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Regional Air Quality Modeling in Los Angeles

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The California Department of Transportation has applied regional air quality models to the Los Angeles area on a limited basis. A Lagrangian, or trajectory, model was used to evaluate the air quality impact of a highway project. An Eulerian, or grid, model is currently being used to evaluate regional transportation plans. The use of these models requires a costly and extensive data base for validation and the cooperation of local and regional agencies. A large aerometric sampling program was undertaken for one of the data bases. Technical problems in model application were related to electronic data processing and reconciliation of data that are tied to different geographic grid systems. In-house computer expertise is essential for application of the model. Model output tends to be voluminous and requires simplification for analysis and presentation.

The Los Angeles region is reputed to have one of the world's most intractable oxidant problems. In June 1974, for example, a 5-d oxidant episode created a peak 1-h value of about 860 $\mu g/m^3$ (44 pphm) in the eastern portion of the Los Angeles basin. The national ambient air quality standard (NAAQS) of 160 $\mu g/m^3$ (8 pphm) was violated for 1400 h that year. In years prior to 1974, even higher values of oxidant have been observed.

The Los Angeles Federal Air Quality Control Region (LAAQCR) encompasses all parts of the six counties shown in Figure 1. This region is roughly 129 km (80 miles) long and 257 km (160 miles) wide and includes approximately 25 205 km^2 (9736 $miles^2$) of land and a population of 10 million people. The principal agency for overall planning in the region is the Southern California Association of Governments (SCAG). This agency is supported by the 127 member cities and five counties within the region and by the California Department of Transportation (Caltrans).

The air quality management planning effort is funded by the U.S. Environmental Protection Agency (EPA). The funds are channeled through the California Air Resources Board (CARB) to the Air Quality Maintenance Planning (AQMP) group, which is also supported by the staffs of the CARB, SCAG, the four-county Southern California Air Quality Management District (SCAQMD), the Ventura County Air Pollution Control District (VCAPCD), the Santa Barbara County Air Pollution Control District (SBAPCD), and Caltrans.

The LAAQCR is a plain, bounded on the north by a high mountain range and on the west by the Pacific Ocean. Some internal geographic features divide it into subregions but do not usually block the west-to-east movement of air through the basin. Typical meteorology during an oxidant episode is a west-to-east air movement at moderate speed, a subsidence inversion producing a mixing depth of 300 to 460 m (1000 to 1500 ft), clear skies, and high ambient temperature. During the night, a wind reversal produces a sloshing effect. These conditions occur several times during the oxidant season (May to October). Other weather patterns (such as weak Santa Ana winds) also produce episodes, but this pattern typically produces the highest levels of oxidants.

The LAAQCR has 44 stations that measure air quality and many that measure wind speed and direction. Much of these data must be used with caution as the wind instruments at the measuring stations are not necessarily sited to produce wind data that are representative of the surrounding area. The sources of pollution are highly variable and geographically dispersed. The CARB emission inventory for the region estimated a background level (geogenic origin) of 1.36×10^5 kg/d (150 tons/d) of reactive hydrocarbons (RHC). In 1975, the daily production of RHC from anthropogenic sources was about 1.41×10^6 kg/d (1550 tons/d). This was generated 40 percent from light-duty vehicles, 20 percent from all other forms of transportation, and 40 percent from industrial and area sources. Much of the RHC is the result of industrial activities in the western part of

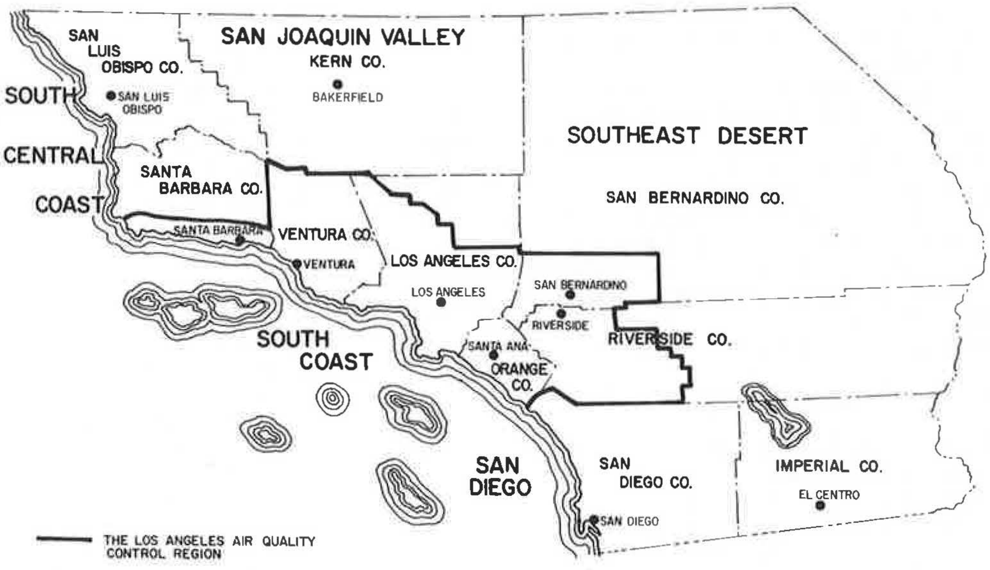

Figure 1. Los Angeles air quality control region.

the basin that are transported to the east. Typically, the highest levels of oxidant are recorded in the middle to east portion of the basin. The shear size of the region, the dispersed emission sources, and complex meteorology make the acquisition of a regional photochemical air pollution model essential.

MODELING ACTIVITIES

To date, Caltrans has used the following models: (a) the proportional model to assess regional impact of project and transportation plans, (b) the Lagrangian grid photochemical trajectory model to assess the impact of the Century Freeway on the region, and (c) a regional Eulerian grid photochemical model to assess regional impacts for SCAG and AQMP.

The proportional model has been used extensively out of necessity, but it yields unsatisfactory results because of its weak basic assumptions and inability to give spatial and temporal variation in concentrations.

The Lagrangian model (DIFKIN) was developed by the General Research Corporation for EPA. The model is used to compute the changes in concentrations that occur within a moving column of air for the various species of pollutants, both photochemical and inert. The air parcel moves across a fixed grid from which pollutants are injected into the air parcel. Caltrans applied the model to the proposed 27-km (17-mile) Century Freeway. The freeway was split into three approximately equal segments. Trajectories for each segment were developed for four beginning hours—7:00 a.m., 9:00 a.m., 11:00 a.m., and 1:00 p.m. This was accomplished by setting the trajectories back in time (from the center of the segment) to some appropriate time (early morning) for each beginning hour. The trajectories were then run ahead in time using the full photochemical diffusion program. Trajectory runs were made for the analysis years of 1980 and 2000, for the with and without project alternatives, and for the segments and hours previously mentioned. This required a total of 48 trajectories.

The results of the runs showed low peak oxidant concentrations, which did not seem realistic. Later analysis indicated that the unrealistic values were the result of inadequate diffusivity parameters. For comparison of the project alternatives, however, the results were judged to be satisfactory. The results indicated no essential differences among alternatives on a regional scale. The diffusivity parameter has since been corrected by CARB; DIFKIN is an adequate model for point source and single freeway analysis.

A trajectory model could not handle the requirements for analyzing the LAAQCR for the areawide transportation systems and other regional plans. Practical considerations such as economics, time, and personpower available require the use of an Eulerian grid model in making the analysis for the entire LAAQCR. The model selected was developed for EPA by Systems Applications, Inc. The model was subsequently modified for Caltrans. It uses the same basic input data required for DIFKIN and operates on the same grid system. A reasonably good validation of this model was made for an episode that occurred in June 1974. No other validations have been attempted.

The model moves the air through the three-dimensional cell matrix in accordance with the wind field data (including wind shear) and the wind field algorithm and incorporates a horizontal and vertical diffusion mechanism. The photochemistry is performed for each cell using hourly variations of solar radiation (UV). The model outputs consist of hourly averaged concentrations for six species of pollutants [ozone (O_3), nitrogen dioxide (NO_2), nitric oxide (NO), carbon monoxide (CO), RHC, and nonreactive hydrocarbons (NRHC)].

The AQMP has used the Systems Applications, Inc., model for four emission scenarios developed by the AQMP planning group. The scenarios varied the total basin emissions of RHC by only 6 percent but made spatial changes in the emission sources. Results of the model runs indicate that only small changes in concentrations occurred in the affected cells, as might be expected from the small emission changes. Additional model runs are not in progress; it is expected that three more days of meteorological episodes will be used and other scenarios will be assessed in the near future. Indications are that the model is useful for estimating the impact of various future scenarios and strategies designed to improve the air quality in the LAAQCR.

Model Data Base

The emission data base grid for both of the models used is a 3.2 × 3.2-km (2 × 2-mile) matrix, 40 cells long by 80 cells wide. Emissions from major stationary sources are placed in the appropriate cells and all other stationary sources are proportioned to the cells by existing or proposed land use. This facilitates the spatial placement of emissions for scenarios in future years. All species involved in the model are given a diurnal variation by hour.

Mobile emissions are obtained from the Los Angeles Regional Transportation Study model. Through computer programs, emission factors are applied to the travel data and the resulting emissions are placed in the appropriate cells (diurnally varied by hour). The meteorological data base is positioned on the same matrix. The necessary meteorological data are hourly values of surface wind speed and direction, values of UV, and inversion height. Air quality data from the regional monitoring stations are required to establish boundary and initial concentrations of the pollutant species.

Problems in Applying Regional Models

The two major technical problems encountered with the Systems Applications, Inc., model were (a) computer connected and (b) model grids. The version of the model available to Caltrans at the time the modeling effort was initiated was based on a 25 × 25-cell matrix. The model was written in a research code, which may be satisfactory for some purposes but does not facilitate improvements or changes. The change from the 25 × 25-cell matrix to the 80 × 100-cell matrix caused many problems in programming.

Another major computer problem stemmed from the state computer system operation. Originally, the model was put on the state system, which uses two IBM 370-168 computers and serves all state agencies. After considerable effort, it became apparent that the core requirements of the Systems Applications, Inc., air pollution simulation program (APSP) of 1.2 megabytes and the way that the state computer system was operated made the two incompatible. The APSP was ultimately set up, therefore, on a CDC 7600 computer at the Lawrence Berkeley Laboratory. The problem could have been avoided if computer expertise had been available in-house during the early planning of the effort.

A rectangular grid system of cells would not seem to be the source of problems, but in this case, it was. The problem is in the correspondence of a grid in the plane on which the model operates with a grid on a curved surface. This is not a problem on a small grid, but became a large problem on a large grid. An emission data base for stationary sources had been established on a 1.6-km (1-mile) grid based on local mapping, which had less than adequate horizontal control. The model grid is based on a reference point designated by a latitude and longitude. All grid cell lines were then placed 3.2 km (2 miles) apart and parallel to the east-west and north-south lines at the reference point. These two grid systems did not correspond throughout the modeling region; in some places the differences were major.

A third coordinate system, the universal transverse mercator (UTM), was also involved. UTM is being used by others to reference present and future emissions and other model input data. This grid system is curved and has a substantial and constantly changing skew with respect to the other grid systems. The problem is to translate the model input data from one of the grid systems into the correct cell in the model grid. Regression equations were computed for correspondence between the grids, but the best solution was to plot the model grid on U.S. Geological Survey (USGS) quad sheets (which include the UTM coordinates) and fit the stationary source data base grid to it. The solution, however, was complicated by the several different agencies involved, each having different interests and ideas as to the best solution.

Generally, relations with the consultant were satisfactory. The consultants were somewhat overly optimistic as to what the models could do, what they could furnish in terms of model modifications, and especially on what amount of time was needed to accomplish the tasks. One notable deficiency experienced by Caltrans was the lack of comprehensive documentation and a user's manual of instructions sufficiently complete to operate the model without considerable consultant assistance.

Problems in Validation

Validation of the model was only attempted for O_3. The principal problem encountered in validation was the expense and time involved to develop an adequate data base to measure model performance. Two sets of data bases were developed. The first was an episode from June 25 to 29, 1974. Meteorological and air quality data were gathered after the fact. This effort involved contacting many agencies such as the National Oceanic and Atmospheric Administration (NOAA), the air pollution control districts in five counties, and CARB. In some cases the data had to be copied by hand. The sheer volume of data required more than 2 person-years of effort to gather, code, punch, and edit. The cost of this data base was about \$75 000. As previously mentioned, many of the wind instruments were not placed by using the modeling requirements as criteria, and, therefore, the wind data are suspect; however, these were the only data available at that time.

A subsequent effort was made to obtain a data base of sufficient meteorological data to reflect the three-dimensional wind field and also to contain the pollutant concentrations within the mixing layer that are needed to establish the initial conditions. This was accomplished through a multiagency cooperative effort, initiated and coordinated by Caltrans. The agencies involved were Caltrans, CARB, air pollution control districts (APCD) in five counties, NOAA, EPA-Research Triangle Park, National Environmental Research Center-Las Vegas, U.S. Navy, and the University of California at Los Angeles.

The sampling program consisted of

1. Instrumented aircraft flights,
2. Pilot balloon (Pibal) launches (for winds aloft) through the basin,
3. A network of mechanical weather stations sited to obtain an adequate representation of the surface wind field for the region,
4. Solar radiation measurements both above and below the inversion layer and covering the modeling region, and
5. Air quality data from all the measuring sites in the region.

Except for air quality data, Caltrans accomplished the bulk of the effort. The sampling of a particular day was triggered by the San Bernardino County APCD when their predictions indicated that an oxidant episode the following day would exceed 690 $\mu g/m^3$ (35 pphm). The message to begin the sampling in accordance with a prearranged plan was then relayed to all parties in the sampling program. This system worked very well. One such episode, on July 9 and 10, 1975, was sampled with very satisfactory results. The total cost of obtaining these data, including the costs of coding, editing, and entering it in the computer, is estimated to be about \$150 000. Caltrans paid about 80 percent of the cost. Validation runs on this data base will be made in the near future; this base is expected to give better validation than that of 1974.

One area of validation that has not been researched, and should be, is the representativeness of the air quality measuring stations. The air quality stations measure the air from one point, but the model averages the concentrations over an area of 10.4 km^2 (4 $mile^2$). There is no evidence that values from the station are representative of the cells or of the surrounding area. Some of the stations are located on sites where the local vehicular traffic may have a significant influence on the recorded concentrations; therefore, the concentrations may not be representative of the modeling cell.

The costs of running the model on the Lawrence Berkeley Laboratory computer vary considerably, depending on the priority the run is given. For example, a 24-h run at a priority 10 (highest priority range) costs about $3500. On the other hand, the same run at priority 3 (lowest range) would cost $800. Costs also vary considerably, depending on the number of cells in the model.

The most valuable expertise to have in running the models is a knowledge of computers. The Systems Applications, Inc., model has a number of preliminary data preparation programs in addition to APSP and when glitches occur (which is not uncommon), knowledge of computers, computer systems, and computer programming is invaluable.

OUTPUT ANALYSIS

The printed output for the Systems Applications, Inc., model is quite voluminous—24 h of simulation yield about 1200 pages of computer printout. The only practical way to analyze the output, therefore, was to have the output read onto magnetic tape and write computer programs against this file. The output file was, therefore, put into the state computer system and these programs were written. Three principal programs are now available to compare the output of different scenarios. All are printed out by the computer on standard sheets and displayed by gridded cell array over the entire modeling region. These programs produce

1. The maximum concentration of O_3 and the hour it occurred.
2. A grid array that is shaded by using a different symbol for each concentration range. The symbol is progressively darker as the step ranges increase. There is an array for each hour. Thus, the overall impact can be seen qualitatively at a glance.
3. Changes in maximum concentration from the base scenario. This is done by printing the numbers 1 through 9 if the concentrations go up and the letters A through I if the concentrations go down. No change would be a 0. All 9s and I's require examination to see if the change is greater than 9.

The above data displays are useful in assessing a particular strategy's effect on maximum concentrations. They do not give an easily understandable evaluation of the overall impact, either regionally or subregionally. This can be done by developing an index by which the various plans and strategies can be compared. Comparison of hourly concentrations of oxidant for different emissions scenarios for approximately 2500 grid cells is impossible. A powerful approach, then, would be a people-concentration index for the total region and for critical subregions. This index can be obtained by the use of a program that multiplies the population residing in a cell and the sum of all the hourly concentrations in the cell. This product is then divided by the number of hours of simulation to normalize the index. The individual cell indexes can then be aggregated by subregion or the entire region, as desired. This programming is not yet completed. The ability to analyze rapidly the immense amount of output numbers makes computer programming capability a necessity.

AVOIDANCE OF MAJOR PROBLEMS

The following suggestions are for those about to undertake air quality modeling. They may help avoid some of the pitfalls that were experienced by Caltrans.

1. Buy only a modularized model that can be altered easily to keep up with the changes in the state of the art;
2. Have in-house computer expertise available;
3. Insist on a user's manual that gives complete step-by-step procedures on exactly how to operate the model;
4. Know from the beginning what size matrix is needed. If the matrix is too large, it will cost more to run the model and to collect the input data; and if it is too small, the required answers will not be available. Also, carefully examine the correspondence between the model grid and data source grids;
5. Edit all input data carefully; and
6. Be prepared for unforeseen problems.

Oxidant Model Applications: Denver

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In the Denver air quality control region, the abundance of sunlight, the high altitude, and the large per capita automobile population have resulted in a serious oxidant pollutant problem. Local officials have required and the public has supported the use of the latest state of the art to analyze existing air quality and to determine what may be expected in the future. The photochemical oxidant model developed by Systems Applications, Inc., has been used to assess local conditions. The model was calibrated in the winter for a bad carbon monoxide condition and in the summer for a bad ozone condition. The 120 h of carbon monoxide data sets used to compare the measured versus model-predicted values resulted in a correlation coefficient of 0.71. Ozone data for 74 h resulted in a correlation coefficient of 0.80. Linear regression equations were used to adjust the model for minor unaccountable error for each pollutant. To date, the model has been used to analyze regional air quality situations given various transportation and land use scenarios. This use includes the assessment of air quality control strategies, transportation system alternatives, and alternative routing of a major freeway proposal. Recent innovations in the model have improved chemistry reaction rates; the model output now approaches the precision of pollutant monitoring equipment. The improved model has been used to analyze various land use strategies and will be incorporated into the transportation planning process.