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Project Summary

Analyses of PEM-2 Model Evaluation Results for Short-Term Urban Particulate Matter

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The Pollution Episodic Model Version 2 (PEM-2), an urban dispersion model, has been evaluated with measurements from the 1982 Philadelphia Aerosol Field Study data base in order to investigate its ability to model 12-hour average concentrations of particulate matter less than 10 micrometers (PM_{10}). Modeled fine and coarse particulate total masses were combined and then statistically evaluated against corresponding PM_{10} measurements at six monitoring sites for a 29-day experimental period.

Model performance was determined from statistical measures of difference and correlation between observed and modeled concentrations paired in time and location. The regional background dominated many of the evaluation statistics since it contributed about 70% to the measured urban PM_{10} concentrations.

Concentration estimates from PEM-2 and the RAM model are compared from independent evaluations with this same data base. Mean and high-five PM_{10} concentrations from the PEM-2 model were about 25% lower than RAM predictions at four sites within the city limits. Differences in model results are attributed to particulate removal by dry deposition and settling processes in PEM-2 and the different treatments of area source emissions by these models. Results of statistical measures were still quite similiar for both models. Due to the dominant role of regional background concentrations in this evaluation study, it was not possible to conclude which model performed more accurately.

This Project Summary was developed by EPA's Atmospheric 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 proposed National Ambient Air Quality Standards (NAAQS) regulations will establish a 24-hour standard for particulate matter in the size range less than 10 micrometers (PM_{10}). Once this short-term standard is promulgated, state and local regulatory agencies will be required to develop implementation plans to attain and maintain the new standards. Air quality dispersion models are expected to be relied upon for urban regulatory applications and emission control strategies contained in the state implementation plans. In support of the Agency's policy to regulate urban particulates, the Atmospheric Sciences Research Laboratory has sponsored the development and evaluation effort of the Pollution Episodic Model Version 2 (PEM-2). The PEM-2 is an urban-scale Gaussian plume diffusion-deposition model which has been designed to compute short-term (up to 24-hours) ground-level concentrations of one or two species of particulate or gaseous pollutants. The model accounts for the transport, dispersion, and the deposition and settling processes of particulates from multiple point and/or area emission sources.

This report contains the results of various analyses to evaluate the ability of

PEM-2 to model PM_{10} concentrations. The model results for fine and coarse particulates were aggregated and statistically evaluated against corresponding PM_{10} measurements derived from observed fine and coarse particulate concentrations from the Philadelphia data base. Statistical measures of difference and correlation for modeled and measured concentrations paired in time and space were used to examine model performance. In addition, comparative results from PEM-2 and the RAM are presented.

Model Evaluation Data Base

All the measurements necessary to perform a model evaluation for urban particulates were obtained during the Philadelphia Aerosol Field Study (PAFS). The PAFS field program was conducted during an intensive 31-day period from 14 July to 14 August 1982 in the metropolitan region of Philadelphia, Pennsylvania.

A comprehensive inventory of fine (FP) and coarse (CP) particulate total mass emissions was developed specifically for the experimental period. Some real-time sampling was performed and an effort was made to determine whether important sources were operating continuously or off-line at times during the study period Nevertheless, it is acknowledged that the hourly emissions were primarily derived from long-term values and should not be construed to represent actual emissions measurements. The components of the inventory included 300 major point sources, 289 area sources, gridded mobile sources, gridded minor point sources, and 25 sources of Industrial Process Fugitive Particulate Emissions (IPFPE) The area, gridded mobile, and minor point source emissions were combined into a single file for input to the model because they were constructed on the same 17 x 17 grid with individual cell sizes of 2.5 km on a side. The IPFPE sources were also incorporated into this emissions grid where each existed, although their grid cell sizes were either 0.2 km or 0.5 km.

There were six PAFS monitoring sites equipped with dichotomous filter samplers which provided continuous FP and CP measurements during the 31-day experimental study. All 6 sites were located within the urban emissions region and 4 sites were situated inside the city limits The FP and CP total mass measurements consisted of 12-hour average concentrations. The two averaging periods of 0600-1800 EDT and 1800-0600 EDT are essentially representative of daytime and nighttime conditions, respectively.

The model requires hourly values of wind speed and direction, temperature, mixing height, and stability class. Hourly surface observations made by the National Weather Service at the Philadelphia International Airport (PHL) located in the southwest section of the city were obtained for the model evaluation. High resolution upper air temperature and relative humidity measurements up to 2000 m were obtained by an airsonde system which was launched three times daily at 0400, 1000, and 1600 EDT from 16 July through 14 August. The height of the lowest elevated temperature inversion base defined the mixing height. The observed morning and afternoon mixing heights, and hourly surface observations were input to the RAMMET meteorological processor in order to derive hourly values of mixing height and stability class required by PEM-2.

Model Evaluation Results

The technical features and options chosen for the model runs included: urban wind profile exponents, stack-tip downwash, new plume rise/penetration methods, and a constant height of 10 m was specified for all area sources. The deposition (V_d) and gravitational settling (W) velocities for the particulate species are given below.

Dry Deposition and Settling Velocities for the PEM-2 Evaluation Runs

Particulate Range	V_d (cm/s) Day	V_d (cm/s) Night	W (cm/s) Day	W (cm/s) Night
Fine (FP)	0.2	0.1	0.0	0.0
Coarse (CP)	0.5	0.5	0.25	0.25

There is uncertainty associated with these values since there is a lack of experimental deposition measurements in urban areas. Nevertheless, these estimates provide for differences between the time periods and for different size ranges.

PEM-2 was executed to compute hourly concentrations of FP and CP due to hourly emissions and hourly meteorological parameters for the 29-day period from 16 July through 14 August 1982.

The determination of the regional particulate component is an important factor of urban PM_{10} modeling because it may be a relatively large fraction of the total measured concentration at urban receptor sites. The regional background measurement must be representative of the incoming concentration into an urban domain. Hence, it should be measured at an upwind site or suitable 'remote' location that is not impacted by nearby sources or influenced by emissions from the urban area being modeled. Unfortunately the PAFS sites, were all located inside the Philadelphia emissions area. The hourly surface wind observations were averaged over 12-hour intervals corresponding to the time period of the measured concentrations in order to determine which site was upwind of the city. In an attempt to account for these contributions of urban emissions at the upwind site, the regional background (PM_b) was determined by subtracting the predicted concentration (P_i) from the observed concentration at the upwind site (PM_{up}) for each period.

Two separate sets of statistical results were determined in this model evaluation. For Set 1, observations (O_i) were compared to the corresponding sum of model predictions and background (i.e. $P_i + PM_b$). For Set 2, results were obtained for model predictions (P_i) and corresponding resultant observed values derived by subtracting the background for each period from the measured concentration (i.e. $O_i - PM_b$).

In the analysis where PM_b was included with predictions, paired values from the upwind site were omitted in the sample data set. Although this criterion reduced the sample size, the statistical measures would be artifically improved if upwind values were included due to the method of determining PM_b. PEM-2 slightly underestimated PM_{10} concentrations with an overall positive bias (d) of 5.3 $\mu g/m^3$. The mean modeled concentration was 43.9 $\mu g/m^3$. A value of 0.96 ± 0.3 for the ratio of P/O was favorable. However, measures of correlation from linear regression analysis departed from desired values. A relatively large intercept (A) of 23.7, a slope (b) of only 0.41, and a correlation coefficient (R) of 0.56 were determined from all available paired concentrations. A few cases of high observed concentrations being greatly underpredicted had a definitive influence on the linear correlation measures and also effected the difference measures, such as bias.

Due to the large influence of PM_b on the previous evaluation statistics, the Set 2 of statistical results were obtained with concentration pairs composed of model predictions and resultant observed values

minus the regional backgrounds. Several of the statistical measures revealed poor model performance as results differ largely from the other set of values. Although bias and absolute error were nearly equivalent in both sets of results, their magnitudes represented a much greater fraction of the observed and predicted means for these concentration pairs. The relatively large absolute error, near zero slope, and small R also indicate considerable scatter and little correlation between these paired concentrations. In fact, the standard deviations were comparable to the mean resultant observed values. These results also demonstrated the powerful role of the regional particulate background in this evaluation process.

Both PEM-2 and the RAM model are Gaussian plume models with many of the same technical features and options. However, there are a few important differences between these models, which may yield variations in estimated concentrations. A relevant factor is that PEM-2 accounts for dry deposition and gravitational settling, while these processes cannot be considered by the RAM model. Another difference between these models is in the treatment of area emissions and their source heights. PEM-2 computes contributions from up to eight upwind area cells to the concentration at a given receptor, while RAM can consider the impact at a particular receptor from all upwind area sources. Additionally, a single area source height can be specified in the PEM-2 runs. In contrast, RAM allows for input of different area source heights. Both models were executed with the same emissions data base, and hourly meteorological parameters, although there may be small differences in the mixing height since values from a nearby rawinsonde site were used instead of the PAFS airsonde site data.

A single area source height of 10 m was input in the PEM-2 model runs. In contrast, one of three possible source heights was specified for area sources in RAM; namely, 13.7 m, 9.1 m, or 4.6 m, were assigned to area sources based on emission rate. The grid size for both models was 2.5 km. This means the contributions from area sources beyond 20 km from a site were not considered by PEM-2 in the concentration calculations for a given site. All area sources upwind of a site were included in RAM.

The RAM evaluation results were taken from another report and its background values were used with the PEM-2 model results in this phase of the analysis to make the direct comparison with RAM possible. The common feature found from both sets of statistics was that PEM-2 predictions were consistently lower than RAM's results in the mean and peak concentrations. In the set where modeled predictions were considered alone, the PEM-2 mean value of 10.1 $\mu g/m^3$ is 3.1 $\mu g/m^3$ less, or about 75% of RAM's mean concentration of 13.2 $\mu g/m^3$. The model differences described earlier were believed responsible for the different predictions. Modeled concentrations by PEM-2 were reduced due to losses by deposition processes. RAM's consideration of more upwind areas sources and lower source heights for some area sources, particularly those grid cells outside the city, compared to a uniform 10 m height for PEM-2 also contributed to higher concentrations since PEM-2 computations are limited to eight upwind area grids.

The relative similarity in results for both models made it difficult to state which model performed better or more accurately. While the correlation measures for PEM-2 are slightly better than the RAM results, the large positive biases revealed both models greatly underpredicted observed values.

An interesting feature explored was the difference in model predictions for the various sites. A revealing result when comparing these model predictions was the ratio of this difference to the RAM prediction (i.e. $P_{RAM} - P_{PEM} / P_{RAM}$) at each site. Interestingly, the percentage of this ratio was about 20% for the central urban site and at the 3 sites closet to it, but results jumped to 35% and 40% at two outlying sites. These latter two sites were most distant from the central downtown area. It appeared that differences between the models were accentuated when approaching the boundary of the model domain, which in this case was farthest from the city and larger emissions.

Of particular relevance in regulatory applications is how a model simulates the highest concentrations since these are the values which may exceed a pollutant standard and provide the basis for the design concentration upon which a control strategy is implemented. Results for high-five concentrations were similar to those obtained from the mean concentration results. PEM-2 predictions were almost always lower than RAM's results. The values of the concentration ratio PEM-2/RAM were lowest at the 2 outermost sites. Both models significantly underpredicted the peak observed concentrations even when the regional background values were used.

Large positive biases in the comparison of PEM-2 and RAM results may be explained by underestimated regional backgrounds used in the RAM evaluation. The strong similarity in the statistical results revealed little evidence to distinguish between the performance of these models. Model accuracy was also difficult to assess from the evaluation statistics due to the dominant role of the regional background component.

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The complete report entitled "Analyses of PEM-2 Model Evaluation Results for Short-Term Urban Particulate Matter," (Order No. PB 87-199 667/AS; Cost: $13.95, subject to change) will be available only from:

National Technical Information Service
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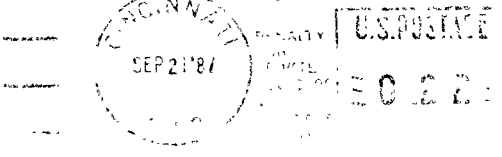

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