Validation of Mobile Mesonet Pressure Observations

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ABSTRACT

The aim of the project was to explain problems with the methods used to make station pressure measured by Mobile Mesonet useful and to evaluate the performance of the vehicle platform while the vehicle is in motion. Tests were performed at Five Miles Flat and Highway 9 to evaluate GPS elevation and pressure ports. All three pressure ports were tested in this study. Also, a sample data was collected by a thunderstorm passing over University of Oklahoma to compare the data from the storm to those produced during tests. Overall, both silver and white port had unusual and unexpected errors in data when the vehicle was in motion. Yet, there is no meaningful data on black port yet due to human error. In case of GPS sensor, errant and previously unreported behavior in altitude data warranted a further investigation in quality of GPS altitude data. Therefore, there is more testing on pressure ports and GPS sensor that is necessary to resolve the issues with the instruments in question.

1. Introduction

In thunderstorm microphysics, dynamics, and forecasting, high quality data from observations and measurements are essential for advancing knowledge in the field. Most data are collected from fixed weather stations and radiosondes; however, any individual thunderstorm has to pass over fixed sites for the most useful data. A solution to this issue during the VORTEX I (Verification of Rotation in Tornadoes Experiement) project in the early 1990's was mobile weather platforms, also known as Mobile Mesonets. These mobile weather stations collected data from thunderstorms as the fleet of vehicles followed the storms (Straka et al. 1996).

Both fixed and mobile weather stations typically measure standard parameters: temperature, dewpoint, winds, pressure, solar radiation, and rain. Most of these parameters can be analyzed and compared easily to the other stations. However, a parameter that has shown uncertainties that are yet to be explored is barometric pressure, which can be affected by errors in elevation and winds.

The first objective of this project is to review different methods used to make station pressure and the problems with converting it to sea level pressure. Station pressure refers to the actual barometric pressure measurements taken at any location. Sea level pressure is estimated pressure at a location as if its elevation is at sea level. There are several factors that can affect the pressure measurements, such as accuracy of the elevation of the station and dynamic wind effects.

A commonly accepted equation used to convert the station pressure to sea level pressure is the hypsometric equation:

$$h = z_2 - z_1 = \frac{R_d \overline{T_v}}{g} \ln(\frac{p_1}{p_2})$$

In the equation, z_1 and z_2 are two different heights (in m) at pressures p_1 and p_2 (in mb). The elevation of the weather station z_2 is referred to as height above sea level,

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and sea level is z_1, or 0 m. R_d is the gas constant for dry air (287 $\frac{J}{Kkg}$). $\overline{T_v}$ is the mean virtual temperature in K, and g is gravity (9.81 ms^{-2}). The equation derives an equivalent pressure as if a hole was drilled to sea level and a pressure measurement was taken at the bottom of the hole. Station pressure is represented as p_1, and sea level pressure is p_2, which can be solved for using this equation. In the equation, when the temperature or altitude increases, the pressure decreases (Wallace and Hobbs 2006).

One important factor for converting station pressure to sea level pressure is the elevation of the station itself. As the elevation increases, the barometric pressure decreases, and consequently errors in the station elevation can lead to errors in pressure conversion. There are several methods for determining the elevation of the station. One of them is a GPS survey of station location. A second option is a manual transit survey method for finding elevation. Topography maps can be useful, but if the station is distant from known surveyed points, the elevation accuracy decreases.

Another major influence on station pressure measurement is wind. A weather station constantly experiences wind effects from typical breezes to even occasional severe gusts ($\geq$ 24.5 m/s) from intense storms. Yet, the pressure ports were not designed with these strong winds in mind. Thus, their response in high winds is unknown. Even in a gentle breeze, the pressure sensor can still pick up pressure perturbations caused by wind flowing over the port or nearby objects.

For a fixed weather site, the two issues with pressure measurements of elevation and winds can be somewhat managed. However, mobile platforms have more difficulties. The elevation changes constantly as the vehicle is driven to different locations. In flat, central Plains states, the rate of change in pressure is about one millibar decrease for every ten meter increase in elevation. The mobile platform also experiences "storm-like" winds at highway speeds in addition to pressure changes from a storm itself.

The second objective of this project is to quantify wind effects on pressure measurements taken on a moving vehicle. Since the vehicle platform is a mobile weather station, the complications mentioned above become magnified. The effects from the wind are complex since they are composed of many factors. One of them is Bernoulli effects from actual winds and vehicle-relative winds at highway speeds. Also, the vehicle shape itself causes Bernoulli effects which can affect the pressure data if the port is mounted in a poor location.

GPS receiver evaluation was not in the original goal, however the issues that were discovered warranted investigation. GPS derived altitude is a problem for both fixed and mobile stations. For example, the plot (Fig 1) showed that the GPS elevation data did vary from 1 to 2.5 meter with time despite that the fact the vehicle was parked. There are alternative methods for finding elevation, including latitude-longitude databases and differential GPS which have not been tested in this study.

2. Equipment

Mobile Platform

The vehicle for this project is a 2014 Dodge Ram 1500 (Fig 2). The platform was constructed on top of the truck to serve two functions: support for instruments and hail protection. The platform provides a flat surface for the rack and areas for working on the rack. The screen laid out on this platform is designed to keep hailstones from causing damage to the windshield.

On the platform is the Mobile Mesonet instrument rack (Fig 3), which is used to measure temperature, relative humidity, winds, pressure, and solar radiation. The pressure sensor is a Vaisala PTB 210, designed for 500 to 1100 hPa within temperature range from $-30 \circ$ C to $45 \circ$ C. The pressure error of the sensor is $\leq \pm$ 0.1 mb. The data collection system is made of several pieces of equipment. Two components in particular are a GPS receiver Garmin 17 HUS and a data logger. The model of the data logger is a Campbell Scientific CR6-WIFI. The wind speed is measured with a R.M.Young wind monitor 05013. All of the data are recorded onto a Panasonic CF43 laptop.

Pressure Ports

While all pressure ports (Fig 4) share similar characteristics, they differ in small details in their designs. Their designs are considered on several factors: accuracy of pressure measurements in high winds, omnidirectional in azmuth, insensitivity to a moderate range of off-vertical tilt, and robustness in severe weather conditions.

The black port, also known as a Gill pressure port, is an ASOS model S100-1A6-MP2 static pressure vent and is constructed from black anodized aluminum. It is designed and tested for NOAA Data Buoys. (Burdette 1979).

The silver pressure port is actually an NSSL modified version of the NOAA Data Buoy design. This design has been used in various field projects such as VORTEX II (Wurman et al. 2012).

The white port is a R.M. Young model G1002, and is made of plastic. One disadvantage of the design is that it is not resistant to hail. While this port has shown usefulness in collecting data, it is not ideal for collecting data in or around powerful thunderstorms, particularly supercells.

Methods

In order to conduct an experiment to test effectiveness of the pressure ports and to investigate any negative influences that result in bias in data sets, the experiment should be conducted in a specific set of conditions.

Location

Two locations for tests are the Five Miles Flat and Highway 9. The Five Miles Flat refers to a relatively flat area of 60th Ave NW in western Norman, OK. The intersection of W. Robinson St. and 60th Ave NW is designated as the southernmost end of the flat, and the northernmost end is at the intersection of W. Indian Hills Rd. and 60th Ave NW (Fig 5a). A secondary location chosen is Highway 9 (Fig 5b) to Big Sky Ranch (10264 E Imhoff Rd) because the road has some hilly terrain to test how GPS altitude performs.

Single Receiver GPS

The single receiver GPS needed to be evaluated for quality of raw elevation data in order to investigate whether it is worthwhile to collect the data for conversion to sea level pressure. During any data collection, the pressure curve should be smooth when plotted without jumps or errant drops. Also, there is another option that was not attempted in the study: GPS elevation database for every latitude and longitude. These tables are useful and typically more accurate but are also cumbersome and time consuming, making their use for real time data limited.

Weather Conditions

The tests on Five Miles Flat and Highway 9 should be conducted on days with no significant weather activity, such as thunderstorms or rain. The aim is to create more controllable air flow around the vehicle by driving in low wind conditions.

Thunderstorm Samples

The exception in this experiment was to collect thunderstorm data from Lloyd Noble Center for comparison with the low wind data. Collecting a thunderstorm sample is encouraged for comparison. The data collected from the truck have more advantage because the data is generated every second, creating a more complete picture of pressure in a thunderstorm. The Oklahoma Mesonet can be useful for analysis of data collected from thunderstorms that passed over the sites, but the disadvantage is that each station collect data every minute at best, which could leave out important pressure data from thunderstorms. Also, thunderstorms have to pass over the sites for any useful data. There are more ASOS and other surface observing networks that can collect and provide thunderstorm data, but they have similar problems to the Oklahoma Mesonet.

Data Analysis

The program strongly recommended for data analysis is Microsoft Excel, since plots from data can be created quickly. Also, it is relatively easy to upload the data from sensors to Excel to create spreadsheets. The data files are CSV files, which are readable by most programs, including Excel. Any data analysis or spreadsheet program will work when straightforward plots of variables are necessary. Thus, Excel is chosen to read in and work with the data to produce the plots needed for analysis.

3. Tests

Five Miles Flat

Due to the constant elevation of the area, all three ports are tested in this area in order to see how varying wind speed affects pressure data . Each port is tested on separate runs to see how different designs respond to wind effects. Rainwater effects are tested only on the silver port to see how precipitation affects the quality of the pressure data. There also were a few runs done with tubing inside the cabin of the truck for testing air pressure inside the cabin while driving with the window slightly open. The aim for this run is to investigate how the pressure inside the cabin of the truck responds when the truck is in motion.

Highway 9 and Big Sky Ranch

Tests are done on Highway 9 to evaluate the performance of GPS pressure data with constant driving speed. The road has elevation changes of up to approximately 40 m from hill to valley. For this test, the vehicle speed is held constant at about 26.8 m/s. The aim for this test is to observe and document variability in pressure and elevation while the vehicle speed is held constant. The only port in use for this test is the silver one.

Thunderstorm Sample

On June 12, a sample data set was collected from a non-severe thunderstorm as the truck was parked near the Lloyd Noble Center, which is across the street from the National Weather Center on the University of Oklahoma campus in Norman, OK. The reason for collecting the sample data is to compare pressure data from the naturally occurring thunderstorm to data collected from the Five Miles Flat and Highway 9. The data from the silver port is examined to see if the silver port has a similar response to the thunderstorm wind as to the test runs.

4. Results

Elevation Using GPS

Overall, the GPS exhibited poor performance in deriving elevation, especially when the truck was parked. In that case, elevation should have been constant at around 345 m at the south end and 352 m at north end, but it was not (Fig 1). On the Five Miles Flat, the line for elevation should be smooth when the vehicle is parked or in motion. In reality, the elevation data was jumpy. The error is +/- 2 m from mean when the vehicle was stationary. However, the GPS showed the best performance on Highway 9 when it followed trends in elevation changes, even though slight errors of less than +/- 1 m (Fig 6) until at the vehicle was parked at the NWC at approximately 15:07.

Pressure Data

The silver port, as shown repeatedly, exhibited poor performance when it was experiencing high winds from driving. When the vehicle is in motion, the pressure increases suddenly and decreases when the vehicle decelerates (Fig 7). When driving north, the pressure increased by 0.5 mb before decreasing by 1.25 mb from the peak when it should have only decreased by 0.75 mb. From north to south, the pressure should increase only by 0.5 mb, but it actually increased by 1.25 mb before decreasing by 0.75 mb. this could be problematic when one tries to document pressure observation of a thunderstorm while the vehicle is in motion.

The white port experienced frequent pressure noise associated with wind and general drops in pressure when the vehicle was in motion (Fig 8). Ideally, the pressure should decrease about 0.5 mb from north to south ends, but it rapidly decreased at about 1 mb before increasing at 0.5 mb. When driving to south end, pressure actually decreasedby 1 mb before rapidly increasing at 1.5 mb when it should have only increased by 0.5 mb. The plot showed that the pressure decreases when the vehicle was in motion. This is significant because the white port has a somewhat different design, and the main issue is how the Bernoulli effects act on similar designs.

No useful data is available from the black port because the nut that is used to connect the port to tube was not hollow as was believed. This effectively sealed off the pressure port from the pressure sensor and resulted in erroneous pressure readings. It was not discovered until later that a mistake was made. Even though the mistake was corrected, there is still no meaningful data available yet on that port.

Interestingly, during a non-severe thunderstorm, the pressure data exhibited only minimal error of +/- 0.1 mb, but the RMY speed was at most approximately half of those from Five Miles Flat. When driving, the error did increase slightly to +/- 0.2 mb (Fig 9).

Conclusion

The results showed that the pressure ports do not respond as well as previously thought. The silver and white ports have different responses, which indicate possible design issues. In this case, the pressure increased with silver port, but decreased with white port. There are several possible factors that could affect the pressure measurements, such as winds from driving and location of the port, but they are not investigated in depth here. This can be an issue since the silver port is used extensively in field projects, and the majority of pressure data collected are from that port.

There is no clear hypothesis on why the GPS altitude show errant trends as shown in Fig 1. The problem with GPS altitude is currently still under investigation.

Future Work

This manuscript documents errors in pressure observations that have not been previously reported, and a further investigation into the cause of the errors in the pressure data is necessary. There are several modifications to port designs that have not been tested yet. Additionally, there is a completely new design for the pressure port that has yet not been tested. The ports also may have to be redesigned. In regard to locations of the ports, there have been no tests done on them. The port locations need to be investigated to see if the air flow around the vehicle is affecting pressure measurements and producing errors in data. Finally, the issues with GPS elevation data have to be investigated and resolved to produce more useful data. In that case, the GPS sensor has to improve for accuracy in elevation, and other methods of finding accurate elevation need to be tested.

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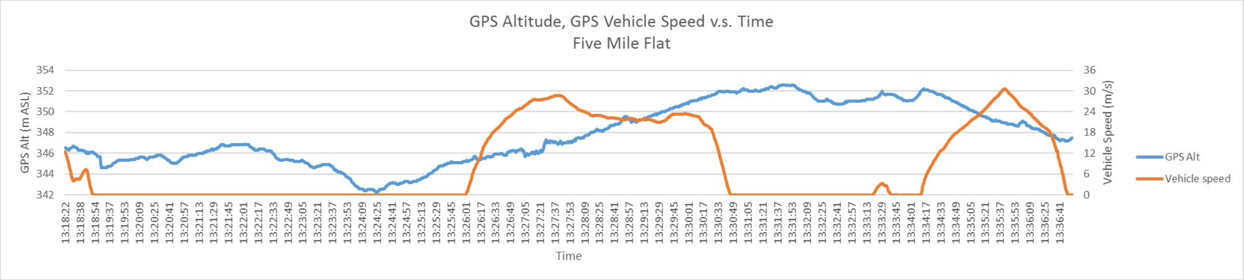

FIG. 1. GPS Altitude and vehicle speed vs time over Five Miles Flat (Note: 13:22 to 13:26- parked at south end, 13:16 to 13:30- driving north, 13:30 to 13:34- parked at north end, 13:34 to 13:36- driving south)

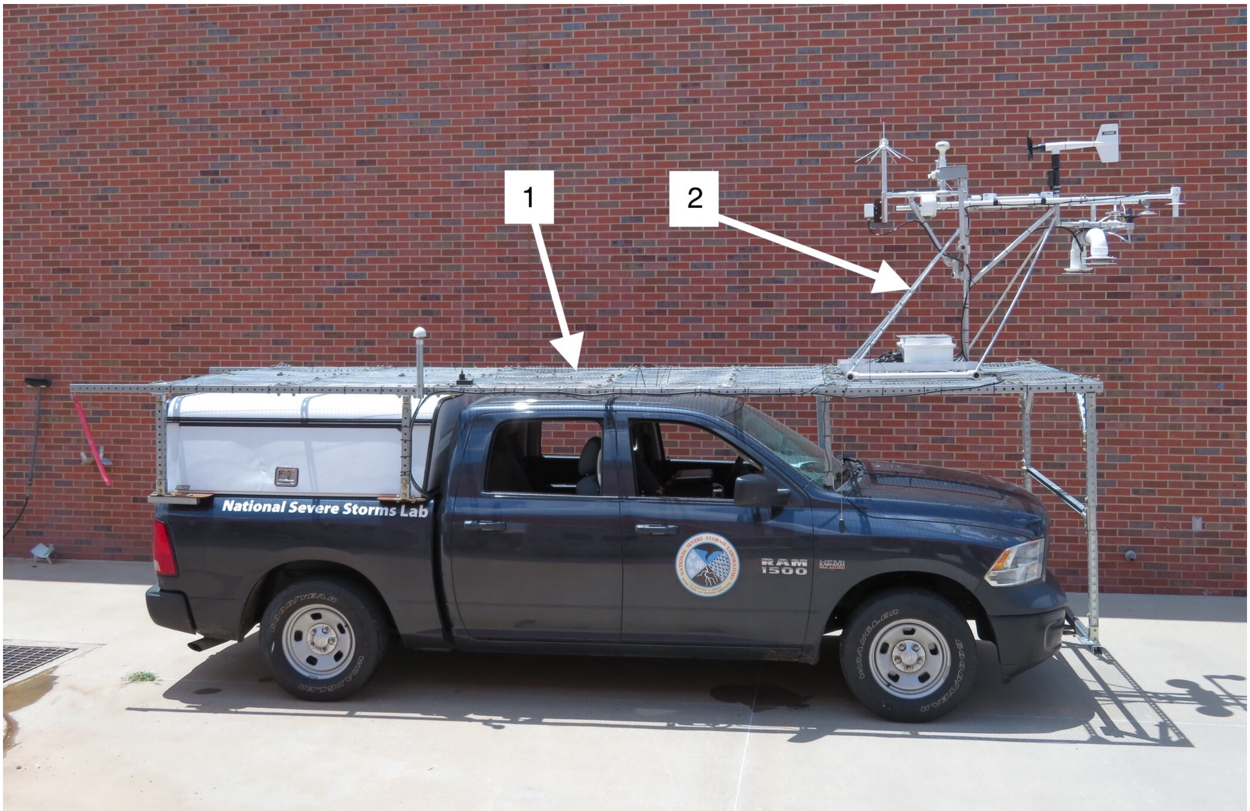

FIG. 2. Side view of Dodge Ram 1. Screen 2. Instrument rack

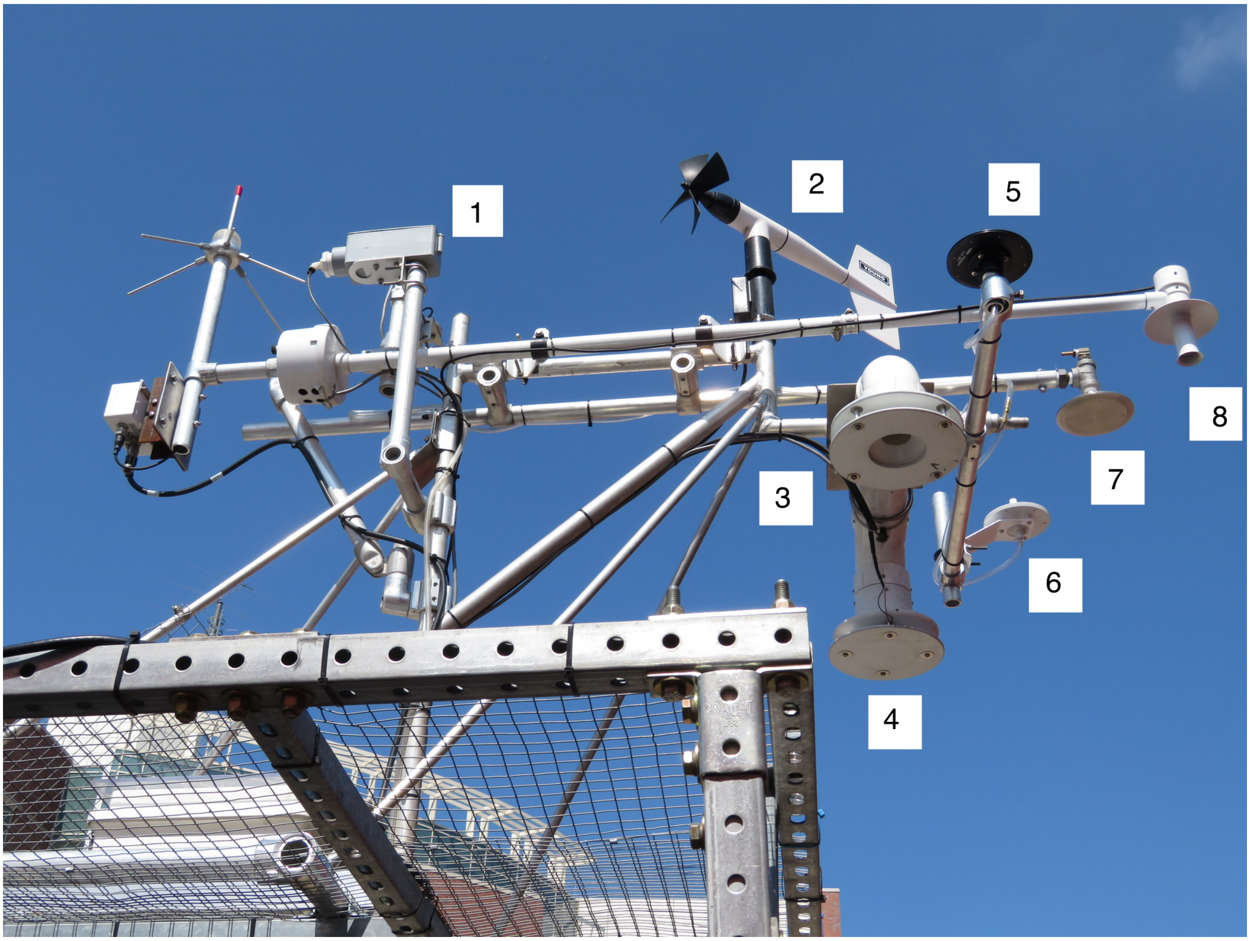

FIG. 3. Instruments on rack 1. GPS 2. R.M. Young wind monitor 3. U-tube aspirator temperature intake 4. U-tube aspirator temperature exhaust 5. Black port 6. White port 7. Silver port 8. R.M. Young temperature aspirator intake

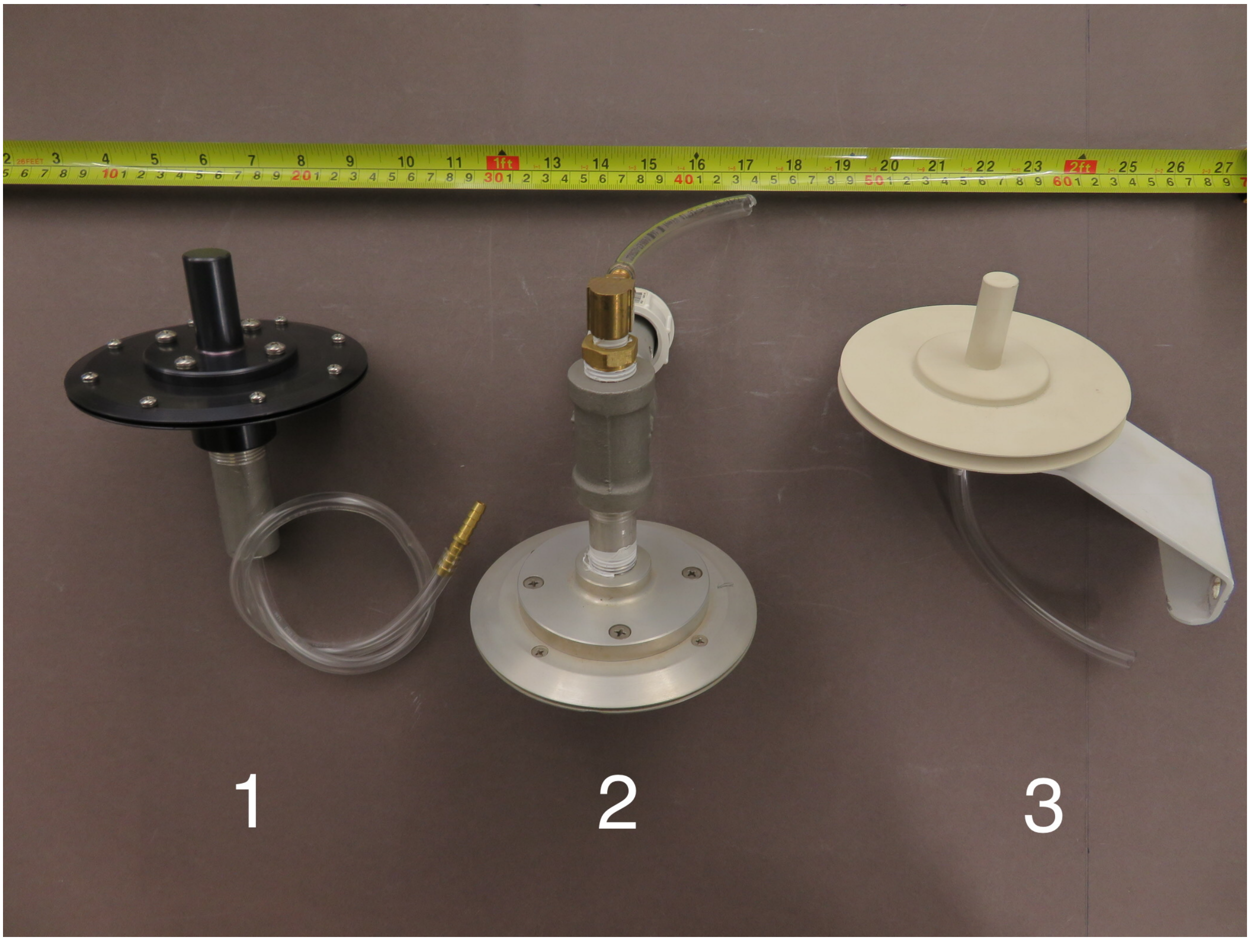

FIG. 4. Pressure ports: 1. Black Port 2. Silver port 3. White port

FIG. 5. Maps of portions of Five Miles Flat (A) and Highway 9 (B)

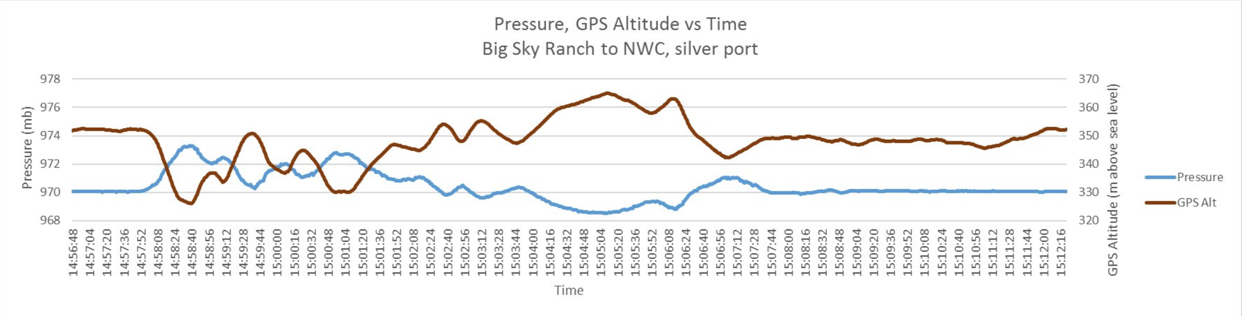

Fig. 6. Plot of pressure and GPS altitude versus time over Highway 9 from Big Sky Ranch to National Weather Center (Note: 14:56 to 14:58- parked at Big Sky Ranch, 14:58 to 15:07- driving on Hwy 9, 15:07 to 15:12- parked at National Weather Center)

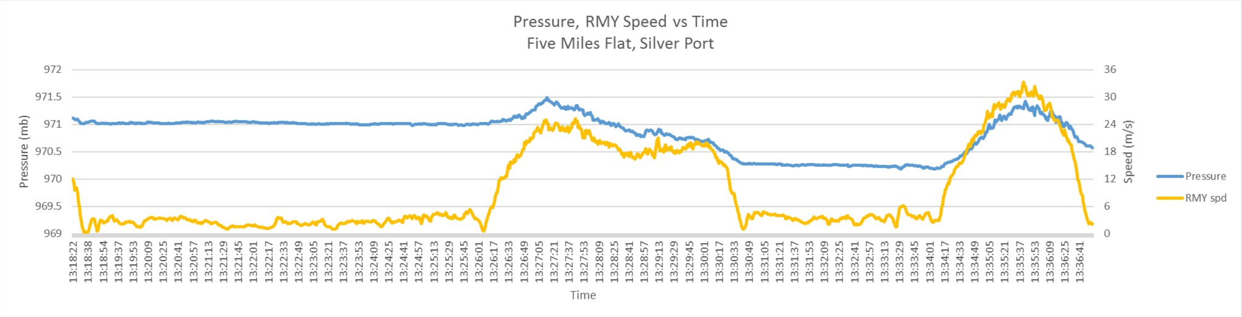

Fig. 7. Plot of pressure, RMY speed versus time, silver port (Note: 13:22 to 13:26- parked at south end, 13:16 to 13:30- driving north, 13:30 to 13:34- parked at north end, 13:34 to 13:36- driving south)

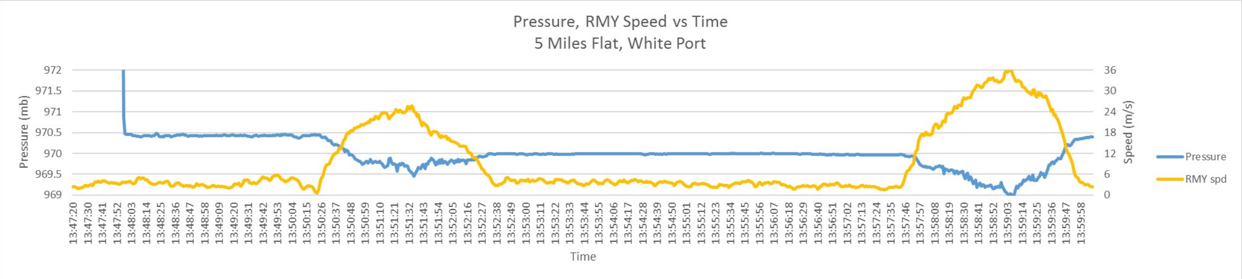

Fig. 8. Plot of pressure, RMY and vehicle speed versus time, white port (Note: 13:47- switched from black port to white port, 13:48 to 13:50- parked at south end, 13:50 to 13:52- driving north, 13:52 to 13:57- parked at north end, 13:57 to 14:00- driving south)

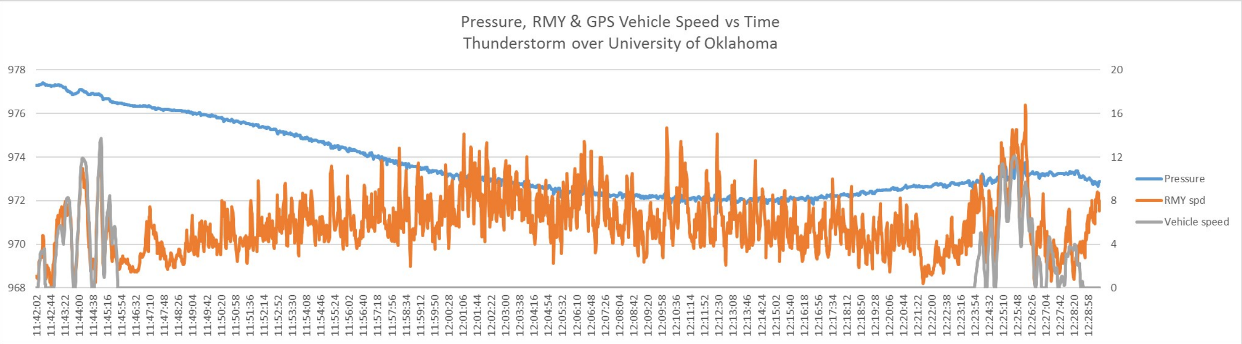

Fig. 9. Plot of pressure, RMY and vehicle speed versus time in thunderstorm passing over University of Oklahoma (Note: 11:42 to 11:45- driving to Llyod Noble Center, 12:23 to 12:29- driving to National Weather Center, all other times- parked at Lloyd Noble Center lot)