$PM_{2.5}$ SIP

Appendix B

Meteorological Analysis

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Analysis of Meteorology for the $PM_{2.5}$ 2012 NAAQS

Anthony J. Sadar, CCM
Allegheny County Health Department
Air Quality Program

Weather conditions observed from 2009 through 2013, with a focus on 2011, the base year modeled for the attainment demonstration, were examined for representativeness of the modeling scenario as well as effects on $PM_{2.5}$ concentrations in Allegheny County.

Temperature Inversions

Ground-level temperature inversions contribute to elevated levels of $PM_{2.5}$. A low-level temperature inversion occurs when the air at the surface becomes cooler than the air above it, i.e., the rate of cooling of the air is greater at ground level versus at elevated levels. The cooler, heavier air then becomes trapped at the lower elevation. As the major and minor sources in the area continue to emit $PM_{2.5}$ pollution and the lower, cooler air becomes buoyantly stable, the $PM_{2.5}$ is limited in its upward movement to disperse into the regional flow, and so $PM_{2.5}$ levels can increase.

There is a general diurnal trend to temperature inversions. Usually, an inversion will begin shortly after sunset, persist through the overnight hours, and then break up within several hours after sunrise. Typically, upon the surface inversion's break, local $PM_{2.5}$ is released into the upper atmospheric flow. Observations have shown that after this break, the Liberty monitor, which samples air at the location of the county's traditionally highest $PM_{2.5}$ concentrations, returns to a level comparable to or less than the concentrations measured at surrounding monitors.

Temperature inversions are measured across the globe at least twice daily by a balloon-borne instrument called a radiosonde. In southwestern Pennsylvania, the radiosonde is sent into the atmosphere between 6 and 7 am EST and 6 and 7 pm EST by the National Weather Service (NWS) forecasting office near the Pittsburgh International Airport (PIT). Upper-air data transmitted by this instrument are assumed to represent stability conditions all across the county. (However, the many low-lying river valleys throughout the county are more likely to experience a greater frequency of inversions than recorded at the higher elevation PIT NWS location.)

The radiosonde data show that the five-year period (2009 – 2013) was characterized by 41% of mornings experiencing, on average, moderately strong surface inversions of 3.8 °C, with an average height above ground of 237 m and an estimated break time at PIT NWS of about 9:30 a.m. EST. The months with the strongest inversions on average during the period were November (4.6 °C), October (4.4 °C), and March (4.3 °C).

The modeled base year, 2011, was characterized by 37% of mornings with moderate surface inversions of 3.7 °C and an average height of 246 m, with an estimated break time at PIT NWS of about 9:30 a.m. EST. The months with the strongest inversions on average during 2011 were October (6.1 °C) and November (5.0 °C). Note that the October 2011 inversion strength was the largest of any month during the five-year period. A comparison of 2011 conditions with the four other years during the five-year period reveals that the 2011 average inversion strength was near

the mean of the other four years. The average height of the 2011 inversions was the highest during the period. The 2011 estimated break time at PIT NWS matched the other years. The total days of inversions was near the low end of the range of total days of inversions.

Overall, surface inversion characteristics for the modeled year, 2011, were within or close to the range of typical inversion conditions for PIT NWS upper-air measurements. October 2011 with a large average surface inversion strength was a bit of an exception.

INVERSION STATISTICS* FOR **2009–2013**, DERIVED FROM PIT NWS** DATA

Year	Avg. Strength (°C)	Strength Std. Dev. (°C)	Avg. Top (m)	Top Std. Dev. (m)	Est. Break Time*** (EST)	Total Days of Inversion (%)
2009	3.8	2.1	244	149	9.5	154 (44)
2010	4.1	2.3	226	115	9.5	171 (47)
2011	3.7	2.1	246	118	9.5	134 (37)
2012	3.9	2.1	229	96	9.5	158 (43)
2013	3.4	1.8	244	113	9.5	127 (35)
2009-2013	3.8	2.1	237	119	9.5	149 (41)
With No 2011	3.8	2.1	235	120	9.5	153 (42)

*** For morning (12Z) surface inversions of at least 1.0 °C in strength** (shallow isothermal and/or unstable conditions may also be present below or within ground inversion).
****** PIT NWS = Pittsburgh National Weather Service.
******* Estimated break time is to nearest half hour, Eastern Standard Time.

AVG. STRENGTH (°C):*** 2009–2013**, DERIVED FROM PIT NWS DATA

Month	2009	2010	2011	2012	2013	2009-2013	With No 2011
JAN	3.4	5.2	3.1	4.1	4.0	4.0	4.1
FEB	4.2	3.1	3.4	3.3	4.3	3.6	3.7
MAR	3.8	4.9	3.6	5.1	3.2	4.3	4.5
APR	4.4	4.4	3.6	4.0	3.1	4.0	4.0
MAY	4.1	3.5	2.9	3.8	2.6	3.5	3.6
JUN	3.3	2.3	3.0	3.0	2.7	2.8	2.8
JUL	2.9	3.3	3.1	3.0	2.6	3.0	3.0
AUG	3.0	4.8	3.3	4.3	3.1	3.7	3.8
SEP	4.0	3.8	3.0	4.3	4.7	3.9	4.1
OCT	3.9	4.7	6.1	3.7	3.9	4.4	4.0
NOV	3.7	5.9	5.0	4.5	3.3	4.6	4.5
DEC	5.2	2.9	4.3	3.6	2.4	3.8	3.6
Annual	**3.8**	**4.1**	**3.7**	**3.9**	**3.4**	**3.8**	**3.8**

*** For morning (12Z) surface inversions of at least 1.0 °C in strength** (shallow isothermal and/or unstable conditions may also be present below or within ground inversion).

AVG. TOP (m):*** 2009-2013**, DERIVED FROM PIT NWS DATA

Month	2009	2010	2011	2012	2013	2009-2013	With No 2011
JAN	384	373	206	265	220	286	300
FEB	295	208	278	257	301	266	262
MAR	274	204	381	220	235	250	230
APR	265	239	221	259	245	247	250
MAY	216	218	236	205	232	220	216
JUN	236	194	196	189	250	214	217
JUL	173	195	251	214	176	205	191
AUG	207	196	205	219	214	209	210
SEP	286	229	270	217	273	253	250
OCT	219	261	253	231	256	244	243
NOV	208	264	282	251	296	257	252
DEC	323	205	207	241	235	241	253
Annual	**244**	**226**	**246**	**229**	**244**	**237**	**235**

*** For morning (12Z) surface inversions of at least 1.0 °C in strength** (shallow isothermal and/or unstable conditions may also be present below or within ground inversion).

Total Days of Inversions: **2009-2013**, DERIVED FROM PIT NWS DATA*****

Month	2009	2010	2011	2012	2013	2009-2013	With No 2011
JAN	7 (23)	5 (16)	5 (16)	9 (29)	8 (26)	34 (22)	29 (23)
FEB	8 (30)	8 (30)	10 (36)	10 (36)	6 (21)	42 (30)	32 (29)
MAR	12 (43)	17 (55)	7 (23)	11 (35)	6 (19)	53 (35)	46 (38)
APR	11 (37)	20 (67)	6 (20)	12 (40)	10 (33)	59 (39)	53 (44)
MAY	18 (64)	16 (52)	13 (43)	14 (45)	9 (29)	70 (46)	57 (47)
JUN	14 (61)	14 (47)	8 (28)	13 (43)	13 (43)	62 (44)	54 (48)
JUL	16 (52)	17 (55)	18 (60)	15 (48)	9 (29)	75 (49)	57 (46)
AUG	16 (52)	15 (48)	21 (68)	19 (61)	16 (53)	87 (56)	66 (54)
SEP	15 (50)	20 (67)	12 (40)	14 (47)	14 (47)	75 (50)	63 (53)
OCT	15 (48)	16 (52)	11 (35)	15 (48)	18 (60)	75 (49)	64 (52)
NOV	14 (47)	17 (57)	12 (40)	17 (57)	10 (33)	70 (47)	58 (48)
DEC	8 (26)	6 (19)	11 (35)	9 (29)	8 (27)	42 (27)	31 (25)
Annual	**154 (44)**	**171 (47)**	**134 (37)**	**158 (43)**	**127 (35)**	**744 (41)**	**610 (42)**

*** For morning (12Z) surface inversions of at least 1.0 °C in strength** (shallow isothermal and/or unstable conditions may also be present below or within ground inversion). Percent based on available days of data is given in parenthesis.

Est. Break Time (EST):*** 2009-2013**, DERIVED FROM PIT NWS DATA******

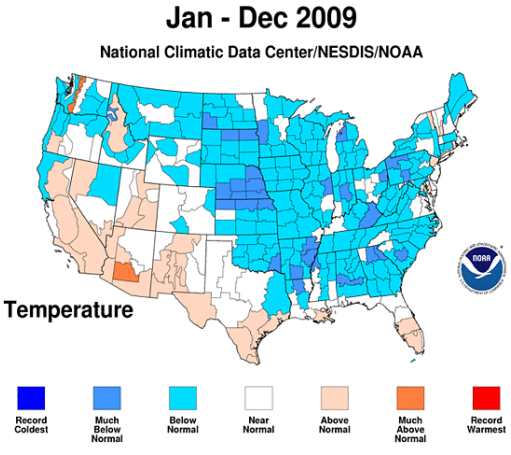
Month	2009	2010	2011	2012	2013	2009 - 2013	With No 2011
JAN	10.5	11.5	10.5	10.5	11.0	11.0	11.0
FEB	9.5	11.0	9.5	9.5	11.5	10.0	10.0
MAR	9.5	10.5	11.0	10.0	9.5	10.0	10.0
APR	9.0	9.0	9.0	9.0	9.0	9.0	9.0
MAY	9.0	9.0	9.0	8.5	8.0	8.5	8.5
JUN	8.5	8.5	8.0	8.5	8.5	8.5	8.5
JUL	8.5	8.5	9.0	9.0	8.5	8.5	8.5
AUG	9.0	9.0	8.5	9.5	9.0	9.0	9.0
SEP	9.5	9.0	9.5	9.5	10.0	9.5	9.5
OCT	10.0	10.5	11.0	10.0	10.0	10.5	10.0
NOV	10.5	11.0	11.0	11.0	11.0	11.0	11.0
DEC	11.0	9.5	10.5	11.0	11.0	10.5	10.5
Annual	**9.5**	**9.5**	**9.5**	**9.5**	**9.5**	**9.5**	**9.5**

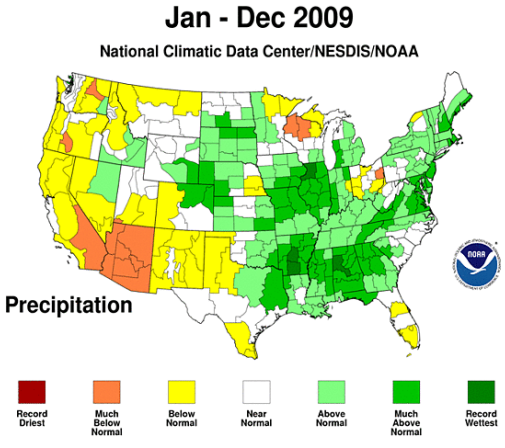
***** Estimated break time is to nearest half hour, Eastern Standard Time.

**** For morning (12Z) surface inversions of at least 1.0 °C in strength** (shallow isothermal and/or unstable conditions may also be present below or within ground inversion).

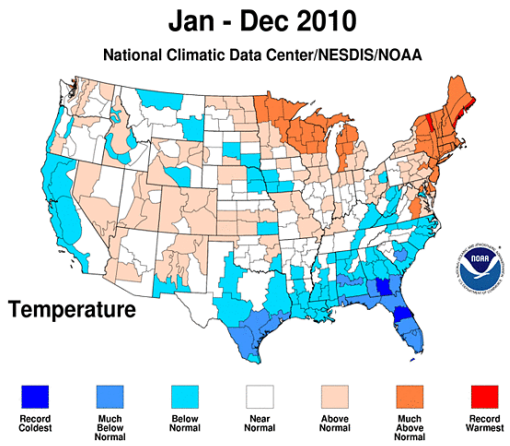
Temperature, Precipitation, and Wind

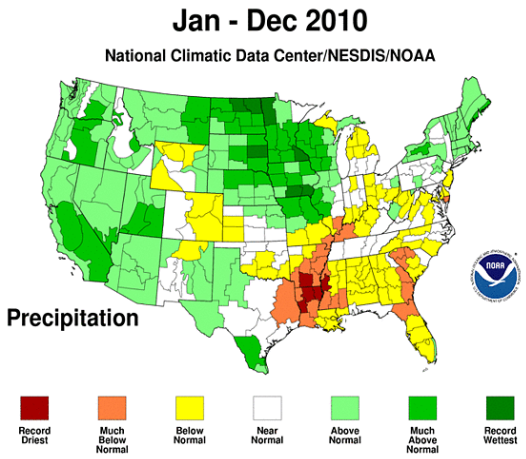
As depicted in the following divisional rank maps accessed from the National Climatic Data Center[1], temperature data from 2009 through 2013 reveal southwestern Pennsylvania annual average temperatures ranging from below normal in 2009 to much above normal in 2012. Precipitation data from 2009 through 2013 show southwestern Pennsylvania annual total precipitation amounts ranging from near normal in 2009 and 2010 to much above normal in 2011.

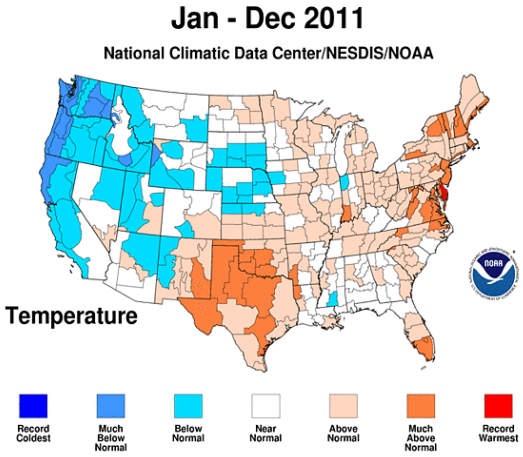


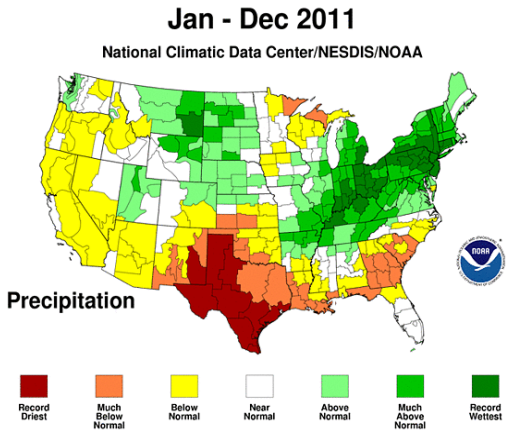


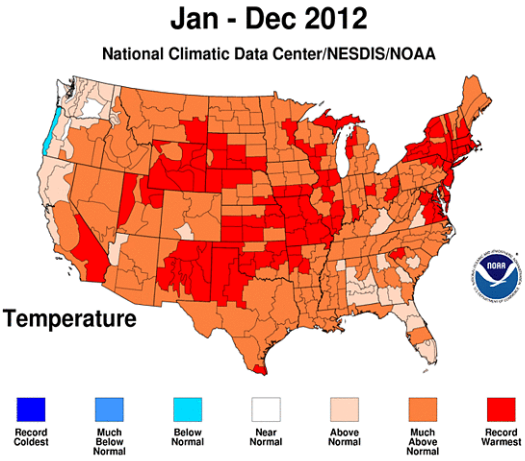
[1] https://www.ncdc.noaa.gov/temp-and-precip/us-maps/

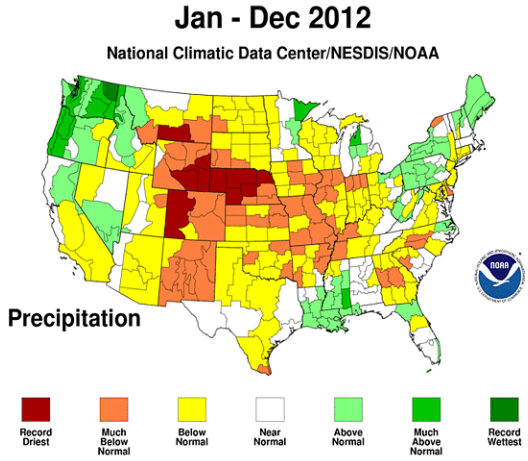

Jan - Dec 2010
National Climatic Data Center/NESDIS/NOAA
Temperature
Record Coldest
Much Below Normal
Below Normal
Near Normal
Above Normal
Much Above Normal
Record Warmest

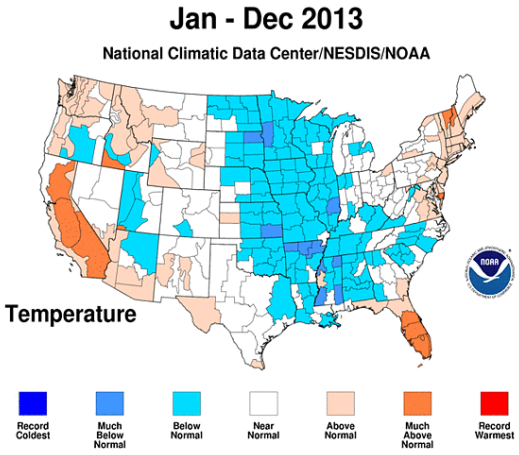

Jan - Dec 2010
National Climatic Data Center/NESDIS/NOAA
Precipitation
Record Driest
Much Below Normal
Below Normal
Near Normal
Above Normal
Much Above Normal
Record Wettest

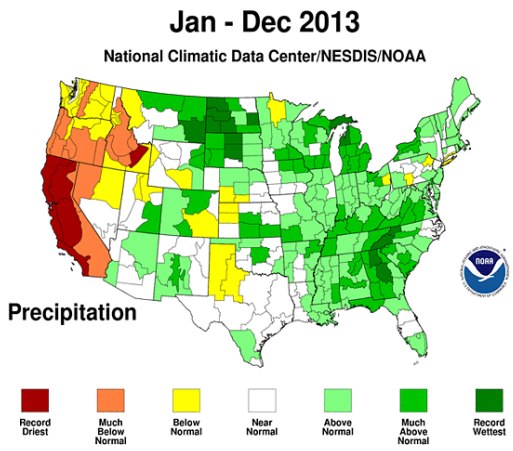

Jan - Dec 2011
National Climatic Data Center/NESDIS/NOAA
Temperature
Record Coldest
Much Below Normal
Below Normal
Near Normal
Above Normal
Much Above Normal
Record Warmest


Jan - Dec 2011
National Climatic Data Center/NESDIS/NOAA
Precipitation
Record Driest
Much Below Normal
Below Normal
Near Normal
Above Normal
Much Above Normal
Record Wettest


Jan - Dec 2012
National Climatic Data Center/NESDIS/NOAA
Temperature
Record Coldest
Much Below Normal
Below Normal
Near Normal
Above Normal
Much Above Normal
Record Warmest


Jan - Dec 2012
National Climatic Data Center/NESDIS/NOAA
Precipitation
Record Driest
Much Below Normal
Below Normal
Near Normal
Above Normal
Much Above Normal
Record Wettest





For a closer examination of conditions within the nonattainment area, annual average temperature and total precipitation conditions observed within the county at the Pittsburgh and Allegheny County airports (PIT and AGC) follow. These measurements can be compared with the 1981 – 2010 normal conditions for PIT and AGC. As the annual weather conditions indicate, temperatures at both locations were generally above normal, while precipitation at both locations ranged across the normal level. For 2011, the modeled base year, PIT average temperature was 1.4 °F above normal, while total precipitation was 5.3" above normal. For 2011, AGC was 1.5 °F and 4.82" above normal.

PIT

MeanAvgTemp	
2009	51.0
2010	51.8
2011	52.8
2012	54.2
2013	51.5
TotalPrecip	
2009	32.84
2010	37.85
2011	43.51
2012	41.74
2013	36.65

PIT Normal Conditions:
AvgTemp = 51.4ºF
TotalPrecip = 38.19"

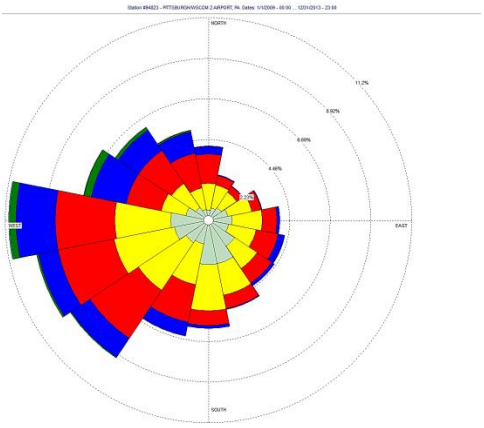
AGC

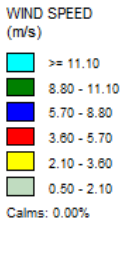
MeanAvgTemp	
2009	51.2
2010	52.6
2011	53.3
2012	55.0
2013	51.9
TotalPrecip	
2009	33.29
2010	36.13
2011	44.11
2012	38.13
2013	41.19

AGC Normal Conditions:
AvgTemp = 51.8ºF
TotalPrecip = 39.29"

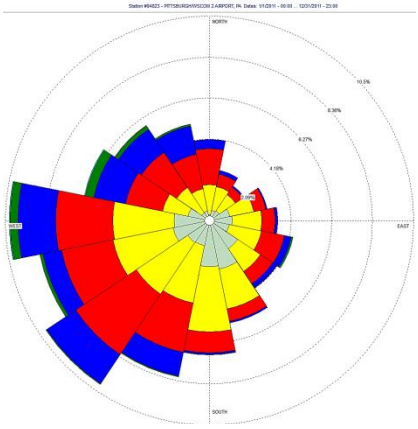
Following are wind roses that graph conditions observed at PIT and AGC for 2009 through 2013 and for 2011, the modeled base year. Winds generally flow from the southwest through west across Allegheny County, except for the preponderance of winds from the south at AGC (which is likely the result of topographical effects on the wind sensor). When wind speeds slow down, which occurs frequently overnight and often during temperature inversions, $PM_{2.5}$ levels can increase substantially, especially in the many river valleys throughout the county. (See additional sections of this appendix for further discussions relative to airflow in valleys.) Note that the PIT and AGC wind roses for 2011 are similar to the wind roses for 2009 through 2013, as well as the other individual years in the timeframe (given at the end of this appendix).

PIT Wind Rose, 2009 – 2013

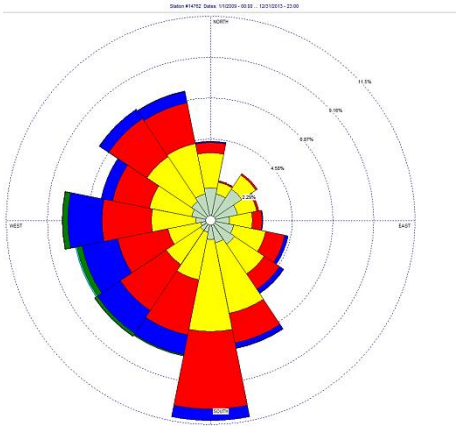


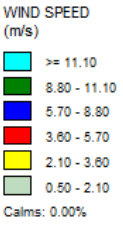


PIT Wind Rose, 2011

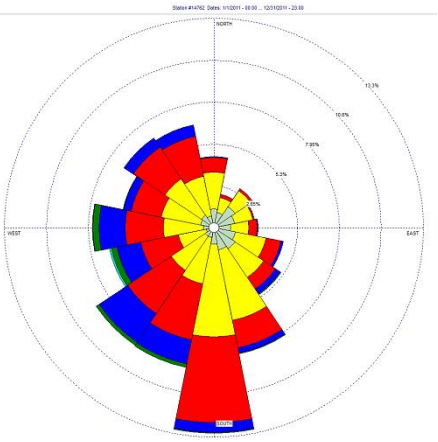


AGC Wind Rose, 2009 – 2013



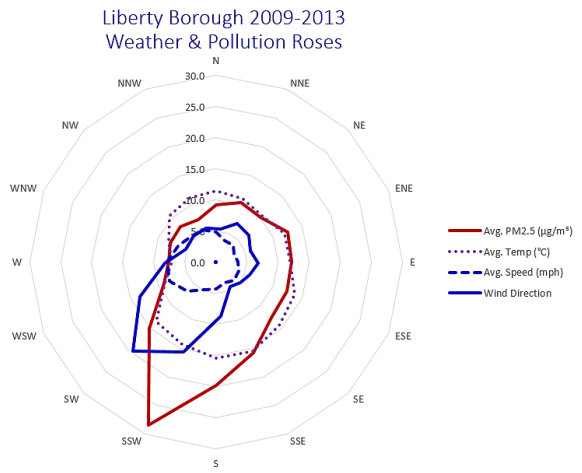


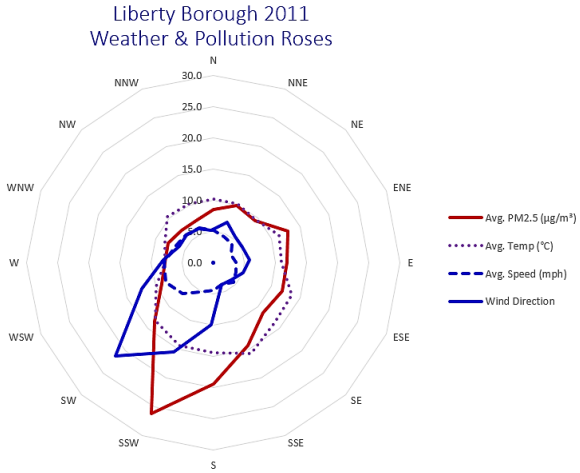
AGC Wind Rose, 2011

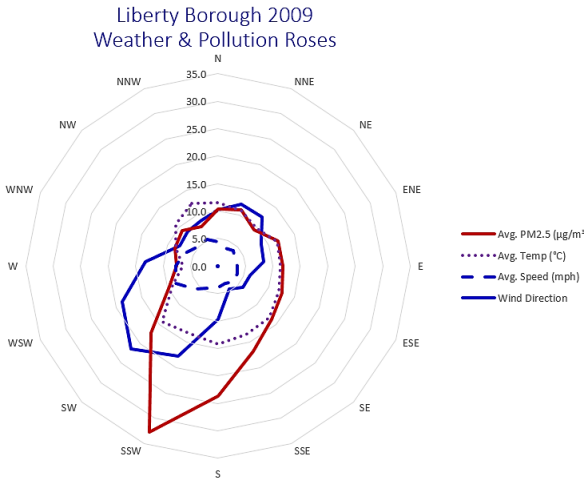


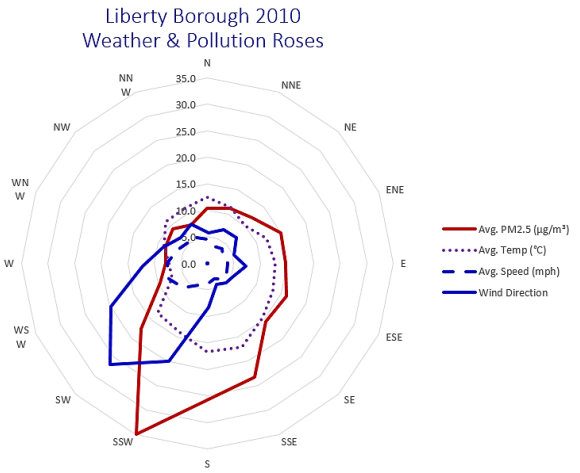
Focusing in on the Liberty Borough area, the following figures show wind frequency and speed, temperature, and $PM_{2.5}$ concentration roses for the Liberty monitor site for 2009 through 2013and for 2011. (Individual year roses for other years in the timeframe are also presented for comparison.)

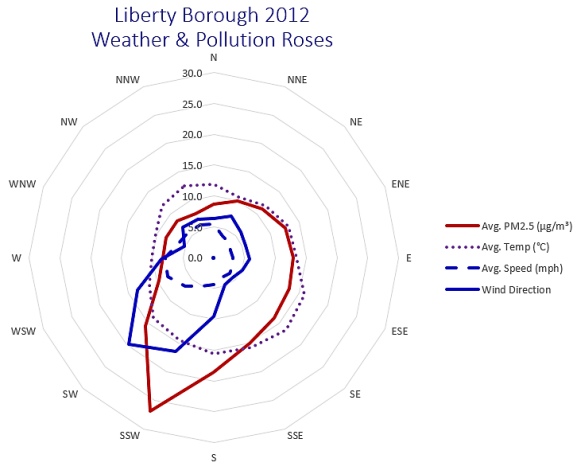
As the roses indicate, wind, temperature, and pollution patterns for 2011 were similar to each individual year and overall averages. For all graphs, the most frequent wind direction was southwest, the fastest wind speed on average was also from the southwest, the highest average temperature was from the south-southeast through south-southwest, and the highest concentration of $PM_{2.5}$ on average came from the south-southwest.

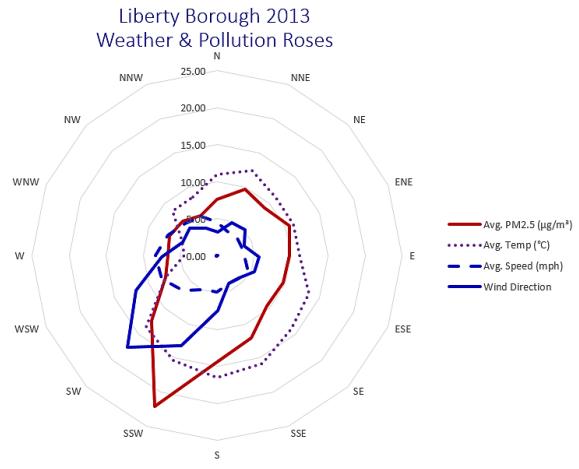

Liberty Borough 2009-2013
Weather & Pollution Roses
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Avg. PM2.5 (µg/m³)
Avg. Temp (°C)
Avg. Speed (mph)
Wind Direction


Liberty Borough 2011
Weather & Pollution Roses
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Avg. PM2.5 (µg/m³)
Avg. Temp (°C)
Avg. Speed (mph)
Wind Direction


Liberty Borough 2009
Weather & Pollution Roses
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Avg. PM2.5 (µg/m³)
Avg. Temp (°C)
Avg. Speed (mph)
Wind Direction


Liberty Borough 2010
Weather & Pollution Roses
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Avg. PM2.5 (µg/m³)
Avg. Temp (°C)
Avg. Speed (mph)
Wind Direction


Liberty Borough 2012
Weather & Pollution Roses
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Avg. PM2.5 (µg/m³)
Avg. Temp (°C)
Avg. Speed (mph)
Wind Direction


Liberty Borough 2013
Weather & Pollution Roses
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
25.00
20.00
15.00
10.00
5.00
0.00
Avg. PM2.5 (µg/m³)
Avg. Temp (°C)
Avg. Speed (mph)
Wind Direction

Concentrations

Periods of elevated $PM_{2.5}$ concentrations at Liberty generally coincide with the presence of temperature inversions. Average temperatures and precipitation can also affect the formation of $PM_{2.5}$ regionally, but inversions have an apparent greater effect on localized extremes. This may be evident when comparing yearly inversion statistics and temperature/precipitation rankings to monitored data.

Annual monitored weighted means for Liberty and Lawrenceville FRM data are shown in the table below for 2009-2013. Lawrenceville generally represents the Pittsburgh metropolitan area and is measured on a daily basis similar to Liberty. Liberty localized excess in this table is the difference of Liberty and Lawrenceville.

$PM_{2.5}$ Concentrations, with Meteorological Statistics, 2009-2013

Metric	2009	2010	2011	2012	2013
Liberty weighted mean (µg/m³)	15.0	16.0	14.0	14.3	12.0
Lawrenceville weighted mean (µg/m³)	11.6	12.2	11.1	10.1	9.8
Liberty localized excess (µg/m³)	*3.4*	*3.8*	*2.9*	*4.2*	*2.2*
Percent of days with inversions	44	47	37	43	35
Average strength of inversion (°C)	3.8	4.1	3.7	3.9	3.4
Average temperature ranking*	<	=	>	>>	=
Total precipitation ranking*	=	=	>>	>	>

* Rankings (as taken from the NOAA rank maps on previous pages): below normal (<), near normal (=), above normal (>), much above normal (>>)

While concentrations are declining overall through the timeframe due to regional and local emissions reductions, yearly variations in the Liberty monitor data indicate some dependence on the frequency and strength of inversions. For example, Liberty showed an increase in annual concentration from 2011 to 2012, while Lawrenceville showed a steady decrease in concentration from 2010 through 2013. Even if wetter conditions led to lower regional concentrations in 2010-2013, localized excess is still present at Liberty in these years.

2011 is also an appropriate year for concentrations in general for the five-year timeframe, with monitored values for Liberty and Lawrenceville that are close to midpoints and averages for 2009 through 2013.

Summary and Conclusions

A review of weather conditions throughout 2009 through 2013 indicates that the five-year period (2009-2013) was characterized by 41% of mornings experiencing, on average, moderately strong surface inversions of 3.8 °C, with an average height above ground of 237 m and an estimated break time at PIT NWS of about 9:30 a.m. EST.

The modeled base year, 2011, shows statistics similar to the averages for the five-year period, with 37% of mornings with moderate surface inversions of 3.7 °C and an average height of 246 m, with an estimated break time at PIT NWS of about 9:30 a.m. EST.

Temperature data from 2009 through 2013 reveal southwestern Pennsylvania annual average temperatures ranging from below normal in 2009 to much above normal in 2012, while precipitation data from 2009 through 2013 show southwestern Pennsylvania annual total precipitation amounts ranging from near normal in 2009 and 2010 to much above normal in 2011.

Within Allegheny County, annual average temperature and total precipitation conditions observed at the airports (PIT and AGC) indicate that temperatures at both locations were generally above normal, while precipitation at both locations ranged across the normal level. For 2011, the modeled base year, PIT and AGC average temperature and total precipitation were above normal.

PIT and AGC wind roses for 2009 through 2013 indicate that air generally flows from the southwest through west across the county, except for the preponderance of winds from the south at AGC. Low wind speeds, which occurs frequently overnight and often during temperature inversions, can lead to increased $PM_{2.5}$ levels, especially in the many river valleys throughout Allegheny County. PIT and AGC wind roses for 2011, the modeled base year, are similar to the wind roses for 2009, 2010, 2012, and 2013.

At the Liberty monitor – the location of the county's traditionally highest $PM_{2.5}$ concentrations – for 2011 in particular and for 2009 through 2013 in general, the most frequent wind direction and fastest wind speed on average were from the southwest, the highest average temperature was from the south-southeast through south-southwest, and the highest concentration of $PM_{2.5}$ on average came from the south-southwest.

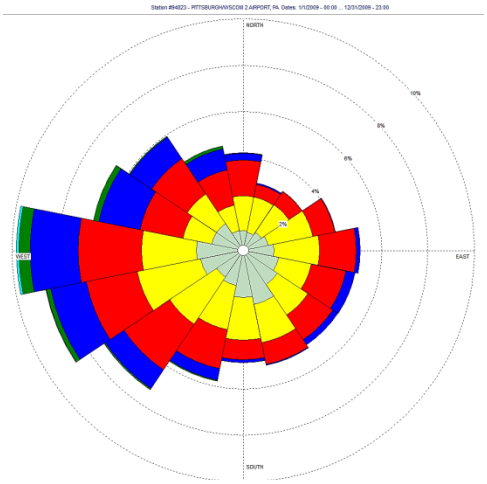
Overall, the meteorological review shows that the modeled base year of 2011 is rather suitable to represent typical conditions of the period. Exceptions include one month, October 2011, recording the largest inversion strength of any month during the five-year period, as well as substantially higher than normal precipitation for southwestern Pennsylvania and Allegheny County during the full year. More recent years have recorded above normal average temperatures along with precipitation amounts substantially above normal; therefore, the 2011 base year may well represent these more current conditions.

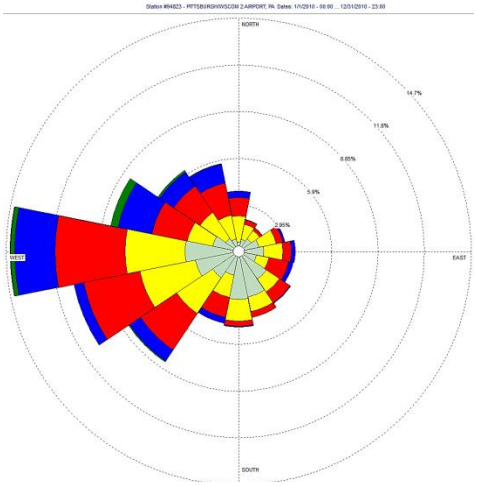
As noted above, concentrations generally declined at monitors throughout the county. However, the decline in $PM_{2.5}$ concentrations during the five year period of interest was not steady. In 2010, all monitors increased by about 1 to 2 $\mu g/m^3$ before continuing the downward trend in subsequent years. From a meteorological perspective, this increase may have resulted from the

increased occurrence and characteristics of morning surface temperature inversions during 2010. The greatest strength of any year during the period, 4.1 °C, occurred in 2010. This strength can be compared with the 2009, 2011, 2012, and 2013 average of 3.7 °C. In addition, 2010 had the lowest top during the period, 226 m, which can be compared with the remaining four year average of 240 m. (A lower height to inversions can help further confine $PM_{2.5}$ to the lowest layer of the atmosphere.) 2010 also recorded the highest inversion frequency of 47%, which can be compared with the remaining four year average frequency of 40%. Finally, as the following PIT and AGC wind roses display, 2010 was characterized by a high frequency of winds from the west, which may have contributed to increased primary and secondary $PM_{2.5}$ from large emitters west of Allegheny County.

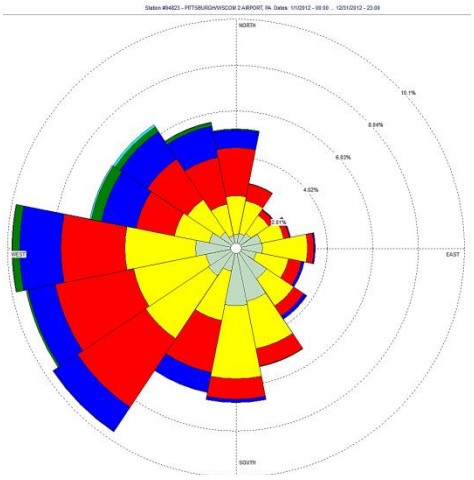
Additional Airport Wind Roses

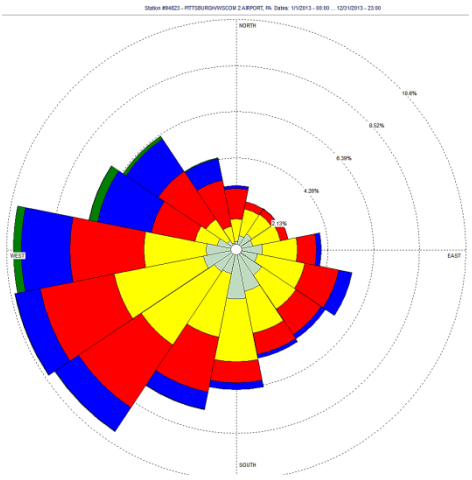
PIT Wind Roses 2009, 2010, 2012, 2013 (See earlier page for **2011**.)





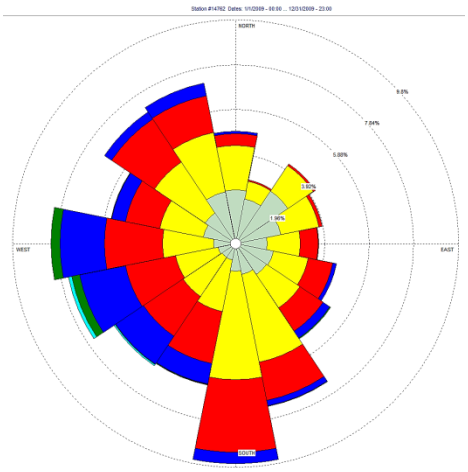
2009 **2010**



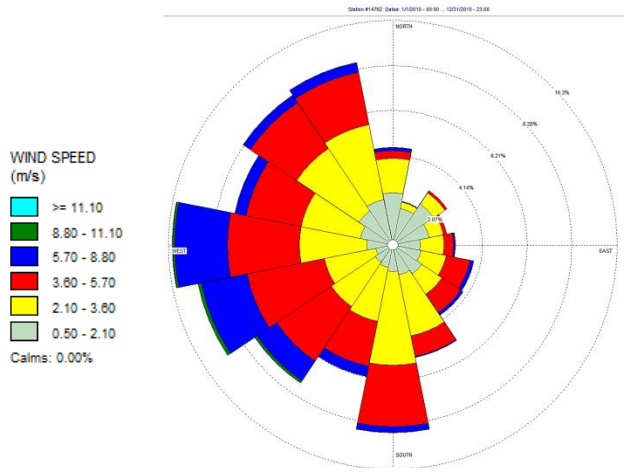


2012 **2013**

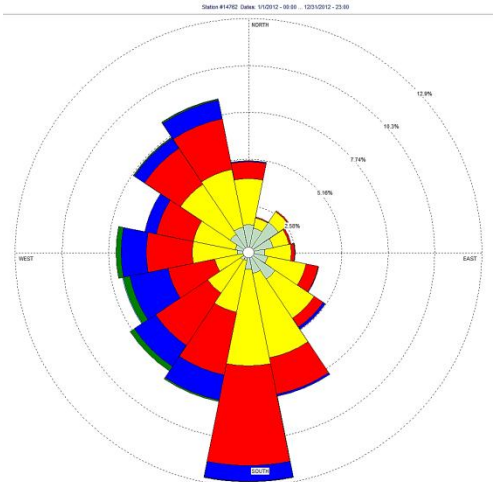
AGC Wind Roses 2009, 2010, 2012, 2013 (See earlier page for **2011**.)



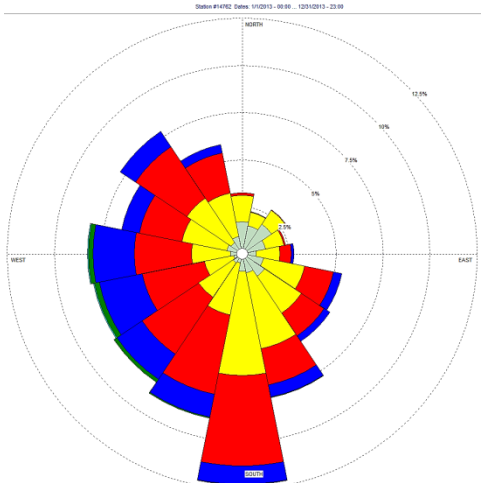
2009



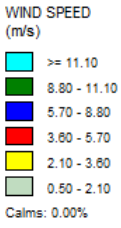
2010



2012



2013



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