Chapter 8 –Session 3 Overview: Linking Air Quality and Human Health

Contents

Session 3 Overview: Linking Air Quality and Human Health

8.0 Introduction

The first two sessions on air quality model development and evaluation have summarized various aspects of AMAD's research portfolio addressing Long Term Goal (LTG) 1 in ORD's Clean Air Research Multi-Year Plan. Session 3 on linking air quality and human health introduces an emerging research area for AMAD, and it addresses ORD's Clean Air Research LTG 2, to reduce the uncertainties in linking air pollution sources and health outcomes to support effective air quality strategies.

8.1 Research Summary

Expanding beyond the Division's primary mission of constructing, evaluating, and delivering air quality modeling tools and methods to support attainment of national air quality standards, this new research seeks to link air quality modeling tools with human exposure and health outcomes. Currently, most epidemiological studies rely on ambient observations from sparsely-sited monitoring stations to provide metrics of exposure. Yet for many pollutants in urban-areas, large spatial variations exist—particularly near roadways and major industrial sources—and ambient concentrations do not necessarily track actual exposures, which can be influenced by the infiltration of ambient concentrations into indoor facilities (such as automobiles, homes, schools, and work places) and the daily activity patterns of individuals (such as outdoor exercise, walking, commuting, etc.). Also, when exposure models have been applied to health studies, they have usually relied on a small number of ambient measurements rather than on high-resolution concentration surfaces that can be obtained from air quality modeling. In the first poster, a methodology is presented to couple regional air quality modeling results (from CMAQ) with near-field dispersion modeling results (from AERMOD), which are then integrated directly into the Stochastic Human Exposure and Dose Simulation (SHEDS) model and the Hazardous Air Pollution Exposure Model (HAPEM).

While testing the linkage of air quality modeling to exposure modeling, the Division began to recognize that a fundamental weakness in the approach was the need to better characterize the variability of air pollution near roadways, especially since several millions of Americans live, work, and attend school near a major roadway. Also, health studies are suggesting a linkage of adverse health effects and exposure to pollution from roadways. In the second poster, we report on the Division's collaborative research (with other scientists from ORD and NOAA) that is aimed at improving the spatial characterization of air pollution near roadways. This promising research area is beginning to yield improved parameterizations to inform exposure assessments near roadways, and it is resulting in improvements to line-source algorithms in the widely-used AERMOD dispersion model.

Historically, the success of air pollution regulations has been measured by tracking trends in emissions and ambient air concentrations. However, the Division has begun to explore the potential of extending the concept of measuring the impact to a more complete understanding of the relationships along the entire source-to-outcome continuum. The 2004 National Academy of Science's report on "Air Quality Management in the U.S." calls for an air quality management system "to track health and ecosystem exposures and effects and to document improvements in health and ecosystem outcomes achieved from improvements in air quality." In addition, implementation of the Government Performance and Results Act (GPRA) and the Program Assessment Rating Tool (PART) has created additional incentives to demonstrate relationships between environmental policies and human and ecological outcomes. To assess whether air quality management decisions are achieving the originally-anticipated results from sources through outcomes requires (1) the development of indicators that capture changes in source emissions, ambient air concentrations, exposures, and health outcomes, and (2) the ability to characterize the processes that impact measurements and model outputs as well as to characterize relationships between sources, ambient air concentrations, human exposure and health outcomes. In exploring this issue of "accountability", Poster 3 presents research in which regional air quality modeling is used to assess the effectiveness of air quality regulations in improving human health.

The Division has also been involved in several other related areas that could not be included in the poster session. These include the following: (1) an investigation of sub-grid scale spatial variability and the calculation of probability density functions as inputs to human exposure models; (2) research on urbanized versions of the MM5 and WRF meteorological models, including the creation of an urban morphology prototype called the National Urban Database and Access Portal Tools (NUDAPT) system (www.nudapt.org); and, (3) collaboration with sponsors of the National Urban Air Toxics Center (NUATRC) in Houston, Texas, to test the application of CMAQ at a 4 km grid mesh to capture concentration "hot spots" and to relate these concentrations to hospital admissions data.

The posters shown in this Session represent a new effort in the Division, having emerged only during the past three years. However, this research is beginning to help establish the link between air quality and human exposure models, to improve the characterization of near-roadway air pollution, and to assess the effectiveness of air quality management decisions on ambient concentrations, human exposure, and human health.

8.2 Future Research

AMAD plans to continue to improve and evaluate approaches for linking air quality and exposure models and to demonstrate the feasibility of using these linked modeling systems to assess the effectiveness of air pollution control strategies in improving human health outcomes.

One of the greatest challenges in applying the hybrid modeling approach – which entails the use of results from AERMOD and CMAQ in conjunction with each other – is to obtain spatially-resolved monitoring data to evaluate the model-predicted concentration fields. We plan to continue to collaborate with other organizations sponsoring field studies, and we plan to pursue the use of available datasets, such as the Detroit Exposure Assessment Research Study, to accomplish this model evaluation. We also recognize that the ability to model "hot spots", especially near major roadways, needs to be improved. In concert with the near-roadway research effort, we anticipate that an improved line-source algorithm will be implemented in AERMOD. In addition, we plan to conduct air quality modeling using the hybrid approach to support two environmental health studies (in Baltimore and Atlanta) as a part of cooperative research agreements with the University of Washington and Emory University. An analysis from this effort will be used to assess whether air quality modeling provides an added value to the health assessments.

Roadways are characterized by many types of configurations that affect the flow and dispersion of traffic-generated pollutants. These configurations can include noise barriers, vegetative buffers, and roadway "cuts". AMAD will be analyzing existing wind tunnel and field study data (including the recently-completed barrier tracer study) and testing the resulting parameterizations to make improvements in AERMOD's line-source algorithms, CMAQ, and hybrid modeling approaches. The Division is also committed to its collaboration with other groups in NERL and EPA's National Risk Management Research Laboratory (NRMRL) to plan and analyze data from field campaigns scheduled during 2009-2011 in Las Vegas, Detroit and Raleigh. These campaigns are designed to better understand the relationship between traffic emissions and roadway-related air pollution concentration gradients. To assist in building improved numerical modeling techniques for operational air quality models, we are planning to work with scientists in NRMRL and NERL to incorporate computational fluid modeling results. Related to the linkage effort described above, we plan to use the improved near-road dispersion model (within the hybrid approach) as part of the study planned in Atlanta during 2009. This is an integral part of the "Air Pollution Exposure and Health Cooperative Agreement" between EPA/NERL and Emory University. The modeling of near-road dispersion will directly support the planned environmental health studies in Atlanta. Ultimately by 2012, we are committed to identify assessment tools to aid urban planners in considering near roadway effects.

Working with the dynamic evaluation of CMAQ's concentration response to emission changes resulting from the NO_x SIP Call assessment (see Poster 2.5), the methodology developed under this research effort will be expanded to include additional years (1997-2006) for an epidemiology study and risk assessment. In addition, an approach for assessing future regulations is being developed to include metrics (predictions of changes associated with the promulgation of a rule) and indicators (actual levels of the same or closely related parameters observed during implementation) established *a priori*. We plan to continue our research on data combination techniques to produce the best air quality analyzed fields for assessments, using both observed and modeled concentrations. Finally, building upon the linkage to human exposure research, the ability to model fine-scale features within 12 km x 12 km CMAQ grid cells is being investigated to better assess spatial textures in air quality on human health endpoints.

8.3 Impact

Although this is an emerging research area, AMAD's research on linking air quality and human health has directly contributed to the agency's mission. The hybrid modeling system and its linkage with human exposure models is serving as a prototype for air quality and exposure assessment community air pollution health studies. Further, the coupled urban/regional air quality modeling system is being tested by the regulatory community to determine its adequacy for assessing impacts from regional- and local-scale air pollution control measures. These same models can also be used to estimate the projected air quality and exposures on human health in the community for future years, considering projected air pollution control measures or urban/industrial growth. The New Haven air accountability feasibility project was a pilot study to test these techniques. Although this project targets one city, the lessons learned will have broad applicability to other areas around the United States. In addition, this study can be used as a resource for future air accountability studies, such as that described in Poster 3.3.

The Division's near-roadway research effort is improving the understanding of the impacts of mobile sources on air quality, exposures, and health effects at regional and local scales. On an operational basis, the laboratory and field observations are yielding improvements to the AERMOD dispersion model, which is widely used for urban dispersion applications involving air quality permit designations for new and modified industrial sources. While focused on improving our understanding of the relationships between mobile emissions and adverse health effects and the development of tools to assess roadway impacts and proposed targeted mitigation strategies, the product of this work will inform decision making within existing EPA and Federal Highway regulatory programs such as the National Environmental Policy Act, the Conformity rule, and enforcement of the Clean Air Act (i.e. NAAQS). Additionally, programs within the Department of Health and Human Services, Department of Education, Department of Housing and Urban Development and the Centers for Disease Control and Prevention (as well as state and local governments) will also benefit from this research to assist in the siting of schools, hospitals, and residential housing near major roadways.

Understanding whether costly regulatory actions are providing the intended benefits is important economically, but perhaps more critically in ensuring that the public is adequately protected from exposure to harmful pollutants. This research has begun to develop methods for discerning a relatively small signal of change in ambient pollutant levels embedded in a highly confounded set of outcomes (e.g., secondary pollutant levels, exposure levels). In addition, this research is leading to development of indicators and methods to link among indicators, with a focus on the source-to-exposure portion of the environmental risk paradigm.

8.4 Session Posters

The following three (3) posters will be presented in this session:

(1) Linking Local-Scale and Regional-Scale Models for Exposure Assessments (3.1)
(2) Characterizing the Spatial Variation of Air Quality near Roadways (3.2)
(3) Evaluating the Effectiveness of Regulatory Actions from the Source-to-Outcome Perspective (3.3)

Abstracts for each of these posters follow.

Linking Local-Scale and Regional-Scale Models for Exposure Assessments (3.1)

Vlad Isakov, James Crooks, Steven Perry, David Heist, Jawad Touma,
James Godowitch, Jason Ching, and Thomas Pierce

Collaborators: Janet Burke, Halûk Özkaynak (EPA/NERL/HEASD); Danelle Lobdell (EPA/NHEERL); Tyler Fox (EPA/OAQPS); Al Cimorelli (EPA Region 3); Mohammed Majeed (Delaware Department of Natural Resources and Environmental Control)

Population-based human exposure models predict the distribution of personal exposures to pollutants of outdoor origin using a variety of inputs, including air pollution concentrations; human activity patterns, such as the amount of time spent outdoors versus indoors, commuting, walking, and indoors at home; microenvironmental infiltration rates; and pollutant removal rates in indoor environments. Typically, exposure models rely upon ambient air concentration inputs from a sparse network of monitoring stations.

We have developed a new method to enhance air quality and exposure modeling tools so that they can address finer-scale air toxics concentrations and exposures. The hybrid modeling approach combines the results from two types of regional- and local-scale air quality models (the CMAQ chemistry-transport model and the AERMOD dispersion model). The resulting hourly concentrations are used as inputs to population exposure models (the Hazardous Air Pollutant Exposure Model [HAPEM] and the Stochastic Human Exposure and Dose Simulation [SHEDS] model) to enhance estimates of urban air pollution exposures that vary temporally (annual and seasonal) and spatially (at census block group resolution). Thus, the new method establishes a linkage between air quality and exposure modeling and will improve health assessments that include near-source impacts of multiple ambient air pollutants.

We demonstrate how this linked air quality/exposure modeling approach may be used in future community-level environmental health studies by providing exposure estimates that reflect residences near large industrial facilities or major roadways. This research is an important component of an EPA feasibility study being conducted in New Haven, CT, that is examining the cumulative impact of various air pollution reduction activities (at local, state, and national levels) on changes in air quality concentrations, human exposures, and potential health outcomes in the community. In conjunction with local data on emission sources, demographic and socioeconomic characteristics, and indicators of exposure and health, the methodology presented here can serve as a prototype for providing high-resolution exposure data in future community air pollution health studies. For example, the methodology can be used to provide the baseline air quality assessments of impacts due to regional- or local-scale air pollution control measures. It can also be applied to estimate the likely impact of future projected air pollution control measures or urban/industrial growth on human exposures and health in the community.

The extent of variability in spatial and temporal concentration gradients associated with large point sources and roadways shown in this research is especially important, given the growing body of literature on the potential adverse health effects associated with elevated concentrations near such sources.

Characterizing the Spatial Variation of Air Quality near Roadways (3.2)

Steven Perry, David Heist, Vlad Isakov, Thomas Pierce

Collaborators: Alan Vette (NERL/HEASD); Richard Baldauf (EPA/NRMRL); Richard Cook (EPA/OTAQ); Kirk Clawson (NOAA Field Research Division); Akula Venkatram (University of California – Riverside); Stefanie Sarnat, Jeremy Sarnat (Emory University)

Recent studies have identified increased adverse health effects in the large percentage of the population that lives, works, and attends school near major roadways. EPA's Clear Air Research multiyear plan therefore emphasizes air research to better understand the linkages between traffic-pollutant sources and health outcomes. The effort described here is to further understand the atmospheric transport and dispersion of emissions within the first few hundred meters of the roadway, a region often characterized by complex flow (e.g., sound barriers, road cuts, buildings, vegetation) and where steep gradients of concentration have been observed. Work within AMAD has focused on developing and improving various numerical modeling tools necessary for assessing potential human exposure in near-road environments.

Regarding modeling tools for simulating near-road concentration gradients, over the past decade the Division has played a central role in developing the AERMOD near-field dispersion model, adopted by EPA as the preferred tool for urban-scale (or smaller) analyses. While the model can simulate simple roadway-type scenarios, it does not specifically account for many complexities commonly found near roads. However, after a thorough review of publicly available modeling tools, AERMOD was selected as the preferred platform upon which improvements could be made for local-scale dispersion simulations of near-road applications and for inclusion in hybrid modeling (with CMAQ) for urban-scale exposure assessments. After initial wind tunnel studies, algorithms for estimating the concentration gradients downwind of roadways in the presence of noise barriers and depressed roadways have been developed and show much promise. Additional wind tunnel studies with variations in wind direction, barrier height, and surrounding surface characteristics are in progress. Computational fluid dynamics modeling of these and other scenarios is in progress and is expected to yield a significant database from which further improved parameterizations will result. Ongoing and future field campaigns and tracer studies will provide excellent development and evaluation databases.

Once improved and evaluated, the new near-road dispersion model will be used in the Air Quality Modeling Study in Atlanta as a part of a Cooperative Research Agreement between EPA/NERL and Emory University. In this project, air quality estimates will be correlated with a ten-year history of emergency room data and with the experiences of over 800 patients with Implanted Cardiac Defibrillators. Air quality estimates will be based on the hybrid approach using combined regional (CMAQ) and local-scale (AERMOD) modeling. Various source configuration options will be tested in a sensitivity study to estimate the impact of noise barriers on air quality and exposure near roadways. Similar hybrid modeling activities will be conducted for Baltimore as a part of another Cooperative Agreement with the University of Washington.

Finally, related urban research in AMAD prior to the near-roadway program involved focus on homeland security. Between 2002 and 2005, the Division's Fluid Modeling Facility (FMF) examined flow and dispersion in three actual urban settings. Using the meteorological wind tunnel, AMAD provided critical modeling information for EPA's response to the tragic events in Manhattan in late 2001. As part of the Pentagon Shield Program, FMF scientists examined the flow and potential exposure to hazardous releases around the Pentagon building. In collaboration with EPA's National Homeland Security Research Center, wind tunnel measurements were conducted for an examination of street canyon flows in an urban neighborhood in Brooklyn, NY.

Evaluating the Effectiveness of Regulatory Actions from the Source-to-Outcome Perspective (3.3)

Valerie Garcia, Alice Gilliland, James Godowitch, Kristen Foley

Collaborators: Halûk Özkaynak (EPA/ORD), John Langstaff (OAR/OAQPS), Shao Lin, Rena Jones and Chris Pantea (NYS DOH), Christian Hogrefe and Gopal Sistla (NYS DEC), Pat Kinney (Columbia University), Steve Porter and Edith Gego (University of Idaho)

A core objective of the Clean Air Act is to "protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the productive capacity of its population." To achieve this goal, billions of dollars are spent annually by the regulated community and federal and state agencies on promulgating and implementing regulations intended to reduce air pollution and improve human and ecological health. Historically, the impact of air pollution regulations has been measured by tracking trends in emissions and ambient air concentrations. Now, however, the EPA is exploring the potential of extending the concept of measuring impact to a more complete understanding of the relationships along the entire source-to-outcome continuum. Assessing whether air quality management activities are achieving the originally anticipated results from sources through outcomes requires (1) the development of indicators that capture changes in source emissions, ambient air concentrations, exposures, and health outcomes; and (2) the ability to characterize the processes that impact the relationships among these indicators. The NO_x SIP Call was recently implemented by EPA to reduce the emissions of nitrogen oxides (NO_x) and the secondarily formed ozone, in order to decrease the formation and transport of ozone across state boundaries. Over the past three years, AMAD's research has demonstrated reductions in observed and modeled ozone concentrations resulting from the NO_x SIP Call. The Community Multiscale Air Quality (CMAQ) model was used to characterize air quality before and after the implementation of the NO_x SIP Call and to evaluate correlations between changes in emissions and pollutant concentrations. Model simulations were used to estimate the anthropogenic contribution to total ambient concentrations and the impact of not implementing the regulation. Methods were developed to differentiate changes attributable to emission reductions from those resulting from other factors, such as weather and annual and seasonal variations. Trajectory models were used to investigate the transport of primary and secondary pollutants from their sources to downwind regions.

We will continue to develop ways to systematically track and periodically assess progress in attaining national, state, and local air quality goals—particularly those related to criteria pollutants regulated under the NAAQS and related rules. Current research is focused on relating NO_x emissions and ambient ozone concentrations to human exposure and health endpoints. Improved air quality surfaces that combine observed and modeled data are being generated for use in exposure models, epidemiological health studies, and risk assessments. These studies will examine the benefits of using improved air quality surfaces versus central monitoring approaches, and of using exposure probability factors versus ambient ozone concentrations in health studies. In addition, these studies will evaluate changes in predicted exposure and risk assessments and actual changes in health endpoints (e.g., respiratory diseases) between the pre- and post-NO_x SIP Call time periods. Finally, research is moving beyond the NO_x SIP Call to assess upcoming regulations. An approach for evaluating the Clean Air Interstate Rule (CAIR) is being investigated to establish and integrate "metrics" (predictions of changes associated with the promulgation of CAIR) and "indicators" (actual levels of the same or closely related parameters observed during the implementation of CAIR).

8.5 Session Publications

This section presents the products (generally from 2004-2008) associated with each poster in this session. Some products are associated with multiple posters, so they are listed as products under more than one poster.

Linking Local-Scale and Regional-Scale Models for Exposure Assessments (3.1)

Cook, R., **Isakov, V., Touma, J.S., Benjey, W**., Thurman, J., Kinnee, E., Ensley, D. Resolving Local Scale Emissions for Near Road Modeling Assessments. *J. A&WMA.* **58**: 451-461. (2008).

Isakov, V., Touma, J.S., Burke, J., Lobdell, D., Palma, T., Rosenbaum, A., Özkaynak, H. Combining Regional and Local Scale Air Quality Models with Exposure Models for Use in Environmental Health Studies. *J. Air & Waste Management Association* (accepted).

Isakov, V.; Özkaynak, H. In *Air Pollution Modeling and its Applications XIX*; Borrego, C., Ed.; Springer Science & Business Media B.V., The Netherlands, 2008; pp 616-624.

Isakov, V., Irwin, J., **Ching, J**. Using CMAQ for exposure modeling and characterizing the sub-grid variability for exposure estimates. *Journal of Applied Meteorology and Climatology,* **46**:1354-1371 (2007)

Isakov, V., **Touma, J.S.,** Khlystov, A. A Method of Assessing Air Toxics Concentrations using Mobile Platform Measurements. *J. A&WMA.* **57**: 1286-1295 (2007).

Isakov, V., Venkatram, A., **Touma, J.S.**, Koračin, D., **Otte, T. L**. Evaluating the Use of Outputs from Comprehensive Meteorological Models in Air Quality Modeling Applications. *Atmospheric Environment*. **41**: 1352-2310 (2007).

Isakov, V., Venkatram, A. Resolving neighborhood scale in air toxics modeling: a case study in Wilmington, California. *J. A&WMA.* **56**: 559-568 (2006).

Isakov, V., Graham, S., Burke, J., H. Özkaynak. Linking air quality and exposure modeling. *EM Magazine.* **9**: 26-29 (2006).

Koračin, D., Panorska, A., **Isakov, V., Touma, J.S., Swall, J**. A Statistical Approach for Estimating Uncertainty in Dispersion Modeling: an Example of Application in Southwestern U.S. *Atmospheric Environment.* **41**: 617-628 (2007).

Pierce, T., **V. Isakov**, B. Haneke, J. Paumier. *Emission and air quality modeling tools for near-roadway applications.* EPA Technical Report (in press), RTP, NC, 38 p. (2008).

Stein A., **Isakov, V., Godowitch, J.**, R. Draxler. A hybrid approach to resolve pollutant concentrations in an urban area. *Atmospheric Environment,* **41**: 9410–9426 (2007).

Touma, J.S., Isakov, V., Cimorelli, A., Anderson, B., Brode, R. Using Prognostic Model Generated Meteorological Data in the AERMOD Dispersion Model: An Illustrative Application in Philadelphia. *J. A&WMA.* **57**: 586-595 (2007).

Touma, J. S., Isakov, V., Ching, J., Seigneur, C. Air quality modeling of hazardous pollutants: current status and future directions. *J. A&WMA.* **56**: 547-558 (2006).

Venkatram, A., **Isakov, V**., Seila, R., Baldauf, R. Modeling the impact of traffic emissions to air toxics concentrations near roadways. *Atmospheric Environment* (in review).

Venkatram, A., **Isakov, V**., Thoma, E., Baldauf, R. Analysis of air quality data near roadways using a dispersion model. *Atmospheric Environment.* **41**: 9481–9497 (2007).

Characterizing the Spatial Variation of Air Quality near Roadways (3.2)

Baldauf, R., N. Watkins, **D. Heist**, P. Rowley, R. Shores, 2008: Factors affecting network design and interpretation of data for near-road air quality monitoring. Submitted to *J. Air Quality, Atmosphere & Health.*

Brixey, L., J. Richmond-Bryant, **D. Heist**, G. Bowker, **S. Perry**, R. Wiener, 2008: The effect of a tall tower on flow and dispersion through a model urban neighborhood. Part 2: Pollutant dispersion. Submitted to *J. Environmental Monitoring*.

Cook, R., **V. Isakov, J. Touma**, **W. Benjey**, J. Thurman, E. Kinnee, D. Ensley, 2008: Resolving local-

scale emissions for modeling air quality near roadways. *J. Air and Waste Manage. Assoc.*, **58**, 451-461.
Cimorelli, A., **S. Perry**, A. Venkatram, J. Weil, R. Paine, R. Wilson, R. Lee, W. Peters, R. Brode, 2005: AERMOD: A dispersion model for industrial source applications Part I: General model formulation and boundary layer characterization. *J.Appl.Meteor*., **44**, 682-693.
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Heist, D., **S. Perry**, L. Brixey, 2008: The effect of roadway configurations on the dispersion of traffic-related pollution: a wind-tunnel study. Submitted to *Atmospheric Environment*.
Isakov, V., J. Touma, A. Khlystov, 2007: A method of assessing air toxics concentrations in urban areas using mobile platform measurements. *J. Air and Waste Manage. Assoc.*, **57**, 1286-1295.
Perry, S., A. Cimorelli, J. Weil, A. Venkatram, R. Paine, R. Wilson, R. Lee, W. Peters, 2005: AERMOD: A dispersion model for industrial source applications II: Model performance against seventeen field-study databases. *J.Appl.Meteor*., **44**, 694-708.
Perry, S., D. Heist, R. Thompson, W. Snyder, R. Lawson, Jr, 2004: Wind Tunnel Simulations of Flow and Pollutant Dispersal around the World Trade Center Site. *Environmental Manager*, Feb.,31-34.
Smolarkiewicz, S., R. Sharman, J. Weil, **S. Perry, D. Heist**, G. Bowker. 2007: Building resolving large-eddy simulations and comparison with wind tunnel experiments. *J. Comput. Physics,* **227** 633–653.
Stein, A. F., **V. Isakov**, **J. Godowitch**, R. R. Draxler, 2007: A hybrid modeling approach to resolve pollutant concentrations in an urban area. *Atmospheric Environment,* **41**, 9410–9426.
Venkatram, A., **V. Isakov**, E. Thoma, R. Baldauf, 2007: Analysis of air quality data near roadways using a dispersion model. *Atmospheric Environment,* **41**, 9481–9497.
Venkatram, A., **V. Isakov**, R. Seila, R. Baldauf, 2008: Modeling the impacts of traffic emissions to air toxics concentration near roadways. Submitted to *Atmospheric Environment*.
Vette, A., S. Gavett, **S. Perry, D. Heist**, A. Huber, M. Lorber, P. Lioy, P. Georgopoulos, **S. Rao,** W. Petersen, B. Hicks, J. Irwin, G. Foley, 2004: Environmental Research in Response to 9/11. *Environmental Manager*, Feb. 14-22.

Five EPA reports with associated databases related to urban and near-roadway wind tunnel studies; operational Venkatram line-source algorithm completed; AERMOD completed and adopted as an Agency preferred dispersion model under 40 CFR Part 51 Revisions to the Guideline on Air Quality Models.

Evaluating the Effectiveness of Regulatory Actions from the Source-to-Outcome Perspective (3.3)

Garcia, V., N. Fann, R. Haeuber, and P. Lorang. Assessing the public health impact of regional-scale air quality regulations. Air & Waste Management Association, EM, 29-34 (2008).
Gego, E., P. Porter, **A. Gilliland**, and **S. Rao**, Observation-based assessment of the impact of nitrogen oxides emissions reductions on ozone air quality over the eastern united states, Journal of Applied Meteorology and Climatology, 46(7), 994-1008 (2007).
Gego, E., P.S. Porter, **V. Garcia,** C. Hogrefe and **S.T. Rao**. Fusing Observations and Model Results for Creation of Enhanced Ozone Spatial Fields: Comparison of Three Techniques. Air Pollution Modeling and Its Applications XIX, NATO ITM (2007).
Gego, E., S. Porter, **A. Gilliland**, C. Hogrefe, **J. Godowitch**, and **S. T. Rao**. Modeling analysis of the effects of changes in nitrogen oxides emission from the electric power sector on ozone levels in the eastern United States. Journal of Air & Waste Management Association. 58(4): 580-588 (2008).
Gilliland, A.B., C. Hogrefe, **R. W. Pinder, J. M. Godowitch, K.M. Foley**, and **S.T. Rao**. Dynamic evaluation of regional air quality models: Assessing changes in O3 stemming from changes in emissions and meteorology. Atmospheric Environment, 42(20): 5110-5123 (2008) 06/01
Godowitch, J. M., A. Gilliland, R. R. Draxler, and **S. Rao** (2007), Modeling assessment of point source NOx emission reductions to ozone air quality in the eastern United States, Atmospheric Environment, 42(1); 87-100 (2008).

Godowitch, J., M., C. Hogrefe, and **S. T. Rao**. Diagnostic analyses of a regional air quality model: Changes in modeled processes affecting ozone and chemical-transport indicators from point source NOx emission reductions. Journal of Geophysical Research. Accepted.

Zheng, J., **J. Swall**, W. M. Cox, and J. M. Davis. Interannual variation in meteorologically adjusted ozone levels in the eastern United States: A comparison of two approaches, Atmospheric Environment, 41(4):705-716, (2007).