

THE SOUTHERN OXIDANTS STUDY: SCOPE, ACCOMPLISHMENTS, AND FUTURE*

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The Southern Oxidants Study (SOS) has developed and demonstrated the effectiveness of a new paradigm for policy-relevant, air-quality research in the United States. This new paradigm is based on a long-term commitment to improve scientific and public understanding of the fundamental chemical, meteorological, biological, and sociological processes that lead to the formation and accumulation of ozone (O₃) in the lower atmosphere of the earth. SOS uses the southern United States as a natural laboratory for systematic observation-based testing and evaluation of essentially every assumption undergirding the U.S. EPA's present emissions-based thinking and modeling, an approach which has yet to achieve significant progress in the abatement of photochemical ozone pollution over the past 20 years.

THE SOS PARADIGM

The progress SOS has made during the past five years has largely been a result of harnessing a diverse array of conceptual, scientific, financial, and organization resources into a well coordinated scientific research and assessment program with the following characteristics:

1. Scientific and intellectual leadership from a select team of skilled scientists and engineers from the university, industry, and federal and state government communities;
2. Significant financial and in-kind support provided by mutual agreement of executive leaders from major stakeholders in the ozone air quality issue;
3. Technical oversight by a select group of internationally distinguished independent scientists;
4. Participation by nearly 200 research personnel from 21 states including:
 - More than 80 university scientists and engineers and 40 graduate students from 24 research universities; and,
 - 75 government and industry scientists and engineers from 35 different federal, state, and industrial organizations, and public interest groups;
5. A common commitment to:
 - Developing climatologically as well as meteorologically relevant observation-based tools and models that complement emissions-based tools and models;
 - Formulating statements of scientific findings that are useful in public decision making and documenting these findings in the refereed journal literature;
 - Maintaining interactions between SOS and other regional air-quality research programs in the U.S. and abroad, especially the newly emerging North American Research Strategy

for Tropospheric Ozone (NARSTO) and Photochemical Assessment and Monitoring Stations (PAMS);

- Developing a proactive program of outreach and extension to federal, state, regional, and local air-quality managers, public interest groups, and the public at large; and,
- Increasing the number and ability of skilled air-quality professionals by providing opportunities for graduate education and research.

SOS RESEARCH GOALS AND FINDINGS

SOS was initiated in 1988 following *The Workshop on Atmospheric Photochemical Oxidants: A Southern Perspective*. In 1991, SOS entered into its first set of five-year Cooperative Agreements with the U.S. EPA. The resources provided by these Agreements, as well as other contracts, grants, and in-kind support from other agencies and organizations has fostered a comprehensive, university implemented research program focusing on understanding the causes of O₃ accumulation in the southern United States and developing tools needed to design and implement strategies to mitigate the harmful effects of O₃ accumulation in the South and in the nation as a whole.

Research efforts over the past five years have resulted in significant, policy-relevant scientific findings in the areas of

- Chemical Climatology of the South;
- Role of Biogenic Hydrocarbon Emissions;
- Non-Traditional Sources of NO_x Emissions;
- Measurement Science;
- Development of an Observation-Based Paradigm for Elucidating Ozone Precursor Relationships and Evaluating Emission Inventories;
- Air Pollution Meteorology;
- 3-Dimensional Photochemical Grid Modeling; and,
- Determining VOC- or NO_x-Limitation In Oxidant Formation

Studies from the SOS Regional Networks have shown the South to be a region where O₃ accumulates in high concentrations in both rural and urban areas. These rural O₃ concentrations frequently are high enough to inhibit photosynthesis in many of the region's extensive crops, forests, and ornamental plants. Because of the broad regional nature of these high rural concentrations of O₃, development of a secondary standard for ozone based on a longer averaging time could cause large parts of the rural South to be designated O₃ non-attainment areas. In contrast to the northeastern United States, regional episodes in the South are characterized by a disperse and spatially incoherent increase in oxidant concentrations, i.e., a "rising tide" of ozone, instead of the spatially coherent "river of ozone"--a metaphor often (and appropriately) used to describe O₃ episodes in the northeast.

Observations in Atlanta indicate that maximum O₃ concentrations can occur downwind of the city center within a series of embedded plumes (i.e., a power plant or other similar point-source plume within a more general urban plume, which, in turn, is embedded within a wide spread regional "tide" of O₃). It is theorized that O₃ non-attainment episodes may occur in southern cities when these three regional, urban, and point-source plumes converge with each other, producing an additive or cumulative effect which raises the O₃ concentration above the current standard. If correct, this would imply that these peak O₃ concentrations are largely controlled by stochastic interactions between regionally dispersed processes and smaller-scale urban-plume and point-source plume phenomena.

These stochastic interactions, if they do indeed occur, will be difficult to simulate in the current generation of gridded air-quality models and probably also will be difficult to control using traditional pollution abatement strategies. For these reasons, SOS will test these hypotheses further in 1995 during its second major urban intensive in Nashville/Middle Tennessee. In the Nashville studies, SOS will use a series of research aircraft, supplemented by ground-based measurements, to investigate embedded plume phenomena in an urban setting.

Analyses of data gathered in SOS and calculations with both Emissions-Based Models (EBMs) and Observation-Based Models (OBMs) suggest that O₃ in the South is more sensitive to changes in anthropogenic nitrogen oxide emissions than to changes in anthropogenic VOC emissions. While still preliminary, these results suggest that strategies that focus on decreasing nitrogen oxide emissions may be more effective in abating regional and urban O₃ pollution than strategies that focus on decreasing anthropogenic VOC emissions. UAM simulations for the Atlanta area using EPA guidelines for State Implementation Plans (and thus are based on a worst-case meteorological scenario) indicate that a 90% decrease in NO_x emissions will be required to bring Atlanta into attainment with the National Ambient Air Quality Standard (NAAQS) for O₃. (According to these same simulations, even a 100% decrease in anthropogenic VOC emissions will still leave the city some 20 ppbv above the NAAQS for O₃.) However, comparisons of UAM-predicted concentration fields with SOS observations indicate some problem areas. For instance, the model does not appear to be able to simultaneously reproduce observed concentrations of ozone and isoprene.

In addition to elucidating the processes responsible for O₃ formation and accumulation in the South, SOS has focused and will continue to focus on developing the technological, intellectual, and human resources required by the nation and the southern region to effectively address the complex technical issues associated with air quality management today and in the future. Toward that end, SOS has:

- Implemented a three-tiered set of regional oxidant networks;

- Developed and evaluated a new generation of observation-based models; and,
- Developed and field-tested state-of-the-science measurement techniques as well as devised protocols and sampling strategies for their effective use.

THE MAJOR POLICY-RELEVANT FINDINGS OF SOS

Ozone Abatement In the South

- Ozone management strategies that focus on decreasing nitrogen oxide emissions will be more effective in decreasing ozone concentrations in the rural South and in Atlanta and similar urban centers than strategies that focus on decreasing anthropogenic emissions of volatile organic compounds.

Regional Chemical Climatology

- No significant change was observed in the average ozone concentration in most rural and urban areas of the South from 1980 to 1992. This occurred despite the sizable investments made in volatile organic compound emissions controls in the region, and possibly because of the significant economic growth of the region over the period.
- During the summer months of many of these years, high concentrations of ozone occurred in rural as well as urban areas of the South;
- Ozone concentrations in rural areas of the South were not as high as in urban areas, but they frequently were high enough to inhibit photosynthesis in the region's extensive crops, forests, and ornamental plants.
- Because of these high rural ozone concentrations, revision of the current ozone standard, or promulgation of a secondary ozone standard based on a longer averaging time but a lower ozone concentration, could cause large portions of the rural South to be designated for ozone non-attainment.
- Because of the different temporal patterns of ozone episodes in rural and urban areas of the South, the promulgation of an ozone standard based on longer averaging times will tend to shift the regulatory focus in the South from urban centers to more rural areas.

Urban Non-Attainment

- Maximum ozone concentrations in Atlanta can occur downwind of the city center but within power plant or similar point-source plumes as they emerge from the city. These point-source plumes occur within a more general urban ozone plume from biogenic, mobile, and other area sources, which, in turn, is embedded within a wide spread regional tide of enhanced ozone concentrations.
- This phenomenon of plume convergence suggests that ozone non-attainment events in the South can occur when enhanced ozone concentrations within the region, the urban plume, and smaller-scale point-source plumes intersect, producing a cumulative ozone concentration in excess of the standard.

Emissions

- The primary source of nitrogen oxides in the South is the burning of fossil fuels in power plants, industrial boilers, motor vehicles, and other internal combustion engines. Nitrogen oxides also are emitted during the burning of biomass--in open fields, recovery furnaces of pulp mills, other space and water heating furnaces stoves, incinerators, etc., and from well fertilized crop lands, pastures, and lawns. Under some meteorological conditions, nitrogen oxide production from lightning may be significant.
- On-road measurements in two interstate highway tunnels indicate that the latest vehicle emissions models developed by EPA's Office of Mobile Sources (MOBILE 4.1 and MOBILE 5.0) provide reasonably good estimates of volatile organic compound, carbon monoxide, and nitrogen oxide emissions from a fleet of well maintained vehicles operating under highway conditions. It is therefore likely that these emissions models underestimate the emissions of the fleet of vehicles operating under urban conditions.
- On-road tests in Atlanta suggest that severe power enrichment caused by acceleration and other heavy engine loads is a major source of carbon monoxide and a significant source of volatile organic compound emissions from motor vehicles.

Attainment Demonstration For Atlanta Using UAM

- Urban Airshed Model (UAM) simulations for the Atlanta metropolitan area using EPA State Implementation Plan guidelines suggest that a 90% decrease in nitrogen oxide emissions will be required to bring Atlanta into attainment with the present ozone standard. These simulations also suggest that complete elimination of anthropogenic volatile organic compounds emissions will decrease peak ozone concentrations in Atlanta, but still leave parts of the metropolitan area about 20 ppbv above the present ozone standard under some meteorological conditions.
- Analysis of the UAM simulations for the Atlanta metropolitan area using EPA State Implementation Plan guidelines indicates that the model, and/or its application following these guidelines, have significant technical deficiencies. These deficiencies include: An inability to simultaneously reproduce observed concentrations of ozone and its precursors, an inaccurate representation of urban wind fields and, thus, an inaccurate reproduction of the direction, altitude, and dispersion of the urban ozone and precursor plumes. Because of these deficiencies, the conclusions drawn from UAM simulations using EPA State Implementation Plan guidelines cannot yet be viewed with confidence.

THE FUTURE OF SOS IN 1996-2000

The SOS Science Team has just initiated its second five-year Cooperative Agreement with the U.S. EPA and the other federal, state, and industrial sponsors for the years 1996-2000. In the near term, SOS will focus on interpreting the results from an extensive Urban Intensive Field Measurement and Modeling Campaign in Nashville/Middle Tennessee during the summer of 1995.

Looking toward the longer term, it is currently envisioned that the major scientific and policy-relevant research themes within SOS during the 1996-2000 time period are outlined below.

1. Research Aimed At Elucidating Processes Responsible For Ozone Formation, Transport, and Accumulation in the South, including:

- Continued and expanded interpretive use of the data from these networks and the SOS urban intensives in Atlanta and Nashville/Middle Tennessee;
- Continued emphasis on chemical climatology, with expansion of the three-tiered regional oxidant networks to the west and north;
- Implementation of one or two Intensive Field Studies; and,
- Monitoring the impact of ozone management strategies in the South.

2. Meeting National Needs Through Outreach, Tech Transfer, and Infrastructure Development, including:

- Enhanced Observation-Based and Emissions-Based model development and evaluation;
- Continuation of SOS's traditional focus on Measurements, Technology, and Standards;
- Continuation of research on the improvement of methodologies used for developing emissions inventories;
- Further collaboration and cooperation with other national and regional air quality studies in the United States and abroad, especially the North American Research Strategy for Tropospheric Ozone (NARSTO);
- Outreach and technology transfer from SOS to federal, state, regional, and local air-quality managers, public interest groups, and the public at large (especially as it relates to PAMS); and,
- Continued graduate education of skilled air quality professionals.

3. Research On Alternate Strategies For Implementing the Clean Air Act Amendments of 1990 and Beyond, including:

- Examination of underlying paradigms and methods used in current strategy;
- Exploration of strategies based on alternate forms of the National Ambient Air Quality Standard for ozone; and,
- Exploration of feasibility and merits of alternate paradigms and strategies for managing O₃ pollution.

* Excerpt from "The State of the Southern Oxidants Study".