Metastability in Atmospheric Jets

Synopsis

Atmospheric flows on rotating planets are prone to form jets that are surprisingly stable in time. This behaviour can be predicted by simulating the planet's atmosphere numerically. In certain parameter regimes, the underlying dynamical system has multiple locally stable solutions, corresponding to atmosphere configurations with different numbers of jets. This project explores the mechanisms by which random turbulent fluctuations in the atmosphere drive the system to transition between these fixed points, effectively creating or destroying atmospheric jets in the process.

Supervisor

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Background

Atmospheric flows on rotating planets are described by partial differential equations, such as the 2D barotropic equations, and have been known to lead to large-scale atmospheric patterns in the form of jets, such as Earth's jet stream, or the jets of Jupiter or Saturn, as depicted in the figure. One can use the separation of time-scales between jet formation (weeks, months) and turbulent fluctuations (hours, minutes) to formulate a simple model system for jet formation [1].

The existence of multiple stable fixed points in this system allows to reason about transition probabilities and lifetimes of atmospheric jets. The main question is: Under what conditions, and from what mechanisms, can the system switch, and with what probability, i.e. how likely is it that Jupiter looses one of its jets. The question received particular interest recently when the Juno space probe reached Jupiter, and Jupiter's jets were found to be very precisely in the same state as when the Voyager probe visited (in 1976), i.e. jets are extremely stable. Nevertheless it is believed that Jupiter DID loose a jet sometime in the 1940ies or so.

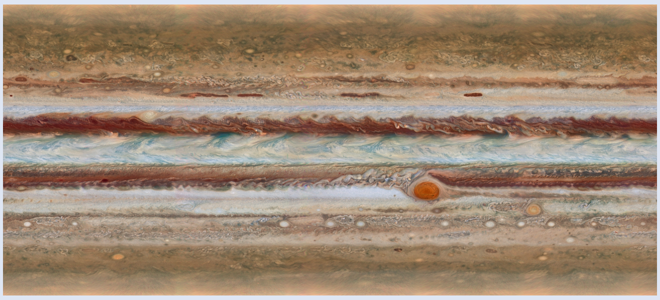
Miniproject aims and objectives

The main goal of the miniproject would be to implement a simple numerical solver to search for jet solutions in atmospheric flows. By identifying parameter regimes where multiple fixed points exist, a bifurcation analysis can be carried out, and the landscape of the dynamical system can be mapped. This allows to predict regimes where transitions are possible, and transition states may be identified.

PhD Project

Possible continuations of the miniproject involve exploring the landscape of fixed points, including saddle points, by rare events techniques such as the string method [2] to gain knowledge on the transition dynamics. These results can in turn be used to inform more sophisticated approaches harnessing the time-scale separation [3].

Jupiter's Jets



Atmospheric jets on Jupiter as observed by Cassini

Student Requirement

Many of the objectives necessitate writing small proof-of-work scripts and experience in scientific computing. Prospective students should therefore bring some prior experience in matlab or python.

References

[1] F. Bouchet, C. Nardini, and T. Tangarife, Journal of Statistical Physics **153**, 572 (2013).

[2] W. E, W. Ren, and E. Vanden-Eijnden, Physical Review B **66**, 052301 (2002).

[3] F. Bouchet, T. Grafke, T. Tangarife, and E. Vanden-Eijnden, Journal of Statistical Physics , 1 (2016).