12.3 COMPARISON OF RADIOSONDE AND SODAR / RASS TEMPERATURE MEASUREMENTS IN THE LOWEST LEVEL OF THE ABL IN COMPLEX TERRAIN

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1. SYNOPSIS

A better understanding of the lowest level of the atmospheric boundary layer (ABL) is important to improved air pollution forecasting, deciphering air quality trends, more-realistic dispersion models, and public health protection. Various equipment is used to sense the lowest level. Here we examine the simultaneous measurements made by a U.S. National Weather Service (NWS) radiosonde and a sodar/RASS unit. Included are observations from a 10 m meteorological tower installed to supplement the sodar/RASS measurements.

The area examined is the complex terrain of Allegheny County, Pennsylvania. Analysis is based on radiosonde data collected from the Pittsburgh NWS field office (PIT NWS) in western Allegheny County and sodar/RASS/10 m tower data collected from an industrial site located in Clairton, PA in southern Allegheny County.

Readings taken during the spring of 2019 are evaluated. The PIT NWS radiosonde data represent 12Z (7 am EST) and 00Z (7 pm EST) readings, while the Clairton sodar/RASS/10 m tower values are measurements typically made during the actual time of the initiation of the radiosonde launch.

Results reveal differences in topography and suburban (PIT NWS) versus more-urban (Clairton) settings along with differences in the measurement techniques and challenges related to establishing sensors in an industrial locale. The impact of synoptic conditions and the urban heat island effect are also considered.

2. SETTING

Air quality in general across the United States has been improving. Yet, each year, in many U.S. locations there are still numerous days and extended periods of unhealthy air pollution levels. This is particularly true in areas susceptible to atmospheric stagnation. Allegheny County, in southwestern Pennsylvania, is one of those areas because of its complex terrain. Air can become trapped in the valleys associated with the three rivers of Pittsburgh, PA (located near the center of Allegheny County), namely the Allegheny, Monongahela, and Ohio rivers. Once confined, pollution levels can rise quickly, especially along the Monongahela River south of Pittsburgh where America's largest coking operation is located in the city of Clairton.

3. SENSING THE LOWEST PART OF THE ABL

In 2018, the Allegheny County Health Department (ACHD) completed installation of a Scintec sound detection and ranging / radio acoustic sounding system (sodar/RASS) on the property of the United States Steel Corporation Clairton coke works. The sodar/RASS senses the air above the industrial site every 15 min, from 40 m to 200 m, at 20 m intervals. In 2019, the sodar/RASS was complemented onsite with a 10-meter meteorological tower with Met One temperature sensors positioned at 2 m and 10 m and a sonic anemometer at 10 m.

Data collected from the sodar/RASS/tower output were compared with Pittsburgh National Weather Service (PIT NWS) radiosonde observations (RAOBs) to help understand atmospheric conditions across the complicated terrain of Allegheny County. Figure 1 shows the relative locations of PIT and the sodar/RASS/tower and typical terrain in the county. The direct distance between the two sensing points is about 38 km. In addition, PIT NWS is at an elevation 128 m higher than the sodar/RASS/tower site.

PIT NWS RAOBs from 00Z and 12Z are produced from equipment that usually begins measuring the upper atmosphere at shortly after 23Z and 11Z, respectively. Therefore, sodar/RASS/tower output covering the time periods between 23:00-23:15Z and 11:00-11:15Z, respectively, is used in the PIT NWS and sodar/RASS/tower temperature comparisons, unless the actual PIT NWS launch time is later, then sodar/RASS/tower periods are adjusted to match. In the Eastern Standard Time (EST) zone, these evening and morning times are near the beginning and maximum times of surface temperature inversion

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formation as shown in Figure 2. Measurements made at these times are important to understanding and predicting inversions that have a substantial impact on air quality (Sadar, 2018).

Since moisture conditions were not measured at the sodar/RASS/tower site, PIT NWS mixing ratios were used to convert sodar/RASS raw virtual temperatures to dry air temperatures in order to compare temperatures from the two sites.

4. VALIDATION OF MEASUREMENTS

On two consecutive days in September 2019, Dr. Richard Clark and two of his students from Millersville University in Pennsylvania released a series of radiosondes to help ACHD validate its sodar/RASS/tower measurements. Examples of comparisons made with 00Z and 12Z September 25th PIT NWS soundings are given in Figure 3. As the diagrams indicate, except for ACHD sodar/RASS values in the lowest levels, data match well with PIT NWS soundings.

The lowest level Millersville radiosonde data showed superadiabatic conditions that may have been produced by thermal mass within the first few meters of flight. These values are not graphed. Values from the first two levels (40 m and 60 m) of the sodar/RASS unit did not adequately match the radiosonde values at those levels and so those values were also excluded from the data sets. Considering the industrial setting and previous work with sodar/RASS systems, the questionability of the data from the lowest levels of our sodar/RASS is not necessarily unusual (Angevine, 2000; May et al., 1990; May et al., 1989).

Figure 4 displays the data with the lowest-level Millersville radiosonde data and questionable sodar/RASS lowest level values removed. Subsequent analysis and related graphics were performed without such data. In addition, the radiosonde plot is the result of volume averaging of individual readings to match the sodar/RASS levels of 80 m through 200 m at 20 m intervals.

The right-side set of graphs in Figure 4 give an extended comparison of the Millersville radiosonde raw data with PIT NWS soundings. (In these comparisons, the lowest level readings from the Millersville radiosonde are included.) The results demonstrate the general reliability of the remaining data sets with the PIT NWS soundings at 00Z and 12Z on September 25, 2019. As shown, 00Z conditions were nearly adiabatic, while at 12Z the atmosphere was stable with a strong surface temperature inversion (6.6°C for 185 m at PIT NWS).

The comparisons show what was discovered to be generally true between the data sets from measurements in the somewhat urban Clairton river valley location and the more suburban and elevated PIT NWS location. During September 25 (00Z) low-level unstable conditions, as shown in the top graphs of Figure 4, mixing is present and the Clairton valley is noticeably warmer than the PIT NWS higher elevation. Conversely, when the atmosphere is stable, as in the September 25 (12Z) bottom graphs of Figure 4, air in the valley is substantially cooler than out of the valley.

5. PRELIMINARY SITE-TO-SITE COMPARISONS, SPRING 2019

With data reliability demonstrated by the onsite Millersville radiosonde flights, the sodar/RASS/tower data from Spring 2019 was compared with available PIT NWS sounding data for 00Z and 12Z from March 1, 2019 12Z through June 1, 2019 00Z. Examples of those comparisons are provided in Figure 5. Note that although 10-meter tower data is graphed in the examples, this data is tentative and solely provides an approximate measure of temperatures for comparison to sodar/RASS measurements that begin at 80 m above surface. In addition, several PIT NWS soundings were unavailable at the beginning and middle of April, so a total of 86 comparisons of 00Z and 87 of 12Z data were made.

Although the immediate timeframe is limited to a few hours at most, the spatial considerations must include the micro-, meso-, and synoptic scales of atmospheric motion along with topographic considerations.

For the most part, as indicated by comparisons shown in Figure 4 during the September 25th Millersville validation work, with low-level unstable conditions in the evening, mixing is present, and the Clairton valley is a bit warmer than the PIT NWS higher elevation. Conversely, when the atmosphere is stable in the morning, air in the valley is substantially cooler than out of the valley. (See Figure A in the Appendix for an adjusted graph for unstable conditions that provides a comparison of soundings with relative elevation differences between the out-of-valley PIT NWS site and the in-valley sodar/RASS/tower site. Note that the sodar/RASS/tower site is about 38 km to the southeast of PIT NWS as indicated in Figure 1.)

In addition, there are times when PIT NWS observes no surface inversions (or only a weak one) and the valley sodar/RASS/tower data indicates an inversion or one stronger than at PIT NWS.

A more in-depth evaluation of the data sets reveals some further insight into the temporal and spatial atmospheric dynamics in the complex terrain of Allegheny County.

The coke works property stretches approximately 4 km along the Monongahela river (see Figure 6) and the heaviest industrial activity onsite is roughly aligned in a SE to NW direction in the top (NW) portion of the plant. Since the sodar/RASS/tower site is located near the plant's upper end, winds from the SE would generally transport coke works' heat over the monitoring site. This transport can generate substantial dynamics as the expansive industrial setting can mimic an urban heat island (UHI) (Singh, et al., 2017; Yuval, 2009). And, determining and understanding any influence of a UHI on the atmosphere at the plant would be beneficial for various activities including air quality forecasts and dispersion modeling.

With respect to identifying airflow over the industrial site and vicinity, the sodar/RASS/tower wind data are presently being evaluated. In the interim, general mesoscale airflow was determined from local airport and ACHD meteorological towers to assess the possible influence of the coke works heat on the valley air. Plus, since the UHI is most dramatic at night with light winds and clear skies (Oke, 1987), other synoptic conditions are being included in the ongoing analysis of the local weather situation.

Figure 7a provides examples of sodar/RASS/tower values during times when the mesoscale winds indicated that air in the valley upwind of the sensor site was passing over the plant. Although at such times the effect of a UHI should be apparent, analysis of the data so far does not consistently substantiate this effect. Interestingly, with such wind alignment, the two sets of measurements nearly match (first graph). This varies from the general observation noted above that with unstable atmospheres the sodar/RASS/tower data typically shows substantially warmer results (similar to second graph). As in-valley wind values become available during continued data analysis, relationships are expected to be sorted out.

Figure 7b shows times when the winds were light with some hours of mist and clear skies or occasional cloud cover. Two 12Z (7 am EST) conditions in early March are presented, since this is the time in the spring data set closest to nighttime (EST was just before sunrise on the two days examined). Some warming can be seen, especially in the second graph where sodar/RASS temperatures remain low in the stable inversion conditions in comparison with PIT NWS temperatures and continue to warm beyond the PIT NWS readings.

6. CONCLUSIONS

To date, a comparison of spring 2019 sodar/RASS data with PIT NWS soundings indicates what can be expected from basic principles. With a well-mixed atmosphere, temperatures are warmer at a lower elevation, decreasing with increasing altitude. When the air is stable with a temperature inversion, cooler air sinks into a lower level. There are also times when PIT NWS observes no (or weak) surface inversions and the sodar/RASS/tower data indicates an inversion or one stronger than at PIT NWS. Plus, initial data analysis indicates some influence of a UHI in the Clairton river valley. More investigation is underway to substantiate the extent of such influence on local airflow.

Extra care must be taken when siting remote sensing acoustic equipment on industrial property. Factory buildings and activity (including intermittent noise) can have a deleterious effect on sodar/RASS performance. As the validation work for our units showed, the lowest level sodar/RASS values were suspect and subsequently removed from the data set. The remaining validated data are helping us understand the ABL in and around the county's major, expansive industrial operation. We expect this understanding to help improve air pollution forecasting, decipher air quality trends, and develop more-realistic dispersion models to ultimately assist us with our primary effort to protect public health.

7. ADDITIONAL INFORMATION

Analysis is continuing at ACHD to compare data for all of 2019 including wind measurements. A subsequent report is expected to be presented at the Air & Waste Management Association's annual conference in June 2020. Please contact the corresponding author for additional details, including raw data and further assessment.

8. REFERENCES

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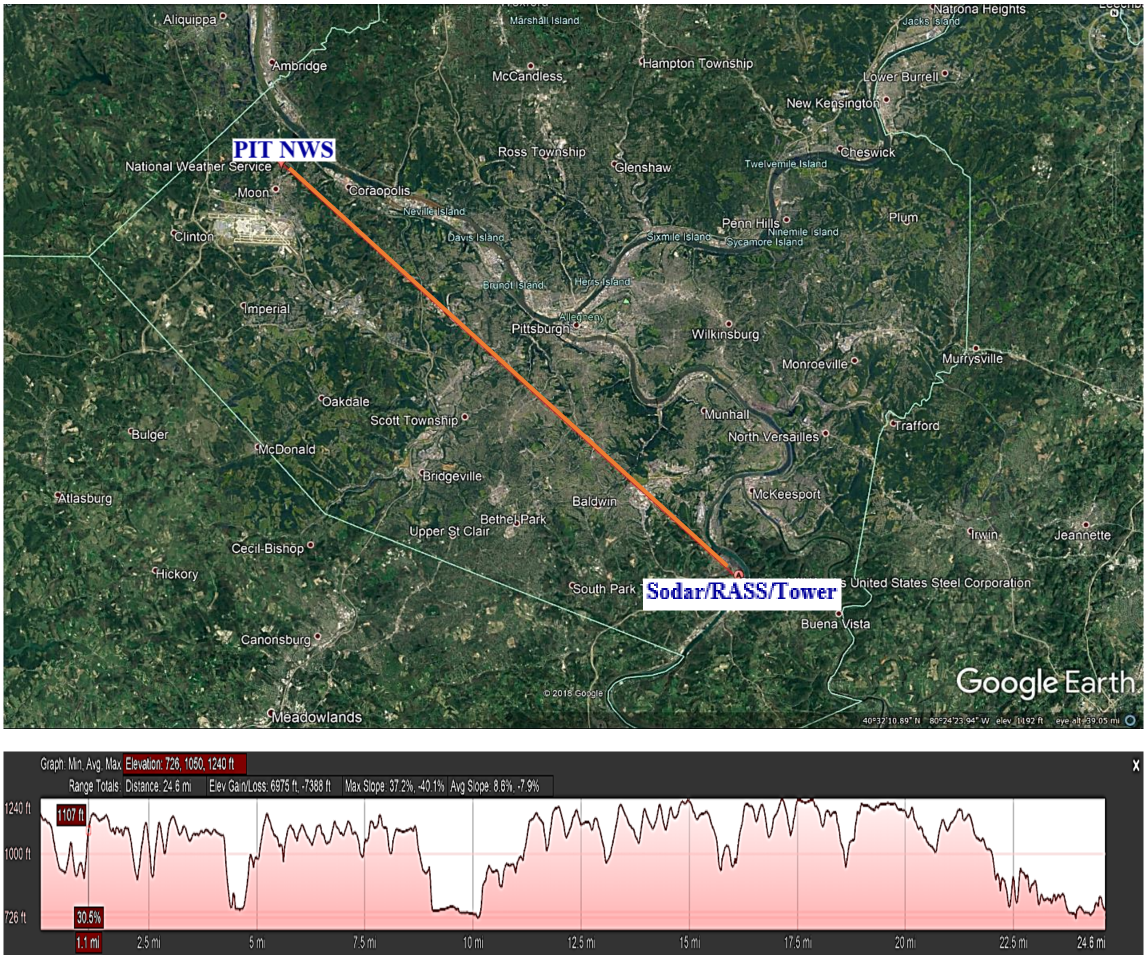
FIGURE 1. Location of PIT and Sodar/RASS/Tower with Terrain Profile Between the Two.



PIT NWS (Distance between PIT and Sodar/RASS/Tower is ~38 km.) **Sodar/RASS/Tower**

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FIGURE 2. Stylized Diurnal Variation of Temperature, Sunlight Intensity, and Vertical Temperature Profile in Continental Mid-latitudes.

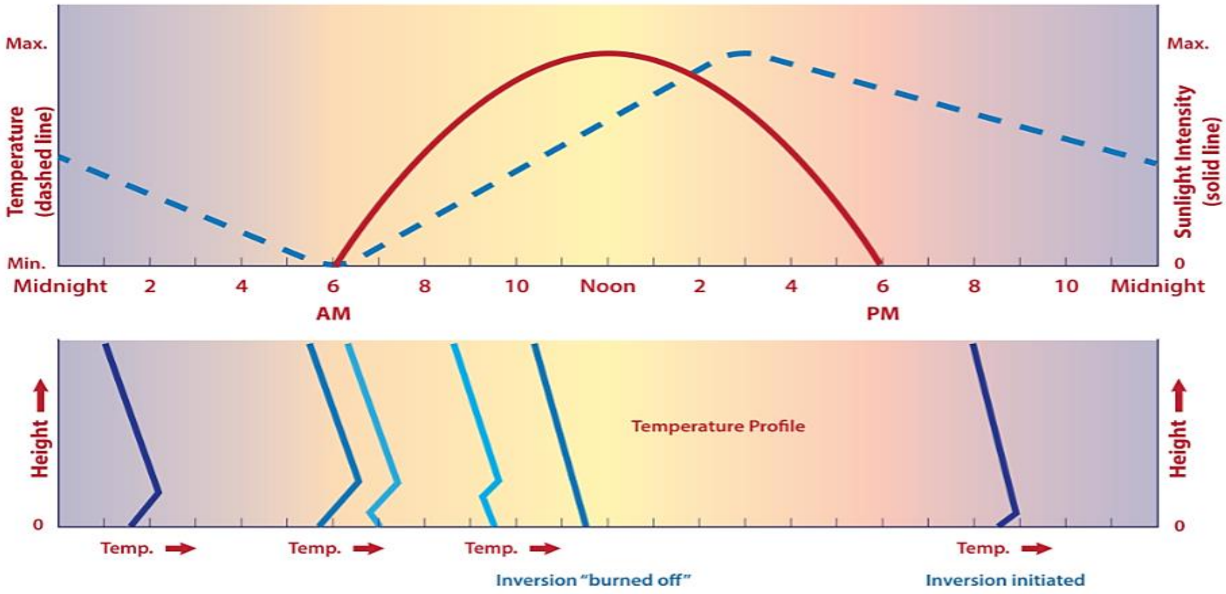


FIGURE 3. Comparisons of PIT NWS September 25, 2019 00Z and 12Z Soundings with Nearly Simultaneous Measurements at Sodar/RASS/Tower Site (Radiosonde Data Volume Averaged).

(Note that PIT NWS is located at an elevation 128 m above the sodar/RASS/tower site and ~38 km to NW.)

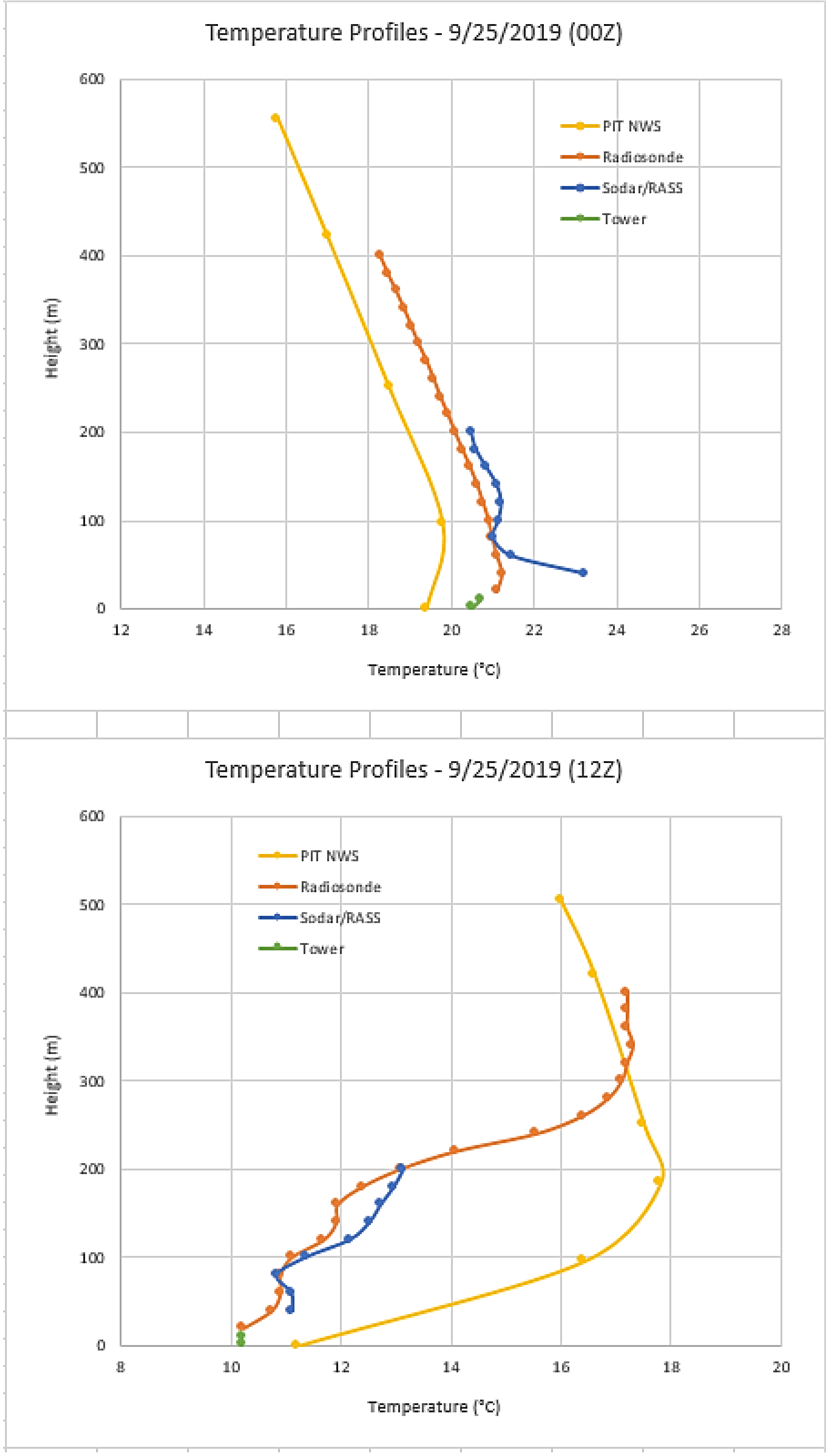


FIGURE 4. As in Figure 3, but with Questionable Sodar/RASS Data Removed, Radiosonde Data Volume Averaged, and Extended Comparison of PIT NWS with Raw Radiosonde Results.

(Note that PIT NWS is located at an elevation 128 m above the sodar/RASS/tower site and ~38 km to NW.)

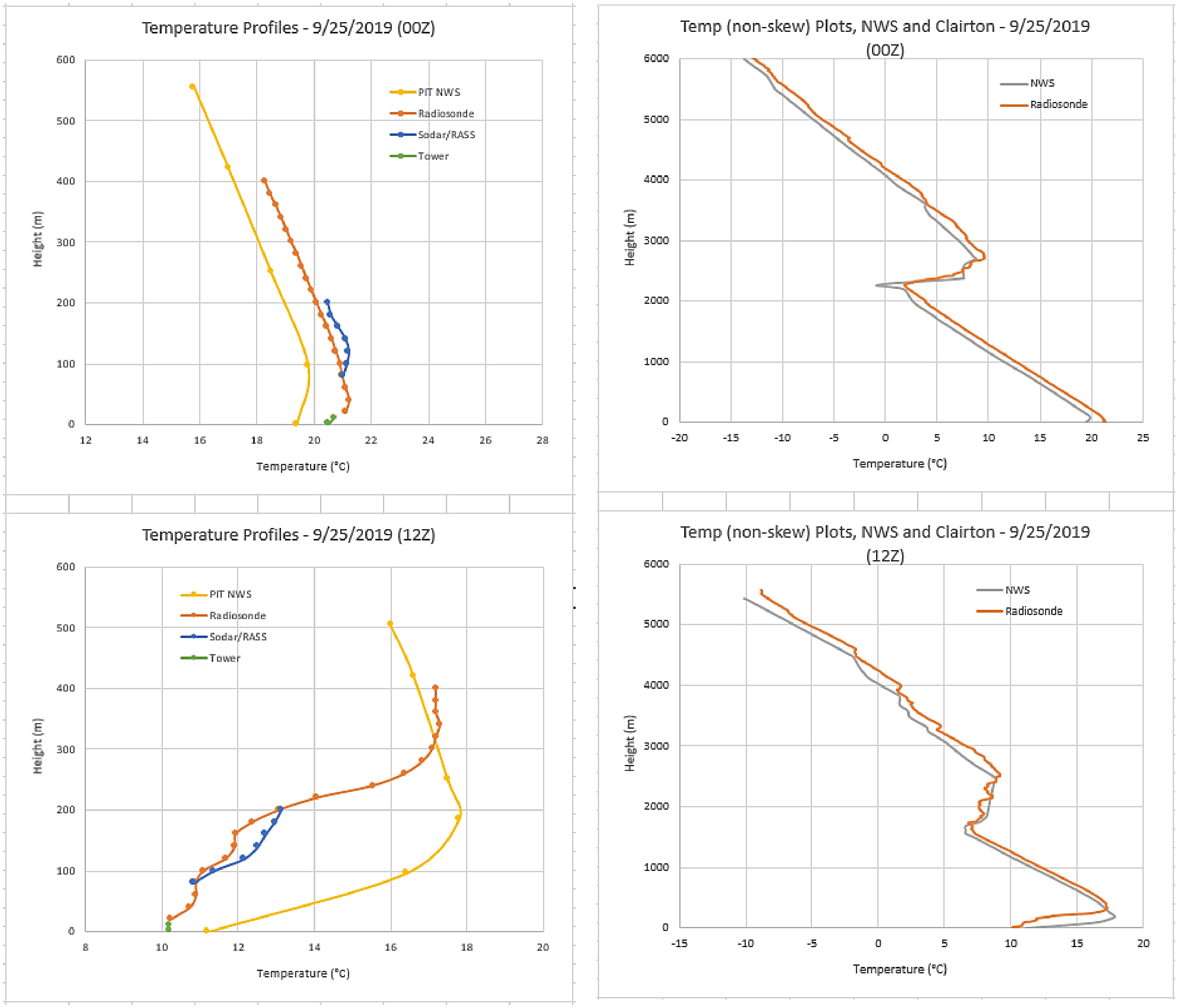


FIGURE 5. Comparisons of Sodar/RASS/Tower Data with PIT NWS Soundings for 12Z and 00Z, Spring 2019.

(Note that PIT NWS is located at an elevation 128 m above the sodar/RASS/tower site and ~38 km to NW.)

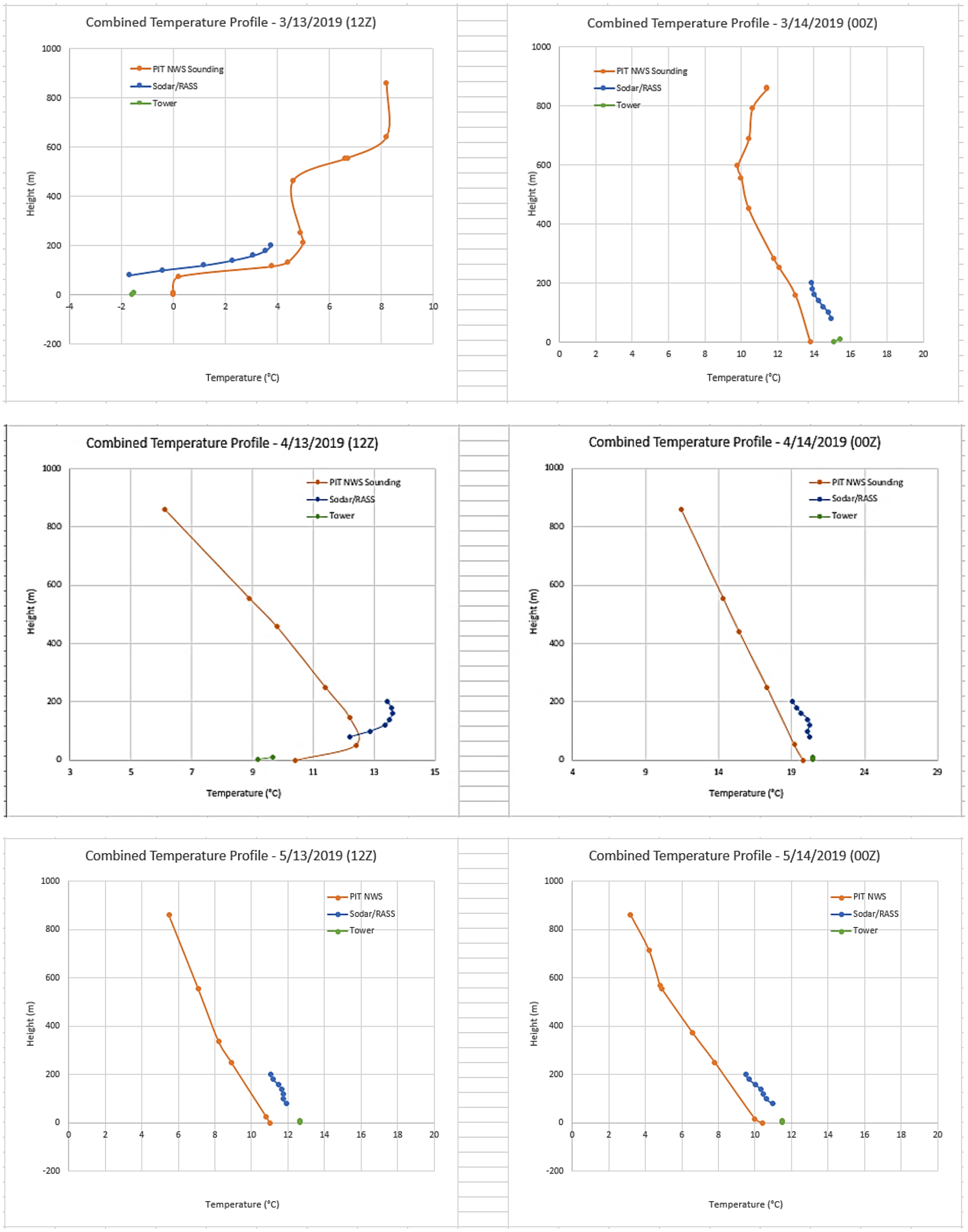
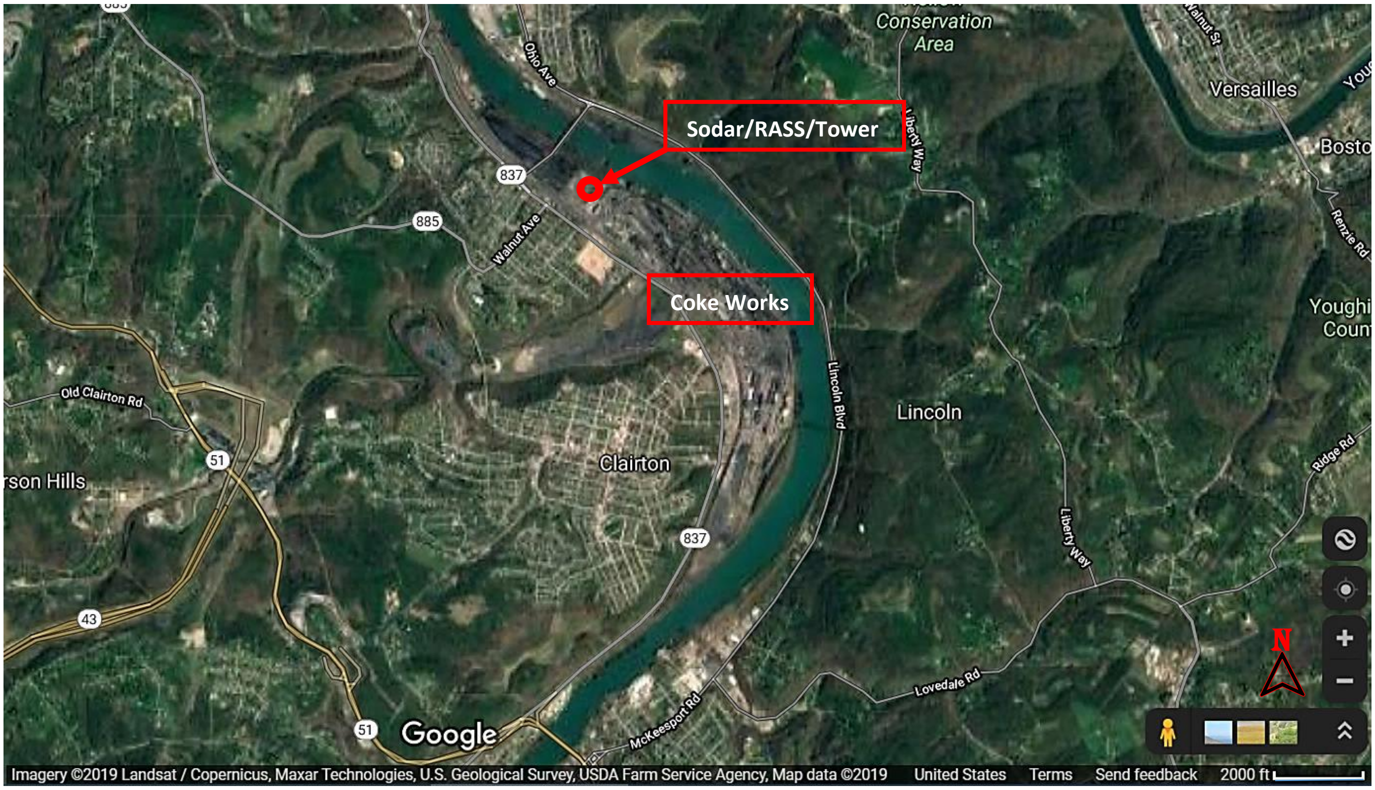


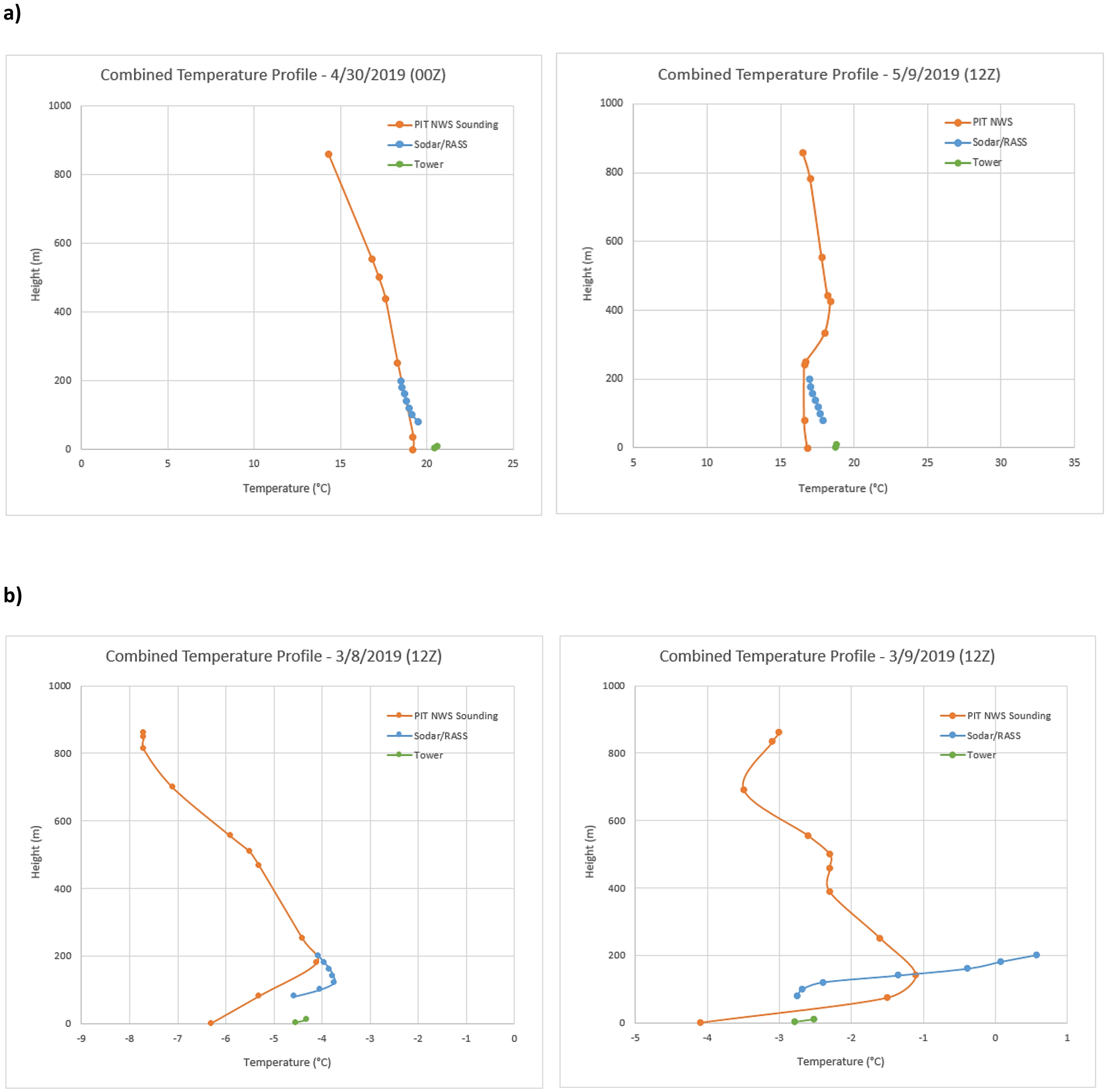
FIGURE 6. Clairton Coke Works Showing Location of Sodar/RASS/Tower Site.



Source: Google Maps, downloaded and adapted, 12-12-2019.

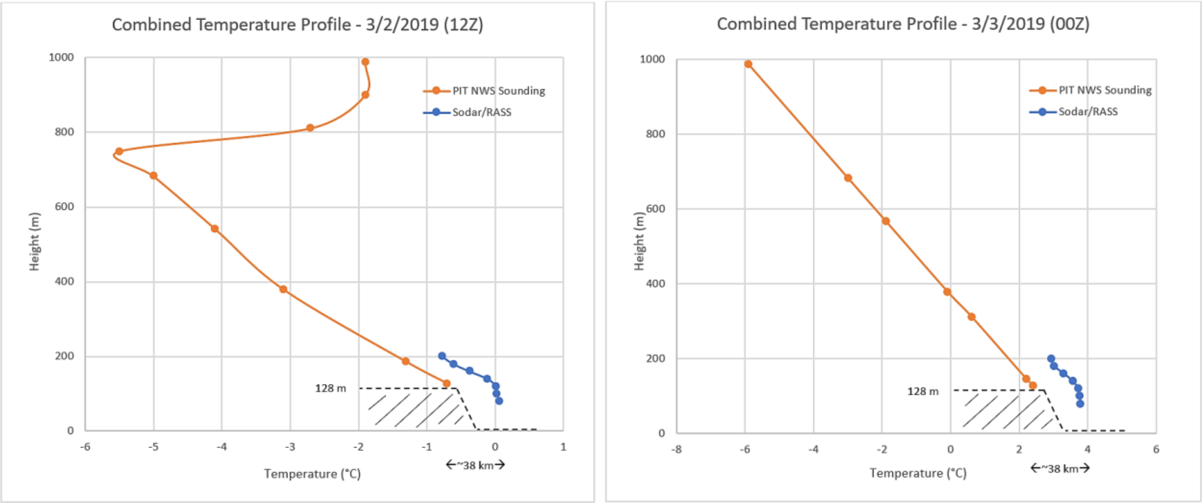
FIGURE 7. **Examples of Sodar/RASS/Tower and PIT NWS Results when a) Winds Move from Coke Works and b) Winds are Light with Mist and Clear Sky or Some Clouds.**

(Note that PIT NWS is located at an elevation 128 m above the sodar/RASS/tower site and ~38 km to NW.)



APPENDIX

FIGURE A. **Comparisons Between the Out-of-Valley PIT NWS Site and In-Valley Sodar/RASS Site**



<u>Note</u>: Tower data not included since sensors were not fully operational in early March 2019.