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Three-dimensional inertial wave attractors produced by external forcing of different types

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Internal and inertial wave attractors may appear in many geophisical and astrophisical problems. In present work we study inertial wave attractors in an axisymmetric rotating annulus having a trapezoidal cross section and a vertical axis of revolution. The rotating fluid volume is confined between two vertical co-axial cylinders, with truncated cone as a bottom surface. The large-scale forcing is applied to the fluid volume by specific motion of the upper lid. The spectral element method is used to solve the Navier-Stokes equations in rotating fluid, with the no-slip boundary conditions at all rigid walls, and a prescribed vertical velocity field at the upper lid.

We consider two types of forcing. The first one simulates a small-amplitude nutation (Euler-disk-type motion) of the rigid lid, where the vector normal to the lid undergoes precession in such a way that the tip of the vector describes a horizontal circle of small radius around the axis of rotation of the annulus. This motion is modelled by prescribing the vertical velocity field with cosine-shaped running wave in azimuthal direction and linear variation in the radial direction. The response to such forcing mimics some essential features of tidal excitation. We show that attractors are formed only when the sense of nutation in azimuthal direction (in rotating coordinate system) is opposite to the sense of the background rotation (in a fixed laboratory system). In a horizontal cross-section of the flow we see then a rotating pattern with 'Yin-Yang' interplay in laminar mode, and when instability occurs with growth of the amplitude of external forcing, we see the interplay between the large- and small-scale 'Yin-Yang' patterns.

The second type of forcing is purely axisymmetric. At the upper lid we prescribe the vertical velocity profile in radial direction, with the amplitude in form of half-wave of the Bessel function, and simple harmonic time dependence. Such forcing excites a purely axisymmetric motion in linear regime. As the forcing increases, the axial symmetry of the inertial-wave motion is broken: in the horizontal cross-section we observe the development of fine-scale 'Mandala' patterns possessing rotational symmetry whose complexity grows with time.

In both cases of forcing the triadic resonance is responsible for development of instability, and at sufficiently large forcing we observe a transition to three-dimensional wave turbulence. We show thus for the first time that fully three-dimensional simulations are necessary to capture the essential features of nonlinear regimes in inertial wave attractors in a rotating fluid annulus.