

Simulations and observations of boundary layers in the moist troposphere using GNSS radio occultations

Understanding the atmosphere is essential for predicting extreme weather events, such as tropical cyclones and atmospheric rivers, which can bring heavy rainfall, flooding, and significant disruption to communities. The key driving factor that can affect storms development is the amount of water vapor which can abruptly change in the lower section of the atmosphere - the troposphere. The planetary boundary layer (PBL) that is formed as a result near the surface acts as a natural barrier, influencing the movement of heat, moisture, and air. However, measuring and modeling its characteristics remains a challenge, especially in tropical regions saturated with moisture that have a profound impact on weather systems. Tropical cyclones often form and intensify in regions with strong temperature and humidity gradients. Atmospheric rivers, which are narrow corridors of concentrated moisture, rely on PBL distribution to transport water vapor over long distances.

Radio occultation (RO) is amongst few satellite techniques that allows observing vertical profiles of temperature, pressure, and humidity down to and below the height of PBL. The occultation occurs between a pair of satellites when they are about to set or rise behind the Earth's horizon to perform a series of rapid measurements. The radio signals from Global Navigation Satellite Systems, such as GPS, are bend and slow down while passing through the atmosphere which depends on the meteorological properties. Unlike traditional methods, RO can capture data even over remote areas, above oceans, and through dense clouds, making it an invaluable tool for studying the severe weather.

This research will extend the capabilities of RO technique beyond observations to the satellites by incorporating data from balloon-borne and airborne platforms. These innovative concepts allow to observe the atmosphere closer to active weather systems to study the evolution during their life cycle. The project will focus on studying the lower troposphere to understand how sharp gradients in temperature and moisture influence weather dynamics. Advanced numerical models will complement observations by simulating atmospheric conditions and validating results against real-world data from sensors like dropsondes that are deployed into storms from aircraft to measure atmospheric properties. While they descend from high altitudes, they might capture the tropopause layer that marks the upper boundary of the troposphere. The atmospheric instability and surface heating can lift warm, moist air up to the tropopause which might extend at heights of 15 km and above. The amount and distribution of moisture in the tropopause can influence long-term weather patterns, playing a central role in Earth's climate system.

The balloon-borne and airborne RO techniques alongside well-established satellite-based variant will provide unprecedented detail about the atmosphere with the emphasis of near-storm environments. New methods and data products will be developed to detect the heights and strengths of boundary layers with high accuracy. Additionally, the project will explore new measures of atmospheric activity through analysis of raw satellite signals that carry information about extreme weather which is otherwise invisible in conventional meteorological parameters. Understanding these signals could reveal new ways to predict weather patterns with improved forecast skill.

The project's outcomes are expected to benefit both science and society with new measurements and refined models to enhance weather forecasts, particularly for summer and winter storms. This in turn would enable earlier warnings to prevent socio-economic losses. New findings will also deepen our understanding of how the atmosphere behaves in moisture-rich regions, contributing to climate research and global forecasting systems.