Interactive comment on "A Theory of Pleistocene Glacial Rhythmicity" *by* Mikhail Y. Verbitsky et al.

Mikhail Y. Verbitsky et al.

verbitskys@gmail.com

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This paper presents a three variable system of the glacial climate and models its response to astronomical forcing. The system sensitivity to 8 parameters is evaluated using a V-number, which measures the relative intensity of 'ocean' feedbacks on the system. When ocean feedbacks are weak, the system shows glacial cycles with a period of 40kyr, when ocean feedbacks strengthen glacial cycles shift to a period of 100 kyr. This increase in length of glacial cycles is consistent with the transition across the mid-Pleistocene transition.

This paper follows in the path of previous simplified models of the Pleistocene glacial cycles, but has many novel aspects. I have no major criticisms but have a few suggestions to improve the clarity of the manuscript. Overall this is an excellent and insightful paper and I recommend it for publication.

We are very thankful to the reviewer for the comprehensive and insightful review. Though suggestions are minor, we find them to be very helpful. Our answers are given below in bold blue.

Minor points:

1) The ω variable is called 'ocean temperature' although is a combination of all aspects of the climate system outside of the ice sheet itself. The ocean is probably the largest component but this could be misleading to casual readers. I do not have a better suggestion for what to call this, but suggest the authors consider changing it. Although there are many warnings about this throughout the manuscript.

We accept this suggestion. To better articulate our message in the revised version of the manuscript: (a) we will introduce variable ω as "characteristic temperature of outside-of-glacier climate" and use "climate temperature feedback" instead of "ocean feedback" throughout the text; (b) paragraph 3.3 will be renamed accordingly as "3.3 Characteristic temperature of outside-of-glacier climate", (c) we will emphasize that ocean, and particularly deep ocean, is an important part of the outside-of-glacier climate.

2) In the introduction it would be useful to include a more detailed summary of the model, the three variables and the 8 parameters varied in the later analysis (similar to the useful reminder around P20, L8). The 11 parameters and the values used for the steady state solution could be moved to a table.

This definitely will be done.

3) P13, L1: It would be useful to introduce the 400kyr/Stage 11 problem when the model misfit around 400 kyr is mentioned. This is especially relevant given the later discussion of double obliquity periodicity.

The deglaciation associated with termination V leading to stage 11 is indeed a nice problem. We find it remarkable that our model does actually simulate a deglaciation around 430 ka BP (the celebrated Imbrie and Imbrie 1980 model missed it, and that termination remains a challenge for a model of intermediate complexity with interactive carbon cycle such as CLIMBER, V. Brovkin - personal communication). Furthermore, our model reproduces the fact that the termination V was a slower process than other deglaciations, which is reasonably consistent with sea-level reconstructions (Rohling et al., 2010, 2014). However, the simulated sea-level during stage 11 is not as high as the observations suggest, and it is possible that our model, by using mid-June insolation as the forcing metric, is not giving enough weight to obliquity.

Nevertheless, it should be taken into consideration that V-number (as well as each of eight parameters involved in its definition) does not have to be a constant, as it has been implied in section 4.2, but may experience a slow trend. When V-number evolves from its low early-Pleistocene value to its higher late-Pleistocene value to simulate mid-Pleistocene transition (see section 4.5), the glacial variability, consistently with instrumental records, is at maximum amplitude around 400 ky ago. The timing of the last glacial cycle for evolving V-number is also close to LR04 record (Figs. 12-14).

We briefly discuss this point in the revised version of the manuscript.

ref:

Rohling E. J., K. Braun, K. Grant, M. Kucera, A. P. Roberts, M. Siddall and G. Trommer (2010), Comparison between Holocene and Marine Isotope Stage-11 sea-level histories, Earth and Planetary Science Letters, (291) 97 - 105 doi:10.1016/j.epsl.2009.12.054

Rohling E. J., G. L. Foster, K. M. Grant, G. Marino, A. P. Roberts, M. E. Tamisiea and F. Williams (2014), Sea-level and deep-sea-temperature variability over the past 5.3 million years, Nature, (508) 477--482 doi:10.1038/nature13230

4) P15, L7 and Fig 6: The four astronomical ‘challenges’ are precession cycles?

Yes, they are. We will clarify it in the text

5) Fig 6. I suggest including a version of this figure for the other modes as well. You could also include the LR04 derivative, similar to Roe (2006).

We reviewed the derivatives pictures, similar to Fig.6, for Modes II and III and concluded that they do not provide enough of additional insight relative to Fig.6 to grant their inclusion into the text of the paper. However, we are planning to include them into supplemental materials upload.

6) I’m not sure of the need for the double obliquity model here; the full model seems able to explain the 100 kyr period. More justification is needed, i.e. is it to explain the Stage 11 problem?

We consider the period-doubling analysis to be an important part of the paper and would like to keep it for the following reasons:

(a) Though the full model has been able to reproduce 100-ky periods when V~0.75, the interpretation of this phenomenon in terms of dynamical systems theory has not been clear until we probed our system with a single sinusoid of the obliquity period to demonstrate obliquity-period doubling;

(b) The same probing with a single sinusoid of the precession period revealed that the glacial rhythmicity of early Pleistocene (V~ 0) exhibits doubled precession periods;

(c) There are empirical evidences that LR04 variability contains signatures of such period doubling: Vakulenko, N. V., et al. "On periods of multiplying bifurcation of early Pleistocene glacial cycles." Doklady Earth Sciences. Vol. 436. No. 2. SP MAIK Nauka/Interperiodica, 2011.

We are planning to add some discussion in the text including this reference;

Typos etc:
1) P2, L25. Change ‘resort to’ as may appear derogatory 2) Units are missing from several figure axes: Fig 3, 4, 7, 8, 9, 10, 11, 12. Also check label on Fig 8 right bottom.
3) P15, L7, ‘Force’ to ‘Forcing’.

This will be fixed.