SPATIALLY RESOLVED ENSTROPHY FLUXES IN QUASI-TWO-DIMENSIONAL FLOW

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Abstract Using filter-space techniques, we study the spatially resolved scale-to-scale transfer of enstrophy in a quasi-two-dimensional weakly turbulent experimental flow. These enstrophy fluxes show very complex spatial structure, which we explore and quantify. We consider the relationship of these patterns to coherent structures in the flow field.

OVERVIEW

Turbulent flows are typified by strong interactions between dynamics on different length and time scales. But even though such interactions are central to our understanding of turbulence, they are very difficult to measure directly, particularly in experiments where only incomplete information about the flow can be measured. Transport of physical quantities such as energy and momentum between scales is typically inferred from measurements of Fourier spectra, which necessarily remove all information about the spatial structure of the spectral transfer properties.

In recent years, however, new tools based on filtering [2, 1, 5] have begun to allow the direct measurement of fluxes between scales. In an approach that is conceptually related to Large Eddy Simulation, the flow field is filtered at a certain scale r, removing all motion on smaller length scales. By comparing the resulting filtered field with the full field, information about the coupling between the two (and therefore the transfer of energy, momentum, and other quantities) can be extracted.

Two-dimensional turbulence has tremendously rich spectral dynamics, since both energy and enstrophy cascade away from the scale at which the flow is forced. We have previously studied the spatial structure of the spectral energy flux in quasi-2D flow [4]; here, we consider the structure of the *enstrophy* fluxes.

EXPERIMENT

We generate quasi-2D flow experimentally using an electromagnetic flow cell [3]. We place a thin layer (roughly 5 mm deep) of salt water over a lattice of permanent magnets. When an electric current is driven laterally across the layer, Lorentz forces set the fluid into motion. If the current is large enough, the flow breaks the symmetries of the magnet lattice, becomes weakly turbulent, and shows the net spectral properties expected for 2D turbulence (albeit with no developed inertial ranges) [4]. We measure the flow field using Particle Tracking Velocimetry, following the motion of small fluorescent tracer particles with a high-resolution camera. After measuring raw velocity fields, we project them onto a basis of streamfunction eigenmodes so as to ensure the two-dimensionality of our data [3].

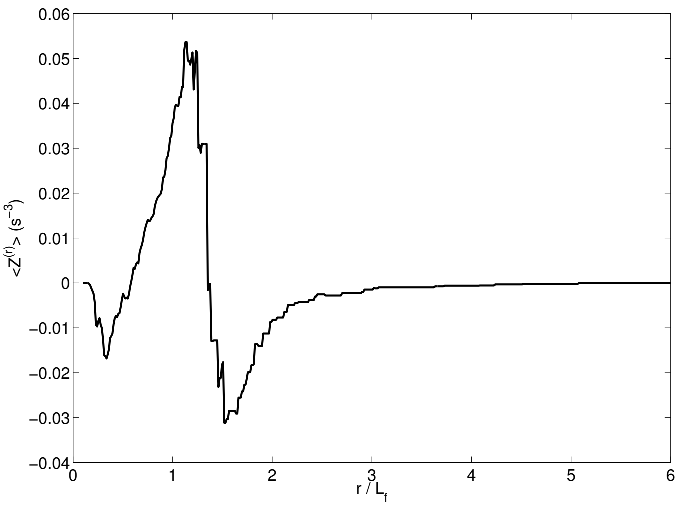

Figure 1. Spatially averaged spectral enstrophy flux $Z^{(r)}$ as a function of filter scale r, for a Reynolds number (based on the root-mean-square velocity and the energy injection scale L_f) of $\mathrm{Re} = 185$. Positive values denote transfer to smaller scales; negative values denote transfer to larger scales.

ANALYSIS

To measure the scale-to-scale flux of enstrophy, we filter the measured velocity and vorticity fields by convolving them with a round Gaussian filter kernel [5, 4]. The spatially averaged enstrophy flux, shown as a function of the filter scale r in Fig. 1, clearly shows a region of forward enstrophy transfer, as expected in the classical Kraichnan–Leith–Batchelor picture of 2D turbulence. But our filtering techniques allow us to do more than simple spatial averages; instead, we can study the spatially localized enstrophy fluxes. An example flux field is shown in Fig. 2. We will present characterizations of the spatial patterns of the enstrophy fluxes, as well as the Lagrangian properties of the enstrophy flux fields.

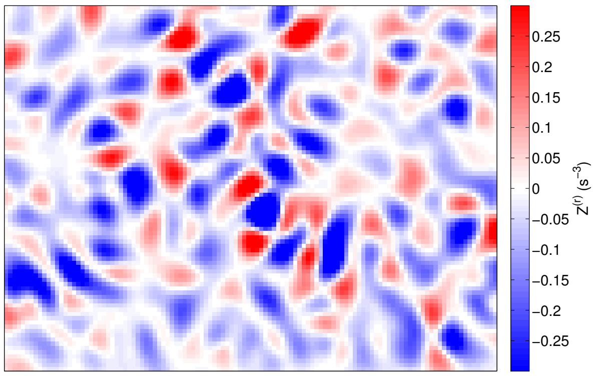

Figure 2. Spatially resolved enstrophy fluxes, at a filter scale of $r = 1.6L_f$. The scale bar shows the magnitude of the enstrophy flux, which can be much larger than the average value and is spatially heterogeneous.

References

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