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Quantification of “turbulent eddies” in energy cascade based on the multi-level dissipation element structure

Lipo Wang
UM-SJTU Joint Institute, Shanghai Jiao Tong Univ., Shanghai, China (lipo.wang@sjtu.edu.cn)

According to the classic energy cascade notion, large eddies as energy carrier are unstable to break up, through which energy is transferred from large scales till the smallest ones to dissipate the kinetic energy. A fundamental issue hereof is how to quantify the eddies of different sizes, else the energy cascade scenario remains illustrative. A possible remedy is the idea of dissipation element (DE) analysis, which is a topological approach based on extremal points. In this method, starting from each spatial point in a turbulent scalar field , a local minimum point and a local maximum point will inevitably be reached along the descending and ascending directions of the scalar gradient trajectory, respectively. The ensemble of spatial points whose gradient trajectories share the same pair of minimum and maximum points define a spatial region, called a DE. The entire filed can thus be partitioned into space-filling DEs. Typically, DE can be parameterized with l, the linear distance between the two extremal points, and Δ = _max – _min, the absolute value of the scalar quantity difference between the two extremal points. It needs to mention that dependence of the DE structure on the field is conformal with the physics that different variable fields are different structured, although related. In the past years, DE analysis has been implemented to understand the turbulence dynamics under different conditions. Since inside each DE, the monotonous change of the field variable (from _min to _max along the trajectory) depicts a laminar like structure in a local region, the space-filling DEs can be recognized as the smallest eddies.

In a more general sense, a newly defined multi-level DE structure has been developed. Introducing the size of the observation window S, extremal points are multi-level, based on which the DE structure can be extended to multi-level. At each S-level, the turbulent field can be decomposed into space-filling DEs, which makes it possible to understand to entire field from the properties of such individual units. In this sense, it is tentatively possible to define turbulent eddies of different scales as DEs at different S-levels. Conventional analyses based on “turbulent eddies” can be implemented using such idea. For instance, during energy cascade, eddy breakup corresponds to the splitting of DEs at higher levels (with larger S) to smaller ones at lower levels (with smaller S). Because of DE can be exactly defined, eddies can be quantified as well, but not just demonstrative. Such kind of multi-level DE structure is uniquely different from other existing approaches (e.g. vortex tube, PoD, Fourier analysis etc.) in the following senses. First, DEs at any S-level are quantitatively defined, rather than qualitatively visualized. Second, DEs at any S-level are space-filling. The multi-level DE approach is generally applicable in turbulence analysis.