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Earth System Dynamics Discussions

Interactive comment on "ESD Ideas: Propagation of high-frequency forcing to ice age dynamics" *by* Mikhail Y. Verbitsky et al.

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Review

Verbitsky et al. (submitted to ESD) show evidence that short-term fluctuations can affect the long-term spectrum of climate variability of Pleistocene ice ages. In previous work (Saltzman and Verbitsky, 1994; Paillard and Parrenin, 2004; Verbitsky et al., 2018) the nature of Pleistocene ice ages was explored using simplified/conceptual climate models. Some papers call for an ice-carbon dioxide oscillator to produce 1000 kyr cycles, the recent Verbitsky et al. (2018) work does not require a nonlinear response of the carbon cycle. The underlying dynamical system has 11 parameters, linked to empirical data of present ice sheets and others are linked to ice sheet and climate models.

One beauty in the approach is that the system behavior can be described by the dimensionless V number (Verbitsky et al., 2018). Using the Π-theorem (Buckingham, 1914), the authors derive a scaling for the disruption potential ΔS for the phase space analysis (eq. 1). The authors find that when adding deterministic millennial modes to the system, the spectrum can be dramatically different.

Recomendation:

The manuscript provides a new perspective of Pleistocene ice ages by using a conceptual model of Verbitsky et al. (2018). It shows a potential coupling between orbital and centennial-millennial variability. The paper needs only moderate revisions before acceptance. In the following, I list some specific comments.

Specific comments:

- The wording "non-linear system response". Due to the Northern Hemisphere summer forcing (Berger, 1978), the system receives already a strong non-linearity. Please clarify this somewhere.
- Reference to the Π-theorem (Buckingham, 1914), the idea goes even further back with Bertrand (1878). Though the Barenblatt (2003) book is a potential reference, I suggest using the older literature here.
- The sentence "This observation makes centennial, decennial, and maybe even annual variations potentially able to contaminate the spectrum throughout the millennial and multi-millennial range and perturb ice age dynamics." (lines 36 ff.) is essential for the conclusions. I would ask to substantiate it more with physics.

- The authors proposed that their deterministic approach has advantages to show that the forcing propagates upscale. I find the deterministic forcing a little arbitrary. I cannot follow the sentence " ... presents the advantage of using the non-linear character of ice sheet dynamics, which was derived naturally from the conservation laws ...". Given the stochastic nature of the millennial variability (Ditlevsen, 1999), the paper would benefit from an additional stochastic analysis which could be added. You mention that "the dynamics at the centennial, millennial, and astronomical time scales should not be considered separately. "

- Related to the last point: The single 5-ky high-amplitude sinusoid, moving the system into the phase-plane domain of higher temperatures and lower ice volume, is not motivated. Known modes are in the $\sim$2.5, 0.9, and 0.5 ky-bands (e.g., Dima and Lohmann, 2008). The periods spread between 3 ky and 9 ky are not really motivated. You may also mention that the mechanism you found is probably different from "noise-induced transitions" where the stochastic forcing generates new equilibria, which do not have a deterministic counterpart.

- The implications are only roughly sketched. Would your result imply that we need high-resolution data to understand the variations on orbital time scales? This is, of course, difficult because of the limited space and references allowed here.

- Please check the internal consistency of notations, e.g. ky and ka.

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