Clustering and Staircase Formation in Fingering Convection

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Fingering convection is a peculiar convective flow that occurs when two buoyancy-changing scalars with different diffusivities, such as salt and temperature, make an overall bottom-heavy density stratification, but the least-diffusing one, taken alone, would produce a top-heavy stratification. In the fingering regime, a fluid parcel displaced from its equilibrium height exchanges the better diffusing and stabilizing scalar faster than it exchanges the destabilizing one, developing a buoyancy anomaly that further increases the displacement [1].

The linear stability properties of the doubly-diffusive instability are well understood and, close to marginality, tall, finger-like convection plumes emerge (hence the name). Far from the instability, in the highly nonlinear regime, these tall structures appear just as a short transient, after which the convection is sustained by the motion of almost spherical, blob-like structures, and the statistics of the fluctuations of the scalars become non-Gaussian [2].

An intriguing phenomenon that happens at high Rayleigh number and low density ratio (a measure of the relative contribution to the buoyancy of the two scalars) is an instability of the horizontally averaged profiles of temperature, salinity, and buoyancy. Laboratory experiments show that initially constant vertical gradients develop kinks which steepen and evolve into an alternation of well-mixed zones characterized by Bénard-like convection cells and high-gradient layers populated by fingers. Such staircase profiles are found in the main thermocline of the subtropical oceans and of many marginal seas [1].

We performed three-dimensional staircase-forming simulations at very high numerical resolution (to our knowledge unprecedented for this problem). We find a previously unreported phenomenon of self-organization of fingers that cluster together to form large-scale coherent structures. We suggest [3] a mechanism of staircase formation that occurs in two phases: first, the fingers group to form coherent structures at larger scales; then, the mechanical mixing induced by those clusters forms the staircases with a mechanism analogous to that of staircase formation in a stably stratified (nonconvective) stirred fluid [4].