

Subject Panel: Mathematical Methods and Applications

Suggested title of dissertation: β -plane turbulence - vortices vs zonal jets

Dissertation supervisor: Dr. Vassilios Dallas

Description of proposal:

Zonal jets - generally banded, shear flows (see Jovian atmosphere in Fig. 1) - are spontaneously generated from turbulence and have been reported in the context of planetary atmospheres [1]. Zonal flows are playing a crucial role in the regulation of turbulence and turbulent transport of atmospheres [2]. A greater understanding of zonal flows behaviour is valuable for untangling a host of non-linear processes in geophysical and astrophysical fluids. Zonal flows remain incompletely understood, even regarding the basic question of the jet width.

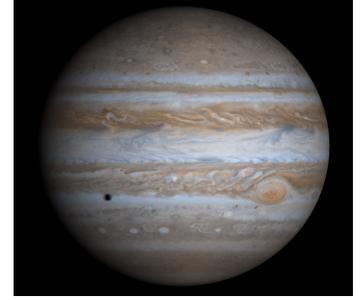


Figure 1: Zonal jets in the atmosphere of Jupiter

This project will involve numerical simulations of the incompressible 2D Navier-Stokes equation on a β -plane, which reads

$$\partial_t \omega + \mathbf{u} \cdot \nabla \omega = -\alpha \omega + \beta \partial_y \psi + \nu \nabla^2 \omega + f$$

where $\omega = -\nabla^2 \psi$ is the vorticity, ψ is the streamfunction, f is an external mechanical force driving the flow, α is the large scale friction coefficient and the term $\beta \partial_y \psi$ takes into account the effects of differential rotation. The computations will be performed in a square domain with periodic boundary conditions using a pseudospectral code that is designed to run on parallel computer clusters [3].

Possible avenues of investigation:

The main focus of this project is to systematically increase the β -effect and study the transition from coherent vortices to zonal flows. The results will provide new insights into the non-linear, multi-scale and statistical dynamics of these flows. This project will provide a unique experience on geophysical fluid dynamics, turbulence theory, numerical methods and scientific computing. Important results will be prepared for publication in a peer-reviewed journal.

Pre-requisite knowledge (listed as essential, recommended, useful)

Essential: some familiarity with numerical methods for PDEs and a programming language will be helpful.

Useful: The analysis is going to involve tools from turbulence theory, bifurcation theory, signal processing.

Useful reading

1. Maltrud M. E. and Vallis G. K. Energy spectra and coherent structures in forced two-dimensional and beta-plane turbulence. *J. Fluid Mech.* **228**, 321–342 (1991)
2. Danilov S. and Gurarie D. Scaling, spectra and zonal jets in beta-plane turbulence. *Phys. Fluids* **16**, 2592–2603 (2004)
3. Gómez D. O., Mininni P. D. and Dmitrum P. Parallel simulations in turbulent MHD. *Phys. Scripta* **T116**, 123–127 (2005)