and enhanced energy transport that combine to give polar amplification (Alexeev et al, 2005). However, we neglected to mention possible cloud feedbacks, and this has now been added.

Section 4.4: This section is somewhat superfluous, and doesn't add much to the

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manuscript unless the location of late Eocene palms are plotted on Figure 13.

[We agree and have removed this section.](#)

**Technical comments:**

Figure 1a – get rid of the ‘hole’ at the north pole and 0 degrees east.

[We have interpolated the Arctic region onto a regular lat-lon grid to remove the gaps.](#)

Figure 3 caption – state the CO<sub>2</sub> concentration.

[This has been added.](#)

Coloured circles in figure 8 are difficult to see – put a black line around the circumference.

[Black outlines have been added to the coloured dots.](#)

P15, section 4 title – CO<sub>2</sub> not CO2.

[We have included the subscript in the title.](#)

Figure 9 would be better presented as both plots being a warming, i.e. 1600-800 and 800-400. In fact, throughout the paper I would prefer presenting the simulations as 3 in a series, rather than one in the middle with a warmer and a cooler either side, to aid consistency.

[We have adjusted the plots to show a warm-cold comparison in both cases, as suggested.](#)

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Interactive comment on Clim. Past Discuss., <https://doi.org/10.5194/cp-2017-161>, 2018.

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