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DOE/SC-ARM-20-002

Micropulse Differential Absorption Lidar (MPD) Network Demonstration Field Campaign Report

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ARM

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Acronyms and Abbreviations

AC	air conditioning
AERI	atmospheric emitted radiance interferometer
AGL	above ground level
ARM	Atmospheric Radiation Measurement
CF	Central Facility
CLAMPS	Collaborative Lower Atmospheric Mobile Profiling System
DOE	U.S. Department of Energy
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
MPD	micropulse differential absorption lidar
MRI	Major Research Instrumentation program
MSU	Montana State University
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
PWV	precipitable water vapor
SGP	Southern Great Plains

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1.0 Summary

The National Center for Atmospheric Research (NCAR) and Montana State University (MSU) are nearing completion of a National Science Foundation (NSF) major research instrumentation grant to build five micropulse differential absorption lidars (MPDs) for water vapor profiling (Spuler et al. 2015). The first demonstration of the MPD configured as a five-unit network occurred at the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility Southern Great Plains (SGP) field sites near Lamont, Oklahoma from 17 April–21 July 2019 for a total of 96 days of operation. The field deployment was funded in part by DOE (which provided support for the MPD installation, power at the field sites, personnel to launch 3-hourly radiosondes from the Central Facility, and the cost of the radiosondes themselves), internal NCAR funds (to support the MPD shipping costs and NCAR staff travel expenses), and NSF/Major Research Instrumentation (MRI) funds (to support the MSU travel expenses to participate in the instrument setup).

During the network demonstration project, one of the MPDs was collocated with the ARM Raman lidar and the location of the 3-hourly radiosonde launches at the Central Facility (CF). All five MPDs were collocated with atmospheric emitted radiance interferometers (AERIs) and Doppler lidars and were operated within the range of the Vance Air Force Base WSR-88D scanning weather radar (Figure 1); note that the AERI at the E41 site was part of the Collaborative Lower Atmospheric Mobile Profiling System (CLAMPS; Wagner et al. 2019) deployed by the NOAA National Severe Storms Laboratory. Three Global Navigation Satellite System (GNSS) receivers were collocated with MPDs at the E37, E41, and CF sites. The GNSS data were processed by the GFZ German Research Centre for Geosciences in Potsdam, Germany to provide precipitable water vapor (PWV).

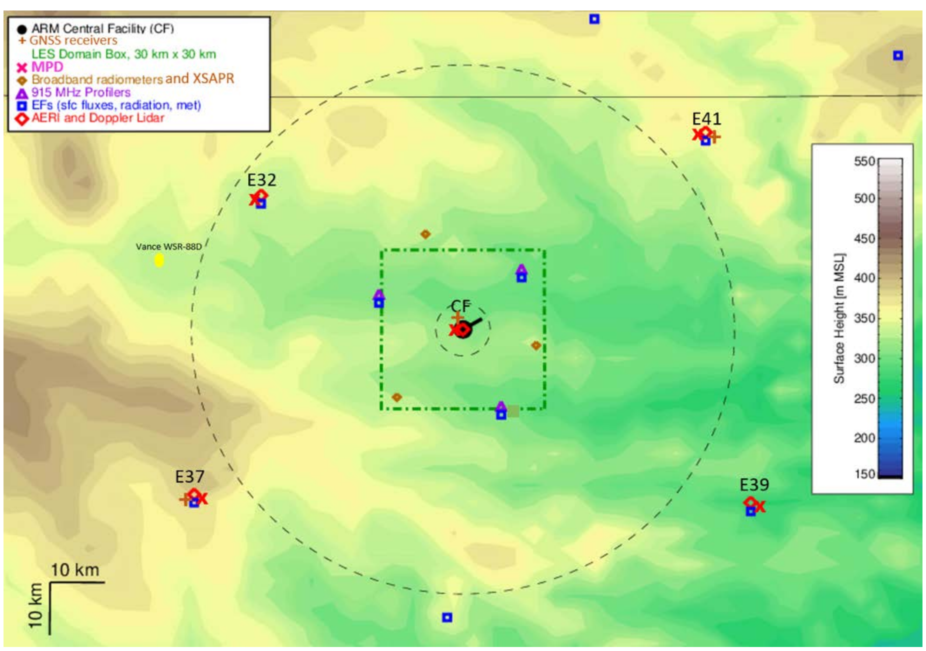

Figure 1. Map showing locations of MPD network (pink x's) relative to relevant ARM instruments. Terrain height is shown in color.

The project goals were to: i) demonstrate the network configuration, communications, and long-term operational capabilities of the five MPDs; ii) compare the MPD water vapor profiles with radiosonde, AERI, and Raman lidar profiles and GNSS PWV to confirm the accuracy of the MPD systems; iii) collect thermodynamic and wind data during the 2019 spring-summer storm season to obtain precursor data on convective weather events; and iv) evaluate the impact of combining MPD and AERI profiles on improving the basic knowledge and forecasting skill of convective weather events via observational analyses and data assimilation efforts.

Observations of numerous different weather types were collected during the field campaign. Convective storm observations include the full convective storm life cycle, convection initiation events, and dissipating squall lines. Data were collected during passages of several low-level boundary-layer convergence zones, including gust fronts, nocturnal bores, and cold fronts. Numerous days were sampled during the complete evolution of the daytime convective boundary layer and the formation of the stable boundary layer and residual layer. There are several examples of intriguing elevated moist and dry layers.

2.0 Results

2.1 Network Demonstration

The primary goal of the MPD Network Demonstration Project was to evaluate the engineering performance of five MPD units during a deployment in order to glean information about shipping, setup/tear-down, remote monitoring of five units, and how the systems would perform during long-term unattended operation in a high-humidity environment.

The first demonstration of continuous, high-vertical-resolution water vapor profiles from a low-cost Diode Laser-Based Differential Absorption Lidar (DIAL) network was largely successful. The long-term operation in a high-humidity environment, during the transition from spring to summer, offered an opportunity to fully evaluate the instruments. As a result of the rigorous testing, many lessons were learned. Specifically, it we determined that several instrument modifications need to be made before the MPD testbed is made available to the larger scientific community. The known deficiencies that stand in the way of robust field deployments are primarily due to operations in a high-humidity environment. MPD problems included:

1. Formation of condensation inside the environment enclosure. During periods of high humidity (15−20 g m^{-3}), condensation could form on the optics – specifically the telescope primary mirror. Air blowing from the AC unit on the primary mirror mount would chill the mirror below the dew point in the environmental enclosure and condensation would form, effectively blocking the transmitter and receiver optical paths. This caused a banding pattern in the data (following the AC cycles) that were identified as periods of bad data quality. The repeated condensation events also degraded instrument performance over time. This issue had varying impact on the data quality, affecting MPD04 most significantly and MPD02 least significantly. Due to this issue, humidity mitigation techniques have been identified and are scheduled to be implemented to each MPD.
2. Formation of condensation on the environment enclosure window center. During periods of high humidity, condensation formed on the external surface of the center of the environmental enclosure window that effectively blocked the transmitter beam and resulted in continuous dark periods in the data. This issue will be resolved by adding a warm air blower.

3. Seed laser fiber coupling was unstable under the combined condensation from high humidity in the container and large thermal variation and thermal hysteresis. During spring and autumn, the environmental enclosure heating and air conditioning unit will alternate between heating and cooling modes resulting in temperature fluctuations greater than +/-5ºC, resulting in a slow degradation of the fiber coupling alignment. This issue has since been resolved with the implementation of two-stage (master oscillator power amplifier) fiber-coupled seed laser modules.

2.2 Validation of MPD with Radiosondes

A thorough validation of MPD was performed with data from earlier campaigns by Weckwerth et al. (2017). One of the goals of the SGP campaign was to further validate the MPD network against similar mature instruments (e.g., radiosondes, Raman lidar, GPS receivers, and AERIs). Preliminary intercomparisons with radiosondes during the Network Demonstration show encouraging results.

MPD05 was located at the CF site and the full 96 days of its operation, 17 April to 21 July 2019, is shown in Figure 2. Relatively dry conditions occur at the start of the field campaign with absolute humidity values typically < 5 g m^{-3} in the boundary layer. Significant amounts of rain and clouds occurred from late April to early May and the lidar was unable to penetrate through the optically thick clouds and measure water vapor. Toward the end of this time period shown, after mid-June, absolute humidity values typically exceeded 15 g m^{-3} in the boundary layer.

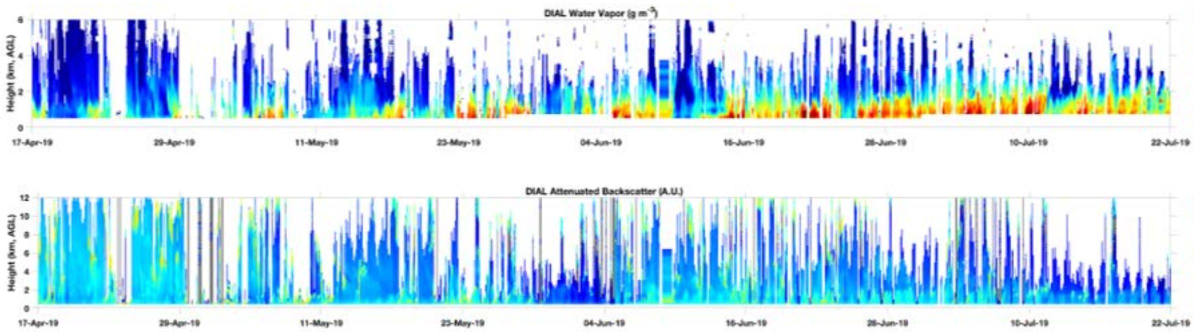

Figure 2. Attenuated backscatter from 0-12 km AGL (top) and absolute humidity from 0-6 km (bottom) measured by MPD05 from 17 April–21 July 2019.

Radiosondes were launched every three hours by the DOE ARM SGP staff from the CF. This provided a large number of independent water vapor profile measurements (a total of 689 Vaisala RS41 radiosondes during this time frame) that were collocated with MPD05 and could be used for validation and comparison. Figure 3 shows the frequency histogram (left) and scatter plot (right) illustrating the correlation between MPD05 and the radiosondes. The least-square linear fit is shown (red dashed line) with a slope of 1.00 and offset of 0.224. The correlation coefficient of 0.887 indicates very high correlation between the two measurement methods. Further intercomparisons between MPD05 and the SGP Raman lidar similarly show good agreement.

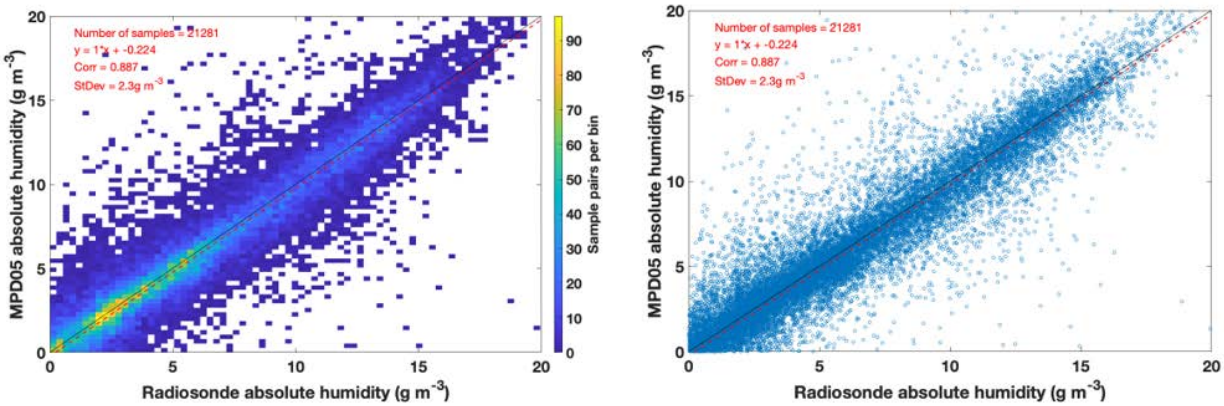

Figure 3. Frequency histogram (left) and scatter plot (right) showing the correlation between MPD05 and collocated radiosondes for the entire project. The lowest range gate was 500m, or 750m if the seed power was flagged as poor quality. For the frequency histogram, the colors indicate the number of sample pairs per bin, 0.1x0.1 g/m^3 bin sizes. For both plots the solid black line shows the ideal one-to-one relationship, and the dashed red line shows the least-square linear fit.

The third and fourth goals of the MPD Network Demonstration Project were to study the impact of the water vapor distribution upon convective weather understanding and forecasting, via observational analyses and data assimilation efforts. This research is ongoing using the combined MPD and collocated ARM instrument data sets.

3.0 Publications and References

3.1 Publications

Stillwell, RA, SM Spuler, M Hayman, KS Repasky, and CE Bunn. 2020. “Demonstration of a Combined Differential Absorption and High Spectral Resolution Lidar for Profiling Atmospheric Temperature.” *Optics Express* 28(1): 71–93, https://doi.org/10.1364/OE.379804

3.2 Presentations

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3.3 References

Spuler, SM, KS Repasky, B Morley, D Moen, M Hayman, and AR Nehrir. 2015. “Field-deployable diode-laser-based differential absorption lidar (DIAL) for profiling water vapor.” *Atmospheric Measurement Techniques* 8(3): 1073–1087, https://doi.org/10.5194/amt-8-1073-2015

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Weckwerth, TM, KJ Weber, DD Turner, and SM Spuler. 2016. “Validation of a water vapor micropulse differential absorption lidar (DIAL).” *Journal of Atmospheric and Oceanic Technology* 33(11): 2353−2372, https://doi.org/10.1175/JTECH-D-16-0119.1

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