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Deconstructing an Atmospheric Model: Variability and Response, Unstable Periodic Orbits, and the Fluctuation-Dissipation Theorem

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Unstable periodic orbits (UPOs) provide the so-called skeletal dynamics of a sufficiently well-behaved chaotic dynamical system and provide a powerful tool for relating the response of the system to its variability. In fact, UPOs constitute natural modes of variability of the system, and resonant behaviour of the response of the system to can be associated to good correspondence between the geometry of one UPO and of the forcing term and between their periodicities. We have here analyzed a simple barotropic model of the atmosphere and constructed and found algorithmically a large number of UPOs. We have then studied the change in the climate resulting from changes in the forcing, in the orography, and in the Eckman friction. The most interesting result is the presence of a strong resonance in the orographic response on time scales of the order of about 3 days, corresponding to forced waves. Interestingly, such a spectral feature is entirely absent from the natural variability of the system and correspond to the excitation of a specific group of UPOs. This clarifies the fact that, as opposed to the case of quasi-equilibrium systems, it is far from obvious to associate forced and free variability in the spirit of the fluctuation-dissipation theorem (FDT). Reassuringly, ysing the complementary point of view of covariant Lyapunov vectors, we discover that the forcing projects substantially in the stable direction of the flow, which is exactly the mathematical setting under which the FDT cannot be applied.