The Impact of High Wind Events on the Central Business District of Oklahoma City

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August 1, 2003

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ABSTRACT

It is critical to understand airflow through cities due to the possibilities of biological and chemical terrorist attacks, pollution, and accidental chemical spills. Currently very few studies have used field measurements of wind conditions within a city to study urban air flow. This paper investigates the airflow at specific locations within Oklahoma City during two synoptic high wind events using data collected at fifteen different sites within the central business district. Wind speed and direction were averaged for each site before and after the frontal passages. The wind shifts and changes in the magnitude of the wind vectors were analyzed at specific locations and time periods to understand air flow based on street orientation and building structures within the city.

1. Introduction

In 2000, approximately 77% of the population of the United States lived in urban areas (Trumbull et al., 2002, p. 675). This is up from 75% in 1990 and 74% in 1980 (Trumbull et al. , 2002, p. 817). As population steadily increases in urban areas, it is becoming increasingly important for a thorough understanding of wind flow within cities due to the possibilities of biological and chemical terrorist attacks, pollution and accidental chemical spills. Still, while years of research have been poured into airflow prediction, atmospheric transport through cities still remains a mystery (Biological…Questions, 2003). The U.S government has been attempting to create, improve, and validate models that simulate air flow through a city to aid emergency responders as well as to prepare for the possibility of a terrorist attack or chemical spill within an urban environment (Biological…Purpose, 2003). However, very few studies have been conducted that involve a high density of field measurements of wind within an urban area. Thus, the purpose of this study is to gain a better understanding of how airflow inside of a city is impacted during high wind events using wind data collected in Oklahoma City.

During July 2003, the largest urban dispersion field experiment in history took place in Oklahoma City, OK. This experiment, named Joint Urban 2003 (JU2003), was initiated to learn more about how chemicals and other particles move through a city, both inside and outside of the buildings (Biological…Purpose, 2003). The data obtained through the experiment will help refine computer models that simulate how particles move through and around a city. (Biological…Purpose, 2003). To assist with the Joint Urban experiment, approximately 200 portable wind stations were placed within a one-mile radius of the main central business district of Oklahoma City (Biological…Purpose, 2003). These sensors were placed on buildings, on light poles, and within secure areas (Biological…Purpose, 2003).

Though most of the sensors used in the experiment were installed during the week leading up to the experiment, a subset of weather stations were put in position up to a year before JU2003 was conducted. These stations measured the wind flows through the city in many different weather conditions. This study uses the data obtained from these PWID (Portable Weather Information Display) stations during a subset of high wind events observed between Jan-May 10, 2003.

Data obtained during two high winds event were analyzed and comparisons were made between the “true” wind vector magnitudes and direction (the wind vector magnitudes and direction outside the city or high atop buildings within the city) to the wind vector magnitudes and directions reported by the street level sensors within the urban canyons of Oklahoma City. Average wind vector magnitudes and directions were computed before and after two cold fronts propagated through the city. In addition, the impact of the sites by the high winds is discussed.

2. Data

A portion of the data used in this research was obtained by wind instrumentation installed at Oklahoma Mesonet weather stations (Brock et al. 1995) and National Weather Service Automated Surface observing Stations (ASOS). The Oklahoma Mesonet uses the R.M. Young model 5103, which is a propeller and wind vane combination sensor (Brock et al. 1995, p.10). These sensors are located at the standard World Meteorological Society (WMO) height of 10 m and are accurate to within 2% of the wind speed value and 3 degrees of the wind direction (Brock et al. 1995, p.10). The ASOS stations use modernized and automated versions of the "F240" series of instruments, which have become standards for measuring wind speed and direction within the U.S. (NOAA Guide, p. 14). These instruments include a "cup-driven Direct Current (DC) generator with an output calibrated in knots and a vane coupled to an indicator by means of a DC synchro-system" (NOAA, 1998, p. 14). They are usually located at 33 feet or 27 feet above the ground, "depending on local site-specific restrictions or requirements" (NOAA, 1998, p. 14). These instruments are accurate to plus or minus 2 kts or 5% (whichever is greater) and plus or minus 5 degrees when the wind speed is greater or equal to 5 kts (NOAA, 1998, p. 14). The data available was the ASOS hourly reports, (with occasional special reports) and Oklahoma Mesonet reports, which contained five-minute wind data. In addition, the average daily wind speeds and peak wind gusts reported for a given day (found in the Daily Climatological Summaries of both ASOS and Mesonet data) were used.

It should be noted that there are discrepancies on how the peak wind is reported in the daily summaries for both. At Mesonet stations the maximum wind speed values are calculated the averaging the wind over three seconds (Oklahoma, 2003). Conversely, ASOS reports the highest 5-second average wind value (NOAA, 1998, p. 15). This discrepancy was considered insignificant with regard to this study.

Wind data inside the city was obtained from fifteen Portable Weather Information Display (PWID) stations scattered throughout the city. Figure 2 displays the locations of each of these sites. However, PWID 15 did have erroneous wind directions in the cases I looked at and PWID 04 contained missing data from the March 4, 2003 case that was analyzed. These stations consisted of a prop and vane anemometer, a temperature sensor, and humidity sensor. Only the data from the vane and anemometer was used in this research. The prop and vane anemometer was of the same make and model used by the Oklahoma Mesonet – the R.M Young 5103. Most of the wind sensors were mounted on street poles 28 feet above the surface. The two exceptions are PWID's 09 and 10, which were mounted atop the main branch of the Oklahoma City Post Office. Data was logged every ten seconds between January 1 through May 31, 2003 from each station. The data for the specific dates chosen (Feb 15 and March 4) was averaged to calculate the five-minute average wind vector magnitudes and direction. To accomplish this task, the data were averaged by converting each 10-second wind measurement to a vector. This vector was then divided into its u and v components. The u components of each vector in a five-minute span was then averaged. Similarly, the v components were also averaged. The average u and v component provided an average vector, with a specific direction and magnitude. This direction is the average wind direction for a given five minutes and the magnitude is referred to as the wind vector speed. While the wind vector speed is not equivalent to the average wind speed, it is very similar. The Mesonet also reports five-minute average wind vector magnitudes and directions.

3. Method

Since the purpose of the experiment was to analyze wind data within Oklahoma City during high wind events, the first part of the research consisted of determining days consisting of high winds within the downtown Oklahoma City area. The specific period investigated was Jan 1 – May 10, 2003. To determine high wind dates, Mesonet and ASOS data from sites surrounding the city was viewed. All Mesonet sites within approximately 40 miles of downtown Oklahoma City and the two closest ASOS sites were used in the determination of a high wind event (Fig. 1). For the Mesonet sites, the daily climatological summary for each site was examined. Similarly, for the ASOS sites, the unedited local climatological data for each month was analyzed. The peak gust and average winds speeds on these summaries for each specific day was examined. The days in which there was 35 mph (15.65 ms^{-1}) or higher wind gust reported or a daily average wind speed greater than or equal to 15 mph (6.7 ms^{-1}) was noted. At least sixty cases were identified where one site met the required high wind criteria. Next, a list compiled by Mr. Peter Hall that contained some of the "significant weather events" that occurred in and around Oklahoma City during the past year was scrutinized. This list included many, if not all the stronger synoptic and convective events that occurred within the downtown area between Jan 1 and May 10, 2003.

Just because one site within the vicinity of the city reported high winds did not guarantee that there was high wind within the city on that given day. By comparing the dates of the list of significant weather events to the compiled high winds days, a criteria was created that would both insure the inclusiveness of the significant weather days with a strong probability of high wind event within the city. A new list was compiled of only the dates in which at least forty percent of the examined sites reported a daily average wind of at least 15 mph and/or a gust of at least 35 mph on given day. In addition, a significant synoptic event must have occurred in the vicinity (approximately 40 mi) of the city.

Each of these events was examined to determine the best synoptic cases. This was accomplished by plotting such variables as temperature, dewpoint, wind speed, wind direction, barometric pressure, and precipitation. For the synoptic cases, the strength of the winds and wind direction change was closely examined. Days with the greatest consistently of high wind speeds throughout the day and had the most abrupt direction change were used. The two events that best met these criteria were cold fronts that passed through the area on February 15, 2003 and March 4, 2003.

Once these events were identified, the PWIDs data for these particular dates were investigated. For each case, cold front propagation was identified by inspecting the wind direction data from the PWID 10 site. PWID 10 is located high atop the Post Office Building with little obstruction to the wind. A comparison was made with the Norman Mesonet Site, and it was discovered that the wind directions at both locations were similar, although the wind speeds of PWID 10 were consistently greater due to its elevation above the surface. Because the wind directions were similar, PWID 10 was used to determine when the fronts passed through the downtown area. Once the wind direction change was noted, the two hour time period between approximately two and one half hours before the front passage and approximately a half hour before the front passage was analyzed. In addition, the two hour time period approximately a half hour after the front passage to approximately two and one half hours after the front passage was analyzed. PWID 10 was used to determine the front passage time within the city and the Norman Mesonet site was used to determine the front passage at Norman. Finally, the time period during the wind shift (approximately 7 minutes before to approximately 7 minutes after) was analyzed. Average wind vectors for both before and after the front were compiled for each station. In addition, average wind direction change and wind vector magnitude changes were compiled. Finally, the data was graphed and analyzed to determine specific impacts on the city as a whole and also at individual sites. Some of these impacts are discussed in the discussion section.

4. Results

a. PWIDS 09 and 10

PWIDs 09 and 10 are located on top of the Post Office building and are not located within the central business district. PWID 10 is located on top of a tower on the building while PWID 09 is located just above roof level. A comparison was made between PWID 10 and the Norman Mesonet Site and it was found that there were little discrepancies between the two regarding wind direction. Thus, PWID 10 was used as the "standard" wind direction impacting the city at any given time.

b.) Cases

1.) FEBRUARY 15, 2003

The February 15 case was characterized by a strong cold front that approached from the northwest. The significant feature of this front was the rapid temperature drop accompanied with it. At the Norman Mesonet site, strong winds were generally from the south to south-southwest ahead of the front and out of the north and northwest behind the front. Also at Norman, winds were generally 3-4 $m\text{-}s^{-1}$ ahead of the front and 4-6 $m\text{-}s^{-1}$ behind the front with higher gusts.

Overall, huge variations occurred in the wind vector magnitudes and directions before, during, and after the front. Before the front passage, PWID 10 indicated southerly winds. However, only PWIDs 05, 06, 07 were within 20 degrees of the PWID 10 value. Average direction values ranged from 132 degrees (PWID 03) to 274 degrees (PWID 08). Average wind vector speeds were very different as well and ranged from 0.5 $m\text{-}s^{-1}$(PWID 05) to 3.5 ms^{-1} (PWID 13). After the front passage, even more differences occurred. Only the PWID 05 wind direction was within 20 degrees of PWID 10's average direction. The directions ranged from 8 degrees (PWID 13) to 352 degrees (PWID 05). This wide range is partly due the fact that no directional degree value is allowed past 360 degrees. Only a few of the sites experienced large average wind vector speed changes after the frontal passage. These sites were PWID 01 (-1.5 deg), 13 (-3.1 deg), and 15 (1.8 degr). Furthermore, PWID 10 averaged a wind shift of 154 degrees, while most sites experienced a wind shift of at least 100 degrees. Sites that did not were PWIDs 02 (61 degrees), 11 (40 deg), and 12 (79 deg). These results for the February 15 case are summarized in Figure 3.

2.) MARCH 4, 2003

The cold front that passed through the city on Mar 4 was characterized by strong south to south-southwest winds ahead of the boundary and even stronger northwest winds behind it. Average wind speeds at the Norman Mesonet Site were 5-7 ms^{-1} ahead of the front and 6-8 ms^{-1} behind the front with higher gusts. In addition, very little precipitation was associated with this front.

Before the front passage, PWID 10 recorded an average wind direction of 209 degrees. Again, very few sites were near this average value. The sites that were within 20 degrees of PWID 10 were 02, 05, 06, and 07. With the exception of PWID 02, all these sites were within 20 degrees of PWID 10 in the February 15 case (before the front) while the ranges were a little less pronounced than the February 15 case. The wind directions ranged from 159 degrees (PWID 13) to 271 degrees (PWID 08). In addition, average wind vector magnitudes were very different. PWID 05 recorded an average of just 0.5 ms^{-1}, while PWID 13 recorded an average of 5.3 ms^{-1}. After the frontal passage, PWID 10 reported an average wind direction of 336 deg. Most of the sites reported average directions from W to N. Those that were within 20 degrees of PWID 10 were 05 (349 deg), 07 (320 deg), 08 (325 deg), and 09 (331 deg). The ranges for the average wind vector magnitudes were again very widespread. PWID 13 only averaged 0.7 ms^{-1} while PWID 02 averaged 4.4 ms^{-1}.

The average wind shifts observed were very peculiar. PWID 10 experienced a 129-degree wind shift. However, only PWID 05 (146 deg) was within 20 degrees of this. In fact, PWID 11 reported only an 11-degree change while PWID 6 had a 175-degree change in wind direction! The average wind vector magnitude changes associated with this front were very sporadic. PWID 11 had a 3.2 ms^{-1} increase, while PWID 13 had a 4.7 ms^{-1} decrease! The results for the March 4 case are summarized in Figure 4.

4. Discussion

Figures 3 and 4 demonstrate that the high wind events in this study had very different impacts within various locations inside Oklahoma City. The city buildings and structures have a significant effect on wind distribution. This discussion outlines a few of the more noticeable ways different areas within the city were impacted due to the strong wind events. Conclusions were also drawn about how or why these impacts occurred.

a. Possible Large Scale Impacts (>2 blocks)

1.) COVERGENT WINDS AT THE INTERSECTIONS OF PARK & ROBINSON AND PARK & BROADWAY

The observations from these two intersections revealed some amazing features that suggest the presence of a significant wind flow pattern through the city. PWIDs 02, 11, and 12 (Park and Robinson intersection) showed an obvious deviation to the SW from the standard PWID 10 during the southerly winds that occurred before each frontal passage (Fig. 5a). However, PWID 01 did have a constant south wind. In addition, PWIDs 03, 04, 13, and 14 (Park and Broadway intersection) had an obvious deviation to the southeast. (Fig. 5b). Thus, a convergent region of winds is occurred within the Park Avenue urban canyon. However, what is causing this convergence? It is possible that winds may be curving around the Galleria Parking Garage and around the Oklahoma Tower from the west into Park Avenue, providing a westerly component to the ambient south winds. The Parking Garage is mainly underground and only a parking lot with somewhat varying elevations is left at the top resulting in a spacious area for winds to flow through. Once the winds enter the wake of the Oklahoma Tower, they veer down Park Street from the west.

It is very odd that PWID's 03, 04, 13, and 14 would have an easterly component to their wind direction. However, a large building resides a block to the east of the intersection, which causes Park Avenue to come to an end which may not be tall enough to prevent wind from blowing over it, but it is still an obstruction.

To fully understand what occurred, it is important to look at the larger picture. On the east side of the central business district, train tracks run the length of the downtown area. South winds could be directed up through this area and into the little alley that is located between the Santa Fe Plaza and the Bank One Center located on the north side of Main Street. If this occurred, then the wind would be impacted by the wake behind the Bank One Center and into the intersection. This setup would provide the intersection with an easterly component to the wind.

2.) CHANNELING – PWID's 01 AND 07

PWIDS 01 and 07 are both located on north-south oriented streets. PWID 07 is located nearly due south of the beginning of Robinson Street; PWID 01 was also located on Robinson Street. During the southerly winds ahead of the front on February 15, both of these PWIDs experienced southerly flow. Thus, PWID 07 was monitoring the entry flow to Robinson Street. PWID 01 was monitoring the wind flow further north through Robinson Street within the urban canyon structures. However the average wind vector magnitudes recorded at PWID 01 was consistently greater than the wind vector magnitudes reported at PWID 07 (Fig. 6). Yet, PWID 07 was actually more exposed to the ambient wind than PWID 01. Robinson Street is a street with very large structures, and as the wind was forced into this area, it is channeled through the urban canyon. This was probably very common throughout the city given the appropriate location and wind direction.

b.) Localized Impacts

1.) PWID 08

PWID 08 is located, on the southern corner of Broadway at the intersection of Sheridan. To its due south, is the Cox Convention Center, which spans nearly two blocks. Ahead of both fronts, PWID 08 experienced westerly winds (Fig. 7).Thus, the winds may have traveled north through Ronald Norick Boulevard and, in the wake of the Convention Center, to the west through Sheridan Ave. PWID 08 also experienced westerly wind ahead of the Mar 4 front when winds were more southwesterly.

2.) PWID 14

PWID 14 was located at the intersection of Robinson and Park. During the period ahead of the March 4 front, minor variability in the wind vector speed at PWID 14 was observed. For approximately fifteen minutes, winds shifted from the south-southeast to east-southeast. This small shift in wind direction at this particular location was accompanied by noticeable drop in wind speed at PWID 14. Thus, when direction changed to a specific threshold value, wind vector magnitude decreased. Inspection of figure 8 , demonstrates that the threshold value is approximately 130 degrees. PWID's 03, 04, and 10 (the other PWIDs at this intersection) did not appear to experience this phenomenon. This demonstrates small wind shifts at a local level can cause significant wind vector magnitude variations.

3.) WIND SHIFT AT THE PARK & ROBINSON INTERSECTION

During the wind shift that occurred with the 4 March frontal passage, every PWID station had a slightly different shift in wind speed and direction (Fig. 4c). However, PWID's 02, 11, and 12 experienced very little shift in wind. (Fig. 9) Furthermore, PWID 10 experienced a wind shift of nearly 130 degrees, while PWID 01 experienced a shift of only 11 degrees. These two PWIDs are just across the street from each other! PWID's 02 and 12 experienced shifts of about 49 and 45 degrees respectively. The discrepancies between 01 and the other PWIDs at this intersection can be partially explained by the fact that 01 is more exposed to a north wind and PWID 11 is blocked on the north side by a building. Since the wind direction after the frontal passage was more northerly, it appears that somehow the winds were diverted or channeled down Harvey Street, to the west around the Park Harvey Center, and finally through Park Street. This would explain the westerly component of the wind at PWID 11 after the front passage, but does not explain the southerly part.

It would seem that either some large-scale wind flow was occurring or that the buildings around the intersection were significantly altering the wind directions. It is difficult to determine a sound theory for this phenomenon.

4.) SMALL DIRECTIONAL CHANGE AT PARK & ROBINSON

At approximately 20:50 GMT on March 4, a very small wind direction change occurred at PWID 10. (Figure 10) The wind changed direction from about 194 degrees to about 205 degrees. This small fluctuation to the ambient flow resulted in larger fluctuations at the intersection of Park & Robinson. In figure 10, PWID's 11, 12, and

02 experienced much larger wind shifts towards the southwest. Yet, PWID 01 recorded only minor changes in wind direction. This could be explained by the simple fact that these PWIDs observe significant south and west winds because of the street orientation. The slight shift in winds towards the west allowed the winds to be channeled through Park Ave. from the west. Southerly flow still occurred through Robinson Street (as can be seen by PWID 01), but the slight shift allowed the winds channeled through Park to become greater. Furthermore, PWID 01 may have not experienced much of a directional change because of the building directly to its west.

5. Conclusions

A study of airflow through Oklahoma City was performed using fifteen portable weather stations installed within the central business district. The average wind direction, wind vector magnitudes, and wind shifts that occurred at each site during two synoptic an event was recorded. The study demonstrated that the airflow within Oklahoma City was very complex and different locations revealed very high variations of wind directions and vectors. In addition, very small variations in wind direction and wind vectors were found to sometimes have very large impacts on certain locations of the city. Furthermore, each site was impacted differently and uniquely. Future research might include the impacts on each site during different types of weather conditions, including thunderstorms, warm front and dry line passages, and outflow boundaries to understand wind flow during a myriad of weather condition.

If a chemical/biological attack, an accidental chemical spill or severe pollution were to occur in downtown Oklahoma City, the toxic plume would not necessarily flow in simple patterns. Additional future research with similar urban observing systems is necessary to better understand these complex air patterns so that preparedness and response for accidental chemical spills, biological/chemical attacks, and air pollution is adequate.

ACKNOWLEDGEMENTS

This research was funded by National Science Foundation grant NSF 0097651. I would like to thank Dr. Jeff Basara, my mentor for giving me the idea for the research, the ability to access such data, and some help with the research process and the writing of this paper. I especially thank Peter Hall for his collaboration and willingness to help with the research. He was very instrumental in interpreting the PWID data. I wish to thank the Oklahoma Climatological Survey staff, especially Dale Morris, Mark Shafer, Michael Wolfinbarger, Justin Greenfield, Billy McPherson, and Chris Fiebrich. Also, thanks to Donald Storwold for obtaining the actual PWID data. In addition, thanks to Donald Giuliano and Lynn Perkinton for the help they offered. Finally, thanks to Daphne Zaras, coordinator of the Research Experiences Program.

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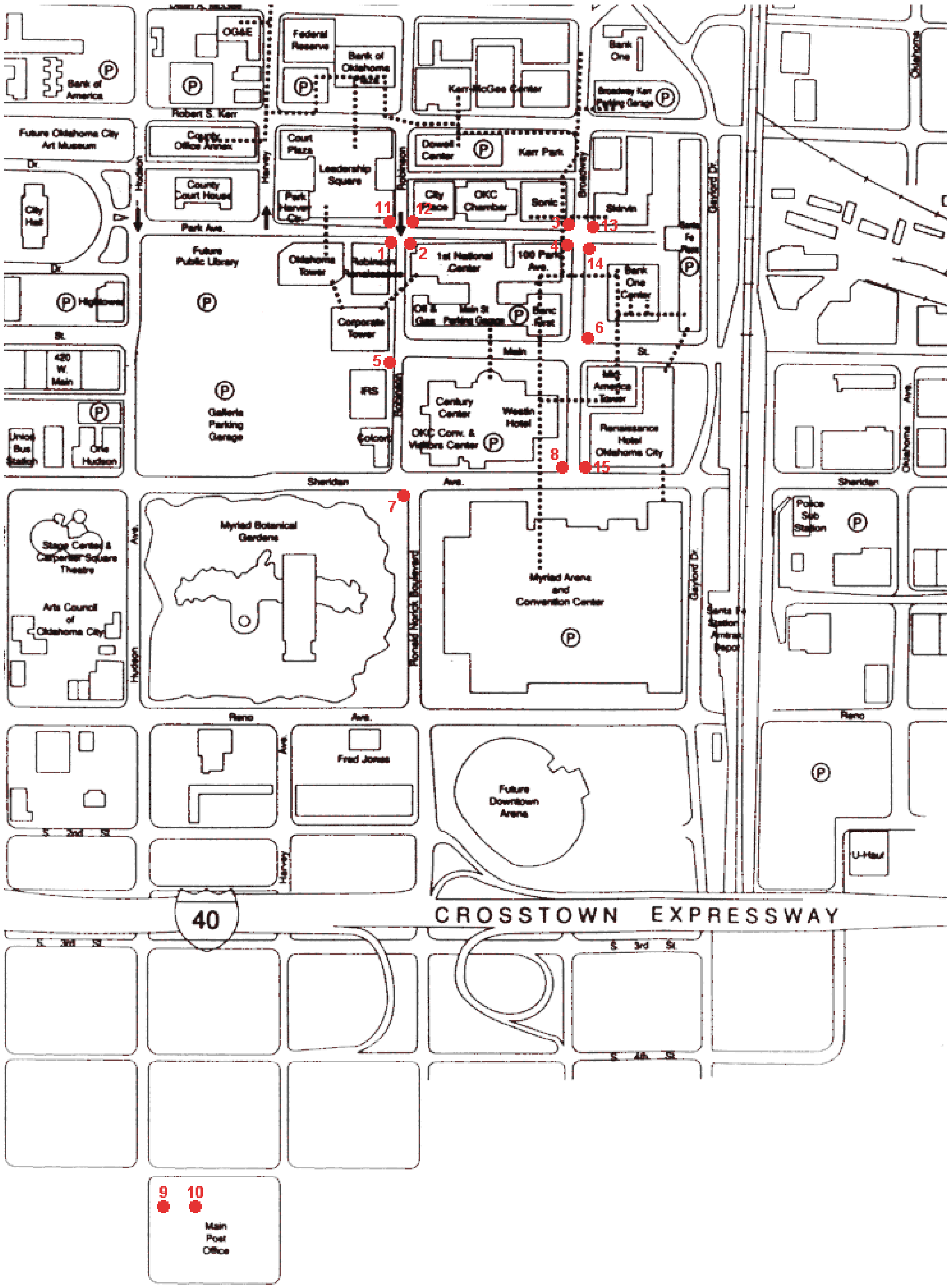

Figure 1 – A map of the locations of the PWID sites used in this research. Most were located on street poles 28 feet above the ground. PWID 09 and 10 were located on top of the Main Post Office

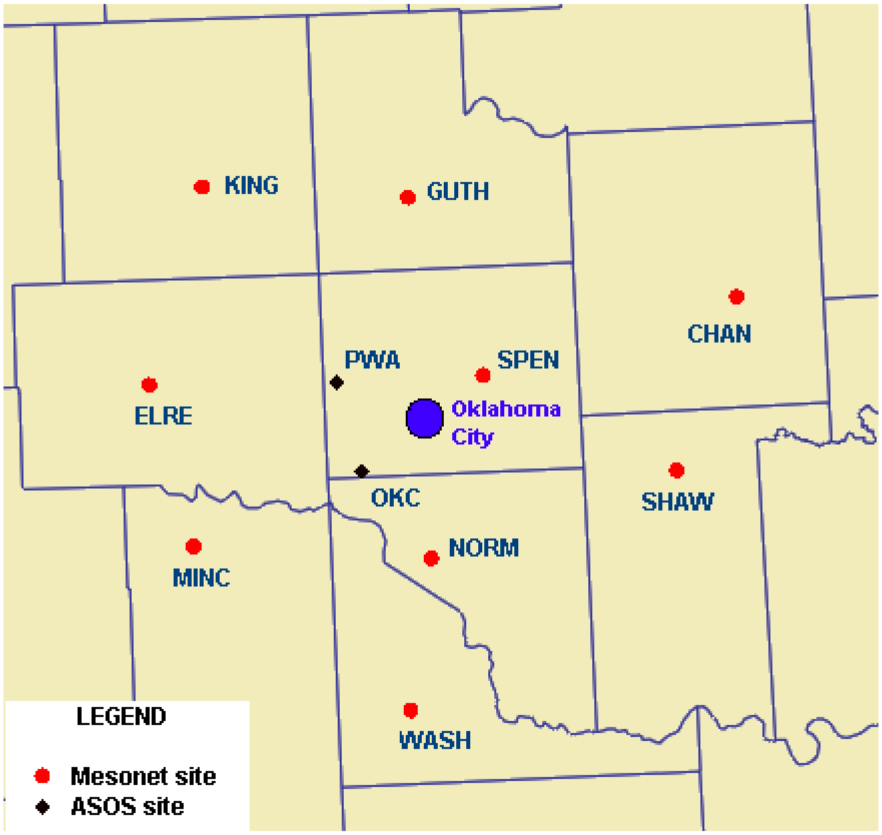

Figure 2 - A map of the Mesonet and ASOS sites used in this research.

Figure 3a

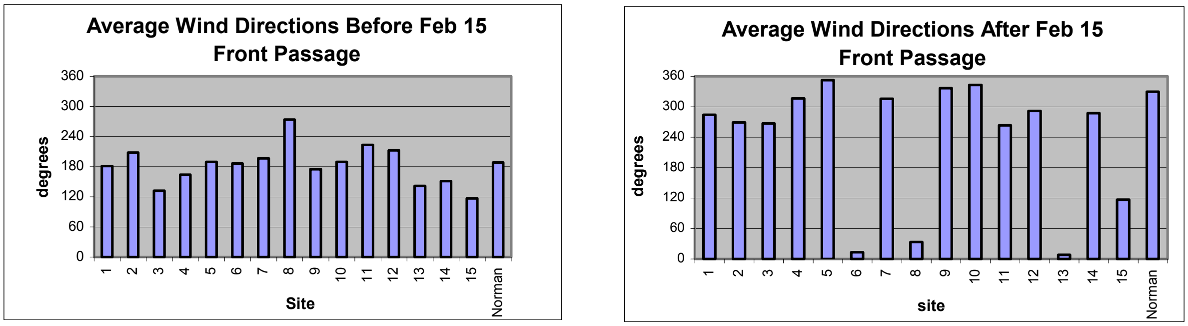

Figure 3b

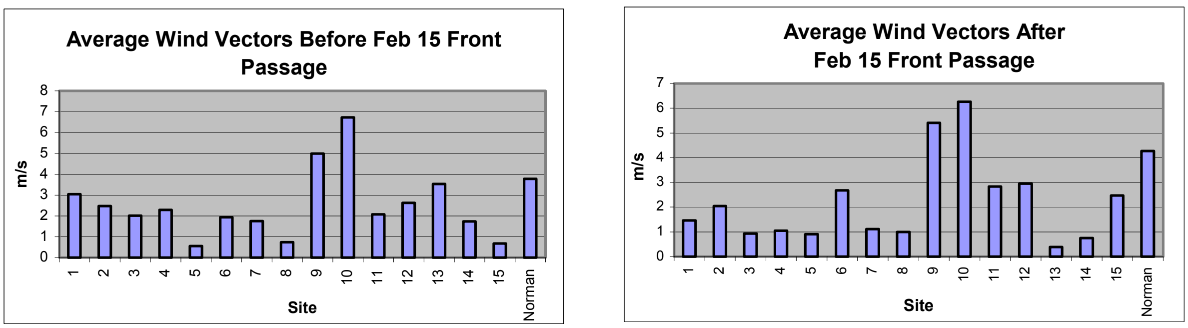

Figure 3c

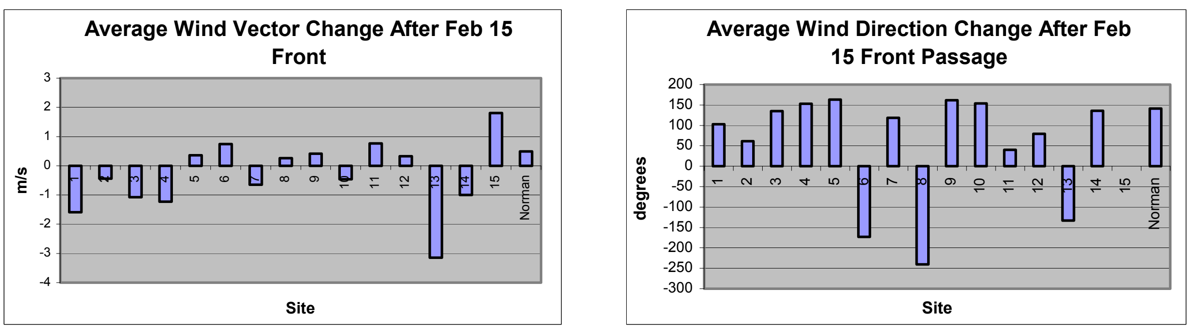

Figure 3 - The average wind vector speeds and directions before and after the February 15 front. The changes in average wind vector magnitude and direction caused by the front are found in 3c. PWID 15 directions in these graphs are erroneous.

Figure 4a

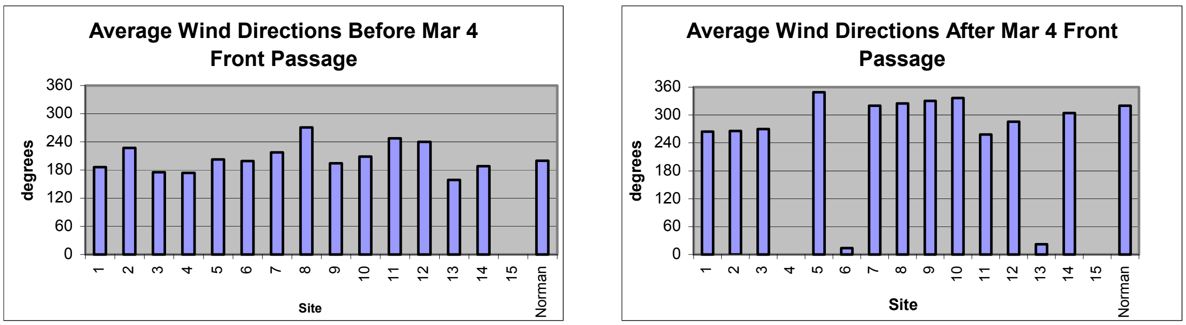

Figure 4b

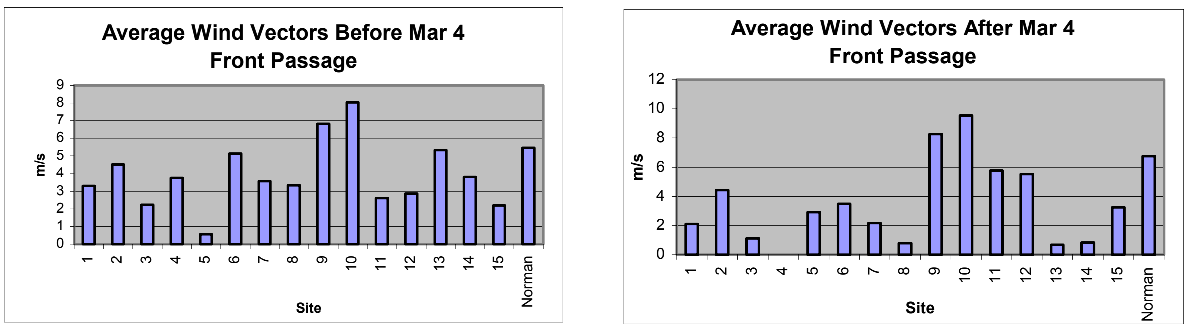

Figure 4c

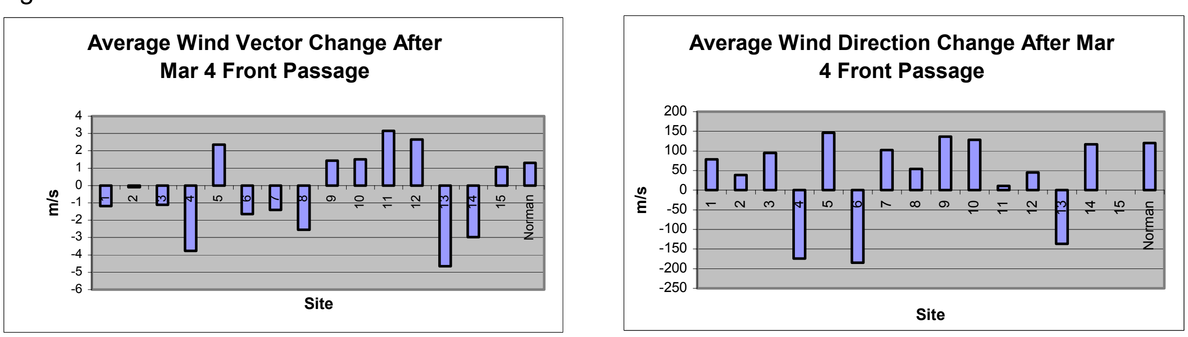

Figure 4 - The average wind vector magnitudes and directions before and after the March 4 front. The changes in vector speed and direction caused by the front are found in 3c.

Figure 5a

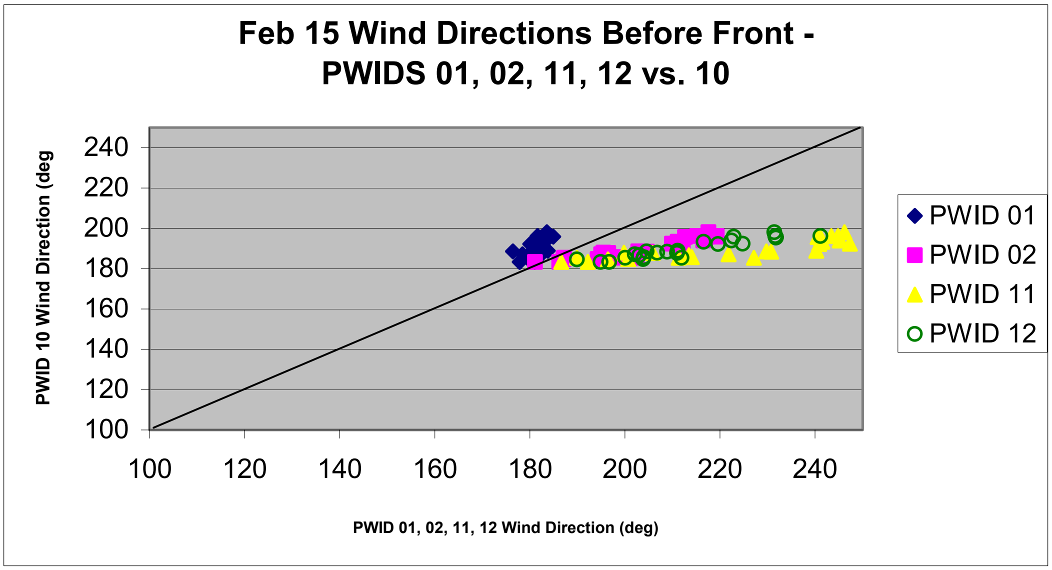

Figure 5b

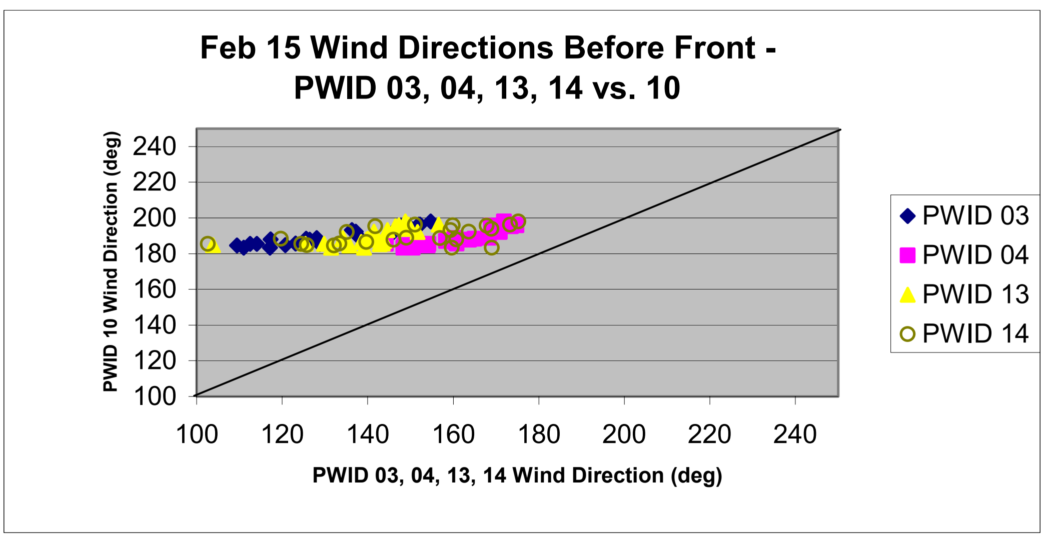

Figure 5 – The wind direction values before the Feb 15 front at the PWIDs Figure 5a shows the directions at the intersection of Robinson and Park. Note that the winds are shifted slightly to the SW of PWID 10. Figure 5b shows the directions at the intersection of Broadway and Park. Note the winds are shifted slightly SE of PWID 10. The diagonal lines represent the y = x line.

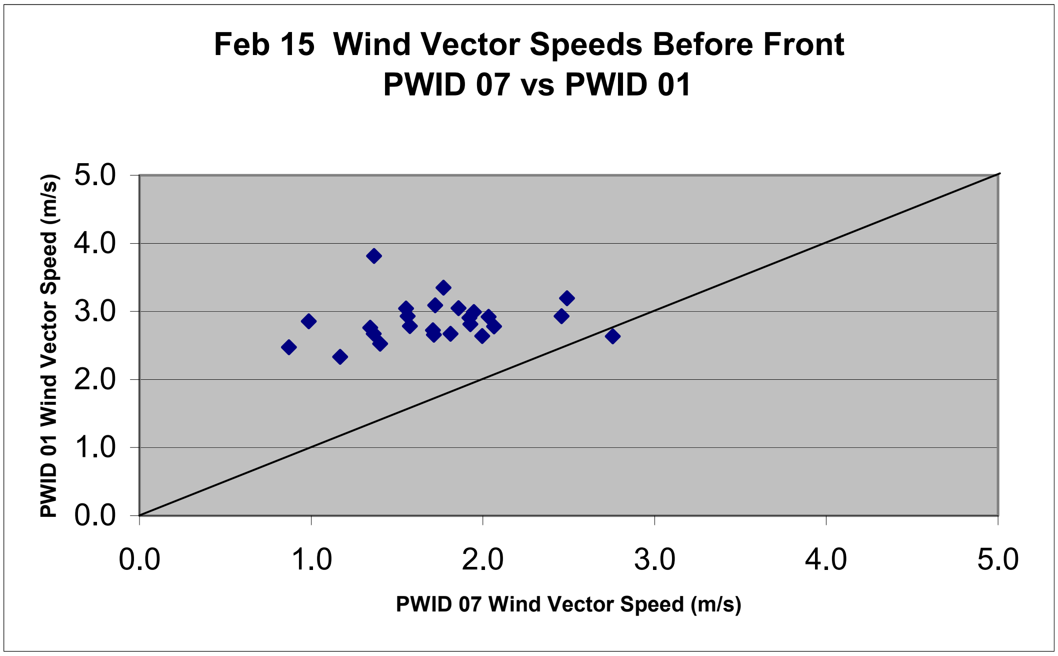

Figure 6 - A graph of the wind vector magnitudes at PWID 07 graphed against the vector magnitudes at PWID 01. Note that PWID 01 has noticeably higher winds, indicating the possibility of wind being channeled through Robinson Street.

Figure 7a

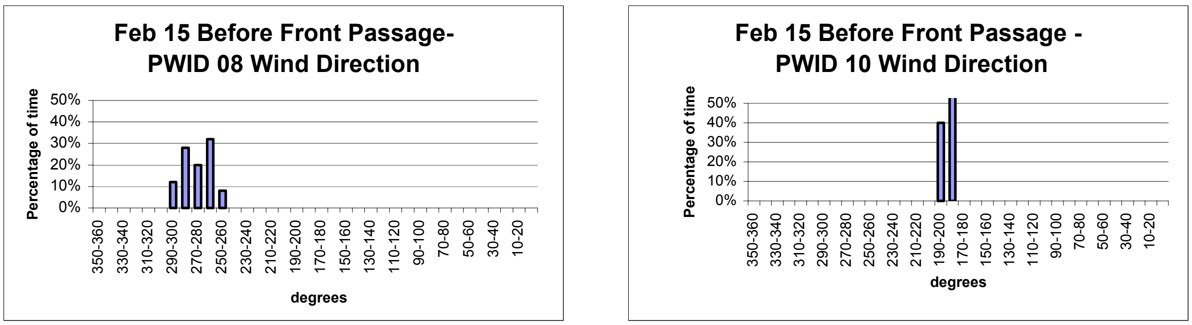

Figure 7b

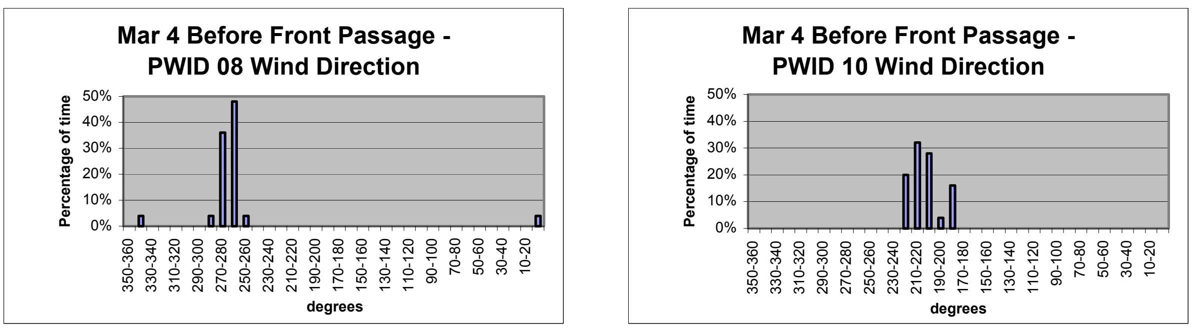

Figure 7 – The average wind directions of PWID 08 before the two frontal passages. Note that although the winds were southerly at PWID 10, PWID 08 experienced nearly constant west winds. PWID 08 is blocked to the south by a convention center.

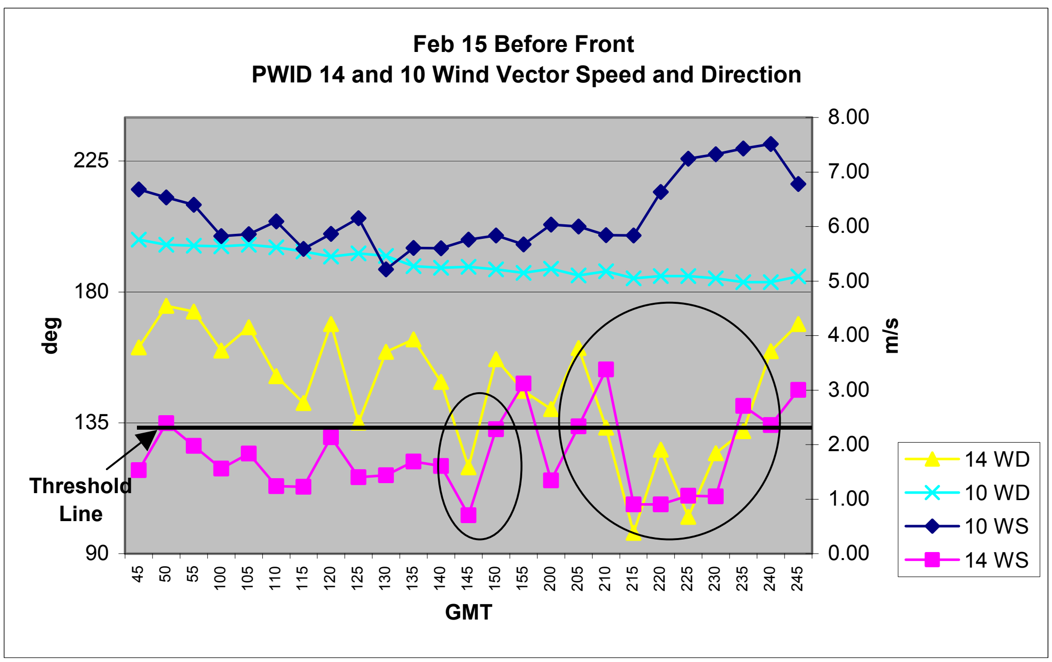

Figure 8 – An interesting occurrence at PWID 14. Although PWID 10 had a fairly constant wind direction, PWID 14 experienced a significant wind shift.

Figure 9a

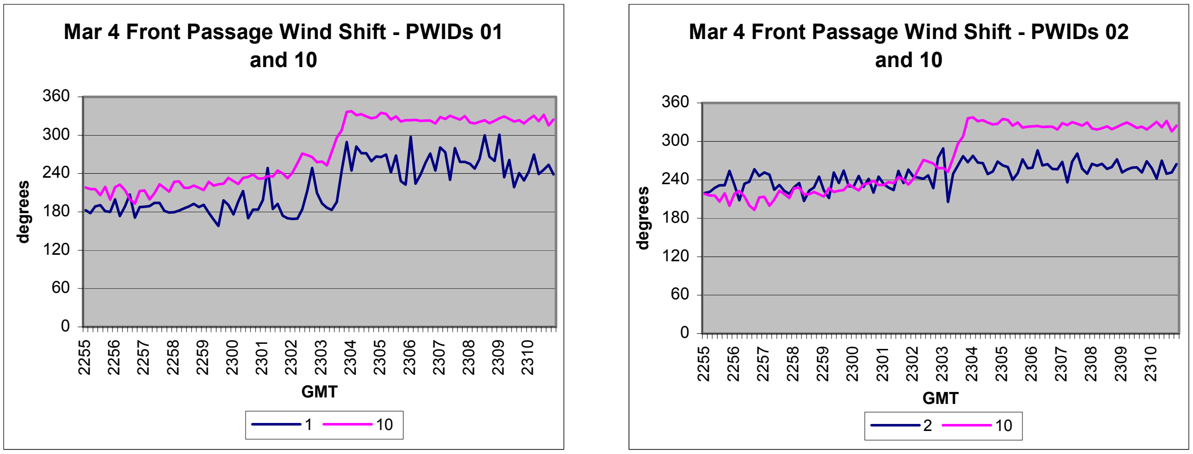

Figure 9b

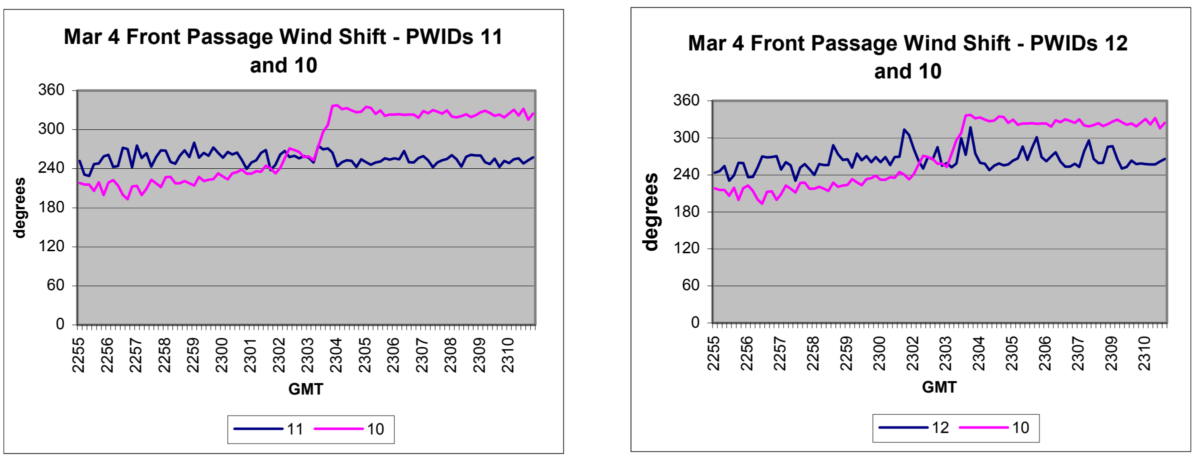

Figure 9 – Wind directions reported by the PWIDs located at the intersection of Park and Robinson compared with wind direction at PWID 10 using 10 sec. wind data. As the March 4 front passed through, PWID 10 experienced a shift in direction from about 240 degrees to nearly 330 degrees. However, note the limited directional change at PWIDs 02, 11, and 12.

Figure 10a

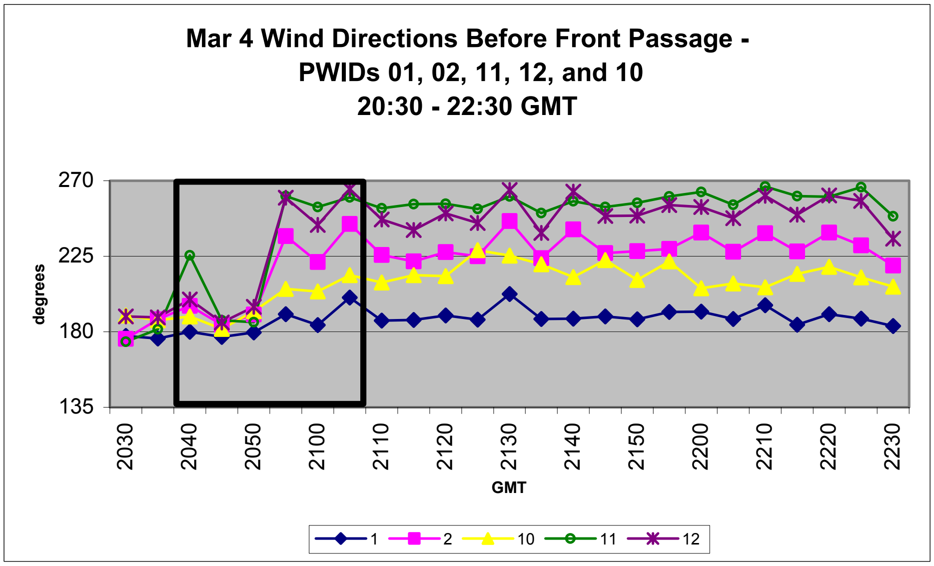

Figure 10b

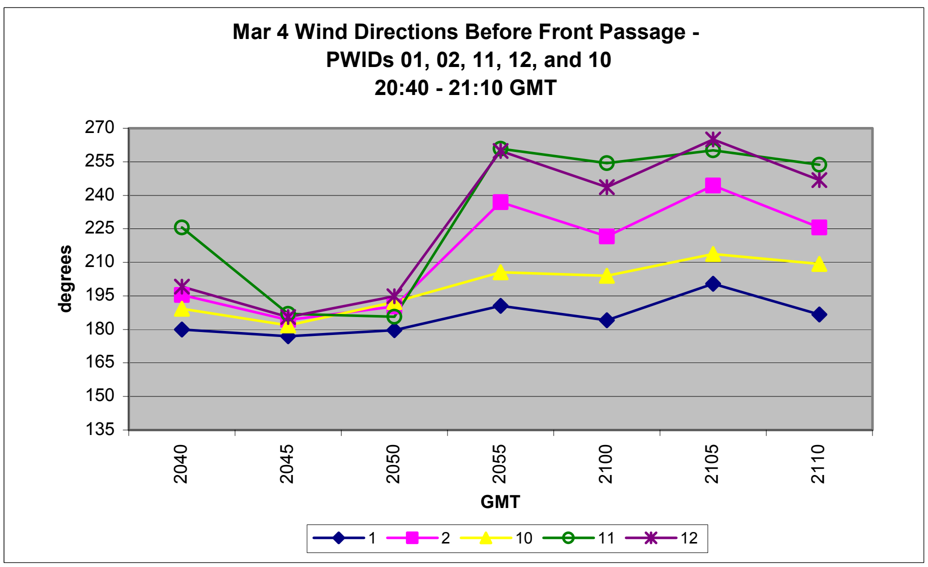

Figure 10 – The wind directions of the PWIDs located at the intersection of Park and Robinson compared with PWID 10. PWID 10 experienced a slight wind shift from 20:45-20:55 from the south to the south-southwest. Note the large shifts that occur at PWID 02, 11, and 12. Figure 10b is a zoomed in shot of the box in Figure 10a.