Doctoral Dissertation
Doctoral Program in Electrical, Electronics and Communications Engineering (36th cycle)

The radiosonde cluster network: A novel approach to track Lagrangian fluctuations inside atmospheric clouds

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Summary

Understanding cloud dynamics and turbulence within clouds is critical for climate modeling and weather prediction. However, directly measuring cloud fluctuations remains challenging, especially for small-scale phenomena. Traditional radiosonde deployments lack the ability to track fluctuations over extended distances and the entire range of turbulence spatial scales. This work proposes two novel approaches for studying cloud processes: in-field observations using a radiosonde cluster network and numerical simulations of turbulent cloud-clear-air interactions in the presence of water droplets.

The radiosonde cluster network comprises miniaturized radiosondes equipped with sensors for pressure, humidity, temperature, velocity, acceleration, magnetic field strength and position information. The system offers advantages over traditional radiosonde deployments. It tracks fluctuations of physical quantities within clouds and provides simultaneous measurements across the cloud volume. Furthermore, it enables the direct quantification of Lagrangian turbulent dispersion. In-field experiments validated the system's accuracy and demonstrated its ability to perform spectral analysis of fluctuations and distance neighbor graph statistics of Lagrangian dispersion.

The numerical simulations employ three-dimensional direct numerical simulations (DNS) to investigate the interactions between turbulence and cloud droplets in the highly anisotropic interfacial layer, the region where the cloud interacts and entrains to clear air or vice-versa. The simulations closely resemble actual warm clouds, incorporating the same level of supersaturation, liquid water content, number of droplets, density stratification perturbation, and kinetic energy ratio between cloud and clear air regions. The simulations shed light on the intermittency acceleration within the interfacial layer, droplet population dynamics, collision kernel and its relation with turbulent fluctuations, supersaturation balance and microphysical time scales.

These studies provide valuable insights into cloud dynamics and turbulence evolution, contributing to a deeper understanding of cloud formation, growth, and dissipation. The combined use of in-field observations and numerical simulations offers a powerful approach for advancing cloud research and improving climate modeling.