Interactive comment on ““Mending Milankovitch theory: amplification by surface feedbacks”

Written by

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Reviewed by

N. B.

Feedback analysis of a climate model to insolation changes during the Early-Pleistocene

Tabor et al. investigated the paradox of the amplitude modulations of obliquity reproduced quasi-linearly in the δ^{18}O palaeoclimate record during the Early Pleistocene. They showed that positive surface feedbacks enhance the ice-volume response to the cycles of obliquity relative to precession. Referred to Milankovitch's hypothesis that summer insolation determines glacial-interglacial cycles via the snow-albedo feedback (Milankovitch, M., (1998) and that during the Early-pleistocene obliquity modulated ice sheet variations, they demonstrate using a feedback sensitivity analysis, the amplification of surface feedbacks by obliquity with and without dynamic ice sheets and in a duration-standardized experiment. The results present a new solution to the Early- Pleistocene Milankovitch theory witch needed to be comprehended, explained and completed.

They analyzed positive feedback mechanisms between hight latitude annual mean insolation and sea-ice, ocean heat fluxes and vegetation changes. As mean annual (and integrated summer) insolation is dominantly controlled by obliquity, the study readily explain the observed cyclicity during the Early-Pleistoce. But it bring element of response for the importance of surface feedbacks, using a classical approach of sensitivity analysis (feedback analysis).

The paper is concise, well written and structured, on modeling ice-volume changes to obliquity compared to precession, during the Early Pleistocene. The authors started from information provided by the palaeoclimate climatic record and adapted a simulation study based on physical knowledge of the climate system and to important climatic components that contribute to the ice sheet variation process. The methodology applied in this work is coherent and robust regarding the assumptions made.

This work is a step before the use of a more complex climate simulator with a adapted sensitivity analysis for the consideration of forcing variations (insolation) and their interactions for the combined effect on climate response (temperature). I certainly support the publication of this paper as it has the potential to address a such issue and try to better identify mechanisms responsible of the Milankovitch theory paradox. The manuscript should be published in Climate of the Past under a minor revision.

A general question

What is your reference about the range 2.6-0.8?

Suggestions for future work

What is important nowadays is to gain understanding of the mechanisms responsible of climate changes and the quantification of factor contribution

- It is important to keep in mind that 'a simulation study' is a way to gain understanding of mechanisms related to a phenomena and not to conclude about any final conclusion about the real mechanisms. The later needs to be completed by a comparison to real observed data, and a global sensitivity analysis, where all the important parameters (forcing and feedbacks) are varied by large amounts and simultaneously.

- The quantification of direct and combined effect of factors to insolation and feedback changes may be done using a global sensitivity analysis. Sensitivity analysis in a global sense, especially when more than two parameters are varied, need a considerable computational resources and time to be realized. This is due to the big number of simulations required in one hand and the fact of using complex climate models which are expensive in the other hand. The combination of statistical methods with the classical simulation approach using a computer model, is a way to tackle this burden . Among the existing sensitivity analysis for computer codes Sobol' (1993), Kleijnen, (1997), Oakley and O'Hagan (2004), Saltelli et al. (2008).

More specifically :

In this study, the authors followed a classical methodology in paleoclimatology of sensitivity analysis which is performed using a feedback analysis, based on a single parameter perturbation or a One at a time test, to evaluate the contribution of a specific input parameter to the output change (an input is for instance the obliquity, an output is temperature, a computer climate model is called a simulator). This is assessed by analyzing the difference between a simulation where the influence of this parameter is considered, and of a simulation where the influence of this parameter is omitted. However, explaining the resulted difference when more than one parameter is considered becomes hard to interpret (Stein and Alpert, 1993 ; Alpert and Sholokhman, 2011). Moreover, only small perturbations around a reference state is considered and does not consider the synergism between the different parameters (Alpert and Sholokhman, 2011). This method has been extended by Claussen (2001) by considering feedbacks as well as synergisms[1].

The aim of using this method is to understand the amplification of the output initial signal due to feedbacks and synergisms. This approach provides an easy way to objectively separate the pure contribution of one input parameter from its synergism with the others. It is applied to better understand the contributions of a single feedbacks and synergisms to an output simulation result.
Many applications of these methods may be found in Paleoclimatology. For instance, Berger (2001) to analyze the impacts of vegetation changes on climate over the last glacial-interglacial cycle and Crucifix and Loutre, (2002) during the he Last Glacial Maximum.

Minor comments (page.line)

- May I suggest to the authors to write more specifically, in the introduction, that the analysis needed for their study/aim is a sensitivity analysis. Moreover, to specify

[1]it is the combined effect of factors which is greater then the individual effect of each factor to produce an effect greater than the sum of their individual effects. Synergism is essentially the second order effect.

that the analysis needed/applied here is a sensitivity analysis known as the feed-back analysis using a climate model (for instance make changes in the paragraph from 3771.27 to 3772.2).

- 3770.17: change to :These climate variations known as Milankovitch cycles are quasi-cyclic.
- 3770.17-18 : change to : They are attributed to **the direct** and combined effects of changes in the astronomical forcing parameters (obliquity, precession and eccentricity)
- 3770.19 : add a reference.
- 3771.10: add a reference.
- 3770.21-3770.22 : The influence of the three Earth's orbital and rotational parameters.
- 3778.31-3778.20 : Move this paragraph to the end of the section. Combine it with the last sentence (3779.26) "Future work will examine the combined interactions between obliquity and precession.". change the later to "'Future work will examine the effect of interactions between obliquity and precession ' or "'Future work will examine the combined effect of obliquity and precession'. Explain that an adequate sensitivity analysis, which is able to take into account the combination effect, is needed to verify this "idea" in one hand, and to estimate/quantify the contribution of direct and combined effects of the factors in the other hand (see for the methodology Stein and Alpert, 1993 ; Alpert and Sholokhman, 2011)
- 3779.24: change 'a new solution' to 'a new explanation of the mechanisms related to...'.
- 3779.25: note: 'emphasize the importance of using complex models ' : It is important to consider more climate components and feedbacks in climate models to best represent the physical processes. But, be aware that complex climate models are expensive to achieve alone a global sensitivity analysis.

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