Dimensionality influence on passive scalar transport

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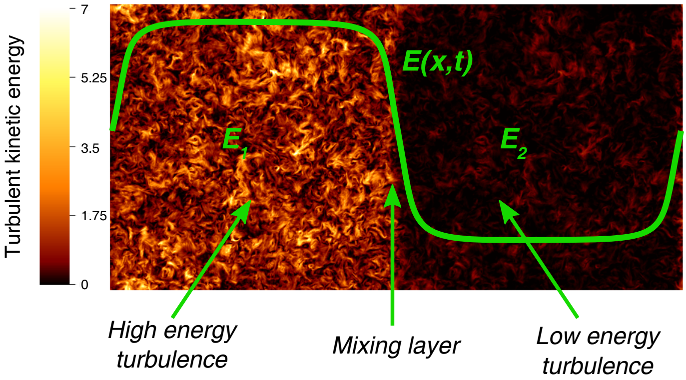
Passive scalar

Basic phenomenology

- A passive scalar is a contaminant present in so low concentration that it has no dynamical effect on the fluid motion,
- Turbulence transports the scalar by making particles follow chaotic trajectories and disperses the scalar concentration if exists scalar concentration gradient.
- Fluctuations reach the smaller scales.

Turbulent shearless mixing

General flow configuration:



periodic boundary condition ⇒ 2 mixing layers

Main features of mixing layers

Shearless mixing layers shows the following properties:

- no gradient of mean velocity, thus no kinetic energy production
- the mixing is generated by the inhomogeneity in the turbulent kinetic energy and integral scale
- the mixing layer becomes very intermittent at both large and small scales
- the presence of a gradient of energy is a sufficient condition for the onset of intermittency [Tordella and iovieno (2006); Tordella et al. (2008)]
- 2D and 3D mixings: different asymptotic layer thickness growth exponent

Passive scalar transport

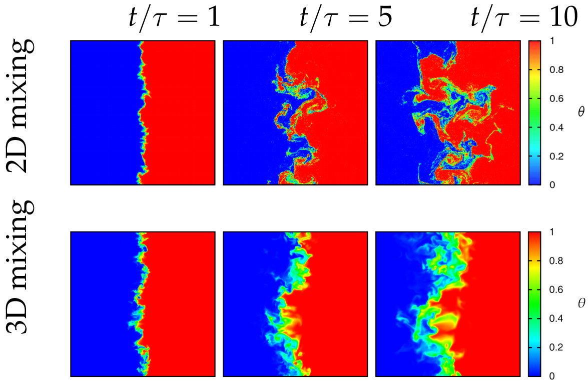
We solve the passive scalar advection-diffusion equation

$$\frac{\partial \vartheta}{\partial t} + u_j \frac{\partial \vartheta}{\partial x_j} = \frac{(-1)^{n+1}}{Re\, Sc} \nabla^{2n} \vartheta$$

for the shearless mixing configuration.

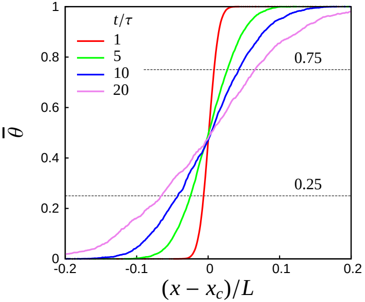
DNS simulations have been performed at $Re_\lambda = 150$ in 3D turbulence ($600^2 \times 1200$ grid points, $n = 1$) and $Re_\lambda = 60$ in 2D turbulence (1024^2 grid points, $n = 2$).
Assume Schmidt number $Sc = 1$

Visualizations of the mixing layer

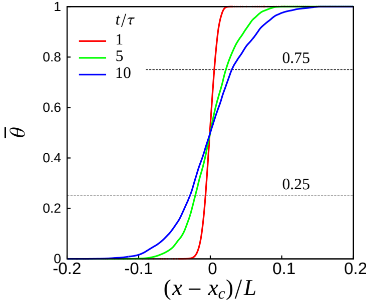


Mean Scalar Diffusion

3D Mixing

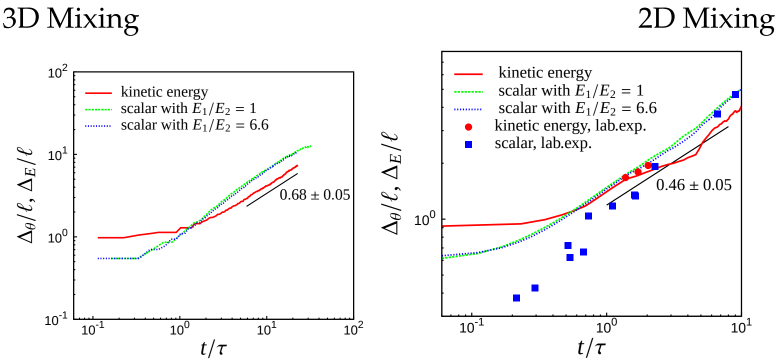


2D Mixing



Energy ratio $E_1/E_2 = 6.7$

Scalar mixing layer thickness

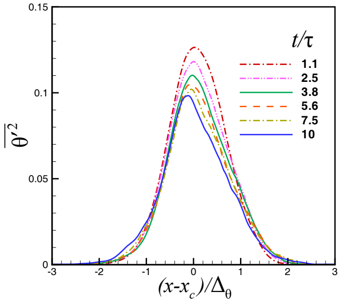


Scalar layer thickness: $\Delta_\vartheta = x_{\vartheta=0.75} - x_{\vartheta=0.25}$

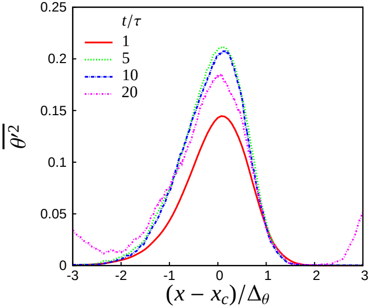
3D mixing: $\Delta_\vartheta \sim t^{0.45}$, 2D mixing: $\Delta_\vartheta \sim t^{0.7}$

Scalar variance

3D Mixing



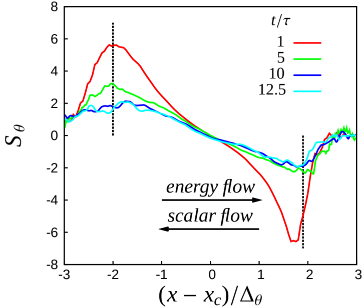
2D Mixing



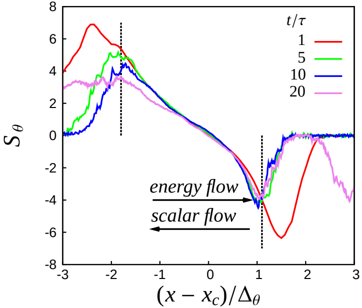
Self-similar distribution, peak shifted toward the high kinetic energy region

Scalar skewness

3D Mixing



2D Mixing



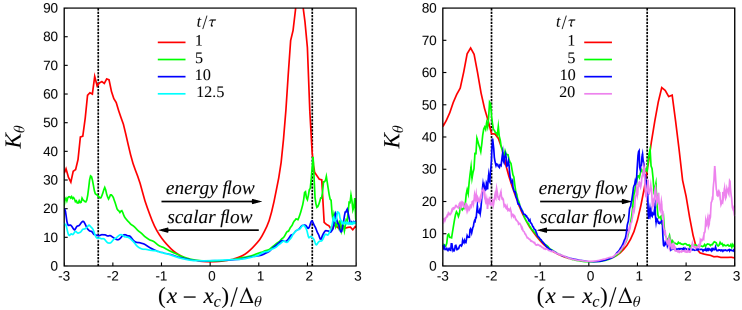
Strong non-gaussian statistic at the mixing layer border

2D: intermittency penetrates more in the direction opposite to the energy gradient.

Scalar kurtosis

3D Mixing

2D Mixing

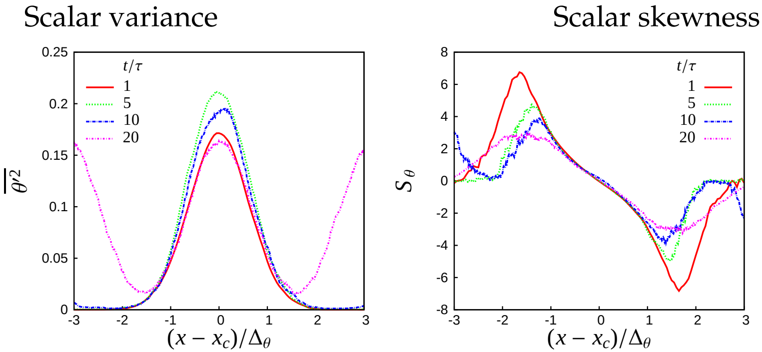


2D: higher asymmetry, wider intermittent region

Intermittency gradually reduces as the mixing procedes

No energy gradient

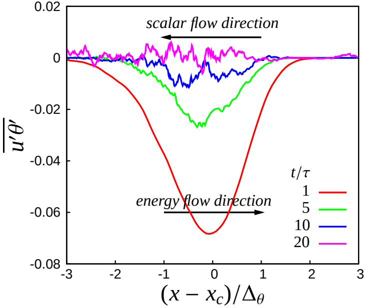
2D mixing - numerical validation



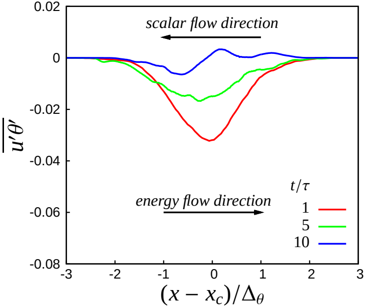
No energy gradient $\Rightarrow$ no asymmetry

Scalar flux

3D Mixing



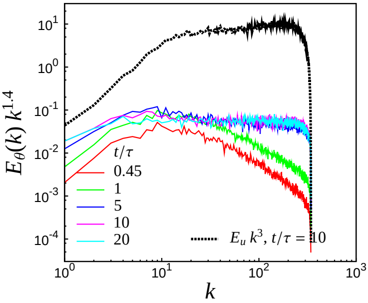
2D Mixing



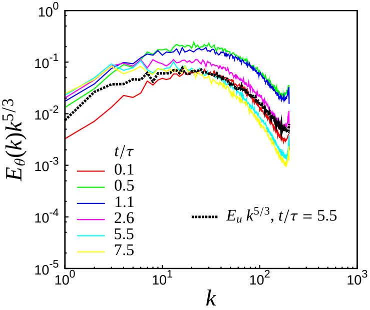
$$\overline{u'\vartheta'} \sim 1/\Delta_\vartheta(t)$$

Spectra in the mixing layer

3D Mixing



2D Mixing



Compensated scalar and velocity one-dimensional spectra in the same position

Conclusions

2D/3D Passive scalar diffusion across an energy step:

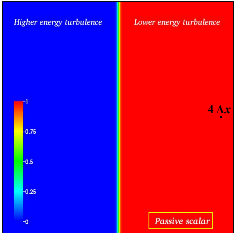
- all moments profiles are skewed towards the higher kinetic energy region
- self-similar profiles of first and second order moments
- large intermittency and non-gaussian behaviour on both sides of the mixing, even where the scalar flux is small.
- larger asymmetry in moment distributions in 2D mixing
- 2D: no stretching, inverse cascade, long-range interaction which penetrate more against the energy gradient

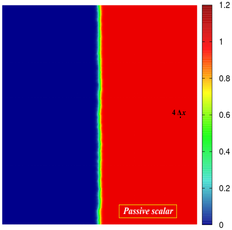
Scheme of the flow

Passive scalar

3D Mixing
($600^2 \times 1200$ grid)

2D Mixing
(1024^2 grid)





Run 3D Movie

Run 2D Movie