Practical Implications of Applying the DRR Modeling TAD Using AERMOD

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ABSTRACT

The AERMOD Model has become the workhorse of regulatory modeling analyses even more so than its decade-ago predecessor, the Industrial Source Complex Model in its short-term mode (ISCST3). To this end and much to their credit, the Environmental Protection Agency has added better science in many respects as well as optional selections to group sources and concatenate results that allow easy tabulation of concentrations in formats commensurate with the form of the 2010 SO_2 and NO_2 1-hour National Ambient Air Quality Standards. In addition, a number of beta options are being considered to meet modeling community and regulatory demands, some of which are included in the proposed 2015 *Guideline on Air Quality Models*. On the regulatory front came the SO_2 2015 Data Requirements Rule (DRR) and two associated technical assistance documents (TADs) which would allow an unclassified area to be either modeled to determine compliance or to set up and operate ambient monitors. In either case, the use of the AERMOD Model, now in its 2015 version, v15181, is recommended for use in the DRR modeling studies. In some cases, for example, where short stacks are located in terrain situations, the "beta options" may have applicability to produce more representative modeling results. This paper examines the application of AERMOD in this DRR context using the ADJ_U* option. The paper is designed as an example to show a proposed level of documentation that may be required and acceptable for using this particular beta option.

INTRODUCTION

The AERMOD Model[1,2] was introduced to the regulatory dispersion modeling community in 1995 as part of EPA's proposed updates and later introduced as a regulatory preferred model in 2005 in Section 4.2.2.b of the *Guideline on Air Quality Models* (GAQM)[3] where it states that AERMOD is the recommended model for "a wide range of regulatory applications in all types of terrain". Along with AERMOD are preprocessors also recommended for preparing data sets applicable to running the AERMOD algorithms for transport, dispersion, convective boundary layer turbulence, stable boundary layer, terrain influences, building downwash, and land use. Draft versions of the EPA's guidance for modeling to designate an area as attainment or nonattainment via either modeling[4] or monitoring[5] where modeling is used as part of the designation process recommended the use of AERMOD. The current applicable version of the

AERMOD Model is Version 15181[6] which was released on June 30, 2015 on the U.S. EPA's website. The proposed update to U.S. EPA's modeling guidance in the form of the *Guideline on Air Quality Models*, was released on July 15, 2015 via the U.S. EPA technical website[7]. This proposed guidance and revised AERMOD model have options that could affect the outcome of designation modeling with respect to low wind speeds and stable nighttime turbulence in the model.

When AERMOD is run with a meteorological dataset derived from one-minute meteorological data as is currently recommended by U.S. EPA, low wind speeds are much more prevalent than in prior versions of the modeling system that did not rely on one-minute meteorological data. These low wind speeds have been linked to potential overestimates in ambient concentrations by AERMOD. These overestimates occur, in part, due to an underestimate of friction velocity (u*) by the AERMET meteorological processor. EPA recognized this underestimation as a potential issue with AERMET (and subsequently, AERMOD) and released AERMET Version 12345 which included a beta option, ADJ_U*, which allowed the friction velocity (u*) to be adjusted using the methods of Qian and Venkatram[8] to better account for turbulence in the atmosphere during low wind speed, stable conditions. This beta option was first released in AERMET version 12345, was updated to incorporate a modified Bulk Richardson Number in version 13350, was further modified to adjust u* for low solar elevation angles with version 14134, and was most recently in Version 15181, used to modify the calculation of the turbulence measure, Monin-Obukhov length. Given the refined nature of this beta option and the peer reviewed studies which have acknowledged its accuracy, the use of ADJ_U* may allow more representative and more accurate modeling results. The documentation and use of such an option are mentioned in the draft guidance[7] as well as other guidance available from EPA which says:

> "…Appendix W allows flexibility to consider the use of alternative models on a case-by-case basis when an adequate demonstration can be made that the alternative model performs better than, or is more appropriate than, the preferred model for a particular application."

The remainder of this paper addresses the broad application and results of applying the ADJ_U* option in AERMOD as well as a synopsis of the required documentation to substantiate its use.

METHODOLOGY

The AERMOD Model was used to perform modeling for a facility under the DRR for SO2 using a common meteorological data set and methodology for the meteorology at the London-Corbin Regional Airport (KLOZ, 03849) in London, Kentucky. ASOS one minute data were also available and AERMET was used along with upper air data from the Nashville International Airport (KBNA, 13897) to generate three years of AERMOD-ready meteorology including the ADJ_U*. Along with this data preparation was the assemblage of the documentation of the procedures and requirements from Section 3.2 (Use of Alternative Models) of the current Guideline. Rather than just compare modeling results of AERMOD for a power plant where the default concentrations are compared to various beta option combinations of ADJ_U*, LOWWIND1, LOWWIND2, LOWWIND3, the focus here will be on the assumption that the AERMOD_ADJ_U* version gave the most representative results (based on model to monitor comparisons). The focus in this paper is on the alternative model acceptability documentation in the form preferred by the Guideline.

Overview of Section 3.2 of the Guideline on Air Quality Models

Unfortunately, because the u* option is not a default option in AERMOD, the combined use of AERMOD plus the u* adjustment in the meteorology file does not have "preferred" status in the sense that it is a model to be used for regulatory purposes without additional regulatory authority approval. To substantiate that the adjusted friction velocity option in AERMOD is a valid model to use, Section 3.2 of Appendix W describes steps to be considered, on a case-by-case basis, to allow the use of the u* adjusted AERMOD as an acceptable alternative model. The section also describes criteria for determining the acceptability of an alternative model. Section 3.2.2.b states that satisfying any one of the three alternative conditions may make use of an alternative model acceptable. Condition 1 states that the alternative model will demonstrate equivalency. But in this case the AERMOD Model is the preferred model of choice with just an option change (making it alternative). Because the model cannot have a demonstration of equivalency to itself and the option change will result in different results, this condition is not applicable. This leaves the satisfaction of Conditions 2 and 3 as criteria to accept the u* option in AERMOD. Condition 2 requires the formal submittal of a protocol to allow demonstration of superior performance which is acceptable to a regulatory control agency. This type of study would require appropriate ambient air quality monitoring and side-by-side modeling and comparisons which are generally beyond the scope of most permitting and regulatory projects.

Thus, Condition 3 remained and offered the best path toward alternative model demonstration by following the individual criteria to meet its requirements. Section 3.2.2.e states that a preferred model may be used provided that five criteria are met. These are:

i. The model has received a scientific peer review;
ii. The model can be demonstrated to be applicable to the problem on a theoretical basis;
iii. The data bases which are necessary to perform the analysis are available and adequate;
iv. Appropriate performance evaluations of the model have shown that the model is not biased towards underestimates; and
v. A protocol on methods and procedures to be followed has been established.

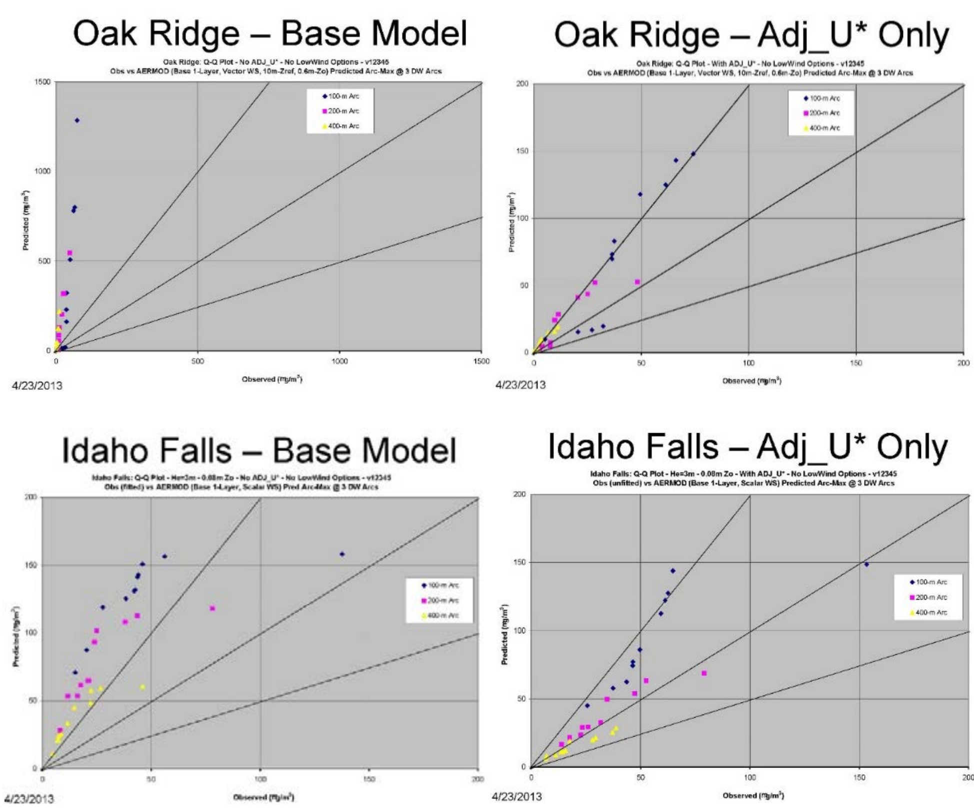
Review of these criteria as well as the responses to each within the context of modeling show that the use of the u* option in AERMET and used in AERMOD to be valid and representative under general demonstration conditions. A proposed response to each criteria is given in the following subsections.

Criteria 3.2.2.e.i - Scientific Peer Review

The use of an adjusted friction velocity in AERMOD has received scientific peer review and been evaluated both by U.S. EPA modelers as well as others in the scientific and modeling community. Two examples are:

- The paper entitled "Performance of Steady-State Dispersion Models Under Low Wind-Speed Conditions" by Wenjun Qian and Akula Venkatram, Boundary Layer Meteorology, Volume 138, pp 475-491, 2011[8]. This paper examined the AERMOD Model to estimate dispersion under low wind speed events. Two tracer studies, the Prairie Grass Experiment and the Idaho Falls experiment, were compared to the use of AERMOD with and without u* adjustments. The analysis reports that the tendency of AERMOD to overestimate ambient air impacts during low wind speed events was reduced by incorporating an empirical modification. This modification is incorporated into the AERMET program through the ADJ_U*. This option generates the enhanced friction velocity based on low wind speeds and stable atmospheric conditions on an hour-by-hour basis. Also in his email memorandum dated June 26, 2013, George Bridgers of the U.S. EPA's Office of Air Quality Planning and Standards, notes that "The AERMET BETA option is based on a peer reviewed study (Qian and Venkatram, 2011) which also includes independent evaluations of the new u-star estimates…".
- In his April 23, 2013 presentation at the Regional/State/Local Modeling Meeting in Dallas, Texas, Roger Brode[9] showed "improved AERMOD performance" when including the u* adjustment. The figures in Figure 1[9] below from Mr. Brode's presentation demonstrate the enhanced performance of AERMOD for two field data bases, namely the Oak Ridge Study and the Idaho Falls Study. The closer the points are to the center line of each graph, the better the model performance.

Figure 1. Comparison of the AERMOD Model with and without the u* Adjustment



Criteria 3.2.2.e.ii- Applicable on a Theoretical Basis

Over the past several years many scientific studies have noted that Gaussian dispersion models tend to over predict concentrations at low wind speeds. In the early days of dispersion modeling when the threshold velocities of the National Weather Service anemometers were a few miles per hour, the common use of 1.0 m/s as the lowest wind speed that would be considered in the model was prevalent. The modeling community recognized that winds lower than that would result in ambient concentration estimates that were not coincidental with ambient monitored values at these same low wind speed conditions. Because concentration is inversely proportional to wind speed, as wind speeds dip below 1 m/s, concentrations are greater. In addition, other studies and field research showed that winds tend to meander during low wind speeds, meaning that the wind was not in only one direction during the time step of the Gaussian models, namely one hour, but tended to change over the time step. The relationship between this phenomenon and the friction velocity calculations in AERMET determined that adjusting the u* could have the same effect as adjusting plume meander and was better estimated empirically (as demonstrated in the peer review paper by Qian and Venkatram).

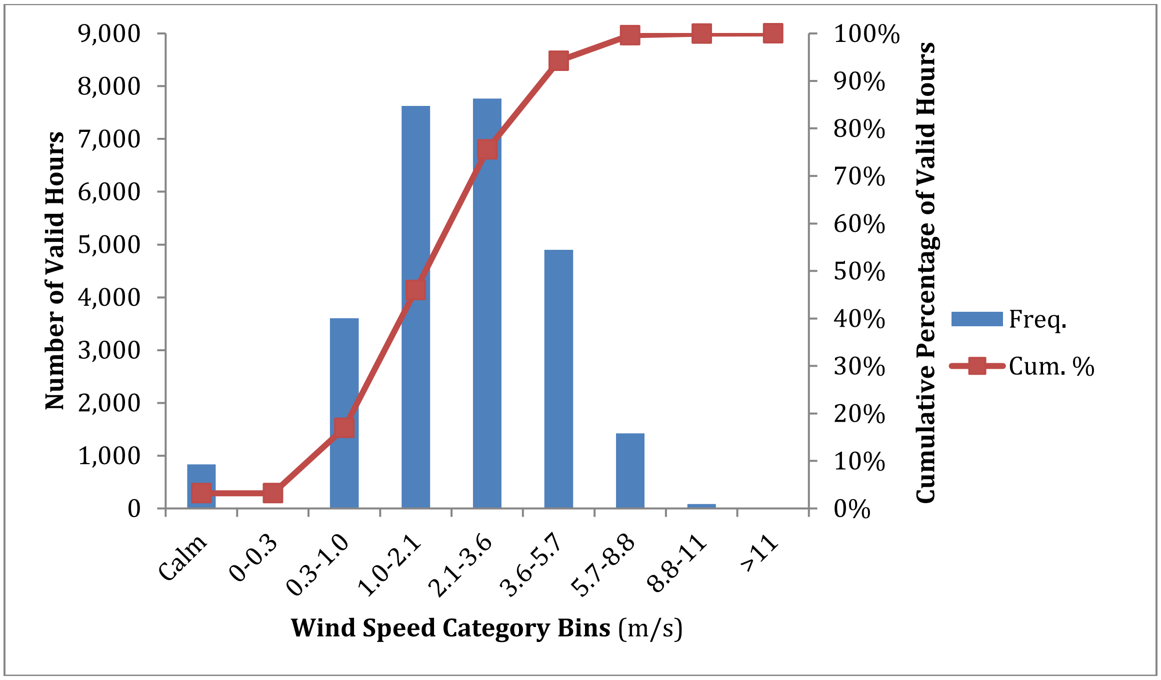
In reviewing the frequency distribution of winds from the London-Corbin Airport for the 2012-2014 period of record, the number of hours in the range of 0.28 m/s (the lower limit where AERMOD will make a calculation) to less than 2.1 m/s wind speed is 11,224 hours over the three year period of record or 42.7%. This distribution is shown in Table 1 and Figure 2. Thus, the consideration of better science in terms of the u* adjustment is applicable and reasonable given this relatively high frequency of low wind occurrences.

Table 1. Distribution of Hourly Observations by Wind Speed and Wind Direction

Dates: 7/1/2012 - 00:00 ... 6/30/2015 - 23:00

	Directions / Wind Classes (m/s)	0.3 - 1.0	1.0 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.0	>= 11.0	Total
1	348.75 - 11.25	228	446	469	320	32	0	0	1495
2	11.25 - 33.75	234	634	740	330	20	0	0	1958
3	33.75 - 56.25	212	350	546	121	10	0	0	1239
4	56.25 - 78.75	154	222	259	44	0	0	0	679
5	78.75 - 101.25	178	285	241	28	1	0	0	733
6	101.25 - 123.75	223	333	123	12	0	0	0	691
7	123.75 - 146.25	429	682	192	52	8	0	0	1363
8	146.25 - 168.75	604	1247	434	66	11	0	0	2362
9	168.75 - 191.25	479	942	794	551	172	6	0	2944
10	191.25 - 213.75	236	668	899	533	182	10	1	2529
11	213.75 - 236.25	166	476	755	639	196	5	1	2238
12	236.25 - 258.75	85	325	532	489	179	19	0	1629
13	258.75 - 281.25	93	286	502	495	287	36	3	1702
14	281.25 - 303.75	80	262	456	510	188	9	2	1507
15	303.75 - 326.25	92	236	400	391	78	0	0	1197
16	326.25 - 348.75	112	225	398	321	57	0	0	1113
	Sub-Total	3605	7619	7740	4902	1421	85	7	25379
	Calms								837
	Missing/Incomplete								64
	Total								26280

Figure 2. Distribution of Hourly Observations by Wind Speed Category Bin



As a further measure of assessing the importance of low wind speeds in the meteorological dataset, wind speeds associated with maximum concentrations when the default AERMET processing was employed and when the ADJ_U* option were assessed. For any hourly impacts above a nominal 100 µg/m^3 (approximately 50% of the 1-hr SO_2 NAAQS) identified in the results from the default and ADJ_U* modeling runs, a wind speed was determined that was associated with each event. The resulting wind speed dataset was then plotted in a histogram format to show a cumulative frequency of impacts within selected bins of wind speed. These plots, shown in Figures 3 and 4 for the default and ADJ_U* cases, respectively, show a significant number of cases with low wind conditions with the highest concentrations relative to the overall distribution of wind speeds within the meteorological dataset. The percentage of wind speeds below 2.1 m/s contributing to impacts above 100 µg/m^3 in the default case is 78.3% (only hours >100 µg/m^3) versus only 42.7% in the distribution of all ranges of concentration (all hours, not shown). When such a large percentage of high impacts are controlled by a single type of meteorological condition (i.e., low wind speeds), a potential overestimate inherent to the model is most likely the cause rather than an underlying meteorological phenomenon influencing plume dispersion.

When the ADJ_U* option is used, the percentage of winds below 2.1 m/s contributing to impacts above 100 µg/m^3 drops significantly to only 49.3%. This value is in line with the overall percentage of wind speeds below 2.1 m/s in the selected meteorological dataset (42.7%), and thus, indicates the ADJ_U* option yields a profile of controlling meteorological conditions for maximum impacts that is not unrealistically biased towards low winds.

Figure 3. Distribution of Wind Speeds for Impacts above 100 μg/m³ with the Default AERMET Dataset

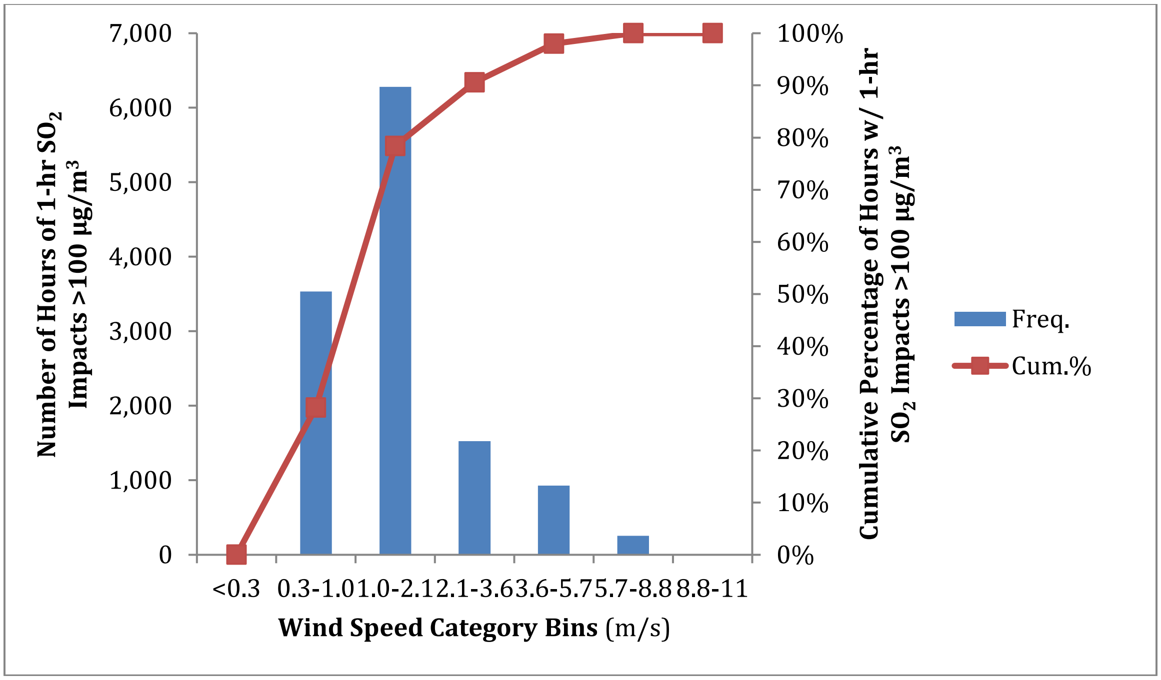
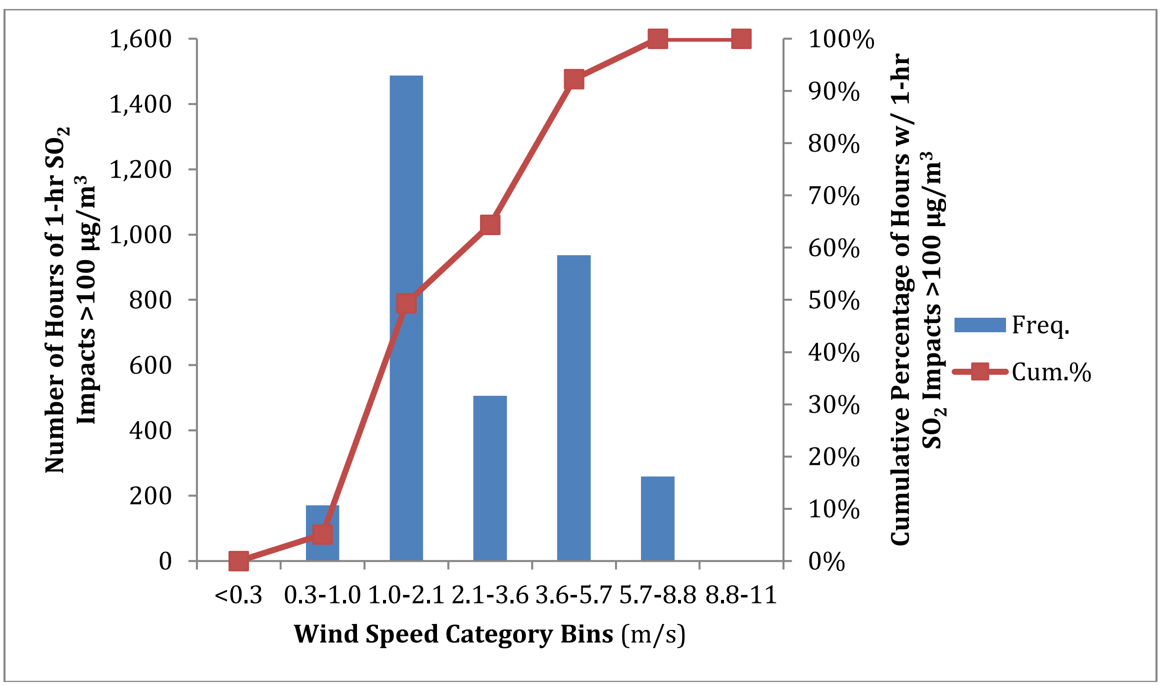


Figure 4. Distribution of Wind Speeds for Impacts above 100 μg/m³ with the ADJ_U* AERMET Dataset



Criteria 3.2.2.e.iii – Availability of Databases

The test data bases and reporting for low wind speed observations and evaluation are available to assess model performance. The data bases applicable to this discussion and use of the u* option in AERMET and AERMOD are:

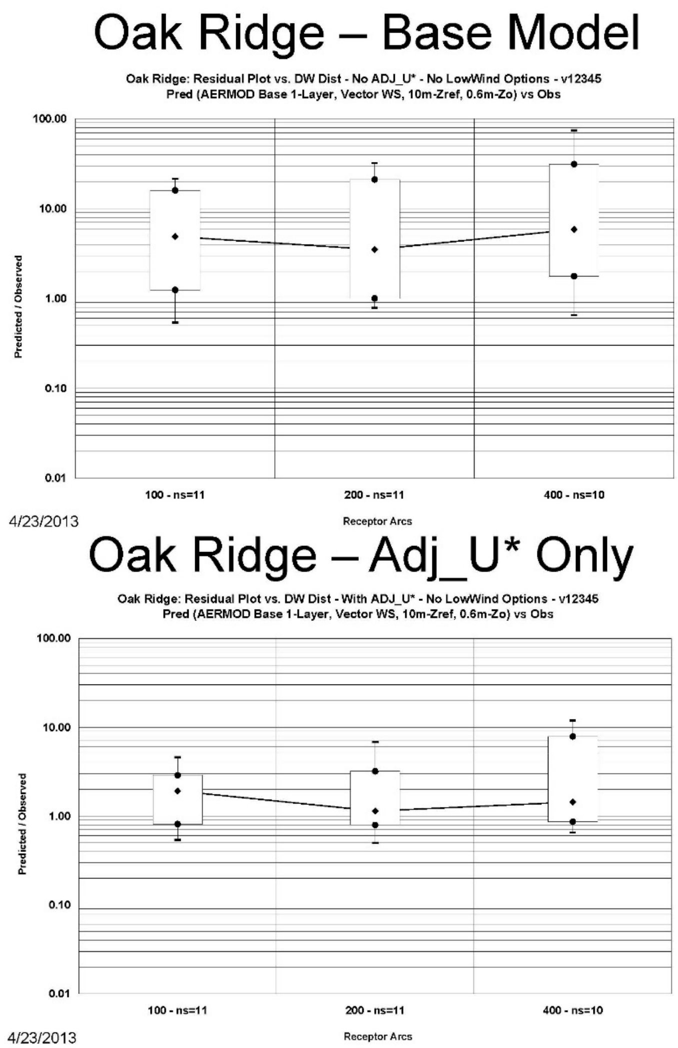
- Idaho Falls Study- Sagendorf JF, Dickson CR (1974) Diffusion under low wind speed, inversion conditions. NOAA Technical Memorandum ERL ARL-52, 89 pp.
- Prairie Grass Study - Barad ML (ed) (1958) Project Prairie Grass. A field program in diffusion. Geophysical research paper no. 59, vols I (300 pp) and II (221 pp). AFCRF-TR-58-235. Air Force Cambridge Research Center, Bedford, Massachusetts; under Model Evaluation Databases on U.S EPA's website - http://www.epa.gov/ttn/scram/dispersion_prefrec.htm
- Oak Ridge Study - NOAA Technical Memorandum ERL ARL-61, 1976. Diffusion under Low Wind Speed Conditions near Oak Ridge, Tennessee. Wilson, R. B., G. Start, C. Dickson, N. Ricks. Air Resources Laboratory, Idaho Falls, Idaho.

In addition, the AERMET source code and all input data required for implementing the ADJ_U* are publicly available on U.S. EPA's SCRAM website.

Criteria 3.2.2.e.iv – Demonstration of No Biases Towards Underestimates

As demonstrated in a number of studies over the past 3-5 years, including the 2010 study by AECOM[10], the use of the u* adjustment in dispersion modeling has not shown any bias towards underestimating the ambient concentrations due to sources and emissions. A repeat use of the same Oak Ridge data set in 2013 by the U.S. EPA in their model performance evaluation demonstrates both the improved performance of AERMOD with u* option and no bias towards underestimation as shown in Figure 5.

Figure 5. Residual Plots Showing Improved Performance with u* and No Bias toward Underestimation[10]



Criteria 3.2.2.e.v – A Protocol Has Been Established

A modeling protocol can be provided to a regulatory agency prior to any modeling to be performed. This protocol should provide a detailed overview of the model selection process, potential options to be considered, source and building considerations, receptor grids, meteorological data, other source inventories, and anticipated tabular and graphical outputs. The protocol should describe the potential frequent occurrence of low winds, if appropriate, due to the EPA-recommended use of the one-minute meteorological data. The consideration of the use of the ADJ_U* and other LOWWIND options should be discussed and why they may be applicable for a modeling situation. Comments should be solicited from the regulatory agency. No specific protocol for implementing the ADJ_U* option in AERMET is needed since invoking this option only includes the selection of a single keyword.

CONCLUSIONS

This presentation of the potential documentation needed to meet the requirements of demonstrating that an alternative model is appropriate provides a strawman for consideration. Of course more lengthy discussions and data reviews can be prepared but the adequacy and sufficiency of more reviews may be called into question. What was important in this study was to make use of available modeling studies as presented and interpreted by EPA as well as to consider local features of low wind speeds.

REFERENCES

1. *User's Guide for the AMS/EPA Regulatory Model - AERMOD.* U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Revised September 2004.

2. *AERMOD Implementation Guide*. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Revised January 2008.

3. *Guideline on Air Quality Models.* Appendix W to 40 CFR Parts 51 and 52. Federal Register, November 9, 2005. pp. 68217-68261.

4. *Modeling TAD*, *EPA*-453/R-XX-XXX, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. 2013.

5. *Monitoring TAD*, *EPA*-453/R-XX-XXX, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. 2013.

6. *https://www3.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod*

7. *Revision to the Guideline on Air Quality Models: Enhancements to the AERMOD Dispersion Modeling System and Incorporation of Approaches to Address Ozone and Fine Particulate Matter; Proposed Rule.* Federal Register, July 29, 2015. pp. 45339-45387.

8. Wenjun Qian and Akula Venkatram, *Performance of Steady State Dispersion Models Under Low Wind-Speed Conditions*, Boundary-Layer Meteorology, no. 138 (2011): 475-491.

9. http://www.cleanairinfo.com/regionalstatelocalmodelingworkshop/archive/2013/agenda.htm

10. *AERMOD Low Wind Speed Evaluation Study Results*, prepared for the American Petroleum Institute and utility Air Regulatory Group, prepared by AECOM, Westford, MA, March 22, 2010.

KEYWORDS

AERMOD, U-star, NAAQS, beta options, LOWWIND, dispersion modeling