MicroPulse DIAL (MPD) ground-based network for Thermodynamic Profiling in the Lower Troposphere

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What is the problem?

- High-resolution vertical profiles of atmospheric humidity and temperature at roughly 150 km grid spacing are two of the highest priority observations needed to address current inadequacies
    - 2009 Observing Weather and Climate from the Ground Up, NRC Study
- Height-resolved atmospheric boundary layer profiling is critical for improved severe weather forecasts and quantitative precipitation forecasts
    - 2010 When Weather Matters, NRC Study
- Huge observational gaps exist in thermodynamic profiling of the lower troposphere. Low-cost ground-based passive and active remote sensing systems are the best means to close gaps and essential for progress in weather and climate research
    - 2015 Wulfmeyer et al. Rev. Geophys.
- Atmospheric boundary layer measurements must include remotely-sensed measurements of humidity and temperature
    - 2018 Future of Atmospheric Boundary Layer Observing Understanding and Modeling, BASC Workshop, NASEM

Solution

MicroPulse DIAL (MPD):

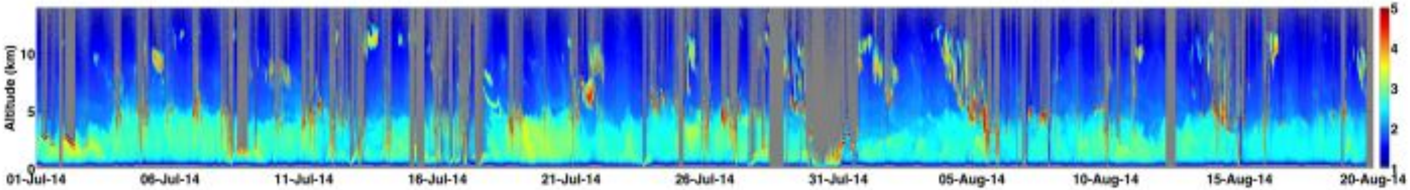
- Laser transmitter is inherently low-maintenance, low-cost, and eye-safe
- Provides continuous full-diurnal autonomous water vapor measurements from 300 m above ground level to 4-6 km (or cloud base) with 5 minute, 150 m resolution
- A testbed of five validated instruments have been constructed
- Quantitative aerosol and temperature profiling has been demonstrated

Photo of the five MPD units (Apr 2019)

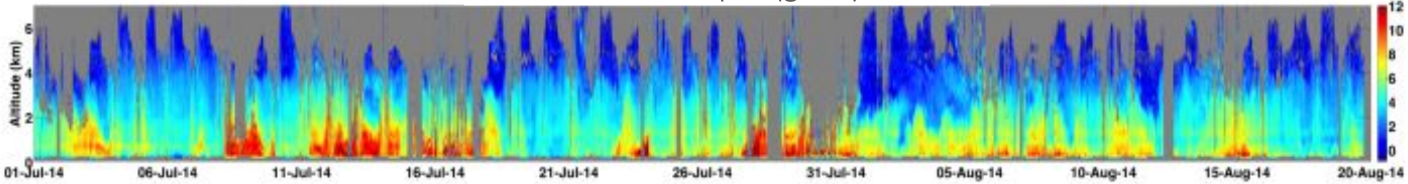
Differential Absorption Lidar (DIAL) Technique

- Measures difference in transmission between absorbing and non-absorbing wavelengths
- Uses elastic scatter as a distributed backscatter reflector
  - Operation at significantly lower power than Raman lidar systems
  - Lower power requirements enable use of low maintenance, low cost, eye-safe semiconductor lasers
- Narrowband DIAL is self calibrating differential technique (i.e., no radiosondes needed)
- Requires stable, “single frequency” laser sources corresponding to species absorption features
- Requires rough estimates of atmospheric temperature and pressure (obtained from surface)

Relative Backscatter



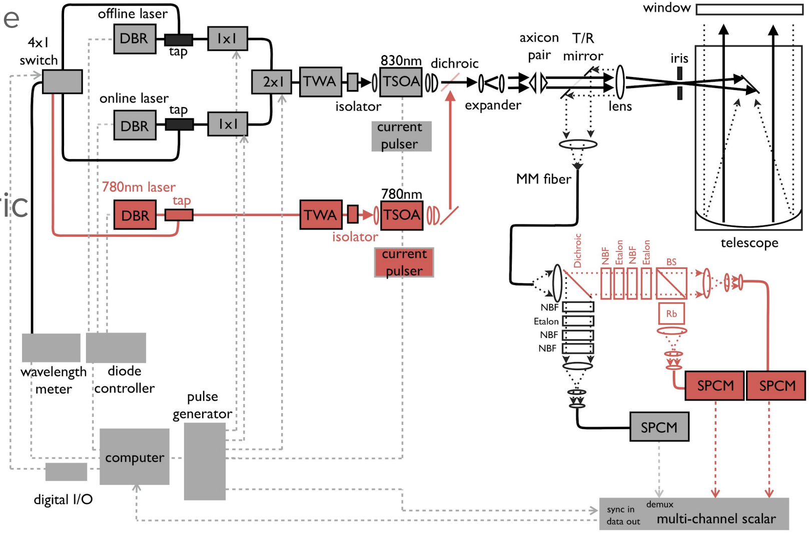
Water Vapor (g m^{-3})



2014 FRAPPE field campaign data set of continuous water vapor profiles

Diode-Laser-Based Lidar Architecture

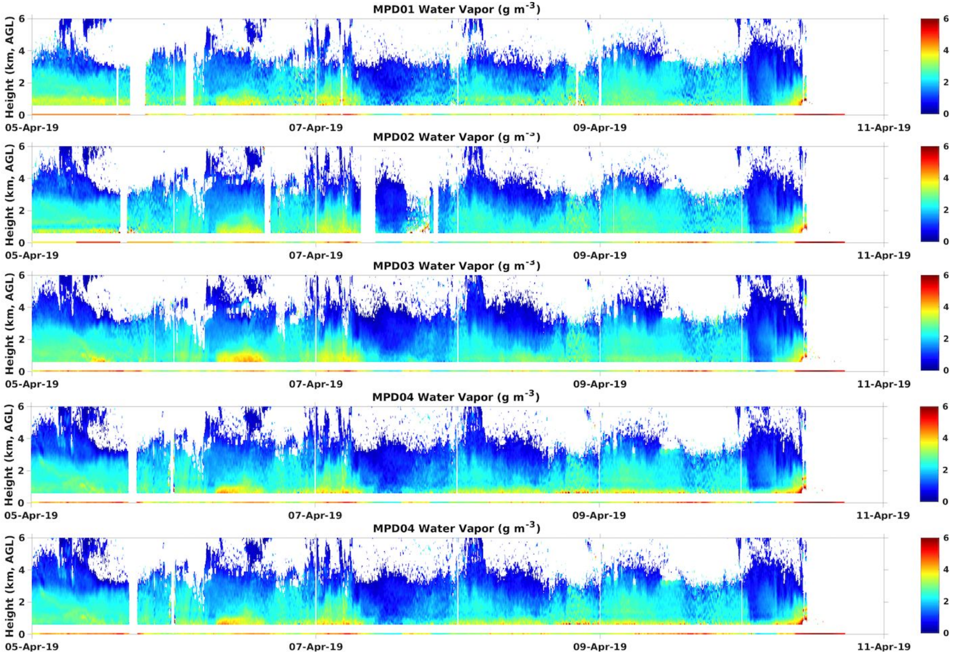
- Robust, compact, low cost, fiber-coupled electrically pumped semiconductor laser transmitter
  - Butterfly packaged Distributed Bragg Reflector (DBR) seed lasers
  - Butterfly packaged Traveling Wave Amplifier (TWA) booster stage
  - Pulsed Tapered Semiconductor Optical Amplifier (TSOA)
- High spectral purity, frequency stable, output
  - 5 µJ/pulses at 7 kHz repetition rates
- Wavelengths actively stabilized and optimized for atmospheric conditions
- Stable shared transmit/receive telescope design
- Daytime operation enabled two stage receiver
  - Narrow field of view (110 µrad)
  - Extremely narrow-band optical filtering (<15 pm) matched to transmit wavelengths
  - Fiber coupled single photon counting modules (SPCM)
- Demonstrated HSRL and Temperature channels

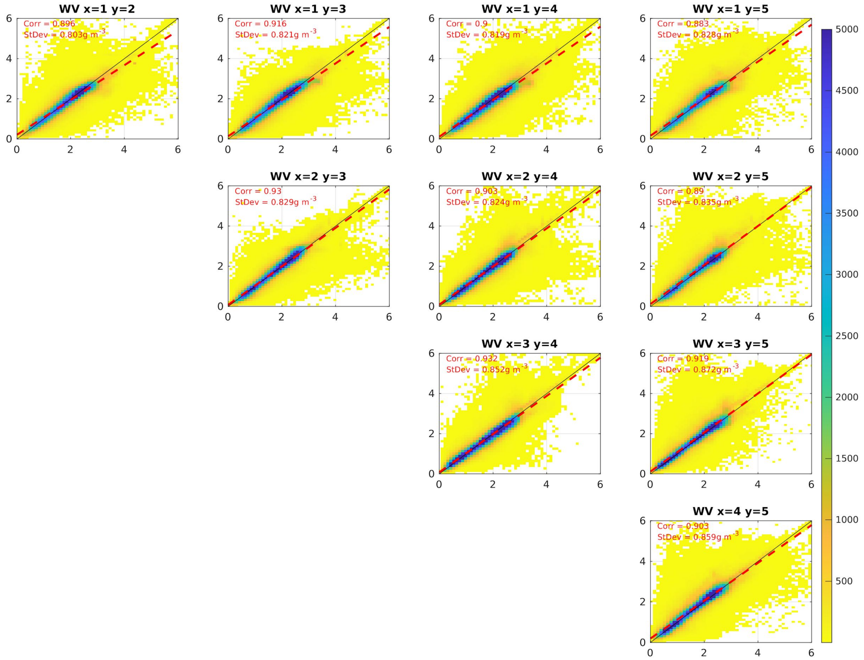


MPD schematic for combined water vapor and quantitative aerosol profiling via High Spectral Resolution Lidar (HSRL) channel

MPD Network Validation

2019 comparison of the five MPD units against themselves



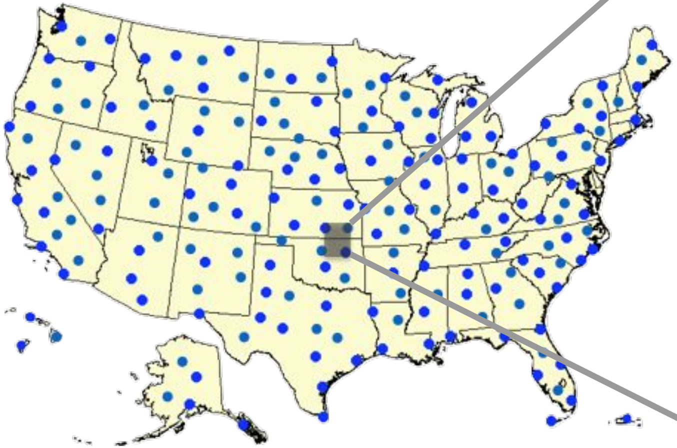


- MPD measurement of water vapor agree with one another
- Addition of temperature + HSRL (MPD5), or HSRL only (MPD2) does not affect data quality

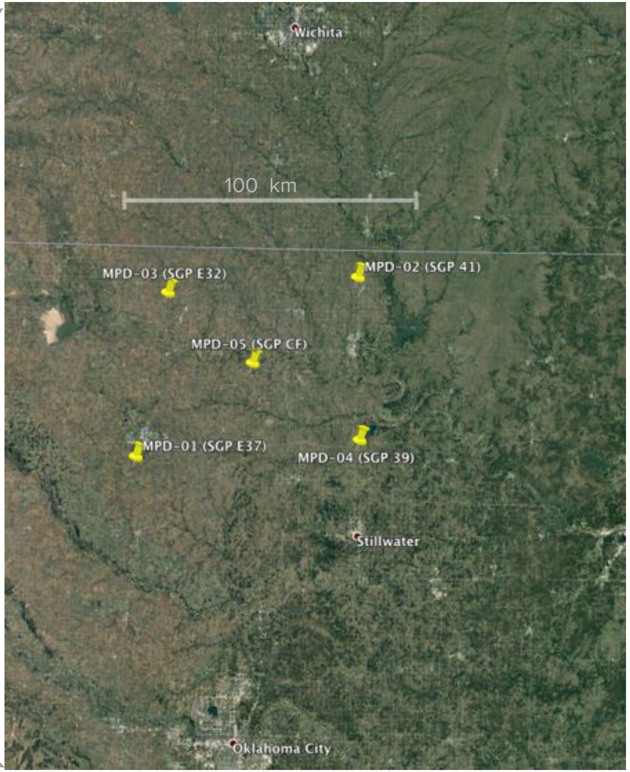
MPD Network Demonstration

2019 test of the five MPDs as a field network

- Location: DOE/ARM/SGP sites in Oklahoma USA
- Dates: 19 April – 19 July 2019
- 8 radiosondes/day at Central Facility
- Raman lidar (WV and temp) at Central Facility

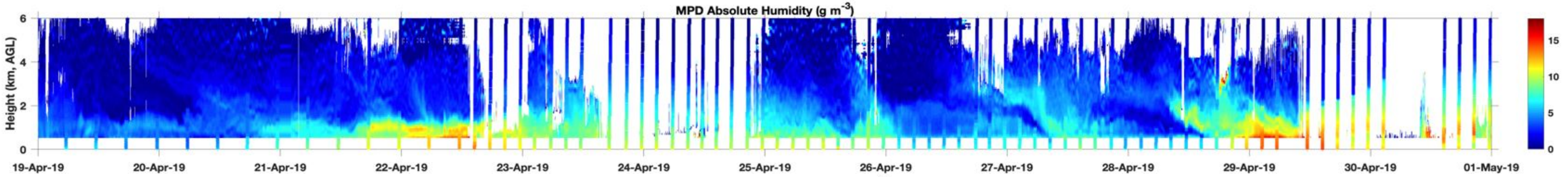


Blue dots represent hypothetical continuous, high-vertical-resolution thermodynamic profiles **needed at several hundred sites** (for a future US network)

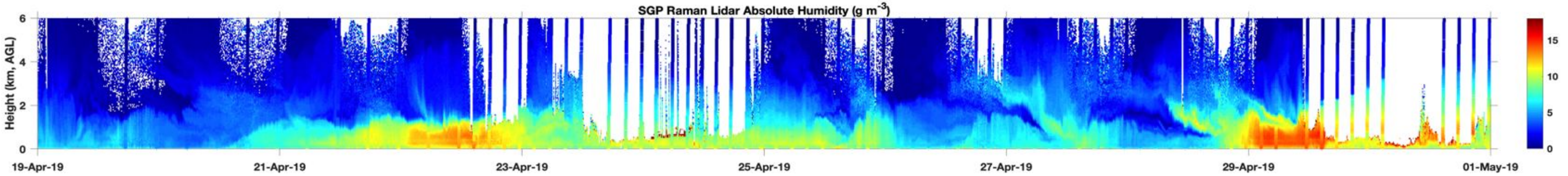


MPD Network Demonstration

Comparison of MPD units with radiosondes and Raman lidar

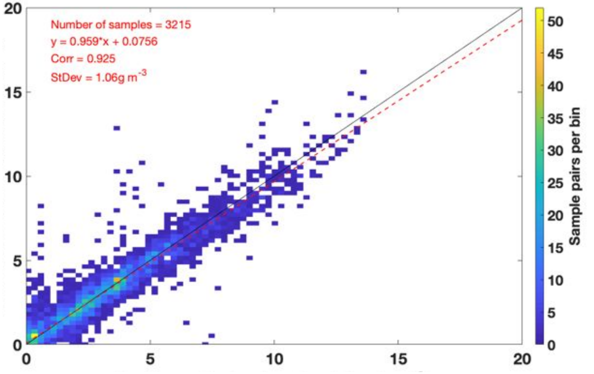


MPD
(10min 150m)
& sondes

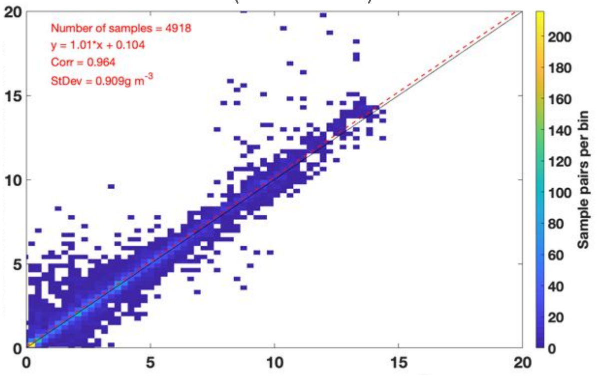


Raman Lidar
(10min 60m)
& sondes

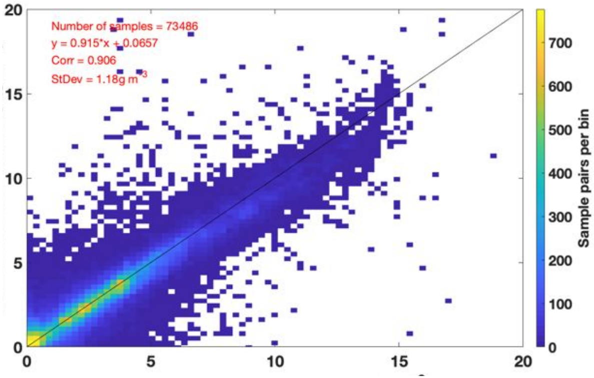
MPD (10min 150m) vs 77 sondes



SGP Raman Lidar (10min 60m) vs 77 sondes



MPD vs Raman Lidar



MPD Network Demonstration

Temperature Profiling

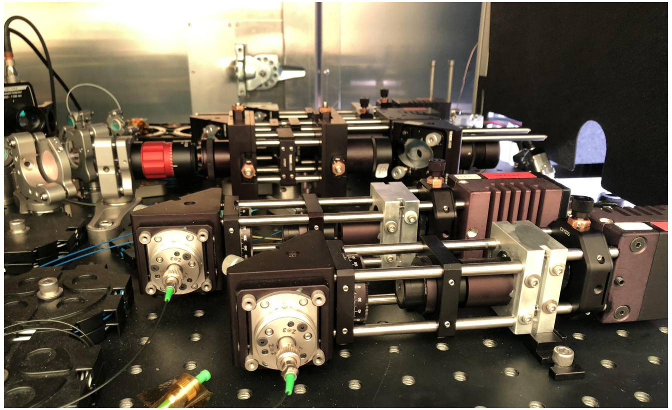


Photo of MPD WV, temp, HSRL transmitter 6-May 2019

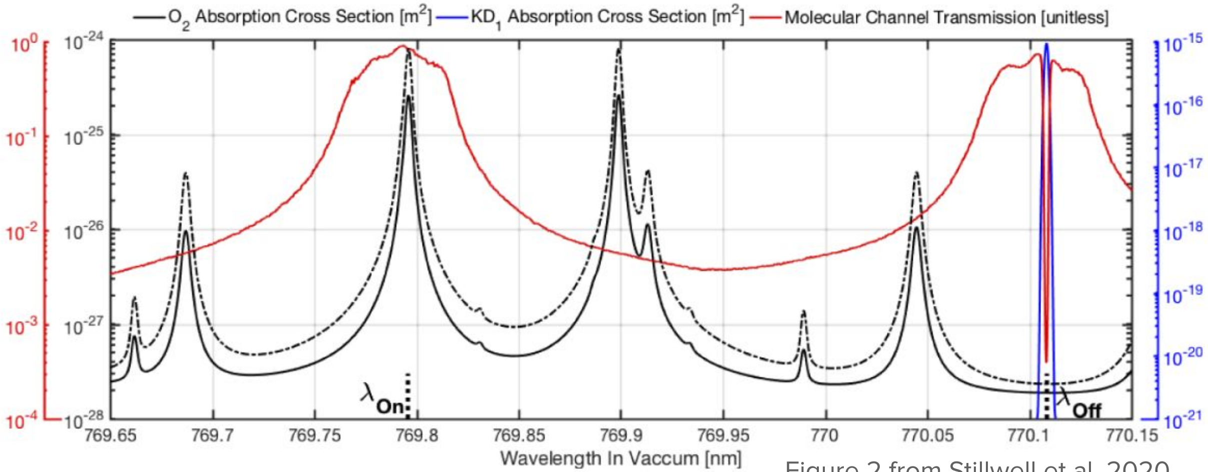


Figure 2 from Stillwell et al. 2020

- System simultaneously measures water vapor, backscatter ratio, and oxygen absorption using a combination of DIAL and HSRL
- Temp DIAL online centered on line center of a temperature sensitive oxygen line
- Temp DIAL offline centered on Potassium HSRL filter and in region of minimum oxygen absorption

MPD Network Demonstration

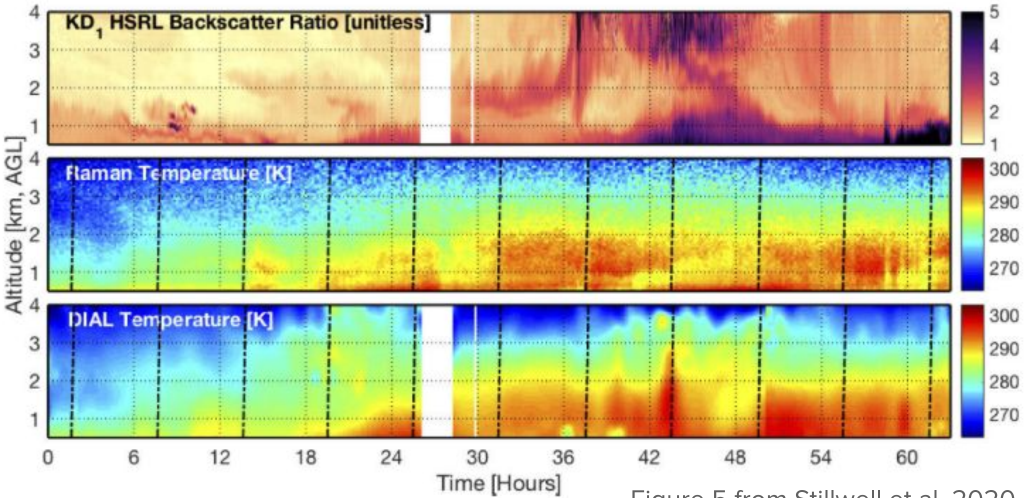


Figure 5 from Stillwell et al. 2020

Temperature Profiling

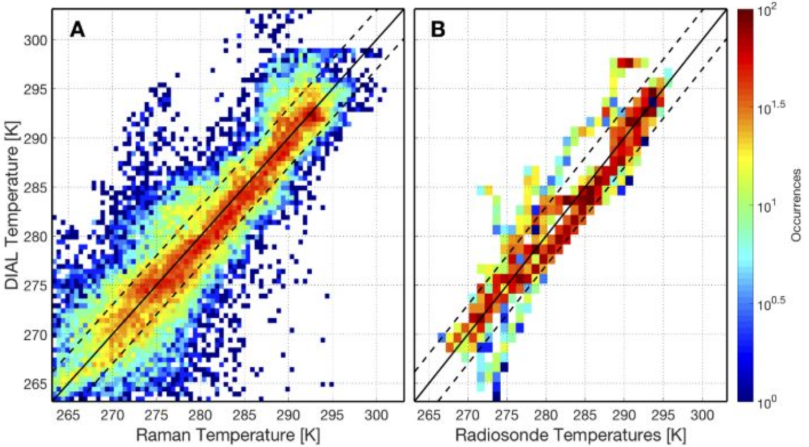


Figure 6 from Stillwell et al. 2020

- Temperature and aerosol measurement from the MPD Net Demo field campaign
- Comparisons with Raman Lidar and Radiosondes indicate good agreement
- Demonstrated ability to measure atmospheric temperature using the DIAL technique with accuracy that can increase forecast predictive skill
- Currently funded by NOAA to improve and advance this technique

MPD Improvements and Ongoing Research

- Improved measurements closer to the ground surface
    - Demonstrate afterpulse corrections and near range channel – measuring to 125 m AGL
    - Investigating combined main & near (and high and low gain) channel receiver
- Improved long range performance and uncertainty estimates
    - Developed Poisson thinning for optimal scene smoothing
    - Developing improved ‘bootstrap’ error estimates
    - Developing Poisson Total Variance processing of water vapor (increases range to 8km)
- Improved technology readiness for WV and Temperature
    - Developed a two stage all-fiber-coupled seed laser
    - Developing a fiber-coupled TSOA with industry partner
    - Developing Automated Receiver scanning
    - Developing improvements to Temperature algorithms
- Assessing impact on Numerical Weather Prediction
    - Performing Observing System Simulation Experiments (OSSE) on 2015 dataset
    - Performing Data Assimilation tests on 2019 network dataset
    - Investigating novel methods for assessing instrument impact
- Working towards commercialization with industry partner via phase II SBIR

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