Turbulence in Geophysical Flows

Stratified Rotational Instabilities

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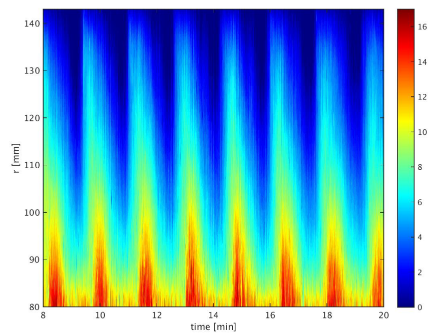
In Short

- Geophysical fluid dynamics
- Secondary instabilities and pattern formation in stratified rotating flows
- Turbulence in stratified stratified flows

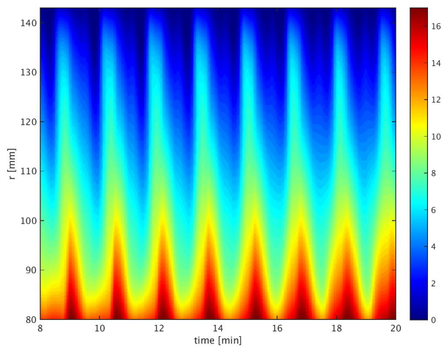
Understanding the mechanisms that can result in an outward angular momentum transport is the central problem of planet formation, particularly in the theory of accretion disks. When a planet forms in a disk, angular momentum has to be carried away from the planet otherwise its rotation speed would be far too large. Only turbulence can achieve such a large angular momentum transport. For disks coupled to a magnetic field the Magneto Rotational Instability (MRI) occurs and, regardless of other angular momentum transport processes, one expects the fluid to sustain Magneto Hydrodynamic Turbulence. However, accretion disks can be turbulent even in the absence of a magnetic field, e.g. in regions where the ionization fraction is low. In such regions, the disk cannot be unstable due to MRI and it is an important question to ask whether other instabilities can excite turbulence there. Among other candidates the stratorotational instability (SRI) has attracted attention in recent years. The SRI is a purely hydrodynamic instability and much insight can be obtained from particularly designed laboratory experiments and numerical simulations in an axially-stratified Taylor-Couette setup.

The experiment that has been designed and operated at the BTU Cottbus-Senftenberg is shown in Figure 2. Experimental results and a linear stability analysis of the stratorotational instability have been published in Rüdiger et al. (2017) and Seelig et al. (2018).

Numerical simulations of high Reynolds numbers turbulent flows in closed cavities are notoriously difficult and very computer time consuming. To take advantage of modern generation computing hardware, a scalable numerical method, based on a higher-order compact scheme, was developed to solve rotating stratified flows in cylindrical annular domains. An original approach combining 2d-pencil decomposition and reduced Parallel Diagonal Dominant is proposed to improve the parallelization performance during the computation of Poisson/Helmholtz solvers and time explicit terms. The developed technique was validated with respect to analytical solutions, using the method of manufactured solutions, and available data for two specific configurations. The ability to correctly capture the flow characteristics in stratorotational instability and in baroclinic instability with associated small-scale features was demonstrated in Abide et al. (2018). Moreover, this code is found to drastically reduce the huge execution times often preventing detailed numerical investigations of these complex phenomena. Strong scaling tests have been carried out to assess the performance for up to 576 cores using grid up to $32 \times 512 \times 512$ in azimuthal, radial, and axial directions, respectively.



(a)



(b)

Figure 1: *Space-time diagrams of the azimuthal velocity profiles with Reynolds number* 400 *and rotation ratio between inner and outer cylinders of* 0.35 *(a) Experiment. (b) Numerical simulation performed on the Cray XC30 in Berlin.*

Figure 1 shows space time diagrams comparing the SRI oscillations observed experimentally and in a numerical simulation performed at the HLRN machines during the last year. In Figure 1, the x-axis represents time and the y-axis the radial position between the inner and outer cylinder, while the color map shows the azimuth velocity profile. As can be seen, experiment and numerical simulations show excellent agreement. Comparisons in the more turbulent regimes are still to be performed in the proposed project. The full 3-D field of the SRI mode can be seen in Figure 3.

The present code still needs to be adapted to better simulate higher Reynolds number flows. After this, the model will be suitable to reach so far unexplored Reynolds number regimes that are characterized by small-scale turbulence. High-performance computing has been helping to solve the puzzling outward momentum transport that is necessary to explain aspects of planet formation from accretion disks.

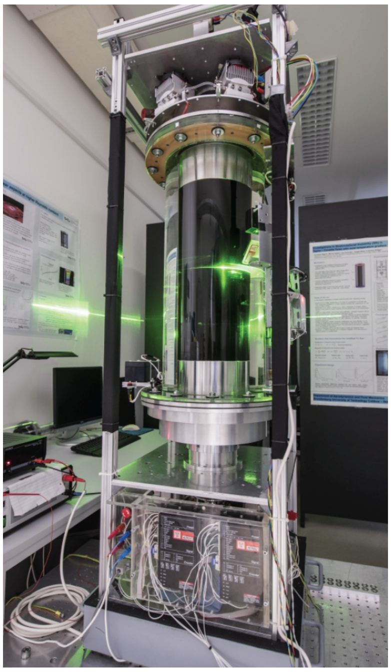


Figure 2: The SRI experiment at BTU Cottbus-Senftenberg with inner/outer cylider radius of $75mm/145mm$, and length of $700mm$. The system is cooled at the bottom and heated at top.

WWW

https://www.b-tu.de/fg-aerodynamik-stroemungslehre/forschung/schwerpunkte/stroemungsmechanik/sri

More Information

[1] G. Rüdiger, T. Seelig, M. Schultz, M. Gellert, C. Egbers, U. Harlander, *Geophys. and Astrophys. Fluid Dyn.* **111**, 429 - 447 (2017)

[2] T. Seelig, U. Harlander, M. Gellert, *Geophys. and Astrophys. Fluid Dyn.* **112**, 239 - 264 (2018)

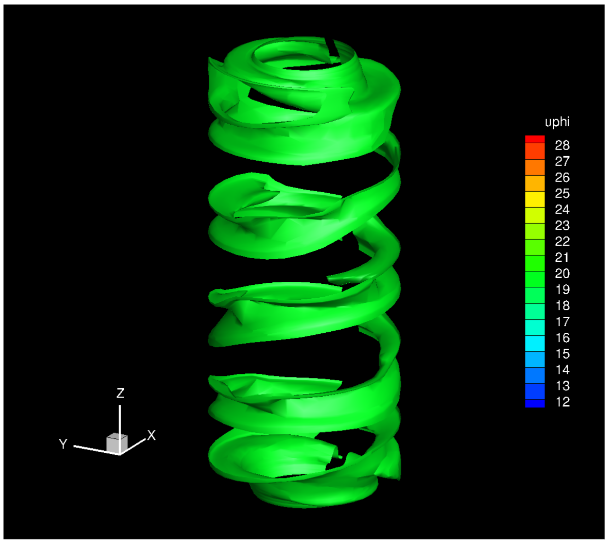


Figure 3: Azimuthal velocity isocontour showing the SRI 3-D structure.

[3] S. Abide, S. Viazzo, I. Raspo, A. Randriamampianina, *Computer and Fluids* **174**, 300 - 310 (2018)

Project Partners

Aix-Marseille University

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