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Demonstration of Vaisala Prototype Differential Absorption Lidar (DIAL) Field Campaign Report

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DISCLAIMER

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Acronyms and Abbreviations

AERI	Atmospheric Emitted Radiance Interferometer
AGL	above ground level
ARM	Atmospheric Radiation Measurement (Climate Research Facility)
DIAL	Differential Absorption Lidar
DOE	U.S. Department of Energy
ESRL	Earth System Research Laboratory
g	gram
IR	infrared
JPL	Jet Propulsion Laboratory
kg	kilogram
km	kilometer
m	meter
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
PBL	planetary boundary layer
PNNL	Pacific Northwest National Laboratory
RMS	root mean square
SGP	Southern Great Plains
SPC	Storm Prediction Center
UTC	Coordinated Universal Time

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1.0 Summary

Continuous water vapor profiling within the atmospheric boundary layer is a major unmet measurement requirement for improving weather analysis and prediction. Humidity profile information can be used in mesoscale numerical models for severe weather prediction, flash flood prediction, energy management, and other applications. The U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility has conducted several experiments at its Southern Great Plains (SGP) observatory in North Central Oklahoma to test and develop techniques for tropospheric water vapor measurements (Turner et al. 2016). This campaign concentrated on a new compact water vapor DIAL (DIfferential Absorption Lidar) instrument that the instrument manufacturer Vaisala has recently developed using a ceilometer-type telescope design (Dabberdt 2016, Roininen, 2017). The DIAL system uses eye-safe class 1M semiconductor laser sources in the sub-micron wavelength range. The instrument reports water vapor mixing ratio profiles up to 3000 m within the atmospheric boundary layer, or up to the cloud base, whichever is lower.

Figure 1. Vaisala DIAL prototype at the ARM SGP site.

The purpose of the campaign was to test the Vaisala DIAL prototype (Figure 1) in high-humidity convective conditions at the ARM SGP site, comparing measurements against other instrumentation at the site (Münkel and Roininen 2017). Comparisons were made against Raman lidar and RS92 radiosonde observations of water vapor mixing ratio profiles. The same DIAL prototype has previously been tested in campaigns in Central and Northern Europe (Roininen et al. 2016). The ARM campaign was a collaboration between Vaisala and researchers from Pacific Northwest National Laboratory (PNNL), National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL), and National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL). The DIAL was located next to the Raman lidar at the ARM SGP site (Figure 2). Two Vaisala employees visited the site for the installation work, which was carried out on May 15, 2017.

Figure 2. DIAL location next to the Raman lidar.

The variety of weather conditions during the campaign represented typical mid-latitude continental summertime conditions in the Southern Great Plains. Two severe weather systems moved over the region during the campaign period (Storm Prediction Center [SPC] archives, 2017). The weather system on May 18-19 brought hail, high winds, and tornadoes to parts of Oklahoma and Kansas. The associated high atmospheric humidity and dynamic vertical structures can be seen in the Raman and DIAL results (Figure 3). Another severe weather event occurred on May 27. Judging from high-humidity periods in Raman and DIAL profiles, other local weather systems moved over the area in early June.

The DIAL algorithm software version used for the results in this report is a Vaisala internal release 18 and includes algorithm developments based on this campaign and a later campaign at the Hong Kong Observatory, September-October 2017. The Raman lidar water vapor fields were processed using a height-dependent blending algorithm to merge the wide and narrow fields of view, to reduce a discontinuity in the transition region in the lowest 1.3 km.

The DIAL operated continuously and error-free for 28 days from May 15, 2017 until June 12, 2017. The campaign results suggest that the new technology is capable of unattended continuous water vapor profiling at low altitudes. The compact low-cost instrument design would enable networks of instruments to be deployed in the future to improve numerical weather prediction models.

2.0 Results

During the campaign the DIAL measured 20-minute averaged water vapor mixing ratio profiles with updates every two minutes, using surface pressure, temperature, and humidity data as auxiliary information. The measurement algorithm estimates the highest reliable measurement altitude, the so-called DIAL range, by observing the stability of measured profiles. During the campaign, the DIAL range was at 1187 m AGL or higher for 50 % of the time.

A total of 83 radiosondes were launched during the campaign. For comparison, mixing ratio profiles from radiosondes were interpolated to the 10 m height resolution of the DIAL and compared with 20-minute DIAL profiles centered on the radiosonde launch time. Mixing ratio profiles from the Raman lidar were interpolated to 10 m height resolution and the original 10-minute profiles were averaged into 20-minute profiles to match DIAL profiles.

Figures 4 and 5 summarize key statistical variables comparing the DIAL prototype with the RS92 radiosonde and the Raman lidar. The results show that the DIAL agrees well with both the radiosonde and the Raman lidar. Mean deviations against both reference instruments remain within ±0.6 g kg^{-1} at heights where DIAL availability exceeded 10 %. The DIAL measures with excellent accuracy over a wide dynamic range from 2 to 18 g kg^{-1} observed during the measurement campaign. The low-altitude bias shown in Figure 5 is likely from the Raman data. Some artifacts are seen in DIAL data near the DIAL range, indicating that the methods for deriving the DIAL range and mixing ratio values close to that range need further investigation.

The high atmospheric humidity and dynamic vertical structures on May 18 are shown in detail in Figure 3. Three RS92 radiosondes were launched during the day. The night launch monitors mixing ratio values up to 8 g kg^{-1}. During the morning hours the mixing ratio in the boundary layer rises to nearly 14 g kg^{-1}; this value is still measured at noon throughout the boundary layer. The boundary-layer height rises from about 600 m in the morning to 1500 m at noon. Up to about 100 m below the DIAL range, both DIAL and Raman lidar agree well with the radiosonde; above that point, DIAL data tend to feature an artifact structure, as mentioned above.

2.1 Conclusion

The campaign demonstrated the capability of the DIAL prototype for unattended continuous water vapor profiling at low altitudes. The results show excellent agreement compared with Raman lidar and radiosonde reference measurements, and indicate that water vapor mixing ratio profiles of high quality can be measured over a wide dynamic range.

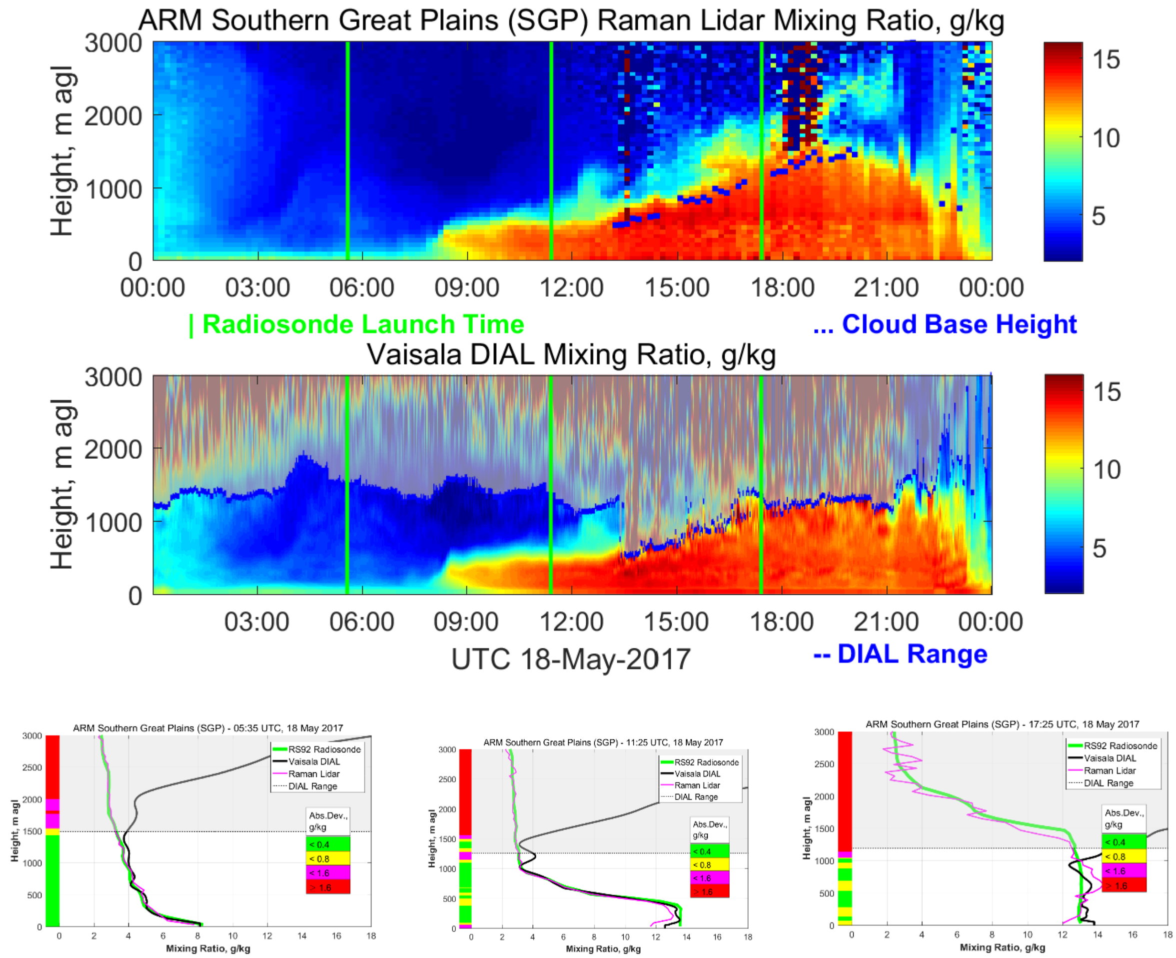

Figure 3. Time series of water vapor mixing ration (g kg^{-1}) profiles from Raman lidar and DIAL on May 18, 2017. Green vertical lines indicate times of radiosonde (green). DIAL (black) and Raman lidar (magenta) comparisons shown in the three lower graphs. The dotted black line indicates the highest reliable measurement altitude for DIAL, the so-called DIAL range. Local time is 5 hours behind UTC.

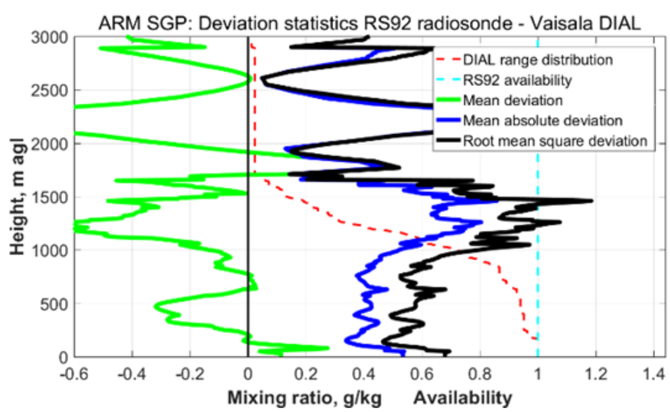

Figure 4. Vertical profiles of mean deviation (green), mean absolute deviation (blue), and root-mean-square error (RMSE; black) for comparing RS92 radiosonde and DIAL water vapor mixing ratio (g kg^{-1}), based on 83 radiosonde launches during the campaign. Data availability as a function of height is indicated with dashed lines.

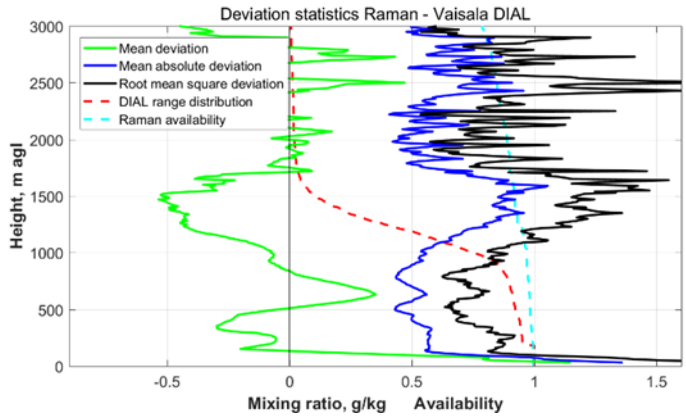

Figure 5. Vertical profiles of mean deviation (green), mean absolute deviation (blue), and RMSE (black) for comparing Raman lidar and DIAL water vapor mixing ratio (g kg^{-1}), based on 26 days of measurements (approximately 18,000 DIAL profiles). Data availability as a function of height is indicated with dashed lines.

2.2 Further Research Opportunities

The following further research opportunities were discussed within the team:

1. Publish the campaign results in a paper similar to (Weckwerth et al, 2016) comparing the DIAL with radiosondes, Raman lidar, and Atmospheric Emitted Radiance Interferometer (AERI) retrievals. Include bias, RMS and correlation profiles, scatter plots, and Taylor plots.
2. From a modeling perspective, it would be good to identify the effective resolution of the DIAL profiles versus other competing measurement methods. Also, a PDF comparison of the highest measurement level (optionally by time of day and in relation to the planetary boundary layer [PBL] top) would be useful for identifying the applicability to different uses, e.g., data assimilation on the model input side versus model evaluation of the output.
3. Other research opportunities, such as an IR spectrometer to utilize the DIAL profile to improve temperature and humidity profiling. Compare the impact on high-resolution models, which gives an indirect model impact evaluation.

Finally, we would like to acknowledge the ARM Facility and personnel for excellent support during the campaign.

3.0 Publications and References

As of November 2017, preliminary results from this campaign have been presented in the annual meeting of the European Meteorological Society (see Münkel and Roininen 2017).

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4.0 Lessons Learned

We were very pleased with cooperation with the ARM Facility. The DIAL installation work proceeded smoothly and without problems. The personnel were very helpful when we required some specific access settings with the internet connection. Remote connection worked well and the packing and shipping of the instrument proceeded without problems.