

Reply to Reviewer #1

We are grateful to the Reviewer for the comments that helped us improve the manuscript.

- *By taking the Langevin equation (1) as a conceptual model, what are the limitations imposed on the system dynamics? What kind of system dynamics is excluded by choosing this particular model, for example, by using the white noise term?*

The Langevin equation used in the present paper as a conceptual model is a fairly natural starting point which is already quite general but admittedly has limitations. The model is of first order; a higher-order model could accommodate a richer dynamics. Moreover, the model does not allow for non-random external forcing, e.g. orbital forcing. Also the possibility of state-dependent noise rather than purely additive noise as well as coloured noise would be interesting to include. The proposed approach is initial, and further generalization of the method is to be developed.

We have added some discussion on this to the manuscript.

- *Sometimes, the glacial cycles are treated as oscillations (e.g. Ghil et al., 1987). Are limited cycles excluded from the analysis by Livina et al. by definition? If so, is there a way to further develop the dynamic framework to account for oscillation behavior? (Ghil M, Mullhaupt A, Pestiaux P (1987) Deep water formation and Quaternary glaciations. Climate Dyn., 2, 1-10.*

Oscillatory behaviour is not excluded from the analysis by definition. The present approach can readily be generalised to the second-order stochastic differential equation

$$\ddot{z} = -U'(z) - \gamma\dot{z} + \sigma\eta$$

which supports limit-cycle behaviour. Such a model is discussed by Kwasniok and Lohmann (2009b).

- *Estimation of empirical probably density using the Gaussian kernel estimator needs more discussion. Again, what are limitations of this method?*

We applied Matlab code with built-in `kdensity` function and NAG Fortran library (computing Gaussian kernel density estimator using a fast Fourier transform). The smoothness of the estimator

$$\hat{f}(z) = \frac{1}{nh} \sum_{i=1}^n K\left(\frac{z - z_i}{h}\right)$$

depends on the bandwidth h . Following Silverman (1986), we chose $h = 1.06s/n^{1/5}$, where s is the standard deviation of the data set and n its length.

We have added this note to the manuscript.

Please note that we adjusted the contour plots in the manuscript to map the results to the middles of the sliding windows instead of the ends, which is more natural way of plotting due to aggregation of histogram data within intervals.

We hope that the manuscript is suitable for publishing in the *Climate of the Past*.

Yours sincerely

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