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High-resolution temperature profiling in the Π Chamber

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The Π Chamber, a turbulent aerosol–cloud reaction chamber, stands as a highly advanced facility for conducting controlled experiments on cloud microphysics. Its unique design enables reproducible and controlled measurements across a broad range of temporal scales, from hours to days, while maintaining consistent thermodynamic conditions. The chamber induces Rayleigh-Bénard convection (RBC), wherein air is heated from below and cooled from above. In this study, we focus on analyzing small-scale temperature fluctuations at selected points along the vertical axis to characterize convection inside the chamber. Understanding these fluctuations is crucial for comprehending the variability in thermodynamic conditions within the chamber, which significantly influences the formation, growth, and evaporation processes at the smallest scales of turbulence.

Our methodology involved collecting high-resolution temperature time series (2 kHz) using the UltraFast Thermometer (UFT) and comparing this data with Direct Numerical Simulations (DNS) conducted under similar thermodynamic conditions. The UFTs, developed at the University of Warsaw, are designed for airborne in-cloud measurements with resolution extending down to scales within and below 1 cm (i.e., reaching the dissipation range). The current sensor version (UFT-2B) features a resistive platinum-coated tungsten wire, 2.5 μm thick and 3 mm long, mounted on a miniature wire probe, facilitating easy replacement of the sensing head. This sensor design allowed for undisturbed vertical temperature profiling spanning from 8 cm above the floor to 5 cm below the ceiling.

The research investigated three distinct temperature gradients (10℃, 15℃, and 20℃) between the top and bottom, maintaining convective conditions inside the chamber. The dataset comprised both long (19 min) and short (3 min) measurement time series, revealing intriguing inhomogeneities near the vertical plates associated with local thermal plume dynamics. We identified two spectral regimes termed inertial and dissipative ranges, characterized by slopes oscillating around -5/3 and -7, respectively. Furthermore, our analysis unveiled a robust relationship between the periodicity of large-scale circulation (LSC) and the temperature gradient, describable by an exponential relation. Notably, the experimental findings demonstrate strong agreement with DNS data, illustrating a rare comparative analysis of this nature.

In our presentation, we will delve into the outcomes of our investigations, engaging in a comprehensive discussion and outlining future research directions.