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Equatorial superrotation through wave-jet resonance and Hadley cell feedbacks

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A long standing question in the study of the general circulation of the atmosphere is the uniqueness of the solution, for fixed boundary conditions. This is not just an academic question: it could profoundly impact climate dynamics through the potential appearance of tipping points associated to bistability.

An interesting candidate for such a global bifurcation of the general circulation of the atmosphere is equatorial superrotation: it corresponds to the appearance of a strong westerly jet in the tropical troposphere. While present-day Earth has weak easterlies in the tropics, superrotation is actually observed on other planets of the Solar System, such as Jupiter, Saturn (and its moon Titan) or Venus, and is widely believed to be relevant for the atmosphere of tidally-locked exoplanets, for instance. Furthermore, it has been suggested that it might have played a role in some climates of the past, such as the Cenozoic.

Several routes to superrotation have been suggested, involving various wave-mean flow interaction mechanisms. A crucial point is that such mechanisms should be able to transport angular momentum up-gradient, resulting in positive eddy momentum flux convergence in the tropics. Here, we focus on a related but different question: under which conditions can a conventional and a superrotating circulation coexist, for the same values of the flow parameters?

For bistability to occur, a feedback mechanism is necessary. The Hadley cell provides such a mechanism: in principle it deccelerates the wind in the tropical upper troposphere, but its strength decreases with increasing vertical shear. Another possibility is that equatorial waves, for instance generated by some non-zonally symmetric tropical heating, exhibit a resonance phenomenon with the background mean-flow. Using a low-dimensional model based on a simplified zonal momentum balance, as well as simulations of the axisymmetric primitive equations and full GCM simulations, we shall discuss the interplay between these two feedback mechanisms, and show that bistability between a conventional and a superrotating state may indeed be observed.