§20. Statistics of Passive Scalar Convected by Turbulence

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Fluctuations of scalar quantity such as the energy and matter are injected at large scales, mixed in space and transferred to small scales and then finally smeared out under the molecular action. During the transfer to small scales, the mixing is not necessarily uniform in space and time due to the complex random motion of fluid so that the strong fluctuations are generated and enhanced as the scale becomes smaller and smaller. In the MHD turbulence, similar strong fluctuations can be observed in the distributions of ions and magnetic field and lead to the anomalous transport. In this study we analyze the anomalous transport of a passive scalar in turbulence by the direct numerical simulation (DNS). Fluctuations in the passive scalar tend to be stronger than in the case of the velocity due to the absence of the pressure. We have performed a series of DNSs of the passive scalar at low Schmidt numbers (ν/κ, where ν and κ are the molecular kinetic viscosity and diffusivity, respectively, such as mercury for which few studies have so far been made. The spectrum and spatial distribution of the passive scalar are computed by numerically integrating the equation

$$\partial\theta/\partial t + \boldsymbol{u}\cdot\nabla\theta = \kappa\nabla^2\theta + f_\theta$$

by using the spectral method. where f_θ is the injection of the passive scalar fluctuations at large scale. We considered the two cases (i) decaying with $f_\theta = 0$, and (ii) steady by the injection due to the uniform mean scalar gradient in z direction $f_\theta = -Gu_3$.

The scalar spectrum which is defined by $\langle\theta^2\rangle/2 = \int E_\theta(k)dk$ was theoretically studied [1,2] and two types of the spectrum form were proposed at low Schmidt numbers as $E_\theta \propto k^{-17/3}$ [1] and $E_\theta \propto k^{-3}$ [2], but there seems no conclusions on which form is realized. This is partly due to the insufficient resolution in DNS and due to the toxic nature of the fluid in experiments.

Figure 1 shows the time evolution of the scalar spectrum in the decaying turbulence at $Sc = 0.01$ which is the lowest value ever studied in DNSs. The spectrum slope in the inertial diffusive range is not $-17/3 \approx -5.33$ but very close to it.

Figure 2 shows the bird's eye view of the total passive scalar $T(\boldsymbol{x}, t) = Gz + \theta(\boldsymbol{x}, t)$ in a plane parallel to the mean scalar gradient which is applied in the direction from lower left to upper right $(R_\lambda = 468, Sc = 1)$. It is well known that the ramp-cliff structure exists, and this structure is clearly seen. In the plateau regions, the scalar fluctuation is relatively weak but has large jump at cliff. Generation of these strong fluctuations are closely related to the intermittency.

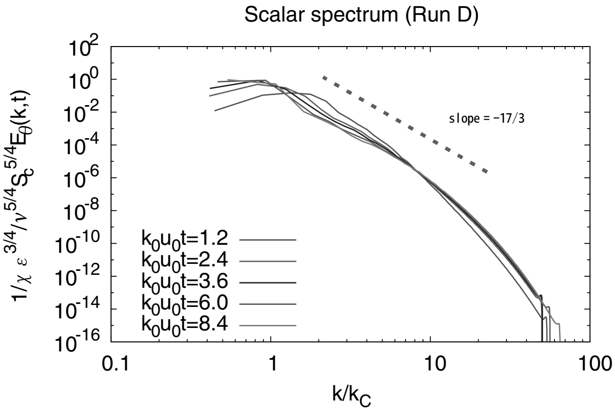

FIG. 1: Evolution of the spectrum of passive scalar variance for $Sc = 0.01$ for decaying turbulence.

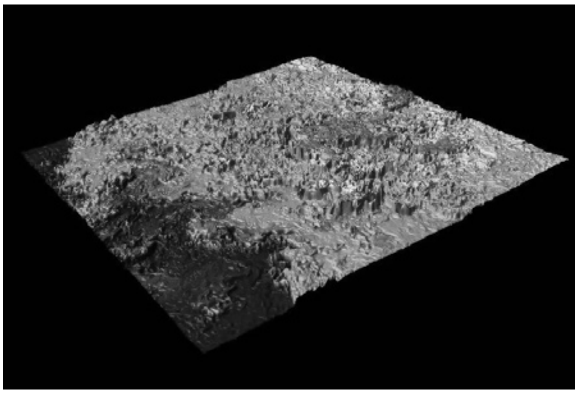

FIG. 2: Bird's eye view of the total scalar amplitude $T = Gz + \theta$ at $G = 1, R_\lambda = 468, Sc = 1$. Mean gradient is applied to the direction along the lower right side of the square domain.

[1] Batchelor, G. K. and Howells, I. K. and Townsend A. A., J. Fluid Mech. **5**, 134–139 (1959).
[2] Gibson, C. H. Phys. Fluids **11**, 2316–2327 (1968).