4B.2 PROJECT PRIME: EVALUATION OF BUILDING DOWNWASH MODELS USING FIELD AND WIND TUNNEL DATA

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1. INTRODUCTION

Aerodynamic building downwash is a phenomenon caused by eddies created by air movement around building obstacles. Through the use of the Industrial Source Complex (ISC) model, EPA modeling guidelines have incorporated these effects in ground-level concentration calculations. Unfortunately, the current ISC model retains numerous discontinuities.

In several modeling scenarios, permit applicants have found that their design concentrations are based upon modeled downwash concentrations. An accurate determination of building downwash effects is now and may increasingly become more important. Unfortunately, few evaluation studies have been conducted in this area.

In 1992, the Electric Power Research Institute (EPRI) decided to embark upon a program (project PRIME: Plume Rise Model Enhancements) to design a new downwash model to correct the deficiencies mentioned above. The resulting downwash module, PRIME (see Schulman et al., 1998), has been installed in the ISCST3 model as a replacement for the current algorithm; the resulting model is referred to as "ISC-PRIME". As part of the study, EPRI contracted with ENSR to prepare existing data bases for use in model development as well as an independent ("hands-off") model evaluation study. This report describes in detail the results of the evaluation of ISCST3 and ISC-PRIME with data bases reserved for the independent model evaluation study.

The central approach of PRIME is to explicitly treat the trajectory of the plume near the building, and to use the position of the plume relative to the building to calculate interactions with the building wake. The trajectory of the rising plume downwind of a building is the result of two competing processes: (1) descent of the air containing the plume material, and (2) rise of the plume relative to the streamlines due to buoyancy or momentum effects. For a given source-building configuration, the dominant effect depends on the wind direction relative to the building face (affecting the amount of streamline descent) and the wind speed (controlling the rate of rise of the plume.) PRIME explicitly calculates the local slope of the mean streamlines as a function of building shape and wind angle, and coupled with a numerical plume rise model, determines the change in plume centerline location with downwind distance. This approach directly addresses the current deficiencies in the downwash algorithm of the ISC model.

2. SUMMARY OF EVALUATION DATA BASES

After an extensive search, ENSR identified 14 candidate data bases for the model evaluation, as discussed by Paine, 1995. These data bases, consisting of 8 tracer experiments, 3 long-term (1 year) data sets, and 3 wind tunnel studies, have been documented by Paine, 1996.

The four data sets reserved for the independent model evaluation are briefly summarized below.

- Conventional Network: Bowline Point Station, New York

  Source type: electric utility; two 600-MW units, each with an 86.9-m stack; dominant roof tier was 65.2 meters high; rural area

  Length of period: 1 year

  Monitor coverage: four close-in sites at distances from 251 to 848 meters

- Tracer Site: American Gas Association (AGA) Study (Texas and Kansas)

  Source type: Gas compressor station stacks; stack height to building height ratio ranged from 0.95 to 2.52; rural areas

  Number of hours available: 63

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Tracer sampler coverage: from 50 to 200 meters

- Tracer Site: EOCR Test Reactor Building (Idaho)

  Source type: Non-buoyant releases at 30 m, 25 m, and ground level; dominant roof tier 25 meters high; rural area

  Number of hours available: 22 elevated release hours

  Tracer sampler coverage: 37, 68, 187, 386, 794, 1200, and 1600 meters

- Wind Tunnel Study (Melbourne and Taylor; Monash U.; Lee Power Plant)

  Source Type: steam boiler stacks, each 64.8 meters high; dominant roof tier was 42.6 meters high; neutral cases were simulated with urban dispersion characteristics, stable cases with rural characteristics

  Number of cases studied: in neutral conditions, 78 combinations of wind direction, wind speed, and plume buoyancy; in stable conditions, 14 combinations of wind direction and plume buoyancy

  Tracer sampler coverage: ground-level concentrations at six distances ranging from the cavity zone to beyond the wake (150-900 meters)

The Bowline Point data base represents a full year of data for a moderately buoyant source reflective of electric utility plants, which tests the models under a wide variety of meteorological conditions. The American Gas Association experiments feature a much more buoyant plume with a wide variety of stack height to building height ratios. The inclusion of these two data bases for the independent evaluation provides historical continuity with the American Petroleum Institute (API) study (which included the AGA and the Bowline Point data; see Schulman and Hanna, 1986), while actually giving ISCST3 a potential advantage in the model competition over the contending model, ISC-PRIME, because the Scire-Schulman algorithm has already been evaluated with these data bases. (To provide the developers of the ISC-PRIME model with additional data near steam electric plants, one-half of the days in the full year were selected at random to be used for model development purposes.) The EOCR data base represents a nonbuoyant release, which is an important class of sources for consideration of air toxics releases. The Lee Power Plant data base considers a steam boiler stack in both neutral and stable conditions at six distance ranges. As such, the inclusion of this wind tunnel data base significantly enhances the scope of the evaluation tests, since it is recognized that the use of actual field-study data bases restricts model testing in terms of the available choices of building aspect ratios and building-stack orientations.

3. MODEL EVALUATION PROCEDURE

For the Bowline Point 1-year data base, each model was run for the full year with hourly emissions, and concentration predictions were obtained at four close-in monitors. Results from two of the monitors were set aside as representing too few significant concentrations. Products resulting from the evaluation include tabulations of the top several observed and predicted concentrations at each monitor, quantile-quantile (Q-Q) plots of ranked 1-hour predicted versus observed concentrations at each monitor (for all cases as well as certain meteorological classes), and other assorted concentration scatterplots and residual plots of the ratio of the predicted to the observed concentration (C_p/C_o) versus variables such as wind speed.

For the tracer data bases (EOCR and AGA), the observed data for each hour and arc of monitors was carefully analyzed to determine the locations of the peak concentrations on the monitoring arcs. The models were then run with the plume directed toward the peak observed concentration. There were a total of 214 arc-hours available from the EOCR data set, and 78 arc-hours from the AGA data set. Consistent with procedures developed by Irwin (1996), a Gaussian fit to the arcwise observed concentrations in the vicinity of the peak location was computed and was used as the appropriate observed value for comparing predicted values against. For these two data bases, concentration scatterplots as well as several residual plots of C_p/C_o against variables such as distance and stability class were prepared.

The wind tunnel observed concentrations (Lee Power Plant) were available in the form of one "centerline" concentration at various distances. The models were run by advecting the plume directly toward the line of monitors. A total of 1,062 "arc-hours" were available for the Lee data set. Concentration scatterplots and residual plots similar to those produced for the tracer data bases were produced.

Other evaluation procedures involved computing test statistics from the observed and predicted concentrations. These are discussed in detail by Paine (1997) and are summarized here. For full-year data bases with only a few monitors such as the Bowline Point data base, an appropriate test statistic is the robust highest concentration (RHC) estimate, which is based upon the highest 25 concentrations (Cox and Tikvart, 1990). For the two tracer data bases and the wind tunnel data base, a test statistic based upon the median of the upper quartile of the predictions and observations has been used for each evaluation subset, or "regime". For all data bases except the Bowline Point site (which features two stacks with some considerable separation), concentrations are normalized the dividing by the emission rate; the resulting units are micro-seconds per cubic meter.

Three downwind distance regimes considered in the evaluation (contingent upon a sufficient number of cases) are the cavity zone (up to 3 L_b downwind, the wake zone (from 3 to 10 L_b downwind), and the region beyond the wake zone. Meteorological regimes chosen for the evaluation include: (1) stable conditions (stabilities 5 or 6) and the 10-m wind speed less than 4 m/s, (2) unstable or neutral conditions (stabilities 1-4) and the 10-m wind speed less than 4 m/s, and (3) any stability condition with the 10-m wind speed at least 4 m/s. The choice of two stack height / building height ratio regimes was made based upon the nature of the available data bases. A ratio of 1.25 was chosen to divide the data into tall stack / buoyant releases versus low stack or nonbuoyant release cases.

For each data set within each evaluation regime, the primary statistic is the Fractional Bias (FB), defined as:

$$FB = [\, 2*(C_o - C_p) / (C_o + C_p)], \text{ where}$$

C_o is the average of the observed concentration test statistics, and

C_p is the average of the predicted concentration test statistics.

The absolute fractional bias (AFB) ranges in magnitude from 0.0 for a perfect model to a value approaching 2.0 for a poor model. Therefore, the model with the lowest AFB value is the best performer. The test statistic, either the RHC or the median of the upper quartile of the values, varies by data base.

4. SUMMARY OF EVALUATION RESULTS

Evaluation results are shown in graphical form as follows:

- For the Bowline Point site, as quantile-quantile (Q-Q) plots for the two relevant monitors in Figures 1a and 1b;
- As box (whisker) residual plots of predicted to observed concentration ratios as a function of distance in Figure 2 for the AGA data base, and in Figure 3 for the EOCR data base;
- As residual plots in Figure 4a for neutral cases and Figure 4b for stable cases for the Lee Power Plant data base.

The overall conclusions from the performance evaluation are as follows:

- ISC-PRIME is generally unbiased or overpredicts, so its use is protective of air quality.
- ISCST3 is especially conservative in stable conditions, and ISC-PRIME performs much better under these conditions.
- Under neutral conditions, the performance of the two models is more comparable, but ISC-PRIME is somewhat better.
- ISC-PRIME has a statistically better performance result for each data base in the independent evaluation.

5. REFERENCES

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Figures Not Included. Refer to AMS paper hardcopy.

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