Figure 1

Figure 2

Figure 3

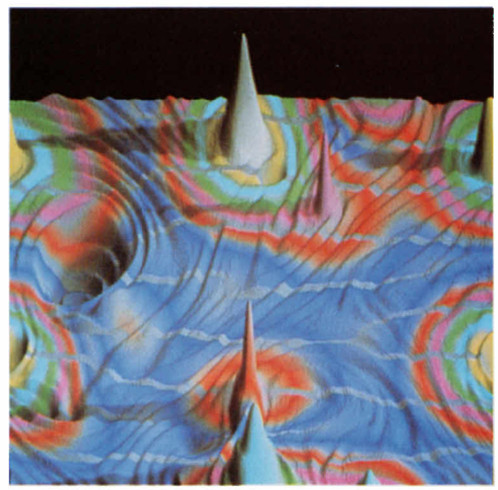

Figure 4

WAVELET ANALYSIS OF COHERENT STRUCTURES IN TWO-DIMENSIONAL TURBULENT FLOWS

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A generic behavior of two-dimensional turbulent flows is the condensation of the vorticity field into vortexlike patterns, called coherent structures, which concentrate most of the energy and enstrophy of the flow. They play an important dynamic role, not yet well understood.

Figures 1, 2, and 4 show the vorticity field for different realizations of a two-dimensional decaying turbulent flow, obtained by computing Saint-Venant's equations in the geostrophic case.[2] Figures 1 and 2 correspond to an early stage of the flow, during which we observe the emergence of spiral-like coherent structures from an initially random vorticity distribution. Figure 3 corresponds to a later stage of the flow, characterized by the further condensation of the vorticity field into isolated axisymmetric vortices, which from time to time strongly interact.

We then use the wavelet transform to analyze these vorticity fields in terms of both space and scale.[3] We thus measure the coherent structures' contribution to the energy spectrum and study the spatial intermittency of the flow. We choose a Morlet wavelet, which is complex valued, and therefore can split the wavelet coefficients into modulus and phase.

Figure 3 shows the one-dimensional wavelet transform of a slice taken from the vorticity field shown in Fig. 2. Figure 4 represents the superposition of the vorticity field (perspective representation), the modulus of its wavelet coefficients at a given scale (color coded, white being the highest value and blue the lowest), and their phase at the same scale (the phase zero corresponds to the gray isolines).

These wavelet decompositions show that the smallest scales, which are not very localized in space during the early stage close to the initial random conditions, become more and more concentrated within the coherent structures during the flow evolution.[4–6] This small-scale concentration confirms the conjectured relation between the flow intermittency and the coherent structures.

The two-dimensional wavelet code has been developed in collaboration with Matthias Holschneider, from the Centre de Physique Théorique, Marseille-Luminy. The visualizations have been computed at LACTAMME, Ecole Polytechnique, Palaiseau, with Jean-François Colonna. All the computing has been performed on the Cray-2 of the Centre de Calcul Vectoriel pour la Recherche, Palaiseau.