MicroPulse DIAL for Thermodynamic Profiling of the Lower Troposphere

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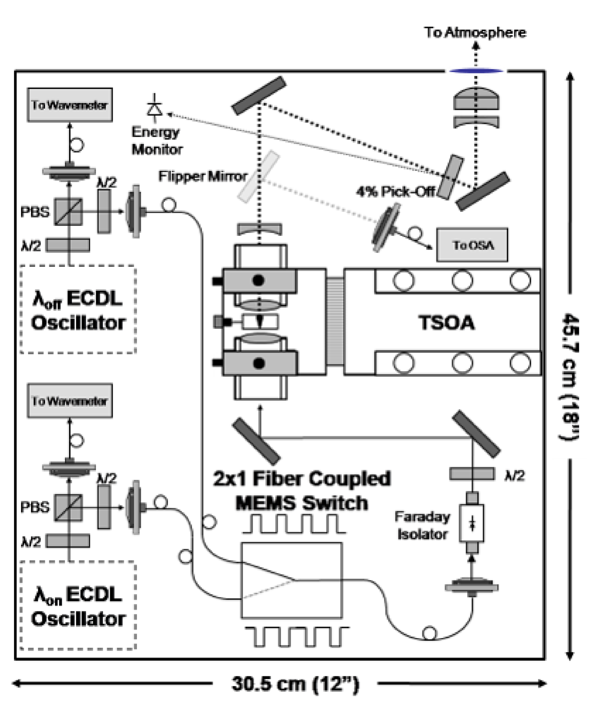
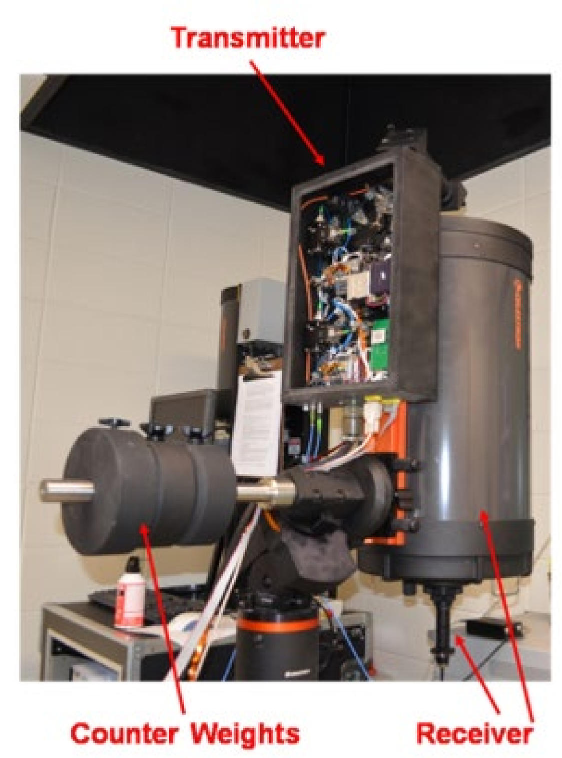
Introduction

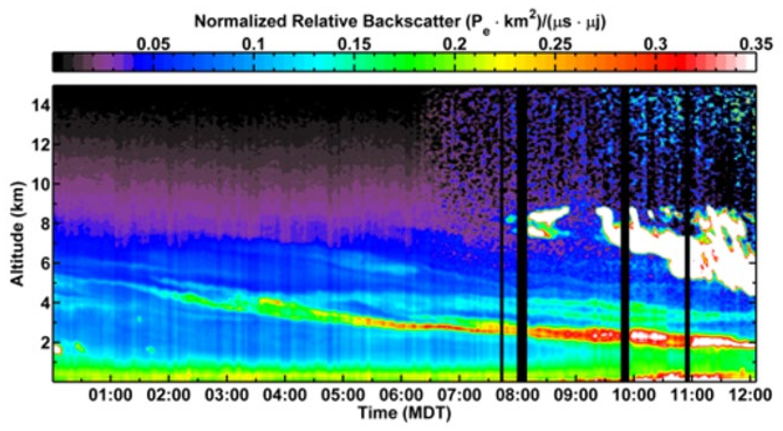
Researchers at Montana State University and the National Center for Atmospheric Research have developed a collaborative research program to develop diode laser based micropulse differential absorption lidar (MPD) instruments for thermodynamic profiling. This collaborative effort has led to the development of a network of five MPD instruments available for the research community. The current state of the MPD network including measurement capabilities as well as continuing research and development is discussed.

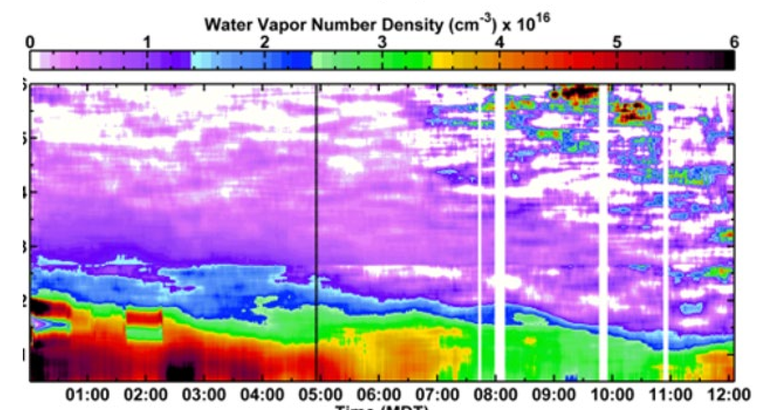
Humidity Profiling

A diode-laser-based differential absorption lidar was developed at Montana State University (MSU). This instrument used a pulse train that produced microjoule pulses with a high pulse repetition frequency and employed a photon counting detector in the optical receiver. A schematic of an early micropulse differential absorption lidar (MPD) is shown in left-hand figure below while the prototype instrument built 2010-2012 is shown in the right-hand figure.

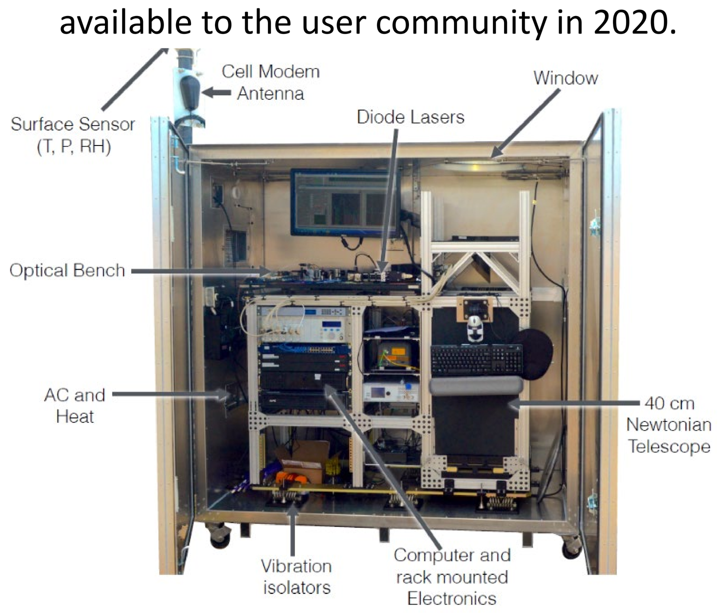


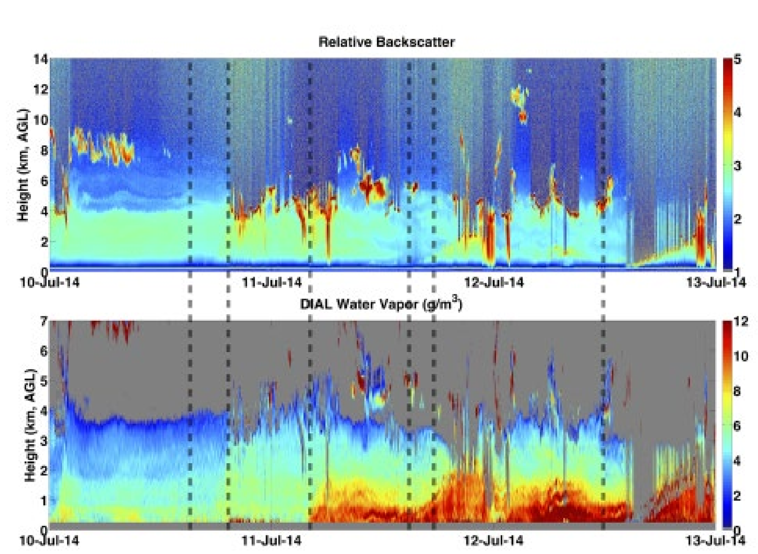






The MPD instrument provide continuous normalized relative backscatter and water vapor number density profiles. With the successful demonstration of an MPD prototype, a collaborative effort between Montana State University and the National Center for Atmospheric Research was formed in 2012 to develop field deployable MPD instruments for the science community. A picture of the field deployable MPD is shown in the figure below. Data includes the relative backscatter and the water vapor number density. These instruments became available to the user community in 2020.



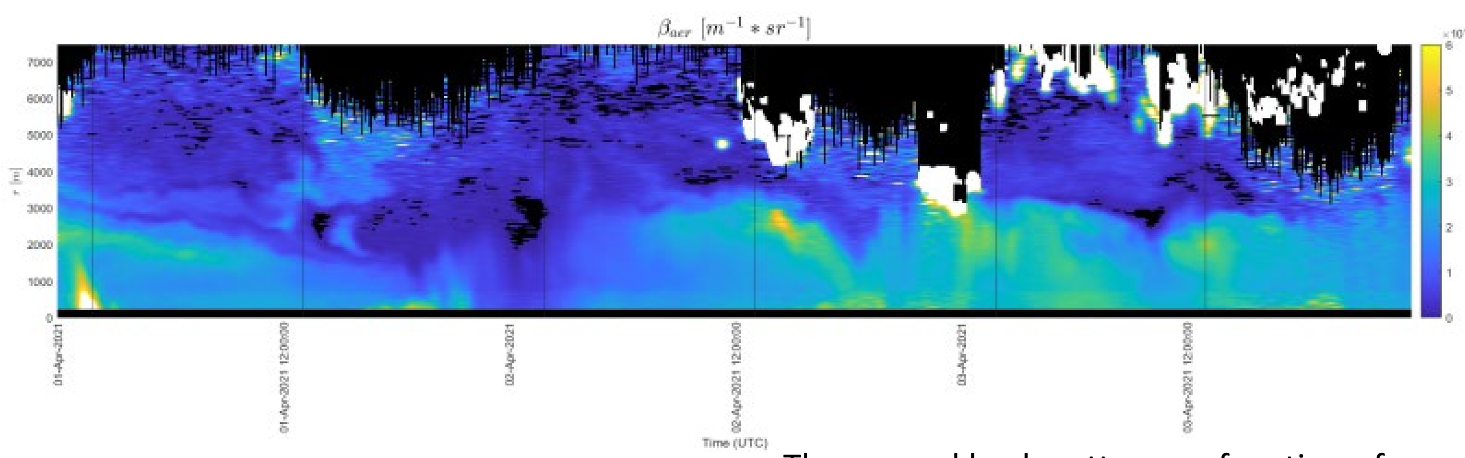


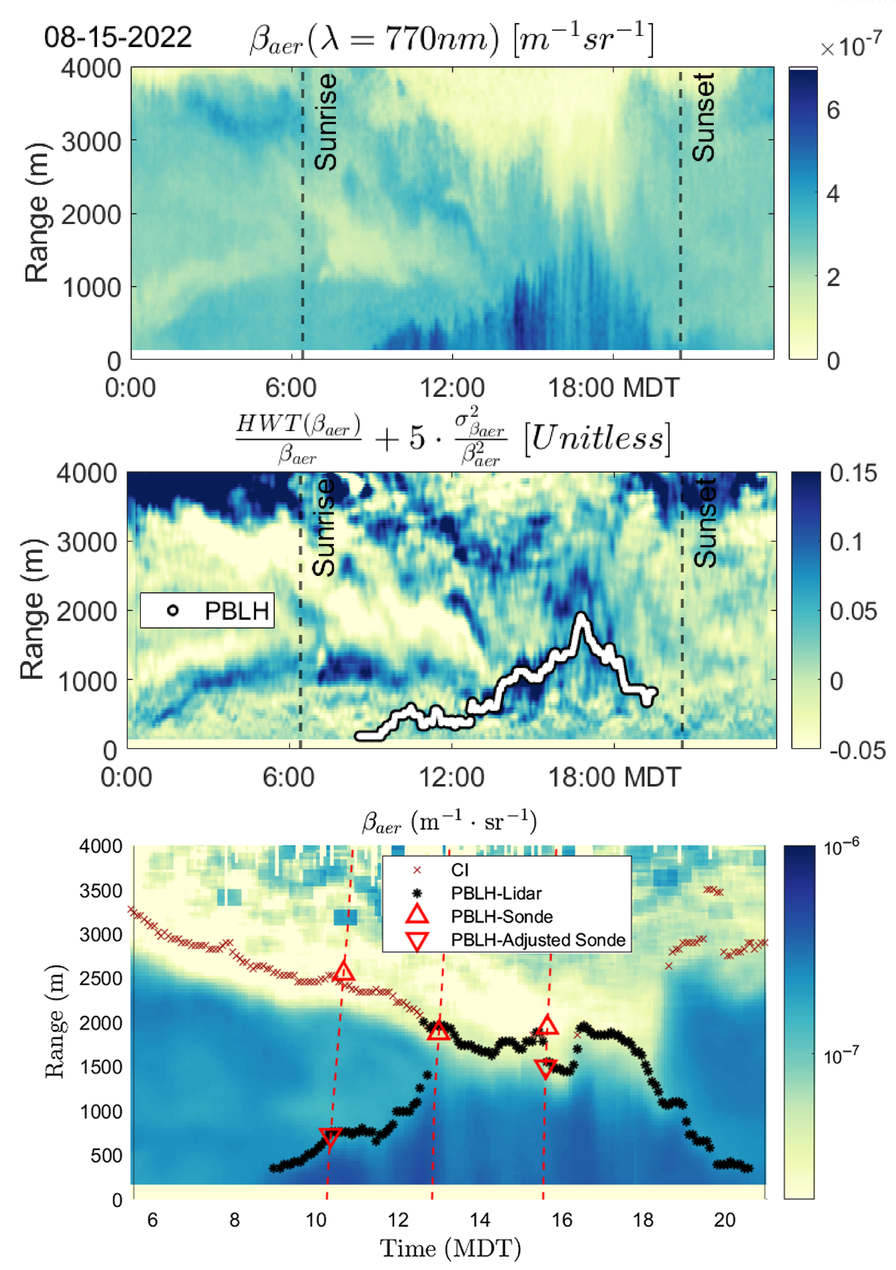
The humidity profiling is the most mature measurement capability of the MPD instruments. Taking advantage of the diode laser and semiconductor optical amplifier technology and commercial off the shelf (COTS) components, the MPD instrument architecture allows for other measurement capabilities.

Aerosol Profiling

Using atomic vapor cells, a high spectral resolution lidar (HSRL) instrument architecture for the MPD instruments was developed in 2017 by the National Center for Atmospheric Research. The HSRL MPD instrument provides calibrated aerosol backscatter profiles and can be used along with a model atmosphere to estimate the lineshape of the backscattered signal. The ability to estimate the lineshape of the backscattered signal is needed for both the temperature and wind profiling discussed later.

Aerosol Profiling (continued)

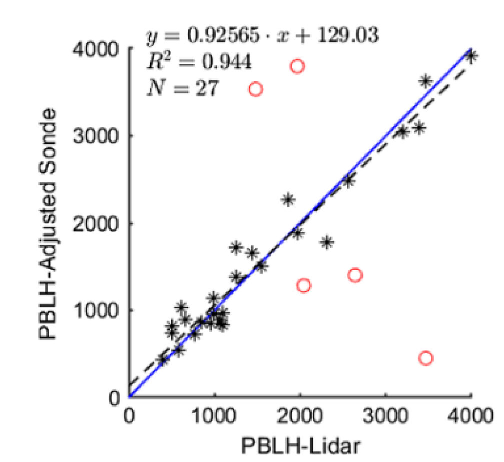




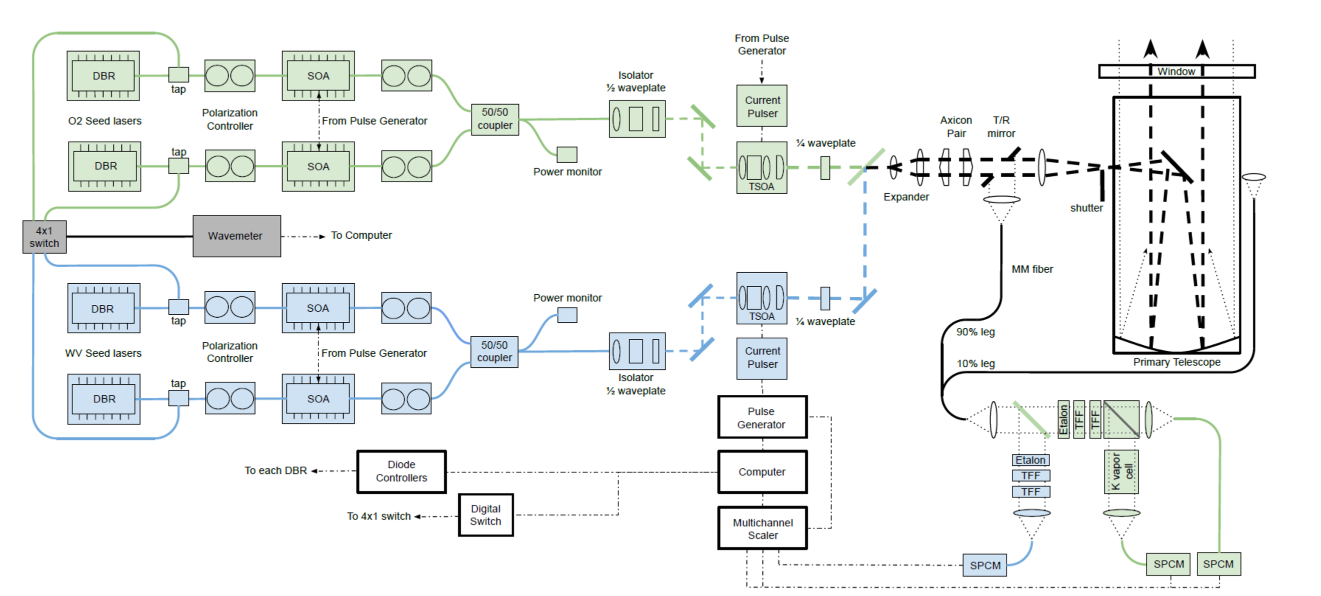
The aerosol backscatter as a function of range and time from the HSRL MPD instrument is shown in the above plot while the aerosol backscatter ratio, the ratio of the total backscatter to the molecular backscatter, is shown in the upper left-hand plot.

A boundary layer retrieval has been developed by Montana State University in 2022 based on a Haar wavelet transformation and the temporal variance. A cost function is generated and a pathfinding algorithm is used to find the convective boundary layer. The cost function plot along with the convective boundary layer is shown in the middle left-hand plot.

The bottom left-hand plot shows a convective boundary layer, a capping inversion layer, and a radiosonde comparison. The bottom right-hand plot shows a comparison of the boundary layer retrieval and the boundary layer found using co-located radiosondes.

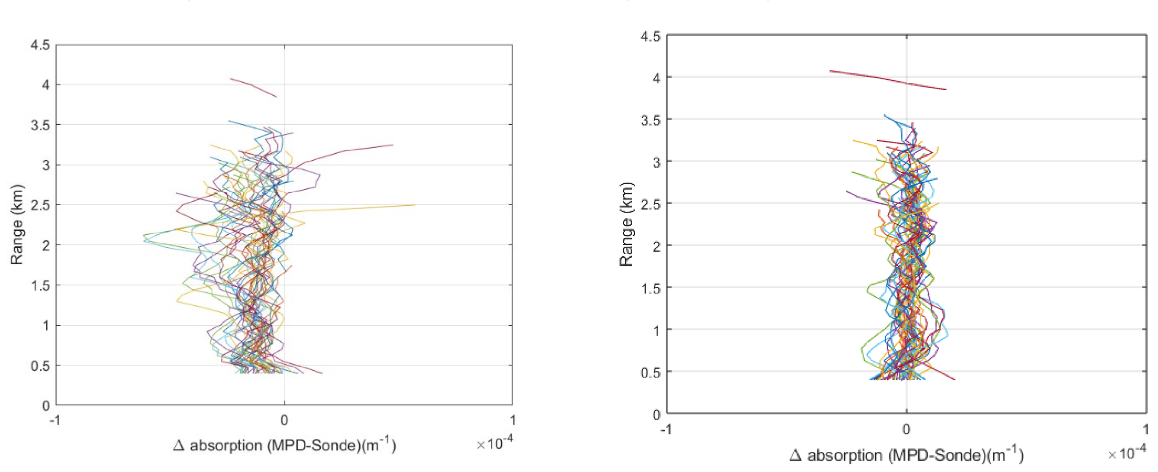


Temperature Profiling

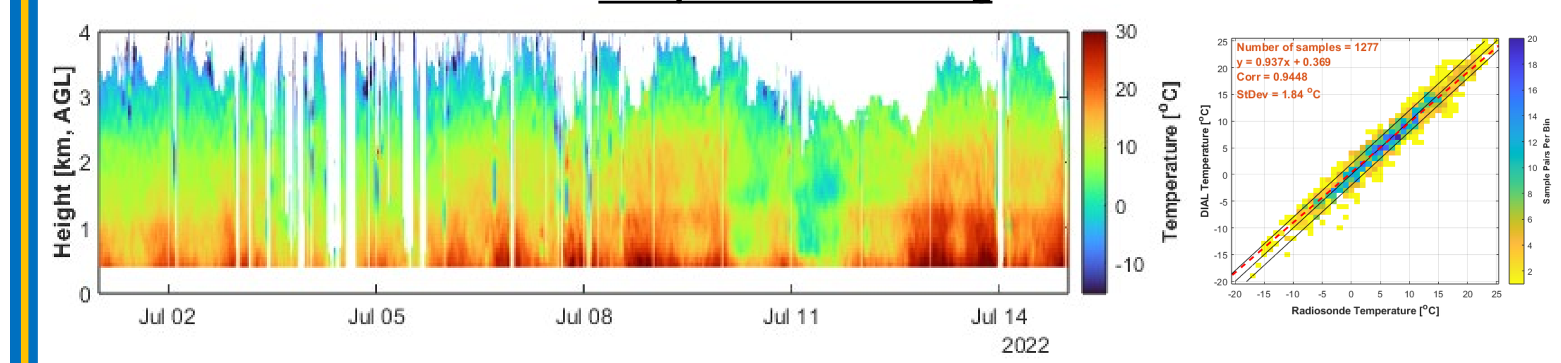


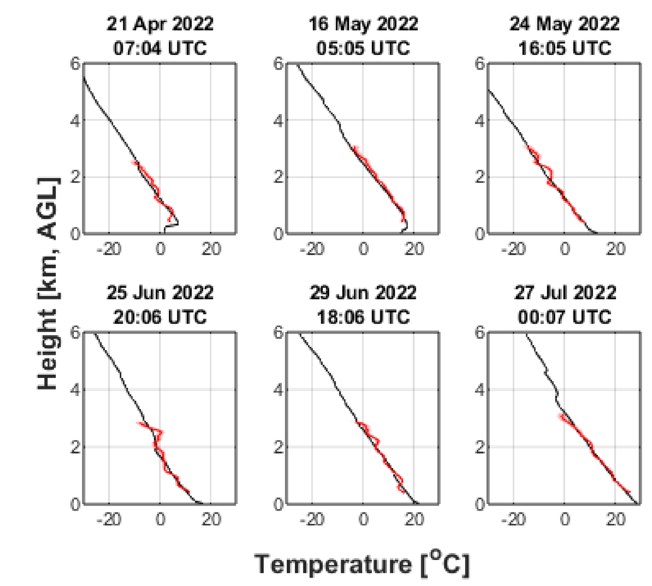
A schematic of the thermodynamic profiler is shown above. The blue boxes indicate operation near 828.2 nm for water vapor profiling. The green boxes indicate operation near 769.8 nm and allows for both HSRL calibrated aerosol and temperature profiling.

Temperature profiling is based on DIAL measurements of a temperature sensitive O_2 absorption line. A perturbative retrieval technique has been developed by Montana State University in 2018-2019 to retrieve the absorption coefficient profile. This perturbative retrieval uses the HSRL measurement to infer the lineshape of the backscattered signal. The left-hand plot below shows a comparison of the standard DIAL retrieval of the O_2 absorption coefficient using the MPD and co-located radiosondes while the right-hand plot shows the same comparison based on the perturbative retrieval that accounts for the lineshape of the backscattered signal. Once the O_2 absorption coefficient is retrieved, an iterative retrieval also developed at Montana State University is used to find the final temperature profile.



Temperature Profiling

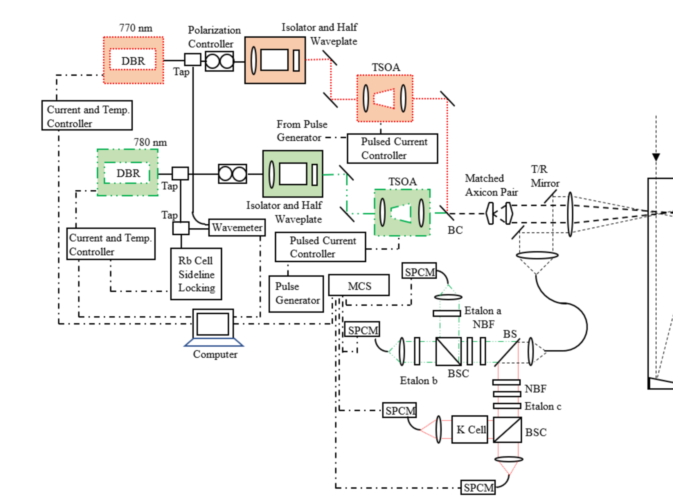


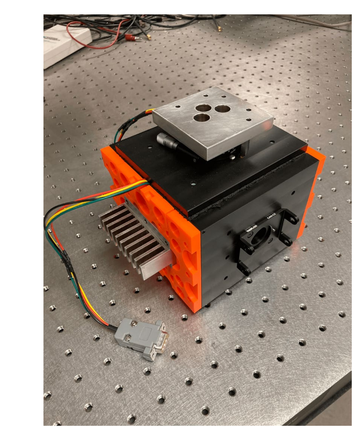


A plot of the retrieved temperature as a function of range and time is shown in the upper left-hand plot. A comparison of individual temperature profiles retrieved from the MPD and temperature profiles measured using co-located radiosondes is shown in figure to the left. A scatter plot showing the comparison of the MPD retrieved temperature with thirty nine radiosondes is shown in the upper right-hand plot.

The National Center for Atmospheric Research is updated the all five MPD instruments to include temperature profiling. Development and improvements with the temperature profiling is ongoing.

Wind Profiling



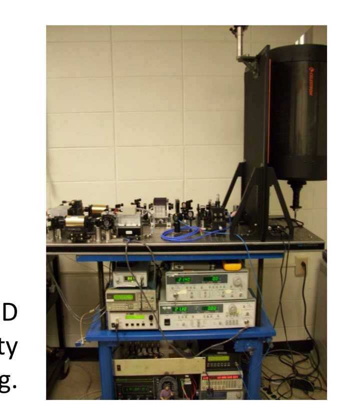


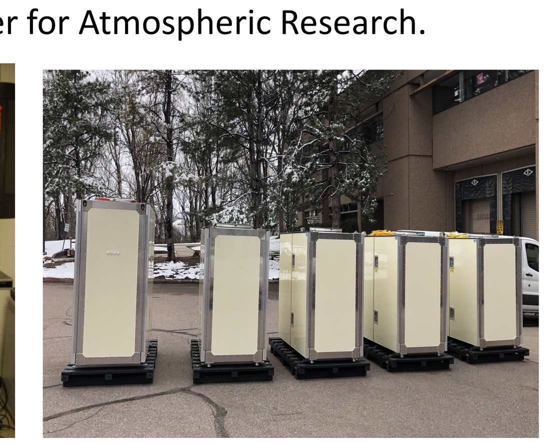
A diode-laser-based Doppler wind lidar is currently under development at Montana State University. This lidar will use a dual edge detection scheme to determine line of sight wind velocity. A schematic of the proposed instrument is shown in the upper left-hand figure. The instrument uses the Pound-Drever-Hall locking technique to stabilize the laser transmitter and two stabilized etalons offset from the laser transmitter center frequency to detect the Doppler shift of the scatter light allowing the line of sight wind velocity to be inferred. The stabilized etalon is shown in the upper right hand figure. An integrated HSRL measurement is used to account for the lineshape of the scatter light in the wind velocity retrieval. Initial testing of the instrument is expected to begin in early 2024.

Summary

The versatile diode-laser-based MPD architecture has been used to develop remote sensing instruments for humidity, calibrated aerosol, and temperature profiling. Continuing work is allowing the development of boundary layer height retrievals and incorporating wind profiling capabilities. This development work is the result of a successful collaboration between Montana State University and the National Center for Atmospheric Research.

The Initial MPD instrument for humidity profiling.





The current network of five thermodynamic profilers.

Acknowledgments

Past Grants:

This work was supported by the National Science Foundation grant number 1624736.

This material is based upon work supported by the Observations Program within NOAA/OAR Office of Weather and Air Quality under Award No. NA19OAR4590323 and NA19OAR4590324.

Current Grants:

This work was supported by the National Science Foundation grant number 1917851 and 2234047.