Idealized Simulation of Jupiter's Midlatitude Circulation [1]

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Below are shown idealized numerical simulations of the midlatitude circulation on Jupiter within the weather layer, which contains the visible clouds. The simulations assume conservative quasigeostrophic dynamics in a one-layer reduced-gravity setting on a midlatitude doubly-periodic β plane:

$$\partial_t q + [\psi, q] = 0 \tag{1a}$$

where [,] is the Jacobian bracket,

$$q = \nabla^2\psi - R^{-2}\psi + \beta y \tag{1b}$$

is the quasigeostrophic potential vorticity (often referred to as PV), and R is the deformation radius.

The quasigeostrophic equation (1) is solved pseudospectrally assuming an Arakawa Jacobian representation and using an Adams–Bashforth time-stepping scheme. The stability of the integration is controlled by applying a weak exponential cutoff filter and including a small amount of hyperviscosity. The initial condition of the simulation is a small perturbation, consisting of a superposition of periodic displacements of PV contours with random phases uniformly distributed on $[0, 2\pi]$, to a piecewise constant PV distribution (PV-staircase) where the ideal PV jumps have smooth transition regions with tanh dependence on y locally. The associated flow resulting from PV inversion consists of bands of alternating zonal sharp eastward and broader westward jets. The separation between adjacent eastward jets, $2b$, is 8000 km and $\beta = 3.442 \times 10^{-9}$ km^{-1}s^{-1} is used. The simulations shown correspond to a deformation radius $R = b/2$. These parameter choices approximately reproduce conditions on Jupiter.

Movie 1 (p. 2) corresponds to a 1-year high-resolution simulation (1.6 Mb), whereas Movie 2 (p. 3) to a 10-year lower-resolution simulation (6.8 Mb). Note in these animations that both eastward *and* westward jets' cores act as robust meridional transport barriers, which provides a simple explanation of the observation that neighboring belts and zones in Jupiter's atmosphere maintain distinct chemical compositions. That both eastward and westward zonal jets serve as robust meridional transport barriers is consistent with the strong KAM stability mechanism (Rypina et al., 2007a;b), but not with the PV-barrier mechanism (McIntyre, 1989).

References

McIntyre, M. E. (1989). On the antartic ozone hole, *J. Atmos. Terr. Phys.* **51**: 29–43.

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Rypina, I. I., Brown, M. G., Beron-Vera, F. J., Kocak, H., Olascoaga, M. J. and Udovydchenkov, I. A. (2007b). Robust transport barriers resulting from strong Kolmogorov–Arnold–Moser stability, *Phys. Rev. Lett.* **98**: 104102.

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Movie 1 (Top-Left Panels) Instantaneous zonally-averaged zonal velocity (left) and streamfunction (right). (Top-Right Panel) Instantaneous direct finite-time Lyapunov exponents as a function of initial position. (Bottom-Left Panel) Instantaneous zonally averaged potential vorticity (left) and potential vorticity in (x, y) plane (right). (Bottom-Right Panels) Instantaneous tracer distributions for particles initially lying on lines midway between the eastward and westward jets in the upper-left-most panel at $t = 0$. Instantaneous values of energy and enstrophy normalized by their initial values are indicated on the top of the upper-right panel.

Movie 2 (Top-Left Panels) Instantaneous zonally-averaged zonal velocity (left) and streamfunction (right). (Top-Right Panel) Instantaneous energy and enstrophy normalized by their initial values along the simulation. (Bottom-Left Panel) Instantaneous zonally averaged potential vorticity (left) and potential vorticity in (x, y) plane. (Bottom-Right Panels) Instantaneous tracer distributions for particles initially lying on lines midway between the eastward and westward jets in the upper-left-most panel at $t = 0$.