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Airborne lidar observations of mid-latitude mid-tropospheric water vapour variability

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Water vapor, a minor constituent of the earth's atmosphere, plays a major role in the radiation budget and the water cycle with important implications for weather and climate. Due to the heterogeneous distribution of its sources, evaporation, and sinks, condensation and precipitation, and due to the complexity of atmospheric motion and mixing, its distribution is highly variable. The complex dynamics of water vapour in the free troposphere spans a range of source and sink processes from convective clouds on the kilometre scale, to cloud systems associated with motions on scales of a thousand or more kilometres, as well as advection of water vapour as a passive tracer outside of clouds. While large-scale advection of water vapour is well represented in general circulation models, the simulations are greatly dependent on the parameterizations of small scale processes. A lack of knowledge of humidity fluctuations on scales smaller than the mesoscale model grid leads to errors in the development of deep convection and increases the prediction uncertainty. This problem can be addressed with the use of stochastic parameterisations that attempt to explicitly describe variability near the model grid length. However, the design and testing of such schemes depends on an accurate characterisation of small-scale variability in nature.

The COPS/ETReC 2007 (Convective and Orographically-induced Precipitation Study/European THORPEX Regional Campaign) field experiment conducted in July 2007 over middle and southwest Europe provided an ample set of long-range water vapour differential absorption lidar (DIAL) measurements onboard the DLR Falcon research aircraft. After discarding flights with weak lidar signals or with large data gaps, and after horizontal averaging to a resolution of 2 km to obtain a high signal to noise ratio, we were able to investigate a total of 8 flights with lengths of 225 - 700 km and vertical extents from 2 - 10 km altitude. Most flight segments have a length of 300 km and a vertical range of 4 km. Given the vertical DIAL resolution of 200 m we obtained a total of 98 time series of specific humidity, resulting in a total length of about 38,000 km.

The observed humidity distributions are highly non-stationary and intermittent. Hence, second-order statistics and Fourier spectra are inadequate to describe their variability. Instead, horizontal structure functions up to fifth order were computed. They exhibit power-law scaling between about 10 and 100 km in range. The second-order structure function shows scaling exponents equivalent to spectral slopes that vary from around 5/3 in the lower troposphere to 2 at upper levels. In particular, humidity smoothness is found to increase with height, while intermittency decreases. A classification of the data according to whether the series occurred above or below the level of nearby convective cloud tops gives a separation of the scaling exponents in the two air masses. The results are consistent with a water vapour distribution determined at upper levels by a downscale cascade of variance by advective mixing, but increasingly influenced at lower levels by local injection of humidity by moist convection. Our results show that the structure function exponents provide a compact statistical description of moisture variability on scales just below the resolution of weather and climate models. There is hope that this will help improve stochastic model parameterisations.