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Project Summary

An Evaluation of Alternative Gaussian Plume Dispersion Modeling Techniques in Estimating Short-Term Sulfur Dioxide Concentrations

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A routinely applied atmospheric dispersion model was modified to evaluate alternative modeling techniques that allow for more detailed source data, onsite meteorological data, and several dispersion methodologies. These techniques were evaluated using hourly measured SO_2 concentrations at fixed receptors around coal-fired power plants near Paradise, Kentucky, during 1976, and near Johnsonville, Tennessee, during 1977. A significant finding of the evaluation was that the more sophisticated models did not appreciably outperform the routinely applied models. The models using airport meteorological data performed as well as the models using onsite wind data. With the Pasquill-Gifford and Briggs dispersion schemes, small differences in model performance were observed. More substantial differences occurred with models using onsite turbulence measurements. The model using Pasquill's recommendations tended to overpredict peak concentrations. The models based on Draxler's and Cramer's approaches using onsite turbulence yielded mixed results, perhaps in part because the lateral standard deviation of wind direction available was the 1-h average of 5-min values (rather than a 1-h value), thus eliminating the longer period fluctuations that are important in estimating 1-h concentrations in addition to the shorter period fluctuations. Additional research is recommended to improve the application of onsite turbulence measurements and to provide more accurate estimates of plume trajectories for input to atmospheric dispersion models.

This Project Summary was developed by EPA's Environmental Sciences Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The EPA routinely uses Gaussian plume models to make decisions having important environmental and economic impacts on air quality. Despite the economic and environmental importance placed on air quality modeling, the predictions from dispersion models are often no better than within a factor of two of the observations. Recognizing the limitations of these models, the EPA and the American Meteorological Society (AMS) have initiated steps to improve current modeling practices. The general consensus is that more validations of air quality simulation models are needed to improve existing models and to guide the development of future models.

In the current study, a Gaussian plume dispersion model incorporating alternative techniques was evaluated using a comprehensive data base developed for two Tennessee Valley Authority coal-fired power plants: Johnsonville and Paradise. Alternative modeling techniques were included in a routinely applied Gaussian dispersion model, including different approaches for emissions, meteorology, and dispersion.

The benchmark model from which the alternatives were developed was the MPTER algorithm, Multiple Point Gaussian Dispersion Algorithm with Optional Terrain Adjustment, an air quality simulation model that is used by EPA in regulatory applications. The MPTER was especially suited for this study because actual coordinates for each monitoring site could be specified, along with the physical separation between stacks. Furthermore, the author's in-depth experience with MPTER allowed for careful and expedient inclusion of the alternative models.

Modeling Alternatives Used

In modeling for regulatory applications, the design capacity or the maximum operating capacity of resulting SO_2 emissions and source parameters are often required as model inputs. The daily and seasonal operating rates vary significantly at most coal-fired power plants. Furthermore, maximum surface concentrations at a power plant can occur under less than full-load conditions. Thus, for the Johnsonville and Paradise locations, hourly SO_2 emissions, stack gas temperatures, and gas exit velocities were computed for comparison to full-load conditions.

The meteorological data required for EPA regulatory applications are often selected from the National Weather Service (NWS) stations that are most representative of the site being modeled. In this study, the airport data from Nashville, Tennessee (BNA) were used as model inputs for the Paradise and Johnsonville sites. Evansville, Indiana (EVV) surface data were also included for comparison at the Paradise site. Because the use of onsite meteorological data is preferred, the hourly average 110-m onsite wind data were used at both power plants.

An accurate estimate of dispersion is critical in air quality analysis. In this regard, much effort was made in developing the alternative models in this study. The MPTER uses Pasquill-Gifford (PG) dispersion coefficients. As one alternative, Pasquill's approach for estimating buoyancy-induced dispersion (BID) was evaluated. Briggs' rural dispersion coefficients combined with Pasquill's[1], Draxler's[2], and Cramer's[3] that use onsite turbulence measurements were evaluated for the Johnsonville site.

A matrix of model alternatives was developed for use in Paradise in 1976 and for use in Johnsonville in 1977. These matrices are shown in Tables 1 and 2 respectively. In the development of the alternative models, an effort was made to keep each change in a technique independent of the other techniques.

Accomplishments

Short-term SO_2 concentrations were evaluated at Paradise with seven modeling alternatives and at Johnsonville with eleven modeling alternatives. The accomplishments of this study included the following:

1) The development of two years of data (one year for Paradise and one year for Johnsonville) consisting of hourly SO_2 emission rates and stack characteristics, hourly SO_2 concentrations monitored at ten to twelve receptor sites, hourly average onsite meteorological parameters, and hourly NWS meteorological data collected at BNA, and EVV;

2) The incorporation of alternative modeling techniques into the EPA Gaussian plume dispersion model, MPTER, including modifications of MPTER to allow for the input of onsite meteorological data, the development of an algorithm for calculating dispersion using Briggs' rural interpolation formulae, and adaptations of onsite turbulence schemes using methods described by Pasquill, Draxler, and Cramer;

3) The implementation of these models using the available data on EPA's UNIVAC computer; and

4) The analysis of the model's results and observed SO_2 concentrations using relatively straightforward statistical comparisons.

[1]Pasquill, F. 1976. *Atmospheric Dispersion Parameters in Gaussian Plume Modeling Part II Possible Requirements for Change in Turner Workbook Values.* EPA-600/4-76-030b. Environmental Protection Agency Research Triangle Park, North Carolina. 53 p.

[2]Draxler, R. 1976. "Determination of Atmospheric Diffusion Parameters." *Atmos. Environ.* 10: 99-105.

[3]Cramer, H. E. 1976 "Improved Techniques for Modeling the Dispersion of Tall Stack Plumes." In: *Proceedings of the Seventh International Technical Meeting on Air Pollution Modeling and Its Application.* N. 51, NATO/CCMS Airlie House, Virginia. pp. 731-780.

Results

Paradise

At the Paradise plant, greater differences in predicted SO_2 concentrations resulted from using various emissions data than from using alternative dispersion schemes and meteorological data. Furthermore, the "conservative" full-load emissions models compared more favorably to peak observed concentrations than the "more realistic" models using hourly emissions data, which underpredicted peak concentrations by about a factor of two. This unexpected result was attributed to inaccuracies associated with estimating stability, mixing heights, wind vectors, and/or SO_2 emission rates.

Another unexpected feature of the Paradise analysis was that the models incorporating onsite wind data did not show significant improvements over the models using airport meteorological data.

Although the concentrations from the two modeling alternatives differed hour to hour, the overall results, especially for the peak concentrations, were similar.

Although emissions input and meteorological data have been recognized as having important effects in dispersion modeling, dispersion schemes are usually discussed as a primary basis for model differences. The concentrations predicted with the three dispersion schemes at Paradise, however, resulted in average differences of less than 10 percent. Buoyancy-induced dispersion did seem to increase concentrations with the models using the Briggs and PG dispersion coefficients, although the Briggs coefficients potentially can yield lower concentrations for downwind distances up to two kilometers. Furthermore, measurements taken from receptors closer to the source than those located at Paradise should be examined for comparison with the Briggs and PG curves.

Johnsonville

With the 11 Johnsonville alternative models, the principal emphasis was on the prediction of peak concentrations, especially the concentrations related to the National Ambient Air Quality Standards for SO_2. Some additional analyses were used to diagnostically evaluate the models.

The significant differences between the emissions data alternatives that were

Table 1. *Modeling Alternative Matrix Used for Paradise*

Technique	*Model Number* 1	2	3	4	5	6	7
Emissions input							
Full-load conditions	X	X					
Hourly averages			X	X	X	X	X
Meteorology input							
BNA airport data	X		X				
EVV airport data				X			
Onsite wind data		X			X	X	X
Dispersion scheme							
PG	X	X	X	X	X		
PG with BID						X	
Briggs formulae with BID							X

Table 2. *Modeling Alternative Matrix for Johnsonville*

Technique	*Model Number* 1	2	3	4	5	6	7	8	9	10	11
Emissions input											
Full-load conditions	X	X									
Daily averages			X								
Hourly averages				X	X	X	X	X	X	X	X
Meteorology input											
BNA airport data	X		X	X							
BNA, exclude calms		X			X						
Onsite wind data						X	X	X	X	X	X
Dispersion scheme											
PG	X	X	X	X	X	X					
PG with BID							X				
Briggs with BID								X			
Pasquill's 1976 scheme									X		
Draxler's scheme										X	
Cramer's scheme											X

noted in the Paradise analysis were not evident in the Johnsonville analysis. In fact, the models using full-load emissions data compared similarly to the models using hourly and daily emission data for the peak concentrations. The differences between the models using daily and hourly emissions data seemed insignificant; in retrospect, it probably would have been more cost effective to use the daily emission rates rather than the hourly emission rates. The similar performance noted for the models using full-load, daily, and hourly emission rates may have been due to the increased plume rise associated with full-load stack parameters, which would cause a reduction in maximum surface concentrations.

It appeared that the procedure to eliminate calm winds had little effect on peak concentrations. At other power plant sites where the receptors are located closer to the source and where A- and B-stability has a greater effect on peak concentrations, the elimination of calm winds might be an important consideration.

As with Paradise, little additional benefit was gained by using onsite wind data in preference to airport data. This is probably because the airport site, BNA, and the Johnsonville site are similar in topography. In the diagnostic evaluation, the model using onsite wind data did show better performance over the airport model, resulting in higher correlations and mean fractional errors closer to zero.

The differences between the models using different dispersion schemes were again small in contrast to the differences noted with the emission and meteorological alternatives. In predicting the peak concentrations, the three basic dispersion models (PG, PG with buoyancy-induced dispersion, and Briggs) performed about equally. The models using on-site turbulence data, however, did not perform as well as expected. The Pasquill scheme overpredicted most peak concentrations. The modeling alternatives using the Cramer and Draxler dispersion schemes gave results that were comparable to the models using the PG curves but differed substantially, on occasion, from the observations. Because the Cramer and Draxler models limited dispersion during nighttime hours, further work is needed to develop a scheme to practically estimate dispersion using routine meteorological measurements during all meteorological regimes. In this study, the PG model appeared to perform as well as the other dispersion schemes.

Conclusions and Recommendations

In studies of this kind, the results often suggest a need for improving modeling techniques and for obtaining more sophisticated input data. This study did not deviate from this tradition. The alternative modeling approaches used with the Johnsonville and Paradise plants yielded results that were within an order of magnitude of the peak SO_2 concentrations. Yet, further improvements are possible with more accurate source term data, more site-specific meteorological data, and more refined dispersion schemes.

The major differences in model performance resulted from differences in emission rates and to a lesser extent from the use of different meteorological data. The use of alternative dispersion schemes was not as significant. However, efforts to improve the measurements of the standard deviations of horizontal and vertical wind direction (as well as other turbulence parameters) could provide a more reliable means for estimating dispersion.

The task of model evaluation in this study was especially onerous, because slight differences in predicted plume trajectories overwhelmed the statistical comparison used to examine the alternative modeling approaches. This further substantiates the observation that the Gaussian plume dispersion model is especially sensitive to the input of wind direction. Model evaluations could perhaps be simplified by following the advice of Calder and Johnson, i.e., that each model component be separately evaluated. Otherwise, it is difficult to compare the strengths and weaknesses of different modeling techniques. The difficulty in performing model evaluation is further compounded by lack of field data. The availability of field data from studies such as Cinder Cone Butte, Idaho, and Kincaid, Illinois, will hopefully make the tasks of model evaluation and model improvement less formidable.

*The EPA author **Thomas E. Pierce** was on assignment to the Environmental Sciences Research Laboratory, Research Triangle Park, NC 27711 from NOAA, U.S. Department of Commerce (presently with NUS Corporation, Gaithersburg, MD).*

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The complete report, entitled "An Evaluation of Alternative Gaussian Plume Dispersion Modeling Techniques in Estimating Short-Term Sulfur Dioxide Concentrations," (Order No. PB 84-223 627; Cost: $16.00, subject to change) will be available only from:

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