Boulder Fluid Dynamics Seminar Series

Wednesday, February 11, 2015
3:30pm-4:30pm (refreshments at 3:15pm)
Bechtel Collaboratory in the Discovery Learning Center (DLC)
University of Colorado at Boulder

Turbulent Mixing In Stably Stratified Wall-Bounded Flows

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Stably stratified wall-bounded turbulent flows are ubiquitous in nature such as in estuaries, lakes, oceans and atmospheric boundary layer. In such flows, the simultaneous existence of density stratification and solid wall results in anomalous mixing of momentum and active scalar (density) compared to other turbulent flows. Hence, there is no surprise that stratified wall-bounded flows are usually considered as one of the most complex flows. The focus of this study is to analyze stably stratified wall-bounded turbulent flows to highlight a number of issues that have implications for predicting turbulent mixing in these flows. By invoking the equilibrium assumption between the production rate of the turbulent kinetic energy (P), the dissipation rate of the turbulent kinetic energy (ε) and the turbulent potential energy dissipation rate (ε_{PE}) as $P \approx \varepsilon + \varepsilon_{PE}$, we first propose that the irreversible flux Richardson number $R^*_f = \varepsilon_{PE} /(\varepsilon + \varepsilon_{PE})$ can be approximated with the reversible form of the flux Richardson number $R_f = -B/P$ (where B is the buoyancy flux), especially for low gradient Richardson numbers. Second, we propose that the turbulent viscosity $\nu_t \approx 1/(1-R^*_f)\ \varepsilon /S^2$, where S is the mean shear rate. We then extend our analysis to propose appropriate velocity and length scales. Tests using direct numerical simulation (DNS) data of stably stratified turbulent channel flow are performed to evaluate our propositions. The comparisons are excellent. Finally, by invoking the equilibrium assumption between the buoyancy flux (B) and the dissipation rate of the turbulent potential energy (ε_{PE}) as $-B \approx \varepsilon_{PE}$ we infer the turbulent diffusivity as $\kappa_t \approx \varepsilon_{PE} /N^2$, where N is the buoyancy frequency. The comparison of the proposed turbulent diffusivity with the exact turbulent diffusivity computed from DNS data is good especially in the near-wall region but the agreement deteriorates far away from the wall, indicating the breakdown of the equilibrium assumption which is attributed to the presence of linear internal wave motions in this far-wall region.

Reaction Enhancement of Initially Distant Scalars by Lagrangian Coherent Structures

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Turbulent fluid flows have long been recognized as a superior means of diluting initial concentrations of scalars due to rapid stirring. Conversely, experiments have shown that the structures responsible for this rapid dilution can also aggregate initially distant reactive scalars and thereby greatly enhance reaction rates. Indeed, chaotic flows not only enhance dilution by shearing and stretching, but also organize initially distant scalars along transiently attracting regions in the flow. We demonstrate that Lagrangian coherent structures (LCS), as identified by ridges in finite time Lyapunov exponents, are directly responsible for this coalescence of reactive scalar filaments. When highly concentrated filaments coalesce, reaction rates can be orders of magnitude greater than would be predicted in a well-mixed system. This is further supported by an idealized, analytical model that quantifies the competing effects of scalar dilution and coalescence. Chaotic flows, known for their ability to efficiently dilute scalars, therefore have the competing effect of organizing initially distant scalars along the LCS at timescales shorter than that required for dilution, resulting in reaction enhancement.