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Inertial modes and their transition to turbulence in a differentially rotating spherical gap flow

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We present a study of inertial modes in a spherical shell experiment. Inertial modes are Coriolis-restored linear wave modes, often arise in rapidly-rotating fluids (e.g. in the Earth's liquid outer core [1]). Recent experimental works showed that inertial modes exist in differentially rotating spherical shells. A set of particular inertial modes, characterized by $(l, m, \hat{\omega})$, where l, m is the polar and azimuthal wavenumber and $\hat{\omega} = \omega/\Omega_{out}$ the dimensionless frequency [2], has been found. It is known that they arise due to eruptions in the Ekman boundary layer of the outer shell. But it is an open issue why only a few modes develop and how they get enhanced. Kelley et al. 2010 [3] showed that some modes draw their energy from detached shear layers (e.g. Stewartson layers) via over-reflection. Additionally, Rieutord et al. (2012) [4] found critical layers within the shear layers below which most of the modes cannot exist.

In contrast to other spherical shell experiments, we have a full optical access to the flow. Therefore, we present an experimental study of inertial modes, based on Particle-Image-Velocimetry (PIV) data, in a differentially rotating spherical gap flow where the inner sphere is subrotating or counter-rotating at Ω_{in} with respect to the outer spherical shell at Ω_{out}, characterized by the Rossby number $Ro = (\Omega_{in} - \Omega_{out})/\Omega_{out}$. The radius ratio of $\eta = 1/3$, with $r_{in} = 40$mm and $r_{out} = 120$mm, is close to that of the Earth's core. Our apparatus is running at Ekman numbers ($E \approx 10^{-5}$, with $E = \nu/(\Omega_{out} r_{out}^2)$), two orders of magnitude higher than most of the other experiments. Based on a frequency-Rossby number spectrogram, we can partly confirm previous considerations with respect to the onset of inertial modes. In contrast, the behavior of the modes in the counter-rotation regime is different. We found a triad interaction between three dominant inertial modes, where one is a slow axisymmetric Rossby mode [5]. We show that the amplitude of the most dominant mode $(l, m, \hat{\omega}) = (3, 2, \sim 0.71)$ is increasing with increasing $|Ro|$ until a critical Rossby number Ro_{crit}. Accompanying with this is an increase of the zonal mean flow outside the tangent cylinder, leading to enhanced angular momentum transport. At the particular Ro_{crit}, the wave mode, and the entire flow, breaks up into smaller-scale turbulence [6], together with a strong increase of the zonal mean flow inside the tangent cylinder. We found that the critical Rossby number scales approximately with $E^{1/5}$.

References

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