Geophysical Research Abstracts
Vol. 17, EGU2015-12330-1, 2015
EGU General Assembly 2015

The lamellar representation of mixing in turbulent and porous media flows

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We present a general modeling framework for mixing in heterogeneous flows, in which scalar mixtures are represented as an ensemble of lamellae evolving through stretching, diffusion and aggregation (Le Borgne et al., PRL 2013). Elongated lamellar structures in concentration fields are naturally created by the stretching action of temporal and spatial fluctuations in fluid velocities. The lamella deformation process controls the local concentration gradients and thus the evolution of the concentration Probability Density Function (PDF) through stretching enhanced diffusion. At late times, lamella interaction is enforced by confinement of the mixture within the dispersion area. This process is shown to be well represented by a random aggregation model, which quantifies the frequency of lamella coalescence and allows predicting the temporal evolution of the concentration PDF in this regime. This framework is shown to provide accurate analytical predictions of concentration distributions for a range of flow systems, including turbulent and porous media flows. In particular, it relates the temporal behavior of mixing, as quantified by concentration moments, scalar dissipation rate, dilution measures, or spatial increments of concentration, to the degree of flow heterogeneity.