Allegheny County Surface Temperature Inversion Analysis - 2019

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As with the 2018 report, this report begins with a discussion of the relationship between air pollution dispersion and ground level temperature inversions. Then, morning inversion conditions over the past twelve years as determined from Pittsburgh National Weather Service upper-air data are reviewed. The report concludes with perspective on 2019 dispersion conditions based on temperature inversions and the potential influence of another year of excessive precipitation. An appendix provides further details on Pittsburgh morning surface inversions.

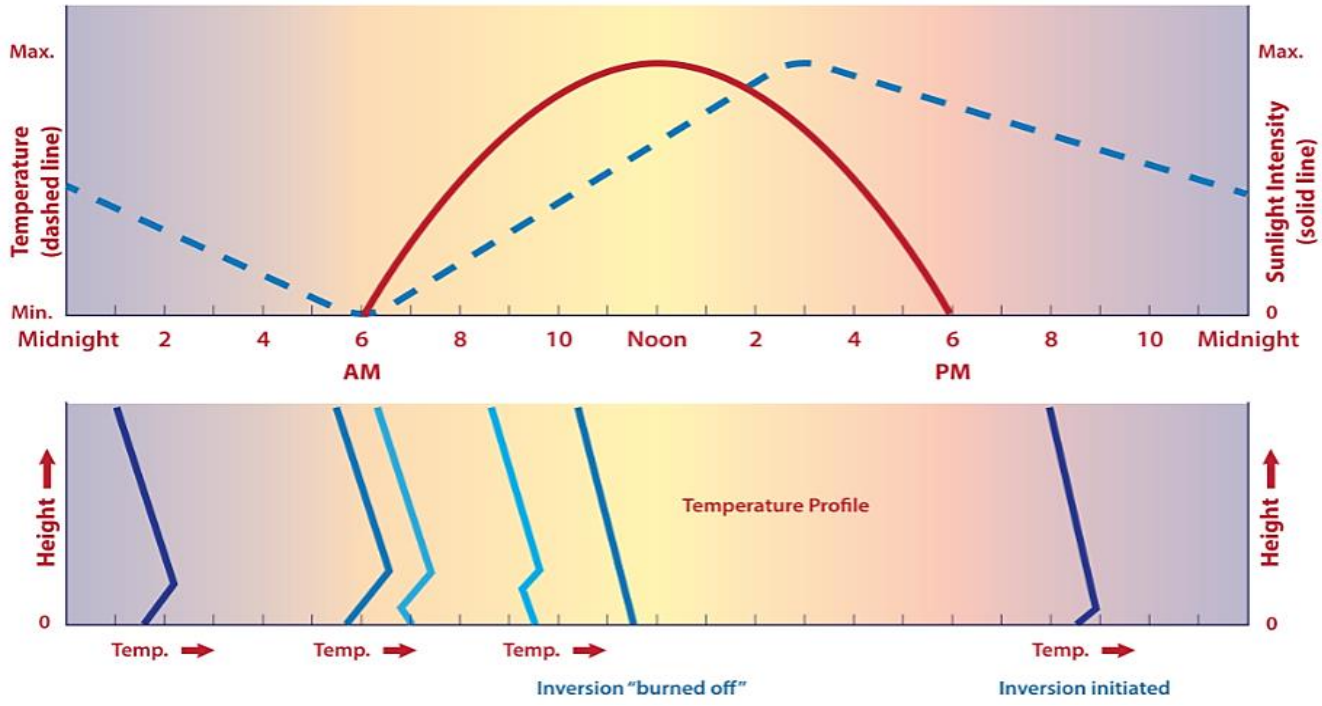
Air Pollution Dispersion and Surface Temperature Inversions

Worst case air pollution dispersion conditions in the lowest layer of the atmosphere usually involve times when temperature increases with height above the surface of the earth. This condition is referred to as a ground level "temperature inversion." During times of such inversions, mixing of the atmosphere is suppressed and contaminants released into the air tend to remain at higher concentrations. Temperature inversion conditions typically form soon after sunset and last until a few hours after sunrise; although, conditions extending beyond 24 hours have occurred.

The following figure depicts the usual sequence of events leading to the formation and destruction of a ground-level radiation-type inversion. The assumption is that few or no clouds exist during the sequence of events shown and that wind speeds remain light.

DAILY LIFECYCLE OF SURFACE TEMPERATURE INVERSIONS

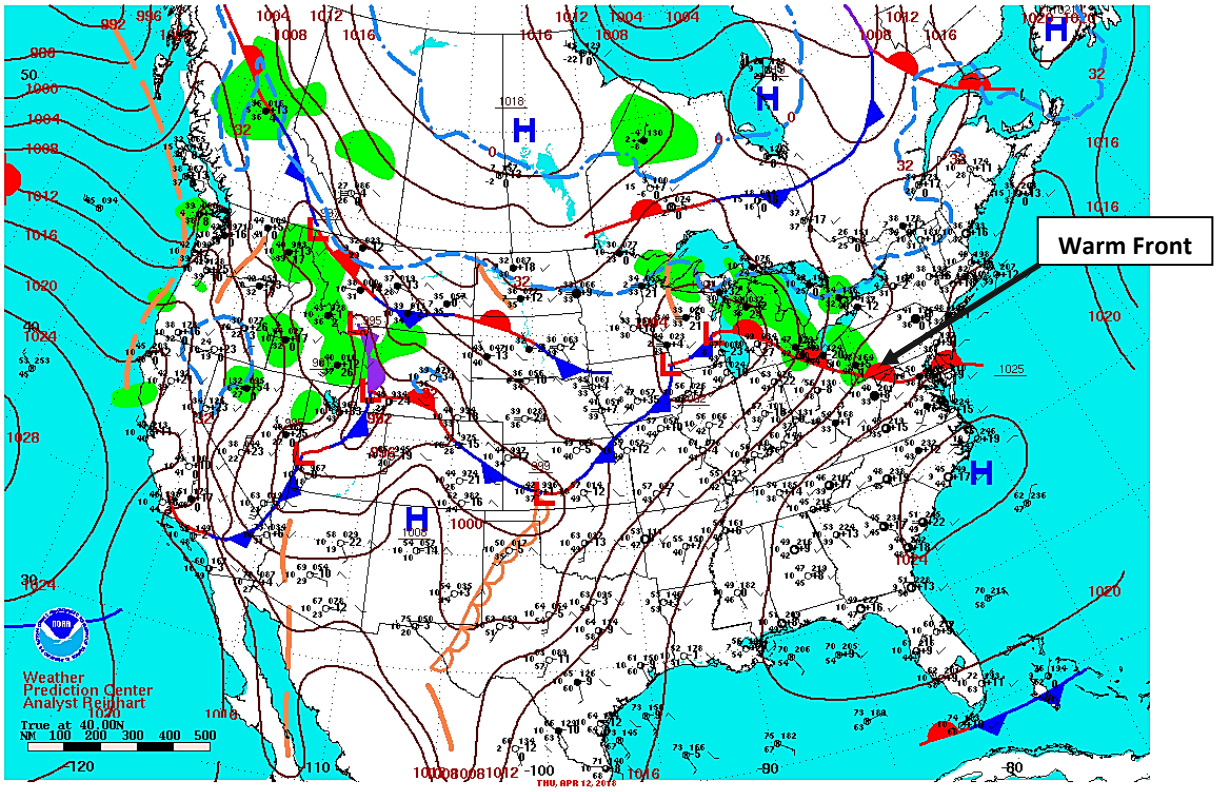
STYLIZED DIURNAL VARIATION OF TEMPERATURE, SUNLIGHT INTENSITY, AND VERTICAL TEMPERATURE PROFILE IN CONTINENTAL MID-LATITUDES

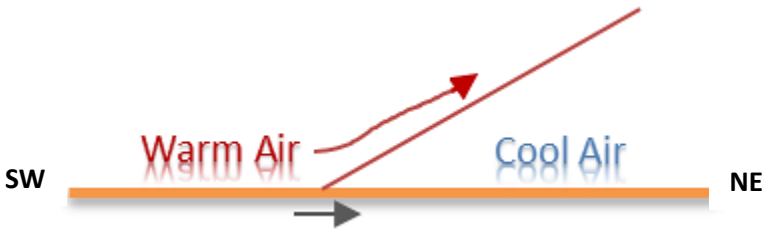


EXPLANATION:

6 AM (Sunrise) - Sunlight intensity weak, surface temperature begins to increase from overnight minimum, ground inversion strongest.	**Noon** - Sunlight intensity maximum.
7 AM - Sunlight intensity increases as sun rises and ground is warmed, which in turn, warms the air. Thus, inversion "burns off" from ground up.	**3 PM** – Approximate time of maximum temperature (because of time lag between ground heating and subsequent air heating).
11 AM – Inversion completely burned off (i.e., typical daytime profile developed).	**6 PM** (Sunset) - Sunlight intensity negligible, temperature decreasing, ground inversion soon to begin. **At night**, temperature decreases, ground inversion strengthens.

Surface-level inversions can form in other ways, such as when warm air moves over cooler surface air as a warm font is advancing into an area (see map and schematic below) or with strong southerly flow over a cool ground, or when cool maritime air undercuts warm continental air as in the Los Angeles basin.





The schematic shows that, as viewed from the side, the advancing warm, light air from the southwest would be riding up over the cooler, heavier air ahead of it to the northeast. Under these conditions, above the head of the short black arrow in the figure, a surface inversion is occurring with warm air above cool air. In addition, precipitation often accompanies the advection of a warm front.

Surface Temperature Inversion Data for Pittsburgh

The table below gives the strength and frequency of substantial surface-based temperature inversions estimated from NWS balloon launches near Pittsburgh, PA from 2008 through 2019. In this recent twelve-year period, the strength of the morning (7:00 a.m. EST) inversions was 3.8^{o}C on average. The depth of the inversion layer topped out at an average height of 243 meters above the ground. Following sunrise and solar heating of the ground surface, the inversions tended to dissipate by 9:30 am EST. (Understandably, stronger, deeper inversions typically take longer to dissipate.) The frequency of morning inversion occurrence during this period averaged 43 percent of all days annually (about 157 days per year), a substantial amount.

INVERSION STATISTICS* FOR **2008–2019** 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 (%)
2008	4.1	2.4	263	155	10.0	160 (44)
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)
2014	3.4	1.9	233	117	9.5	141 (39)
2015	3.9	2.1	250	139	10.0	166 (45)
2016	4.1	2.5	262	146	10.0	167 (46)
2017	3.8	2.1	214	134	9.5	203 (56)
2018	3.3	2.0	260	170	10.0	146 (40)
2008-2018	**3.8**	**2.2**	**242**	**135**	**9.5**	**157 (43)**
2019	**3.8**	**2.1**	**253**	**128**	**10.0**	**157 (44)**
2008-2019	**3.8**	**2.2**	**243**	**134**	**9.5**	**157 (43)**

* **For morning (12Z) surface inversions of at least 1.0°C in strength** derived from Pittsburgh National Weather Service (PIT NWS) sounding data observed at 7 am EST. Shallow isothermal and/or unstable conditions may also be present below or within the ground inversion. A minimum surface inversion strength of 1.0^{o}C was chosen to ensure that an inversion observed at the NWS office at a relatively high elevation was indicative of conditions throughout most of the rest of the county.
** Estimated break time is to nearest half hour Eastern Standard Time (EST). Method for calculating break time (developed by A.J. Sadar) was altered slightly for 2008 and 2014 through 2019; however, values are comparable with other years.

In the many valleys and low-lying areas of southwestern Pennsylvania, inversions can form first and/or be more intense and persistent than at elevated locations. The surface inversion minimum of 1.0^{o}C was chosen to make sure that an inversion observed at the Pittsburgh NWS station in western Allegheny County at a relatively high elevation was also indicative of conditions throughout most of the rest of the county where elevations can be lower. In addition, surface inversions were required to be typically at least 15 m deep to be considered significant.

Besides the annual inversion data for Allegheny County tabulated above, the county's inversion frequency and strength are analyzed by month. See the Appendix for these data, which also provides very useful information regarding the seasonal variation of inversion severity.

The season with the overall worst-case morning inversions is Fall (September, October, and November). Fall has the strongest inversions and those inversions are statistically deep, frequently-occurring, and persistent. By

contrast, the season with the overall most-favorable dispersion conditions (as measured by morning surface inversions) is Summer (June, July, and August). Even though inversions occur the most frequently in Summer, those inversions are also the weakest, the most-shallow, and dissipate sooner than for any other season because of an earlier sunrise and later sunset during the Summer.

Perspective on 2019 Conditions

Although the Pittsburgh area did not experience the record-setting precipitation amounts it received in 2018, the amount of annual precipitation was quite large at about 14¼ inches above the normal (30-year average) value of 38.19 inches. (Note that reliable meteorological records have been kept for Pittsburgh since 1871.)

Like last year's unprecedented amount of precipitation, an excess of more than 14 inches is a lot of extra water on the ground and in the air. Water mitigates temperature extremes. So, although Pittsburgh temperatures on average were about 1°F above normal for the year, the additional moisture was not only the result of increased total precipitation from storms passing through the area, but in turn impacted the micrometeorology of the county.

Unlike 2018, the additional moisture apparently did not have much impact on the total days of inversions in 2019. In fact, as seen in Table A1, annual conditions this year were quite consistent with the 2008 – 2018 average. Yet, Fall experienced some near average to below average conditions, especially in November. As discussed in the previous section, Fall is usually the season with the poorest dispersion conditions relative to morning surface inversions. September and October registered substantially above average amounts of inversions and strengths and depths were roughly near average, but precipitation totals each month were excessive. Alternatively, even with a well-below average monthly precipitation total, November measured substantially lower strength and depth inversions. These conditions helped to keep the atmosphere from concentrating excessive pollution levels during the Fall. So, while there were six SO_2 and nine $PM_{2.5}$ exceedances in 2019, none of the 15 exceedances occurred during the Fall of 2019. (Note that there were no O_3 exceedances in 2019.)

All the $PM_{2.5}$ exceedances in 2019 occurred during two stagnation periods. The first period was February 2 – 4; the second one was December 21 – 26. Both events happened as a high pressure systems settled into the area. Strong inversions were present and their effects persisted throughout the morning and in some cases apparently did not completely dissipate the entire day.

The December stagnation period was one of the strongest during the 12-year period of record (November 2016 underwent a similar event). As the tables in the appendix show, December 2019 was a remarkable month for surface inversions when compared to December statistics on record since 2008. The percentage of December 2019 morning inversions was substantially higher than the average percentage of monthly morning inversions from the previous Decembers. The average strength of the December 2019 morning surface inversions was much higher than the December monthly average strengths. In fact, December 2019 had the strongest morning surface inversion average on the record that goes back through 2008. In addition, the December 2019 average depth of 307 m was higher than the previous December averages, and the average estimated break time of the December 2019 surface inversions was an hour longer than the average of the previous Decembers. Finally, as mentioned above, several morning inversions apparently did not break generating extended stagnation periods in mid- and later- December.

Acknowledgements

The author is grateful for compilations/evaluations and additional assistance provided by **Allason Holt**, **Fiona Gao**, **Carlos Lopez**, and **Qiao Lin**, Allegheny County Health Department (ACHD), Air Quality Program. The author also thanks **Christopher Letzelter** of ACHD for the graphic depiction of sunlight intensity and temperature profile and **Matthew Kramer** at the Pittsburgh National Weather Service and **Stan Penkala** of Air Science Consultants, Bridgeville, PA for helpful comments on the 2018 report content. Additional beneficial comments/redactions by Air & Waste Management Association's *EM* magazine Editorial Advisory Committee members who were reviewers of an *EM Plus* version of portions of the 2018 report are also acknowledged.

APPENDIX: ANNUAL, MONTHLY, and SEASONAL DIFFERENCES in Pittsburgh Morning Surface Temperature Inversions

Table A1. INVERSION STATISTICS***** FOR 2008–2019 DERIVED FROM PIT NWS DATA

Year	Avg. Strength (ºC)	Strength Std. Dev. (ºC)	Avg. Top (m)	Top Std. Dev. (m)	Est. Break Time** (EST)	Total Days of Inversion (%)
2008	4.1	2.4	263	155	10.0	160 (44)
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*** For morning (12Z) surface inversions of at least 1.0ºC in strength** derived from Pittsburgh National Weather Service (PIT NWS) sounding data (shallow isothermal and/or unstable conditions may also be present below or within ground inversion).
****** Estimated break time is to nearest half hour Eastern Standard Time (EST). Method for calculating break time was altered slightly for 2008 and 2014 through 2019; however, values are comparable with other years.

Table A2. AVG. STRENGTH (ºC):* 2008–2019, DERIVED FROM PIT NWS SOUNDINGS

Month	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2008-2018	2019
JAN	2.7	3.4	5.2	3.1	4.1	4.0	4.2	4.1	4.0	4.3	4.0	3.9	2.8
FEB	4.9	4.2	3.1	3.4	3.3	4.3	3.2	3.1	3.1	2.8	5.1	3.6	5.0
MAR	3.7	3.8	4.9	3.6	5.1	3.2	3.0	4.3	4.6	2.9	2.4	4.0	4.4
APR	4.2	4.4	4.4	3.6	4.0	3.1	3.6	3.7	4.4	3.6	3.7	3.9	3.0
MAY	4.0	4.1	3.5	2.9	3.8	2.6	3.5	4.0	3.2	3.0	3.3	3.5	4.2
JUN	3.3	3.3	2.3	3.0	3.0	2.7	3.3	2.5	2.9	2.9	3.1	2.9	3.2
JUL	4.0	2.9	3.3	3.1	3.0	2.6	2.7	3.6	3.2	3.7	2.7	3.2	2.6
AUG	3.3	3.0	4.8	3.3	4.3	3.1	3.6	3.3	3.0	3.5	2.8	3.5	3.3
SEP	4.7	4.0	3.8	3.0	4.3	4.7	3.8	4.0	5.1	5.3	2.8	4.2	3.9
OCT	6.0	3.9	4.7	6.1	3.7	3.9	3.1	3.9	4.7	5.9	2.9	4.4	4.3
NOV	4.1	3.7	5.9	5.0	4.5	3.3	3.3	4.8	5.5	4.5	2.9	4.5	3.0
DEC	5.3	5.2	2.9	4.3	3.6	2.4	3.6	4.9	5.9	3.2	4.4	4.0	6.2
Annual	**4.1**	**3.8**	**4.1**	**3.7**	**3.9**	**3.4**	**3.4**	**3.9**	**4.1**	**3.8**	**3.3**	**3.8**	**3.8**

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

Table A3. AVG. TOP (m):* 2008–2019, DERIVED FROM PIT NWS SOUNDING DATA

Month	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2008-2018	2019
JAN	257	384	373	206	265	220	314	322	224	307	311	286	339
FEB	278	295	208	278	257	301	226	237	262	278	404	275	280
MAR	261	274	204	381	220	235	197	327	320	202	189	255	258
APR	278	265	239	221	259	245	270	258	244	209	196	246	207
MAY	204	216	218	236	205	232	238	231	200	180	264	220	294
JUN	208	236	194	196	189	250	241	267	231	223	191	219	295
JUL	214	173	195	251	214	176	208	228	243	140	216	203	212
AUG	280	207	196	205	219	214	219	213	208	168	274	216	221
SEP	239	286	229	270	217	273	180	204	260	215	263	235	232
OCT	344	219	261	253	231	256	231	210	327	286	203	259	271
NOV	299	208	264	282	251	296	237	278	326	302	298	277	219
DEC	541	323	205	207	241	235	315	327	399	223	356	286	307
Annual	**263**	**244**	**226**	**246**	**229**	**244**	**233**	**250**	**262**	**214**	**260**	**242**	**253**

*** 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).

Table A4. Est. Break Time (EST):* 2008–2019, DERIVED FROM PIT NWS SOUNDINGS**

Month	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2008-2018	2019
JAN	10.5	10.5	11.5	10.5	10.5	11.0	11.0	11.5	11.5	13.0	13.0	11.5	12.5
FEB	12.0	9.5	11.0	9.5	9.5	11.5	11.0	10.0	11.0	10.5	11.5	10.5	11.5
MAR	10.5	9.5	10.5	11.0	10.0	9.5	9.5	10.0	10.0	9.5	9.5	10.0	10.0
APR	9.0	9.0	9.0	9.0	9.0	9.0	9.5	9.0	9.0	9.0	8.5	9.0	9.5
MAY	9.0	9.0	9.0	9.0	8.5	8.0	9.5	8.5	8.5	8.0	8.5	8.5	9.5
JUN	9.0	8.5	8.5	8.0	8.5	8.5	9.0	9.5	9.0	8.5	9.0	8.5	9.5
JUL	9.0	8.5	8.5	9.0	9.0	8.5	8.5	9.0	9.0	8.0	9.0	8.5	9.0
AUG	9.5	9.0	9.0	8.5	9.5	9.0	9.5	9.0	9.0	8.5	9.5	9.0	9.0
SEP	9.5	9.5	9.0	9.5	9.5	10.0	9.5	9.0	9.5	9.5	9.5	9.5	9.5
OCT	11.0	10.0	10.5	11.0	10.0	10.0	10.0	10.0	10.5	10.5	9.5	10.5	11.0
NOV	11.0	10.5	11.0	11.0	11.0	11.0	10.0	11.0	11.0	11.0	9.5	11.0	11.5
DEC	12.0	11.0	9.5	10.5	11.0	11.0	12.0	13.0	13.0	11.0	12.5	11.5	12.5
Annual	**10.0**	**9.5**	**9.5**	**9.5**	**9.5**	**9.5**	**9.5**	**10.0**	**10.0**	**9.5**	**10.0**	**9.5**	**10.0**

***** Estimated break time is to nearest half hour Eastern Standard Time (EST). Method for calculating break time was altered slightly for 2008 and 2014 through 2019; however, values are comparable with other years.

**** 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).

Table A5. Total Days of Inversions: 2008–2019, DERIVED FROM PIT NWS SOUNDINGS*

Month	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2008-2018**	2019
JAN	8 (26)	7 (23)	5 (16)	5 (16)	9 (29)	8 (26)	7 (23)	7 (23)	12 (39)	9 (29)	13 (42)	8 (26)	5 (16)
FEB	7 (24)	8 (30)	8 (30)	10 (36)	10 (36)	6 (21)	8 (29)	8 (29)	9 (31)	10 (36)	9 (32)	7 (30)	8 (30)
MAR	8 (27)	12 (43)	17 (55)	7 (23)	11 (35)	6 (19)	8 (29)	11 (35)	15 (48)	9 (29)	9 (29)	9 (34)	10 (32)
APR	18 (60)	11 (37)	20 (67)	6 (20)	12 (40)	10 (33)	14 (47)	11 (37)	12 (40)	23 (77)	6 (20)	12 (43)	9 (38)
MAY	17 (55)	18 (64)	16 (52)	13 (43)	14 (45)	9 (29)	13 (42)	19 (61)	15 (48)	16 (52)	17 (55)	14 (50)	11 (35)
JUN	15 (50)	14 (61)	14 (47)	8 (28)	13 (43)	13 (43)	13 (43)	8 (27)	11 (37)	20 (67)	14 (47)	12 (44)	12 (40)
JUL	18 (60)	16 (52)	17 (55)	18 (60)	15 (48)	9 (29)	11 (37)	19 (61)	16 (52)	27 (87)	18 (58)	16 (54)	16 (52)
AUG	18 (58)	16 (52)	15 (48)	21 (68)	19 (61)	16 (52)	17 (55)	21 (68)	21 (68)	27 (87)	17 (57)	18 (61)	21 (68)
SEP	19 (63)	15 (50)	20 (67)	12 (40)	14 (47)	14 (47)	20 (67)	20 (67)	18 (60)	25 (83)	14 (47)	16 (58)	23 (77)
OCT	16 (52)	15 (48)	16 (52)	11 (35)	15 (48)	18 (58)	13 (42)	14 (45)	15 (48)	14 (47)	12 (39)	14 (47)	19 (61)
NOV	13 (43)	14 (47)	17 (57)	12 (40)	17 (57)	10 (33)	9 (30)	13 (43)	21 (70)	13 (43)	7 (23)	12 (44)	11 (37)
DEC	3 (10)	8 (26)	6 (19)	11 (35)	9 (29)	8 (27)	8 (26)	15 (48)	2 (6)	10 (32)	10 (33)	8 (27)	12 (39)
Annual	**160 (44)**	**154 (44)**	**171 (47)**	**134 (37)**	**158 (43)**	**127 (35)**	**141 (39)**	**166 (45)**	**167 (46)**	**203 (56)**	**146 (40)**	**157 (43)**	**157 (44)**

*** 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.

****** For 2008-2018 values, "total days" listed per month are weighted averages for comparison to 2019 data.

Missing/Incomplete Days in 2019 include: February 12, April 1, 2, 20, 21, 22, and 23.

The tabulated Pittsburgh, Pennsylvania NWS morning surface inversion data show the following:

The season with the **overall worst-case dispersion conditions** (as measured by morning surface inversions) is **Fall** (September, October, and November). Fall has the strongest inversions, while being the season with the second most deep, second most persistent, and second most frequent occurrence of inversions.

The season with the **overall best-case dispersion conditions** (as measured by morning surface inversions) is **Summer** (June, July, and August). Although the most inversions occur in Summer, these inversions were also the weakest, the most-shallow, and dissipated sooner than for any other season. In addition, the 10-year frequency of Summer inversions was skewed upward substantially by an unusually high frequency of Summer 2017 inversions.

The season with the **strongest** inversions is **Fall** (September, October, and November).
The season with the **weakest** inversions is **Summer** (June, July, and August).
The season with the **deepest** inversions is **Winter** (December, January, and February).
The season with the **most-shallow** inversions is **Summer** (June, July, and August).
The season with the **longest-lasting** inversions is **Winter** (December, January, and February).
The season with the **shortest** inversions is **Summer** (June, July, and August).
The season with the **most** inversions is **Summer** (June, July, and August).
The season with the **fewest** inversions is **Winter** (December, January, and February).

Trends in this data set are difficult to see. Except for some occasional substantial excursions from the average, inversion strengths, depths, and estimated break times all appear to be somewhat steady overall.

Finally, the following recent seasonal tables indicate that with respect to morning surface inversion conditions, 2019 was a year that fit roughly between 2017 and 2018 with respect to data categories. Hence, 2018 had generally good atmospheric dispersion conditions, 2017 had poor conditions, and 2019 experienced moderate conditions by comparison.

2019 Seasonal Morning Surface Inversion Frequencies

2019 SEASONAL MORNING SURFACE INVERSIONS	INVERSION STRENGTH (Total = 357*) (% of Season)				
	None	Slight	Weak	Moderate	Strong
Winter (Dec '18-Feb '19)	71	3	11	3	11
Spring (Mar-May)	58	7	14	9	12
Summer (Jun-Aug)	37	10	26	23	4
Fall (Sep-Nov)	37	4	19	24	15
All Seasons	50	6	18	15	11

* Eight days (Dec. 21, 2018 & Feb. 12, Apr. 1, 2, 20, 21, 22, 23, 2019) had missing or incomplete data.

2018 Seasonal Morning Surface Inversion Frequencies

2018 SEASONAL MORNING SURFACE INVERSIONS	INVERSION STRENGTH (Total = 364*) (% of Season)				
	None	Slight	Weak	Moderate	Strong
Winter (Dec '17-Feb '18)	60	7	13	8	12
Spring (Mar-May)	60	5	20	11	4
Summer (Jun-Aug)	44	3	26	23	3
Fall (Sep-Nov)	60	3	20	12	4
All Seasons	56	5	20	13	6

* For 2018, one day (August 19) had missing data.

2017 Seasonal Morning Surface Inversion Frequencies

2017 SEASONAL MORNING SURFACE INVERSIONS	INVERSION STRENGTH (Total = 364*) (% of Season)				
	None	Slight	Weak	Moderate	Strong
Winter (Dec '16-Feb '17)	70	7	6	12	6
Spring (Mar-May)	34	15	24	18	9
Summer (Jun-Aug)	11	8	33	37	12
Fall (Sep-Nov)	36	6	10	20	29
All Seasons	37	9	18	22	14

* For 2017, one day (October 18) had missing data.

Surface inversion strength was determined from daily observations made at the Pittsburgh National Weather Service. Definitions of inversion strength include, "None" (<~0.2°C); "Slight" (~0.3 °C ~0.8°C); "Weak" (~0.9°C ~ 3°C); "Moderate" (~3°C ~ 5°C); and, "Strong" (≥ ~5°C).

Additional information and discussion related to the content of this document can be obtained by contacting: Anthony.Sadar@alleghenycounty.us.

A.J. Sadar, ACHD/AQP, March 9, 2020 (Rev. 4/8/'20)