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The Emissions Inventory and Emissions Modeling System for the Lake Michigan Ozone Study

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INTRODUCTION

The States of Illinois, Indiana, Michigan, and Wisconsin, and the United States Environmental Protection Agency (USEPA) have joined together to study ambient air quality levels of ozone in the Lake Michigan area. The Lake Michigan Ozone Study (LMOS) will involve the collection of data bases (air quality, meteorology, and emissions), and the development, evaluation, and establishment of a technically credible modeling system for the Lake Michigan area. A major field program will be conducted during the summer of 1991 to gather the air quality and meteorological data. The modeling system will include emissions, meteorological, and photochemical models. This paper discusses the development of the emissions inventory and the associated emissions model.

The LMOS modeling system will be employed to simulate three to five ozone episodes that occur during the 1991 field program. A complete set of emissions, meteorological, and air quality inputs will be prepared for each episode. Model performance will be evaluated in light of actual observed air quality levels. Performance evaluation procedures, performance measures, and acceptance criteria will be established in advance of evaluating model performance.[1]

To support the photochemical modeling activities, it will be necessary to develop emissions inventories for the Lake Michigan area. The counties for which emissions data will be compiled are shown in Figure 1. The inventories must include gridded, hourly estimates of carbon monoxide (CO), nitrogen oxides (NO_x), and speciated volatile organic compound (VOC) emissions from mobile and stationary anthropogenic sources. The inventories must also include VOC emissions from biogenic sources. To the extent possible, the 1991 inventories should represent day-specific conditions. For example, temperatures actually measured on the selected days should be used for calculating biogenic emission rates and activity levels at major industrial sources should reflect actual conditions.

An emissions model will be developed to modify emission parameters efficiently and rapidly, account for variations in emissions as a function of meteorological conditions, and provide for estimates of uncertainty. The required level of data processing and manipulation can be readily accommodated with a geographic information system (GIS). A GIS is a perfect tool to: (1) speciate, grid, and temporally allocate the data for input to the photochemical grid model, (2) allow for changes in the VOC classification scheme, or the dimensions of the geographic grid elements, (3) generate maps of various input and output variables, and (4) prepare future inventories reflecting changes in the spatial distribution, magnitude, and speciation of emissions due to potential control measures. Because three of the four Lake Michigan States and USEPA are currently using ARC/INFO for other activities, the LMOS emissions model will be designed for the ARC/INFO system.[2]

EMISSIONS MODEL

The emissions inventory system (or emissions model) which will be developed for the LMOS goes beyond a collection of data which might be termed an inventory. The ability to modify emission rates, activity levels and other factors in a systematic manner to yield modifications to the emissions estimates is required. An emissions model is an integrated collection of calculational procedures or algorithms, properly encoded for computer-based computation, that may be used to derive estimates of ozone precursor emissions rates (i.e., VOC, NO_x and CO) as a function of grid location and time (usually hourly). Emissions source data are the "raw" information that serve as inputs to the emissions model. These data, taken as a whole, comprise the emissions source inventory, the product of collating or aggregating primary emissions data in a convenient form. Emissions estimates are the information produced by exercising the emissions model. These estimates are given as emissions rates of primary pollutants as a function of grid location and time.

In contrast with the definition above, "emissions inventory" is most commonly used to refer to what we term "emissions estimates". We will not adopt this common use here, as we wish to distinguish clearly between true "data" and estimates that are the product of a calculational procedure. Data are measured values contaminated by measurement uncertainty alone. Estimates are model output, reflecting uncertainty in both the input data and the model formulation.

Historically, overall emissions estimates have been constructed by combining estimates for individual sources and categories of sources. These overall estimates are frequently aggregated; that is, they are made available in "combined form". Thus, the emissions contributions of selected source categories, or of geographical subregions, or of specific time intervals cannot be separated from the whole or changed to make tailored modifications to the overall estimates. A major purpose of the emissions model is to allow desired modifications of overall emissions estimates to be made rapidly and easily.

The requirements (attributes) that the emissions model must satisfy are:

> the facility to account for variability in emissions, as a function of location and time, that is attributable to changes in meteorological parameters, such as wind speed, solar radiation, ambient temperature, and relative humidity;

> the flexibility to alter any estimated contribution to overall emissions (whether it is characterized by pollutant, VOC species category, source type, geographical location, or time of day) and generate easily and rapidly a modified set of spatially and temporally resolved overall emissions estimates;

> the inclusion of best available procedures for emission estimation to minimize bias and provide an acceptable level of accuracy in the emission estimates;

> the capability to develop quantitative estimates of uncertainties in estimated overall emissions, spatially and temporally resolved, as a function of uncertainties in individual components of the emissions model, whether they are emissions rates or activity levels;

> the capability of adding modules to estimate emission rates or activity levels for area and mobile source categories and to alter the algorithms in these modules (as new information becomes available) easily and rapidly; and

> the capability of adding modules to project future emissions levels, where feasible, or more generally, potential alternative outcomes, spatially and temporally resolved, as a response to (a) a range of estimated growth rates; and/or (b) possible disruptive societal or socioeconomic changes, such as a switch from oil to natural gas.

Today's "emissions inventories" - the closest counterparts to emissions models that we now have - generally do not satisfy this set of requirements. The development of an emissions model is intended to assure that these various requirements will be met, and thus that the functions that the emissions model is to possess will be readily available to the air quality simulation model user for the LMOS and subsequent related use.

The main components of the emissions model are:

> individual modules for calculating emissions rates, activity levels, and emissions estimates for relevant source categories;

> modules for generating uncertainty estimates;

> a GIS for stratifying emission-related information in a multiplicity of useful ways - by pollutant, source category, geographical location, time of day, season, nature of source (anthropogenic, biogenic, geogenic), and the like; and

> a skeletal structure designed to house individual algorithms as modules, to organize data in an orderly manner, to accept spatially and temporally resolved meteorological data as input, to facilitate data transfers, to facilitate the combining of emissions estimates developed using individual algorithms, to link projection algorithms with algorithms used to generate base case estimates, to "drive" emissions uncertainty calculations, and to combine emissions estimates with corresponding uncertainty estimates.

(Note, modules for generating alternative emissions projections for future years will be specified and added in subsequent LMOS-related work.)

EMISSIONS DATA

The four States will develop baseyear and 1990 (and/or 1991) emission estimates of CO, NO_x, and VOC from anthropogenic point sources, as well as daily emissions from some major anthropogenic point sources during portions of the 1991 field study. In addition, the States will develop baseyear and 1991 (or 1990) countywide-average emission estimates of CO, NO_x, and VOC from mobile and anthropogenic area sources. If the States are able to deliver only 1990 data, then procedures for adjusting the area and mobile source emission rates to represent 1991 will also be provided.

A contractor will be responsible for (1) developing procedures and acquiring all data for calculating biogenic emissions; (2) adjusting baseline mobile and anthropogenic area source emission rates to represent 1991, if necessary; (3) developing and applying procedures for calculating hourly emission rates for specific days during 1991; (4) speciating nitrogen oxide and VOC emission rates; and (5) allocating emission rates to grid elements. In addition, the contractor will evaluate the comparability of source data among the four States. Differences which may be found include the year of record, basis of area source activity data, threshold level for defining a point source, emissions factors, data collection procedures, and rule effectiveness adjustments.

Point sources are generally defined to be facilities with actual emissions of 10 tons (or more) per year (TPY) of VOC, or 100 TPY of NO_x or CO. The existing state emission inventory systems are the basis for most of the point source data. These data are generally updated annually through survey questionnaires sent to facilities and site inspection reports. Typical summer weekday emission rates will be derived based on the available operating data. Special surveys will be sent out to obtain day-specific data for select "major" point sources (i.e., those with emission rates which are high and/or vary significantly).

Area sources represent particular groupings of combustion or evaporative loss sources that are too small or too numerous to inventory individually. General area source categories consist of stationary source fossil fuel use, solid waste disposal, fires and burning, gasoline distribution, stationary source solvent use, waste management practices, leaking underground storage tanks, and nonhighway mobile sources. Several previously uninventoried source categories (e.g., municipal solid waste landfills, publicly owned waste water treatments works, and waste treatment, storage, and disposal facilities) will be included. Of special note is the inclusion of biogenic emissions. Both top-down (using county-wide data) and bottom-up (using land use/land cover data derived from analysis of recent LANDSAT images) approaches will be used to estimate biogenic emissions. The LANDSAT-based land use/land cover data will also be used to improve the spatial allocation of biogenic emissions.

Emissions rates for area sources are generally calculated by multiplying an activity level (or surrogate, such as population or employment) times an emission factor. Activity levels will be obtained by the States from current statistics and adjusted, if necessary, to 1990 and 1991 levels through the application of a nominal growth factor. Special studies will be performed for a few categories to develop improved temporal emission profiles.

Mobile source emissions are comprised primarily of on-highway vehicles. Emissions rates are calculated based on multiplying an emission factor times the vehicle miles traveled (VMT). USEPA's MOBILE4 emissions model will be run to provide emission factors. A look-up table of emission factors as a function of vehicle speeds, ambient temperatures, motor vehicle inspection and maintenance programs, fuel volatility (i.e., Reid Vapor Pressure or RVP), and alcohol-based fuels will be generated for each State. This table will be used by the emissions model to determine the appropriate emission factor for each hour and each area based on the particular speed, temperature, and RVP for that time period and location. Estimates of VMT will be provided for rural areas on a county-wide basis from the state transportation agencies and for urban areas on a link-by-link basis from transportation modeling performed by the local planning organizations. Although these organizations generally calibrate their transportation models using available traffic count data, the accuracy of the VMT (and speed) output data is unknown. Additional quality assurance activities will be performed as part of the LMOS to assess the validity of these VMT data.

CLEAN AIR ACT REQUIREMENTS

The Clean Air Act Amendments of 1990 impose different emissions inventory requirements depending on the relative nonattainment classification of the area. All nonattainment areas, however, need to compile a comprehensive, accurate, and current (i.e., year of enactment) inventory of actual emissions. Because the LMOS model evaluation will be performed using data from the 1991 field program, the Lake Michigan States must have inventories for both 1990 and 1991. Because both inventories are needed within about the same timeframe and because it is not practical for the States to develop two separate inventories, it will be necessary to focus on developing a complete inventory for one year - either 1990 or 1991 - and apply accepted adjustment factors to create the inventory for the other year.

QUALITY ASSURANCE

The States and USEPA desire to use the most reasonable and comprehensive emission inventory data for the LMOS. Quality assurance of the emissions inventory data will, therefore, be a high priority in the preparation of the data base. Each State and the emissions contractor will prepare and implement an approved quality assurance plan. In addition, quality assurance audits will be performed by a separate contractor. The purposes of these audits are to assess the extent to which all measured and derived data are comprehensive, reasonable, and were determined in a controlled manner based on a set of standard operating procedures. The audits will focus on checks on the inclusion of all emission sources in the LMOS region, internal consistency of emission source data, and conformance of source and emissions data with expected ranges. The audits will include both system and data audits and are intended to determine whether the quality control procedures are adequate and being followed, and whether data integrity and traceability are maintained through the data collection and processing and emission calculation processes.

SUMMARY

The LMOS represents a cooperative State and Federal effort to address the regional ozone problem in the lower Lake Michigan area. The preparation of accurate emissions data is necessary for the successful evaluation and establishment of the LMOS air quality modeling system. Among the more significant features of the LMOS emission efforts are the development of a GIS-based emissions model to facilitate data manipulation and processing, the use of LANDSAT imagery to support the estimation of biogenic emissions, the use of VMT data from transportation models (in a regional-scale application), the development of day-specific emissions for major sources, and the high priority placed on external quality assurance. Preparation of model-ready emissions files will be needed by spring/summer 1992 to allow the subsequent data analysis and modeling activities to be completed by spring 1993. It is expected that a fully evaluated, technically credible modeling system will then be available to the Lake Michigan States.

REFERENCES

[1] N. Bowne, P. Roth, S. Reynolds, C. Blanchard, and D. Shearer, 1991, Lake Michigan Ozone Study Conceptual Design Plan.

[2] Radian Corporation, April 1991, Work Plan for Lake Michigan Ozone Study Emissions Modeling System Development, Sacramento, California.

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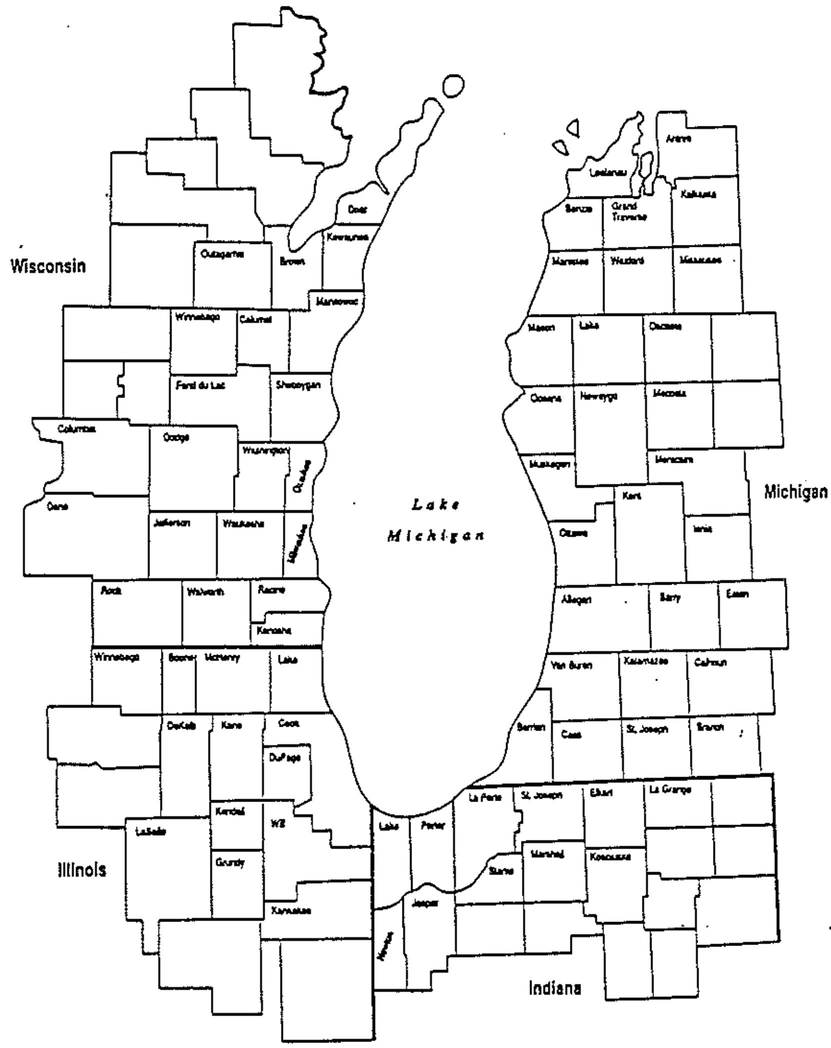

FIGURE 1   Lake Michigan Ozone Study Area.