Profiling of aerosol, water vapor and temperature in the boundary layer during TEAMx pre campaign 2022 and Swabian MOSES 2023 with a Raman-lidar at a high temporal resolution

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Abstract: A newly developed Raman lidar (Purple Pulse Lidar Systems) was applied during two summer measurement campaigns at Innsbruck (2022, Austria) and Villingen-Schwenningen (2023, Germany). We analyze the performance and limits of the instrument under changing weather conditions. Furthermore, we discuss its suitability for resolving turbulent processes and vertical energy fluxes in combination with a vertical wind profiler.

1. Introduction

Atmospheric transport and mixing under turbulent conditions are still a major source of short-term atmospheric variability and, thus, a major source of uncertainty in numerical weather prediction on small spatial scales. For a better parametrization of the transport and mixing processes, a better understanding and an improved quantitative description of the atmospheric dynamics at the timescale of turbulence (~10 s and less) is required. One approach is the observation of the atmospheric state with a high resolution in space and time which was the major motivation in several recent experiments, such as CHEESEHEAD [1], FESSTVaL [2] and Swabian MOSES. With the recent development of powerful and accurate laser transmitters [3], the development of a new generation of lidars capable for boundary layer profiling of water vapor, temperature, and aerosols on the time scale of 10 s has become real [4].

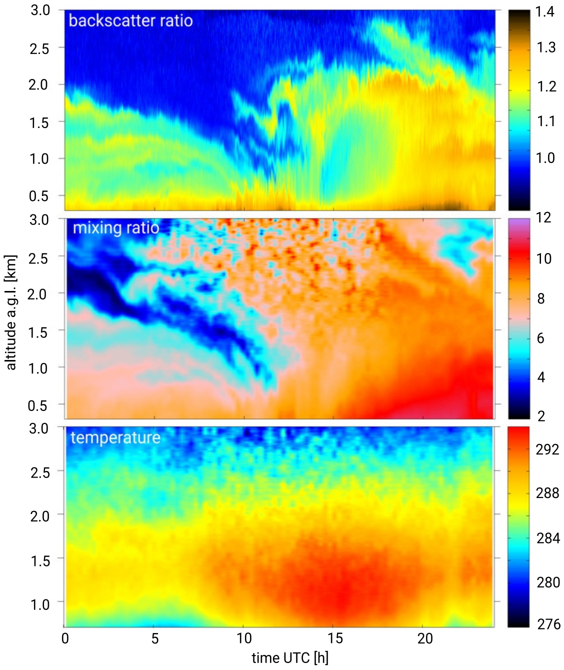

Figure 1: Distribution of aerosol, water vapor mixing ratio and temperature measured with the Raman lidar during one day of the pre-TEAMx-Campaign at Innsbruck. The high temporal resolution allows for a detailed examination of the short-term boundary layer dynamics.

2. Instrumentation and application

A new developed Raman Lidar (Purple Pulse Lidar Systems, Table 1), vertically profiling aerosol, water vapor and temperature with a temporal resolution of 10 s was applied during the TEAMx pre-campaign in Summer 2022 at Innsbruck and during Swabian MOSES in summer 2023. While TEAMx is aiming at the complex atmospheric dynamics in alpine, mountainous surroundings, Swabian MOSES is focused on the development of thunder cells in the region of the black forest (southern Germany). During both campaigns, the Raman lidar was running autonomously to the greatest possible extend, but with the option of remote control. An optical beam expander and a reduced pulse energy (70mJ) but with a high repetition rate of 200Hz allow for eye-safe unattended operation. The laser transmitter is a diode pumped Nd:YAG laser (DPSS) with a third harmonic generator for 355 nm. A 40 cm Cassegrain telescope collects the lidar return in a fiber. The received light is then split into one elastic channel and two rotational Raman channels at 355 nm and a vibrational Raman channel at 407 nm for water vapor. The data acquisition (licel) allows for both analog and photon counting operation with a sample rate of 40 MHz, corresponding to a vertical resolution of 3.75 m. One of the rotational Raman channels is tuned to a region of the rotational Raman spectrum where the lidar return is only slightly affected by temperature in order to serve as a reference for calculating the aerosol backscatter ratio and the water vapor mixing ratio. This also helps simplifying the temperature retrieval. The aerosol backscatter retrieval using a Raman channel as a reference obviates the frequently used Klett inversion which is dependent on uncertain apriori information (lidar ratio) and sometimes comes along with numerical instability [5].

At the Innsbruck measurement site, the Raman lidar was complemented by a vertical Doppler wind profiler (HALO photonics).

Table 1: Technical specs of the Lidar

Laser	355 mJ, 200 Hz, 70 mJ
Telescope/ Receiver	⌀ = 40 cm, 1 x elastic, 2 x rotational Raman, 1 x vibrational Raman
Vertical range (day / night)	aerosol: > 10 / 7 km water vapor: 2.5 / 7 km temperature 3.5 / 10 km

3. Results

During both campaigns, periodic and nearby radiosonde ascents were carried out. Thus, we were able to estimate the overall performance, accuracy and systematic errors of the lidar instrument, with some restrictions due to spatial mismatch. From this, we could show that within the boundary layer the uncertainties of 15-minute-means of water vapor mixing ratio and temperature are smaller than 1 g/kg and 1 K, respectively. While, during daytime, the vertical range of the water vapor channel is generally limited to the boundary layer, the range during the night hours is extended to 7 km and 10 km for the water vapor mixing ratio and temperature, respectively.

For shorter integration times down to 10s the statistical noise increases significantly. But, also a significant fraction of these noise-like variations can presumably be assigned to atmospheric fluctuations caused by turbulence which is suggested by data from the side-by-side wind profiler at the site in Innsbruck. In an other contribution to this conference (ILRC) we show, to which extend short-term variations of water-vapor measured with a differential absortpion lidar can be ascribed to turbulence.

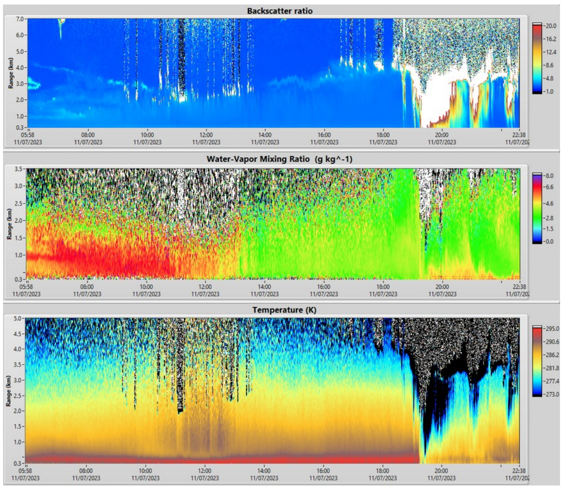

Figure 2: Development during a hot summer day during Swabian MOSES at Villingen-Schwenningen with a cooling shower in the evening and re-evaporation in the later evening.

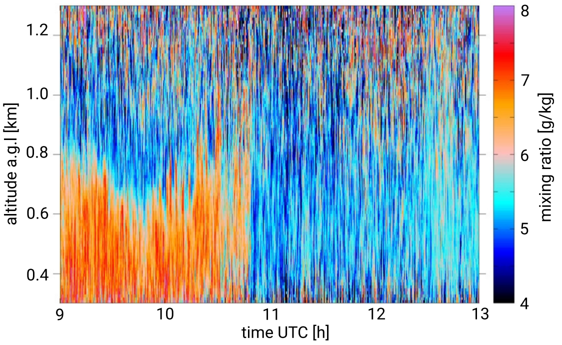

Figure 3: A near ground humid boundary layer is rapidly replaced by dry air from a southerly down wind during a Föhn event at Innsbruck during the TEAMx pre-campaign in summer 2022.

During both campaigns typical summer scenarios were observed with the formation of a convective planetary boundary layer, formation of thunderstorms (Fig. 2) and passage of fronts. At Innsbruck additionally typical phenomena of mountain meteorology occurred during the measurement campaign, such as sudden drying by Föhn (Fig. 3), daytime up-valley winds and nocturnal down-valley winds, affecting temperature and also the transport of humidity and aerosols [7].

4. Conclusions and Outlook

The results from two measurement periods at different sites (Innsbruck, Black Forest) showed the principal performance and limits of the new PPLS Raman lidar. The general capability for covering the boundary layer (roughly up to 2 km above ground) at all day times has been demonstrated.

In particular in combination with a vertical wind profiler this potentially allows for measuring vertical fluxes of water vapor and latent heat. Therefore, with its high temporal resolution, this lidar instrument has the potential for resolving turbulent fluctuations in water vapor and temperature.

Next steps are analysis of the frequency spectra of the short-term fluctuations of water vapor and temperature and to which extend they show a behavior similar to the 5/3-Kolmogorov-law for dynamics caused by turbulence.

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