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One Saddle Point and Two Types of Sensitivities Within the Lorenz 1963 and 1969 Models

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The fact that both the Lorenz 1963 and 1969 models suggest finite predictability is well-known. However, it is less known that mechanisms (i.e., sensitivities) within both models that lead to finite predictability are different. Additionally, the mathematical and physical relationship between these two models has not been fully documented. New analyses along with literature review are performed here to provide insights on the similarities and differences for these two models. The models represent different physical systems, one for convection and the other for barotropic vorticity. From theperspective of mathematical complexities, the Lorenz 1963 (L63) model is limited-scale and nonlinear; and the Lorenz 1969 (L69) model is closure-based, physically multiscale, mathematically linear, and numerically ill-conditioned. The former possesses a sensitive dependence of solutions on initial conditions, known as the butterfly effect, and the latter contains numerical sensitivities due to an ill-conditioned matrix with a large condition number (i.e., a large variance of growth rates).

Here, we illustrate that the existence of a saddle point at the origin is a common feature that produces instability in both systems. Within the chaotic regime of the L63 nonlinear model, unstable growth is constrained by nonlinearity, as well as dissipation, yielding time varying growth rates along an orbit, and, thus, a dependence of (finite) predictability on initial conditions. Within the L69 linear model, multiple unstable modes at various growth rates appear, and the growth of a specific unstable mode (i.e., the most unstable mode during a finite time interval) is constrained by imposing a saturation assumption, thereby yielding a time varying system growth rate. Both models have been interchangeably applied for qualitatively revealing the nature of finite predictability in weather and climate. However, only single type solutions were examined (i.e., chaotic and linearly unstable solutions for the L63 and L69 models, respectively), and the L69 system is ill-conditioned and easily captures numerical instability. Thus, an estimate of the predictability limit using either of the above models, with or without additional assumptions (e.g., saturation), should be interpreted with caution and should not be generalized as an upper limit for predictability of the atmosphere.