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CHARACTERIZATION OF WATER VAPOR FLUXES BY THE RAMAN LIDAR SYSTEM BASIL AND THE UNIVERISTY OF COLOGNE WIND LIDAR IN THE FRAME OF THE HD(CP)^2 OBSERVATIONAL PROTOTYPE EXPERIMENT – HOPE

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ABSTRACT

Measurements carried out by the Raman lidar system *BASIL* and the University of Cologne wind lidar are reported to demonstrate the capability of these instruments to characterize water vapour fluxes within the Convective Boundary Layer (CBL). In order to determine the water vapour flux vertical profiles, high resolution water vapour and vertical wind speed measurements, with a temporal resolution of 1 sec and a vertical resolution of 15-90, are considered.
Measurements of water vapour flux profiles are based on the application of covariance approach to the water vapour mixing ratio and vertical wind speed time series. The algorithms are applied to a case study (IOP 11, 04 May 2013) from the HD(CP)2 Observational Prototype Experiment (HOPE), held in Central Germany in the spring 2013. For this case study, the water vapour flux profile is characterized by increasing values throughout the CBL with lager values (around 0.1 g/kg m/s) in the entrainment region. The noise errors are demonstrated to be small enough to allow the derivation of water vapour flux profiles with sufficient accuracy.

1. INTRODUCTION

Measurements of water vapour flux profiles provide unique and essential information for the characterization of turbulent processes within the convective boundary layer (CBL). Evaporation and horizontal/vertical humidity transport are key components of the hydrological cycle which are still poorly modelled and observed. Most models parameterize convective transport at sub-grid scale, while operational water vapour observations used for this purpose are inaccurate due to instrumental limitations [1].
Additionally, ground-based *in situ* measurements of water vapour and latent heat fluxes, while being difficult to perform, also have a limited significance because they are representative for a given area. Additionally, ground-based *in situ* measurements observe only the lowest part of the CBL and are influenced by local surface properties.
Lidar systems, based on their capability to provide high space and time resolution and accurate measurements of atmospheric water vapour and vertical wind speed, have nowadays reached the level of maturity needed to measure vertical profiles of water vapour and latent heat fluxes [2][3][4]. The major advantage of the lidar techniques is represented by its capability to characterize turbulent variables from the proximity of the surface up to interfacial layer and above.
In the present work we report measurements of the water vapour flux profiles within the Convective Boundary Layer (CBL) obtained from the Raman lidar system *BASIL* and the University of Cologne wind lidar.

2. METHODOLOGY

BASIL is a ground-based Raman Lidar hosted in a transportable sea-tainer. The major feature of *BASIL* is represented by its capability to perform high-resolution and accurate measurements of atmospheric temperature and water vapour, both in daytime and night-time, based on the application of the rotational and vibrational Raman lidar techniques in the UV [5],[6]. Besides temperature and water vapour, *BASIL* is also capable of providing measurements of particle backscatter at 355, 532 and 1064 nm, particle extinction at 355 and 532 nm and particle depolarization at 355 and 532 nm ([7]).

The University of Cologne wind lidar is 1.5-µm Doppler lidar produced by HALO Photonics [8] capable of measuring along-beam wind speeds in any arbitrary direction typically within the range of the atmospheric boundary layer (starting 75 m above the ground). Profiles of horizontal wind speed and direction are determined every hour by means of a VAD scan, the rest of the time is used for vertical wind (w) profiling.

The accuracies of the measurements performed by BASIL and the University of Cologne wind lidar are high enough to allow the retrieval of water vapour flux profiles throughout the atmospheric CBL.

Water vapour flux profiles Φ are obtained as the covariance of the vertical velocity and water vapour mixing ratio fluctuations:

$$\Phi = \langle w'.q' \rangle$$

with w' being the vertical velocity fluctuations and q' being the water vapour mixing ratio fluctuations.

3. RESULTS

In the selection of the case study to be included to this paper, attention was paid on identifying weather conditions characterized by the presence of a consolidated, well-mixed and quasi-stationary CBL. Typically time segments with a duration of 1-2 hours are considered as in fact for longer periods the CBL can no longer be considered as being quasi-stationary, while the consideration of shorter periods would reduce the number of sampled thermals and thus increase the sampling errors.

Figure 1 illustrates the time-height cross section of the vertical wind speed (upper panel) and water vapour mixing ratio (lower panel) in the time interval 14-18 UTC on 04 May 2013. The figure reveals the alternation of updrafts associated with thermals of warm air rising from the ground and downdrafts associated with thermals of cool air sinking from the free troposphere, with the stronger updrafts in the time interval 14:15-15:30 UTC and weaker updrafts afterwards. The largest variability is observed in the interfacial layer, which is characterized by the penetration of the warm humid air rising from the ground and the entrainment of cool dry air sinking from the free troposphere. The lower panel of the figure also reveals an increase in water vapour mixing ratio after 16:30 UTC.

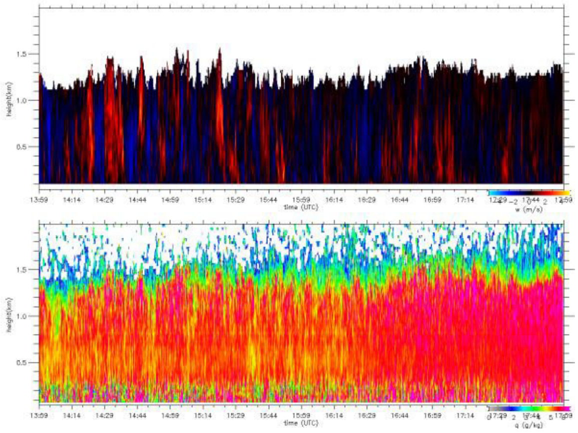

Figure 1: Time-height cross-section of the vertical wind speed (upper panel) and water vapour mixing ratio (lower panel) in the time interval 14-18 UTC on 04 May 2013.

For the purpose of the application of the covariance approach to estimate the water vapour flux profile, we then focused our attention on the time interval 14:15-16:15 UTC on this day.

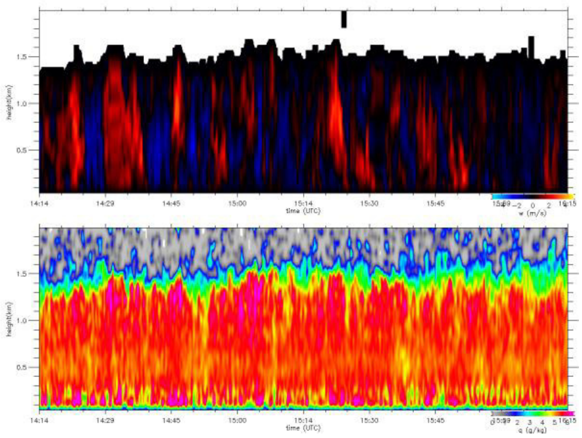

Figure 2: Time-height cross-section of the vertical wind speed (upper panel) and water vapour mixing ratio (lower panel) in the time interval 14:15-16:15 UTC on 04 May 2013.

Figure 2 illustrates the time-height cross section of the vertical wind speed (upper panel) and water vapour mixing ratio (lower panel) in the time interval 14:15-16:15. The data in figure 2 have been smoothed with a gaussian kernel with

L=90m and T=30sec. The integral scale of vertical wind speed and water vapour mixing ratio fluctuations are in the ranges 40-80 s and 40-90 s, respectively. Considering an average wind speed of ~9m/s, length scales for vertical wind speed and water vapour mixing ratio are in the range 360-720 m and 360-800m, respectively. Before applying the covariance approach, specific algorithms for the removal of linear trends and outliers were applied to the wind speed and water vapour mixing ratio time series.

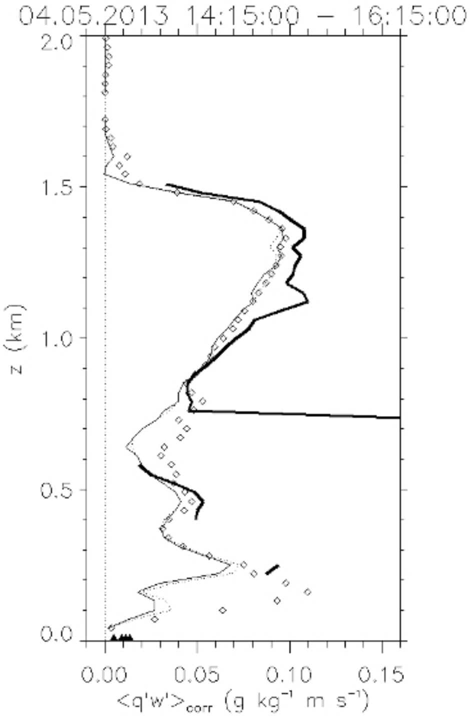

Figure 3: Water vapour flux profiles corresponding to the time interval 14:15-16:15 UTC on 04 May 2013. Thick line: profile corrected for separation, i.e. extrapolation to zero spatial shift; diamonds: profile corresponding to the largest covariance; solid line: profile with zero temporal shift; triangles: independent surface flux measurements.

Figure 3 illustrates the water vapour flux profiles corresponding to the time interval 14:15-16:15 UTC on 04 May 2013. Different profiles are shown for different time shifts. More specifically, the thick line represents the profile corrected for separation, i.e. extrapolation to zero spatial shift, the diamonds identify the profile corresponding to the largest covariance, the solid line represent the profile with zero temporal shift, while the triangles at surface level are independent surface flux measurements.

The flux profile is characterized by values increasing with height, this behaviour being compatible with the presence of a turbulent flux divergence having the same value at all heights within the CBL. In the absence of horizontal advection, this flux profile structure should produce a humidity loss to free troposphere of 8% per hour. However, this humidity loss does not appear in the water vapour lidar data. Consequently, we assume that this loss is compensated by local advection. Arguments is support of this hypothesis will be illustrated and discussed at the Conference.

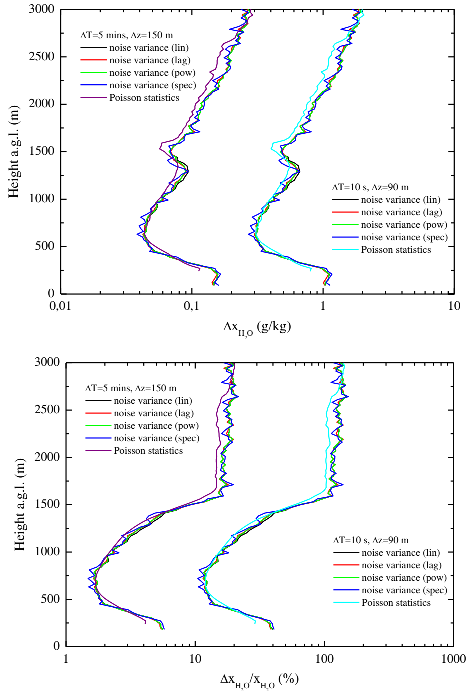

Figure 4: Profiles of noise error affecting water vapour mixing ratio measurements (upper panel in g/kg and lower panel in %).

In order to characterize the quality of water vapour mixing ratio measurements which are considered in the determination of the water vapour flux profile, an accurate assessment of noise error profiles is necessary. Profiles of noise error affecting water vapour mixing ratio measurements are illustrated in figure 4 (as estimated at 11:30 and 13:30 UTC on 20 April 2013), this being quantified as the root-square of the noise variance. For the selection of the vertical and temporal resolution considered for the flux measurements, i.e. 90 m and 10 s, respectively, the statistical error affecting water vapour mixing ratio measurements is smaller than 0.06 g/kg or 50 % up to 1.4 km.

4. CONCLUSIONS

This research effort demonstrates that water vapour flux profiles can be determined throughout the CBL with sufficient accuracy based on the use of state-of-art water vapour Raman and Doppler lidars. For this purpose measurements from the HD(CP)2 Observational Prototype Experiment (HOPE), held in Central Germany in the spring 2013, are considered.

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