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Intraseasonal atmospheric variability under climate trends

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Low-order climate models have played an important role in understanding the low-frequency variability of the atmospheric circulation and how it can be affected by trends in anthropogenic forcing. A simple quasi-geostrophic model of the midlatitudes' circulation (Lorenz, Tellus, 1984, 1990) is studied from the perspective of the theory of nonautonomous dynamical systems (NDS: e.g., Ghil et al., Physica D, 2008).

We start with a study of the model's behavior in the absence of time dependent forcing and determine in this case its steady states. A bifurcation analysis is carried out in order to identify distinct regime behavior types – stationary, periodic and chaotic – in the model's parameter space. Next, we study the nonautonomous system with a meridional temperature gradient that varies seasonally, according to changes in insolation. The snapshot attractor (Tel et al., JSP, 2020) of the seasonally forced model is compared with the standard forward attractor of the autonomous model for two distinct epochs of the year, at peak summer and peak winter. In both cases, the effects of the change in forcing are reflected in a clear change of shape of the attractor. Predictability is lost in both cases: the summer attractor loses its periodicity when the forcing is seasonal. The winter one favors energy transport through one of the two wave components included in the model. For the same value of the forcing, the structure of the attractor in the autonomous case is quite different from that in the nonautonomous one.

Finally, the meridional forcing is subjected to climate trends, both positive and negative, since the jet intensity changes in opposite directions at low and high altitudes (Lee et al., Nature, 2019). The analysis of the snapshot attractor of the system under climate trends suggests that the model does not follow the geostrophic assumption in certain ranges of the forcing, as the average zonal flow does not always show the expected dependence on the equator-to-pole temperature contrast. On the other hand, the energy transported by the eddies does follow the sign of the climatic trend. Overall, distinct effects are observed. Chaotic behavior can be completely suppressed in favor of a regularly periodic one and vice-versa. At the same time, circulation patterns can change, suddenly disappear, and be restored.

In general, the snapshot attractor proved to be a robust tool in studying the internal variability of the midlatitude circulation, as well as the changes arising in it from anthropogenic forcing trends.

The distinct regimes of behavior are being examined more closely by advanced spectral analysis methods (Ghil et al., Rev. Geophys., 2002) to better understand the effects of climate trends on low-frequency variability.