TURBULENT INTERFACES AS SITES TO MEASURE THE PASSIVE SCALAR–VELOCITY INTERMITTENCY RELATIONSHIP

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Abstract
When a passive scalar is advected through an interface placed inside a decaying shearless turbulent mixing layer, two intermittent fronts are generated at the margins of the scalar mixing layer. The velocity field instead presents one front only which is placed in the part of the field where the kinetic energy is lower or, in case the energy is uniform but the correlation is varying, where the integral scale is lower. During the decay these fronts a propagate away form the initial position of the interface. The intermittency intensity is here measured via one point statistics of the passive scalar concentration, velocity and relevant derivatives. At a a certain time instant in a same field we have thus the possibility to observe three intermittency fronts. This allows to empirically estimate over two spatial points the relationship between the intensities of the velocity and passive scalar intermittency.

Although the concentration of a passive substance exhibits a complex behaviour that shows many phenomenological parallels with the behaviour of the turbulent velocity field, the statistical properties of passive scalar turbulence, strongly influenced by the Kolmogorov cascade phenomenology, are in part decoupled from those of the underlying velocity field, Shraiman & Siggia (2000). In last years, this subject is undergoing a reinterpretation as empirical evidence shows that local isotropy, both at the inertial and dissipation scales, is violated (Warhaft (2000), Danaila and Antonia (2009), Bos et al. (2009)).
In this work, we go one step beyond the homogeneous and isotropic turbulence and consider the simplest inhomogeneous and shearfree turbulent Navier-Stokes motion: the system where where one large scale isotropic field is left to diffuse into an isotropic field with the same kinetic energy but a smaller integral scale. We have in fact imagined a numerical experiment to explore the onset of turbulent intermittency associated with a spatial perturbation of the correlation length. We place two isotropic regions, with different integral scales, inside a volume where the turbulent kinetic energy is initially uniform and leave them to interact and evolve in time, see the flow schematic in figure 1. The different length scales produce different decay rates in the two regions. Since the smaller-scale region decays faster, a transient turbulent energy gradient is generated at the interface between the two regions.
The presence of the interaction zone and related lateral intermittency layers, see figure 2, offers the way to carry out a numerical measurement of the relationship between the intermittency of the scalar and velocity field. In practice, through differences over the spatial points where the intermittency peaks, see panels c,g in figure 2 (left) and panel b,d in figure 2 (right), we may estimate the proportionality coefficient between the scalar and the velocity intensities, $C_{u'}$ and $C_{\partial u'}$.

$$I_{\theta'} = I'_{\theta}(I_{u'}) \sim C_{u'} I_{u'}, \quad I_{\partial\theta'} = I_{\partial\theta'}(I_{\partial u'}) \sim C_{\partial u'} I_{\partial u'}.$$

The data-set here presented yields the approximated time averaged values $C_{u'} \sim 12.3$ and $C_{\partial u'} \sim 6.25$. With respect to the velocity field, the passive scalar field thus shows thus a much higher amplification for the large scale intermittency than for the small scale one. In figure 3, a visualization of the skewness of the passive scalar fluctuation evidences the sparsity of the physical points where the third moments take the higher values.
The present results can be of interest for atmospheric turbulence applications. Inside and outside clouds, turbulence has frequently different intensities, which are caused there by the presence of phase changes and thus latent heat release, that affects small-scale turbulence. In this respect, the present approach could provide insights on how turbulence at a clear air-cloud interface could evolve.

References

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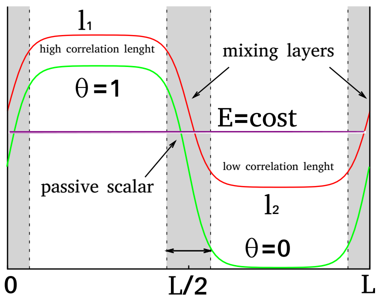
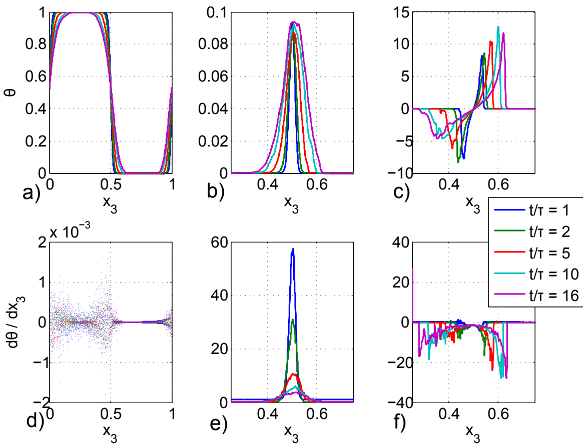
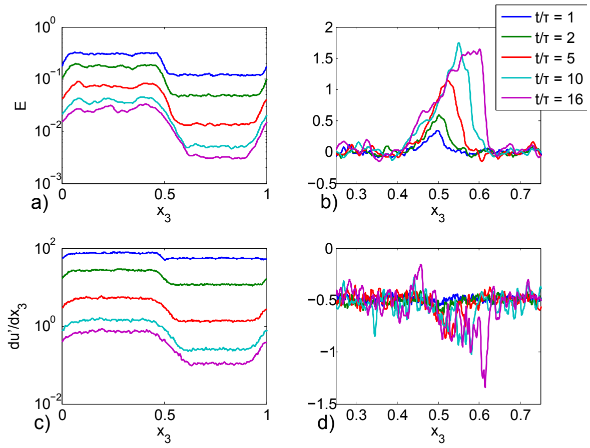


Figure 1. Scheme of the flow. Direction x is the nonhomogeneous direction. L is the domain size, θ is the scalar concentration and l is the integral scale. The initial conditions for the velocity are generated by a linear matching of two homogeneous and isotropic fields over the mixing layer (see [5], [7], [8]. The initial mean scalar distribution is a discontinuity smoothed enough to avoid the Gibbs phenomenon [6]. The Re_λ of the experiment is 150.



(a) Left. Distribution of the first three order moments of the passive scalar fluctuations and of its derivative across the mixing layer at different eddy turnover times. Panels **(a,d)**: mean scalar concentration and related fluctuation derivative, respectively. Panels **(b,e)**: variance of the passive scalar concentration and derivative. Panels **(c,f)**: skewness of the passive scalar concentration and its derivative.



(b) Right. Second and third order moments of the velocity fluctuation and its derivative across the mixing layer at different eddy turnover times. Panels **(a,c)**: mean profiles of turbulent kinetic energy E and of the longitudinal fluctuation velocity derivative $\partial u'/\partial x$. Panels **(b,d)**: skewness of the velocity fluctuation and of its derivative, respectively.

Figure 2.

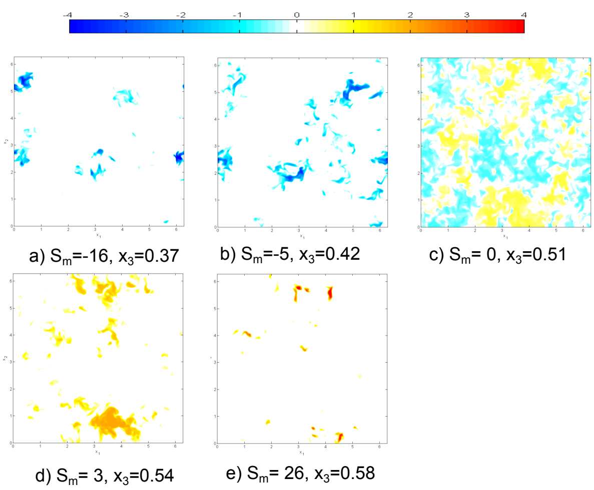


Figure 3. Visualization of the skewness of the passive scalar concentration in different field sections parallel to the mixing layer.