Progress in Measurements of Atmospheric Surface Layer Pressure Perturbations in Space and Time

Jessica Laubender [1], Emily Connick [1], Halleigh MacPherson [1], Kathleen Meehan [2], Shane D. Mayor [1]

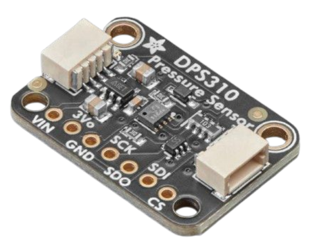
[1] Department of Earth and Environmental Sciences, [2] Electrical and Computer Engineering Department

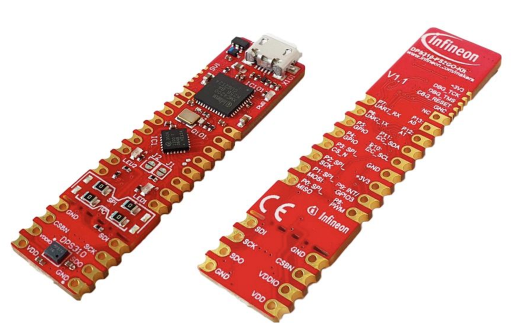
Introduction

What are turbulent pressure perturbations and why are they important?

- Turbulent pressure perturbations are small amplitude and high frequency fluctuations in barometric pressure caused by everyday atmospheric turbulence. In our work, the measurable perturbations with frequencies as high as 20 Hz with detectable amplitudes of about 0.1 - 10 Pa. These fluctuations are on the order of 1 part in 100,000 (and greater) of mean sea level atmospheric pressure.
- Spatial gradients in pressure result in pressure gradient forces and accelerations of the intervening fluid. Therefore, pressure variations are central to fluid movement and the transport of environmental parameters such as traces gases (including carbon dioxide, methane, and water vapor), temperature, and momentum.
- In environmental science and micrometeorology, turbulent pressure perturbations are of interest due to their role of making turbulence isotropic at small scales, and their ability to pump trace gases in and out of porous subsurface media (such as soil and snow).
- Our work investigates state-of-the-art technologies for measuring turbulent pressure perturbations and an exploration of the causes of the fluctuations using data from other observing systems.

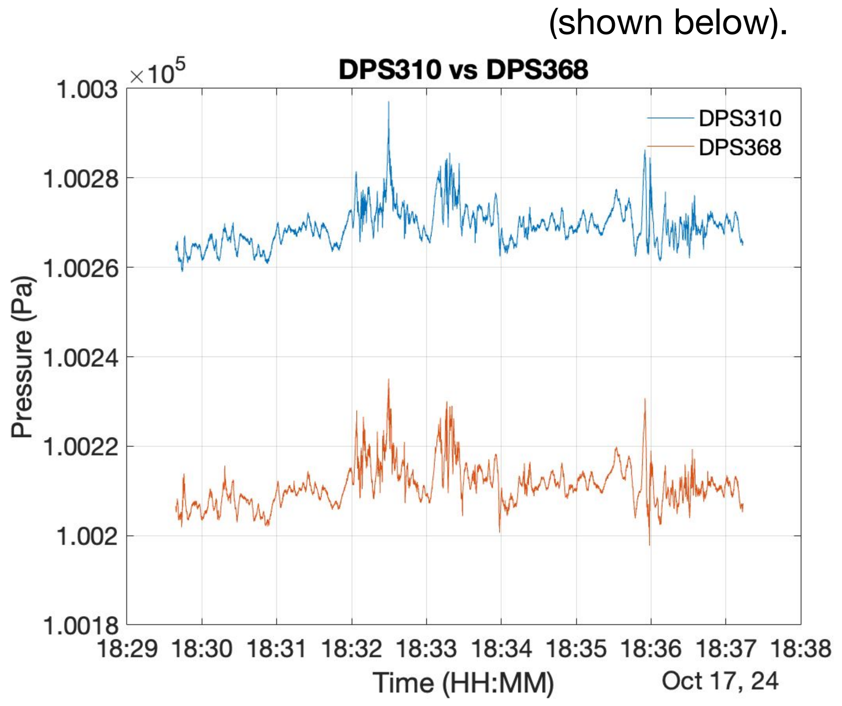
Recent progress with inexpensive pressure sensors: Infineon DPS310 and DPS368





Shown on the left are the Infineon DPS310 (top) and the DPS368 (bottom) which are both inexpensive ($7, $3), highly sensitive, and precise pressure sensors. The DPS368 is the waterproof version of DPS310. The purpose of this experiment was to compare the waterproof version to the original version to determine if the DPS368 is as precise and responsive as the DPS310. A previous test confirmed that the DPS310 measures real coherent pressure signals and, although not very accurate, is fast responding and precise (Mayor et al, 2023).

We planned to use the DPS368 in a porous media such as soil or snow to measure pressure fluctuations as a function of depth. We were unable to finish this project due to challenges associated with the experimental hardware. However, we were able to confirm precision of the DPS368 from one short segment of data collected on October 17, 2024 (shown below).



The figure above shows pressure data recorded simultaneously by the DPS310 and DPS368 over a 7 minute interval. Both sensors were sampled by the same data acquisition system at 23 Hz.

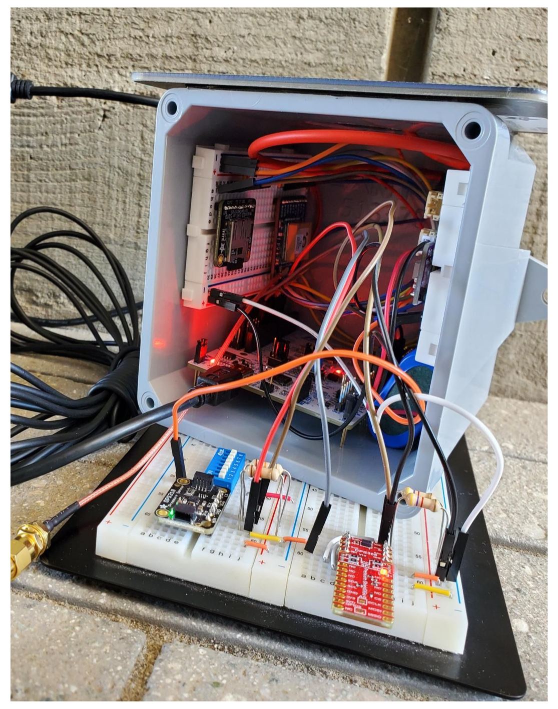
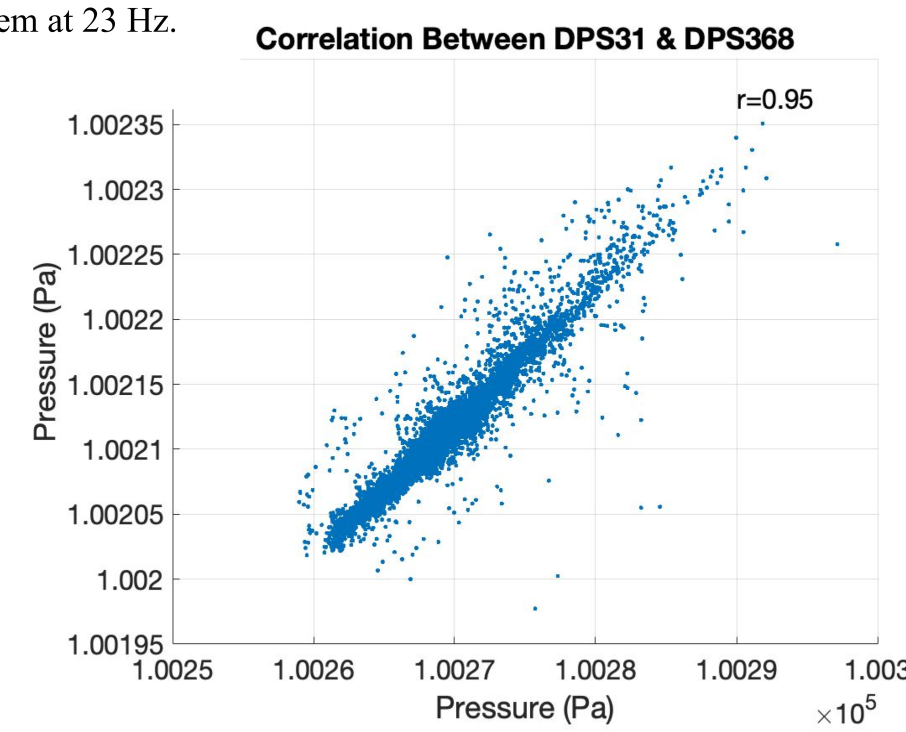


Photo above: the experimental hardware built by Dr. Meehan and Brandon Crowell.



Right: Scatterplot of the timeseries data shown above. This plot confirms the high degree of correlation between the DPS310 and the DPS368 with a correlation coefficient of 0.95.

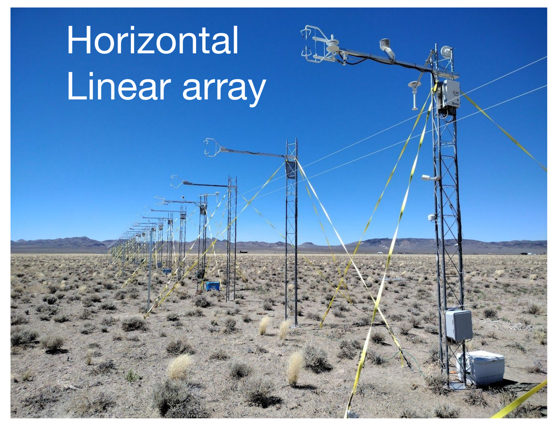
Turbulent pressure perturbations at M^2HATS

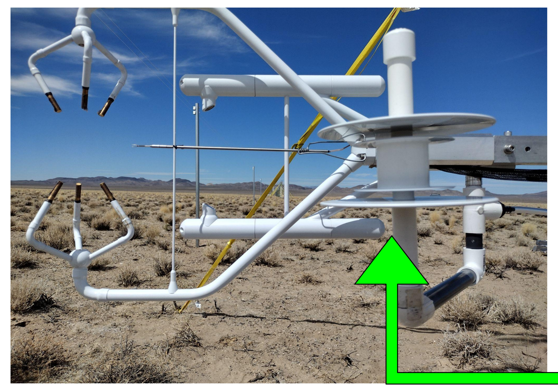
What is M^2HATS?

- Multipoint Monin-Obukhov Horizontal Array Turbulent Study
- A field experiment designed to test a recent extension of Monin-Obukhov Similarity Theory (MOST) (Monin, A. S., & Obukhov, A. M., 1954)
- Tonopah, Nevada July-September 2023
- The original 1954 MOST did not explain horizontal wind fluctuations
  - MOST proposed that there is a relationship between turbulent mixing in the surface layer of the atmosphere and wind and temperature gradients
  - Tong & Nguyen (2015) developed a new theory called the Multipoint Monin-Obukhov theory (MMO) to resolve the shortcomings in MOST.

Paroscientific Nano-Barometer

- ∓0.08 hPa Accuracy
- Range from 620 hPa to 1100 hPa
- Parts-per-billion Resolution
- Stability better than 0.1 hPa per year





Experimental Setup

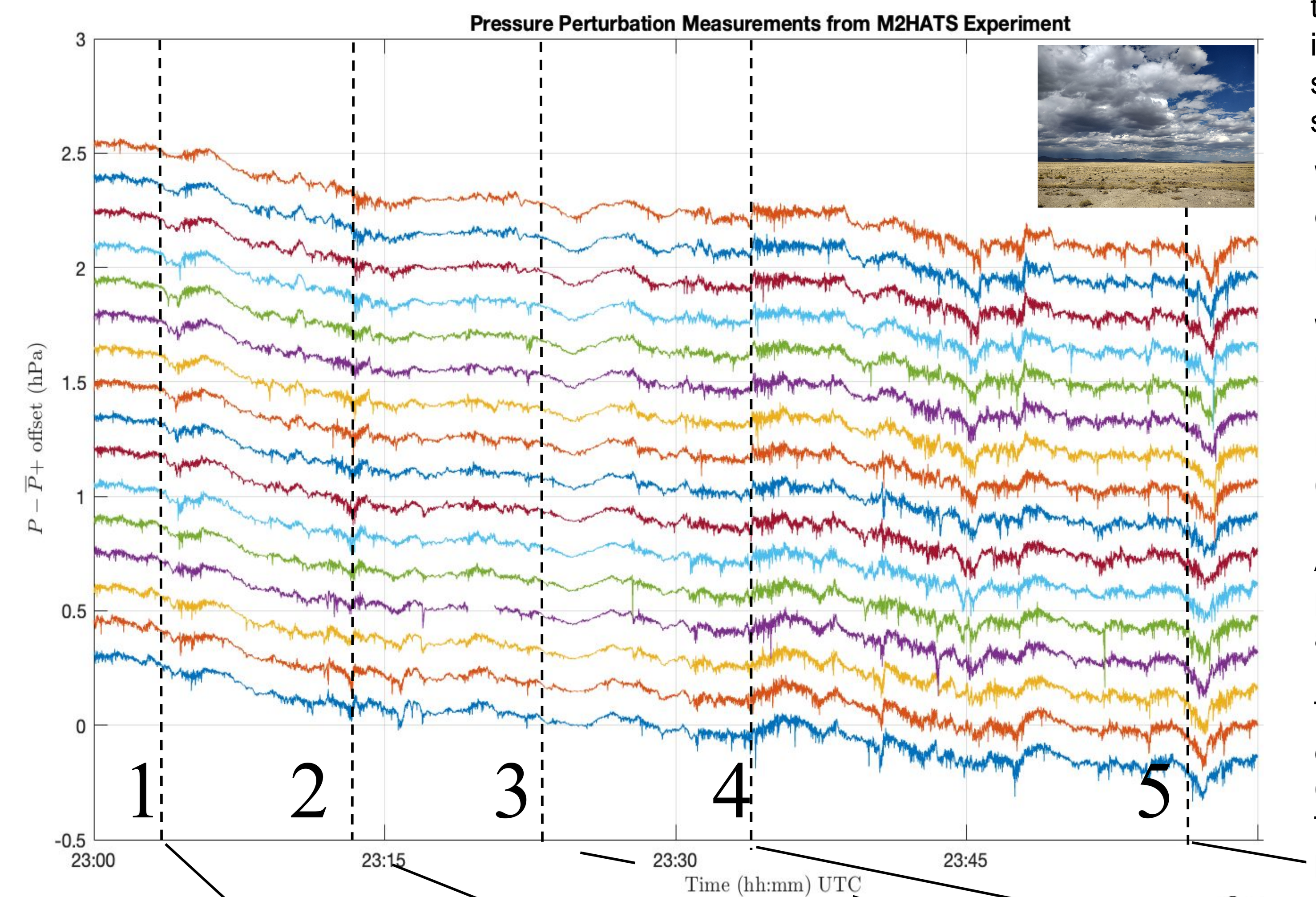
- 50 towers aligned in a horizontal array spanning 245 meters total, each spaced 5 meters apart
  - CSAT 3D sonic anemometer (4m)
  - Every third tower (4m)
    - Nano Barometers
    - Temperature, RH
    - IRGA EC150 H_2O/CO_2 gas analyser
- DTS Fiber temperature system
- Three Doppler lidars
- Chico State REAL
- Two vertically pointing radars
- a short flux tower
- a tall flux tower
- Two NCAR micropulse DIALs
- Radiosonde system

Static pressure ports:

- minimize the inevitable disturbance that a sensor has on air pressure when air is moving around the sensor.

The objective of our work is to determine the cause of significant coherent perturbations in the M^2HATS pressure traces. Here we focus on just one hour of data from 16 nano-barometers spaced 15 m apart

August 2, 2023: 23:00 - 00:00 UTC (4 PM - 5 PM Local PDT)



Turbulent Coherent Structures are 3D regions in a turbulent flow with characteristic structures and lifetimes in terms of velocity, temperature, etc., that are significantly larger or longer-lived than the smallest local scales.

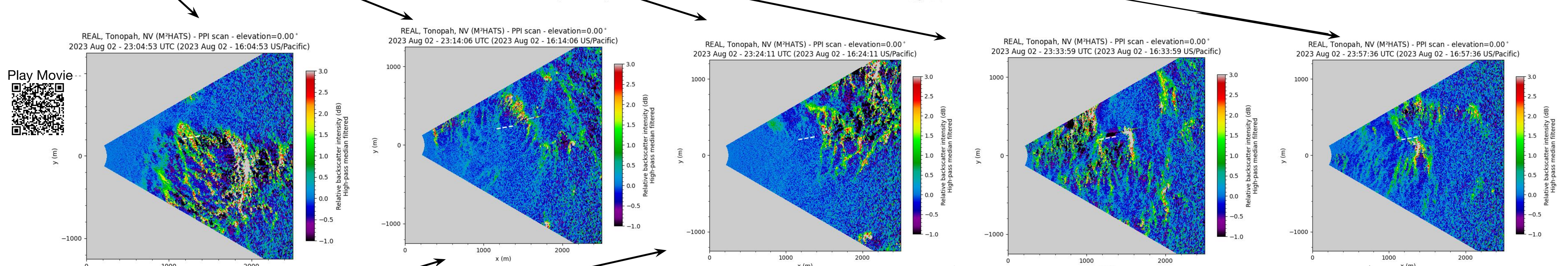
We identified 5 times during the hour where we observed significant changes in the patterns of pressure perturbations.

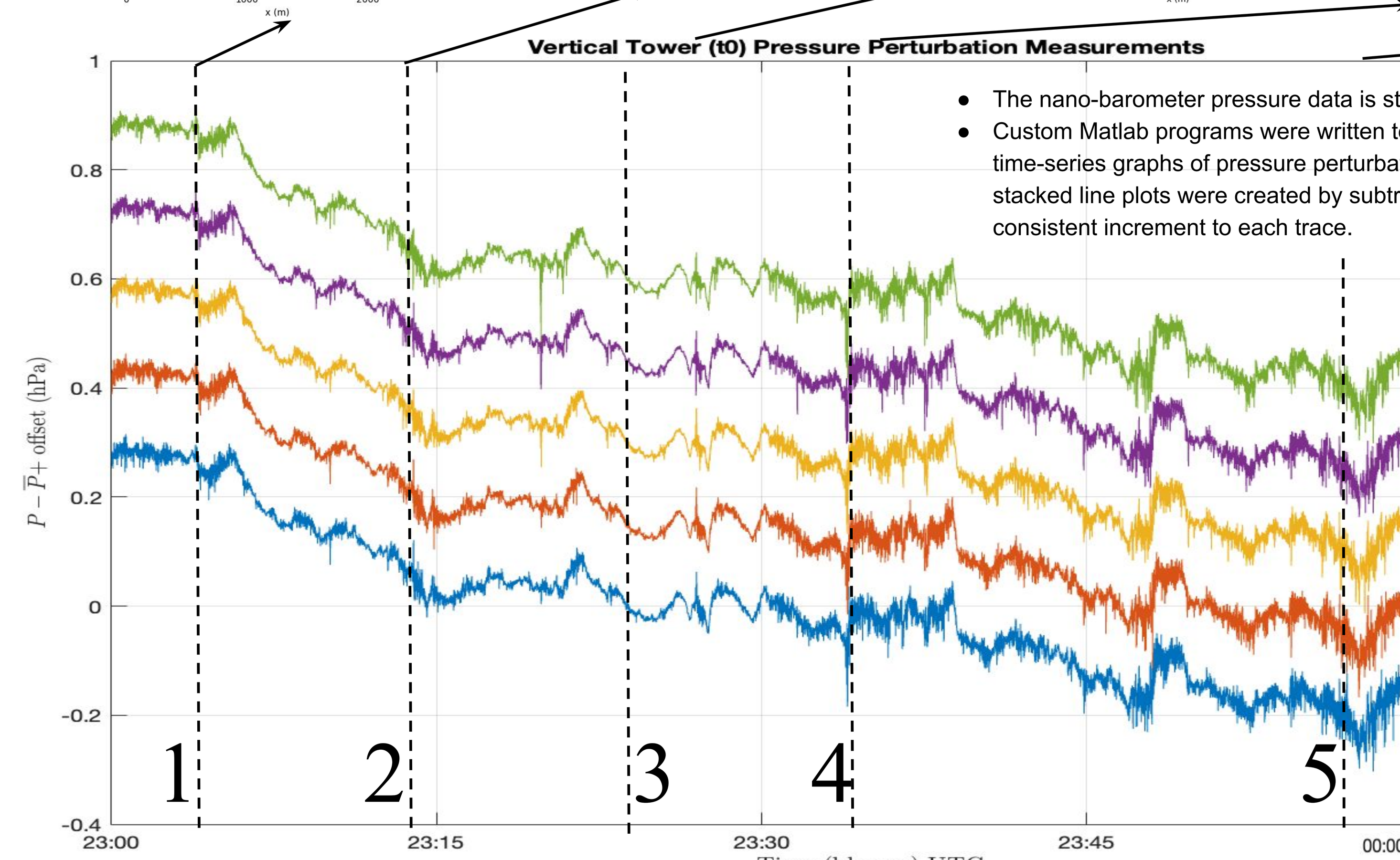
We then inspected horizontal scan images from the Raman-shifted Eye-safe Aerosol Lidar (REAL). The REAL provided scans once every 17 seconds. The REAL images indicate the relative amount of aerosol (particulate matter) scattering in the atmosphere.

A time-lapse animation of the REAL images show large plumes of particulate matter advecting from the south and passing over the location of the linear array.

The weather at the time of these observations was partly cloudy with southerly winds between 3 and 10 m/s. Cumulus clouds suggest a convective boundary layer. The surface was dry. Dust clouds in the lidar images below were subvisual.

Play Movie



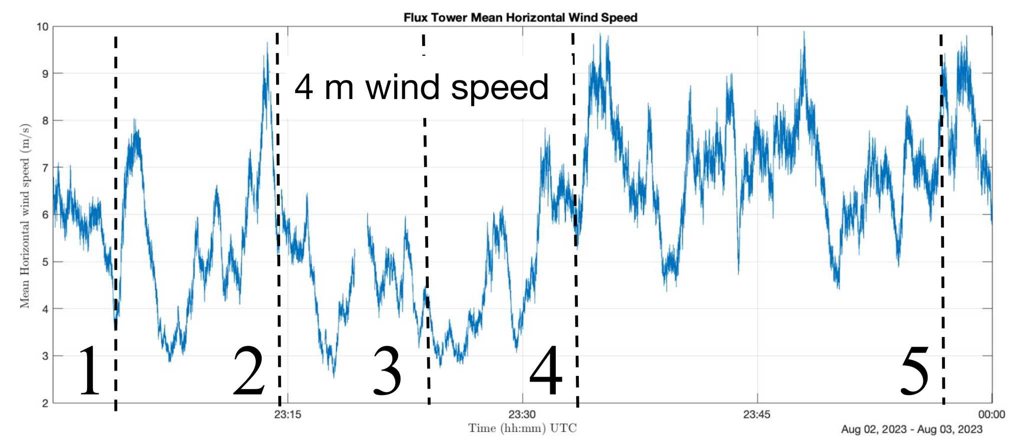


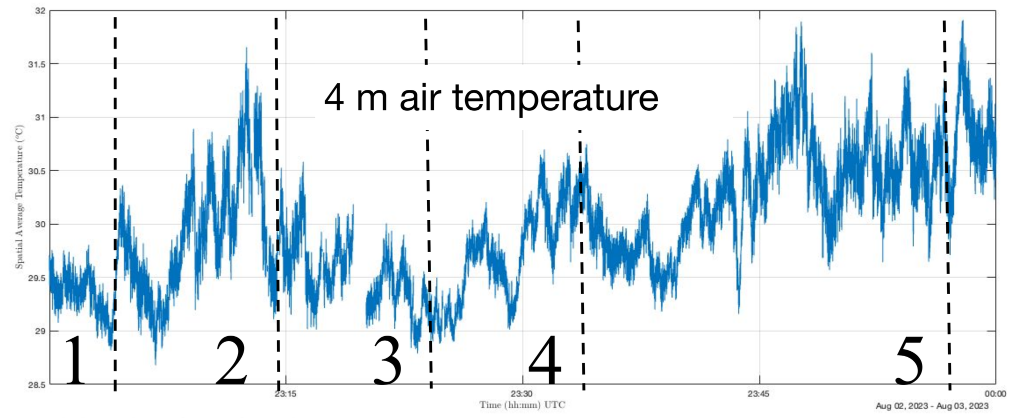
- The nano-barometer pressure data is stored in high rate netCDF files.
- Custom Matlab programs were written to read the NetCDF files and create time-series graphs of pressure perturbation data. Both horizontal and vertical array stacked line plots were created by subtracting the mean pressure and adding a consistent increment to each trace.

Vertical Array

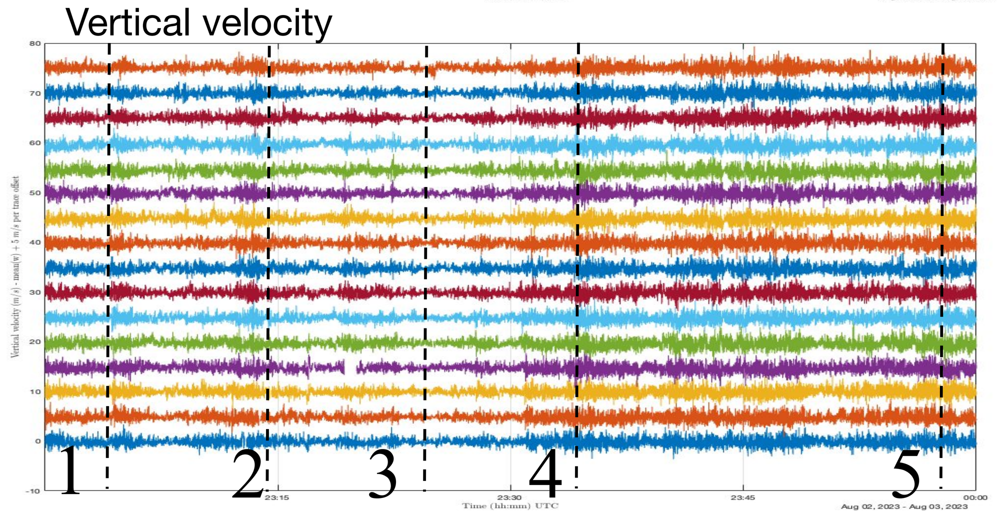
- 5 levels to measure the vertical pressure profiles (0.5m, 1m, 2m, 3m, 4m)
  - CSAT 3D sonic anemometer
  - IRGA EC150 H^2O/CO^2 gas analyser
  - Temperature, RH
  - Nano Barometer

We also inspected traces of other parameters including mean wind speed, temperature, and vertical velocity.





Vertical velocity



1. 23:04:53: P': onset of smooth dip followed by rough rise. REAL: the leading edge of a major dust burst has just passed over the linear array.

2. 23:14:06: P': a small dip in the midst of a rough patch. REAL: The end of a dust burst has just passed over the linear array.

3. 23:24:11: P': the beginning of a relatively "quiet" period. REAL: the dust has moved off to the north and the aerosol field becomes uniform.

4. 23:33:59: P': the beginning of a very rough patch with a step increase in some traces. REAL: onset of a major dust burst.

5. 23:57:36: P': onset of deep dip. REAL: a strong and isolated cloud of particulate matter passes over the instrumentation.

Conclusions: It appears a correlation does exist between the episodes of high-frequency variance of the pressure traces and the appearance of aerosol "bursts" in the REAL images. However, we did not see a repeating relationship in low-frequency rises and dips in the pressure traces. Additional analysis is required.

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