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Elucidating Mesoscopic Dynamics Through Simple Systems

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We report on studies of mesoscopic dynamics in simple systems. The aim is to avoid the geometrical complexity and hidden assumptions of conventional large-scale 'simulations', and instead to examine dynamics in depth. We focus on two related, classic problems — namely staircase structure and evolution, and turbulence spreading.

a) Staircase Resiliency

Layered profile structures, or staircases, have been observed in many systems, including drift wave–zonal flow turbulence. Here, we explore the **resiliency** and **evolution** of staircases. The simplest type of staircase occurs in passive scalar convection in a vortex array, and is a consequence of the existence of two disparate time scales, characteristic of cellular over-turning and diffusion. Since transport thru cell boundaries is purely diffusive, steep concentration gradients form there, yielding a global concentration profile staircase. The mean field scalar transport coefficient for the system is the geometric mean of cellular diffusion and collisional diffusion [1]. This result has important implications for confinement near criticality, and also is related to the well-known Chalker–Coddington model [2] of the Quantum Hall Effect. Interestingly, no assumptions concerning "feedback loops", "shear suppression", etc. are *a priori* necessary. Of course, this model is quite idealized, so we are motivated to explore staircase resiliency to disorder in the presence of fluctuations, mixing, etc. Thus, the fixed cellular array is replaced by a fluctuating vortex array, the model for which was originally developed for a finite-temperature vortex crystal [3]. A series of numerical experiments at modest Reynolds number were performed. Results indicate:

i) Scalar concentration mixing is inhomogeneous, and staircase profiles form.
ii) Staircases persist and are resilient over a broad range of Reynolds number, though coarsening due to step condensations occurs.
iii) Scalar concentration travels **along** streamlines in regions of strong shear. Hence, inter-cell barriers form first, while scalar concentration homogenizes in vortices later. An image of the scalar concentration field thus resembles a web, which gradually fills in.
iv) Scattering by vortices reduces the speed of scalar concentration front propagation. These paths are those of least time.
v) If flow velocity and collisional diffusion are held fixed, only cell geometric properties ultimately determine the mean field scalar diffusivity. The latter does not deviate significantly from the value for the fixed cellular array. This is a consequence of the fact that array fluctuations do not induce vortex boundary crossings.

Extensions of this study to the case of an active scalar (2D MHD) are under study and will be reported. The implications of this basic study for confinement physics will be discussed.

b) Turbulence Spreading

The spreading and propagation of turbulence are widely discussed [4] in the context of fast transients, non-local transport, etc. Amazingly, little or no detailed basic studies of spreading and entrainment dynamics have been pursued in the context of relevant models. We examine the spreading of a turbulent patch resulting from a locally forced excitation in a 2D fluid with viscosity and drag. The forcing is a linear array of stirring, with variable bandwidth. Results indicate that:

i) The turbulent patch expands at roughly constant velocity, so width ~ time.
ii) Finite drag limits expansion, thus defining a finite stopping length. This length is the sought-after "depth of penetration into the stable region".
iii) Vortex dipoles form and contribute to spreading. Recall that a vortex dipole moves at constant velocity, and so is relevant to result (i).
iv) Spreading dynamics are sensitive to the properties of the forcing — especially the bandwidth.

Ongoing work is concerned with extension to systems with waves and zonal flows (i.e. Hasegawa–Mima) and to 2D MHD. 2D MHD is of particular interest, so as to determine the spreading dynamics of (kinetic and magnetic) energy, mean square magnetic potential, etc. The effects of a weak magnetic field threading the system are examined.

References

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