



Project Summary

Tropospheric Ultraviolet Radiation: Assessment of Existing Data and Effects on Ozone Formation

M.W. Gery, R.D. Edmond, and G.Z. Whitten

This study was performed to determine the impact that potential changes in stratospheric ozone concentrations and surface temperatures might have on the chemical processes that create tropospheric ozone and cloud acidification precursors. The investigation consisted of two distinct parts. First, an assessment was performed of the ultraviolet radiation information and molecular absorption cross section and quantum yield data currently used in air quality simulation. This assessment addressed both the quality of existing data and approaches available for utilizing these data to determine chemical photolysis rates in the troposphere. Particular attention was paid to the photolysis reactions of ozone, formaldehyde, and acetaldehyde because these species absorb light in the spectral region where surface ultraviolet irradiance could increase due to decreased stratospheric absorption by ozone.

The algorithms and data resulting from this assessment were used in the second portion of the study to determine photolysis rates that might occur in the troposphere under future conditions of decreased stratospheric ozone. The sensitivity of photochemical dynamic processes was tested for a large number of urban airshed data sets under conditions of decreased

stratospheric ozone and increased surface temperatures. The predicted surface ozone and hydrogen peroxide concentrations resulting from incremental changes in the assumed future stratospheric ozone and temperature parameters were analyzed for each city and for specific groups of cities. Instances of greater future oxidant forming potential were most common for cities with already high hydrocarbon control requirements. The increased energy input during future scenarios provided more rapid ozone formation in all cases, indicating the possible exposure of a larger portion of the urban population to higher ozone concentrations nearer to the center of the urban plume.

This Project Summary was developed by EPA's Atmospheric Sciences Research 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

In recent years scientists have become increasingly aware that potential chemical modification of the upper atmosphere by trace gases may produce an overall global warming by blocking the escape of thermal infrared radiation. This phenomenon is commonly referred to as

the "Greenhouse Effect." In addition, the chemical reactions of halocarbons, methane, and N_2O , may cause future decreases in stratospheric ozone levels. One consequence of this decrease would be an increase in the penetration of ultraviolet radiation to the troposphere, since stratospheric ozone is a principal attenuator of radiation in the middle ultraviolet radiation spectral region. A higher intensity of ultraviolet radiation at the earth's surface, combined with higher global temperatures, might increase the prevalence and intensity of photochemical smog episodes in populated areas and result in an unanticipated deleterious impact on public health.

An increase in the prevalence of photochemical smog might result because a greater transmission of ultraviolet radiation would augment the principal energy source responsible for photochemical reactions in the troposphere. Combined with higher global surface temperatures, this could lead to an increase in the reaction rates of a number of photochemical reactions critical to smog formation. These potential increases in specific photochemical reaction rates have been largely ignored in studies of future chemical changes within the planetary boundary layer. Any enhanced photochemical reactivity could increase the prevalence and magnitude of regional and urban ozone formation, and augment both the rural and urban contributions of acid precursors by increasing the production capacity for oxidized species. It was our intent in this study to address the magnitude and chemical dynamics of such impacts.

Because the rates of photolysis for certain chemical species may vary strongly with increased ultraviolet transmission, the first part of the study assessed the uncertainty associated with the calculation of the tropospheric photolysis rates of specific chemical species. We addressed both the uncertainty in fundamental chemical parameters and the error associated with determining surface actinic flux under present and future conditions. This was followed by an analysis of the possible impacts of increased surface temperature and decreased stratospheric ozone (and thus, increased near-surface photolysis rates) on the photochemistry of various airsheds. Because the effects of projected global changes on near-surface photochemistry will vary with the characteristics of each airshed tested, we chose to analyze a large number of

different test sets so that a reasonable variation in input data could be applied. Large numbers of data sets are currently available only for urban areas whose compliance with the air quality standards for ozone must be verified. Atmospheric oxidant formation in urban areas is one of the most studied atmospheric photochemical phenomena because of the potential health effects of high ozone concentrations in areas of high population. For this reason, these systems are also probably the best understood, and because of high amounts of anthropogenic emissions of oxidant precursors, could be the most immediately sensitive to potential global changes. Thus, we chose to investigate the impacts of potential global changes on this type of system first.

Procedure

Range of Future Values

In such a sensitivity study, it is also necessary to formulate some understanding of the possible ranges of projected surface temperature and stratospheric ozone changes anticipated. Our methodology was to analyze available information and then devise two sets of values, representing moderate and extreme future conditions. The moderate values were selected to be between projections for the period 2010 to 2030, and the extreme values represent even higher but possible conditions, especially for decades later in the next century. From these assumptions we formulated a set of future scenario temperature and ultraviolet light (photolysis rate) conditions. It is beyond the scope of this discussion to consider the complex perturbations that may alter future surface temperatures. However, recent efforts in global climate modeling indicate that global warming could increase the average temperature by as much as 1 to 3 K by the year 2030. Therefore, in the scenarios considered in this work, we used surface temperature increments of 2 and 5 K over the measured temperature profiles for each data set.

The potential changes to mid-latitude ozone column density must be estimated before attempting to calculate representative photolysis rates. We chose a base-case ozone column of 0.300 cm-atm for all simulations. This represents approximately the monthly average at North American latitudes for the July and August period when most measurements in the test data sets were

performed. Daily meteorological conditions specific to each data set are assumed to be contained in the simulation of each base-case data set. As we will discuss later, only base-case simulations that accurately predicted the actual measurements for a specific data set were further utilized for future scenario sensitivity testing. Such a procedure acts as a filter to eliminate days with conditions unlike the assumed (monthly average) base-case conditions. In this way, we attempted to focus on future photochemical changes that were due to the increases in temperature and decreases in ozone column *relative* to the base-case values. The moderate and extreme overhead ozone column conditions chosen in this study were 0.2 and 0.20 cm-atm, representing 16.7 and 33.3 percent decreases in ozone for the future test period. These conditions represent current chemical model estimates (15 percent decrease predicted by the middle of the next century) and Nimbus 7 satellite data (possible decreases of about 0.5 percent/year).

The most direct way that depletion of stratospheric ozone could induce greater photochemical reactivity in the low troposphere would be through alteration in the magnitude of the ultraviolet irradiance at the earth's surface. This variation must be accounted for prior to simulation, and hence, we briefly consider the ozone absorption process and the uncertainties in the calculation of tropospheric photolysis rates.

Below 300 nm, the ability of ozone to absorb radiation increases dramatically into the Hartley bands (200 to 300 nm) resulting in the cutoff of short wavelength ultraviolet transmission to the earth's surface. However, in the spectral region between 300 to 350 nm (the bands Huggins) the ability of ozone to absorb light decreases with increasing wavelength, allowing some transmission of ultraviolet radiation to the earth's surface. Hence, the spectral region, which an increase in ultraviolet irradiance due to diminished stratospheric ozone absorption should be manifest, is probably be confined to a rather small range between 310 and 280 nm because the change depends completely on the absorption characteristics of ozone which is a much poorer absorber of radiation above 310 nm. A number of tropospheric trace species photolyze to very reactive products upon absorption of radiation from this spectral region where ultraviolet irradiance is expected to increase. Therefore, even a relative

small change in total available radiant energy may induce a relatively large increase in certain tropospheric photolysis rates.

Photolysis of stable molecules is the major source of new radicals in tropospheric gas-phase chemistry. In atmospheres capable of sustaining even a moderate rate of photochemical reactivity, a greater production rate for new radicals would tend to increase the initial and continued oxidation of organic compounds, resulting in additional thermochemical radical generation and sustained production of additional stable species capable of more photolysis. Therefore, the increased radical mass flux that would result from potential enhancement of some photolysis reactions could translate into more reactive tropospheric photochemistry. The result could be increased production of those oxidized species now regulated as photochemical oxidants (urban ozone), or of other compounds (peroxides) critical to the formation of acidic precipitation after transport out of an urban area.

Because our goal was simulation of present and future urban atmospheric systems, we felt it was necessary to estimate the values and uncertainty for these rates as they changed with decreasing ozone column densities. We mainly focused on the uncertainty associated with the calculation of surface photolysis rates for ozone [to $O(^1D)$] and formaldehyde, since these are the most significant, radical-generating photolysis reactions in the spectral region of interest and in the urban atmosphere in general. Thus, their associated uncertainty translates almost directly into uncertainty concerning the radical production rate of polluted air masses. We also identified data and algorithms we felt to be potentially useful in the development of a new generation of ultraviolet actinic flux calculation schemes for current and developing models. Our predictions were then compared with actual measurements and the uncertainty associated with each step of the process was examined. Because the calculation of atmospheric photolysis rates is the product of actinic flux and specific molecular properties integrated over wavelength, we addressed three separate areas; (1) the methods and data needed to calculate actinic flux, (2) uncertainties in experimentally derived values for molecular properties, and (3) the integration approach and related uncertainties. We discuss the results in the next section.

Simulation Protocol

The goal of the atmospheric simulation phase of the study was to investigate the potential changes in urban oxidant formation caused by possible future alterations in global climate. More specifically, we were interested in (1) additional photochemical reactivity and (2) the amount of oxidant formation that could occur as a result of future increases in surface temperature and decreases in stratospheric ozone (increases in surface ultraviolet irradiance and photolysis rates). Three different ozone column densities and temperature ranges were used in the future scenario calculations. In addition to 57 single-day city scenarios, we studied multi-day impacts for two cities—one that had attained the National Ambient Air Quality Standard (NAAQS) for ozone, and one in nonattainment status. A second photochemical kinetics mechanism was used in one set of simulations to verify that the results were not mechanism-specific. Also, we felt it appropriate to use the OZIPM photochemical trajectory model in our investigation of future urban impacts since, when combined with the EKMA procedure, this model is most often employed to determine the amount of NMOC reduction needed to achieve compliance with the ozone NAAQS of 0.12 ppm. As we will see, EKMA calculations can also aid in providing estimates of atmospheric and emission conditions expected in future scenarios.

In this study, we felt that a protocol which merely employed the resimulation of a present-day scenario using different photolysis rates or temperature values would not provide a sufficiently reasonable estimate of anticipated future urban conditions because mandated control requirements must necessarily alter present conditions. Since the EKMA procedure is often used to determine the amount of NMOC reduction that will ideally be implemented in the future, we utilized this direct link with the regulatory process to determine more realistic future scenarios. Therefore, all present-day base-case data sets were implemented in OZIPM-3. For those with reasonable fits to the observed data, standard EKMA calculations were performed to formulate scenarios of future attainment in each city based on the alleviation of current smog scenarios. We felt that this approach would provide a much better estimate of future base-case scenarios with which to assess unanticipated (in the EKMA)

perturbations due to changes in the two variables (temperature and ultraviolet radiation) of interest in this study. Of course, this protocol assumes "ideal" performance in the EKMA calculation method and an "ideal" response of an urban atmosphere to EKMA-derived emission controls. As noted, we imposed the constraint that the simulated ozone value and the design (measured) concentration should not vary excessively. In this way, the EKMA program is not required to compensate for a poor fit, but only to calculate the ratio of NMOC reduction needed to "ideally" produce 0.12 ppm ozone. As noted above, this procedure also gives some indication that reasonable replication of daily meteorological and ozone column conditions occurred, so that the future sensitivity tests could focus on the impacts of changes relative to the base case conditions.

Our initial, single-day modeling data set consisted of atmospheric measurements from 45 days in 10 cities. There were actually 57 initial base-case simulations because some days were modeled with a multiple number of trajectories. Individual NMOC, NO_x , and design O_3 values, elevation, location, regional albedo, temperature, and mixing height profiles, were used for each city. The number of overall test sets was reduced to 15 by testing of the goodness-of-fit between measured and simulated hourly maximum ozone concentrations for present base-case simulations. EKMA calculations were then performed to determine the "ideal" NAAQS compliance conditions for each base-case data set. From the EKMA results, a future base-case data set (still with normal temperature and ozone column conditions) was derived and simulated to verify that those conditions produced ozone at the level of the NAAQS. Then, using this future base case as the "ideal" anticipated result of prescribed NMOC reductions, we were able to estimate the extent of unanticipated (by the EKMA) impacts resulting from the photochemical changes caused by increased temperature and ultraviolet irradiance. This was done by the incremental increase of these values and the analysis of resulting changes in the concentrations of ozone and other chemical species.

Since the city-specific data sets span a wide range of urban oxidant production capacities, we consolidated our analysis and the following discussion by creating three general group classifications:

Group 1: High ozone NAAQS exceedence days. In this group we include all days with design values greater than 0.17 ppm. There are ten such days in the 45 days simulated. These data sets are from Los Angeles, Chicago, New York, Boston, Philadelphia, and Washington, representing oxidant production episodes in regions where severe ozone exceedences are common.

Group 2: Less extreme nonattainment days, often representing cities that require moderate control (30 to 50 percent) of organic precursors to achieve the ozone NAAQS. Hourly maximum ozone concentrations are between 0.17 and 0.14 ppm in this group. Local meteorological conditions can influence the magnitude of the ozone production in many of these cases.

Group 3: Days that are nearly in compliance with the NAAQS for ozone. These data sets provide future sensitivity tests with current ozone production at 0.13 ppm or below. The data are scattered among a few test cities, including Boston, Nashville, and Tulsa.

We have used these groupings because common group characteristics facilitate later discussion of chemical dynamics. Although these data could be considered typical of each individual city's ozone formation profile, we will usually name specific cities only to identify the source of input data for an example data set. One notable exception in the following discussion concerns the two data sets chosen from the Seattle data. As with many data sets collected for use in the 1982 SIP process in smaller cities, some measurements needed for OZIPM input parameters appear to be rather uncertain. In this case, we refer to both the precursor concentrations (which appear to be rather high) and the morning mixing height (which may have been less than the 250-m values used in the SIP calculations). The calculated results for those days do not easily fit into any of the grouping schemes. However, their results do demonstrate some important atmospheric processes; so, although they are uncertain, we discuss the conditions and predictions from those two tests to demonstrate certain aspects of chemical dynamics. Therefore, our discussion focuses on the three general groups, and a fourth test based on the Seattle data (denoted as *Group 4* in the

following discussion). We feel that this grouping scheme is as specific as the current data will allow. We stress that though it is based on data from one city, even the Seattle data should be considered a general test case since a much larger and better defined set of city-specific measurement must be considered before the unique characteristics of any individual city can actually be discussed.

Results and Discussion

Assessment of Photolytic Rate Calculations

We initially analyzed the methods and data needed to calculate actinic flux at the earth's surface. The nature of such calculations is complicated because the determination of actinic flux for differing conditions and locations requires consideration of a wide range of complex atmospheric interactions. Rigorous attempts were made a decade ago, resulting in the creation of a number of actinic flux data sets for various conditions. These data sets have been used extensively over the last decade in almost all photochemical modeling studies of tropospheric air masses. We believe that an update of this work is now in order, if for no other reason than to include more recent extraterrestrial flux and atmospheric aerosol data in these calculations and to provide actinic flux results for conditions not addressed in the original work (e.g., variable ozone column densities), but now becoming more important. These new calculations must also be carried out at smaller integration intervals to provide flux data resolved to a magnitude comparable with that of molecular data, so that mathematical averaging errors in the photolysis rate calculations can be limited. This new data would also be very useful in improving the mathematical formulations used to estimate actinic fluxes for conditions not directly included in the data.

Our analysis of fundamental molecular data focused on the short wavelength photolysis reactions of ozone and formaldehyde. The greatest individual area of uncertainty in those reactions is found in the absorption cross-section formaldehyde data. The two key studies in this area obtained results that differed by about 30 percent. Since formaldehyde is a very important photolytic species in the troposphere, these numbers translate into a large uncertainty in the radical production

capacity of organic oxidation products. We believe that this discrepancy should be alleviated, either through reevaluation of existing data sets or through additional experimental work to develop more data. Absorption cross-section and quantum yield data for ozone are less uncertain primarily because they have been the objects of experimental investigation for a longer period of time. A somewhat larger associated error develops for ozone photolysis to form $O(^1D)$, however, because this process occurs at the surface ultraviolet cutoff, where actinic flux calculations are less certain. An experimental program designed to measure surface flux distributions in the middle ultraviolet range (particularly in the region near the solar cutoff) would provide information with which the error of $O(^1D)$ calculations might be diminished and could also yield important data for evaluating and improving actinic flux calculation schemes.

We also investigated the methodology involved in calculating photolysis rates. In cases where two or more of the product terms (actinic flux, quantum yield, and absorption cross section) were highly wavelength resolved, errors resulted if the wavelength intervals used in numerical integration were much larger than the significant resolved features in the individual functions. This averaging error was only on the order of ten percent, but could be easily eliminated if calculations were performed at 1 or 2 nm intervals. Again, this finding points to the need for a new set of more highly resolved actinic flux calculations.

Evaluation of the Impact of Global Changes on Tropospheric Photochemistry

This phase of the report focused on simulating the photochemistry of urban air parcels and evaluating the effects of potential changes in ozone column density and surface temperature. The modeling protocol and input data sets were discussed above. For discussion purposes, the 15 single-day test cases were grouped into four general categories also discussed earlier.

Of primary importance to the impact that future temperature increases on ozone column decreases might have on the photochemical dynamics of an urban system is the method by which the additional energy associated with the changes is input into that system. Increased surface ultraviolet irradiation caused by a diminished ozone absorpti-

capacity in the stratosphere follows a diurnal curve dependent on the elevation of the sun. On the other hand, energy input to the earth's surface through Greenhouse warming takes a less direct route. Regarding impacts on ozone concentrations and other oxidized species, two distinct types of effects can be seen in the future scenarios; these effects can be linked to the differences in energy input dynamics. Because global surface temperature increases were simulated by the addition of 2 and 5 K to the original, city-specific temperature profiles evenly across the day, the effects of temperature increases were slight increases in reaction rates and somewhat greater formation of ozone and oxidized products across the entire simulation period. This is to be expected since most temperature-dependent reaction rates increase with increasing temperature. The second type of impact, resulting from the enhanced (due to depleted stratospheric ozone) ultraviolet irradiation function, was an increase in the rate of photochemical reactivity centered around midday.

In all test cases studied, an increase in photolysis rates due to decreased stratospheric ozone caused a more rapid formation rate for ozone and other oxidized products. Because most additional energy input was concentrated in an already photochemically reactive period of the day, the impact was often more dramatic than that of the temperature change. Levels of ozone at or near the NAAQS (0.12 ppm) were achieved much earlier, sometimes hours earlier, at the time when an air parcel might be over more populated areas earlier in the trajectory. This would occur because the midday enhancement of photolysis rates provides a greater radical production rate and radical concentrations, thereby increasing short-term reactivity so that these photochemical systems can convert precursors to oxidant more efficiently. However, this enhanced reactivity may not always result in greater maximum ozone concentrations because that measure of oxidant-forming potential is also a function of available precursors and meteorological conditions. Hence, while increased ultraviolet irradiance from depleted stratospheric ozone is predicted to increase short-term reactivity in an urban air parcel, these conditions will not always result in greater maximum concentrations because such long-term measures are more a function of the specific system. Air parcels with low precursor emissions and beneficial

meteorological conditions may actually produce lower maximum concentrations of oxidized products because the enhanced reactivity may consume a large fraction of the precursor species under conditions earlier in the day that are less favorable for oxidant formation.

For the general group of scenarios just described, our simulations predict increases in maximum hourly ozone (over the 0.12 ppm of the future base-case scenarios) at about 1.4 ± 0.5 percent per degree Kelvin increase for the first three groups, with the Group 1 cities at the more reactive extreme. With respect to changes in ozone column density, we predicted a 1.1 percent increase in maximum hourly ozone concentration for each percent decrease in ozone column for the Group 1 cities, while the rates of increase for the Groups 2 and 3 cities were very near zero. Some of this variability was seen as an artifact of the EKMA calculation procedure, since the EKMA procedure terminates its calculations at 1800 hours. In this way, additional oxidant-forming potential, which is only realized after 1800 hours, cannot be accounted for. For the Group 1 EKMA attainment and future base-case simulations, 0.12 ppm of ozone was formed at 1800 hours, but there was an increasing slope at that time, indicating additional oxidant-forming potential. Future conditions of enhanced ultraviolet irradiance utilized this potential more efficiently to produce higher levels of ozone prior to 1800 hours. Therefore, those test cases (Group 1) showed more extreme sensitivity to future changes in ozone column densities.

We recognize that simulations in which some of the rates in the chemical mechanism vary between present and future scenarios was never an intended application of the EKMA. On the other hand, when it is possible to account for a large fraction of the oxidant-forming potential, as in the base-case simulations for Groups 2 and 3 where the ozone maximum concentration occurred prior to 1800 hours, very little additional ozone formation was predicted with changes in future parameters because a large fraction of the oxidant-forming potential was already accounted for. Using our estimates of moderate (+2 K and -16.67 percent ozone column density) and extreme (+5 K and -33.3 percent ozone column density) conditions, we predicted group-average ozone concentrations of 0.132 and 0.120 ppm for Groups 2 and 3 at the extreme conditions. Hence, though ozone forms more rapidly in these future

scenarios, the concentrations do not significantly exceed the NAAQS for even the most extreme conditions tested. Conversely, for Groups 1 and 4 average concentration results were 0.148 and 0.150 ppm for moderate conditions and 0.174 and 0.207 ppm for extreme tests. Because of the rather significant changes predicted for the Group 1 and 4 test cases, we also analyzed the data for an indication of whether synergistic interaction between the two perturbations would occur. We found that, for the cases available, the combined effects of coincident increases in both parameters were sometimes additive, but not synergistic. Such a finding is consistent with our description of the urban photochemical processes, assuming that there is a limit to the oxidant-forming potential of an air mass.

The formation of other oxidized products such as nitric acid and hydrogen peroxide was found to be specifically dependent on the types of processes by which they form in an urban atmosphere. For instance, the formation rate and eventual yield of nitric acid is related to the hydroxyl radical concentration and the amount of NO_x available. These two parameters are closely linked to ozone concentration, since NO_x is an ozone precursor and ozone photolysis is the key source of hydroxyl radicals in these systems. Hence, the impacts of potential global changes on nitric acid formation parallel those of ozone and are limited by available NO_x . On the other hand, hydrogen peroxide is formed by the combination of hydroperoxy radicals, which only accumulate after NO_x is depleted. An increase in photochemical reactivity will deplete NO_x faster and allow hydroperoxy radical (and therefore, hydrogen peroxide) to form for longer periods and at higher concentrations. In this study, the predicted future increases in photochemical reactivity stem mainly from projected future decreases in ozone column density; thus, hydrogen peroxide was found to be very sensitive to this parameter.

We have also found that NMOC emission control designed to attain the NAAQS for ozone appears to be a very effective hydrogen peroxide control since one net effect of NMOC control is to reduce the reactivity of a system and thereby reduce the consumption rate of NO_x . Since hydroperoxy radical concentrations are highly sensitive to NO_x concentration, the additional remaining NO_x holds down the hydrogen peroxide formation rate. Conversely, as

projected conditions of future global change were implemented in our test cases, NO_x was again depleted more rapidly and hydrogen peroxide concentrations began to increase significantly. For our moderate test conditions, control of NMOC to attain the ozone NAAQS was predicted to also limit hydrogen peroxide to about 70 to 80 percent of its original base-case concentration. However, as ozone column conditions were changed to the extreme case, more hydrogen peroxide was formed than in the original base case, even with the added NMOC control.

Conclusions and Recommendations

We believe that the current actinic flux, absorption cross section, and quantum yield data sets result in calculations of ozone [to form O(¹D)] and formaldehyde photolysis rates within an uncertainty of about 50 percent. These are the most important photolysis rates in the simulation of tropospheric photochemistry, and more confidence in model results would be gained if this uncertainty could be limited to more acceptable bounds. We feel future efforts to limit this uncertainty would provide additional confidence in all air quality simulation. These efforts should (1) use currently existing information to develop improved actinic flux data sets and computer formulations, and (2) make additional experimental measurements, particularly of formaldehyde absorption cross sections, short wave-length actinic flux distributions, and actinometrically determined *j*-values, to provide critical information in the most uncertain areas.

Our simulations of urban photochemical systems indicate that some areas, predominantly those rich in emissions of oxidant precursor species, exhibit strong tendencies to be more reactive given additional energy input from increased temperatures and increased ultraviolet irradiation. This added reactivity was evident from both higher concentrations of oxidants and radical species and more rapid formation of these species. We have established some limits to the extremes of change that could occur in urban scenarios and suggest that continuation of such an effort should focus on four aspects: (1) Use of the newest and more extensive 1987 SIP data along with the recently developed Carbon-Bond Mechanism-IV/OZIPM-4 model to obtain more

specific information related to the extent of the impacts found in this study; (2) Use of such models and data to study parameters not varied in this study, but now predicted by GCMs to be variable (including water vapor, mixing height and cloud cover); (3) Use of regional models such as the ROM or RTM-III, to analyze linked, multiple, urban trajectories in a unified regional domain; and (4) Use of a more complex gridded urban model, such as the Urban Airshed Model, in conjunction with demographic data to evaluate the exposure-related impacts of reactivity changes predicted to occur with smaller ozone column densities.

M. W. Gery, R. D. Edmond, and G. Z. Whitten are with Systems Applications, Inc., San Rafael, CA 94903.

Bruce W. Gay, Jr., is the EPA Project Officer (see below).

The complete report, entitled "Tropospheric Ultraviolet Radiation: Assessment of Existing Data and Effects on Ozone Formation," (Order No. PB 88-130 133/AS; Cost: \$25.95) will be available only from.

National Technical Information Service

5285 Port Royal Road

Springfield, VA 22161

Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Atmospheric Sciences Research Laboratory

U.S. Environmental Protection Agency

Research Triangle Park, NC 27711