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Symmetry breaking, mixing, instability, and low-frequency variability in a minimal Lorenz-like system

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Starting from the classical Saltzman two-dimensional convection equations, we derive via a severe spectral truncation a minimal 10 ODE system which includes the thermal effect of viscous dissipation. Neglecting this process leads to a dynamical system which includes a decoupled generalized Lorenz system. The consideration of this process breaks an important symmetry and couples the dynamics of fast and slow variables, with the ensuing modifications to the structural properties of the attractor and of the spectral features. When the relevant nondimensional number - Eckert number Ec - is different from zero, an additional time scale of order Ec^(−1) is introduced in the system, as shown with standard multiscale analysis and made clear by several numerical evidences. Moreover, the system is ergodic and hyperbolic, the slow variables feature long-term memory with f^(-3/2) power spectra, and the fast variables feature amplitude modulation. Increasing the strength of the thermal-viscous feedback has a stabilizing effect, as both the metric entropy and the Kaplan-Yorke attractor dimension decrease monotonically with Ec. The analyzed system features very rich dynamics: it overcomes some of the limitations of the Lorenz system and might have prototypical value in relevant processes in complex systems dynamics, such as the interaction between slow and fast variables, the presence of long-term memory, and the associated extreme value statistics. This analysis shows how neglecting the coupling of slow and fast variables only on the basis of scale analysis can be catastrophic. In fact, this leads to spurious invariances that affect essential dynamical properties - ergodicity, hyperbolicity - and that cause the model losing ability in describing intrinsically multiscale processes.