# AtmoFlow: Convective regimes in differential spherical shell rotation with electric central force field

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Convection in rotating spherical shells are often used as analogues investigations of many geophysical and astrophysical flows.[1] To implement these large-scale systems in experiments may come with certain challenges and limitations. One example is their massive size and of course the presence of a central force field, like terrestrial gravity. Small scale experiments such as GeoFow, a rotating spherical shell experiment, serves exactly the purpose to mimic e.g. a planetary interior.[2] GeoFlow is scaled to a relative small spherical shell that does not lose its overall physical meaning. Planetary rotation is implemented simply by spherical shell rotation and an electric central force field mimics terrestrial gravity, inducing thermo-electrohydrodynamic convection. Such systems have to be placed in a zero gravity environment to avoid an influence of natural convection present in any terrestrial laboratory. The GeoFlow experiment has served therefore from 2008 to 2018 on the International Space Station (ISS) and was recently decommissioned and is soon to be replaced by a successor experiment.[345]

In this study we use three-dimensional (3D) direct numerical simulation (DNS) to investigate the successor of GeoFlow, named AtmoFlow. The AtmoFlow spherical shell experiment is meant to investigate planetary atmospheres and planned to start operating in 2026 on the ISS. The parameter space of AtmoFlow considers no-rotation, solid body rotation and differential rotation in the presence of an electric central force field. For the experimental system we conduct the latter by complementing numerical investigations. Here, we present the differential-rotating parameter space in the vicinity of the Keplerian flow regime that is spanned between Taylor number, Rossby number and electric Rayleigh number given by

$$Ta = \frac{4\Omega^2 (R_o - R_i)^4}{\nu^2}, \quad Ro = \frac{\Omega_i - \Omega_o}{\Omega_o}, \quad Ra_E = \frac{\varepsilon_0 \varepsilon_r e \Delta T V_0^2}{2\rho_0 \nu \kappa} \tag{1}$$

indicating the force balances of rotational forcing over viscous diffusion, the intensity of differential rotation and the electric buoyancy over viscous and thermal diffusion, respectively.[3] The 3D DNS provides and indication of the evolving convective patterns. These were classified into distinct regimes by the respective intensity of the above forcing parameters. For large $Ta$, time periodic Taylor vortex flow at the equatorial plane is observed, whereas for large $Ra_E$ irregular convective flow with plumes structures reminiscent of classical Rayleigh-Bénard convection is found. For small forcing parameters in $Ta$ and $Ra_E$ distinct time invariant plume structures are seen. The intermediate forcing of $Ta$ and $Ra_E$ with similar intensity of forcing revealed time periodic fish-bone structures. These structure served as a band between small and large forcing of $Ta$ and $Ra_E$ with equivalent forcing strength even when $Ro$ is increased. While intermediate forcing parameters are not clearly classifiable, a further analysis of the angular momentum flux and heat flux was performed. The numerical calculations used a finite volume technique based on OpenFoam and performed of the HLRN cluster.

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[2] Zaussinger et al., Physical Review Fluids 3 (9) (2018)
[3] Gaillard et al., International Journal of Heat and Mass Transfer 218 (2024)
[4] Gaillard et al., Proceedings in Applied Mathematics and Mechanics (2024)
[5] Szabo et al., Proceedings in Applied Mathematics and Mechanics 23 (2023)