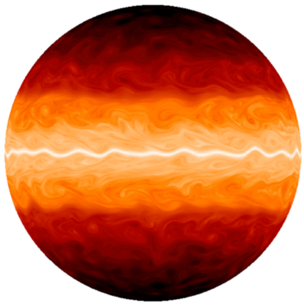
A Statistical Physics Approach To Abrupt Climate Changes: Application To Equatorial Superrotation



Potential vorticity in a numerical simulation of a superrotating equatorial jet (Scott and Polvani, 2008).

Abrupt transitions of the climate of the Earth are believed to have occurred in the past, and are a crucial point in the public debate about global warming. This project aims at putting this question on a robust scientific basis by studying bistability and phase transitions of the general circulation of the atmosphere. In particular, we shall focus on the possibility of an abrupt transition towards a state of strong eastward jet velocities at the equator, referred to as superrotation. Such a bifurcation would drastically change the climate of the Earth at a global scale, modifying the monsoon structure and the mid-latitude weather. In fact, several planetary atmospheres in our solar system exhibit a strongly superrotating equatorial jet (e.g. Venus, Jupiter and Saturn). Moreover, while the paleoclimate evidence is still too scarce for a definitive answer, several authors have hypothesized that the Earth has experienced superrotation in the remote past.

The hypothesis we will test is that for some range of parameters, both a superrotating and conventional circulation can exist, and that random fluctuations of the dynamics may trigger a transition from one state to the other. We will study the relative probability of the two attractors and the dynamics of transitions from one state to the other. A major challenge to address such questions is that they involve the long-term dynamics of turbulent jets at the planetary scale. Running current atmospheric models with many degrees of freedom over such time scales is impossible. To help solving this issue, we propose to use the most modern tools of statistical physics. These tools have been applied to geophysical flows and climate dynamics during the last decade, giving impressive results; for instance to explain the structure of coherent structures such as the Great Red spot of Jupiter [1, 2]. Recently, we have used large deviation algorithms, based on statistical mechanics ideas, to observe rare transitions between states with a different number of atmospheric jets, for Jupiter's troposphere, and to study the probability of extreme heat waves over Europe, gaining several orders of magnitude compared to direct computation [3, 4]. One part of the project is to use such algorithms to study superrotating equatorial jets. We will combine such innovative tools with more traditional approaches. In particular, the project will involve numerical simulations with an idealized atmospheric GCM; we shall rely on the Isca framework, developed recently around the GFDL dynamical core. One goal of the project is to understand the dynamical mechanisms responsible for eddy momentum flux convergence at the equator, which will be diagnosed using classical wave-mean flow analysis as well as new statistical mechanics ideas.

Practical Information

- **Scope:** Funding is available for a one year post-doctoral position. Start date is flexible.
- **Profile:** We are looking for candidates with a PhD either in physics (statistical physics, fluid dynamics) or in geophysical fluid dynamics. The project involves both numerical and theoretical aspects.
- **Location:** *Laboratoire de Physique de l'ENS de Lyon (UMR5672)*, Lyon, France.
- **Supervisors:** Corentin Herbert and Freddy Bouchet (CNRS, ENS de Lyon).

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lyon.fr.

References

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[2] C. Herbert. “An Introduction to Large Deviations and Equilibrium Statistical Mechanics for Turbulent Flows”. In: *Stochastic Equations for Complex Systems: Theoretical and Computational Topics*. Ed. by S. Heinz and H. Bessaih. Springer, 2015. Chap. 3, 53–84.

[3] T. Lestang, F. Ragone, C.-E. Bréhier, C. Herbert, and F. Bouchet. “Computing return times or return periods with rare event algorithms”. *J. Stat. Mech.* **043213** (2018).

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