

Water vapor measurements throughout the planetary boundary layer (PBL) with the ATMONSYS DIAL: From short-term variability to the calculation of vertical fluxes

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Abstract: Water vapor measurements from the newly developed ATMONSYS DIAL system are presented. Besides the presentation of the overall system capabilities, we show that the system, in combination with Doppler wind lidars, is able to capture vertical fluxes of latent heat. In addition, we show a substantial natural short-term relative variability of humidity inside the PBL of ~20%. Finally, an extended intercomparison of 3 humidity lidars and radiosondes shows that the drift of the radiosondes can have substantial implications.

1. Introduction

Water vapor is one of the key atmospheric trace gases as it has a high impact on multiple processes - ranging from weather to climate scales. The planetary boundary layer (PBL) connects the earth's surface, where water vapor is emitted through evapotranspiration, with the free troposphere. In contrast to the free troposphere, transport throughout the PBL is not driven by the mean wind but rather by turbulent eddies with diameters from <1 cm up to 2-3km [1,2].

Current numerical weather forecast models use rather old and simple parameterization for the transport of humidity throughout the PBL. However, with increasing spatial model resolutions, it is known that improved model prediction skills largely depend on improved parameterization of humidity transport throughout the PBL [2-4].

One further role of water vapor in the PBL and above is its impact on available atmospheric energy. Therefore, latent heat can be a relevant driver of convection and cloud formation. If measurements of water vapor/latent heat are combined with wind measurements, it is possible to calculate the fluxes of latent heat, which is the transport of energy [5]. Furthermore, precise measurements of latent heat fluxes throughout the entire PBL are an important part of the energy balance closure problem [6].

All the previously described problems and questions are limited by humidity measurements throughout the entire PBL with sufficient spatio-temporal resolution. Lidars impose themselves as a suitable technology to deliver such measurements. However, up to now, there are only a few systems that promise the capability of measuring at flux-resolving resolutions [7,8]. Differential Absorption Lidars (DIAL) with such high resolutions, which have major physical advantages during daytime, are not at all commercially available.

Therefore, in the following, we present water vapor measurements taken with the in-house developed ATMONSYS (Atmospheric Monitoring System) DIAL. Besides presenting the new DIAL itself, focus is set on the questions of (1) the extent of natural short-time variability in the entire PBL, (2) the suitability of our measurements for flux calculations, and (3) the future benefit of DIAL measurements over radiosondes.

2. Instrumentation and application

Mobile DIALs for measurements throughout the entire PBL with high enough spatio-temporal resolutions to resolve vertical fluxes of latent heat are currently not commercially available. The ATMONSYS DIAL has been developed for such measurements inside the PBL. The newly developed laser setup [9] is

operated in the 817nm wavelength spectrum with a sampling rate of 10s. More details on the technical specifications of the system can be found in Table 1. Also included in the ATMONSYS system is an elastic aerosol backscatter channel operating at 532 nm. Therefore, additional information on the aerosol distribution can be obtained by applying the Klett inversion algorithm [10,11]. The presented ATMONSYS measurements are accompanied by radiosondes, Doppler wind lidars as well as two high-power humidity Raman lidars [8,12]. The data that is presented here has been collected during the Field Experiment on submesoscale spatio-temporal variability in Lindenberg (FESSTVaL) campaign during summer 2021 [13].

3. Results

3.1. Short-term variability

The ATMONSYS system is capable of measuring both temporal and spatially very detailed vertical profiles of humidity and aerosol concentrations (Fig. 1). The vertical measurement range of humidity is largely coupled to the extent of aerosols. Therefore, the limit is not set only to the extent of the PBL. As can be seen in Fig. 1, the vertical range of measurements during clear-sky daytime conditions in this case goes up to ~3.5km. The PBL top height in this case is ~1.5km. Therefore, information not only on the PBL, but also about its exchange and entrainment with the free troposphere can be investigated. With its high temporal resolution, information on the quite substantial short-term water vapor variability can be gained. This can be done by comparing the variance of the measurements with the uncertainties of the calculated mixing ratios. As the results show, a relative variability of 20% during a short period of time is definitely within a reasonable range. On the one hand, this is important information for flux measurements and large eddy simulations and reflects the spatial pattern over heterogeneous terrain. On the other hand, this can add valuable information for instrument intercomparison studies inside the PBL as the assessment of measurement differences between multiple instruments benefits from knowledge on plausible, natural short-time variability.

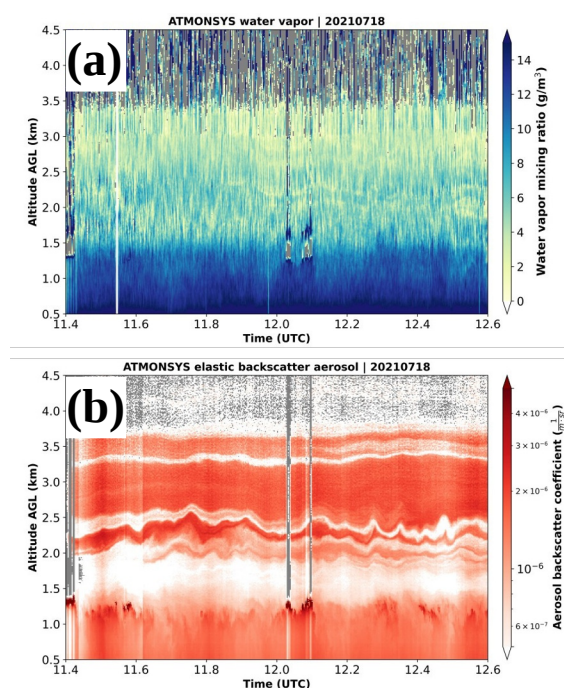


Figure 1. Example plots of vertical-stare time series of (a) water vapor concentration and (b) Aerosol elastic backscatter coefficients.

Table 1. Technical specs of the lidar

Laser repetition rate	100Hz
Averaged output power @817nm	2W
Averaged output power @532nm	1.6W
Temporal resolution/Sampling rate	10s
Effective vertical DIAL resolution	14m - >440m

3.2. Measuring the latent heat flux

The sampling rate of a system itself does not give sufficient information to determine to what extent turbulent fluxes can be resolved. An important feature is, of course, the temporal stability of the measuring system which translates into instrumental noise. In order to test instruments on their capability of whether or not they are suitable of resolving turbulent fluxes, their Fourier-transformed measurements should be tested on whether they fulfill the “Kolmogorov -5/3 law” [14]. Doing so, we can see that the ATMONSYS DIAL itself does not resolve turbulent changes in humidity down to its full temporal resolution due to noise. However, we will show that the combination with stable Doppler wind lidars can ensure the calculation of high-

quality latent heat fluxes anyway, as statistical noise cancels each other out. Therefore, even with this preliminary development of the ATMONSYS DIAL, measurements of vertical latent heat fluxes are possible down to its full temporal resolution of currently 10s.

3.3. Instrument intercomparison

As already indicated in Section 3.1, the intercomparison of water vapor measurements inside the PBL is not always straightforward as the question of short-term variability – induced by eddies and earth surface heterogeneity – remains. In addition to the analysis of errors in Section 3.1, the FESSTVaL campaign offered the possibility to compare the results from 3 high-power humidity lidars with radiosonde data in closest proximity to each other. The unique intercomparison of different measuring systems gives valuable insights. Overall, good agreement between the lidars can be seen, although sometimes limited by factors like system stability or background signal. Quite often, when it comes to the reliability of humidity measurements with lidar in comparison with radiosondes, the radiosonde data quality is considered to be the “gold standard”. We agree that the systematic errors of radiosonde in-situ measurements are lower than those of humidity lidars. However, as we show, the good data quality of the radiosonde is often obtained at different locations due to drifting, which can imply major differences. This has an important impact on model simulations if radiosonde data is interpreted as a vertical point measurement.

show an extended instrument intercomparison between 3 high-power humidity lidars and radiosondes in close proximity to each other. By this, the strengths and weaknesses of the instruments can be seen. As the results show, the interpretation of radiosonde humidity data as a vertical point measurement can have potentially major effects on numerical models. Further developments of the DIAL system itself and extended data analysis will increase the knowledge about vertical fluxes of latent heat and therefore the transport processes within the PBL. Especially the question of whether radiosondes should be treated carefully under certain atmospheric circumstances will be a question worth of further investigation as many models depend on them.

4. Conclusions and outlook

We show the measurement results of the newly developed ATMONSYS lidar during the FESSTVaL campaign. For water vapor DIAL measurements, we show a vertical measuring range exceeding the PBL and reaching deep into the lower free troposphere. With the high sampling rate of 10s, we show the instrument uncertainties as well as the resulting natural short-term variability of humidity inside the PBL which can easily be at relative values around 20%. Furthermore, we show that the combination of the ATMONSYS DIAL with Doppler wind lidar data allows for the resolution of vertical fluxes of latent heat down to its full temporal resolution. Finally, we

5. References

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