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The Middle Pleistocene transition as a generic bifurcation on a slow manifold

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The Quaternary Period has been characterised by a cyclical series of glaciations, which are attributed to the change in the insolation (incoming solar radiation) from changes in the Earth's orbit around the Sun. The spectral power in the climate record is very different from that of the orbital forcing: Prior to 1000 kyr before present (BP) most of the spectral power is in the 41 kyr band while since then the power has been in the 100 kyr band. The change defines the middle Pleistocene transition (MPT). The MPT does not indicate any noticeable difference in the orbital forcing. The climate response to the insolation is thus far from linear, and appears to be structurally different before and after the MPT.

This paper presents a low order conceptual model for the oscillatory dynamics of the ice sheets in terms of a relaxation oscillator with multiple levels subject to the Milankovitch forcing. The model exhibits smooth transitions between three different climate states; an interglacial (i), a mild glacial (g) and a deep glacial (G) as proposed by Paillard (1998). The model suggests a dynamical explanation in terms of the structure of a slow manifold for the observed allowed and "forbidden" transitions between the three climate states. With the model we propose that the synchrony of the climate oscillations with the astronomical forcing is through the mechanism of phase-resetting oscillation in which the internal frequency of oscillation is increased to match the frequency of the forcing, while the opposite possibility of a faster internal oscillation cannot be slowed down to match a longer period forcing.

In spite of its simplicity as a forced ODE, the model is able to reproduce many of the details of oscillations observed in the climate record. A particular novelty is that it includes a slow drift in the form of the slow manifold that reproduces the observed dynamical change at the MPT. We explain this change in terms of a transcritical bifurcation in the fast dynamics on varying the slow variable; this bifurcation can induce a sudden change in periodicity and amplitude of the cycle and we suggest that this is associated with a branch of "canard oscillations" that appear for a small range of parameters. The model is remarkably robust at simulating the climate record before, during and after the MPT.