Quantifying Terrain Influence on Wind for Dispersion Modeling

Technical Support Document

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This document summarizes an objective way to evaluate the significance of terrain influence on local wind patterns. This method can be useful when determining the representativeness of meteorological data for use in dispersion modeling analyses.

Background

Observations of different wind roses around Iowa indicate that wind patterns in some valleys are significantly different from nearby locations outside the valley. In other locations no significant difference is noted between the valley winds and nearby winds. This analysis seeks to determine when terrain is affecting the wind patterns, and when the effect is important in dispersion modeling. Meteorological data is a critical input for dispersion modeling, and can have a dramatic effect on the predicted results. Applying representative data is important to ensure that model results are not significantly over or under predicted. Figure 1 depicts the model sensitivity of one example when valley data is applied to non-valley locations and vice versa.

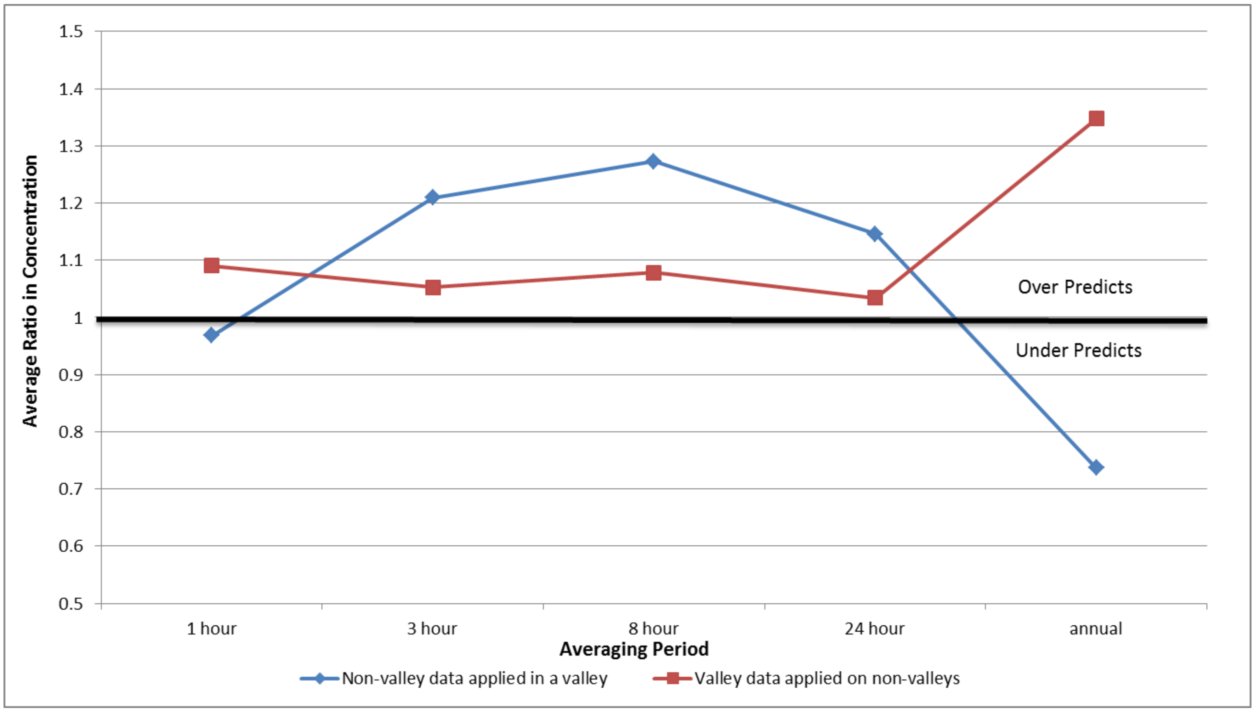

Figure 1. Importance of Representative Data

For each of the two locations, the model prediction using one dataset was divided by the prediction when using the other, thereby simulating the amount of error caused by using unrepresentative data at each location. A ratio equal to one indicates perfect agreement, while values above or below one indicate over and under-prediction respectively.

Goal

The goal of this analysis was to find an objective method to determine if the wind patterns are influenced by terrain features, and at what point this effect is important for modeling. This will help determine appropriate meteorological data for dispersion modeling which will lead to more accurate model results. Within the goal of the analysis, four restrictions/criteria were imposed:

1. Utilize pre-processed AERMET data
2. Use only data at the location in question to determine if that location is influenced by terrain
3. Easy to implement
4. Numerical answer (objective decision)

A complete list of all sites used in the entire analysis is summarized in the Appendix. Most sites have five years of data. Although the data for each site is not always the same five year period, all the data is within the years 2000-2013.

Quantifying Wind Pattern – Evolution of Index

The effects of some river valleys on wind patterns in Iowa have been observed. Figure 2 shows the Missouri River valley near Omaha, NE, where the wind pattern differs significantly between Omaha and Council Bluffs which are separated by only eight miles.

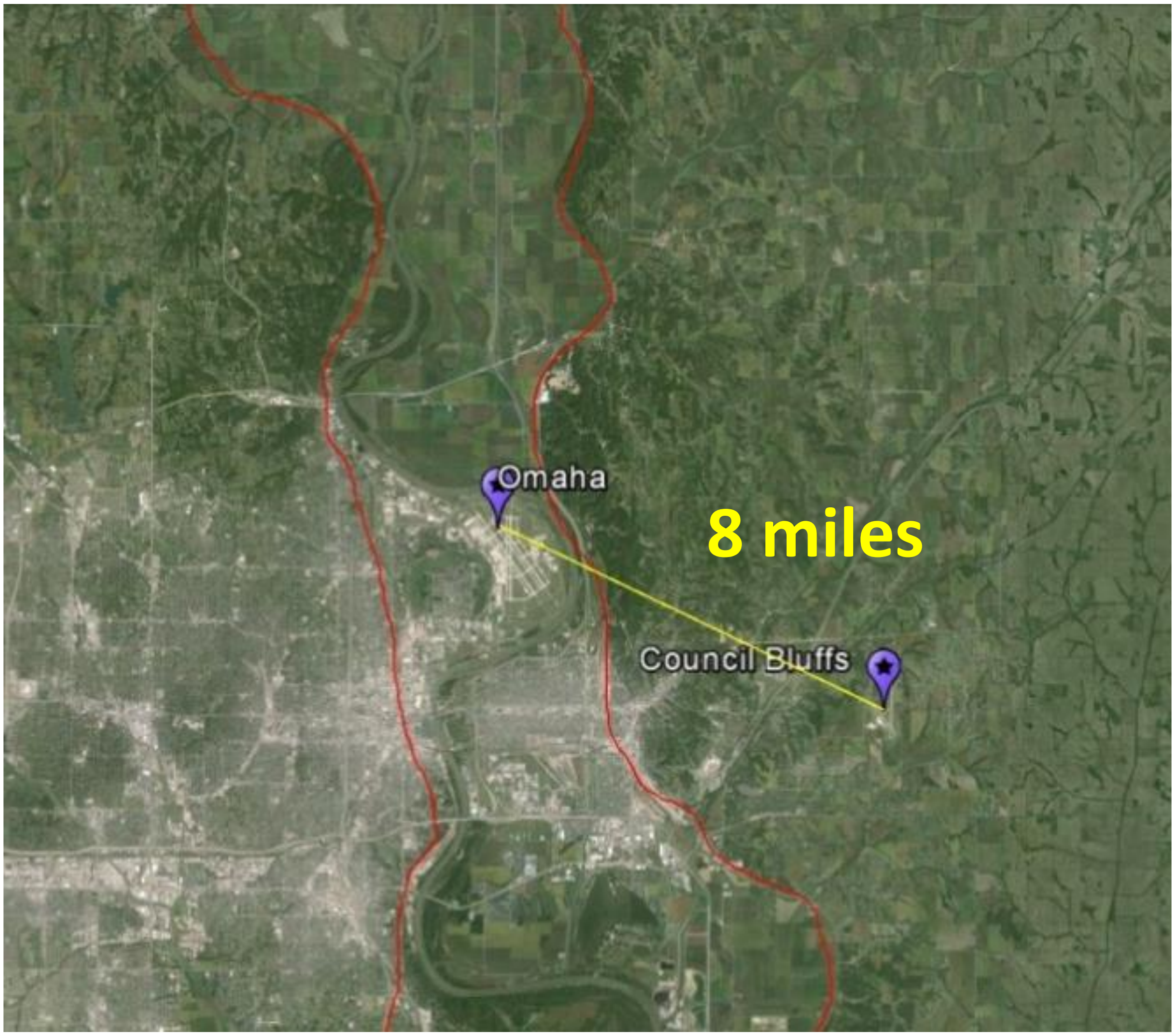

Figure 2. Missouri River Valley at Omaha[1]

In this case diurnal valley wind patterns show a shift in wind direction from in line with the valley during the night to in line with the synoptic flow during the day. This is due to pressure driven channeling. Pressure driven channeling is channeled wind in a valley by synoptic-scale pressure gradients superimposed along the valley axis. At night synoptic winds remain aloft and are isolated from the surface flows due to lack of mixing – hence the winds in line with the valley. During the day, when mixing is stronger the winds aloft are brought down to the surface and the synoptic flow dominates. Figure 3 depict the differences in wind patterns between Omaha, NE (located in the valley) and Council Bluffs, IA (located on the ridge adjacent to valley).

[1] (Google Earth Pro)

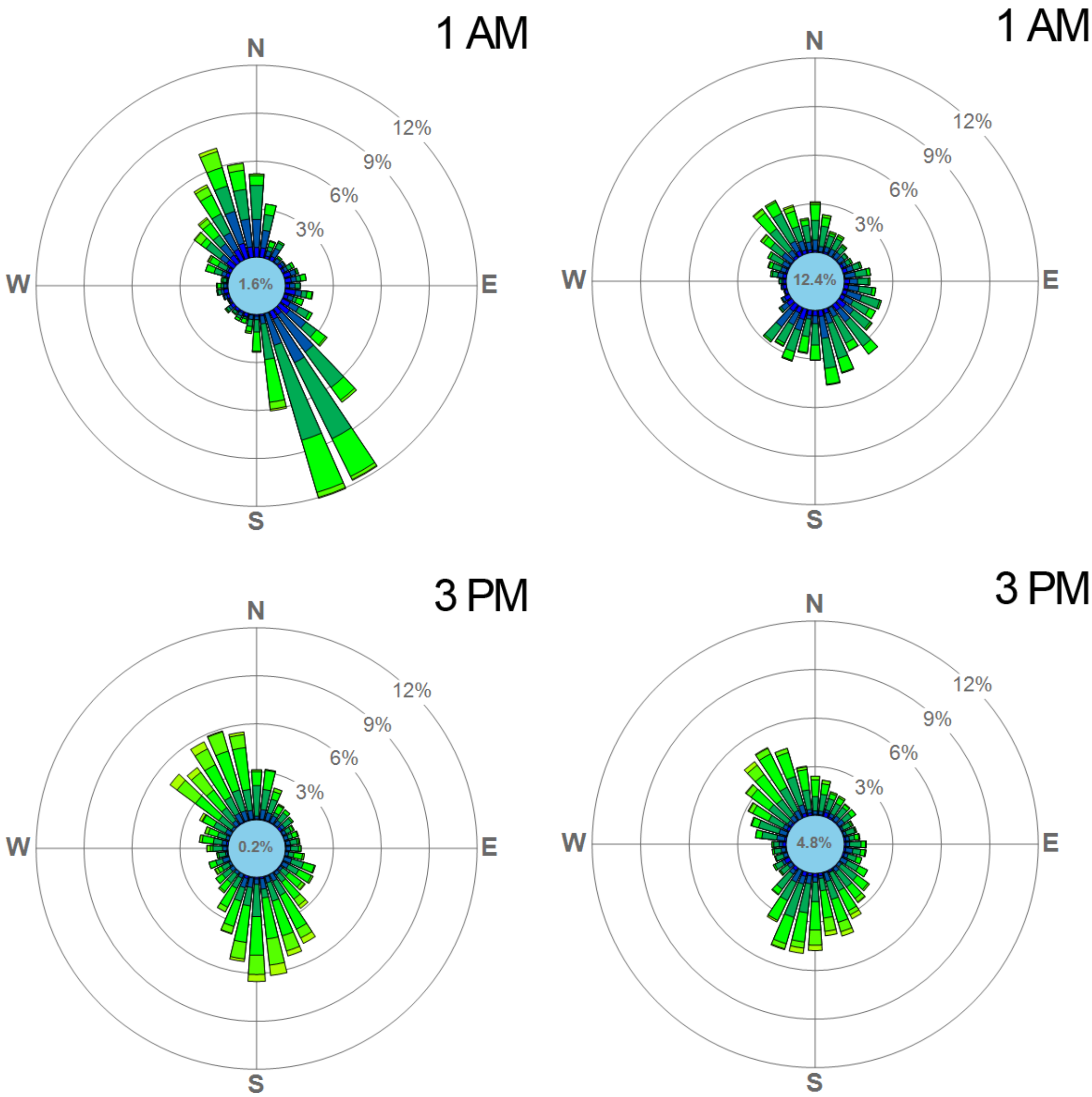

Figure 3.[2] Omaha Wind Rose (valley) Council Bluffs Wind Rose (non-valley)

During the day, when synoptic flow dominates, both wind roses are very similar. This contrasts to the nighttime wind roses (when valley flow dominates at Omaha).

This phenomenon gives some Iowa valley locations a diurnal wind pattern where winds shift from valley orientated flow during the night to a synoptic orientated flow during the day. Similarly, other types of terrain-induced wind patterns – such as slope-flows and land/sea breezes – should be identifiable using a diurnal pattern since their direction depends on the cyclical, and non-uniform, heating and cooling of the air above the terrain. Another type of terrain-induced wind pattern – forced channeling – does not specifically depend on the diurnal heating and cooling of the air, but rather the orientation of the terrain with relation to the direction of the synoptic flow. However, any terrain features of a scale that could cause forced-channeling could also exhibit some level of slope flow or pressure-driven channeling, and therefore may also show some correlation to the diurnal temperature pattern. Based on these hypotheses an index was derived based on diurnal temperature to quantify the effect of terrain on the local wind pattern.

The diurnal temperature is used to represent the cyclical variation of the heating and cooling that occurs each day. Figure 4 is an example of a diurnal temperature profile used to depict the sun's variation throughout the day.

[2] (MetView)

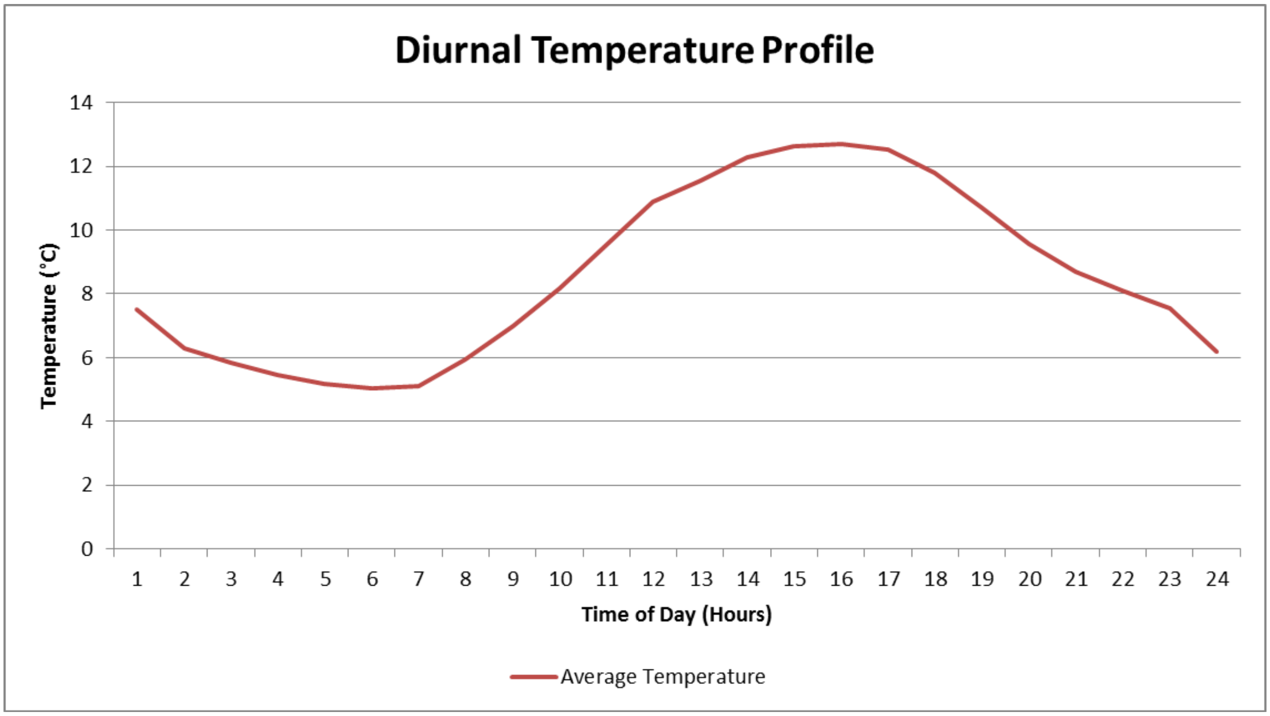

Figure 4. Diurnal Temperature at Council Bluffs (The data set is from 2005-2009)

Since wind speed tends to increase during the middle of the day and decrease overnight, it can be used as a surrogate if no temperature data is available at a location as long as the diurnal pattern is somewhat sinusoidal as in Figure 4 above.

Calculating the Index

The first step is to calculate the percent frequency the wind blows in each direction for each hour of the day. This is essentially the same data that is used to create the wind roses in Figure 3, except that it is not sub-divided by speed. A visual representation of what the percent frequency looks like for Omaha, NE is depicted in Figure 5. The darker-shaded percentages are the wind directions and time of day with a higher percent frequency relative to the others.

Hour of Day

Wind Direction	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
10	3%	3%	3%	3%	3%	3%	3%	3%	4%	4%	3%	3%	3%	2%	3%	2%	3%	3%	3%	3%	3%	3%	3%	3%
20	1%	1%	1%	1%	1%	1%	1%	1%	2%	1%	2%	2%	2%	2%	2%	2%	2%	1%	2%	2%	2%	2%	1%	1%
30	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%	1%	1%	2%	1%	2%	2%	2%	2%	2%	2%	1%	1%	1%
40	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%	1%	1%	1%	1%	1%	1%
50	0%	0%	1%	0%	1%	1%	1%	1%	1%	1%	1%	0%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
60	1%	1%	1%	1%	1%	1%	0%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
70	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
80	1%	1%	1%	0%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%	2%	1%	2%	1%	1%	1%
90	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%	2%	2%	1%	1%	2%
100	2%	2%	1%	1%	1%	1%	1%	1%	2%	1%	2%	1%	1%	1%	1%	2%	2%	2%	2%	3%	2%	2%	2%	2%
110	1%	2%	1%	2%	1%	2%	2%	2%	1%	2%	1%	2%	2%	2%	2%	2%	2%	2%	3%	3%	3%	3%	2%	2%
120	2%	2%	2%	3%	2%	3%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	3%	4%	4%	4%	3%	2%
130	4%	4%	4%	4%	3%	4%	4%	3%	4%	3%	3%	3%	2%	2%	2%	2%	2%	3%	3%	4%	5%	4%	4%	4%
140	7%	8%	7%	6%	7%	7%	7%	7%	4%	4%	3%	3%	3%	3%	3%	4%	4%	4%	4%	6%	6%	7%	7%	7%
150	12%	12%	11%	12%	13%	12%	12%	10%	8%	7%	5%	4%	5%	4%	5%	4%	4%	5%	7%	8%	9%	10%	11%	12%
160	12%	11%	14%	13%	12%	12%	11%	10%	11%	9%	8%	7%	6%	6%	5%	5%	5%	7%	8%	9%	10%	11%	11%	11%
170	6%	7%	7%	6%	6%	6%	6%	8%	9%	9%	8%	7%	6%	7%	6%	7%	8%	8%	6%	6%	6%	7%	8%	8%
180	2%	2%	2%	2%	3%	2%	3%	3%	4%	6%	7%	8%	8%	7%	7%	6%	6%	5%	4%	3%	3%	2%	3%	2%
190	1%	1%	1%	1%	1%	1%	1%	2%	2%	3%	4%	5%	5%	5%	5%	4%	4%	3%	2%	2%	1%	1%	1%	1%
200	1%	1%	0%	1%	0%	1%	1%	1%	1%	3%	3%	3%	4%	4%	4%	3%	2%	2%	2%	1%	1%	0%	1%	1%
210	1%	1%	1%	0%	1%	1%	1%	1%	1%	1%	2%	2%	2%	2%	3%	3%	2%	2%	1%	1%	1%	1%	1%	0%
220	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%	1%	2%	2%	2%	2%	2%	2%	1%	1%	0%	0%	0%	1%	1%
230	1%	0%	0%	0%	0%	0%	0%	1%	0%	1%	1%	1%	2%	2%	1%	2%	1%	1%	1%	0%	0%	1%	0%	0%
240	0%	0%	1%	1%	0%	0%	0%	0%	0%	1%	1%	0%	1%	1%	1%	1%	1%	1%	1%	0%	0%	0%	0%	0%
250	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%	0%	0%	1%	1%	0%	0%	0%	0%
260	1%	1%	1%	0%	1%	0%	0%	0%	1%	0%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	0%	0%
270	1%	1%	1%	1%	1%	1%	0%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
280	0%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%	1%	1%	1%	1%	1%	1%	1%	1%	1%
290	2%	1%	1%	2%	2%	1%	1%	1%	1%	2%	2%	2%	2%	2%	2%	2%	2%	2%	1%	1%	1%	1%	1%	1%
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310	3%	3%	3%	3%	2%	3%	3%	2%	3%	3%	3%	3%	4%	5%	5%	4%	4%	4%	3%	3%	3%	3%	2%	3%
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340	7%	8%	7%	8%	8%	8%	8%	7%	7%	6%	6%	7%	7%	6%	6%	6%	5%	6%	6%	6%	6%	6%	7%	7%
350	6%	7%	8%	8%	8%	8%	8%	8%	7%	7%	6%	6%	6%	6%	6%	6%	6%	7%	6%	6%	6%	7%	7%	7%
360	5%	6%	6%	7%	5%	6%	7%	6%	7%	5%	5%	4%	4%	4%	3%	3%	4%	3%	4%	5%	5%	5%	5%	5%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 5. Percent Frequency at Omaha (This data represents the actual wind data (raw data).)

The percentage frequency is normalized to adjust all values to a common scale based on the number of wind sectors in each data set. All data in this analysis have been normalized.

The data was normalized as shown in Equation 1.

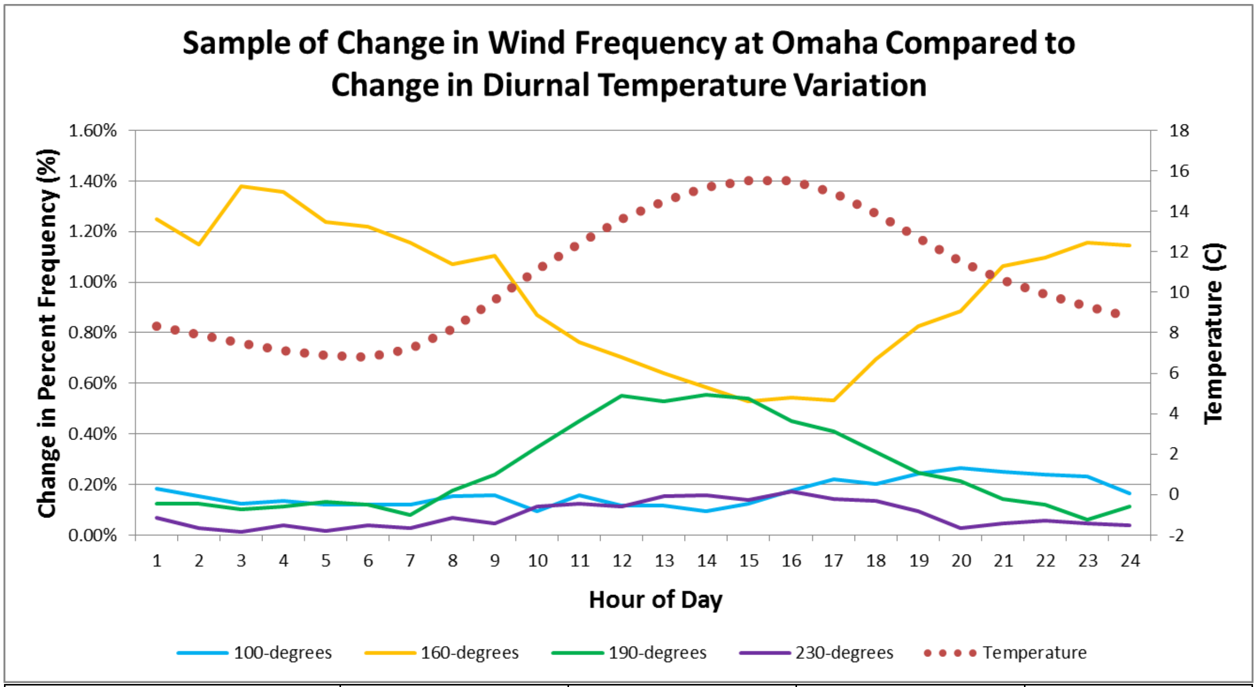
Equation 1

$$N = P * (\frac{S}{360})$$

Where N = Normalized Data
P = Percent Frequency by Hour and Wind Direction
S = the Number of Wind Sectors in Data Set

Each box in Figure 5 is normalized and then used to measure the relationship between the diurnal wind pattern and time of day. This was determined for each wind direction by calculating the correlation between the hourly percent frequencies in each row (wind direction) in Figure 5 and the diurnal temperature pattern. The wind directions with an increased frequency during the day will result in a value closer to one because both percent frequency and the daytime temperature are increasing (i.e., 190°). Wind directions that increase in frequency during the night will result in a value closer to negative one because as the percent frequency increases the nighttime temperature is decreasing (i.e., 160°). A lack of a diurnal pattern will result in a number closer to zero (i.e., 100°).

Next, the standard deviation was calculated for each row in Figure 5 (i.e. the percent frequency for every wind direction over the day) to measure the significance of diurnal percent frequency fluctuation. Insignificant fluctuations in the diurnal pattern will be smaller in magnitude while larger more defined variation will be large in magnitude. It was hypothesized that larger fluctuations are most likely caused by an external force (terrain), whereas smaller fluctuations could be due to instrumentation or random variations in the wind patterns. Examples of the calculations for four selected wind directions follow and are summarized in Figure 6. The selected wind directions are examples of the most meaningful variations of the correlation and standard deviation.



	100°	160°	190°	230°
Correlation	+0.1	-0.97	+0.89	+0.91
Standard Deviation	0.00053	0.0028	0.0017	0.00051

Figure 6. Index Calculation for Individual Wind Directions

100° wind direction:
There is a low correlation between the diurnal temperature and the percent frequency. Winds shift towards this direction slightly at the end of the day whereas the temperature increases during midday. The standard deviation is also small which indicates the fluctuation is insignificant.

160° wind direction:
The correlation between the temperature and percent frequency is very close to negative one because wind shifts away from this direction when the temperature is increasing. The fluctuation in the percent frequency is well defined with a larger standard deviation signifying a significant fluctuation.

190° wind direction:
The wind shifts towards this direction at the same time as the temperature is increasing which is why the correlation is close to one. There is a large change in the diurnal percent frequency and a bigger standard deviation indicates the fluctuation is significant.

230° wind direction:
There is a high correlation between the diurnal temperature pattern and percent frequency that the wind is in this direction throughout the day. However, the wind shift in this direction is not nearly as large or defined as the diurnal temperature pattern. The standard deviation is very small demonstrating that this is an insignificant fluctuation.

The 160° and 190° wind direction are only 30° apart but have a near reversal in correlation (-0.97 to +0.89). This represents the shift in direction from valley orientated flow to synoptic oriented flow. The valley flow (dominates at night) is oriented around 160° (negative correlation) while the synoptic flow (dominates during the day) is oriented around 190° (positive correlation). This shift can also be seen in the Omaha wind roses in Figure 3.

The last step in calculating the index is to use the correlation and standard deviation in such a way that the important wind directions stand out while simultaneously minimizing those directions where the terrain doesn't appear to have an influence. This is accomplished by multiplying the correlation and standard deviation to obtain the Terrain-Wind index shown in Equation 2.

Equation 2

$$T = R \times \sigma$$

Where T = Terrain-Wind Index
R = Correlation
σ = Standard Deviation

The resulting complete Terrain-Wind index for the four selected wind directions are summarized in Table 1.

Table 1. Complete Terrain-Wind Index Calculation

	100°	160°	190°	230°
Correlation	0.1	-0.97	+0.89	+0.91
Standard Deviation	0.00053	0.0028	0.0017	0.00051
Terrain-Wind Index	0.000053	-0.00272	0.00151	0.00046

By multiplying the correlation and the standard deviation the index is amplified when there is both a high correlation and a significant variation. In contrast, when either or both the correlation or variation is low, so will be the index. The variations are summarized in Table 2.

Table 2. Possible Index Variations

	Low Correlation	High Correlation
Small Fluctuation	Small Index	Small Index
Large Fluctuation	Small Index*	Large Index

*Rarely observed

External Force - Terrain

While it is not definite that the external force is from the terrain the indices tend to match up with the valley orientation. As stated above, the valley flow dominates during the nighttime hours therefore those wind directions would have a negative correlation. The percent frequency decreases during the day (160° wind direction in Figure 6). Thus when the Terrain-Wind index for each individual wind direction is plotted, the minimum values should line up with the valley orientation. Figure 7 and Figure 8 show that 150° wind sector is the minimum index value as well as the valley orientation at Omaha.

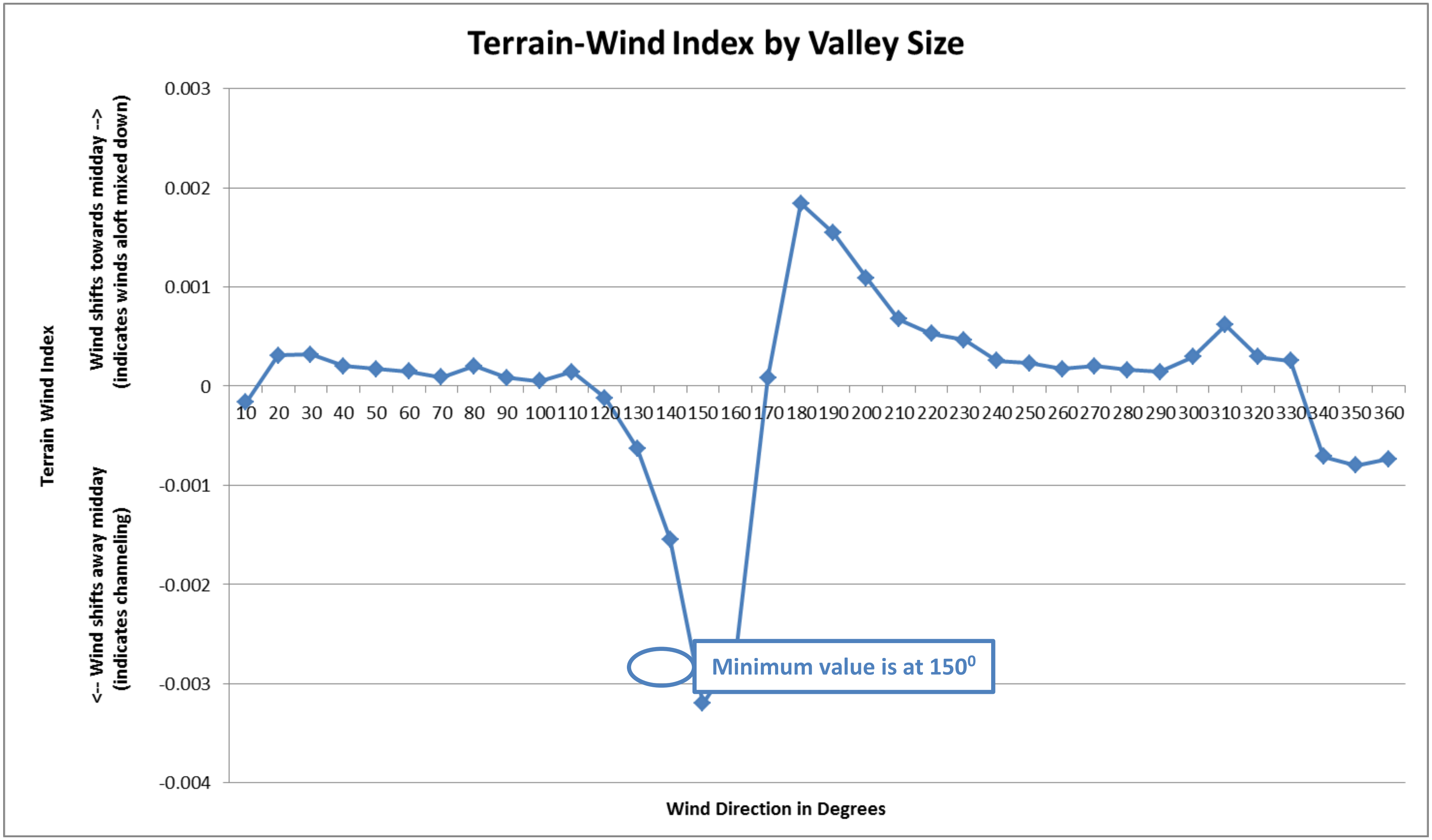


Figure 7. Omaha Terrain-Wind Index

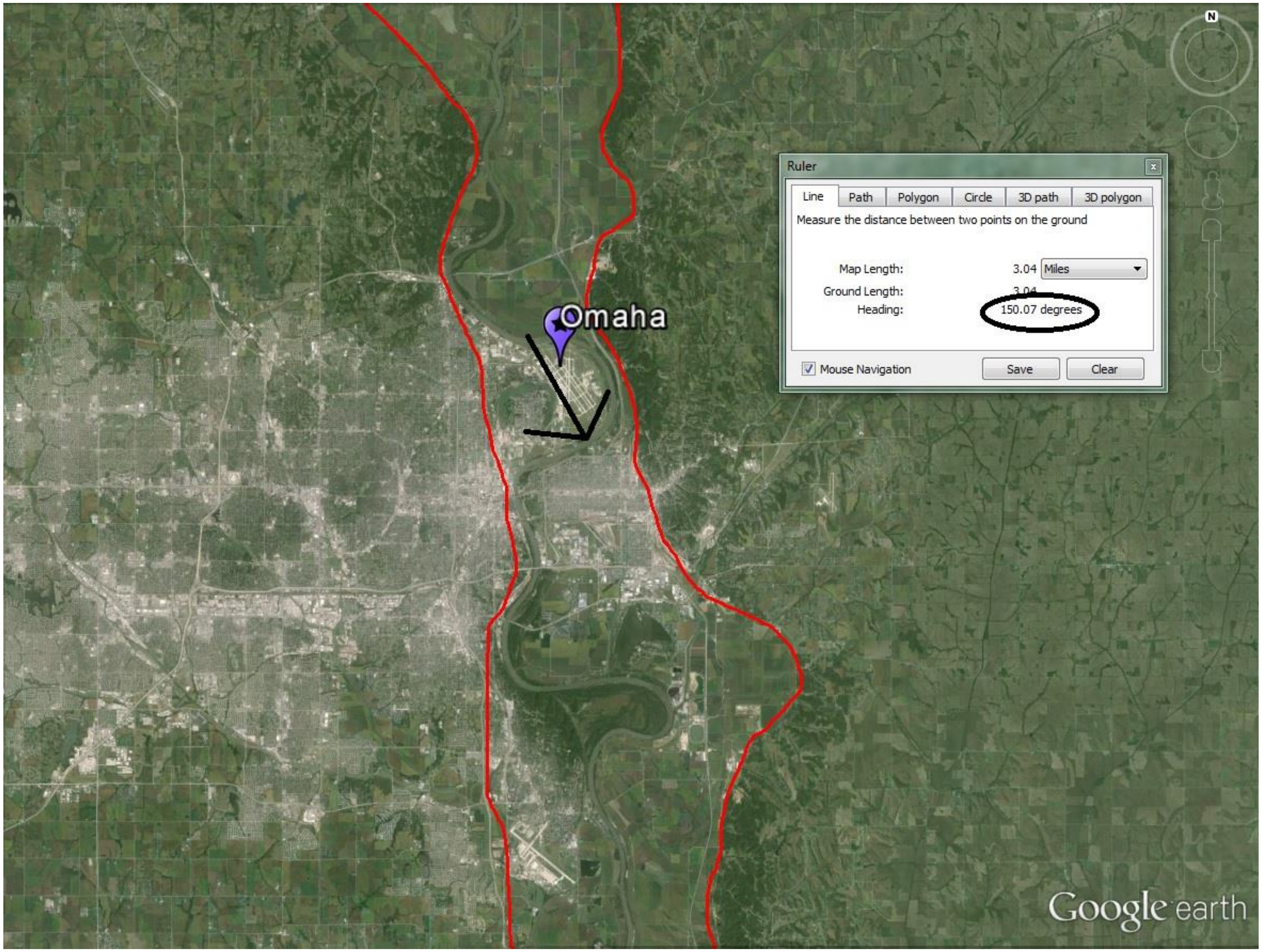


Figure 8. Missouri Valley Orientation at Omaha[3]

[3] (Google Earth Pro)

Summary of the Terrain-Wind Index

- Becomes larger as the diurnal pattern becomes strong and magnitude of variability increases
- Near zero from lack of diurnal pattern regardless of magnitude of variability
- Becomes smaller with a low magnitude of variability even if insignificant fluctuations results in perfect correlation
- Each wind direction has its own Terrain-Wind index

Limitation of the Index

This document is intended to support regulatory modeling applications within the State of Iowa. However, it may also be used by other environmental scientists when deciding what meteorological data is representative. In order for those scientists to apply this procedure correctly, information on areas where this analysis does not appear to work needs to be addressed.

Coastal areas were originally included in the analysis. Coastal areas are affected by land/sea breeze. These breezes follow a diurnal wind pattern due to uneven heating of land and water surfaces. Land heats more quickly than water in the morning. The warmer land heats the air above it causing the air to rise. The rising air lowers the pressure over the land relative to the pressure over the water. The resulting wind blows from the high pressure to low pressure, creating a sea breeze. At night the wind is reversed due to the land cooling off quicker than the sea. Since land/sea breezes are a diurnal pattern the index should be useful in these locations as well. However, while a correlation was observed, index ranges for coastal areas were smaller than expected.

One explanation of this observation could be the buffering effects of the water can cause the temperature to lag behind solar insolation. The temperatures measured on land may not accurately represent the time of day when wind shifts occur due to the slower response to temperature fluctuations over the water. This would cause a smaller correlation value and ultimately a smaller index value.

This is a plausible reason for the observations seen at coastal areas. No further evaluation was completed because Iowa is not located near any major/large bodies of water, and therefore a coastal index was not needed in this analysis. However, there are distinct wind patterns at coastal areas and therefore site specific data is likely necessary in those locations. One must consider the limitation of this index when evaluating meteorological data in coastal areas.

Another limitation is the range of standard deviation will vary based on the number of wind directions sectors included in the data. In order to correct for that the data in this analysis was grouped into 10° sectors. This could still be a problem if the datasets only report winds every 30°. By having fewer wind sectors the percent frequency increases causing the magnitude of terrain-wind index (TI) to vary as well. Indices using 10° sectors should not be compared to indices using 30° sectors. All data sets used in this analysis had 10° sectors or smaller.

AERMOD Sensitivity Tests

The next step after quantifying the terrain influence was to determine when that influence is important for dispersion modeling. To accomplish this, an in-depth AERMOD, **A**MS/**E**PA **R**egulatory **Mod**el, sensitivity analysis was completed.

Control Error

The first phase of the AERMOD sensitivity analysis was to find the average error caused by applying different meteorological data not influenced by terrain to other sites not influenced by terrain. This is the control error.

This analysis was completed by selecting five sites in Iowa that are not influenced by the terrain. Figure 9 shows the location of the five control sites used. These sites were chosen because they are in areas of relatively flat terrain and are not located in valleys.

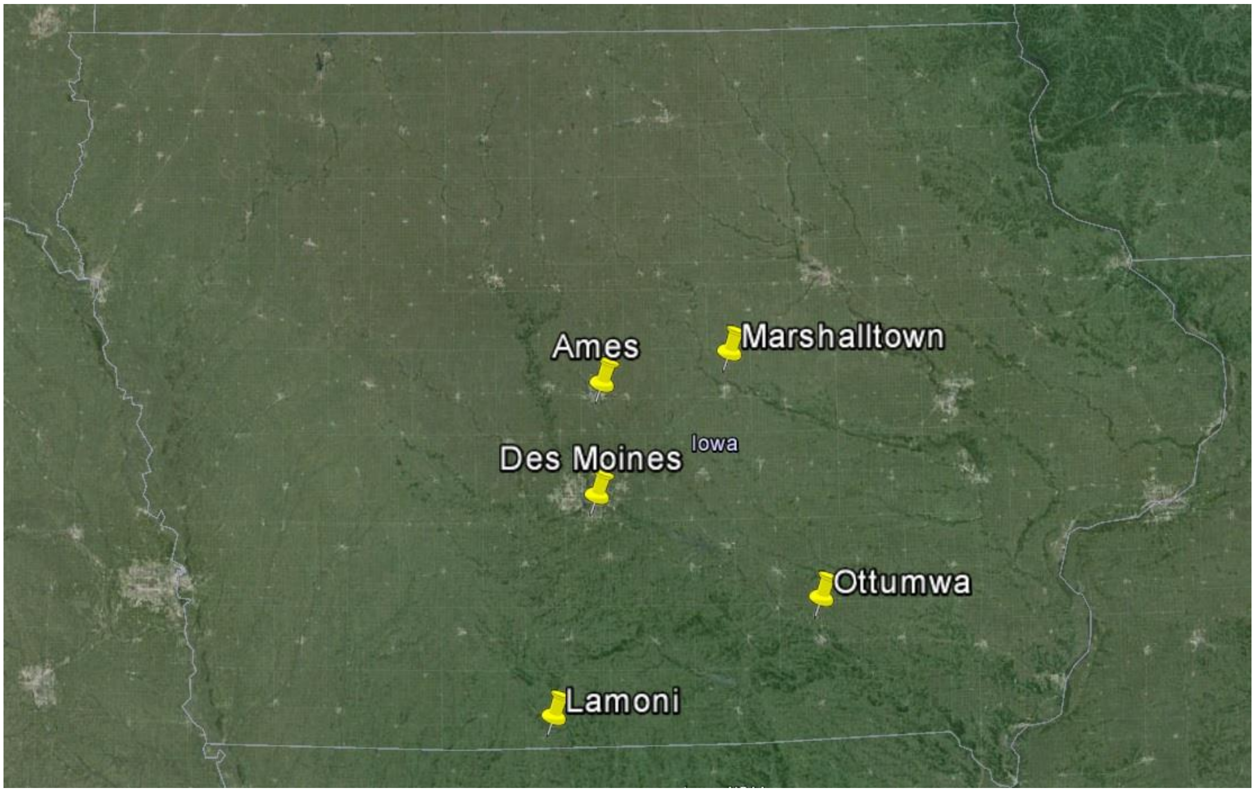


Figure 9. Five Non-Valley Control Sites[4]

Each model run was set up with three point sources with stack heights of 5, 35 and 65 meters and a ground level volume source centered at the meteorology station at each airport. These source types/stack heights were chosen to represent the widest range of realistic sources used in regulatory modeling applications. These sources provide the most meaningful results while balancing the run time of the model. The maximum concentration for each source type was modeled for 1-hour, 24-hour and annual to include the widest range of averaging periods. Each site was first run with the correct meteorology data, i.e. Ames meteorological data with sources located at the Ames airport. The models are centered on the meteorological instruments at the airport with the actual terrain elevation. The predicted concentrations from those runs are treated as the control (the “right” answers).

A sample of the results is summarized in Table 3. The first two columns of Table 3 show the UTM coordinates of the receptor locations. These columns are followed by the maximum predicted concentration for the release heights and averaging period evaluated for point sources and the averaging periods for volume sources (all volume sources were modeled with a ground level release height. There were 1,280 receptors in every model run, which equates to receptors out to 1,500 meters.

[4] (Google Earth Pro)

Table 3. Sample of Predicted Concentrations (μg/m^3)

UTM Coordinates		Point Sources									Volume Sources		
X	**Y**	**5ft_1hr**	**5ft_24hr**	**5ft_ANN**	**35ft_1hr**	**35ft_24hr**	**35ft_ANN**	**65ft_1hr**	**65ft_24hr**	**65ft_ANN**	**1hr**	**24hr**	**ANN**
447301	4647376	32.33	1.93	0.09	4.42	0.76	0.03	2.89	0.45	0.02	228.98	13.00	0.23
447301	4647476	31.32	2.24	0.10	5.48	0.83	0.03	2.87	0.45	0.02	220.05	15.05	0.21
447301	4647576	38.37	2.51	0.10	5.57	0.91	0.03	3.32	0.43	0.02	206.45	22.05	0.27
447301	4647676	26.91	3.60	0.09	4.81	0.94	0.03	3.72	0.46	0.02	252.65	20.01	0.28
447301	4647776	25.21	3.76	0.09	5.88	0.98	0.03	4.03	0.51	0.02	327.81	18.77	0.33
447301	4647876	27.94	2.29	0.09	6.93	1.03	0.03	4.19	0.52	0.02	297.74	15.22	0.36
447301	4647976	23.88	2.42	0.09	7.38	0.96	0.04	4.16	0.56	0.02	365.37	21.75	0.42
447301	4648076	22.93	3.65	0.10	7.18	1.05	0.04	4.22	0.58	0.02	392.10	16.63	0.43
447301	4648176	21.03	4.11	0.10	6.24	1.15	0.04	4.60	0.54	0.02	329.34	24.94	0.51
447301	4648276	21.05	2.86	0.10	5.58	1.17	0.04	4.96	0.58	0.02	343.80	34.10	0.51
447301	4648376	24.56	2.80	0.10	5.66	1.19	0.04	5.06	0.58	0.02	433.22	22.79	0.50
447301	4648476	21.51	2.47	0.10	5.92	1.17	0.04	5.27	0.55	0.02	378.94	19.38	0.58
447301	4648576	20.53	3.10	0.11	5.08	1.56	0.04	4.63	0.58	0.02	401.00	26.13	0.68
447301	4648676	15.50	3.59	0.11	5.09	1.74	0.05	4.30	0.63	0.02	592.99	30.74	0.87
447301	4648776	18.64	3.63	0.13	5.59	2.13	0.05	4.66	0.77	0.03	449.67	32.36	0.79
447301	4648876	18.69	3.58	0.14	7.01	2.07	0.05	4.66	0.72	0.03	428.83	35.90	0.76
447301	4648976	20.87	3.27	0.14	9.81	1.69	0.05	4.28	0.64	0.03	424.73	30.72	0.79
447301	4649076	18.85	2.92	0.15	11.46	1.85	0.06	4.83	0.92	0.03	436.14	24.86	0.90
447301	4649176	12.46	3.90	0.13	11.33	2.03	0.06	5.34	1.04	0.03	620.92	39.92	1.08
447301	4649276	12.30	3.96	0.14	9.36	2.19	0.06	5.47	0.98	0.03	682.23	36.95	1.18
447301	4649376	11.79	2.94	0.14	8.00	1.92	0.06	5.23	0.94	0.04	508.28	48.93	1.22
447301	4649476	13.19	3.12	0.14	9.23	1.77	0.07	4.69	0.90	0.04	535.02	31.89	1.17
447301	4649576	13.90	2.69	0.14	9.75	1.70	0.07	4.38	0.88	0.04	669.06	30.43	1.25
447301	4649676	13.50	3.60	0.15	9.49	1.58	0.07	5.20	0.83	0.04	656.42	40.95	1.35
447301	4649776	12.19	3.87	0.16	8.70	1.32	0.07	5.77	0.72	0.04	785.71	33.10	1.58
447301	4649876	13.36	3.32	0.16	9.05	1.34	0.07	6.03	0.71	0.04	659.68	38.88	1.56
447301	4649976	16.60	3.18	0.17	10.86	1.33	0.07	6.00	0.63	0.04	733.18	36.16	1.55

Each site was modeled with the corresponding site meteorological data and the meteorological data from the other four locations. For example, the Ames error was calculated using Des Moines, Lamoni, Marshalltown and Ottumwa meteorological data at the Ames airport and the Ames meteorological data run at the Des Moines, Lamoni, Marshalltown and Ottumwa airports.

The results from each of the error simulations (use of meteorological data from another location) are divided by the control run, i.e. results from the correct meteorology modeled at the correct site.

Table 4 is a matrix that shows the error calculation methodology for each site. Modeling was performed using meteorological data from one site in conjunction with the location of the same site or another site. This is denoted on the table as the meteorological data from an airport site @ the location of an airport site (e.g. KDSM@KAMW).

The resulting ratio obtained by applying non-site meteorological data at all five locations and dividing those concentrations by the concentrations from applying the corresponding site meteorological data can be used to determine whether the model results are likely to under or over predict concentrations. If the ratio is less than one the concentration is under predicted, and if over one the concentration is over predicted. The "error at site" group (Table 4 columns 1-4) gives the error by applying the non-site meteorological data to the site. The "error applying site" group (Table 4 columns 5-8) gives the error by applying the site's meteorological data to the other four locations. It is important to note that the error is calculated for each receptor, release type, release height and averaging period. This method avoids skewing the data towards the location, source type and averaging period that results in the highest concentration.

Table 4. Site Error Calculations

Error at Site				Site	Error Applying Site			
1	**2**	**3**	**4**		**5**	**6**	**7**	**8**
KDSM@KAMW / KAMW@KAMW	KLWD@KAMW / KAMW@KAMW	KMIW@KAMW / KAMW@KAMW	KOTM@KAMW / KAMW@KAMW	KAMW	KAMW@KDSM / KDSM@KDSM	KAMW@KLWD / KLWD@ KLWD	KAMW@KMIW / KMIW@KMIW	KAMW@KOTM / KOTM@KOTM
KAMW@KDSM / KDSM@KDSM	KLWD@KDSM / KDSM@KDSM	KMIW@KDSM / KDSM@KDSM	KOTM@KDSM / KDSM@KDSM	KDSM	KDSM@KAMW / KAMW@KAMW	KDSM@KLWD / KLWD@KLWD	KDSM@KMIW / KMIW@KMIW	KDSM@KOTM / KOTM@KOTM
KAMW@KLWD / KLWD@KLWD	KDSM@KLWD / KLWD@KLWD	KMIW@KLWD / KLWD@KLWD	KOTM@KLWD / KLWD@KLWD	KLWD	KLWD@KAMW / KAMW@KAMW	KLWD@KDSM / KDSM@KDSM	KLWD@KMIW / KMIW@KMIW	KLWD@KOTM / KOTM@KOTM
KAMW@KMIW / KMIW@KMIW	KDSM@KMIW / KMIW@KMIW	KLWD@KMIW / KMIW@KMIW	KOTM@KMIW / KMIW@KMIW	KMIW	KMIW@KAMW / KAMW@KAMW	KMIW@KDSM / KDSM@KDSM	KMIW@KLWD / KLWD@KLWD	KMIW@KOTM / KOTM@KOTM
KAMW@KOTM / KOTM@KOTM	KDSM@KOTM / KOTM@KOTM	KLWD@KOTM / KOTM@KOTM	KMIW@KOTM / KOTM@KOTM	KOTM	KOTM@KAMW / KAMW@KAMW	KOTM@KDSM / KDSM@KDSM	KOTM@KLWD / KLWD@KLWD	KOTM@KMIW / KMIW@KMIW

Table Key: KAMW = Ames, KDSM = Des Moines, KLWD = Lamoni, KMIW = Marshalltown, KOTM = Ottumwa

Calculation of Control Error

In order to calculate the overall error for a site, ratios were calculated for each error simulation depicted in Table 4. The resulting ratios were separated by under and over prediction. All the ratios under one (under prediction) for column 1-4 were averaged together and all the ratios equal to or greater than one (over prediction) for columns 1-4 were averaged together. The same process was completed for columns 5-8. Table 5 below summarizes a site error calculation using Ames (KAMW row 1 in Table 4) as an example.

The under prediction is always bound between zero and one whereas the over prediction has no upper bound. This skews the results towards over predictions because a ratio error of 0.5 and 2.0 each are off by a factor of two even though the over prediction is twice as large as the under prediction (over prediction = 2 - 1 = 1, and under prediction = 1 - 0.5 = 0.5). To account for this the under prediction is divided into one, which is the italicized number in the under prediction column. Then the under and over prediction (both italicized numbers) are averaged together to get the underlined number. Finally, the error is determined by subtracting one from the total, and converting to the percentage (last column in Table 5).

Table 5. Example of Calculating Site Error

Error at the Site (Columns 1-4 in Table 4)				
Site	**Under Prediction**	**Over Prediction**	**Average**	**Error**
KAMW	0.7981	1.1758	1.2144	21.4%
1/Average	1.2530			

Error applying Site (Columns 5-8 in Table 4)				
Site	**Under Prediction**	**Over Prediction**	**Average**	**Error**
KAMW	0.8676	1.3178	1.2352	23.5%
1/Average	1.1526			

The top bolded number in Table 5 is the error at the site, the error from using the meteorological data from the other four locations at the Ames airport. The bottom bolded number in Table 5 is the error by applying the site, the error from applying Ames's meteorological data at the four other airports. The two bolded numbers are averaged together to calculate the total site error. This process was repeated for the other four sites. Table 6 summarizes the total site error for all four sites.

Table 6. Total Site Error

Ames	Des Moines	Lamoni	Marshalltown	Ottumwa
22.5%	20.3%	23.4%	19.6%	21.1%

After all five site's total errors were calculated, the under and over predictions from all five sites were averaged to obtain the control error. The control error is the error from applying the non-site meteorological data at a site without the influence of significant terrain. The control error was calculated the same way as each total site error in order to be consistent. Table 7 summarizes the control error.

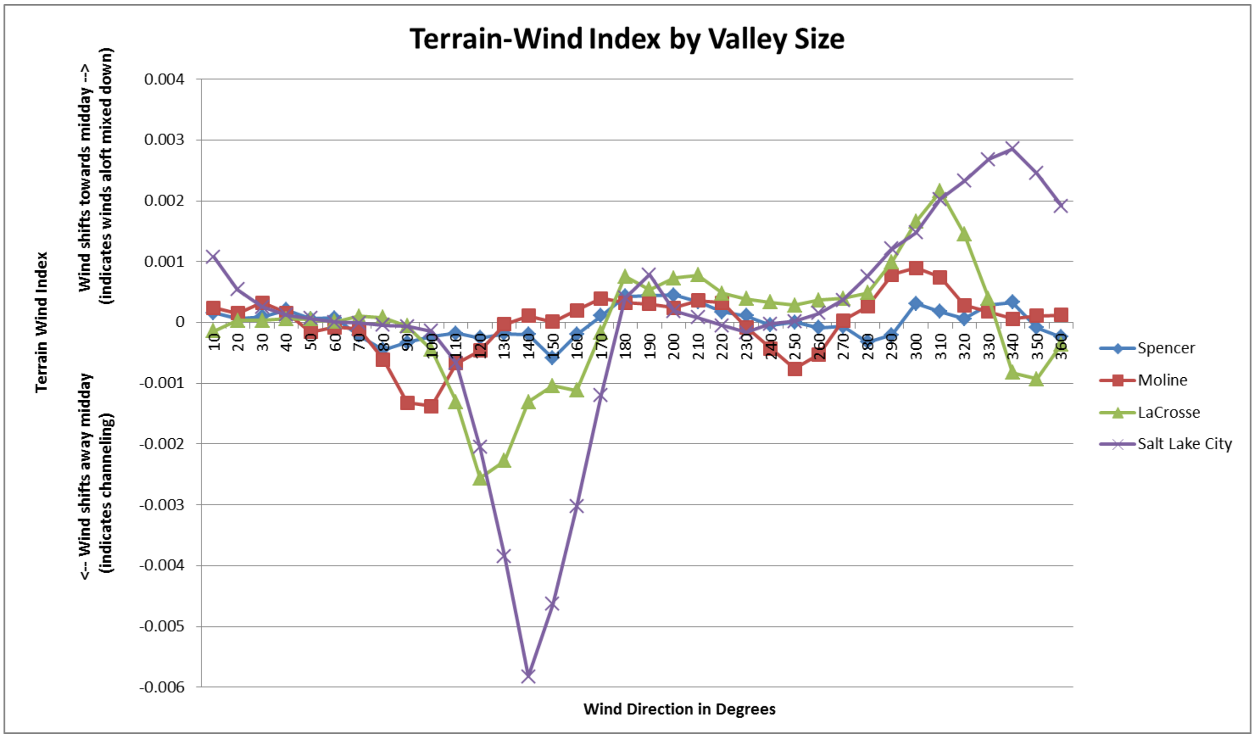
Table 7. Control Error

Under Prediction	Over Prediction	Control Error
0.8371	1.2324 (23.2%)	1.2135 (21.4%)
1.1946 (19.5%)		

Table 7 shows the average over and under prediction from Ames, Des Moines, Lamoni, Marshalltown, and Ottumwa and the control error of a 21.4%. The control error means that the error from applying incorrect meteorological data can on average over or under predicted model concentrations by **21.4%**, even without significant differences in terrain**.**

Terrain Error

The next step of the analysis was finding the possible error due to the terrain. The range of the index was used as a good indication of how much influence the terrain has on the wind pattern. Valley locations tend to have a larger range between the minimum and maximum index values than smaller valleys and non-valley locations. Figure 10 demonstrates this observation.



Spencer = Non-valley, Moline = Small valley, La Crosse = Medium valley, Salt Lake City = Large valley

Figure 10. Magnitude of Index by Valley Size

Using the range of the index turns the subjective observation into a numerical and objective analysis. The minimum index value was subtracted from the maximum index value obtaining the range of the index. Generally, the larger the terrain feature the larger the index range. Table 8 below is a sample of three large valleys, three medium valleys, three small valleys and three non-valleys.

Table 8. Index Range Compared to Terrain

Site	Index Range	Terrain
Bakersfield, CA	0.00951	Large Valley
Salt Lake City, UT	0.00868	Large Valley
Jackson Hole, WY	0.00674	Large Valley
Omaha, NE	0.00504	Medium Valley
La Crosse, WI	0.00472	Medium Valley
Prairie du Chien, WI	0.00365	Medium Valley
Moline, IL	0.00227	Small Valley
Le Mars, IA	0.00211	Small Valley
Lamoni, IA	0.00183	Non-valley
Iowa City, IA	0.00165	Small Valley
Mason City, IA	0.00123	Non-valley
Spencer, IA	0.00103	Non-valley

Valley Depths: Small valley < 60m -- 60m < Medium Valley < 180m -- Large Valley > 180m

Since the index range is a good indication of the influence, the index range is also related to the model error. The larger/deeper valley's meteorology will cause a larger error when placed on flat terrain and vice versa.

In order to perform this analysis readily available pre-processed AERMET data was needed. Table 9 lists the locations meeting this requirement and were used in this portion of the analysis.

Table 9. Sites used in Model Error Analysis

Sites	Terrain	Location
Ames	Non-Valley	Iowa
Burlington	Non-Valley	Iowa
Cedar Rapids	Non-Valley	Iowa
Davenport	Non-Valley	Iowa
Des Moines	Non-Valley	Iowa
Dubuque	Non-Valley	Iowa
Estherville	Non-Valley	Iowa
Lamoni	Non-Valley	Iowa
Marshalltown	Non-Valley	Iowa
Mason City	Non-Valley	Iowa
Ottumwa	Non-Valley	Iowa
Spencer	Non-Valley	Iowa
Waterloo	Non-Valley	Iowa
Bakersfield	Valley	California
Danbury	Valley	Connecticut
Fresno	Valley	California
Iowa City	Valley	Iowa
Key Field	Valley	Mississippi
La Crosse	Valley	Wisconsin
Lemoore	Valley	California
Modesto	Valley	California
Moline	Valley	Illinois
Naughton	Valley	Wyoming
Omaha	Valley	Nebraska
Sioux City	Valley	Iowa
Stockton	Valley	California
Tracy	Valley	Nevada
Visalia	Valley	California

The correlation between index range and model error was tested at different valley location throughout the United States (listed in Table 9). Table 10 demonstrates how the valley locations were tested. The error at each valley location was determined by running the model using Ames, Des Moines, Lamoni, Marshalltown and Ottumwa meteorological data at the valley locations (in Table 9). The error applying valley data is calculated by running the valley location (in Table 9) meteorological data at Ames, Des Moines, Lamoni, Marshalltown and Ottumwa.

Table 10. Calculating Model Error due to Terrain

<table>
<tr><th colspan="2">ERROR AT VALLEY LOCATION</th></tr>
<tr><td>KAMW</td><td rowspan="5">MET DATA @ VALLEY LOCATIONS IN TABLE 9</td></tr>
<tr><td>KDSM</td></tr>
<tr><td>KLWD</td></tr>
<tr><td>KMIW</td></tr>
<tr><td>KOTM</td></tr>
</table>

<table>
<tr><th colspan="2">ERROR APPLYING VALLEY LOCATION</th></tr>
<tr><td rowspan="5">VALLEY LOCATIONS IN TABLE 9 MET DATA @</td><td>KAMW</td></tr>
<tr><td>KDSM</td></tr>
<tr><td>KLWD</td></tr>
<tr><td>KMIW</td></tr>
<tr><td>KOTM</td></tr>
</table>

The analysis is similar to that used to calculate the control error. However, now valley wind data is applied at non-valley sites, and non-valley data is applied at valley sites. The process used to find the site error was completed the same way for each of the valley sites listed in Table 11. All data used in this analysis was generated from the most recent version (14134) of AERMET. Table 11 summarizes the net error calculated at various sites.

The net error in Table 11 is the total model error minus the control error (21.4%). The control error is a baseline for potential error not caused by significant terrain. After subtracting out the baseline, the remaining error should therefore be due to significant terrain influences.

Table 11. Valley Net Error

State	City	Net Error
California	Bakersfield	51.0%
California	Fresno	56.8%
California	Lemoore	39.2%
California	Modesto	50.4%
California	Stockton	47.7%
California	Visalia	45.6%
Connecticut	Danbury	25.7%
Illinois	Moline	9.5%
Iowa	Iowa City	5.1%
Iowa	Sioux City	8.7%
Mississippi	Keyfield	22.8%
Nebraska	Omaha	19.5%
Nevada	Tracy	89.8%
Wisconsin	La Crosse	15.6%
Wyoming	Naughton	81.1%

Terrain Error Cutoff

The net error calculated in Table 11 was plotted against the range of the index for each site, shown in Figure 11.

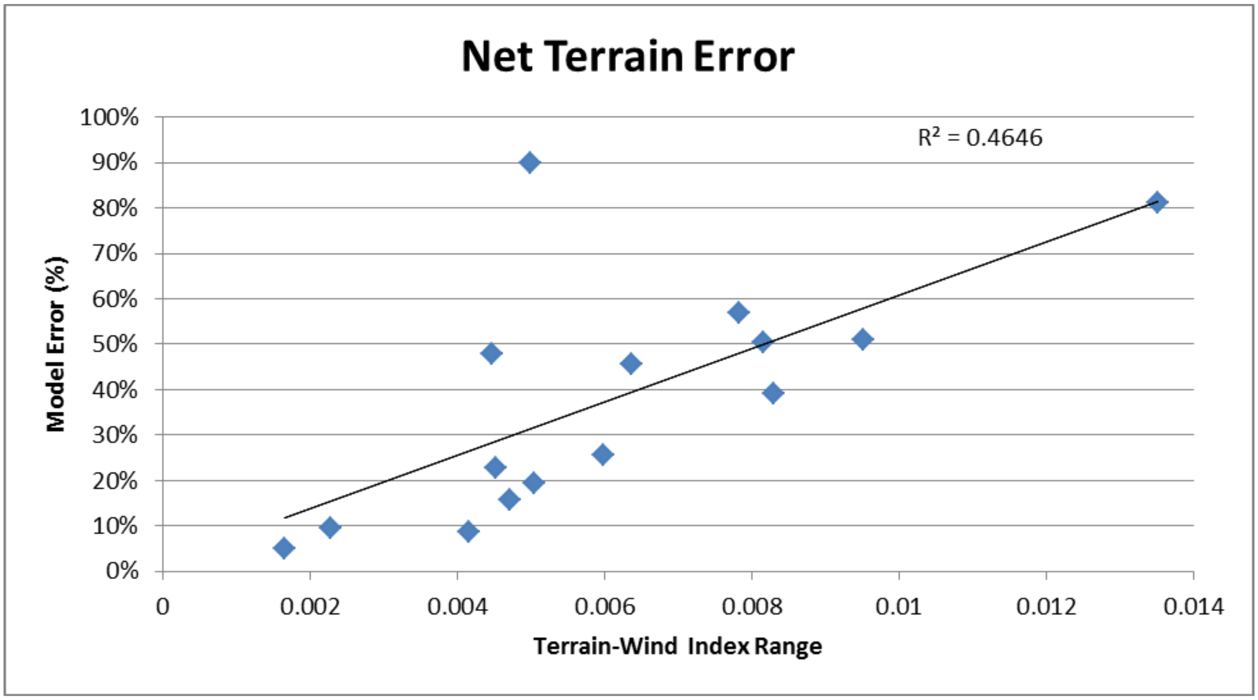


Figure 11. Index Range Compared with Net Error (Valley locations only)

This scatter plot can be used in conjunction with control error to find a cutoff for when terrain is influencing the wind pattern. This is depicted in Figure 12. The control error is represented by the error from all five non-valley sites (Ames, Des Moines, Lamoni, Marshalltown, Ottumwa) used to calculate the total control error. These locations are represented as red squares in Figure 12. There is a clear divide between the non-valley error and the terrain error with the exceptions of two valleys. These two valleys are Moline and Iowa City; both are considered a small valley (under 60 meters deep).

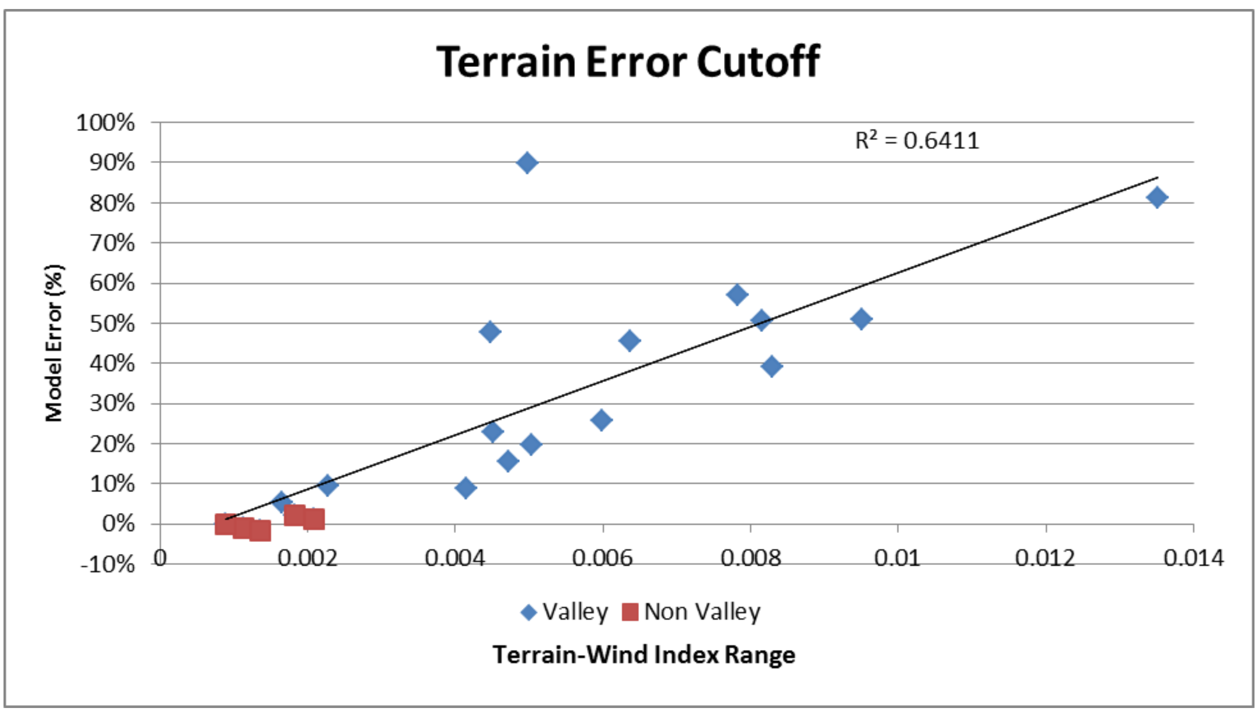


Figure 12. Index Range Compared with Net Error (Valley and non-valley locations)

Figure 12 shows that there is a relationship between the range of the index and the net error.

It should be noted that the control error was calculated using only Iowa sites but is being compared to sites to the west with very different climatological averages. This was done because no western data were available that were not influenced by terrain. Using the same non-valley data set in each error calculation reduced that number of variables in each calculation. Iowa data, uninfluenced by terrain, was the nearest available pre-processed data to the western valleys and was therefore deemed the most appropriate data set to use.

The chosen cutoff should encompass all non-valley sites to ensure that those sites are not incorrectly flagged as being influenced by terrain that does not exist. Therefore, the first step in finding a numerical cutoff for the influence of terrain on wind patterns was to identify the highest terrain-wind index range for any non-valley site. The maximum terrain-wind index range for any non-valley site was 0.00209 at Ames, so the cutoff should be equal to or greater than this.

An additional sensitivity analysis was conducted for Ames and the non-valley site with the next highest terrain-wind index range (Dubuque). These two sites were analyzed to find the greatest net error from applying the incorrect meteorology without significant terrain influence. The model error was calculated to ensure that these non-valleys did not have an error larger than the smallest valleys. It was used as a double check that the non-valley locations were representative of actual non-valley sites. Table 12 shows the index range for all non-valley sites in Iowa. The two highlighted have the first and second largest index range.

Table 12. Iowa Non-valley Index Range

Sites	Terrain-Wind Index Range
Ames	0.00209
Dubuque	0.00185
Lamoni	0.00183
Waterloo	0.00169
Estherville	0.00144
Marshalltown	0.00136
Cedar Rapids	0.00134
Mason City	0.00123
Des Moines	0.00113
Burlington	0.00110
Spencer	0.00103
Davenport	0.00103
Ottumwa	0.00089

Ames and Dubuque were analyzed at the 12 other locations listed in Table 12 and the 12 other locations were analyzed at Ames and Dubuque. This was to ensure that all possible error was considered in the cutoff. The net error for Ames and Dubuque are summarized in Table 13 as an indication that these non-valley sites are on the upper edge of non-valley indices ranges. Remember that the index range and model error have a proportional relationship. As expected, the net error for both locations is above 0% but below the smallest net terrain error (5.1%) which was Iowa City. These results support the use of this data to estimate the expected maximum terrain-wind index range for sites in the absence of terrain influence.

Table 13. Highest Non-valley Net Error and Index

Sites	Ames	Dubuque
Net Error	3.1%	4.6%
Index	0.00209	0.00185

As noted above only Ames and Dubuque were evaluated. This was done to avoid the need to evaluate every combination of the 13 locations. The assumption being that the two sites with the highest terrain-wind index would also have the highest net error. In the chance that one of the other sites would result in a slightly higher error, the 90% confidence interval of Ames and Dubuque was calculated to make sure that the cutoff does not capture any non-terrain influenced sites. The 90% confidence interval is equal to **0.0023.**

Therefore, the resulting index range cutoff for terrain influence is **0.0023**. A meteorological dataset with a terrain-wind index range equal to or greater than the cutoff is likely significantly influenced by the surrounding terrain. The index range is used as a cutoff instead of the net error because the goal was to find an easy to implement numerical cutoff. The index range is calculated straight from pre-processed AERMET data. No modeling is needed to calculate the index range. This allows the pre-screening of meteorological data for use in dispersion modeling.

Valley Depth Cutoff

No index range can be calculated in places where there is no readily available meteorological data. Since modeling analyses are often conducted in areas where onsite meteorological data is not readily available, it is necessary to have a way of determining whether or not offsite meteorology is representative. It was hypothesized that the valley depth could be used as a surrogate of the index range.

Valley depths can be estimated using the elevation profile ruler tool in Google Earth. Figure 13 shows how the valley depths were calculated in this analysis using La Crosse as an example. This tool was used to approximate the elevations directly outside and inside the valley. A "z" shape was drawn in Google Earth to obtain a sample of three cross sections of the elevations near the valley location. Three cross sections were used in order to minimize the possible error that would occur if any one cross-section happened to be located in an area of the valley with uniquely high or low elevations. The very extreme elevations were cutoff on both the high and low end to estimate the 5th and 95th percentile elevations (see black line in Figure 13). After the extremes where taken out, the lowest remaining elevation was subtracted from the highest remaining elevation to compute the valley depth (rounded to the nearest five meters). In Figure 13, the highest elevation was 1,215 feet and the lowest was 630 feet therefore the valley depth for La Crosse was 585 feet (1,215 - 630). The valley depth was converted into meters and rounded to the nearest five meters. In the La Crosse example the final valley depth would be 180 meters. The converted and rounded valley depths can be found in Table 14. This process was completed for all valley locations.

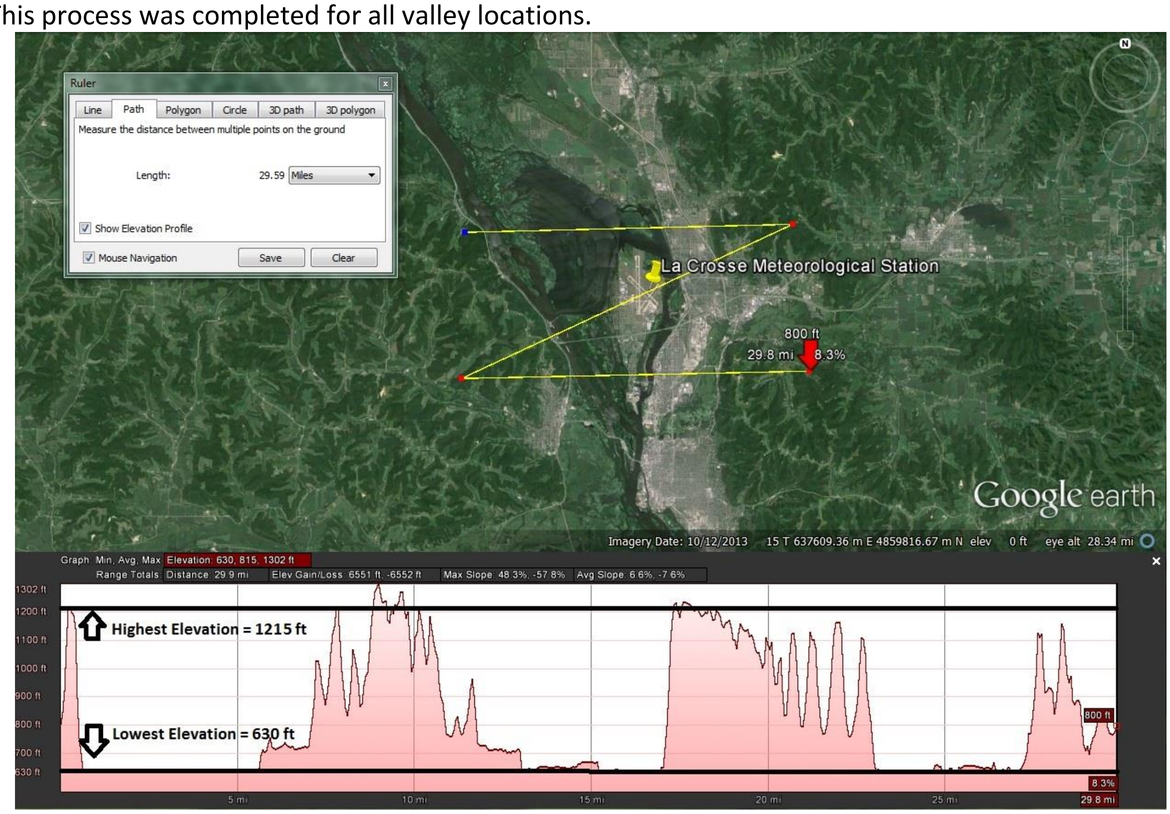


Figure 13. Elevation Profile Ruler and Calculation of Valley Depths[5]

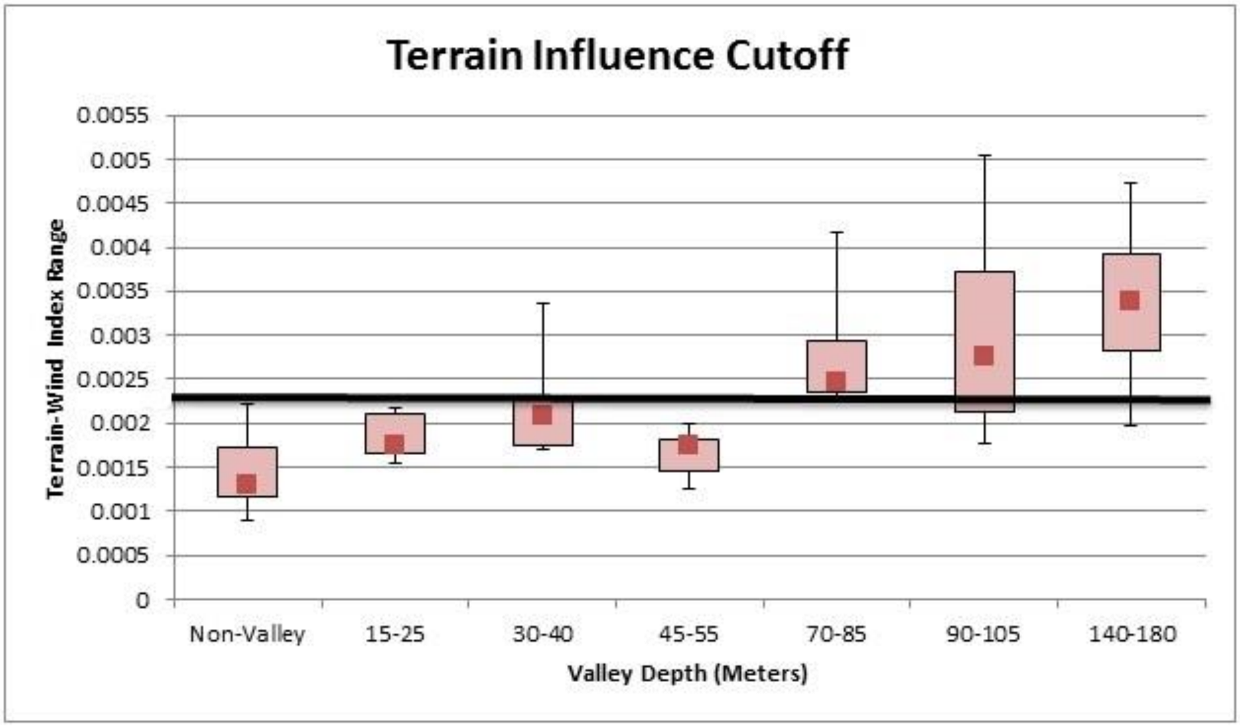
[5] (Google Earth Pro)

The 0.0023 index range cutoff was compared to index ranges of different valley depths in order to find where the 0.0023 value falls in relationship to the valley depth. Where ever the 0.0023 line falls would define the valley depth cutoff. A box and whisker plot of 11 non-valleys, 15 small valleys (under 60 meters), and 12 medium valleys (60 meters to 180 meters) was used to determine the valley range cutoff, Figure 14 below. Table 14 lists all the sites used in the box and whisker plot. Large valleys (greater than 180 meters) are assumed to influence the wind and are therefore not included in this analysis. The valley groups were based off of valley depths in Iowa.

Table 14. Sites used in Box and Whisker Plot

Sites	Terrain	Valley Depth (meters)
Arcadia	Non-Valley	N/A
Blair	Non-Valley	N/A
Council Bluffs	Non-Valley	N/A
Dubuque 1	Non-Valley	N/A
Dubuque 2	Non-Valley	N/A
Iowa City RWIS	Non-Valley	N/A
Kellogg	Non-Valley	N/A
Mason City	Non-Valley	N/A
Nebraska City	Non-Valley	N/A
Plattsmouth	Non-Valley	N/A
Ridgeway	Non-Valley	N/A
Sioux Falls	Small valley	15
Le Mars	Small valley	20
Iowa City ASOS	Small valley	25
Luverne	Small valley	25
Vinton	Small valley	25
Atlantic	Small valley	30
Millard	Small valley	30
Shenandoah	Small valley	35
Clarinda	Small valley	40
Moline	Small valley	40
Audubon	Small valley	45
Red Oak	Small valley	45
Harlan	Small valley	50
Tekamah	Small valley	50
Muscatine	Small valley	55
Savanna	Medium valley	70
Sidney	Medium valley	70
Sioux City	Medium valley	70
Offutt	Medium valley	85
Missouri Valley	Medium valley	90
Omaha	Medium valley	90
Onawa	Medium valley	100
Boscobel	Medium valley	105
Prairie du Chien ASOS	Medium valley	140
Prairie du Chien RWIS	Medium valley	150
Winona	Medium valley	150
La Crosse	Medium valley	180

Figure 14. Index Range by Valley Size



The top and bottom of the red boxes represent the first and third quartile for the each group. The upper and lower bounds of the whiskers represent the extreme values of the group. The dark red square in the boxes represent the median value for each group.

The small and medium valleys were broken up into three groups to ensure that all of the small and medium valley extremes were represented. Warranting that all extremes are represented ensures that the valley cutoff will be an accurate representation of when terrain is influencing the wind pattern. Each group had roughly the same number of valley locations, either 4 or 5.

The bold black line shows the index cutoff of 0.0023. All non-valley sites and almost all small valley sites are under the index cutoff of 0.0023. Therefore if there is a valley **less than 60 meters** assume that the terrain is not significantly influencing the wind and that valley-specific data is not necessary.

The 60 meter cutoff should only be used if there is no available pre-processed data to calculate the index range. The index range (with cutoff value of 0.0023) should take precedent over the valley size cutoff in applications of this methodology.

Iowa City and Sioux Falls are both valley locations that were used in this analysis. Currently, however, neither location is used as a valley specific data set. Both locations are used to represent three different counties in Iowa. Each location is considered a small valley and therefore falls below the 60 meter and the 0.0023 index cutoff. This analysis supports the conclusion that these sites are representative of non-valley locations[6].

[6] (2005-2009 AERMOD Meteorological Data)

Summary

Overall, the wind patterns are quantified by using the diurnal temperature. The percent frequency is correlated to the diurnal pattern along with the standard deviation of the percent frequency to calculate the Terrain-Wind index. The range of the index is used for a numerical and objective decision in order to measure the influence of terrain on a location. The index range and net error has a relationship with a cutoff of 0.0023 for terrain influence. Any meteorological data set with a Terrain-Wind Index range below 0.0023 is considered not to be influenced by terrain. Meteorological data set with an index range above 0.0023 is considered influenced by the terrain and should only be used in areas influence by the same or similar terrain features. In locations where data is not available a 60 meter deep cutoff for valley locations should be used. Valleys equal to or greater than 60 meters should utilize data from a location influenced by the same or similar terrain features.

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Glossary

AERMET - The meteorological pre-processor that produces the meteorology data used in AERMOD

Climatological - Prevailing weather conditions, averaged over many years

Diurnal - Daily

Forced Channeling - Channeling of upper winds along a valley's axis when upper winds are diverted by the underlying topography

Pressure Driven Channeling - Channeling of wind in a valley by synoptic-scale pressure gradients superimposed along the valley's axis

Receptor - Concentration calculation location

Synoptic - Weather occurring over a large region (from 100 km to 5,000 km) for at least 12 hours

UTM Coordinates - Orthomorphic projection that uses a 2D Cartesian coordinate system for locations on earth

Wind Direction - The direction **from which** the wind is blowing

Wind Roses - A diagram showing the frequency and speed of the wind from various directions

Appendix –Every Site used in Analysis

Sites	Terrain	Location	Sites	Terrain	Location	Sites	Terrain	Location
Boston[7]	Coastal	Massachusetts	Ridgeway[6]	Non-Valley	Minnesota	Missouri Valley[6]	Valley	Iowa
Groton[8]	Coastal	Connecticut	Spencer[9]	Non-Valley	Iowa	Modesto[11]	Valley	California
Gulfport[9]	Coastal	Mississippi	Waterloo[9]	Non-Valley	Iowa	Moline[9]	Valley	Illinois
San Francisco[6]	Coastal	California	Atlantic[10]	Valley	Iowa	Muscatine[10]	Valley	Iowa
Ames[10]	Non-Valley	Iowa	Audubon[10]	Valley	Iowa	Naughton*[12]	Valley	Wyoming
Arcadia[6]	Non-Valley	Wisconsin	Bakersfield[11]	Valley	California	Offutt[11]	Valley	Nebraska
Blair[6]	Non-Valley	Nebraska	Boscobel[10]	Valley	Wisconsin	Omaha[9]	Valley	Nebraska
Burlington[9]	Non-Valley	Iowa	Clarinda[10]	Valley	Iowa	Onawa[6]	Valley	Iowa
Cedar Rapids[9]	Non-Valley	Iowa	Danbury[7]	Valley	Connecticut	Prairie Du Chien-ASOS[10]	Valley	Wisconsin
Council Bluffs[9]	Non-Valley	Iowa	Elko[6]	Valley	Nevada	Prairie Du Chien-RWIS[6]	Valley	Wisconsin
Davenport[9]	Non-Valley	Iowa	Fresno[12]	Valley	California	Red Oak[10]	Valley	Iowa
Des Moines[9]	Non-Valley	Iowa	Hailey[6]	Valley	Idaho	Salt Lake City[6]	Valley	Utah
Dubuque-ASOS[9]	Non-Valley	Iowa	Harlan[10]	Valley	Iowa	Savanna[10]	Valley	Illinois
Dubuque-RWIS[6]	Non-Valley	Iowa	Hayden[6]	Valley	Idaho	Shenandoah[10]	Valley	Iowa
Estherville[9]	Non-Valley	Iowa	Iowa City-ASOS[9]	Valley	Iowa	Sidney[6]	Valley	Iowa
Iowa City-RWIS[6]	Non-Valley	Iowa	Jackson Hole[6]	Valley	Wyoming	Sioux City[9]	Valley	Iowa
Kellogg[6]	Non-Valley	Minnesota	Key Field[8]	Valley	Mississippi	Sioux Falls[9]	Valley	South Dakota
Lamoni[9]	Non-Valley	Iowa	La Crosse[9]	Valley	Wisconsin	Stockton[11]	Valley	California
Marshalltown[9]	Non-Valley	Iowa	Le Mars[10]	Valley	Iowa	Tekamah[6]	Valley	Nebraska
Mason City[9]	Non-Valley	Iowa	Lemoore*[11]	Valley	California	Tracy*[13][13]	Valley	Nevada
Nebraska City[6]	Non-Valley	Nebraska	Luverne[10]	Valley	Minnesota	Vinton[6]	Valley	Iowa
Ottumwa[9]	Non-Valley	Iowa	Millard[10]	Valley	Nebraska	Visalia*[11][14]	Valley	California
Plattsmouth[6]	Non-Valley	Nebraska	Missoula[6]	Valley	Montana	Winona[6]	Valley	Minnesota

*Fewer than five years

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[7] http://mesonet.agron.iastate.edu/
[8] http://www.ct.gov/deep/cwp/view.asp?a=2684&q=450396
[9] http://www.deq.state.ms.us/MDEQ.nsf/page/epd_AERMET_Preprocessedmetdata?OpenDocument
[10] http://www.iowadnr.gov/InsideDNR/RegulatoryAir/Modeling/DispersionModeling/MeteorologicalData.aspx
[11] http://www.ncdc.noaa.gov/
[12] http://www.valleyair.org/busind/pto/Tox_Resources/AirQualityMonitoring.htm
[13] http://deq.state.wy.us/aqd/construction.asp
[14] http://ndep.nv.gov/baqp/planning.html