Inhomogeneities and caustics in passive particle sedimentation in incompressible flows

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Sedimentation of small particles in complex flows is an outstanding problem in science and technology. In particular, the sinking of biogenic particles from the marine surface to the bottom is a fundamental process of the biological carbon pump, playing a key role in the global carbon cycle. A complete understanding of this problem is still lacking. It has been recently shown that despite fluid incompressibility, sedimented particles, moving as passive tracers in the ocean, show density inhomogeneities when accumulated on some bottom surface.

Here, we analytically derive the relation between the geometry of the flow and the emerging distribution for an initially homogeneous sheet of tracers. From a physical point of view, we identify the two processes that generate inhomogeneities to be the stretching within the sheet, and the projection of the deformed sheet onto the target surface. We point out that an extreme form of inhomogeneity, caustics, can develop for sheets. We exemplify our geometrical results with simulations of tracer advection in a simple kinematic flow, study the generic dependence on the various parameters involved, and illustrate that the basic mechanisms work similarly if the initial (homogeneous) distribution occupies a more general region of finite extension rather than a sheet.

In Fig. 1 we show the positions of particles (projected onto a vertical plane) at different times in a realistic ROMS (Regional Ocean Model) simulation of the Benguela zone. The numerical experiment consisted in releasing 6000 particles from initial conditions randomly chosen in a square with sides of 1/6 deg, centered at 10.0°E 29.12°S and 100 m depth. The particles' trajectories $\mathbf{r}(t)$ were calculated from

$$d\mathbf{r}/dt = \mathbf{v}_{\text{ROMS}} - W\mathbf{k}, \qquad (1)$$

where $\mathbf{v}_{\text{ROMS}}$ is the velocity from the ROMS model, and $W = 10$ m/day corresponds to the sinking velocity, pointing in the vertical direction given by the unit vector **k**.

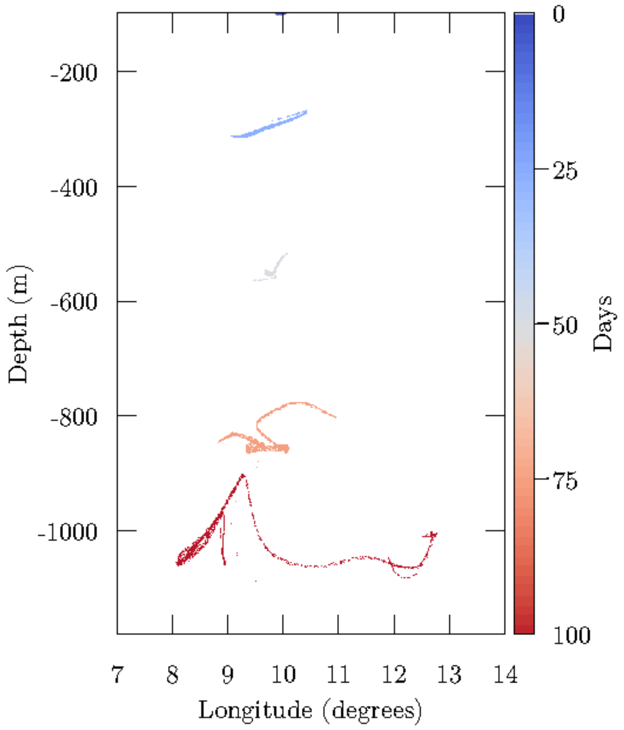

Fig. 1. The positions of particles at different times as they sink in a realistic oceanic flow.

[1] G. Drotos, P. Monroy, E. Hernández-García, C. López, Inhomogeneities and caustics in passive particle sedimentation in incompressible flows, arXiv:1801.10116.