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General statistical properties of Lyapunov exponents and the role of shear regions in geophysical flows

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Finite Size Lyapunov Exponents (FSLEs) have been often used to identify mixing regions of geophysical flows in terms of stable and unstable manifolds of hyperbolic points. However, FSLEs are sensitive to regions of intense shear and, in this case, they fail to identify mixing barriers as shown through comparison with effective diffusivity. In order to solve this problem, we examine the geometrical relation between the stable and unstable manifolds. Statistical properties of FSLEs and manifold relative angle are computed in the ocean and the atmosphere using altimetry data and ERA-40 reanalysis. We find that in both cases the distribution of the angle has a width that narrows for increasing FSLEs. The compared distributions of the FSLEs and the angle provide a characterization of mixing in terms of the proportion and strength of shear regions. This suggests that, in regions of intense shear, the statistical distribution of the angle between forward and backward invariant manifolds favors very small values when FSLEs are large. Using this result, we propose to weight the FSLE by the angle between the invariant manifolds. In this way, the mixing barriers of intense shear regions are correctly identified.