Abstract

Atmospheric flows represent a wide range of fluid motions, spanning various spatial and temporal scales, driven by diverse forcing mechanisms, thermodynamic and microphysical changes, and interactions with other phenomena. These overlapping processes give rise to complex dynamics that manifest differently at different scales. To better understand these processes, two main experimental approaches are typically employed. One approach involves isolating specific phenomena in laboratory settings under controlled conditions, allowing for a more selective analysis of flow properties. The alternative relies on deploying multiple instruments in field measurements to capture a broader spectrum of atmospheric variability. This study investigates small-scale temperature fluctuations across the full range of scales in both laboratory facilities and real atmosphere conditions during airborne measurements. The data were collected using miniaturized UltraFast Thermometers, which enable undisturbed, high-resolution (2kHz) scalar field measurements.

The first part of this study focuses on the LACIS-T wind tunnel (TROPOS, Germany), one of the newest operational aerosol–cloud research chambers. As a closed-loop wind tunnel, it enables turbulent, isobaric mixing of two humidified, aerosol-free air streams under independently controlled and repeatable thermodynamic conditions. This work presents results from two dry and clean experiments conducted with temperature differences of 25 K and 16 K between the air streams. These experiments revealed intensified scalar field variability in the central region, recognized thermal inhomogenities, and examined influence of outside conditions on experiments. Moreover, the study identified four distinct power-law spectral regimes, and provided a comparative analysis between scalar and energy-based approaches in the dissipative range.

The second facility examined was the Π Chamber, a convection-cloud chamber operating on the principle of induced Rayleigh-Bénard convection, where air is heated from below and cooled from above. This study analyzed temperature fluctuations under three different temperature differences between the bottom and top plates (10 K, 15 K, and 20 K), corresponding to a Rayleigh number of approximately 10^9 and a Prandtl number of about 0.7. The results revealed significant

variability in both the standard deviation and skewness of temperature fluctuations near the top and bottom plates, as well as in the central region–variations linked to local thermal plume dynamics. Additionally, three spectral regimes were identified, and a power-law relationship was established between the periodicity of the large-scale circulation and the temperature difference. Notably, the experimental results aligned well with Direct Numerical Simulations conducted under similar thermodynamic conditions.

Finally, this study investigated temperature dissipation during airborne operations in the EUREC^{4}A campaign. The collected temperature time series were categorized into three horizontal segments: clouds (liquid water content $\geqslant 10^{-3}\mathrm{g\,m^{-3}}$), boundary layer (pressure $\geqslant$ 1010hPa), and free atmosphere (pressure $<$ 1010 hPa). These classifications enabled statistical analyses of a normalized temperature dissipation rate. The histograms of this quantity exhibited a robust power-law distribution, except for elongated tails at both high and low values of dissipation rates across all segment types. Laboratory datasets displayed similar behavior, albeit with some limitations. Furthermore, the study demonstrated that the power-law coefficients are not interdependent and can be described by a logarithmic relationship–suggesting that this may be a more universal feature of atmospheric flows.