

## Thermal Plumes, Hierarchical Organization and Eulerian–Lagrangian Statistics in Turbulent Rayleigh–Bénard Convection

Prafulla Shevkar, Postdoctoral Researcher, TU Ilmenau, Germany

### ABSTRACT

We investigate thermal-plume organization and Lagrangian transport in turbulent Rayleigh–Bénard convection over Rayleigh numbers ranging from  $10^5$  to  $10^9$ . Using near-wall velocity measurements, we introduce a simple kinematic criterion based solely on the horizontal velocity field to identify line plumes. We first show that the horizontal divergence is negative in two-dimensional laminar similarity solutions of plumes and positive in the corresponding boundary-layer regions. Motivated by the observation that fluid elements predominantly experience horizontal shear within the boundary layers and vertical shear within the plumes, we identify line plumes as regions where the dominant eigenvalue of the two-dimensional strain-rate tensor is negative, equivalently where the horizontal divergence is negative. These near-wall plumes further organize into large-scale superstructures and exhibit self-similar behavior with Rayleigh number and distance from the plate. We further investigate transport and mixing using Lagrangian particle tracking in a high-aspect-ratio cell,  $\Gamma=10$ , at  $Ra=9.3 \times 10^7$  and  $Pr=4.8$ . Approximately 50,000 neutrally buoyant particles are tracked for up to 150 Kolmogorov times, resolving single-particle dispersion from the ballistic to the diffusive regime. Lagrangian velocity structure functions and particle-pair dispersion exhibit distinct temporal scaling regimes, with super-Richardson behavior observed most clearly in the lateral direction. Multi-particle statistics reveal strongly anisotropic cloud dispersion and deformation, while particle-connectivity networks provide a complementary description of collective dynamics. Acceleration statistics further show stronger intermittency in the lateral components and reduced intermittency in the bulk relative to the full measurement volume, underscoring the influence of near-wall plume events.

### ABOUT THE SPEAKER

Dr. Prafulla P. Shevkar is currently a postdoctoral researcher at Technische Universität Ilmenau, Germany, where he studies high-aspect-ratio turbulent Rayleigh–Bénard convection using 4D particle-tracking velocimetry. His research focuses on Lagrangian particles and particle cluster dynamics, small-scale intermittency and the organization and self-similarity of thermal plumes. He completed his PhD in Applied Mechanics at IIT Madras, where he investigated near-wall dynamics in turbulent convection and proposed a velocity-based criterion to separate thermal plumes from boundary-layers, validated using tomographic PIV experiments. He also studied effects of shear on near-wall plumes and boundary layer velocities. His broader interests include experimental turbulence, rotating flows, geophysical flows, advanced particle-tracking methods, simultaneous velocity-temperature measurements, high speed flow measurements using event-based cameras and machine learning in thermo-fluids.

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