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Climate of the Past Discussions

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Interactive Comment

Interactive comment on "Climate bifurcation during the last deglaciation" *by* T. M. Lenton et al.

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1 Summary

Lenton en al. analyse the climate fluctuations throughout the deglaciation, based on ice core records, GRIP, GISP2 and North GRIP and, for each record, two proxies, $\delta^{18}O$ and $\log_e$Ca, the latter having higher resolution.

They look for signs of 'slowing down', i.e., an increase in autocorrelation time, generally accompanied by an increase in variance, which are precursors of a phenomenon of bifurcation. The purpose is to determine which of the series of large climate fluctuations that punctuate the northern hemisphere climate during the deglaciation should be attributed to a bifurcation phenomenon. To this end, they use different analysis techniques, such as ACF, DFA and variance analysis. Given that all these techniques are

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parametric, the authors perform a large number of sensitivity analyses, more specifically, they analyse the sensitivity to detrending frequency and sliding window length and consider trends in ACF, DFA and variance indicators over different intervals of the deglaciation episode.

As a result, the authors present a very large number of plots : 71 x-y plots and 34 contour plots. The paper is concluded on a summary figure (Fig 7) providing a visual illustration of the main conclusions, that is, Bølling warming is a perturbation-induced transition to a pre-existing warm state; Younger Dryas is a perturbation-induced transition to a pre-existing cold state, and end of the Younger Dryas is a stochastic anticipation of a saddle-node bifurcation.

2 Analysis

The article is nicely written and the analysis methods have been published and used before by these authors. I have chosen not to concentrate on their use and robustness at this stage (reviewer 1 has some concerns though, that makes me suggest to formalise the question of positive vs negative trend in terms of a statistical test, perhaps with a surrogate-data approach; just a suggestion). My review rather concerns the basic dynamical system framework in which the study is being analysed and how results are being visualised.

Let us begin with the latter.

The authors have cutely chosen a color scheme for contour plots, so that the dominant color (blue, red) gives a first good visual impression of the dominant trend: upwards if red; downwards if blue; undecided if there is a mix of both colors. This being said, a total of 71 x-y plots and 34 contour plots is leaving the reader with a lot of information to digest. Axis tick labels are small; ranges could be made more consistent across different plots for a same proxy; and titles should be made more explicit (it is hard to figure

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out what the graph is about from the legend when there are so many of them). Finally, DFA Kendall frequencies histograms have unclear meaning (btw, aren't they densities rather than frequencies?). In summary, I would recommend the authors to think again about the best way of displaying the impressive amount of information resulting from their numerous sensitivity analyses.

My main concern, though, is about the dynamical system framework adopted here. As well illustrated by Fig. 7 (but see also the text), the analysis is carried out with a saddle-node bifurcation in mind, with a possible anticipation by stochastic fluctuations. It remains to be seen whether this is the most appropriate approach to climate changes such as the Bølling-Allerød and the Younger Dryas episodes.

Indeed, saddle-node bifurcations consist in merging a stable and unstable node and then disappearance of both of them. The normal form of a saddle-node bifurcation is a 1-D dynamical system. My concern is that this framework may be oversimplified to describe the dynamics of the deglaciation. There is, at the very least, an interplay to be considered between ocean circulation and slower components of the Earth system, such as ice volume. The co-existence of multiple time scales in this problem is obvious when comparing Greenland and Antarctic records, and this requires dynamical systems with more than one dimension.

One more appropriate framework could be a 'slow-fast' system. In a slow-fast system, a bifurcation diagram such as Fig. 7 may be thought of as the stability diagram of the fast system, while the fast variable controls the course of the slow variable (called here the forcing). In this case, Figure 7 remains an insightful description of what happens with the North Atlantic ocean circulation (the fast system in this case). However, a number of dynamical-system oriented articles on Dansgaard-Oeschger events (DO) suggest to interpret the occurrence of DO events as a homoclinic bifurcation or an infinite-loop bifurcation (see recent review in Crucifix, 2012, and many articles from colleagues therein). Such bifurcations radically differ from the saddle-node bifurcation and are not appropriately described by Figure 7.

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Slow-fast systems, and systems exhibiting somewhat sophisticated bifurcations such as homoclinic bifurcations, may often be interpreted in terms of relaxation dynamics. They allow one to formalise phenomena associated with ‘quasi-stable’ states near which the system may reside a long but finite time (formally, they are attracting when being approached in one direction and repelling in another one). The Bølling-Allerød episode could possibly be interpreted as such a quasi-stable state. How would indices such as ACF, DFA and variance indicators behave in such scenarios? Would such scenarios be compatible (or not) with the data presented here?

By addressing the two comments below (presentation and commenting about implications of other possible bifurcation scenarios) the paper would surely be a welcome addition to the understanding of abrupt events during the deglaciation.

3 Bibliography

M. Crucifix, Oscillators and relaxation phenomena in Pleistocene climate theory, Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 370, 1140-1165 2012

Interactive comment on Clim. Past Discuss., 8, 321, 2012.