Appendix 3 to the Risk Assessment Report for the Sterigenics Facility in Willowbrook, Illinois:

Meteorological Data for HEM-3 Modeling

3.1 Introduction

As part of the risk assessment for Sterigenics, 2014-2018 meteorological data from Argonne National Laboratory were processed in AERMET for subsequent input to AERMOD (USEPA, 2018a). Argonne is approximately 7 km southwest of the Sterigenics facility (Figure 1). The closest National Weather Service (NWS) station, Midway airport, is approximately 16 km east of Sterigenics. While Midway can be considered adequately representative of the Sterigenics facility in the absence of other data, given the proximity of Argonne to the facility, the EPA concluded that meteorological data collected at Argonne would be more representative of conditions at Sterigenics than data from Midway. The Argonne meteorological tower also had measurements of wind, temperature, and turbulence (standard deviation of wind direction, σ_θ) at 10 m and 60 m vertical levels, making a more robust dataset over standard airport observations which only have one level of data without turbulence measurements. Sections 3.4 and 3.5 describe the methodology and results to support the EPA's decision to use Argonne data for the risk assessment.

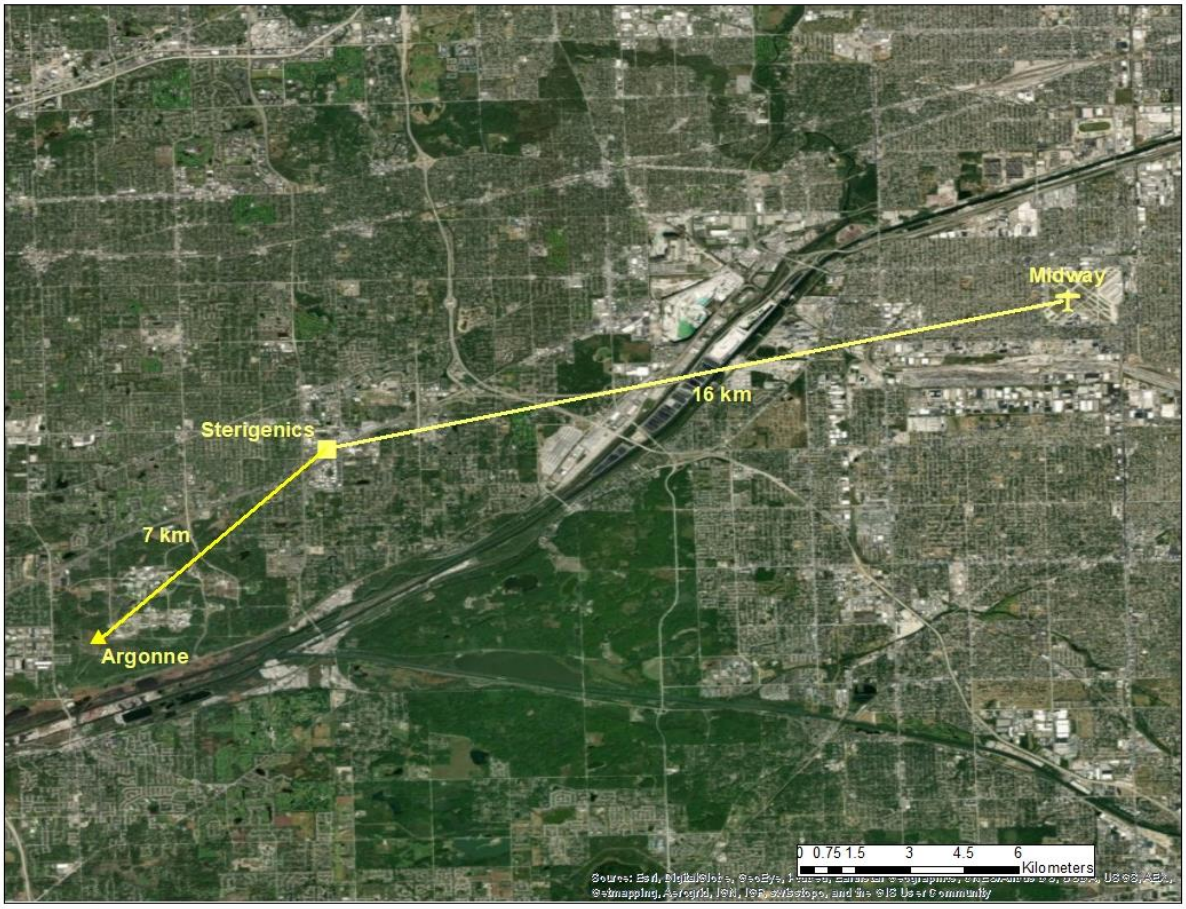
3.2 Meteorological data processing

Meteorological data for Argonne are available for download at http://www.atmos.anl.gov/ANLMET/. Both hourly averaged data and data in 15-minute intervals are available for download. For the purposes of the risk assessment, the hourly averaged data were used. The following variables from Argonne were input to AERMET (USEPA, 2018b):

- Solar insolation
- Surface pressure
- 10 m wind speed
- 10 m wind direction
- 10 m temperature
- 10 m standard deviation of wind direction (σ_θ)
- 60 m wind speed
- 60 m wind direction
- 60 m temperature
- 60 m standard deviation of wind direction (σ_θ)

The wind speed threshold used in AERMET to define valid wind speeds was set to 0.1 m/s. In accordance with the EPA's Guideline on Air Quality Modeling (USEPA, 2017), since the Argonne data included turbulence data (σ_θ), the adjustment to the surface friction velocity (adjusted u* option) was not utilized.

Figure 1. Locations of Argonne National Laboratory tower and Midway Airport relative to Sterigenics.



Upper air data for Davenport, IA were used as the representative upper air station in AERMET. Additionally, in AERMET, when using site-specific data, a representative NWS station can be used to substitute for missing values in the site-specific data during AERMET processing. Midway Airport was used as the representative NWS station. Hourly observations of wind and temperature were subsituted for missing values of wind and temperature in the Argonne data set, and cloud cover data from Midway were used in AERMET processing. Additionally, the hourly observed winds from Midway were supplemented with the hourly averaged 1-minute winds from Midway, via the AERMINUTE processor (USEPA, 2015). For the period of 2014-2018, 4.3 percent of the hours were substituted with Midway data.

3.3 Surface characteristics

Surface characteristics (albedo, Bowen ratio, and surface roughness) are important components in calculating boundary layer variables. To estimate surface characteristics for both Argonne (primary site) and Midway (secondary site), the new draft 2019 version of AERSURFACE (19039_DRFT)(USEPA, 2019) was used. This version of AERSURFACE, an update of the current 2013 version (13016)(USEPA, 2013), allows for the use of more recent National Land Cover Data (NLCD) to estimate surface characteristics. The current official version of

AERSURFACE is limited to the 1992 NLCD. While the 2019 version is draft, it can be used for regulatory purposes if run with the default 1 km radius for surface roughness estimates, use of landcover, impervious surface data, and tree canopy data for the selected NLCD year, and in consultation with the appropriate reviewing authority (U.S EPA, 2019). For this risk assessment, 2011 data were used. Year-specific monthly surface characteristics were calculated for 2014-2018 because there are two inputs to AERSURFACE that can vary by year: 1) moisture conditions for the year (average, wet, or dry year based on precipitation), and 2) the presence of continuous snow cover during the winter. The assumptions of moisture conditions and winter conditions were assumed to be the same for both Argonne and Midway. These assumptions were based on climatological data for Midway for 1989-2018. The assignments for wet, dry, and average rainfall are based on guidance in the AERSURFACE user's guide (USEPA, 2019). Because the lookup tables used by AERSURFACE are based on seasons, when calculating monthly surface characteristics, each month must be assigned to a season. Table 1 lists the seasonal assignments by month for each modeled year as well as the moisture conditions for each year.

Table 1. Seasonal assignments by month and year for AERSURFACE processing.

	Year				
Season	2014 (wet)	2015 (wet)	2016 (average)	2017 (average)	2018 (average)
Winter (no snow)	November, December, March	November, December, March	November, January, February, March	November, January, February, March	November, December, January, March
Winter (continuous snow)	January, February	January, February	December	December	February
Spring	April, May	April, May	April, May	April, May	April, May
Summer	June, July, August	June, July, August	June, July, August	June, July, August	June, July, August
Autumn	September, October	September, October	September, October	September, October	September, October

Surface roughness was calculated for four sectors for Argonne (Figure 2) and three sectors for Midway (Figure 3). AERSURFACE also allows for different treatment of surface roughness for a sector depending on whether the land use around the site in that sector is more like an airport or non-airport. This choice is used when a sector contains impervious surfaces such as buildings, roads, runways, parking lots, etc. If a sector contains mostly flat impervious surfaces such as roads or parking lots, the sector can be treated as an airport even if the site is not an airport. If the sector contains mostly buildings, then it can be treated as non-airport even if the site is an airport but the sector contains the terminal buildings, for example. All sectors at Argonne were treated as non-airport sectors. Sector 1 at Midway was treated as an airport sector while the other two sectors were treated as non-airport. Sector 1 is treated as an airport sector because most of the land use in that sector is a developed category with large flat developed spaces such as runways. The other two sectors are treated as non-airport because they are developed spaces

Figure 2. Argonne surface roughness sectors.

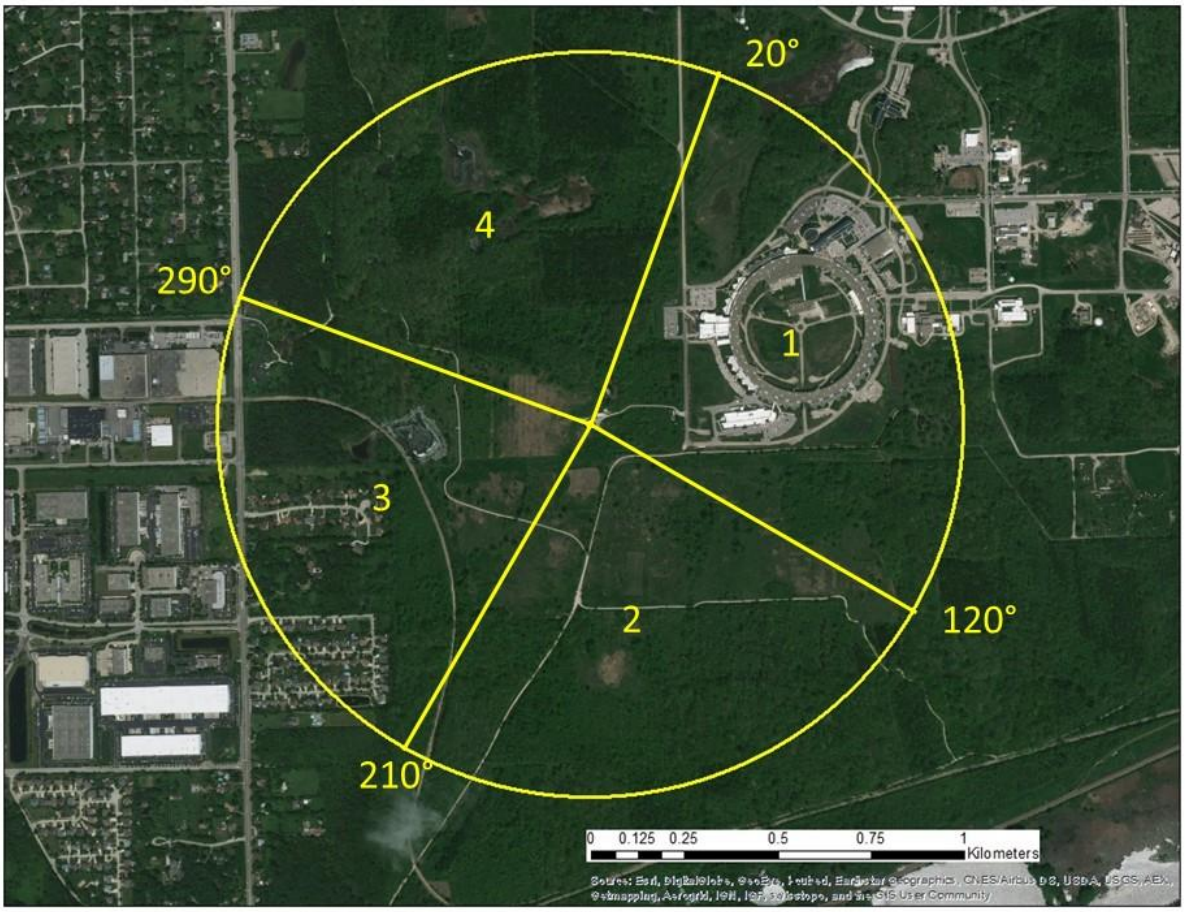


Figure 3. Midway surface roughness sectors.

that are not flat spaces and composed of developed structures such as buildings. See the AERSURFACE guide (USEPA, 2019) for more details on sector treatment.

3.4 Meteorological comparisons for the ethylene oxide sampling period

To determine the representativeness of Argonne for Sterigenics, wind and temperature data from Argonne, Midway, and the meteorological instrument at the EPA warehouse near Sterigenics were compared for the ambient air sampling period of November 13, 2018 through March 31, 2019. Figure 4 shows the location of the EPA warehouse meteorological instrument relative to the two Sterigenics buildings, Willowbrook 1 (WB1) and Willowbrook 2 (WB2). The EPA instrument is located approximately 150 m southwest of WB1 and approximately 300 m from WB2. The height of the EPA instrument is 8.5 m above ground and is indicated by the green triangle in Figure 4. The EPA instrument collected temperature, wind, σ_θ, relative humidity, pressure, and precipitation measurements. The EPA data were processed in AERMET with the inputs listed above except for precipitation, which is only needed for AERMOD simulations involving deposition calculations. The draft 2019 AERSURFACE was run for all three sites for January through March 2019 assuming average moisture conditions, continuous snow for January, and no continuous snow for February and March. For 2018, all three sites used the

moisture conditions and seasonal-month assignments outlined in Table 1 for November and December. AERSURFACE was run for four surface roughness sectors (all non-airport) (Figure 5) for the EPA site. Midway was used as the representative NWS site with surface characteristics as described in the previous section with 5.7 percent of the hours in the data period subsituted with Midway data. As with Argonne, since the EPA warehouse site collected turbulence data, the surface friction velocity adjustment was not performed. AERMET was also run for the sampling period for Midway only to assess how well the representative NWS site performed. Since Midway did not collect turbulence data, the surface friction velocity adjustment was included in the AERMET processing.

Wind roses for the monitoring period are shown for all three locations in Figure 6. The roses indicate that the overall flow pattern among the three sites is similar. However, the EPA site tends to have stronger signals of southerly and northerly flows compared to the other two sites. The differences in flow patterns could be due to building effects near the EPA instrument while the other two sites are in open locations and would represent the more general flow for the area.

Figure 4. Location of EPA meteorological instruments relative to the Sterigenics buildings.

Figure 5. EPA surface roughness sectors.

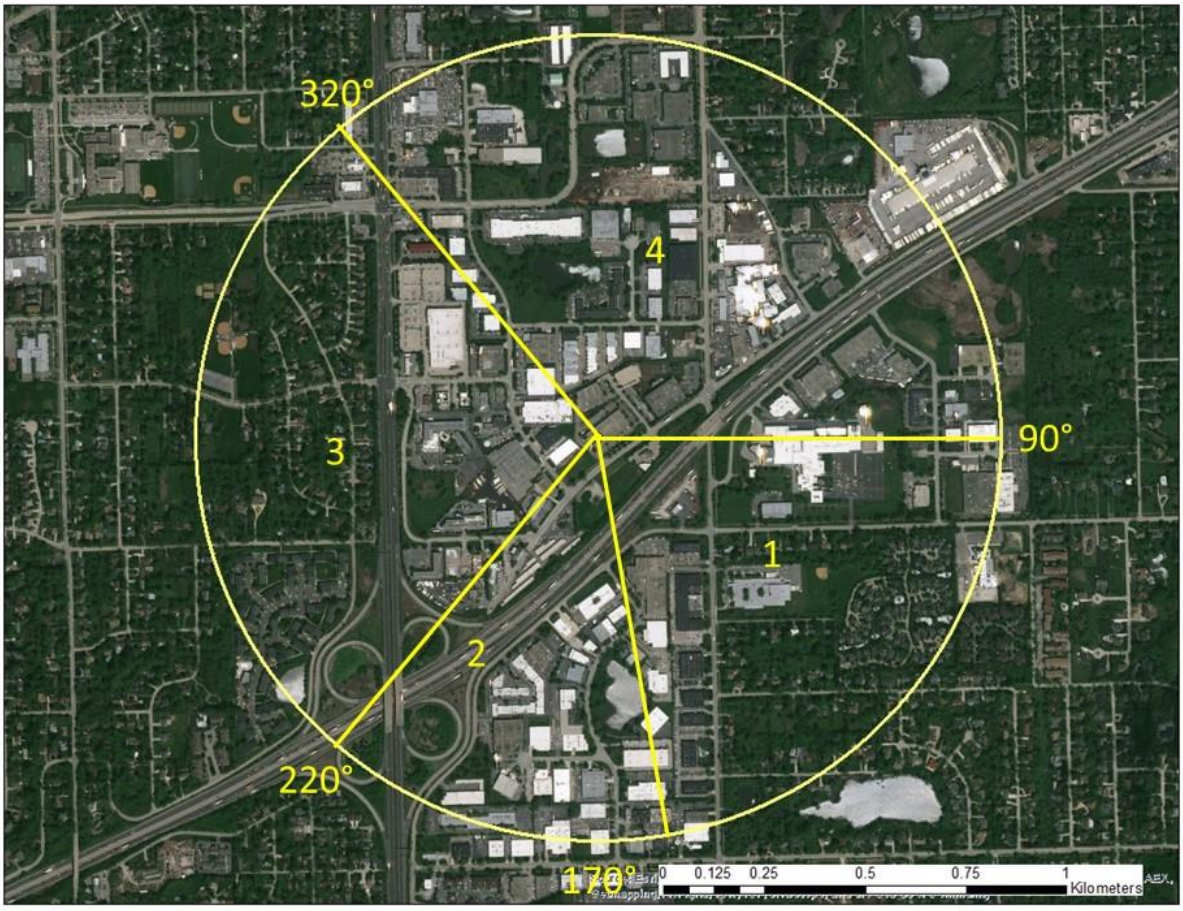
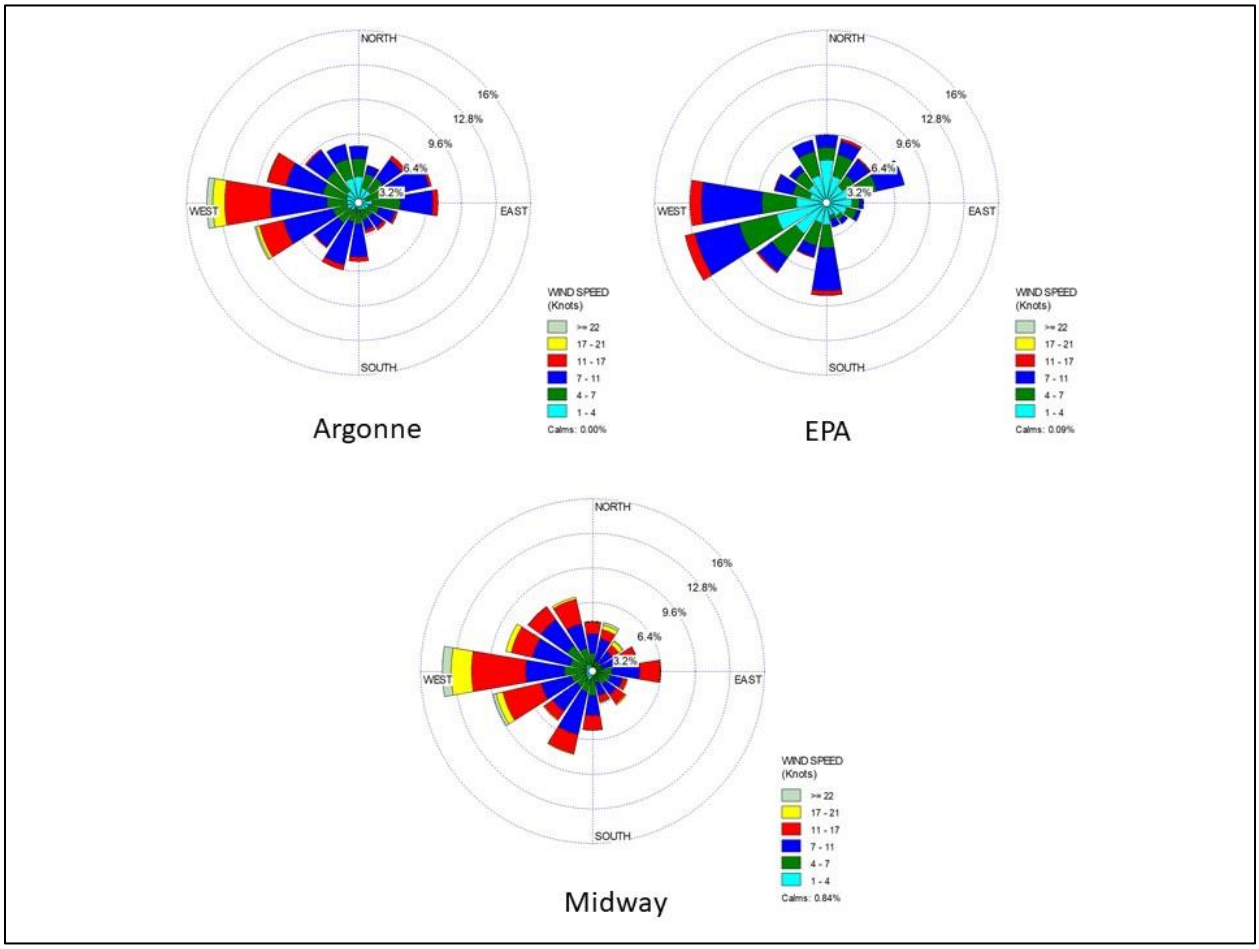


Figure 6. Argonne, EPA, and Midway wind roses for November 13, 2018 - March 31, 2019.



Analyses of wind speeds, directions, and temperatures were conducted among the three sites. Winds and temperatures at the 10 m level for Argonne were compared to the 8.5 m level winds and temperatures for the EPA site, and to the 10 m winds and 2 m temperature for Midway, on an hourly basis. Table 2 lists the minimum, mean, median, and maximum wind speed differences among the three sites. Table 3 lists the minimum, mean, median, and maximum wind direction differences among the three sites[27]. There were 2,920 hours where all three sites had wind data out of a possible 3,300 hours (the EPA instruments started at 13:00 LST on November 13, 2018). The results in Table 2 indicate that Argonne tended to have higher wind speeds than the EPA site. In fact, of the 2,920 hours, there were 2,639 hours where Argonne was higher than the EPA site. Conversely, Argonne tended to have lower wind speeds than Midway (2,537 hours) as did the EPA site when compared to Midway (2,853 hours). When looking at the number of hours where the sites' wind speeds were within 1 m/s of each other, there were 1,515

[27] The maximum difference between two directions is 180°. For example, the difference between a 10° direction and 350° direction is 20. after accounting for the 360° crossover on the compass°, not 340° based on a straight arithmetic difference between 350° and 10°.

hours where Argonne and the EPA site were within ± 1 m/s, 1,388 hours where Argonne and Midway were within ± 1 m/s, and 409 hours where the EPA site and Midway within ± 1 m/s.

Table 2. Hourly wind speed differences among Argonne, EPA site, and Midway.

Difference	Minimum (m/s)	Mean (m/s)	Median (m/s)	Maximum (m/s)
Argonne – EPA	-8.30	1.07	1.00	5.20
Argonne – Midway	-5.34	-1.08	-1.02	3.00
EPA - Midway	-7.38	-2.16	-2.08	8.63

The wind direction differences in Table 3 indicate the wind direction tended to vary within 20° among the three sites, with only a few hours where the winds were in almost opposite directions. There were 1,322 hours where Argonne and the EPA site wind directions were within 10°, 1,573 hours where Argonne and Midway directions were within 10°, and 1,268 hours where the EPA site and Midway directions were within 10°. The number of hours where winds were in almost opposite directions (> 170°) were few. There were only three hours where Argonne and the EPA site direction differences exceeded 170°, one hour where Argonne and Midway direction differences exceeded 170°, and 11 hours where the EPA site and Midway direction differences exceeded 170°.

Table 3. Hourly wind direction differences among Argonne, EPA, and Midway.

Difference	Minimum (°)	Mean (°)	Median (°)	Maximum (°)
Argonne – EPA	0	13	11	178
Argonne – Midway	0	16	9	173
EPA - Midway	0	17	12	180

Table 4 lists the minimum, mean, and maximum hourly temperatures for each site for each month of the sampling period. These statistics were calculated for each site independently of the other two. The results in Table 4 indicate that, on average, the temperatures among the three sites are similar.

Table 4. Monthly minimum, mean, and maximum temperatures for Argonne, EPA site, and Midway.

Temperature (°C)	Site	November	December	January	February	March
Minimum	Argonne	-8.40	-10.20	-31.0	-17.6	-19.9
	EPA	-7.80	-9.90	-30.2	-17.7	-19.5
	Midway	-10.76	-11.26	-32.26	-18.66	-21.96
Mean	Argonne	-0.72	0.51	-6.12	-3.30	1.37
	EPA	-1.20	0.60	-5.63	-2.76	1.66
	Midway	-2.72	-1.92	-8.19	-5.48	-1.01
Maximum	Argonne	9.70	11.50	12.20	10.30	16.90
	EPA	7.90	11.60	12.0	10.60	17.90
	Midway	7.16	9.24	9.74	7.64	15.24

Table 5 lists the minimum, mean, median, and maximum hourly temperature differences among the three sites. There were 3,135 hours where all three sites had temperature data.

Table 5. Hourly temperature differences among Argonne, EPA site, and Midway.

Difference	Minimum (°C)	Mean (°C)	Median (°C)	Maximum (°C)
Argonne – EPA	-4.50	-0.35	-0.3	4.2
Argonne – Midway	-0.74	2.20	2.16	7.96
EPA - Midway	-1.94	2.57	2.46	8.26

While the minimum and maximum hourly differences were greater than 1° for Argonne and the EPA site, the mean and median differences indicated little difference between the two sites. In fact, for the 3,135 hours of temperature data, 2,803 hours had temperature differences within ± 1°C between Argonne and the EPA site. There were larger differences between Midway and the other two sites, with only 111 hours of temperature differences within ± 1°C between Midway and Argonne, and 34 hours of temperature differences within ± 1°C between Midway and the EPA site. These comparisons indicate that the Argonne data seem to better represent the Willowbrook area, supporting the use of the Argonne meteorological data for the risk assessment.

3.5 AERMOD simulations

To further evaluate the representativeness of Argonne, the EPA site, and Midway, AERMOD simulations using day-specific ethylene oxide usage were conducted for 28 of the sampling days. AERMOD performance for the 28 sampling days at the monitors using Argonne, EPA site, and Midway meteorological data was evaluated using methodology from the EPA Protocol for Determining the Best Performing Model (USEPA, 1992) for regulatory application, which focuses on the higher concentrations in the concentration distribution. Normally, the protocol evaluates 1-hour, 3-hour, and 24-hour average concentrations. Since the monitor data for

Sterigenics are only 24-hour averages, the EPA focused only on 24-hour averages. The protocol uses a statistic call Robust Highest Concentration (RHC) and fractional bias for evaluation of model performance. The RHC is calculated at each monitor location for observed concentrations and modeled concentrations. The RHC is calculated as:

$$RHC = \mathrm{X}(N) + [\bar{\mathrm{X}} - \mathrm{X}(N)] \times \ln\left[\frac{3N-1}{2}\right]$$

where X(N) is the Nth highest concentration, $\bar{\mathrm{X}}$ is the average of N-1 values, and N is typically set to 26 values for most model evaluations. However, given the small sample size at each monitor, we started with N=5 to determine performance for the higher concentrations and evaluated results up to N=18 (the fewest number of observations across the monitors) to determine performance across the entire concentration distribution. As stated above, the RHC is calculated at each monitor for observed concentrations and modeled concentrations. Next, a fractional bias is calculated using the maximum observed RHC and maximum modeled (predicted) RHC as:

$$FB = 2\left[\frac{OB - PR}{OB + PR}\right]$$

where FB is the fractional bias, OB is the maximum observed RHC, and PR is the maximum modeled RHC. A positive fractional bias indicates model underprediction, and a negative fractional bias indicates model overprediction. Fractional biases within ± 0.67 are not considered statistically different. Also, note that the two RHC values in the fractional bias may not be from the same monitor location. This is done to assess the model's ability to assess concentrations for regulatory purposes, that is, how well the model predicts maximum concentrations regardless of the spatial location. Table 6 lists the fractional biases for three values of N for Argonne, the EPA site and Midway. For all three sample sizes of N, the EPA site performed best, while Argonne outperformed Midway, which supports the use of the Argonne meteorological data for the risk assessment.

Table 6. Fractional biases for N= 5, 10, and 18 for Argonne, Midway, and the EPA site.

N	Argonne fractional bias	Midway fractional bias	EPA fractional bias
5	1.05	1.29	0.98
10	1.05	1.23	0.98
18	0.85	1.10	0.84

3.6 2014-2018 Argonne vs. Midway meteorological data comparisons

Comparisons of winds and temperatures between Argonne and Midway were made for the full period of 2014-2018, with an additional emphasis on the November-March period over all five years, to ensure that the November 2018-March 2019 period was not an outlier relative to other years. Figures 7 and 8 show the wind roses for Argonne and Midway, respectively, for the entire 2014-2018 period. Figures 9 and 10 show the 2014-2018 wind roses for November-March only,

to coincide with the sampling period from November 2018-March 2019. For the entire 5-year period, while there are some differences, the wind roses are similar in the overall pattern of winds. Both stations exhibit a strong northeasterly wind component and south to west

Figure 7. Argonne 2014-2018 wind rose.

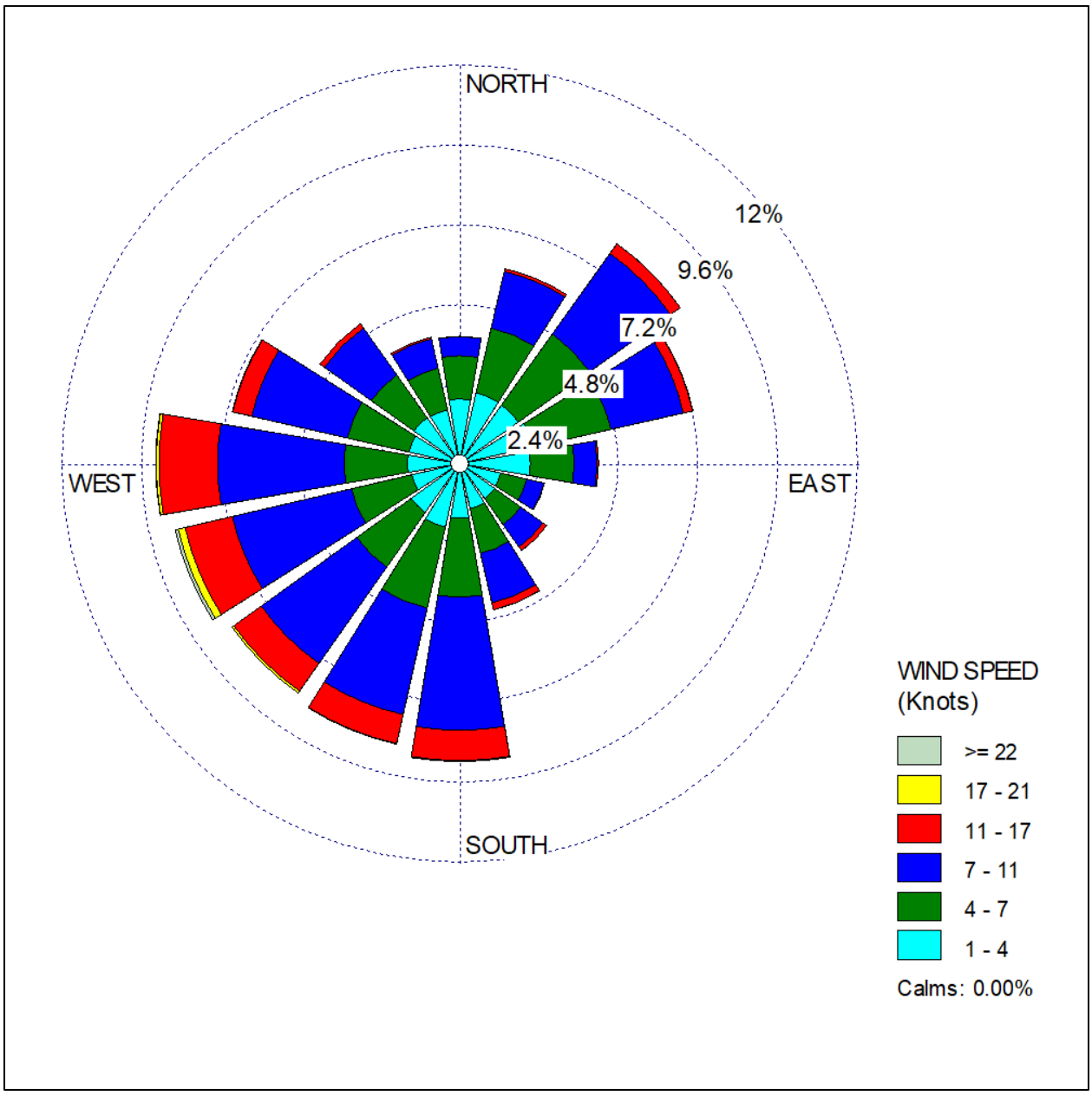


Figure 8. Midway 2014-2018 wind rose.

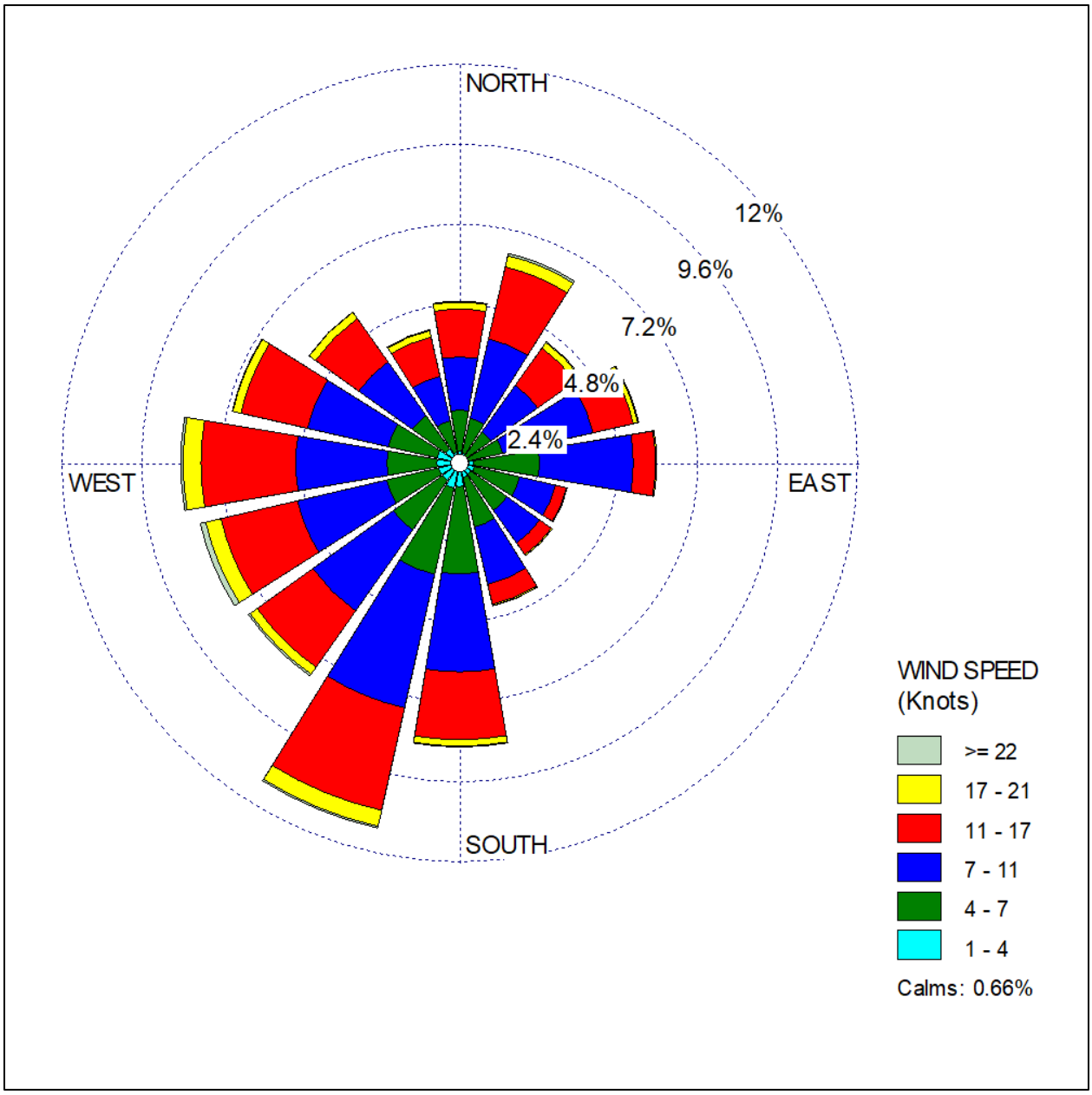


Figure 9. Argonne November-March 2014-2018 wind rose.

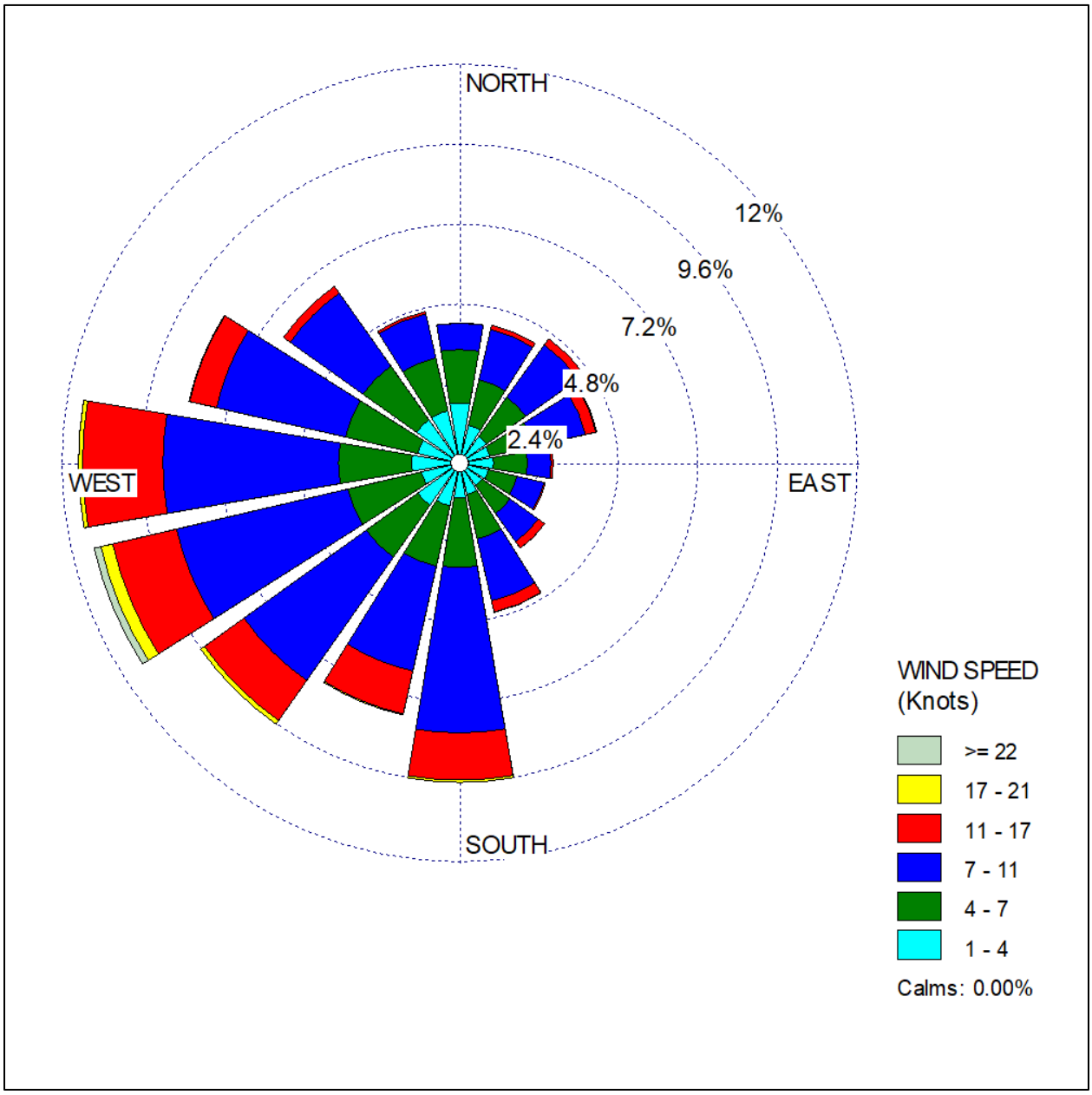
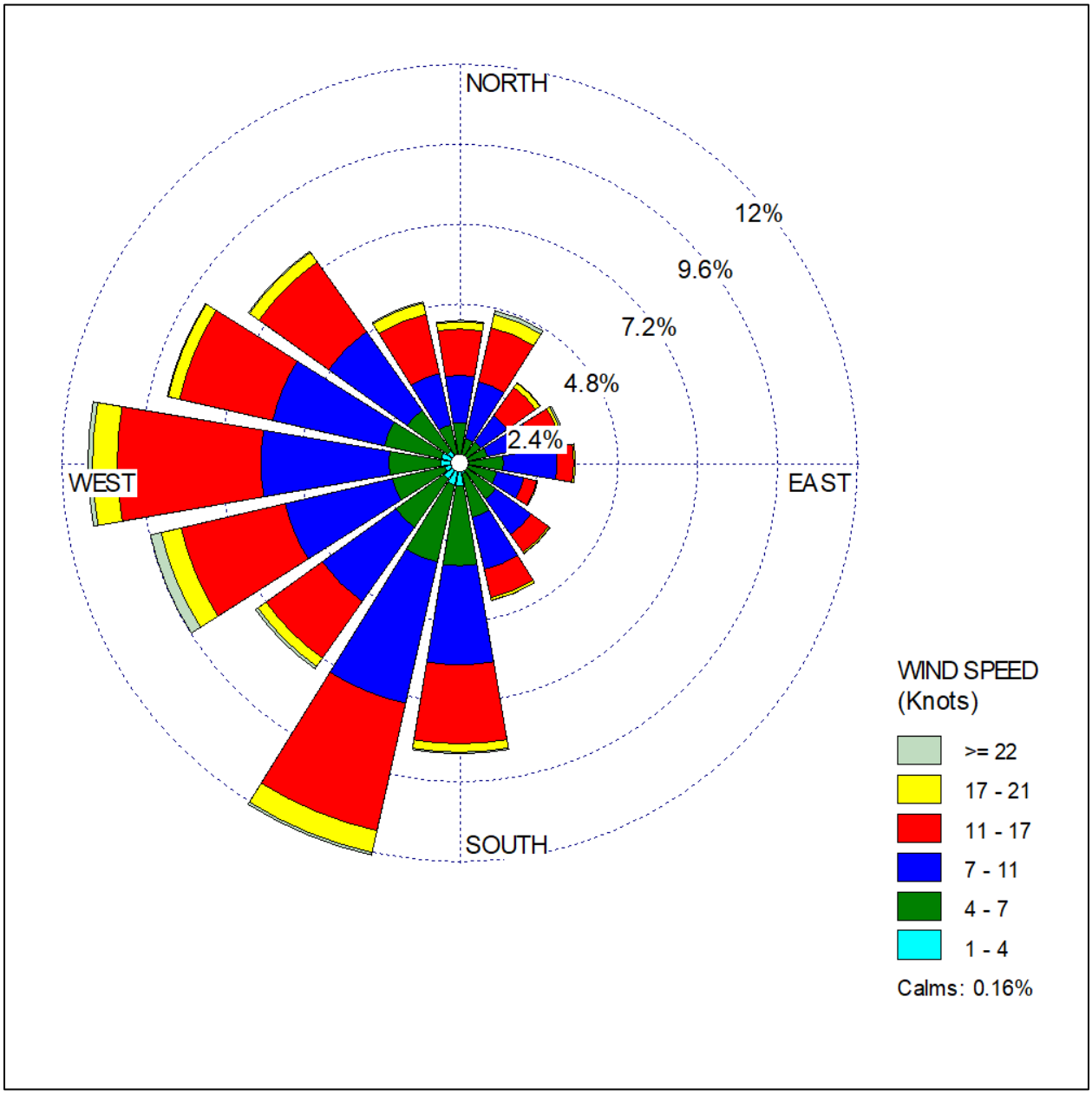


Figure 10. Midway November-March 2014-2018 wind rose.



component (Figures 7 and 8). For November-March periods over the five years, both stations exhibit the same general pattern, with Midway having a higher frequency of mid-range wind speeds (11-17 knots) than Argonne.

Hourly wind difference analyses were conducted between Argonne and Midway for 2014-2018. Table 7 gives the hourly wind speed differences for the entire 5-year period, as well as the November-March period. The distribution of differences for both the entire period and the November to March period were comparable to the distributions in Table 2. Of the 39,043 hours of winds where both sites had data for the full period, 12,937 hours had a wind speed difference within ± 1 m/s. For the November-March months, there were 16,850 hours where both sites had data and 6,417 hours had a wind speed difference within ± 1 m/s. Table 8 lists the wind direction differences between Argonne and Midway, and the distributions of differences in Table 8 compared well with the Table 3 differences. For the wind direction differences, there were 19,144 hours where the wind direction difference was less than 10° for the full 5-year period and 9,566 hours for the November-March period with wind direction differences less than 10°.

Table 7. Hourly wind speed differences between Argonne and Midway for 2014-2018.

Difference	Minimum (m/s)	Mean (m/s)	Median (m/s)	Maximum (m/s)
Argonne – Midway (full period)	-9.05	-1.50	-1.39	4.56
Argonne – Midway (November-March)	-9.05	-1.39	-1.25	3.2

Table 8. Hourly wind direction differences between Argonne and Midway for 2014-2018.

Difference	Minimum (°)	Mean (°)	Median (°)	Maximum (°)
Argonne – Midway (full period)	0	17	10	180
Argonne – Midway (November-March)	0	13	9	179

Table 9 lists the 5-year average minimum, mean, and maximum temperatures by month for Argonne and Midway. As with the November 2018-March 2019 period, the temperatures are similar across all months between the two stations. Also, the statistics for November-March do not indicate that the November 2018-March 2019 differences (Table 4) were unusual when compared to the 5-year averages.

Table 9. 5-year average monthly minimum, mean, and maximum temperatures (°C) for Argonne and Midway.

Month	Argonne			Midway		
	T_{min}	T_{avg}	T_{max}	T_{min}	T_{avg}	T_{max}
January	-23.30	-4.96	10.22	-21.18	-3.74	11.12
February	-18.46	-3.28	14.24	-16.70	-2.17	14.72
March	-12.58	2.75	20.58	-10.90	3.58	21.18
April	-3.60	9.23	26.30	-2.32	9.82	26.92
May	3.70	16.34	31.20	4.60	17.13	32.46
June	12.58	21.85	31.88	11.3	22.47	34.26
July	12.74	22.63	32.10	14.64	24.19	33.72
August	12.38	22.35	31.46	14.12	24.00	33.86
September	7.18	19.6	32.40	8.58	21.00	33.70
October	0.14	12.48	27.26	1.42	13.56	27.96
November	-9.66	4.29	18.24	-8.02	5.48	18.62
December	-16.06	-0.57	13.30	-14.2	0.60	14.44

Table 10 lists the hourly temperature difference statistics between Argonne and Midway. There were 42,291 hours where both sites had data for the entire period and 18,037 hours where both sites had data for the months of November-March. Argonne seems to have slightly cooler temperatures than Midway, possibly due to Midway being in a more urban environment than Argonne. The November-March statistics do vary from the November 2018-March 2019 results in Table 5, especially for the minimum and maximum temperature differences. This would not be unexpected when looking at an individual period (November 2018-March 2019) compared to a longer-term period of 5 years for the same months, but overall the differences for the 5-year period are comparable to the differences for November 2018-March 2019.

Table 10. Hourly temperature differences between Argonne and Midway for 2014-2018.

Difference	Minimum (°C)	Mean (°C)	Median (°C)	Maximum (°C)
Argonne – Midway (full period)	-6.44	-1.14	-1.24	14.86
Argonne – Midway (November-March)	-4.84	-1.10	-1.14	11.16

Based on the analyses in this section, there is nothing to indicate that Argonne would not be representative of Sterigenics for the 2014-2018 period and the analysis of Section 3.5 using November 2018-March 2019 would be valid for the entire period of 2014-2018.

The meteorological analyses presented here indicate that both Midway and Argonne can be considered representative of Sterigenics. A statistical analysis of AERMOD output using

methodology from the EPA's protocol for determining the best performing model shows that Argonne meteorological data outperformed Midway data. These analyses support the conclusion that while both Midway and Argonne are adequately representative meteorological sites for the risk assessment, Argonne would be the most representative of the two sites, given proximity to Sterigenics, available data, and how those data influence model output.

3.7 References

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