The role of coherent structures for transport in fully-developed fluid turbulence

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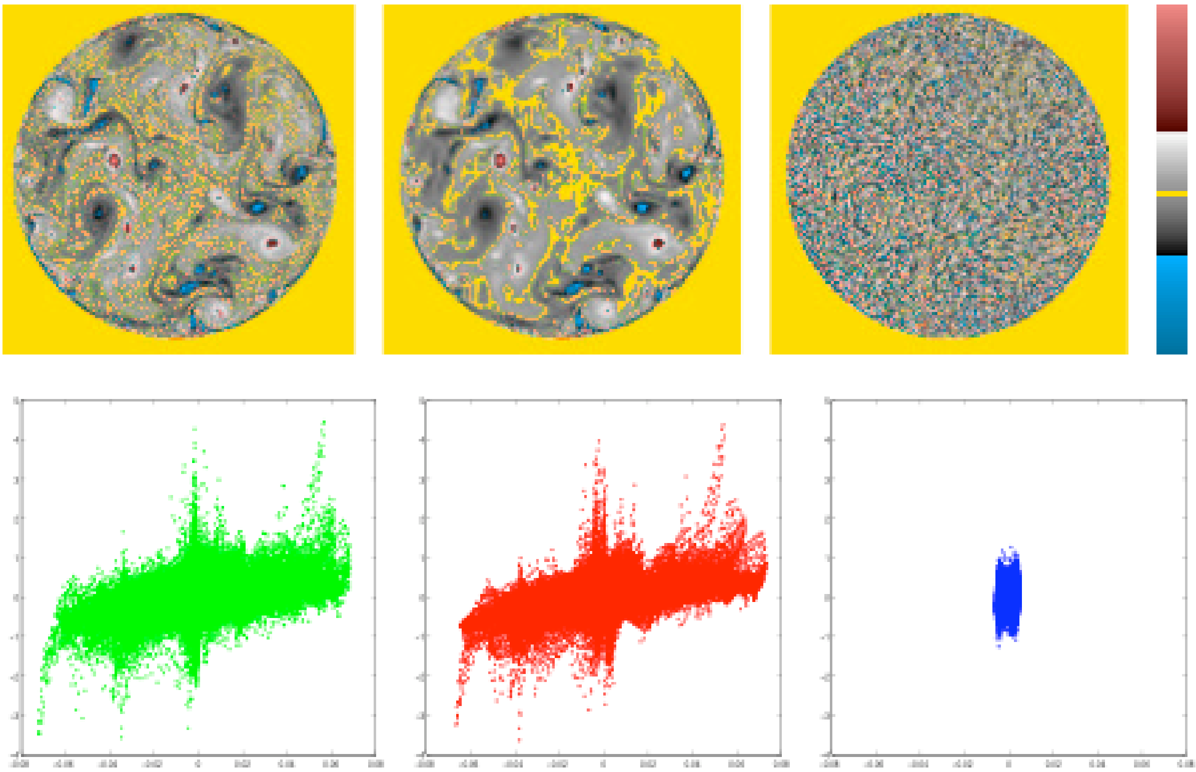
We focus this talk on incompressible fluid flows in the fully-developed turbulent regime, where nonlinear interactions strongly dominate linear behavior (*i.e.*, the Reynolds number is much larger than the critical value corresponding to the transition from a laminar to a turbulent regime). We observe that fully-developed turbulent flows form coherent structures which emerge out of random fluctuations. We conjecture that they drive the flow evolution and, consequently, play a central role for turbulent transport. In 1988 we proposed to replace the Fourier representation by the wavelet representation [1] to analyze turbulence in terms of both space and scale, instead of wavenumber. We have then designed a method to extract coherent structures which is based upon a nonlinear filtering of the wavelet coefficients [2]. This algorithm only assumes that coherent structures are different from random noise. Extracting coherent structures is thus equivalent to denoising and does not require any template or *adhoc* threshold to identify them.

We will illustrate the use of the wavelet representation to analyze and filter different types of two- and three-dimensional turbulent flows, either computed by DNS (Direct Numerical Simulation), or measured by PIV (Particle Image Velocimetry). The turbulent fluctuations of each flow realization are split into two orthogonal components (which exhibit different statistical behavior) :

- **coherent fluctuations** (non-Gaussian and long-range correlated),
- **incoherent fluctuations** (quasi-Gaussian and decorrelated),

which are analyzed and averaged separately. We study their transport properties : the coherent fluctuations are responsible for convective transport, while the incoherent fluctuations correspond to turbulent diffusion [3].

Finally we propose a new interpretation of the turbulent cascade and of the associated energy spectrum. We hope the wavelet representation may bring new insight for interpretating turbulent signals and understanding transport in fusion relevant plasmas, even though the fluid hypothesis may no longer hold.



Top : total (left), coherent (center) and incoherent (right) vorticity fluctuations of a two-dimensional fully-developed turbulent flow of zero mean, which has been computed by direct numerical simulation of the two-dimensional Navier-Stokes equations.
Bottom : scatter-plot between vorticity and stream function which characterizes the presence of coherent structures in the total and coherent, but not in the incoherent fluctuations.

References

[1] Marie Farge, 1992
Wavelet transforms and their applications to turbulence
Ann. Rev. Fluid Mech., ***24***, *395-457*

[2] Marie Farge, Giulio Pellegrino and Kai Schneider, 2001
Coherent vortex extraction in 3D turbulent flows using orthogonal wavelets
Phys. Rev. Lett., ***87****(55), 054501*

[3] Carsten Beta, Kai Schneider and Marie Farge, 2003
Wavelet filtering to study mixing in 2D isotropic turbulence
Comm. in Nonlinear Science and Numerical Simulation, ***8*** *(3-4), 537-545*

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*Our papers can be downloaded from : //**wavelets.ens.fr***