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Lagrangian transport in a class of (anisotropic) subsurface reservoirs

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Subsurface scalar transport of e.g. heat or chemicals by fluid flow is key to problems as enhanced geothermal systems, groundwater remediation or in situ minerals mining. The Lagrangian transport properties of the subsurface flow are crucial in such processes. For example, recent studies in the literature on a two-dimensional (2D) unsteady Darcy flow in a circular reservoir driven by reoriented injection–extraction wells demonstrated that well configurations and pumping schemes designed via chaos theory enable efficient fluid distribution (for e.g. in situ mining) through the entire reservoir. Central to this is accomplishment of chaotic advection, i.e. the rapid dispersion and stretching of material fluid elements, by an "appropriate" flow forcing. Problems as e.g. groundwater remediation may furthermore require targeted delivery (and subsequent confinement) of fluid containing chemicals to designated regions of the reservoir for local contaminant treatment. This may be achieved by systematic creation of Lagrangian transport barriers.

The present study seeks to deepen insight into generic subsurface Lagrangian transport by investigating the formation of so-called Lagrangian coherent structures (LCSs) emerging as e.g. the above transport barriers or chaotic regions. To this end theoretical and computational analyses are performed for said 2D circular reservoir. This reveals that (for given well configurations) appropriate pumping schemes enable robust creation of various Lagrangian transport conditions. A key aspect is the impact of anisotropy in the porous matrix. Such anisotropy generically eliminates key organizing mechanisms, viz. symmetries, and thus tends to promote disorder and, inherently, chaotic advection at the expense of LCSs. However, symmetries are partially preserved — and thus order and coherence partially restored — for certain pumping schemes and well configurations aligned with the anisotropy. Symmetry associated with well alignment in fact gives rise to an intriguing "order within chaos" observed only in such cases: prolonged confinement of fluid to subregions of chaotic seas.

The study furthermore involves first investigations of the role of LCSs in advective-diffusive scalar transport. They namely strongly impact advective-diffusive scalar transport in that certain LCSs essentially "shape" the fundamental dynamic states (the so-called "eigenmodes") that govern the Eulerian evolution of scalar fields. Thus insights in the formation and creation of LCSs may also offers ways to systematically manipulate and regulate subsurface transport in the presence of diffusion.