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Climate of the Past Discussions

Interactive comment on "Sensitivity of the Eocene Climate to CO_2 and Orbital Variability" *by* John S. Keery et al.

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1 Summary

Keery et al. present a sensitivity analysis of the Eocene climate to four factors: CO_2 concentration, eccentricity, obliquity, and precession angle. They use, to this end, the PLASIM-GENIE model (details in their section 3) with suitable palaeogeography. The methodology relies on a 50-member hyper-cube sample of a 5-d space (one extra dummy variable was added), and linear modelling with a Information Criteria for model selection. Experiment output are summarised using fit-for-purpose summaries like "tropical-polar temperature difference" and monsoon indices, as well as principal components obtained from a singular value decomposition. The authors conclude on

the importance of CO_2 for global mean temperature, and of the orbital elements for the spatial distribution and regional weather systems such as monsoons.

2 Main comments

1. The paper is in the line of a number of recent studies attempting to estimate the relative sensitivity of the climate system to CO_2 and orbital forcing, using a methodology founded on ensemble of experiments. This includes, in addition to the Holden et al. (2015) and Bounceur et al. (2015) cited, Araya-Melo et al. (2015) and Lord et al. (2017)[1]. Keery et al. is the only article to focus on the Eocene, which makes it an original contribution. It also uses a much simpler methodology than Araya-Melo et al. (2015), Bounceur et al. (2015), and Lord et al. (2017) because it uses linear regression instead of a Gaussian process emulator. In fact, the authors reference to the word "emulator" is slightly unusual because emulation is, in the climate literature, often used to designate statistical meta-modelling with a focus on uncertainty quantification. Claiming (p. 8) that a "similar emulator approach has been applied by Bounceur et al. 2015" is therefore somewhat misleading. Bounceur et al. and Araya-Melo et al. applied the developments of Oakley and O'Hagan (2004) with, in the case of Bounceur, the additional complication of the PCA emulator. In passing, Araya-Melo et Lord used HadCM3 which shows that ensemble-based sensitivity analysis to orbital forcing is doable with GCMs (this qualifies the author's comment on line 15, p.2). Of course, the fact that other authors have adopted a more sophisticated methodology invalidates by no means the approach used by Keery et al.: there may be no need to use a sledgehammer to crack a nut. It remains that the methodological set up used here is a step backwards compared to recent studies, and this arguably

[1] the later was submitted after Keery et al. and could not of course be cited by these authors.

requires some justification. How much do we lose with the linearity assumption, and which impact does it have on the uncertainties of the quantification of main effects? (see comment 3. more specifically on main effects).

2. Experiment design. The authors do not say much about the ensemble design, except that this is a latin hypercube. There are many ways to do a latin hypercube, and it usually involves additional constraints. In fact this experiment design raises some doubts. For example, why are some secondary structures (periodic up and downs) apparent in the response to obliquity, Figure 5, middle column? Is this just a subjective visual impression? One potentially problematic element is the definition of the sampled astronomical space. It seems that latin hypercube sampling is made on axes along e, ϖ (longitude of perihelion) and ε. If this is what the authors have been doing then this is non-physical. We know that the astronomical forcing generates effects through seasonal and daily insolation, which are very well approximated by linear functions of $e \sin \varpi$ (which the authors call the precession index on Fig. 6) and $e \cos \varpi$. This is the reason why several authors have chosen to sample the astronomical space following the axes $e \sin \varpi$ and $e \cos \varpi$ and regress against these components. Presumably the regression analysis by Keery is indeed done against these indices but the text is not always clear. Lines 1-2 p. 8. rather suggest that the explanatory variables where $\sin \varpi$ and $\cos \varpi$ (instead of their multiplication by e) and the lines 4-5 p. 11 are quite confusing. Hopefully the choice of regression variables is mainly matter of text clarification, but the design of the latin hypercube may have a more fundamental problem.

3. There may be some confusion about the meaning of the *main effects*. Saltelli does not use the phrase "first order" to mean linear approximation. In a case where only one factor would matter (be the relationship linear on not), the main and total effects would match (Saltelli et al. (2004), ch. 1 states clearly the definitions; or refer again to Oakley and O'Hagan (2004)). More generally, computing

main and total effects is not trivial and always involves some approximations. More details on their computation would be welcome.

4. Singular value decomposition is a great dimensionality reduction methodology, but how much is learned by analysing the behaviour of principal components separately is a more contentious subject. Identification of principal components can be fragile to some implementation details, such as, e.g. grid area weighting and experiment design, and the physical phenomena which give rise to climate variability need not be orthogonal. In fact physical modes may project poorly on the orthogonal vectors (Monahan and Fyfe, 2006). These caveats implicitly acknowledged by the authors (p. 11, ll. 20-21) but this state-of-affairs poses some questions about the emphasis on principal components in this article.

3 Minor (scientific) comments

- How Fig. 2 should be interpreted is not entirely clear since the ensemble was not explicitly designed so that the ensemble mean is an estimate of the Eocene climate mean.

4 Minor (editorial) comments

- Introduce subtitle after section 2.
- Material about cyclostratigraphy under section 2.1.2. may possibly be considered for shortening as slightly out of scope of the article. This said this is an interesting read.

- PLASIM-GENIE does not need a specific section: it can fall under section 3. Methods.
- p. 6 reference Gough (1981) is mistakenly repeated.
- p. 7, the sentence “We apply the linear algebraic tool SVD” sounds unnecessarily sophisticated. Why not “We perform a singular value decomposition to identify principal components”
- p. 10, l. 27 : define the word “precession” precisely.
- p. 12, ll. 13-17 : introducing new results so close to the closing words is usually not encouraged.

5 Digital material

- Relevant data of the Eocene runs (at least the summaries and experiment input data) could be provided.

References

P. A. Araya-Melo, M. Crucifix, and N. Bounceur. Global sensitivity analysis of the indian monsoon during the pleistocene. *Climate of the Past*, 11:45–61, 2015. doi: 10.5194/cp-11-45-2015. URL http://www.clim-past.net/11/45/2015/.

N. Bounceur, M. Crucifix, and R. D. Wilkinson. Global sensitivity analysis of the climate-vegetation system to astronomical forcing: an emulator-based approach. *Earth System Dynamics*, 6:205–224, 2015. doi: 10.5194/esd-6-205-2015. URL http://www.earth-syst-dynam.net/6/205/2015/.

P. B. Holden, N. R. Edwards, P. H. Garthwaite, and R. D. Wilkinson. Emulation and interpretation of high-dimensional climate model outputs. *Journal of Applied Statistics*, pages 1–18, 2015. doi: 10.1080/02664763.2015.1016412. URL http://dx.doi.org/10.1080/02664763.2015.1016412.

N. S. Lord, M. Crucifix, D. J. Lunt, M. C. Thorne, N. Bounceur, H. Dowsett, C. L. O'Brien, and A. Ridgwell. Emulation of long-term changes in global climate: Application to the late pliocene and future. *Climate of the Past Discussions*, page 1–47, 2017. ISSN 1814-9359. doi: 10.5194/cp-2017-57. URL http://dx.doi.org/10.5194/cp-2017-57.

A. H. Monahan and J. C. Fyfe. On the nature of zonal jet eofs. *Journal of Climate*, 19: 6409–6424, 2006. ISSN 1520-0442. doi: 10.1175/jcli3960.1. URL http://dx.doi.org/10.1175/JCLI3960.1.

J. E. Oakley and A. O'Hagan. Probabilistic sensitivity analysis of complex models: a bayesian approach. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, 66: 751–769, 2004. doi: 10.1111/j.1467-9868.2004.05304.x.

A. Saltelli, S. Tarentola, F. Campolongo and M. Ratto, Sensitivity Analysis in Practice: A guide to assessing scientific methods *John Wiley and Sons Ltd.*, 219pp., 2004.

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