Denoised MPD M2HATS data, Version 1.0

This dataset contains MicroPulse Differential Absorption Lidar (MPD) data in NetCDF format collected by the MPD 3 during the Multi-point Monin-Obukhov similarity horizontal array turbulence study (M2HATS). The data was simultaneously denoised and processed for temperature, water vapor and aerosol backscatter coefficient using the Poisson Total Variation technique. While two MPDs were deployed to Nevada, USA, for this field project, only data from MPD 3 was processed using this enhanced technique due to hardware issues on MPD 2. Data from both MPDs (processed with the standard technique) is available at https://doi.org/10.26023/2286-1446-JV0E. Data was collected over a period from July 20, 2023 - September 26, 2023. The location of the instrument is listed in the table below. For more information on M2HATS see https://www.eol.ucar.edu/field_projects/m2hats.

MPD #	**Location Description**	**Elevation [m]**	**Latitude**	**Longitude**
MPD 3	Tonopah, NV, USA	1641	38.0406	-117.0876

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 for water vapor and 40-60 pm for oxygen) optical filters. The transmitted laser beam is eye-safe and invisible (Class 1M) and the receiver uses single photon counting detectors.

The MPD retrievals rely on two different lidar techniques. Differential absorption lidar (DIAL) is used at 828 nm to measure molecular water vapor concentration and 770 nm to measure temperature of oxygen molecules (which are assumed to be representative of the temperature of all air molecules in the volume). In addition, the high spectral resolution lidar (HSRL) technique is employed at 770 nm to measure the aerosol backscatter ratio (the relative amount of molecular and aerosol scattering in a volume).

Water Vapor DIAL
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.

Oxygen DIAL

Oxygen DIAL operates on the same principles as water vapor DIAL where two closely spaced laser wavelengths are transmitted with one tuned to an oxygen absorption line (online) and the other just off the line (offline). Where with water vapor DIAL, we use a known absorption feature to estimate the amount of water vapor, with oxygen DIAL we use a known amount of oxygen to measure the amount of (temperature dependent) oxygen absorption, and therefore the temperature. A key caveat to oxygen DIAL is that the amount of absorption observed is different on the return trip from molecular and aerosol scattered light. As a result, the integrated HSRL is needed to inform the oxygen DIAL retrieval. See Stillwell et al. (2020) and Hayman et al. (2024) for further information on this technique.

HSRL

HSRL is a technique for separating molecular and particulate scattered light in the lidar receiver. Return light is split into two different channels. One operates the same as a backscatter lidar, detecting all of the backscattered light (combined channel) while the other has a narrow band filter that blocks the spectrally narrow particulate (or aerosol) scattered light such that only molecular scattering is detected (thus called the molecular channel). With these two observations, we get a direct measurement of the relative amounts of molecular and particulate scattered light being collected by the instrument. See Hayman et al. (2017) and Stillewell et al. (2020) for more information.

MPD Specifications	
Parameter	**Specification**
Wavelength	828.2 nm, 770 nm
Pulse length	1.0 μs
Pulse repetition rate	8 kHz
Vertical sample resolution	37.5 m
Vertical range	300-6000 m
Temporal resolution	5 minute sample resolution 5 minute water vapor resolution 5 minute HSRL resolution 40 minute temperature 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.

Each data product, unless otherwise noted, has an associated mask and uncertainty data array (e.g. “Absolute_Humidity_mask” and “Absolute_Humidity_uncertainty”. A mask value of 1 indicates the pixel should be masked for QC reasons. Uncertainty reporting is done in the same units as the data product and is largely limited to encapsulating uncertainty due to shot noise.

Data products obtained through this processing routine are reliant only on data from this instrument. While each data product has cross dependencies with others (e.g. processing absolute humidity requires temperature information) all of those dependencies are accounted for in the instrument retrievals. All calibrations are internal to the instrument. There are no external calibrations or data products used to obtain the products reported in these files.

Note that data is processed at a base resolution of 5 minutes and 37.5 m (except Temperature and Lapse Rate which uses a base resolution of 40 minutes), however the PTV denoising technique employed will dynamically adjust the averaging intervals based on the observed scene and the accompanying signal-to-noise ratio of the measured photon count signals. There is no strict definition for these resolutions other than the lower limit defined by the base resolution.

The key data products from this instrument are:
Temperature [K] - estimate of the temperature in a parcel of air
Lapse_Rate [K/km] - estimate of the temperature lapse rate in a parcel of air
Absolute_Humidity [g/m^3] - estimate of the water vapor density in a parcel of air
Relative_Humidity [%] - relative humidity calculated from measured Temperature and Absolute Humidity fields
Backscatter_Ratio [unitless] - Amount of aerosol scattering relative to molecular scattering observed at 770 nm.
Aerosol_Backscatter_Coefficient [1/m/sr] - Backscatter coefficient of non-molecular scatterers in the volume (mostly aerosols).
Backscatter_Photon_Counts_770 [photon counts] - Raw photon count observations in the 770 nm offline combined channel. This provides contextual awareness for the scene that would otherwise be inhibited by masking. This has no uncertainty or mask associated with it.
Backscatter_Photon_Counts_828 [photon counts] - Raw photon count observations in the 828 nm offline channel. This provides contextual awareness for the scene that would otherwise be inhibited by masking. This has no uncertainty or mask associated with it.
Surface_Absolute_Humidity [g/m^3] - Absolute humidity measured by the MPD surface station. This has no uncertainty or mask associated with it.
Surface_Relative_Humidity [%] - Relative humidity measured by the MPD surface station. This has no uncertainty or mask associated with it.
Surface_Temperature [K] - Temperature measured by the MPD surface station. This has no uncertainty or mask associated with it.

Surface_Pressure [atm] - Pressure measured by the MPD surface station. This has no uncertainty or mask associated with it.
Pressure_Estimate [atm] - Estimated profile pressure obtained from the temperature retrieval and a hydrostatic assumption and used in the MPD processing. This should not be treated as an observation but rather as a sanity check to ensure the MPD data products are accurate. Inaccurate pressure could result in other data product inaccuracies (particularly Temperature).

Data processing

Data processing is performed by simultaneously inverting and denoising all MPD observations for all data products using regularized likelihood estimation. Total variation regularization is employed to restrict the estimator's responsiveness to noise in the observation channels and a forward model fitting approach enables accounting for interdependencies between all retrieved data products. A detailed description of the processing technique is published in Hayman et al. (2024).

Known problems

The MPD retrievals are photon limited in clear atmosphere. In most cases, cases of excessive noise are typically flagged in the "_mask" field based on the "_uncertainty" fields.

The DIAL experiences significant biases in clouds and, in some cases, rain and virga and high background. While we have attempted to mask these cases using "_mask" fields, there may be a few instances that remain unmasked. Use caution when analyzing data near high backscatter targets such as clouds. Please also note that HSRL data will be similarly masked for high backscatter and high background regions. We highly recommend the use of the "_mask" fields to ensure that the data is in fact valid. Regions that are masked for these reasons are not retrieved in the processing steps.

MPD temperature retrievals demonstrated a 1 K warm bias compared to sondes during the project which is believed to be a product of hardware performance. However, sondes were only launched at two specific times during the day. It is possible that biases below 1 km may be larger during night (~2 K) and the user should be cautious about trusting data to better than 2 K in this altitude region.

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. R. A. Stillwell, S. M. Spuler, M. Hayman, et al., "Demonstration of a combined differential absorption and high spectral resolution lidar for profiling atmospheric temperature," Opt. Express 28(1), 71–93 (2020).

3. M. Hayman and S. Spuler, “Demonstration of a diode-laser-based high spectral resolution lidar (HSRL) for quantitative profiling of clouds and aerosols,” Opt. Express 25(24), A1096–A1110 (2017).
4. M. Hayman, R. A. Stillwell, A. Karboski, W. J. Marais, and S. M. Spuler, “Global estimation of range resolved thermodynamic profiles from micropulse differential absorption lidar,” Opt. Express 32(8), 14442-14460 (2024).

Citation

When using this data set please cite

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