Highlights of and Lessons Learned in Several Years of Automated Thermodynamic Raman Lidar Measurements

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Abstract: We will discuss highlights and present lessons learned in several years of measurements of automated temperature and humidity lidars. ARTHUS (Atmospheric Raman Temperaure and HUmidity Sounder) was developed at University of Hohenheim. This eye-safe lidar participated since spring 2018 worldwide successfully in several field campaigns – among others on a ship in the Caribbean. Furthermore, three additional automated Raman lidars based on ARTHUS but with even improved performances were built by the company Purple Pulse Lidar Systems (PPLS).

1. Introduction

In this contribution, we will show highlights and present lessons learned with several years of measurements of automated temperature and humidity lidars (e.g., Wulfmeyer and Behrendt 2022). ARTHUS (Atmospheric Raman Temperaure and HUmidity Sounder) was developed at University of Hohenheim (Lange et al., 2019). This automatic mobile instrument participated in a number of field campaigns in recent years (Fig. 1). Furthermore, we will present measurement highlights of three automated Raman lidars built in recent years by the company Purple Pulse Lidar Systems (see https://www.purplepulselidar.com/).

2. Technical Details

ARTHUS technical configuration is the following: A strong diode-pumped Nd:YAG laser is used as transmitter. It produces 200 Hz laser pulses with up to 20 W average power at 355 nm. Only this UV light is sent after beam expansion into the atmosphere so that the system remains eye safe. The atmospheric backscatter signals are collected with a 40 cm telescope. A polychromator extracts the elastic backscatter signal and three inelastic signals, namely the vibrational Raman signal of water vapor, and two temperature-dependent pure rotational Raman signals.

The detection resolution of these atmospheric backscatter signals are 1 to 10 s and 3.75 m. All four signals are simultaneously analyzed and stored in both photon-counting (PC) mode and voltage (so-called "analog" mode) with LICEL transient recorders in order to make optimum use of the large intensity range of the backscatter signals covering several orders of magnitude.

3. Realtime Data Products

From these eight primary signals which are stored, four independent atmospheric parameters are calculated by merging the PC and analog signals (level 1 real-time products): temperature, water vapor mixing ratio, particle backscatter coefficient, and particle extinction coefficient. For quality control, also the backscatter ratio is calculated before determining the particle backscatter coefficient (Figs. 2 and 3). The temporal resolution of these data is also 1 to 10 s. In range, the signals are typically averaged over 100 m. These high resolutions allow studies of boundary layer turbulence (Behrendt et al, 2015) and - in combination with a vertical pointing Doppler lidar - sensible and latent heat fluxes (Behrendt et al, 2020).

From the independent level 1 products, profiles of relative humidity, lidar ratio, and potential temperature are also calculated (level 2 real-time products).

For all these data products, also their statistical uncertainties are determined in realtime and quality flags are attributed. From the measured number of photon counts in each range bin, the statistical uncertainty of the measured data due to so-called shot-noise can directly be determined (Behrendt et al, 2020). This procedure also works well with merged analog and PC signals.

4. Performances

Finally, to investigate the stability of the calibration and thus the accuracy of the measured data, we compared the lidar data with local radiosondes. In order to attribute to the unavoidable sampling of different air masses between these different instruments, we are investigating the statistical results of a larger number of comparisons.

We found that the performance of the measured data of ARTHUS reaches the stringent requirements of WMO.

5. Outlook

The results will be presented at the conference.

(a)

(b)

(c)

(d)

Figure 1. Photographs of ARTHUS during (a, b, c) the WaLiNeAs campaign in Corsica, France and (d) at the Meteorological Observatory Lindenberg of the German Weather Service (DWD).

6. References

[1] Behrendt et al. 2015, https://doi.org/10.5194/acp-15-5485-2015

[2] Behrendt et al. 2020, https://doi.org/10.5194/amt-13-3221-2020

[3] Lange et al. 2019, https://doi.org/10.1029/2019GL085774

[4] Wulfmeyer and Behrendt 2022, https://doi.org/10.1007/978-3-030-52171-4_25

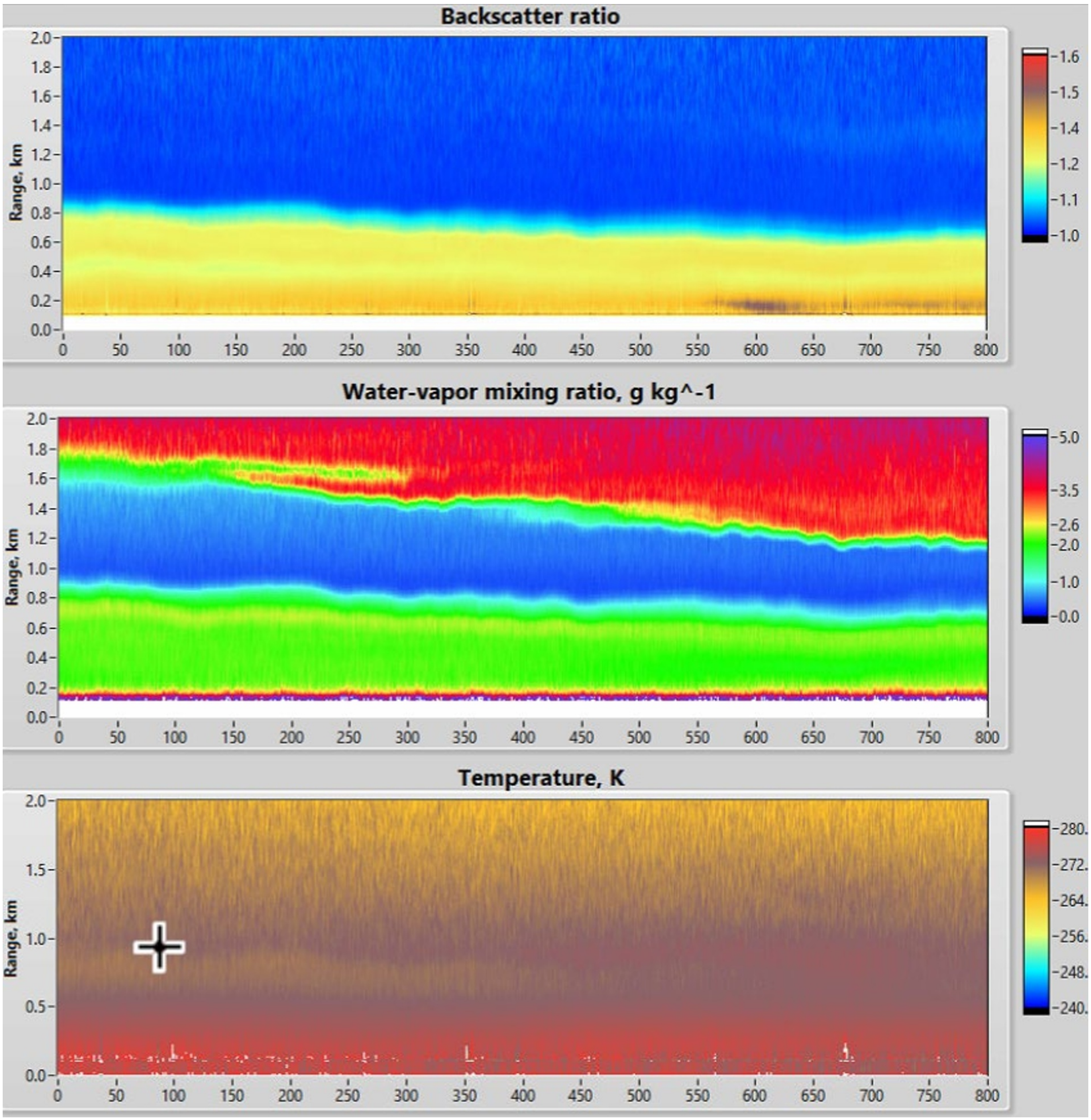

Figure 2. Measurements example 1, nighttime, winter (19 March 2024, 1922 to 2139 UTC). Plots of the analog data products with 10 s resolution and 97.5 m gliding average made by the data acquisition system in real time: (a) Backscatter ratio, (b) water vapor mixing ratio, (c) temperature. In this case, the water vapor mixing ratio in the free troposphere shows interesting layers with lower values in the boundary layer, a very dry layer above and a moist layer on top. A cross marks the inversion layer which changed in height and strength during this period.

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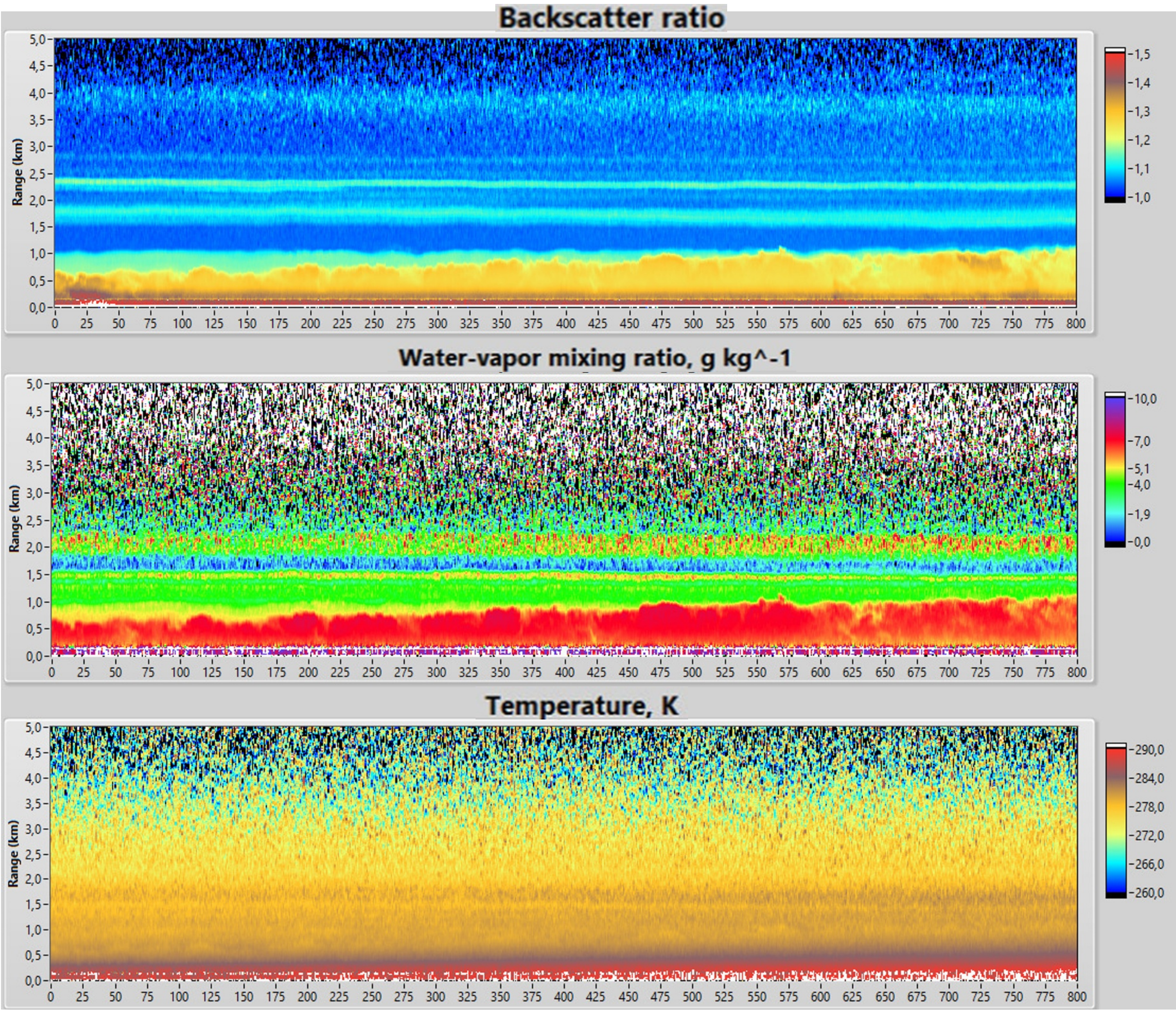

Figure 3. Same as Fig. 2 but for a daytime measurement case around local noon (6 September 2023, 1019 to 1225 UTC). The typical variability of a convective boundary layer is observed in detail. In the free troposphere above, several layers with different aerosol backscatter ratios, moisture contents, and inversion layers are revealed.