Lidar measurements characterizing the thermodynamic and dynamic structure of the boundary layer up to the turbulence scale

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Permantent link to this display: https://doi.org/10.5194/egusphere-egu2020-12164

Introduction

One weakness of today's weather and climate models is the inaccurate representation and parameterization of the boundary layer processes and land-atmosphere (L-A) feedback (see, e.g., references below). In order to investigate these processes, scanning lidar systems allow the observation not only of wind with Doppler lidar but also of humidity and temperature. It is expected that advances in the understanding of L-A feedback and boundary-layer exchange will significantly contribute to better simulations of clouds and precipitation on all temporal and spatial scales.

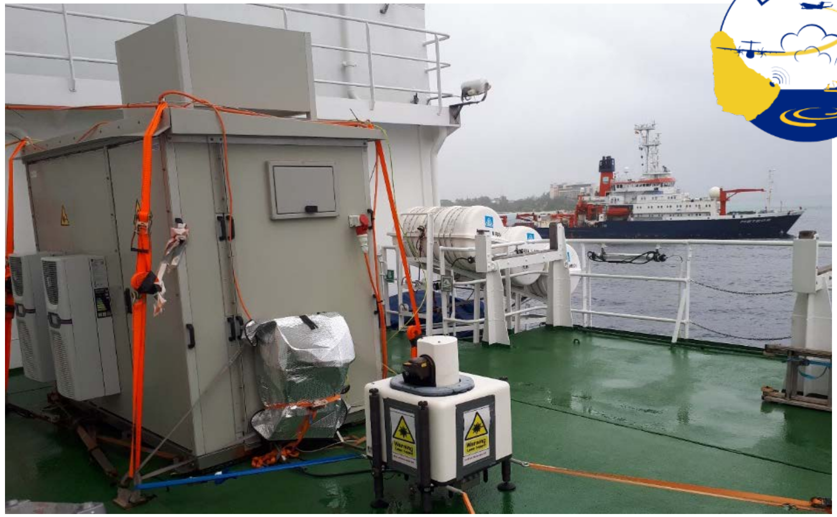
Unfortunately, we are limited by copyright restrictions in the material we can present here. So, we will give an overview but cannot show some material reserved for publications in the peer-reviewed literature...

Wulfmeyer, V., S. K. Muppa, A. Behrendt, E. Hammann, F. Späth, Z. Sorbjan, D. D. Turner, and R. M. Hardesty, 2016: Determination of convective boundary layer entrainment fluxes, dissipation rates, and the molecular destruction of variances: Theoretical description and a strategy for its confirmation with a novel lidar system synergy. J. Atmos. Sci. 73 (2), 667-692.
https://doi.org/10.1175/JAS-D-14-0392.1

Wulfmeyer, V. , et al., 2018: A New Research Approach for Observing and Characterizing Land-Atmosphere Feedback, Bull. Amer. Meteor. Soc., 99, 8, 1639 - 1667.
https://doi.org/10.1175/BAMS-D-17-0009.1

Lidar Systems at University of Hohenheim

The University of Hohenheim (UHOH) operates besides two commercial scanning Doppler lidars (HALO Photonics StreamlineXR), three lidars for thermodynamic profiling which have been developed within the last 15 years by the Institute of Physics and Meteorology itself. These are two scanning lidar systems which are semi-automated and a fully-automated vertical pointing lidar system.



Operation of ARTHUS (see later slides) and the two Doppler lidars of UHOH during the EUREC4A campaign in January and February 2020 onboard of the research vessel Merian.

For more details, please see another display at this conference:

Lidar-based Water Vapor, Temperature and Wind Measurements with Turbulence Resolution during the EUREC4A Field Campaign onboard RV Merian

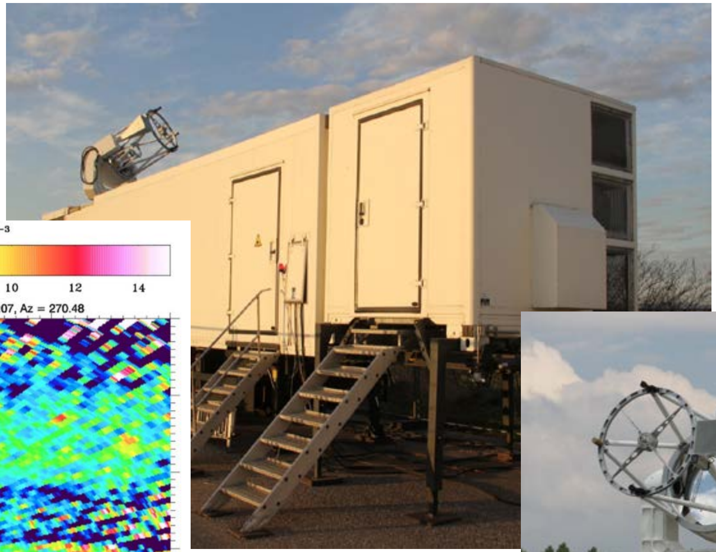
https://doi.org/10.5194/egusphere-egu2020-12144

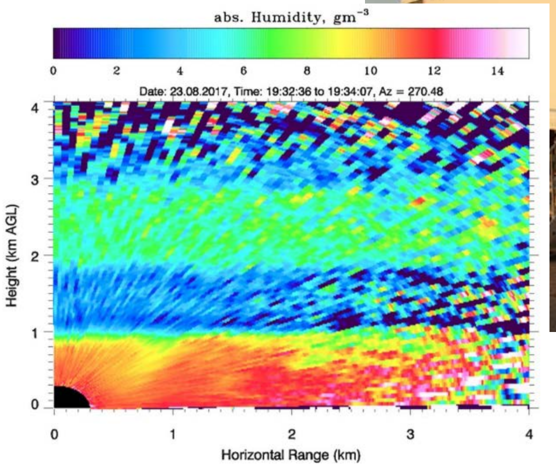
Water Vapor DIAL of University of Hohenheim

The water vapor differential absorption lidar (DIAL) of UHOH is a mobile system with a laser power of up to 10 W at 818 nm with a pulse repetition rate of 300 Hz. The receiver consists of an 80-cm telescope. The raw resolution of the atmospheric backscatter signals is 15 m and single shot. The resolution of the data product, the water vapor number density or absolute humidity, is typically 1 to 10 s and 40 to 200 m.

Muppa, S. K., A. Behrendt, F. Späth, V. Wulfmeyer, S. Metzendorf, and A. Riede, 2016: Turbulent humidity fluctuations in the convective boundary layer: Case studies using water vapour differential absorption lidar measurements. Bound.-Lay. Meterorol. 158 (1), 43-66. https://doi.org/10.1007/s10546-015-0078-9

Späth, F., A. Behrendt, S. K. Muppa, S. Metzendorf, A. Riede, and V. Wulfmeyer, 2016: 3D water vapor field in the atmospheric boundary layer observed with scanning differential absorption lidar. Atmos. Meas. Tech. 9, 1701-1720. https://doi.org/10.5194/amt-9-1701-2016





Temperature Rotational Raman Lidar

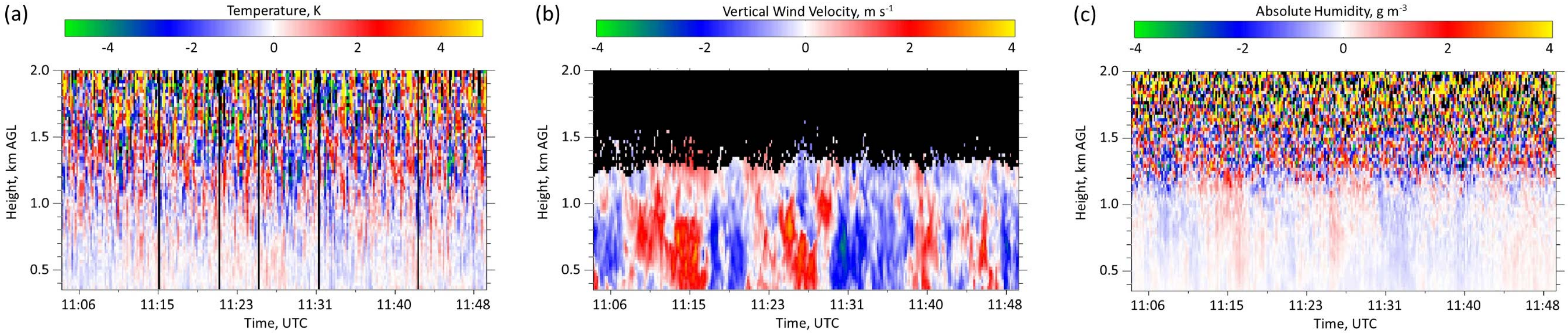
The UHOH Rotational Raman Lidar measures temperature and water vapor mixing ratio as well as aerosol cloud extinction and backscatter. Also this system is mobile. So far, we used as transmitter a flash-lamp-pumped Nd:YAG laser with 12 W at 355 nm at 50 Hz. This laser is currently being exchanged against a similar laser with 20 W at the same pulse repetition frequency. The light backscattered from the atmosphere is received with a 40 cm telescope. Four channels detect the elastic backscatter signal, two rotational Raman signals, and the water vapor Raman signal. The signal intensities are detected in analog and photon counting mode with raw resolutions of 7.5 m and 10 s. Typical resolutions of the data products are 100 m and 10 s.

Hammann, E., A. Behrendt, F. Le Mounier, and V. Wulfmeyer, 2015: Temperature profiling of the atmospheric boundary layer with rotational Raman lidar during the HD(CP)2 Observational Prototype Experiment. Atmos. Chem. Phys. 15, 2867-2881.
https://doi.org/10.5194/acp-15-2867-2015

Behrendt, A., V. Wulfmeyer, E. Hammann, S. K. Muppa, and S. Pal, 2015: Profiles of second- to fourth-order moments of turbulent temperature fluctuations in the convective boundary layer: first measurements with rotational Raman lidar. Atmos. Chem. Phys. 15, 5485-5500.
https://doi.org/10.5194/acp-15-5485-2015

Sensible and Latent Heat Flux Measurements (1)

In the following, we present an example for deriving sensible and latent heat flux profiles in the atmospheric boundary layer by the combined use of temperature (T), humidity (q) and vertical wind (w) lidars. The work has been accepted a few days ago for publication in AMT, see reference below.

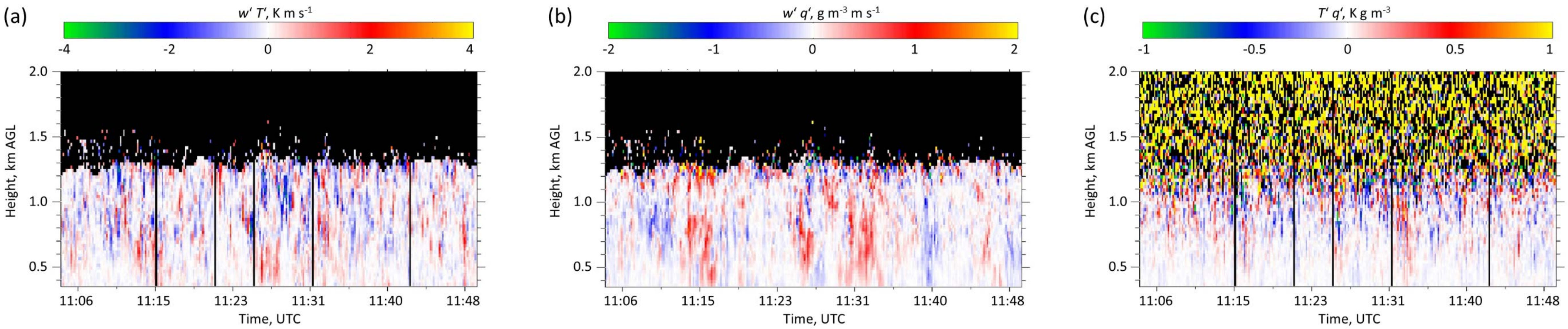


Time–height cross-sections of the measurements of the detrended and despiked fluctuations of (a) temperature T’, (b) vertical velocity w’, and (c) absolute humidity q’ measured with rotational Raman lidar, Doppler lidar, and water vapour DIAL during the HOPE campaign in Germany on 24 April 2013 in the 45-minute period between 1105 and 1150 UTC.

Behrendt, A., Wulfmeyer, V., Senff, C., Muppa, S. K., Späth, F., Lange, D., Kalthoff, N., and Wieser, A.: Observation of sensible and latent heat flux profiles with lidar, Atmos. Meas. Tech., accepted, 2020. https://doi.org/10.5194/amt-2019-305

Sensible and Latent Heat Flux Measurements (2)

Cross-correlations between the parameters:

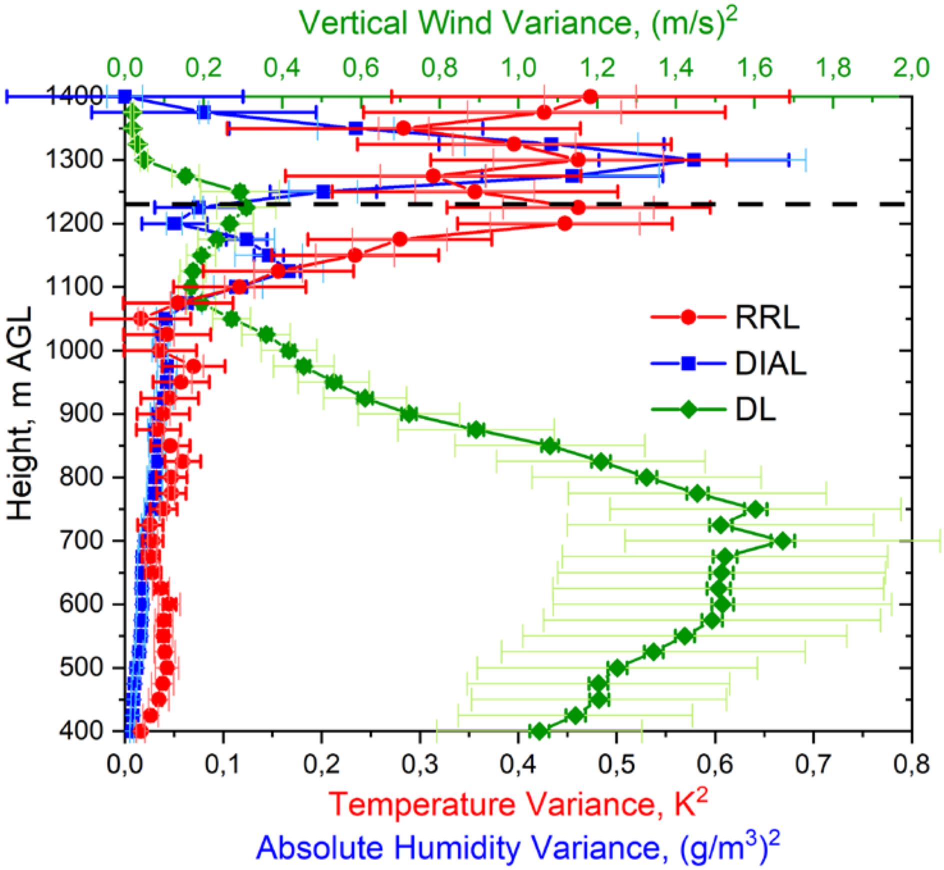


Time–height cross-sections of the fluctuation products (a) w’ T’, (b) w’ q’, and (c) T’ q’ calculated with the fluctuation data shown in the previous slide.

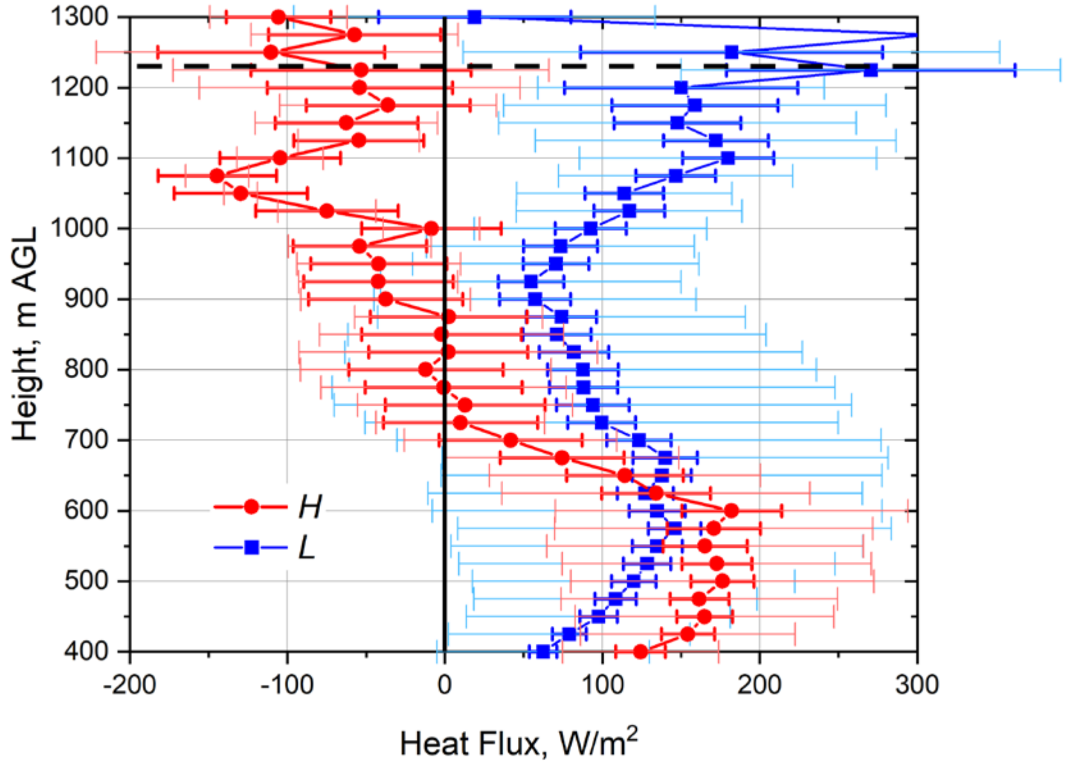
Behrendt, A., Wulfmeyer, V., Senff, C., Muppa, S. K., Späth, F., Lange, D., Kalthoff, N., and Wieser, A.: Observation of sensible and latent heat flux profiles with lidar, Atmos. Meas. Tech., accepted, 2020. https://doi.org/10.5194/amt-2019-305

Sensible and Latent Heat Flux Measurements (3)

Variance profiles in this period



Sensible heat flux profile (H) and latent heat flux profile (L) derived with the lidar data



Behrendt, A., Wulfmeyer, V., Senff, C., Muppa, S. K., Späth, F., Lange, D., Kalthoff, N., and Wieser, A.: Observation of sensible and latent heat flux profiles with lidar, Atmos. Meas. Tech., accepted, 2020. https://doi.org/10.5194/amt-2019-305

ARTHUS - Atmospheric Raman Temperature and Humidity Sounder

In the recent three years, we have developed a compact automatic eye-safe version of our Raman lidar, the Atmospheric Raman Temperature and Humidity Sounder (ARTHUS).

The instrument fulfills even the goal WMO Requirements for Nowcasting/Very Short Range Forecasting in the lower troposphere, also in daytime:

“Breakthrough” requirement (10 min, 300 m):

1 K Fulfilled >> 5 km **5%** Fulfilled up to 3.5 km

“Goal” requirement (5 min, 100 m):

0.5 K Fulfilled up to 4 km **2%** Fulfilled up to 2.2 km

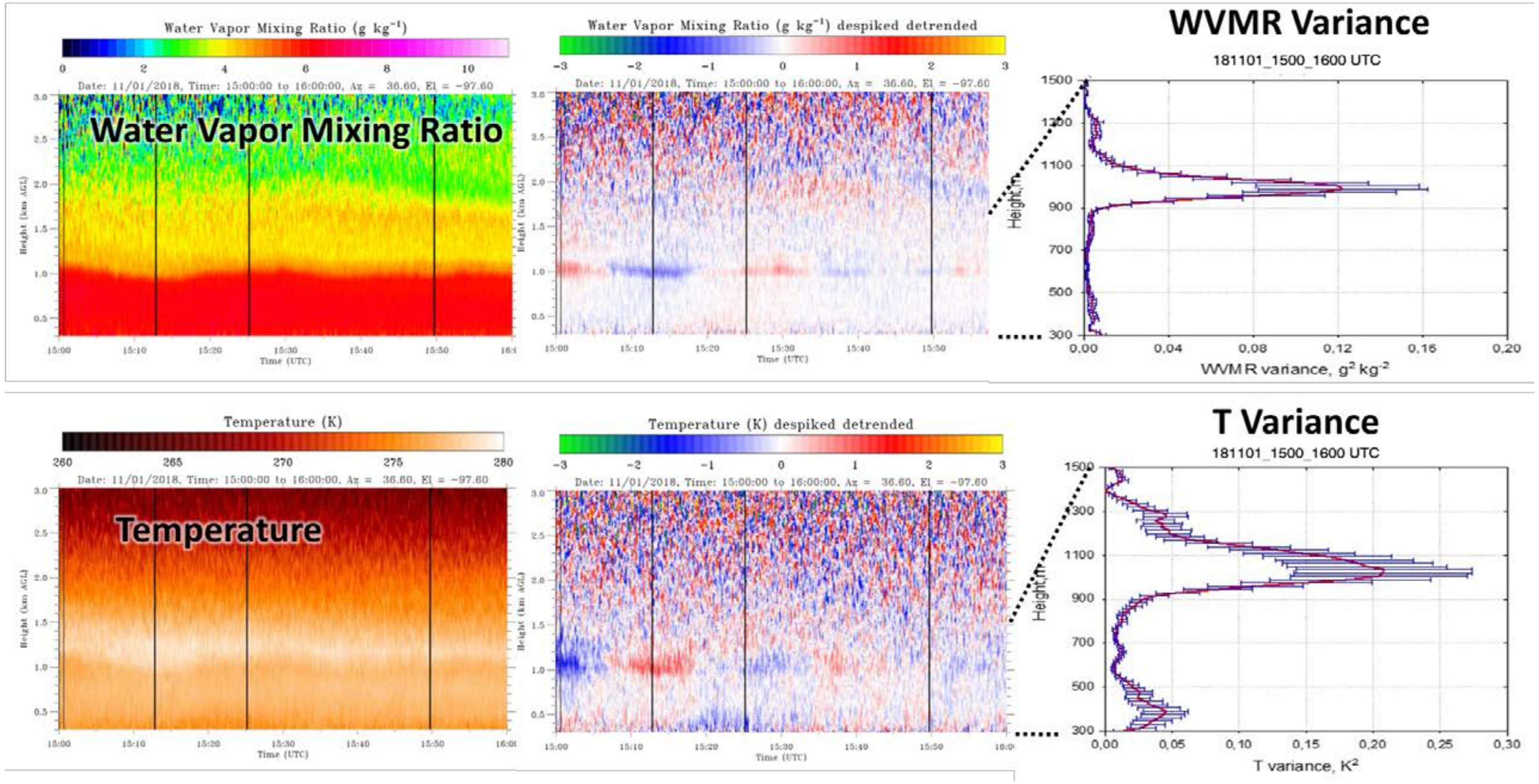
More details in another display at this conference:

Compact Operational Tropospheric Water Vapor and Temperature Raman Lidar with Turbulence Resolution

https://doi.org/10.5194/egusphere-egu2020-12164

ARTHUS – Measurement Example

Temperature and water vapor mixing ratio measurements illustrating the instrument’s performance:



Lange, D., Behrendt, A., & Wulfmeyer, V. (2019). Compact operational tropospheric water vapor and temperature Raman lidar with turbulence resolution. Geophysical Research Letters, 46, 14,844–14,853. https://doi.org/10.1029/2019GL085774

Conclusions & Outlook

- Vertical and scanning temperature and humidity lidars are available for high-resolution profiling of the atmospheric boundary layer
- Combination with Doppler wind lidars yields, e.g., heat fluxes
- Applied in field campaigns. Recently:
  → LAFE (August 2017, see https://www.arm.gov/research/campaigns/sgp2017lafe)
  → ScaleX (May-June 2019)
  → EUREC4A (Jan.-Feb. 2020, see)
- Future campaigns:
  → FESSTVal (August 2020?)
  → LAFO (see https://lafo.uni-hohenheim.de/)
  → …
- Scanning automatic temperature and humidity lidar in development