Three-dimensional Chaotic Advection in an Idealized Ocean Eddy

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We examine the Lagrangian structure of a canonical flow that arises in geophysical fluid dynamics: a homogeneous fluid confined to a rotating cylinder and driven by a stress at the upper surface. This circulation generated has Ekman layers at the top and bottom of the cylinder, frictional side-wall layers, and an interior geostrophic region. Fluid from the horizontally swirling interior is sucked up into the upper Ekman layer and directed outward towards the cylinder walls, where is descends into the bottom Ekman layer, spirals inward, and rises back into the interior. For steady axisymmetric flow, each fluid trajectory lives on a torus and is non-chaotic. We explore the breakup of these surfaces under steady and time-periodic disturbances, introduced through the surface forcing. Velocity fields are obtained from both a kinematic model and numerical integrations of the Navier-Stokes equations. For oceanographically relevant values of the governing parameters (Rossby and Ekman numbers and aspect ratio), and for perturbations of small to moderate amplitude, we find that some of the tori survive the perturbation and act as barriers in the otherwise chaotic flow. We map out the associated structures and connect the results to extended versions of the KAM theorem for this quasi-Hamiltonian flow.

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