GENERATING JOVIAN-LIKE ZONAL JETS IN A RAPIDLY ROTATING FLUID EXPERIMENT

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Abstract

Using a large-scale rotating fluid experiment, we report the formation of strong zonal jets due to topographical effects in rotating turbulence. For the first time, we reach the so-called "zonostrophic" regime, thought to be relevant to Jupiter atmosphere for example. The jets dominate the small-scale turbulent fluctuations in amplitude and appear very stable and long-lived. Although their size is consistent with the so-called Rhines scale, we observe interesting dynamics over very long time-scales such as merging events where the number of jets decreases and their amplitude increases. These first results open new perspectives in the study of large-scale zonal flows in the laboratory.

For our experimental set up (see figure **??**(c)), we use a cylindrical container 1.4 meter high with an internal radius of 0.5 meter filled with up to 400 liters of water and mounted on a rotating table. The depth of the fluid layer at rest is $h_0 = 50$cm and the rotation rate of the table is 75 RPM. This leads to a very large deformation of the fluid layer (topographic β-effect), with a minimum depth after the spin-up phase of $h = 20$cm at the center of the container and a maximum depth of on the side boundary of $h = 88cm$. A turbulent small-scale flow is driven via a basal injection/suction system made of a square tiled set of 64 inlet/outlet ports, generating velocities in the range $U \approx 1 - 5$ cm/s (corresponding to a Reynolds number $2.5 \times 10^3 < Re < 1.3 \times 10^4$ and a Rossby number $3.3 \times 10^{-3} < Ro < 1.6 \times 10^{-2}$). Lagrangian surface velocities are measured using a Particle Tracking method using small floating particles with a typical diameter of 5 mm.

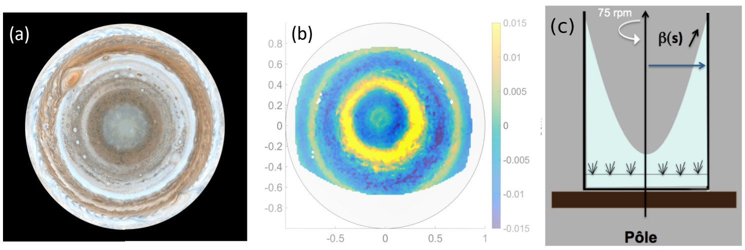

Figure 1. zonal jets visualization and experimental set-up. (a) Polar view of Jupiter atmosphere (Credit: NASA/JPL/Space Science Institute). (b) Time averaged zonal velocity map obtained by particles tracking in our experiment: blue/yellow values are retrograde/prograde jets (velocity non-dimensionalized by the rotation rate times the tank radius). (c) Sketch of our experimental model reproducing the suitable zonostrophic planetary conditions in a cylindrical geometry, i.e. fast rotation, topographic β-effect and small scale turbulent energy injection.

After the spin-up is complete, we start the pumping system forcing quasi-homogeneous small-scale turbulence at the base of the domain. Due to the very low Rossby numbers, the basal forcing very quickly drives a nearly depth-invariant turbulent flow. The dominantly geostrophic flow is confirmed by the numerical simulations and shows that Lagrangian surface measurements are sufficient to characterize the system in a first approach. After several tens of rotation times, alternating zonal jets start to grow as shown figure **??**. The initial number of jets is consistent with the so-called Rhines scale, derived from a balance between the turbulent turn-over time scale and the typical frequency of Rossby waves [**?**]. Contrary to previous experiments, where the zonal jets are mainly observed after time averaging, our jets reach the so-called "zonostrophic" regime, where the instantaneous amplitude of the jets is greater than that of the small-scale fluctuations.

We obtained for the first time strong zonal jets in the so-called zonostrophic regime. These jets are extremely stable and live over many rotation timescales, but we nevertheless observe interesting merging events. Our systematic study allows to understand this dynamics, as well as what fixes the size and the amplitude of the jets. In the near future, implementations of our system will allow tacking many interesting questions in the laboratory, like the formation of large-scales vortices in the presence of a top stratified layer [**?**] and the existence of inertial wave turbulence [**?**] .

References

[1] P. L. Read, et al.: An experimental study of multiple zonal jet formation in rotating, thermally driven convective flows on a topographic beta-plane. Phys. Fluids 27, 085111, 2015.

[2] P. F. Fischer, et al.: Simulation of high-Reynolds number vascular flows. Comp. Meth. App. Mech. and Eng. 196 (31), 3049–3060, 2007.

[3] G. K. Vallis & M. E. Maltrud: Generation of mean flows and jets on a beta plane and over topography. Journal of Physical Oceanography 23, no. 7, 1346–1362, 1993.

[4] M. Heimpel, T. Gastine & J. Wicht: Simulation of deep-seated zonal jets and shallow vortices in gas giant atmospheres. Nature Geoscience 9, 19–23, 2016.

[5] E. Yarom & E. Sharon: Experimental observation of steady inertial wave turbulence in deep rotating flows. Nature Physics 10, 510–514, 2014.