Simulating the synergy of microwave radiometer and differential absorption radar for advancing water vapor profiling in cloudy conditions

Continuous, high vertical resolution water vapor profile measurements are key for advancing the understanding of how clouds interact with their environment through convection, precipitation, and circulation processes. Yet, current ground-based observation systems are limited by low temporal resolution in the case of soundings, signal saturation at cloud base in the case of optical sensors, or too coarse vertical resolutions in the case of passive microwave measurements. Overcoming the limitations of the single sensors, we assess the synergistic benefits of combining ground-based microwave radiometer (MWR) and a novel G-band Differential Absorption Radar based on synthetic measurements generated for typical trade wind conditions as observed during the EUREC^{4}A field study.

Based on the single and multiple cloud layer conditions observed at Barbados Cloud Observatory, we use the passive and active microwave transfer model PAMTRA to generate synthetic measurements of the K-band MWR channels, as well as for a radar instrument operating at frequencies of 167 and 174.8 GHz. The synthetic brightness temperatures and radar dual-frequency ratios are combined in an optimal estimation framework to retrieve the absolute humidity profile. Varying the observation vector setup, the synergy benefits are assessed by comparing the synergistic information content (Degrees of Freedom for Signal) and retrieval errors to the respective single-instrument configuration, and by evaluating the retrieved profile using the initial sounding profile.

In single-cloud conditions, the total synergistic retrieval information content increases by more than one DFS compared to a MWR-only retrieval. While the radar measurements dominate the retrieval below and throughout the cloud layer, the MWR drives the retrieval above the cloud layer. The synergy further enhances the information content above the cloud layer by up to 15% compared to the MWR-only retrieval, accompanied by decreased retrieval errors of up to 10%.
Cases of a shallow cloud layer topped by a stratiform outflow confirm the identified patterns. The radar measurements further increase the information content between the cloud layers by up to 25%. In this case, the results suggest an improved partitioning of the water vapor amount below and above the trade inversion.

Current G-band radar signal attenuation in moist tropical conditions are expected to reduce the feasible synergy potential in a real application. Yet, increased radar signal sensitivities, adjusted frequency pairs, or drier atmospheric conditions motivate the application of this synergy concept to real measurements to advance ground-based water vapor profiling in cloudy conditions.