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New nonlinear mechanisms of midlatitude atmospheric low-frequency variability

Alef Sterk (2), Renato Vitolo (1), Henk Broer (2), Carles Simo (3), and Henk Dijkstra (4)

(1) University of Exeter, College of Engineering, Mathematics and Physical Sciences, Exeter, United Kingdom (r.vitolo@exeter.ac.uk), (2) University of Groningen, Johann Bernoulli Institute for Mathematics and Computer Science, (3) University of Barcelona, Department of Applied Mathematics and Analysis, (4) University of Utrecht, Institute for Marine and Atmospheric Research Utrecht

We investigate the dynamical mechanisms potentially involved in the so-called atmospheric low-frequency variability, occurring at midlatitudes in the Northern Hemisphere. This phenomenon is characterised by recurrent non-propagating and temporally persistent flow patterns, with typical spatial and temporal scales of 6000-10000 km and 10-50 days, respectively.

We study a low-order model derived from the 2-layer shallow-water equations on a β-plane channel. The main ingredients of the low-order model are a zonal flow, a planetary scale wave, orography, and a baroclinic-like forcing.

A systematic analysis of the dynamics of the low-order model is performed using techniques and concepts from dynamical systems theory. Orography height (h_0) and magnitude of zonal wind forcing (U_0) are used as control parameters to study the bifurcations of equilibria and periodic orbits. An equilibrium loses stability ($U_0 \geq 12.5$ m/s) along two curves of Hopf bifurcations and gives birth to two distinct families of periodic orbits. These periodic orbits bifurcate into strange attractors along three routes to chaos: period doubling cascades, breakdown of 2-tori by homo- and heteroclinic bifurcations, and intermittency ($U_0 \geq 14.5$ m/s and $h_0 \geq 800$ m).

The observed attractors exhibit spatial and temporal low-frequency patterns comparing well with those observed in the atmosphere. For $h_0 \leq 800$ m the periodic orbits have a period of about 10 days and patterns in the vorticity field propagate eastward. For $h_0 \geq 800$ m, the period is longer (30-60 days) and patterns in the vorticity field are non-propagating. The dynamics on the strange attractors are associated with low-frequency variability: the vorticity fields show weakening and strengthening of non-propagating planetary waves on time scales of 10-200 days. The spatio-temporal characteristics are "inherited" (by intermittency) from the two families of periodic orbits and are detected in a relatively large region of the parameter plane. This scenario provides a characterisation of low-frequency variability in terms of intermittency due to bifurcations of waves.