Investigating Atmospheric flow field utilizing thermo-electrohydrodynamic convection in spherical shell

Direct numerical simulation of the Atmoflow experiment to model atmospheric phenomena

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In Short

- Investigating atmospheric flow fields and their impact on climate change
- Investigating flow fields in spherical shell capacitor under mircro-gravity utilizing an artificial force field
- Simulation of multiregions using OpenFoam
- Implementation of custom solver to simulating thermo-electrohydrodynamics

Considering the resent increase in focus up on climate change, the study of global cell formation and jet streams become more and more important to study their long term impacts on planetary atmospheres. The Atmoflow project, a project that is capable to model atmospheric phenomena such as on Earth, Mars or Jupiter is able to predict planetary large-scale convection. These convection currents arise out of the temperature difference between a planet's poles and the equatorial region in the presence of planetary rotation and gravity. Instabilities are therefore cause that are responsible for large scale planetary waves such as Rossby waves that meander around the northern and southern hemisphere commonly known as the jet stream. Rossby waves can therefore create different large and small scale convective cells in the atmosphere as shown in figure 1. While such cell can interact with each other, they are also made responsible for extreme weather condition [1].

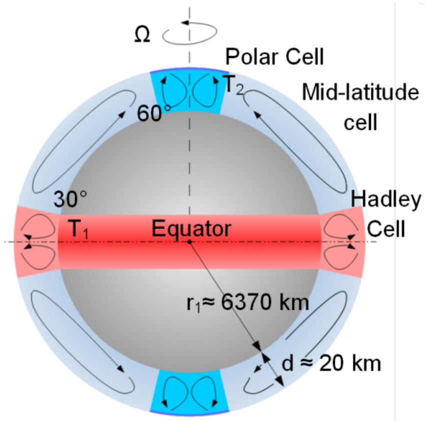

***Figure 1:** Schema of different type of planetary cell due to hot equator and cold poles*

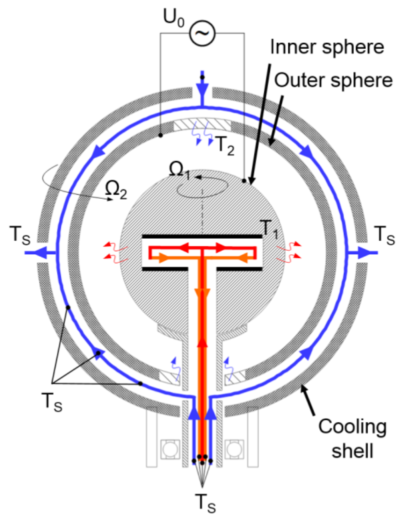

***Figure 2:** Schema of the half-cut of the Atmoflow experiment with location of thermocouples T_S, the electric potential U_0 and the heating and cooling channel*

To study such phenomena simplified geometries are used such as the AtmoFlow spherical shell experiment that is equivalent to a planet 's atmosphere. As the equator of a planet is in general exposed to the sun' radiation, the experiment cell is heated at the equator of the inner shell. Analogously the poles are cooled though copper fins as shown in figure 2. The driving force of terrestrial gravity is modeled by an electric force field causing the desired effect of a central force field by the dielectrophoretic force[2] on the fluid confined within the sphere shell. In addition of modelling planetary convection and climate the project intends to quantify the electrically induced flow via Thermo-Electrohydrodynamics (TEHD) in sphere shells . Furthermore, this experiment will provide information of enhanced thermal transport through electrical induced convection. As the central driving force via an externally applied electric potential between inner and outer shell shall not be disturbed by the terrestrial gravity, Atmoflow is placed in a microgravity environment and will serve about 1 year on the International Space Station (ISS) from 2026 onward [3].

The evolving flow patterns within the spherical experiment are recorded by a Wollaston interference

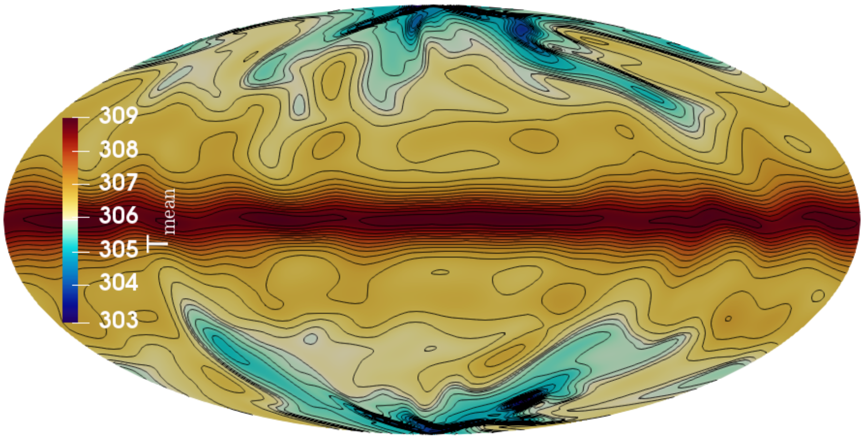

Figure 3: *Contour of hammer projection of the fluid region of the numerical simulation showing patterns of Rosby waves*

system that is capable to capture even small gradients in the working fluid's density. However, the interference system is only able to provide the integral quantity and thus can only provide a qualitative indication of heat transport that is advected by the fluid's velocity. Hence, it is important to be able to reconstruct the experimental investigated flow fields by numerical simulations.

The main region of interests are therefore the patterns created by the fluid between both spherical shells. As by definition of Neumann and Dirichlet boundary conditions for those regions do not fully recapture the boundary conditions and thermal diffusion through solid regions of shells may have to be processed as well. For these simulations the pre-implemented multi-region solver of OpenFOAM is a suitable tool and has in addition a robust framework and the flexibility to adapt solvers to implement the required TEHD equations. While convective structure may be biased by the use of turbulence models, the simulations have to be performed as Direct Numerical Simulation (DNS). Dependent on the flow regime different mesh sizes are required to resolve fully the large- and small-scale patterns as indicated by the mean contour plot of the temperature field given by a hammer projection in figure 3.

While mesh sizes can vary between 1 and 15 million cells depending on the applied temperature difference between equator and pole, rotation speed as well as the apllied electric potential, a transition time is given to be able to investigate equilibrated structures that evolve in time to stationary solutions in a rotation frame and to obtain a time dependent non-questionary flows. To guarante equilibrated, quasi-stationery and time depended time scales, simulations and experiment runs on the ISS require at least 45 min before a recording of the parameters is possible. In total 708 runs with different boundary conditions are planned to generate a wide range of possible planetary systems that are of interest to investigate and to be able to confirm the pre-conducted stability analyses [4]. To be able to succeed with the majority of the numerical investigation prior to the launch of the experiment to the ISS, the use of a High Performing Computing (HPC) provided by the HLRN is an essential requirement.

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https://www.b-tu.de/fg-aerodynamik-stroemungslehre/forschung/schwerpunkte/raumfahrtanwendungen/atmoflow/atmoflow

More Information

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[3] F. Zaussinger et al. *AtmoFlow - Investigation of Atmospheric-Like Fluid Flows UnderMicrogravity Conditions* (2019) doi:10.1007/s12217-019-09717-7

[4] V.Travnikov et al. *Linear stability analysis of the convective flow in a spherical gap with rotating inner surface* (2020) doi: 10.1016/j.ijheatmasstransfer.2019.119052

Project Partners

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