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Relative Dispersion with Finite Inertial Ranges

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The relative dispersion of pairs of particles was first considered in a seminal article by Richardson (1926). The dispersion subsequently was subsequently linked to turbulence, and pair separation statistics can advantageously be used to deduce energy wavenumber spectra. Thus one can, for example, employ surface drifters to identify turbulent regimes at scales well below those resolved by satellite altimetry. The identification relies on knowing how dispersion evolves with a specific energy spectrum. The analytical predictions commonly used apply to infinite inertial ranges, i.e. assuming the same dispersive behavior over all scales. With finite inertial ranges, the metrics are less conclusive, and often are not even consistent with each other.

We examine this using pair separation probability density functions (PDFs), obtained by integrating a Fokker-Planck equation with different diffusivity profiles. We consider time-based metrics, such as the relative dispersion, and separation-based metrics, such as the finite scale Lyapunov exponent (FSLE). As the latter cannot be calculated from a PDF, we introduce a new measure, the Cumulative Inverse Separation Time (CIST), which can. This behaves like the FSLE, but advantageously has analytical solutions in the inertial ranges. This allows establishing consistency between the time- and space-based metrics, something which has been lacking previously.

We focus on three dispersion regimes: non-local spreading (as in a 2D enstrophy inertial range), Richardson dispersion (as in the 3D and 2D energy inertial ranges) and diffusion (for uncorrelated pair motion). The time-based metrics are more successful with non-local dispersion, as the corresponding PDF applies from the initial time. Richardson dispersion is barely observed, because the self-similar PDF applies only asymptotically in time. In contrast, the separation-based CIST correctly captures the dependencies, even with a short (one decade) inertial range, and is superior to the traditional FSLE at large scales. Furthermore, the analytical solutions permit reconciling the CIST with the other measures, something which is generally not possible with the FSLE.