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AN EXAMINATION OF THE TEXAS EPISODIC MODEL AND ITS TIME-SAVING TABLE INTERPOLATION SCHEME

Keith A. Zimmermann
Cyril Durrenberger
Bruce Broberg

Texas Air Control Board
Austin, Texas 78723

1. INTRODUCTION

This paper discusses a model developed by the Texas Air Control Board (TACB) to expedite the air quality studies required by the state permitting process. Since an average of over 100 permit applications are received every month, it is necessary to have a fast, versatile computer program to handle the numerous modeling requests. The Texas Episodic Model version 8 (TEM-8) is a practical short term Gaussian dispersion model with features that enable a timely air quality impact assessment to be made.

Estimating the effect of new sources on air quality levels requires modeling to determine the relative impact on both the National Ambient Air Quality Standards (NAAQS) and the state regulations. For example, for a new source of particulate matter emissions it is necessary to estimate worst case concentrations for averaging times of 1 hour, 3 hours, and 5 hours to satisfy the Texas regulations and 24 hours for the NAAQS. Since much of the engineering data supplied by a company in a permit application is in English units, it is sometimes helpful to have an English units input option in a model. The TEM-8 may be used to estimate concentrations for averaging times from 10 minutes to 24 hours and may utilize point source data in either English or metric units.

In addition to reviewing permit applications, the TEM-8 has been used by industry and consulting engineers for stack design analysis and fuel conversion studies. The versatile output format in the TEM-8 also allows the program to be used for design of monitoring networks. It is anticipated that the TEM-8 will be the principal short term model used by the TACB for the Prevention of Significant Deterioration regulations.

2. MODEL FORMULATION

2.1 Basic Assumptions

The TEM-8 (1979) is a straightforward Gaussian plume model. The vertical and horizontal spread of the plume (σ_y and σ_z) is estimated using the Pasquill-Gifford-Turner (P-G-T) dispersion coefficients. The source emission rate is assumed to be constant. The wind speed measured at a 10 meter height is adjusted to the top of the stack by a power law relation. The limitations of the TEM-8 include neglecting directional wind shear in the vertical and inadequate treatment of highly reactive pollutants.

2.2 Adjustment of Sigma-y

The P-G-T σ_y and σ_z dispersion coefficients are widely accepted as representative of short averaging times--generally about 10 minutes. For longer averaging times, σ_y values should be increased to allow for the greater horizontal plume meander due to fluctuations in wind direction. In the TEM-8, the σ_y values are adjusted to longer averaging times (up to 3 hours) using a method described by Gifford (1975) and suggested by the American Meteorological Society Workshop on Stability Classification Schemes and Sigma Curves (1977). The equation used in the TEM-8 is:

$$\sigma_{y_t} = \sigma_{y_{10}} \left(\frac{t}{10} \right)^{R(S)} \qquad [1]$$

where t is the desired averaging time in minutes and R(s) is an exponent which is a function of stability class.

2.3 Plume Rise

Plume rise is determined by equations derived by Briggs (1969, 1971, 1972, 1975). There are four different categories for plume rise: (1) stable atmosphere with buoyancy dominated plume, (2) stable atmosphere with momentum dominated plume, (3) neutral/unstable atmosphere with buoyancy dominated plume, (4) neutral/unstable atmosphere with momentum dominated plume. In each situation, except for category 2, plume rise is calculated as a function of downwind distance from the source until the final plume rise is obtained. The plume rise treatment may be modified by using Briggs' (1972) stack tip downwash algorithm if the user desires.

2.4 Calculation Procedure

The TEM-8 can calculate ground level concentrations at up to 2500 receptors (50 x 50 grid) for 300 point sources and 50 area sources. (These size limitations are easily expanded.) This program uses stored, pre-calculated values of the Gaussian dispersion equation to determine concentrations in a relatively short amount of computer time. Two pre-calculated variables are used. The variable KY is a function of downwind distance x, atmospheric stability class S, averaging time t, and the crosswind angle Δ. The form of the equation for KY is:

$$KY(x,\Delta,S,t) = \frac{1000}{\sigma_{y_t}} \exp\left[\frac{-(x \tan\Delta)^2}{2\,\sigma_{y_t}^2}\right] \qquad [2]$$

A total of 4,480 values of KY are pre-calculates and stored in data tables.

The second pre-calculated variable, KZ, is a function of downwind distance x, effective source height H, and atmospheric stability class S.

$$KZ(x,H,S) = \frac{1000}{\pi\sigma_z} \exp\left[\frac{-H^2}{2\,\sigma_z^2}\right] \qquad [3]$$

A total of 1,960 KZ values are stored in data tables.

For each receptor, the KY and KZ variable is determined by a fast linear interpolation between stored values. The KZ values are interpolated using x and H, while the KY values are interpolated using x and Δ. The final concentration is calculated by the following equation:

$$X = \frac{Q \cdot KY \cdot KZ}{U} \qquad [4]$$

where Q is the emission rate in grams per second and U is the wind speed in meters per second and X is the concentration in micrograms per cubic meter.

2.5 Auto-grid Routine

The TEM-8 program has an optional subroutine which will automatically select a receptor grid for each scenario. This routine determines the point of maximum concentration for each source. It then develops a grid of up to 2500 receptors with the appropriate spacing between receptors to encompass the overall point of maximum concentration.

2.6 Input Options

The TEM-8 incorporates many features to give it additional versatility for the user. Concentrations may be calculated for averaging times from 10 minutes to 3 hours. By using multiple scenarios averaged together, the user may obtain virutally any sample time from 10 minutes to 24 hours. Wind direction may be entered in either degrees or by sector number. An option is included that can automatically increment the chosen wind direction in order to sweep a large sector for the critical wind direction that results in worst concentrations. Wind speed may be input in either meters per second or by wind speed class. Point source data may be input in either metric or English units.

2.7 Output Options

The output from the TEM-8 can take many forms. These include: (1) a map showing receptor concentrations, (2) a page with the points of maximum concentration identified by coordinates, (3) a culpability list identifying the five greatest contributors to each receptor, (4) a list of receptors and predicted concentrations, and (5) punched cards containing receptor coordinates and predicted concentrations for input to a graphics package. The output from the TEM-8 is designed to be easy to analyze and understandable to non-technical persons.

3. CONCLUSIONS

The TEM-8 was released by the TACB in October 1979 to fill the need in the regulatory sector for a fast, versatile Gaussian model. Test runs were made to determine the speed of the TEM-8 relative to a TEM version using explicit rather than table look-up computations. It was found that the TEM-8 is at least a factor of two faster than the explicit version of the program. Comparisons made with other Gaussian models show that the TEM-8 is extremely efficient in the number of source-receptor combinations that can be computed in a given amount of computer time. In addition, the versatile input and output format of the TEM-8 makes it an attractive model to a wide range of users.

4. REFERENCES

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CIRCULATION CELLS AND PLUME BEHAVIOR NEAR A LARGE INDUSTRIAL HEAT ISLAND

Cyril Durrenberger
Keith A. Zimmermann

Texas Air Control Board
Austin, Texas 78723

1. INTRODUCTION

This paper analyzes plume behavior and local circulation patterns caused by the heat island created by a large petroleum refinery. The refinery is located at Baytown, Texas in a rural area near Galveston bay and about 40 kilometers from the Gulf of Mexico. Plume behavior and circulation patterns were determined from SO_2 measurements, visible plume tracers, and on site meteorological measurements. It was found that the refinery heat island creates a layer of unstable air downwind of the refinery when neutral or stable atmospheric conditions would be expected. The result was that at certain times unusually high ground level concentrations of SO_2 were found near the refinery. The refinery SO_2 sources were modeled using the Texas Episodic Model version 8 (TEM-8) and these results were compared with measured SO_2 concentrations. An air circulation pattern was found that caused unexpectedly high levels of SO_2 to reach the ground when winds were light and variable.

2. THE SO_2 SOURCES AND DATA COLLECTION

The Exxon Baytown refinery is a large refinery with three Exxon Chemical plants located adjacent to its property. Stauffer owns a sulfuric acid plant that is located in the center of the refinery. There are a total of 82 SO_2 sources in this complex. In 1978, the Texas Air Control Board (TACB), Exxon and Stauffer all performed extensive studies of SO_2 in the Baytown area. This study began after high concentrations of SO_2 were measured at the boundary of the refinery. A large number of these episodes occurred at night when the atmosphere would be predicted to be neutral or stable. The TACB used a mobile instrumented van to measure SO_2 and total sulfur concentrations.

3. PLUME BEHAVIOR

Plume cross section concentration profiles were measured with the TACB mobile van. In many cases, consecutively measured plume profiles showed a great variation in SO_2 concentration. These measurements were taken on clear nights when the wind speed and wind direction fluctuation was small. Since the source emission rates did not appreciably fluctuate, the variance in measured concentrations could only be explained by a looping plume. When a visible tracer was added to the Stauffer plume under meteorological conditions similar to those described above, the plume was actually observed to loop. This confirmed the presence of a zone of turbulence in the lower atmosphere near the refinery when neutral or stable atmospheric conditions would usually be predicted by the Pasquill stability classification scheme.

4. MODELING

The monitoring data was screened to identify all 30 minute periods when the average SO_2 concentrations exceeded the TACB standard of 0.28 ppm. For each of these 30 minute periods, the average wind speed and wind direction measured at the monitoring site were determined. Then the TEM-8, a Gaussian model that uses the Pasquill-Gifford dispersion coefficients, was used to predict SO_2 concentrations at the monitor site using the wind speed and wind direction determined for each case. To simulate the turbulent zone, Pasquill atmospheric stability classes B and C were used with mixing heights of 100, 200 and 300 meters. The predicted concentrations were less than the measured concentrations. The ratio of predicted to measured concentrations ranged from 0.19 to 0.66. The mean of these ratios was 0.45. The difference between the measured and predicted concentrations was caused by the poor characterization of the turbulence by the Pasquill-Gifford dispersion coefficients. In this case, these dispersion coefficients do not adequately describe the physical effects caused by the turbulence found in the lower layer of the atmosphere near the refinery.

5. FREE CONVECTIVE CIRCULATION PATTERNS

On several occasions when the winds were light and variable, a small scale circulation pattern was found in the vicinity of the refinery. In one area surface winds were from the North, but at an elevation of approximately 100 to 150 meters, stack plumes were observed to be moving from south to north. At a short distance north of these stacks, high levels of SO_2 were measured at the surface. Farther to the North, no SO_2 was detected. The heat from the refinery set up a free convective circulation on a local scale. SO_2 emitted into the upper boundary of this circulation was brought to the ground when the air subsided to the North of the stacks. This circulation persisted for several hours.

6. CONCLUSIONS

Measurements of SO_2 concentrations, visible plume tracers and on site meteorological measurements were taken in the vicinity of a large refinery. These measurements were used to identify an area of low level turbulence downwind of the refinery when neutral or stable atmospheric conditions would be predicted. This finding supports the contention that stable atmospheric conditions rarely occur close to a large refinery. The SO_2 sources in the refinery were modeled with the TEM-8, but in all cases the predicted concentrations were less than the measured concentrations. The difference between measured and predicted concentrations was due to the poor characterization of the turbulence by the Pasquill-Gifford dispersion coefficients. During times when the surface wind was light and variable, there was a local scale circulation pattern in the vicinity of the refinery. This free convective circulation can under certain conditions bring high concentrations of SO_2 to the ground.

MODIFICATIONS TO THE TEXAS CLIMATOLOGICAL MODEL

Cyril Durrenberger
Keith A. Zimmermann
Bruce Broberg

Texas Air Control Board
Austin, Texas 78723

1. INTRODUCTION

The Texas Climatological Model (TCM) was developed by the Texas Air Control Board in 1975. A revised version, the TCM-2, was released in August, 1980. This paper describes the TCM-2 and compares predictions from TCM-2 with predictions from the EPA Climatological Dispersion Model (CDMQC).

The TCM-2 is designed to predict ground level, long term concentrations of atmospheric pollutants for a rectilinear array of receptors whose size and location is defined by the user. Predictions are based upon the steady state Gaussian plume equation, Briggs plume rise formulations, Pasquill-Gifford dispersion coefficient approximations, and exponential pollutant decay. The model uses a technique developed by Christiansen and Porter (1975) that requires much less computer time than most climatological models. For each run, time averaged concentrations may be determined for up to five different scenarios, each of which can cover different time periods and have different source inventories. Annual and/or seasonal averages are most frequently determined.

2. MODEL FORMULATION

2.1 Meteorology

Meteorological inputs for each of the five scenarios are average ambient temperature and values for the meteorological joint frequency function. This function gives the probability of occurence of any combination of six wind speed classes, sixteen equally sized wind direction sectors, and six atmospheric stability classes. To simplify calculations, the TCM-2 uses a weighted average wind speed for each atmospheric stability class. The weighted average wind speed is adjusted to stack height using a power law relation.

2.2 Point Source Calculations

Point source calculations are made using the long term Gaussian equation. If the urban dispersion option is used, all calculations for stable conditions are made with neutral night dispersion coefficients. Plume rise is determined from equations derived by Briggs (1969, 1971, 1972, 1975). Plume rise can be evaluated for momentum or buoyancy dominated plumes in a stable or neutral/unstable atmosphere. There is an option to use either the final plume rise or the rising stage of plume where appropriate. Pollutant decay may be approximated with a half-life input by the user.

Calculations are made by summing the product of four values: (1) the dispersion function, (2) the meteorological joint frequency function value, (3) the decay factor, and (4) the inverse of the wind speed. Values for the dispersion function were precalculated for each atmospheric stability class with 20 cases of downwind distance and 19 cases of effective stack height. These values are stored in tables and calculations are made by linear interpolation between these stored table entries. Interpolation is based upon downwind distance between the source and receptor and on effective stack height. Within 1.1 km of a stack, calculations are done explicitly.

2.3 Area Source Calculations

The TCM-2 calculates area source pollutant contributions with an algorithm based upon a method developed by Gifford and Hanna (1971).

2.4 Output Options

The TCM-2 has an optional least squares calibration routine to adjust predictions based upon measured concentrations. Alternatively, the user may input calibration coefficients. The five output options are: (1) list of concentrations, (2) concentrations printed in a spatial array map, (3) list of maximum concentrations for each scenario, (4) culpability list of the five highest contributors at each receptor, and (5) punched card output for input to contour plotting routines. The spatial array map is especially useful since it can be used to easily draw concentration isopleths. Interpretation of the results is also easy since all concentrations are shown relative to their geographical location.

3. MODEL EVALUATION

Results from the TCM-2 with the urban option agree favorably with the results from the

CDMQC in the urban mode.* However, the TCM-2 uses less than one-tenth the amount of computer time needed for the CDMQC. Two sets of data from different locations in Texas were evaluated with the TCM-2 and the CDMQC. Both data sets had 50 point sources and predictions were made at 49 uniformly spaced receptors. The mean of the ratio of TCM-2 predictions to CDMQC predictions was 0.948. The equation from a least squares fit of the TCM-2 to CDMQC predictions had an r^2 value of 0.97.

4. CONCLUSIONS

Version 2 of the TCM, TCM-2, was released in August, 1980. It retains the feature of being an extremely fast Fortran model compared to other annual models. Also, this model is easier than other annual models to run and the results are in a form that is easier to analyze. The TCM-2 has several new options, and the precision of the calculations has been increased. Modifications to the first version of the TCM are: (1) a new area source algorithm, (2) explicit calculation within 1.1 km of a point source, (3) better interpolation on table values, (4) more cases of plume rise are evaluated, (5) final or rising stage of plume may be used, and (6) urban or rural dispersion coefficients may be used.

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