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Project Summary

A Study Using a Three Dimensional Photochemical Smog Formation Model Under Conditions of Complex Flow: Application of the Urban Airshed Model to the Tokyo Metropolitan Area

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The purpose of this study is to evaluate the Urban Airshed Model (UAM), a three-dimensional photochemical urban air quality simulation model, using field observations from the Tokyo Metropolitan Area. Emphasis was placed on the photochemical smog formation mechanism under stagnant meteorological conditions. The UAM produced reasonable calculated results for the diurnal, areal and vertical distributions of O_3 concentrations covering the Tokyo Metropolitan Area. The role and significance of the previous day's secondary pollutants on O_3 formation mechanisms were also investigated. During the night time, high values of secondary pollutant concentrations were predicted above the radiation inversion layer. These aged pollutants were then entrained into the mixing layer during the day in accordance with the elevation of the lid. These characteristic features were also observed in the field study.

This Project Summary was developed by EPA's Atmospheric Research and Exposure Assessment 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

High ozone (O_3) concentrations are frequently observed in the Tokyo Metropolitan Area (TMA) in the summer season. The industrial complexes located in the Tokyo Bay area are the largest in Japan and are the major stationary sources of pollutants (NO, NO_2, SO_2, hydrocarbons, aerosols, etc.), while the Tokyo Metropolis is the largest contributor of pollutants from mobile sources. In addition, the topography of the area is very complicated, which leads to complex wind patterns. Reflecting these circumstances, the relationships between the precursor emissions and field-observed O_3 patterns are not clearly understood. Investigating these relationships requires the use of a three-dimensional photochemical air pollution simulation model. Results from such a model allow the analysis of the quantitative effects of the previous day's secondary pollutants, temporal variation of mixing height, and three-dimensional wind field on O_3 formation mechanisms in the atmosphere.

The purpose of this study is an evaluation of the SAI Urban Airshed Model (UAM), a three-dimensional photochemical urban air quality simulation model, using observations from a 1981 field experiment in the Tokyo Metropolitan Area, Japan. From July 15 to July 17 high O_3 concentrations were observed in the To-

kyo Metropolitan Area under conditions of a complex wind field. During this period intensive field measurements of vertical and horizontal winds and pollutants were made. These data provide sufficient information to evaluate the photochemical smog simulation model for this case-study.

Analysis

In the first step, input data were selected from the data base and set up in a suitable format for the SAI-UAM and a test run was then performed. For the second step the simulated results were evaluated using the field observed data. Emphasis was placed on the investigation of diurnal variations and areal and vertical distributions of pollutants. Vertical cross-sections of simulated pollutant patterns are analyzed for the TMA domain, including the diurnal variation in the patterns. The effects of vertical meteorological conditions and the previous day's secondary pollutants are emphasized. Limited O_3 field data from aircraft are compared with the simulated results.

In the Tokyo Metropolitan Area higher concentrations of O_3 are usually observed near the shore in the morning. As the sea breeze layer penetrates inland, this high concentration region travels with it, increasing in concentration with time. When the geostrophic wind is weak, the sea-land breeze circulation and the mountain-valley breeze circulation are the most important meteorological factors in photochemical O_3 formation inland.

A nighttime temperature inversion, which persists into the early morning, prevents the dispersion of primary pollutants emitted from the large coastal industrial zones and the Tokyo Metropolitan Area. Two large industrial complexes, Keihin and Keiyo, are located along Tokyo Bay, while the center of Tokyo is the largest contributor of pollutants from mobile sources. These pollutants are transported seaward by the land breeze. Around noon time the sea breeze brings these pollutants back inland where they become well mixed under thermal convective conditions. These primary pollutants are converted into secondary pollutants and transported inland with the sea breeze penetration. Usually, high O_3 concentrations are observed aloft (500-1000 m) in the early morning. This is an aged O_3 layer, and its associated secondary pollutants are entrained into the growing mixing layer in accordance with the elevation of the lid. This effect is believed to accelerate the formation of secondary pollutants during the next day.

During the period of study, July 15 to July 20, 1981, the weather conditions were typical of this season in Japan. A predominant northern Pacific high pressure cell covered the Japanese archipelago and the pressure gradient was weak. Under these conditions, especially high oxidant concentrations were observed in the southern part of the Tokyo Metropolitan Area due to the orientation of the sea-land breeze circulation system to the metropolitan area.

UAM simulations were conducted over 40 hours beginning 0400 JST, July 16, 1981. Data from 62 selected ground monitoring stations, 4 upper-air sounding sites, and 23 pilot balloon sites were used to determine the boundary concentrations and the meteorological parameter input values for the model. The aircraft measurements showed a very complex vertical and horizontal pollutant distribution mainly caused by the complex wind structure. To simulate this wind field, a three-dimensional mass and momentum-conserving wind model was used to prepare the hourly horizontal winds required by the UAM. The Carbon Bond II chemical kinetic scheme was used for the chemistry calculations in the UAM. Hourly emission rates were calculated from area sources and point sources of NO_2 and non-methane hydrocarbons (NMHC) at each grid cell. NMHC emissions must be distributed into particular reactivity classes. To accomplish this the ratio of 18 NMHC species from the five major hydrocarbon source categories (vehicle exhaust, oil refinery facilities, other petrochemical operations, gasoline vapor, and painting solvents) were determined.

The area modeled around Tokyo was 183 km wide and 172 km long, with each individual cell 6.8 km wide and 5.5 km long. This individual cell size is based on the relative degree length of latitude, longitude of this area. The full horizontal domain is 27 by 30 cells with the outer ring of cells serving as boundary condition cells. There are five layers in the vertical; the depth of each layer is a function of the time of day. The bottom three layers simulated the mixing layer.

Conclusions

Usually, in the Tokyo area, high O_3 concentration areas, which are transported from inland regions by the nighttime land breeze, are observed aloft in the early morning, and these are entrained into the mixing layer in accordance with the elevation of the lid. This effect is believed to accelerate the formation of secondary pollutants during the next day. These observational results were qualitatively reproduced by the Urban Airshed Model. In this study major efforts were devoted to clarify the effects of vertical meteorological conditions and the previous day's secondary pollutants on the second day's O_3 concentrations. Simulated results showed reasonable performance at reproducing a three-dimensional profile of O_3 concentrations. It was found that:

1. The SAI Urban Airshed Model produced reasonable calculated results for the diurnal and areal distributions of O_3 concentrations covering the Tokyo Metropolitan Area.
2. Observed vertical O_3 profiles were also compared with the simulation results. The simulated vertical profiles were in qualitative agreement with the observations although the coarse vertical resolution and hour averaging in the model may have prevented the prediction of the maximum concentrations accurately.
3. Paraffin (PAR) and aromatic (ARO) concentrations were underestimated. This might be caused from an estimation error in the hydrocarbon emissions.

The role and significance of the previous day's secondary pollutants on O_3 formation mechanisms were investigated using the UAM simulations. The largest differences in the vertical pollutant profiles between the two days studied were in the species O_3 and carbonyls (CARB). During the second night of simulation, especially high values of these species were predicted above the radiation inversion layer. These aged pollutants were then entrained into the mixing layer during the day in accordance with the elevation of the lid. In part, because of the higher CARB concentration levels on the second day, O_3 levels increased earlier in time and peaked at higher concentrations than they had on the first day of simulation. The importance of the effects of the previous day's aged pollutants are confirmed using the UAM.

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The complete report, entitled "A Study Using a Three Dimensional Photochemical Smog Formation Model Under Conditions of Complex Flow: Application of the Urban Airshed Model to the Tokyo Metropolitan Area," (Order No. PB91- 168 401/AS; Cost: $17.00, subject to change) will be available only from:

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