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Lagrangian transport and chaotic advection 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 oil recovery, enhanced geothermal systems, carbon sequestration 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 "proper"flow forcing. Problems as e.g. groundwater remediation may, on the other hand, 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 and manipulation 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) as e.g. the above transport barriers as well as the accomplishment of (localised) chaotic advection. To this end theoretical and computational analyses are performed for the above 2D circular reservoir. This reveals that, in general, appropriate pumping schemes enable systematic and robust creation of various Lagrangian transport conditions for given well configurations (e.g. confinement zones of controlled size embedded in a chaotic environment). 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 areas.

References

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