MPD-NetDemo data
Version 1.0

This is an engineering dataset. Several problems remain in the data and it should be used with caution and in collaboration with the NCAR lidar group for scientific analysis.

This dataset contains MicroPulse Differential Absorption Lidar (MPD) data collected during the MPD-NetDemo field campaign. The data were collected from five MPDs between April 16 and July 22, 2019, at the US Department of Energy's Atmospheric Radiation Measurement (ARM) facility Southern Great Plains (SGP) field sites. For more information on MPD-NetDemo, see www.eol.ucar.edu/field_projects/mpd-netdemo.

Instrument description

The diode-laser-based (DLB) lidar architecture developed by NCAR in collaboration with Montana State University (MSU) uses continuous wave seed lasers that are amplified into pulses (5-10 μJ/pulse) at high repetition rates (5-10 kHz)[1]. For high quality daytime operation, suppression of the solar background is achieved with a narrow receiver field of view (100 μrad) and extremely narrow-band (10-20 pm full width half max) optical filters. The transmitted laser beam is eye-safe and invisible (Class 1M) and the receiver uses single photon counting detectors.

The differential absorption lidar (DIAL) technique uses two separate laser wavelengths: an absorbing wavelength (online) and a non-absorbing wavelength (offline). The ratio of the range-resolved backscattered signals between the online and offline wavelengths is proportional to the amount of water vapor in the atmosphere. The technique requires knowledge of the absorption feature (obtained from molecular absorption database) and estimates of the atmospheric temperature and pressure (obtained from surface measurements and standard atmosphere models). For more information, see Spuler et al. (2015) and https://www.eol.ucar.edu/mpd.

MPD Specifications	
Parameter	**Specification**
Wavelength	828.2 nm
Pulse length	1 μs (150 m)
Pulse repetition rate	7 kHz
Vertical resolution (sample grid)	37.5 m
Vertical resolution (effective)	150 m
Vertical range	400 - 6000 m

Temporal resolution (sample grid)	1 minute
Temporal resolution (effective)	5 minute

MPD Network Deployment

The five MPDs were positioned at the ARM Central Facility and four surrounding SGP boundary facilities and were collocated with ARM instrumentation as shown in Fig. 1.

- MPD01 was positioned at E37 in the SW corner of the SGP domain at 36.31 deg N; 97.93 deg W; 387.4 m MSL
- MPD02 was positioned at E41 in the NE corner of the SGP domain at 36.88 deg N; 97.07 deg W; 343.8 m MSL
- MPD03 was positioned at E32 in the NW corner of the SGP domain at 36.82 deg N; 97.82 deg W; 334.4 m MSL
- MPD04 was positioned at E39 in the SE corner of the SGP domain at 36.37 deg N; 97.07 deg W; 306.9 m MSL
- MPD05 was positioned at the Central Facility of the SGP domain at 36.61 deg N; 97.49 deg W; 310.0 m MSL

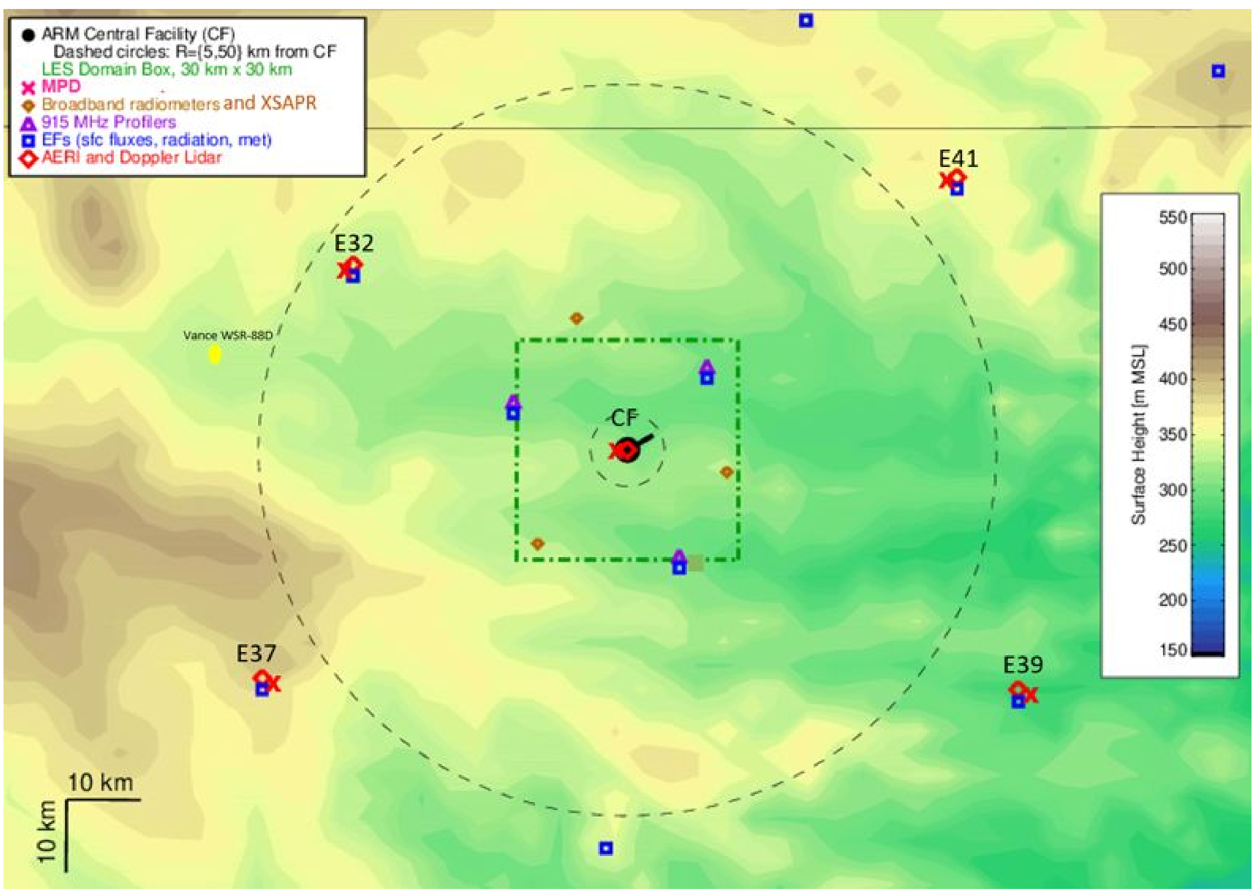


Fig. 1. SGP network illustrating location of MPDs (red X's).

Data description

Data profiles (containing time and range axes) are stored with a variety of ancillary variables where the ancillary variable would be specified
AncillaryName_ProfileName
For example each profile has a time axis associated with it and for the absolute humidity profile this is named
time_Absolute_Humidity

The key data products from this instrument are:
Absolute_Humidity [g/m^3] - estimate of the water vapor density in a parcel of air
Attenuated_Backscatter [arbitrary units] - qualitative image of the backscatter light corrected for range-squared loss and geometric overlap
Absolute_Humidity_variance [g^2/m^6] - estimate of the variance of the water vapor density
Absolute_Humidity_mask - for quality control, indicates if mask (1) or no mask (0) should be applied to Absolute_Humidity field

In addition a weather station records the temperature, pressure and absolute humidity at the lidar's location. This data is stored in variables:
Surface_Absolute_Humidity
Surface_Temperature_WV
Surface_Pressure_WV

Data processing

MPD "online" and "offline" observations have nearly identical backscatter and instrument effects in their signals where the only difference in measurements is due to the difference in water vapor absorption. When the two channels are ratioed, all terms cancel except those relating to water vapor.

Data is processed using the standard DIAL equation where it is assumed all instrument and atmospheric features in the profiles are identical except for the difference in absorption. Water vapor is calculated using the formula

$$n_{wv}(r) = \frac{1}{2\Delta\sigma_{wv}} \frac{d}{dr} \ln \frac{N_{on}(r)}{N_{off}(r)}$$

Where $n_{wv}(r)$ is the range resolved water vapor number density (molecules per m^3), $\Delta\sigma_{wv}$ is the difference in absorption cross-section of water vapor between the online and offline wavelengths, $N_{on}(r)$ and $N_{off}(r)$ are the measured signals when transmitting the online and offline wavelengths, respectively.

The absorption cross section of water vapor is pressure and temperature dependent. To approximate the temperature we used NCEP reanalysis data (Kalnay et al., 2016). The water vapor line has been selected for its low temperature dependence so there is relatively little error contributed by uncertainty in the thermodynamic state parameters.

The data is processed at a base resolution of 37.5 m in range and 1 minute in time. These observations are smoothed using Gaussian kernels in range and time where the kernel size is optimized to minimize the mutual contributions of error due to smearing and random noise. The size of the kernels in range and time are reported in the dataset (e.g. offline_std_range is the kernel standard deviation in the range dimension applied to the offline channel).

Once the water vapor is calculated using the above equation, the mask is identified for regions near clouds where large biases occur due to detector nonlinearity and poorly resolved gradients in the backscatter near clouds. A Gaussian smoothing kernel of 125 m and 5 minutes is subsequently applied. The final profiles are provided at 37.5 m vertical and 1 minute temporal resolution, however, note that the laser pulse length remains 150 m which is generally the limiting factor in the profile range resolution.

Known problems

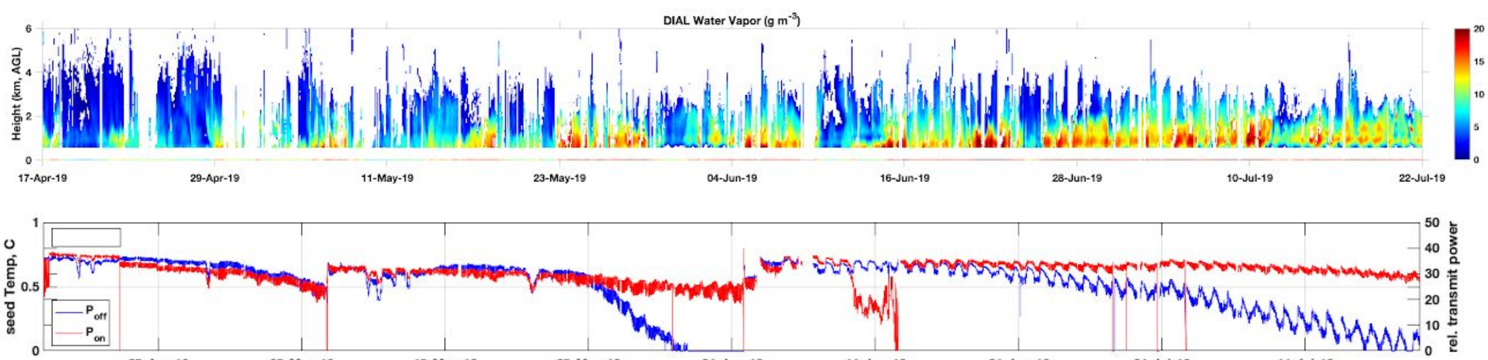
There were several successes resulting from the MPD-NetDemo, including thorough validation of water vapor observations, unattended operations over an extended time period, and a significant milestone – the first demonstration of continuous, high-vertical-resolution water vapor profiles from a low-cost water vapor DIAL network. The long term operation in a high-humidity environment, during the transition from spring to summer, offered an opportunity to evaluate the instruments. Several instrument modifications need to be made before the MPD testbed is made available to the larger scientific community. The known deficiencies identified during MPD-NetDemo that stand in the way of robust field deployments are outlined in detail below.

- It was found that during periods of high humidity (15-20g m^{-3}), condensation would 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 resulted in a banding pattern in the data (following the AC cycles). These bands alternate in time between good and bad data and are accordingly identified by the Absolute_Humidity_mask. The repeated condensation events also degraded performance over time. The amount of degraded data varied from unit to unit. For the 97 day dataset, MPD#4 was the worst, with about 21% of the data being flagged as poor quality from condensation on the primary mirror; whereas, MPD#5 and MPD#3 both had about 7% poor data quality, and MPD#3 had 3.5% poor data quality from condensation inside the enclosure. It appears that MPD#2 did not suffer from condensation within the environmental enclosure. This was likely due to its unusual, yet highly regular AC unit cycle intervals (even at night when it was cooler outside) which kept the air relatively dry inside.
- During periods of high humidity, condensation formed on the external surface of the center of the environmental enclosure window which effectively blocked the transmitter

beam and results in continuous dark periods in the data. The instrument design had anticipated this issue, and the window mounting ring was held nominally at 40ºC to prevent condensation from forming. However, the field project demonstrated the design was not sufficient for the high dew points that were encountered in Oklahoma. Part of the issue stems from the poor heat transfer to the window, due to mounting it on silicone o-rings, while the remainder of the problem stems from the large size of the window and glass itself being a poor thermal conductor. Under certain atmospheric conditions, the interior temperature of the container (typically held around 24-26ºC) can sufficiently cool the window center below the dew point outside. As mentioned above, MPD#2 did not have any banding in the data (associated with condensation forming on the primary mirror) because of its regular AC dehumidifying cycles. Therefore, periods where dark continuous bands occurred in the MPD#2 data were used to estimate when condensation formed on the outside surface of the window. For the 97 day dataset, missing data caused by this problem occurred about 2% of the time. It is likely that all of the units had similar performance.

In addition to the problems with high humidity that are masked in the dataset, further problems do remain in the data:

- Due to the environmental enclosure humidity and temperature stability issues, the seed laser alignment was unstable, resulting in decreased seed power at times. Poorly matched online and offline seed powers result in biased data at low ranges; therefore **periods when the seed powers don't match should not be used**. For example see the figure below for MPD#5. During two such periods (25 May to 4 Jun and 4 to 22-Jul) the offline power drifts well below the online power and corresponding dry biases occur in the measured water vapor at the lower ranges.

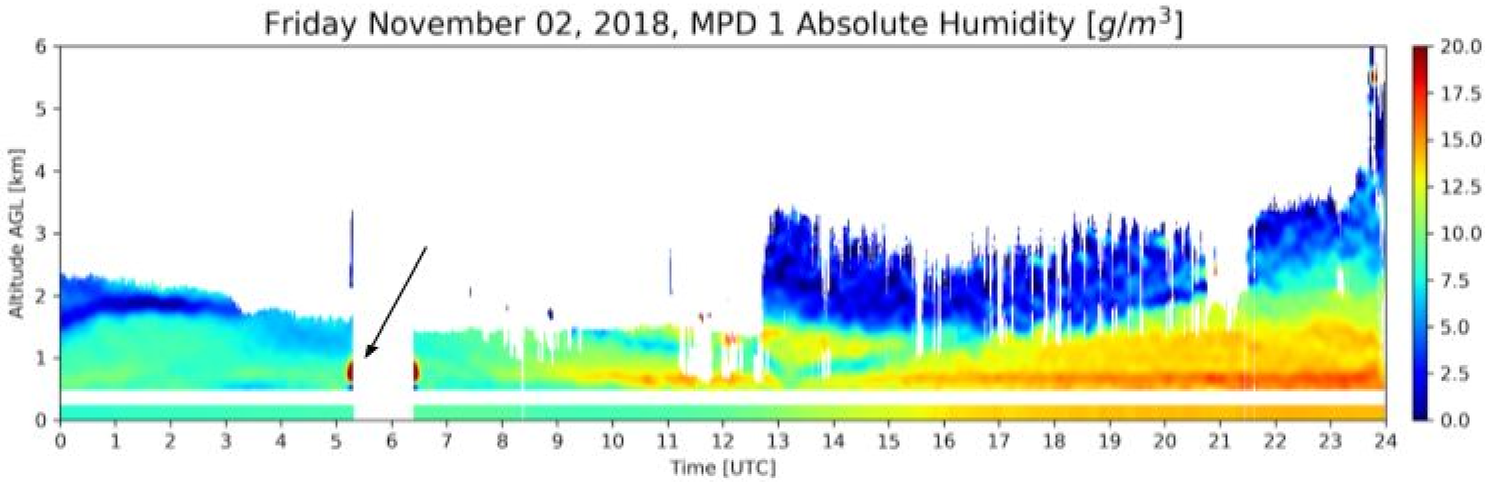


- Regions of high backscatter gradients can induce biases in water vapor estimates. Regions in and near clouds are particularly prone to this effect. These highly biased regions are generally masked, but there may be some leakage outside of the data mask.

- There are occasional wet and dry bands below 1 km that are the result of slight biases in the instrument. They are constant in altitude and therefore generally easy to distinguish from normal atmospheric variability. These regions are *not* masked in the final dataset.

While the humidity data is biased in the regions, the user must make a determination if the bias is significant enough to adversely impact the scientific analysis.

- There are some transition regions between valid and invalid lidar signals where biases are induced. “Bubbles” of high and low water vapor can occur in these regions and should not be regarded as valid data. For an example, see below where the arrow is pointing.



References

1. Spuler et al., Field-deployable diode-laser-based differential absorption lidar (DIAL) for profiling water vapor, Atmos. Meas. Tech., 8, 1073-1087, 2015.
2. Kalnay et al.,The NCEP/NCAR 40-year reanalysis project, Bull. Amer. Meteor. Soc., 77, 437-470, 1996.

Citation

When using this data set please cite

UCAR/NCAR - Earth Observing Laboratory. 2019. NCAR MicroPulse Differential Absorption Lidar (MPD) data. Version 1.0. UCAR/NCAR - Earth Observing Laboratory. https://doi.org/10.26023/9Y30-6ASZ-YH04. Accessed 14 Jan 2020.

Please replace the date with the date of your most recent access.

Contact

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Appendix A
Variables likely to be of greatest interest are in **red**

Variable	**Unit**	**Description**
time_Absolute_Humidity	s since start of day	
range_Absolute_Humidity	m	
Absolute_Humidity	g/m^3	
Absolute_Humidity_variance	g^2/m^6	
Absolute_Humidity_mask	1 = Masked, 0 = Not Masked	Apply to Absolute_Humidity for highest data quality
Absolute_Humidity_ProfileCount	Count	Number profiles 2 second integrated to obtain the estimate
time_WV_Online_Backscatter_Channel	s since start of day	
range_WV_Online_Backscatter_Channel	m	
WV_Online_Backscatter_Channel	Counts	Online backscatter signal used to estimate absolute humidity
WV_Online_Backscatter_Channel_variance		
WV_Online_Backscatter_Channel_mask	1 = Masked, 0 = Not Masked	
WV_Online_Backscatter_Channel_ProfileCount	Count	
time_WV_Offline_Backscatter_Channel	s since start of day	
range_WV_Offline_Backscatter_Channel	m	
WV_Offline_Backscatter_Channel	Counts	Offline backscatter signal used to estimate absolute humidity
WV_Offline_Backscatter_Channel_variance		

WV_Offline_Backscatter_Channel_mask	1 = Masked, 0 = Not Masked	
WV_Offline_Backscatter_Channel_ProfileCount	Count	
time_Temperature	s since start of day	
range_Temperature	m	
Temperature	K	Temperature profile estimated from NCEP reanalysis or the weather station at the lidar location with an assumed lapse rate. See the description in the netcdf for this variable to determine the source.
Temperature_variance	K^2	Not trusted
Temperature_ProfileCount	Count	
time_Pressure	s since start of day	
range_Pressure	m	
Pressure	atm.	Pressure profile estimated from NCEP reanalysis or the weather station at the lidar location with an assumed lapse rate. See the description in the netcdf for this variable to determine the source.
Pressure_variance		Not trusted
Pressure_ProfileCount	Count	
time_Surface_Temperature_WV	s since start of day	
range_Surface_Temperature_WV	m	

Surface_Temperature_WV	K	Temperature measured by the weather station on the lidar
Surface_Temperature_WV_variance		Not trusted
Surface_Temperature_WV_ProfileCount	Count	
time_Surface_Pressure_WV	s since start of day	
range_Surface_Pressure_WV	m	
Surface_Pressure_WV	atm.	Pressure measured by the weather station on the lidar
Surface_Pressure_WV_variance		Not trusted
Surface_Pressure_WV_ProfileCount	Count	
time_Surface_Absolute_Humidity	s since start of day	
range_Surface_Absolute_Humidity	m	
Surface_Absolute_Humidity	g/m^3	Not trusted (error in the reported Absolute Humidity measured by the weather station) user needs to calculate this directly from T, P, and RH
Surface_Absolute_Humidity_variance		Not trusted
Surface_Absolute_Humidity_mask	1 = Masked, 0 = Not Masked	Mask for absolute humidity data provided by the surface station
Surface_Absolute_Humidity_ProfileCount	Count	
WVOnline_wavelength	m	Wavelength of the water vapor online laser
WVOffline_wavelength	m	Wavelength of the water vapor offline laser
WVOnline_wavelength_diff	nm	Difference between water vapor online laser set point and actual wavelength (actual - set point)

WVOffline_wavelength_diff	nm	Difference between water vapor offline laser set point and actual wavelength (actual - set point)
WVOnline_wavelength_spread	nm	Water vapor online laser spread in measured wavelengths for a given time bin.
time_WV_Online_Backscatter_Channel_Raw_Data	s since start of day	
range_WV_Online_Backscatter_Channel_Raw_Data	m	
WV_Online_Backscatter_Channel_Raw_Data	Counts	Raw unprocessed photon counts from the online observations
WV_Online_Backscatter_Channel_Raw_Data_variance		
WV_Online_Backscatter_Channel_Raw_Data_ProfileCount	Count	
time_WV_Offline_Backscatter_Channel_Raw_Data	s since start of day	
range_WV_Offline_Backscatter_Channel_Raw_Data	m	
WV_Offline_Backscatter_Channel_Raw_Data	Counts	Raw unprocessed photon counts from the offline observations
WV_Offline_Backscatter_Channel_Raw_Data_variance		
WV_Offline_Backscatter_Channel_Raw_Data_ProfileCount	Count	
time_Attenuated_Backscatter	s since start of day	
range_Attenuated_Backscatter	m	

Attenuated_Backscatter	Counts s^{-1} ns^{-1} m^2	Qualitative capture of the backscatter scene observed by the lidar. Includes effects of atmospheric backscatter and attenuation.
Attenuated_Backscatter_variance		
Attenuated_Backscatter_mask	1 = Masked, 0 = Not Masked	
Attenuated_Backscatter_ProfileCount	Count	
offline_std_range	pixel	Gaussian smoothing kernel width applied along the range axis of the water vapor offline channel. Specified in units of range bins. Multiply by the range bin resolution to obtain the temporal resolution
molecular_gain		HSRL Variable only used in systems that have the HSRL channel. Multiplier applied to molecular channel to account for difference in efficiency between the combined and molecular channels
lidar_longitude	deg	GPS longitude location of lidar
online_std_range	pixel	Gaussian smoothing kernel width applied along the range axis of the water vapor online channel. Specified in units of range bins. Multiply by the range bin resolution to obtain the temporal resolution
online_std_time	pixel	Gaussian smoothing kernel width applied along the time axis of the water vapor online channel. Specified in units of

		time bins. Multiply by the time bin resolution to obtain the temporal resolution
lidar_elevation	m	Lidar elevation above sea level
offline_std_time	pixel	Gaussian smoothing kernel width applied along the time axis of the water vapor offline channel. Specified in units of time bins. Multiply by the time bin resolution to obtain the temporal resolution
time_offset	s	Small offset in the profile timing used for ranging due to relative delays between the counter start, the laser firing and the laser pulse width
lidar_latitude	degrees	GPS latitude location of lidar