MPD NY-ECLIPSE-2024 data, Version 1.0

This dataset contains MicroPulse Differential Absorption Lidar (MPD) data in NetCDF format which were collected during the MicroPulse Differential Absorption Lidars (MPD) for studying the atmospheric impacts of the total solar eclipse in 2024 (NY-ECLIPSE-2024) projects. Three MPDs were deployed to New York State, USA, for this field project. Data was collected over a period from April 1, 2024 - April 30, 2024. The locations of the instruments are listed in the table below. For more information on NY-ECLIPSE-2024 see https://www.eol.ucar.edu/field_projects/ny-eclipse-2024.

MPD #	Location Description	Elevation [m]	Latitude	Longitude
MPD 2	Webster, NY, USA	86	43.2608	-77.4122
MPD 3	Chazy, NY, USA	62	44.8893	-73.4750
MPD 4	Albany, NY, USA	87	42.6811	-73.8142

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 (10 μJ/pulse) at high repetition rates (8k Hz)[1,2]. 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). The technique also requires the laser wavelength to be stable and confined to a narrow band or "single frequency". For more information, see Spuler et al. (2021) and https://www.eol.ucar.edu/mpd.

MPD Specifications	
Parameter	**Specification**
Wavelength	828.2 nm, 770 nm

Pulse length	1.0 μs
Pulse repetition rate	8 kHz
Vertical resolution	150 m
Vertical range	300-4000 m
Temporal resolution	5 minute sample resolution 10 minute actual water vapor resolution 5 minute HSRL resolution

Data description

Each data product contains time (seconds) and range (meters) dimensions. The lidar is vertically pointing, so range is the same as altitude above ground level (AGL). The conversion to altitude above mean sea level can be obtained by using the ‘elevation’ field in the dataset attributes.

The key data products from this instrument are:
Absolute_Humidity [g/m^3] - estimate of the water vapor density in a parcel of air
Absolute_Humidity_variance [g^2/m^6] - estimate of the statistical variance of the water vapor density estimate due to shot noise. This field also includes an estimate of uncertainty resulting from assumed temperature uncertainty.
Absolute_Humidity_mask - for quality control, indicates if mask (1) or no mask (0) should be applied to the Absolute_Humidity field. Masked data (1) is not considered accurate or valid.
Aerosol_Backscatter_Coefficient [$m^{-1}sr^{-1}$] - estimate of the aerosol/cloud/particle volume backscatter coefficient as obtained from the MPD HSRL channels.
Aerosol_Backscatter_Coefficient_variance [$m^{-2}sr^{-2}$] - estimate of the statistical variance of the aerosol/cloud/particle volume backscatter coefficient resulting from shot noise. This field also includes an estimate of uncertainty resulting from assumed temperature uncertainty.

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 [g/m^3]
Surface_Temperature [K]
Surface_Pressure [atm]

Note that Temperature_model and Pressure_model fields come from HRRRv4 Initializations[3].

Data processing

Water Vapor

Data is processed using the standard DIAL equation where it is assumed all instrument and atmospheric features in the profiles cancel except 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). Note, 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. The size of the smoothing 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, clouds are masked due to large biases that occur due to detector nonlinearity and poorly resolved gradients in the backscatter in and near clouds. A Gaussian smoothing kernel of 125 m and 10 minutes is applied to the masked field to provide the final product.

HSRL

The Aerosol_Backscatter_Coefficient is a calibrated optical measurement obtained by using molecular scattering as a “calibration target” at every range bin. It is calculated based on the observed aerosol to molecular scattering ratio (Backscatter_Coefficient). An HSRL operates by capturing the total backscatter in one detection channel and only molecular backscatter in the other. The backscatter ratio is therefore the ratio of the combined and molecular signals (after accounting for gain differentials)

$$B(r) = \frac{N_{comb}(r)}{N_{mol}(r)}$$

The molecular backscatter coefficient can be estimated to reasonable accuracy based on the temperature and pressure from either an assumed lapse rate or NCEP reanalysis data (Kalnay et al., 2016). With the molecular backscatter coefficient known, the aerosol backscatter coefficient is just

$$\beta_a(r) = \beta_{mol}(r)(B(r) - 1)$$

Photon count signals are initially smoothed to suppress noise and still retain structure and the HSRL products are calculated directly from these signals. As a result, the resolution is typically near that of the base data resolution. The smoothing kernel sizes are reported for each channel in variables with the “_std_range” and “_std_time” tags.

Known problems

The MPD retrievals are photon limited in clear atmosphere. In most cases, instances of excessive noise should be reliably flagged by high Absolute_Humidity_variance.

The MPD estimated water vapor has significant biases in clouds and, in some cases, rain and virga. While we have attempted to mask these cases with the Absolute_Humidity_mask, there may be a few instances that remain unmasked. Use caution when analyzing data near high backscatter targets such as clouds.

MPD 2 experienced an electrical failure at 15:30 UTC on April 29, 2024 which resulted in data being unavailable after that time.

References

1. S. M. Spuler, M. Hayman, R. A. Stillwell, J. Carnes, T. Bernatsky, K. S. Repasky, “MicroPulse DIAL (MPD)–a diode-laser-based lidar architecture for quantitative atmospheric profiling,” Atmos. Meas. Techniques 14(6), 4593-4616 (2021).
2. Spuler et al., Field-deployable diode-laser-based differential absorption lidar (DIAL) for profiling water vapor, Atmos. Meas. Tech., 8, 1073-1087, 2015.
3. Dowell et al.,The High-Resolution Rapid Refresh (HRRR): An Hourly Updating Convection-Allowing Forecast Model. Part I: Motivation and System Description, Wea. Forecasting, 37, 1371–1395, doi:10.1175/WAF-D-21-0151.1, 2022.

Citation

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