Strengths and weaknesses of a synchronisation: possible jumps to other climate histories paced by the astronomical forcing

Bernard De Saedeleer (UCL)

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Paleoclimatic records have shown evidence of glacial/interglacial asymmetric cycles over the last millions years of the Plio/Pleistocene. In Milankovitch's theory, these ice ages may be related to the incoming solar radiation (insolation), induced by a varying Sun-Earth astronomical configuration. This astronomical forcing is often said to be a 'pacemaker' of ice ages (Hays et al. 1976); the underlying idea is that ice ages are a manifestation of dynamics internal to the climate system, but their timing is set by the astronomical forcing. This interpretation may be linked to the universal concept of synchronization in nonlinear sciences and in dynamical system theory.

In this talk, we go a step further in the study of such a synchronization by investigating its robustness and uniqueness by way of a conceptual model of ice ages in order to illustrate the fundamental mechanisms: a modified van der Pol relaxation oscillator, forced by the insolation. Our approach relies on several concepts and tools borrowed from dynamical system theory (like attractors, non autonomous systems, basins of attraction, global and local stabilities, largest Lyapunov exponents, quasiperiodicity, multistability, etc.), from modern mathematical theories like the pullback attractor, and also from statistical analysis.

We discovered that multiple possible locking states (attractors) could coexist for the system; this is a particularly interesting result, as there is an apparent contradiction with the uniqueness hypothesis of [Tziperman et al, "Consequences of pacing the Pleistocene 100 kyr ice ages by nonlinear phase locking to Milankovitch forcing", Paleoceanography, 21:PA4206, 2006]. We also find that climatic orbits could diverge for some period of time, due to a small perturbation. As the attracting trajectories can sometimes lie quite close to the boundary of their basins of attraction, a small perturbation could cause a jump to another climate history, reducing predictability.

In the second part of the talk, we show recent results (extensive Monte Carlo experiments with a simple stochastic toy model to characterise stochastically-induced climate jumps) which confirm previous findings. We also illustrate how the multistability analysis has been extended to other published paleoclimatic models to stress the fact that the conclusion could be generalised, with a potential impact on the overall theory of ice ages, as such jumps reduce the predictability of the timing of the glacial inceptions and terminations. We finally extend the scope of this study by mentioning several ongoing research collaborations.

Reference : "Is the astronomical forcing a reliable and unique pacemaker for climate? A conceptual model" Climate Dynamics, 2012, in Press, DOI: 10.1007/s00382-012-1316-1, available as 'Online First' (Open Access).