Exploiting novel, ground-based Profiling Techniques in the Atmospheric Boundary Layer

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For short-term forecasting on the km-scale, the current global observing system does not meet the requirements stated by the WMO Rolling Requirements Review (RRR). This is especially relevant in the Atmospheric Boundary Layer (ABL), considering temperature, humidity and wind profiling. The new generation of hectometer numerical weather prediction models will presumably require even more observational details to exploit their full potential. This observation gap in profiling the ABL mainly exists due to (1) the limited capability of satellite sounding in the ABL and (2) the temporal and spatial scarcity of profiling observations from radiosondes or commercial aircraft. Novel, surface-based profiling techniques have the potential to aid in filling this gap. In addition, they can deliver new insights into physical processes, which can in turn be used to evaluate and improve ABL parameterizations.

Over the last years, significant progress in profiling the ABL from the surface has been made. Uncrewed Aircraft Systems (UAS) as well as ground-based remote sensing systems such as lidar and MicroWave Radiometer (MWR) yield high potential to reliably profile temperature, humidity, winds and turbulence in a nearly continuous manner so that the temporal ABL evolution is well covered. This contribution will discuss the latest progress towards operational profiling accuracy, highlighting the importance of sensor synergy and showing how scanning sensors can provide information on local water vapor advection, thus providing a key to derive an ABL energy balance.

One focus of HErZ – the Hans Ertel Center, a cooperation on fundamental weather research between the German Meteorological Service (DWD) and German universities, are novel observations. The HErZ VITAL I campaign took place in August 2024 at the Jülich Observatory for Cloud Evolution (JOYCE). It generated vertical profiling data sets in the ABL. We will give an assessment for potential instruments of the next-generation DWD observational network, including UAS, water vapor lidar and microwave radiometer. The observations were compared against satellite data, Doppler lidar, radiosondes and data from a 120m meteorological tower. VITAL I also participated in a core phase of the 2024 world-wide WMO UAS Demonstration campaign with two small UAS applying a novel, improved wind and turbulence estimation technique.

Beyond zenith measurements, MWRs at JOYCE also perform elevation and azimuth scans, which helps to improve near-surface temperature profiles and can be used to identify spatial water vapor inhomogeneities. The presented work shows how horizontal gradients of water vapor can be obtained from 360° azimuth-scanning MWRs at a constant elevation angle. In synergy with vertical profiles of the horizontal wind from a Doppler lidar, they are used to estimate water vapor advection within the local domain of a few km around the instrument, considering a rigorous uncertainty estimation. Combing these retrievals with continuous vertical profiling of temperature and humidity and with surface fluxes of sensible and latent heat, the entrainment rate at the top of the ABL can be obtained via a mixing diagram approach. A case study from the VITAL I campaign will be discussed.