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The mid-Pleistocene transition and slow fast dynamics

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The structure of glacial-interglacial cycles over the last 400 ka, with gradual accumulation of ice and rapid deglaciation, is reminiscent of so-called 'relaxation systems' with slow-fast dynamics. The fundamental idea, which has been expressed in a number of conceptual model, is that certain components the climate system may change state abruptly and that theses state changes affect the other dynamical components of the climate system.

In dynamical system theory, the 'van der pol' oscillator is archetypal of slow-fast dynamics. With only a very few ad hoc hypothesis it is indeed possible to calibrate a van-der-pol oscillator such as to convincingly reproduce the course of the benthic record over the last 800 ka. Furthermore, relaxation oscillators exhibit phase-locking properties on the external forcing, consistent with the paradigm of 'astronomical forcing, pacemaker of ice ages'. In summary, the concept of relaxation oscillations is a attractive model of ice ages because it can be justified on physical grounds and very generic models of theses oscillations are consistent with the late Pleistocene record.

An interesting problem arises when considering the mid-Pleistocene transition. One explanation of the mid-Pleistocene transition is that it is a response to some small change in environmental conditions, for example a tectonically-driven decline in the concentration in CO_2. Within our modelling framework it can therefore be interpreted as a phenomenon of bifurcation. Following the earlier works of Saltzman et al. we therefore study the bifurcation in the van-der-pol oscillator associated with a drift (control) parameter added to the ice-volume equation.

In a slow-fast relaxation system, however, this bifurcation is particularly brutal. The phenomenon is well known as a 'Canard explosion'. The dynamics of this explosion is here visualised using a continuous wavelet transform analysis. They are found to be qualitatively different from those inferred from palaeo-oceanographic data. In the latter, the transition from the 40 kyr regime to 100-kyr oscillations is quite gradual, and passes through a significant period of a 2:1 synchronisation on obliquity. Intriguingly, this transition was much better captured by an earlier model by Saltzman. This earlier model is similar in some respect to a van-der-pol oscillator but it discard the slow-fast assumption. Consequently, the sequence of bifurcations from linear dynamics (typical of the 40-kyr regime) to limit-cycle dynamics (100-kry regime) is easier to analyse and far more regular. By contrast, the physical interpretation of the Saltzman system is arguably more problematic.