

Chaotic advection in wind-induced shallow basin flows: a 3D approach

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As important environmental features, mixing properties of water bodies in closed shallow basins are investigated. Time dependent motion, often resulting in chaotic behavior, requires the Lagrangian description of the transport. Pattantyús-Ábrahám et al. (2008) and Károlyi et al. (2010) considered unsteady hydrodynamics driven by periodical wind forcing in simplified shallow lake geometry to explore chaotic advection properties in a depth-averaged manner. With methods originating in chaos theory it was possible to locate spatial structures which govern the flow and areas where the most effective mixing occurs. Such structures as hyperbolic points (the Lagrangian analogs of Eulerian instantaneous or steady-state stagnation points) and manifolds have long been used for classifying the evolution of trajectories in abstract dynamical systems but their application in the context of fluid dynamics offers a novel tool with clear physical meaning: identifying vortex boundaries, barriers and avenues of transport, or lines of strong stretching. In the sample lake mixing was found typically strong at complex intersection of stretching and contracting manifolds around the hyperbolic points, where trajectories of initially close particles quickly separated from each other along the stretching directions. In fact, near hyperbolic points, the rate of separation of nearby particles is exponential in time, leading to the finite size Lyapunov-exponent (FSLE) as a key parameter for chaos analysis, by which coherent structures as stable and unstable manifolds were also identified.

Using the same simple lake geometry, the complete 3D flow pattern driven by realistic wind shear stress field modeled by proper CFD tool is looked at to identify and analyze chaotic advection features. Instead of one Eulerian stagnation point in 2D steady-state, a tilted inner stagnation line can be found, the impact of which on 3D particle advection and spreading is investigated. Next, periodic wind forcing is applied and particle advection is analyzed primarily by means of Lyapunov-exponent distributions to identify hyperbolic points and chaos behavior. Such hydrodynamic aspects are important to reveal for applied sciences, e.g. for estimating water exchange mechanisms, interpreting plankton movement or planning and operating pollutant outfalls, at last all contributing to the water resources management in shallow lake environments.

References

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