On the Multistability and Excitability Paradigms in Climate Dynamics

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An important dynamical systems paradigm in climate dynamics is *multistability*. In this case the system possesses several (typically two) stable states. Transitions from one of these states to another can occur spontaneously if a certain threshold is exceeded, in which case the system exhibits limit cycles or strange attractors. Otherwise, transitions can occur through the action of an external -random or deterministic- forcing, which may induce abrupt shifts and hysteresis behavior.

On the other hand, the paradigm of *excitable system* also plays an important role in explaining abrupt climate shifts. An excitable system possesses a basic state, which can be either an equilibrium point, a small amplitude limit cycle or even a strange attractor with limited extension in phase space. An abrupt shift leading to an unstable excited state can occur, followed by a spontaneous, slow return to the original state. Such large-amplitude transition, called *relaxation oscillation*, is self-sustained if a certain tipping point is passed; otherwise, it can be excited by a suitable random or deterministic external forcing (*coherence resonance*).

Interestingly, in some cases, both paradigms have been invoked in competing theories proposed to explain the same climate phenomenon. This is, for example, the case of (i) the low-frequency fluctuations of western boundary current extensions, such as those of the Kuroshio Extension in the North Pacific Ocean, and of (ii) the glacial-interglacial variability in the late Pleistocene. Here it is shown that the relaxation oscillation-excitable system paradigm, reformulated in terms of the *deterministic excitation* mechanism, guides the modeling of these two phenomena, with results that are in good agreement with altimeter (i) and proxy (ii) data.