Geophysical Research Abstracts
Vol. 15, EGU2013-6116, 2013
EGU General Assembly 2013

Dimension reduction of some paleoclimate models like Saltzman and Maasch 1990

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A pleiad of paleoclimate models have been proposed in the literature in order to describe the glacial-interglacial cycles. Some have been developed on a strong physical basis, like the models proposed by Saltzman, B. and Maasch, K. A. in 1990 (SM90) and 1991 (SM91), but others are on the contrary simple conceptual toy models, like the van der Pol-like relaxation oscillator (VDP). These models are often able, when driven by the orbital forcing (traditional Milankovitch hypothesis of a northern hemisphere ice-sheet control), to reproduce with some success the actual paleoclimate response, paced by orbital variations.

In order to achieve an unified view on these numerous paleoclimate models, and to better understand their similarities or peculiarities, it is worth to compare their dynamical behaviour and detailed structure. The result of such a comparison would further allow us to determine equivalence classes for the models.

But the formal comparison of two different paleoclimate models is already not easy at all, as they usually may also differ by the dimension of the underlying dynamical system: e.g., the VDP model has two first-order equations, while the SM90 has three. Additionally, it is known that dynamical systems tools become rapidly computationally complex with increasing dimension; hence there is a clear interest to lower the size of a dynamical system as much as possible for itself, even without performing any comparison with another one.

In this study, we propose to reduce the dimension of some three-dimensional paleoclimate models to two, so that the reduced two-dimensional system can then be more easily investigated in-depth and also compared to other two-dimensional competitor systems. We first perform an heuristic reduction which uses the relatively planar geometry of the climatic attractor. We then propose a rigorous approach based on the singular perturbation theory, which yield already good results at low order of expansion; both reductions are coherent.

This study is believed to constitute a significant step towards an unified view and an easier comparison of authoritative low-dimensional paleoclimate models.