Chapter 10 –Session 5 Overview: Linking Air Quality and Ecosystem Health

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Session 5 Overview: Linking Air Quality and Ecosystem Health

10.0 Introduction

The EPA is charged with protecting the health and welfare of the nation. The Clean Air Act definition of welfare effects includes, but is not limited to, effects on soils, water, wildlife, vegetation, visibility, weather, and climate. EPA's National Estuary Program (NEP) was established by Congress in 1987 to improve the quality of estuaries of national importance. Estuaries are places where rivers meet the sea and are critical to the health of coastal environments and to our enjoyment of them. The Clean Water Act Section 320 directs EPA to develop plans for attaining or maintaining water quality in an estuary. This includes protection of public water supplies and the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife, and allows recreational activities, in and on water, that require control of point (e.g., water treatment plants) and nonpoint sources (e.g. diffuse sources such as agricultural runoff) of pollution to supplement existing controls of pollution. Atmospheric deposition is an important nonpoint source of pollution impacting ecosystems. Deposition of both nitrogen (N) and sulfur (S) is the main source of acidification of fresh water and terrestrial ecosystems. Atmospheric deposition of N is a contributor to N-nutrient enrichment and eutrophication affecting estuaries. About 15-40% of the nitrogen loading to coastal estuaries is estimated to come from atmospheric deposition, suggesting that a holistic approach is needed for ecosystem protection.

In this research program area AMAD is developing and applying regional atmospheric modeling tools to link atmospheric deposition with ecosystem models to address ecosystem exposure where the atmospheric deposition is an important contributor to ecosystem health. The initial focus has been on the air-water linkage of nitrogen-nutrients affecting coastal estuaries of interest to EPA's National Estuary Programs (NEPs). The focus has expanded to include air-fresh water and air-terrestrial linkages to address nitrogen nutrients and acidification from sulfur and nitrogen deposition. AMAD is also bringing to bear its expertise in precipitation and temperature modeling as important atmospheric influences on ecosystems as well as its expertise in the emerging area of climate change.

Program goals and the strategic directions and objectives of the research described in this session come from Long Term Goals (LTG) 1 and 3 of the Ecological Research Program Multi-Year Plans (MYP) of 2003. LTG 1 relates to development of improved tools and ability to assess national programs and LTG 3 relates to application of the improved tools by States and relevant EPA offices. Products of LTG 1 are most relevant to environmental problems and policy issues at the national level. LTG 3 is mainly targeted at environmental problems at the state level (often spanning over a region) and the forecast of the impacts of management actions. The LTG's are expected to integrate across scales and programs where appropriate. This is especially true of atmospheric deposition for which the airshed scales for estuaries are regional in nature (fitting with LTG 3) and the drivers of emissions reductions are mainly national and regional air quality regulations (fitting with LTG 1) to meet air quality goals associated with National Ambient Air Quality Standards (NAAQS) connected to human health issues for ozone and fine particulate matter.

10.1 Research Summary

Research in this theme is centered on the wet and dry atmospheric deposition outputs of CMAQ and its meteorological driver as the principal route to ecosystem exposure from air pollutants as shown in Figure 10.1. The research may be categorized into three interrelated areas.

Model Development
Air-Water Linkage
Multimedia Applications

As a whole the research will advance the development and application of state-of-the-science tools to determine the exposure to atmospheric pollution causing and contributing to current ecological degradation. The research also advances and develops the application of causal diagnosis tools, methods and models, providing an improved ability to forecast the impacts of various management actions on future atmospheric deposition. The multimedia attention was directed at nitrogen and coastal estuaries (nitrogen is a limiting nutrient) and mercury and fresh water bioaccumulation. Acidic deposition was considered to have been addressed by the 1990 Clean Air Act but is now returning as an issue to be addressed.

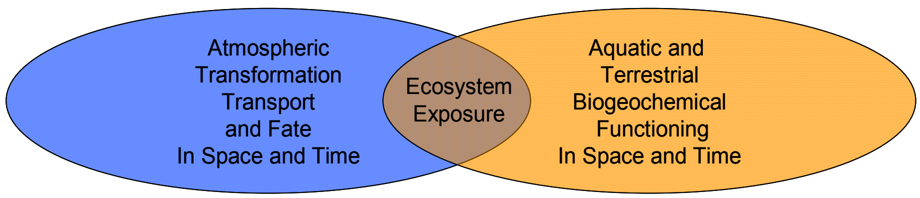

Figure 10.1 Ecosystem Exposure as the Intersection of the Atmosphere and Biosphere

Multimedia Applications

The thrust of the multimedia applications research is to use the model as a laboratory in real world applications to uncover and develop a better understanding of deposition processes that relate to management needs. Managers consistently ask how much is depositing, where is it coming from, and how much it will change in response to management actions. Hence, a model is required to answer these questions. The objective is to use the model to explore air-ecosystem linkage issues, illuminate model functioning and examine areas of model uncertainty to identify critical model development, tool development and application areas that best improve the model in support of management. The lessons inform research planning for linkage research and model development. The research relies on assessments of current deposition, projections of future deposition that incorporate management actions, and model sensitivity analyses. The focus to date has been on nitrogen and mercury. Chesapeake Bay was chosen early to be a laboratory for the air-water linkage of nitrogen because it was one of the first estuary programs to recognize the importance of atmospheric nitrogen deposition to excess nutrient loading in the estuary.

Dry deposition from the Extended Regional Acid Deposition Model (ExtRADM) and now CMAQ has been a priority output for air-water linkage. The communication between air and watershed model has been continually examined with the Chesapeake Bay watershed modeling partners and upgraded as computer power has increased to reduce the temporal scale disparity between the models. The watershed model expects decades worth of input data and the atmospheric model provides one (to a few) year(s) of data (addressed more in Air-Water Linkage below). Approaches to answer source attribution questions have evolved in sophistication from using brute force sensitivities to the DDM-3D sensitivity technique. Forecasts of Clean Air Act (CAA) health-driven reductions were made to contribute to Chesapeake Bay restoration plans and to demonstrate the benefits to water quality management that the CAA reductions represent. The Chesapeake Bay work was intended to be a successful example of air-water linkage that others could emulate or follow. It naturally extended to Total Maximum Daily Load (TMDL) groups concerned about nitrogen as an issue for water quality goals. However, this did not happen (addressed in Air-Water Linkage). Sensitivity studies were performed in the context of the Chesapeake Bay modeling to help set model development directions, in particular the work on sea salt, because the coastal ocean is an important source of nitrogen for Chesapeake Bay and Tampa Bay. In addition, AMAD's work on ammonia bidirectional exchange is significant because it has a major impact on deposition.

For mercury, the major application of CMAQ was for the Clean Air Mercury Rule (since vacated). Source attribution is an important capability desired by the management community that has been addressed by simple sensitivity studies. AMAD researchers pointed out the importance of hemispheric boundary conditions as part of the source attribution context and led a model inter-comparison to demonstrate the issue. A preliminary approach was used to roughly account for the expected influence resulting from the bidirectional exchange of mercury at the earth's surface. A new mercury bidirectional parameterization has been incorporated into CMAQ to replace the preliminary approach. Applications will be made with the new mercury bidirectional parameterization to study its implications on source attribution, which are expected to be large. As science moves forward, CMAQ's chemical reactions along the mercury pathway are continually updated.

Air-Water Linkage

The air-water linkage research addresses the issue of how to best reconcile space-time mismatches and data accuracy requirements for an air deposition model to be able to communicate effectively with an ecosystem model, providing the relevant exposure metrics. The two paradigms are very different. The ecosystem model is calibrated against observational data, using long time series of data. The air deposition model works from basic physical and chemical principles without data assimilation of the critical input or output variables and, therefore, has errors relative to observations. Often, only a limited time period (e.g. a year) is simulated. The objective is to develop and test recommended approaches, to improve them, and to develop an understanding of how the air deposition errors impact the ecosystem model predictions, partnering with NERL's Ecosystem Research Division (ERD) and the Chesapeake Bay Program, to minimize the potential distortion of the predictions of the ecosystem models for management analyses. The focus during this period has been on the linkage to watershed models for nitrogen and mercury biogeochemical cycling. Early on, the emphasis was on provision of dry deposition from the atmospheric model to complete the mass budget, because the watershed modelers used observed wet deposition and precipitation for consistent hydrology and chemistry. During this period the linkage approach shifted from a statistical aggregation of synoptic patterns of deposition (creating a climatological average) to a continuous simulation of deposition for a single year (reported monthly) or a contiguous, multiyear period. The shift, due to increased computing power, created a more definable, interpretable and testable approach to linkage and moved the research to a new plateau.

Much of the testing and advancement of air-water linkage has been performed with the Chesapeake Bay Program, resulting in a long-term collaboration. More recently, testing has expanded to involve NERL/ERD for more in-depth testing of issues and hypotheses, including precipitation error issues affecting hydrology, using watersheds in North Carolina. The successful linkage work with Chesapeake Bay did not translate to groups working on watershed issues. Through surveys and questioning, AMAD found that surface water chemistry modelers needed help to incorporate atmospheric deposition into their watershed and TMDL analyses. AMAD subsequently designed and commissioned development of the Watershed Deposition Tool (WDT) to map CMAQ gridded deposition to the irregular polygons describing watersheds and sub-watersheds used by surface water chemistry modelers. The response to the WDT has been exceedingly positive and it has opened the door to water quality researchers incorporating atmospheric deposition (exposure) into their management analyses. More recent questioning of surface water chemistry and terrestrial modelers has highlighted the importance of being able to link deposition by land-use category to the ecological models, initiating design changes in CMAQ to accommodate this need.

Model Development

The model development research targets and incorporates advances in CMAQ related to atmospheric deposition in close coordination with the model development team. The objectives are to improve deposition process descriptions to reduce uncertainty in deposition calculations by either upgrading process descriptions, including missing pathways, or making a more compatible link with water quality and terrestrial models. During this period the focus of the development work has been on dry deposition, because dry deposition is a key output from CMAQ that is used in all ecosystem exposure applications and is a key link to the ecosystem models. Two areas of major development are the inclusion of sea salt effects on dry deposition and the incorporation of bidirectional fluxes of ammonia and mercury. Regarding sea salt, a special research version of CMAQ, CMAQ-UCD, was commissioned with researchers at the University of California at Davis and tested against special field study data for Tampa Bay, Florida (Bay Region Atmospheric Chemistry Experiment, BRACE). AMAD was involved in the design of the BRACE study. Using the field study data and science model version experience, an operational version of CMAQ with sea salt was then completed and tested. Regarding bidirectional exchange, field research has shown that the flux of ammonia is bidirectional. Ammonia dry deposition is very important and a unidirectional approach introduces error into the CMAQ deposition fields. However, no data existed to parameterize ammonia bidirectional flux for North American conditions and land cover types. AMAD collaborated with EPA colleagues in NRMRL and NOAA Air Resources Laboratory to design and conduct field studies in North Carolina to address the information needs of ammonia bidirectional flux formulations. The CMAQ structure was modified to allow the interaction between air concentrations and surface fluxes and a new surface flux module was developed with the help of the new data. A similar approach is being taken for mercury bidirectional flux and a preliminary bidirectional mercury module has been developed. A hallmark of this model development research is the inclusion of modelers in the field study design and the use of common stand-alone models for data interpretation and atmospheric model parameterizations.

10.2 Future Research

The context for the AMAD research to link air quality and ecosystem health has recently shifted. In response to the National Academy of Sciences, the Agency has undertaken a joint review of the existing secondary (welfare-based) National Ambient Air Quality Standard (NAAQS) for nitrogen oxides (NO_X) and sulfur oxides (SO_X). The review is focused on ecological effects, principally from atmospheric deposition, associated with acidification (S and N) and nitrogen nutrient enrichment (N). The Office of Air Programs (OAP) is exploring the use of critical loads (associated with deposition) as a management tool. Critical loads modeling is focusing in the eastern U.S. on acidification and in the western U.S. on nitrogen nutrient enrichment. In parallel, the Ecological Research Program has shifted over the past year and a half to a total focus on ecosystem services and renamed itself the Ecosystem Services Research Program (ESRP). The ESRP MYP of 2008 describes proposed research on ecosystem services and their relationship to human health and well-being, and our ability to place a value on services in monetary or non-monetary terms. The ESRP MYP has five program-specific LTG's: LTG-1 Effective Decision Support; LTG-2 National Inventory, Mapping, and Monitoring; LTG-3 Nitrogen Assessment; LTG-4 Ecosystem Assessments; LTG-5 Place Based Demonstration Projects (including the impacts of biofuels). The overarching ESRP research questions are: (1) what are the effects of multiple stressors on ecosystem services, at multiple scales, over time; and (2) what is the impact of changes in these services on human well-being and on the services' monetary and non-monetary values.

The direction of the AMAD research that has been established to date continues to align well in spite of the shifts in MYP's, and application context. This is in part due to the continued strong focus on nitrogen and on linkage to ecosystem models. The main effect is to broaden the scope of the research and CMAQ applications and expand and shift the client base. CMAQ and its deposition outputs are being used heavily in the NAAQS review. AMAD scientists are collaborating closely with OAP as part of the Agency's critical loads effort. AMAD research and CMAQ applications are in the ESRP's implementation plans, contributing to LTG-2, -3, and -5.

Multimedia Applications
Future research will be aimed at studying the influence of the new model developments centered on bidirectional flux of ammonia and mercury, and the additional detail in the land use-specific dry deposition velocity estimates (mosaic approach). Guidance and national maps of deposition will be updated to reflect the new science. This work will contribute to the ESRP program and its assessments addressing ecosystem issues such as biofuels. Additional guidance studies will address the expanded capability for source attribution (upgrades to the DDM-3D sensitivity approach) related to sulfur and ammonia. Research priorities will shift to support critical loads analyses and away from National Estuary Program needs, although their needs significantly overlap. Because of the critical loads and NO_X-SO_X NAAQS interests, future research in multimedia applications will see the return and inclusion of acidification as an issue (an expansion), but there will continue to be attention on nitrogen deposition (and ammonia, which is acidifying) because nitrogen is expected to become relatively more important than sulfur in the future in the East and nitrogen is the main issue in the West. Future research will investigate combining monitoring and model data into a single deposition field, or use of data-driven adjustments to modeled fields to better support critical loads analyses. More emphasis will be given to simulating multiple years of historical deposition, starting with 2001, because emissions are now changing. Both the Gulf of Mexico hypoxia modelers and critical load modelers within EPA are interested in using CMAQ predictions across multiple years. CMAQ routine 12km-resolution simulations will be extended to include the continental U.S., not just the eastern U.S. Model intercomparisons will be held with Canada to identify the similarities and differences in the deposition predictions of CMAQ and the Canadian model, A Unified Regional Air-quality Modeling System (AURAMS), which are used in critical load analyses.

Air-Ecosystem Model Linkage
Air-ecosystem linkage research will continue on its currently prescribed course with expansion of purview, however. Future air-ecosystem linkage research will be expanded to include consideration of meteorological inputs to ecosystem models, e.g. precipitation (for hydrology), not just chemical inputs. There will be increased attention given to precipitation error in the linkage, in response to its increase in importance with critical loads and climate change studies. This work will expand to include both the eastern and the western U.S. The linkage research

will study the mass consistency across linked air, watershed and estuarine models and it will be expanded to address air-water and air-terrestrial linkages, to improve the support of critical loads and climate change studies. The temporal scale of the modeling will also be expanded to include multiple, continuous years to examine issues related to the interannual variability of wet deposition and precipitation. The research will implement the proposed plan to examine the importance of land use specific dry deposition (mosaic approach) on chemical budgets. As part of this component, terrestrial vegetation species land-use distributions will be updated and merged with the National Land Cover Database (NLCD 2001). The impact of changes in land use will be explored (e.g. biofuels, long-term growth). A fertilizer application database to support nitrogen bidirectional process modeling will be developed. As the linkage sophistication is increased, the WDT capabilities will be updated to reflect new information availability and transfer capabilities will be augmented.

Model Development
Future model development research will continue to refine and update the parameterizations for bidirectional exchange (NH_3 and Hg). Attention will be given to refining the NH_3 modules with new field study data and evaluate CMAQ predictions against new ammonia and other inorganic data. In coordination with this work, development will be completed of a fertilizer model based on simplified soil biochemistry to derive soil concentrations of NH_4^+ and H^+ for use in the ammonia surface flux model. The land-use specific dry deposition adaptation in CMAQ and the conversion to the NLCD land use data set will be completed. Through collaboration with ecosystem modelers land cover categories will be consolidated where it makes sense. Research will continue on understanding and addressing CMAQ deposition biases, especially those in wet deposition (e.g., the omission of lightning NO_X and dissolved organic nitrogen, DON). AMAD will leverage mercury field campaigns to refine and evaluate the bidirectional mercury model. The AMAD multimedia team will collaborate with the model development team on a hemispheric scale CMAQ with grid nesting for mercury.

10.3 Impact

The research has established CMAQ and the WDT as tools that can be used for assessments and management studies within and outside EPA. CMAQ is being used routinely within EPA (see bullets below). This research, through attention to the science, is increasing the credibility of the deposition budgets from CMAQ for use in management and ecosystem applications. The model applications and tools demonstrate the need for and ability of atmospheric models to address information needs and inform federal and state policymakers on the relative importance of different sources for deposition to specific ecosystems, helping to guide management strategies. The research to make CMAQ more “ecosystem friendly” is making it easier to communicate with ecosystem modelers, to be part of a multidisciplinary team, and easier for CMAQ to be a “model of choice” or a “data source of choice” for ecosystem modeling involving atmospheric deposition. The collaborative research with other Divisions and Laboratories has opened the door to effective inter-laboratory collaboration to produce targeted field studies and to better use EPA resources. The atmospheric model has provided the research community a perspective and a framework to assess knowledge gaps and guide further research. The updates to the CMAQ process science, especially the bidirectional exchange of ammonia and mercury will change the results, changing the source attribution estimates (extending the range of influence), and make the budgets of CMAQ more credible for ecosystem assessments.

- CMAQ deposition results have been incorporated into and are now a vital part of the Chesapeake Bay Restoration strategy.
- CMAQ-UCD is being used for the Tampa Bay TMDL by the Tampa Bay Estuary Program (TBEP).
- CMAQ with mercury was used for the Clean Air Mercury Rule.
- The air-water linkage research opened the door for water quality modelers to include air deposition in their assessments and make their management plans more efficient.
- CMAQ and the WDT are being used for TMDL analyses by States. The WDT was used to bring CMAQ results into EPA/ORD's Regional Vulnerability Assessment (ReVA) Toolkit and is being used by EPA/OAQPS for its analyses.
- CMAQ and its deposition outputs are being used heavily by OAQPS for their NAAQS review. The model is the best means for analyzing the connection between air concentrations and atmospheric deposition. The model application and air-water linkage work, in particular, paved the way for this use.
- AMAD scientists are collaborating closely with OAP as part of the Agency's critical loads effort. CMAQ deposition fields are a critical component of that effort. The air-ecosystem linkage efforts facilitate and enhance the collaboration and will make CMAQ even more useful in the future.
- The use of CMAQ, and its deposition fields, is being incorporated into the ESRP planning process.

10.4 Session Posters

The following four (4) posters will be presented in this session:

(1) Improving Atmospheric Deposition Processes in CMAQ for Ecosystem Applications (5.1)
(2) Linking CMAQ to Watershed/Estuarine Models (5.2)
(3) Providing Guidance and Advice to the Ecosystem Management Community Using CMAQ as a Laboratory (5.3)
(4) Using CMAQ in Managing Mercury Deposition to Sensitive Ecosystems (5.4)

Abstracts for each of these posters follow.

Improving Atmospheric Deposition Processes in CMAQ for Ecosystem Applications (5.1)

Jesse Bash, Prakash Bhave, Jonathan Pleim, Robin Dennis, Christopher Nolte, Ellen Cooter

Collaborators: Jeff Arnold (EPA/NCEA)*; James Kelly (California Air Resources Board)*; John T. Walker (EPA/NRMRL); Matthew Jones (DOE/ Oak Ridge Institute for Science and Education); Uma Shankar (UNC at Chapel Hill); Anthony Wexler (UC Davis); K. Max Zhang (Cornell Univ.); Winston Luke, Tilden Meyers, and LaToya Myles (NOAA/ARL); Robert Mason (Univ. of Connecticut)

Excessive loading of nitrogen from atmospheric nitrate and ammonia deposition to ecosystems can lead to soil acidification, nutrient imbalances, and eutrophication. Accurate nitrogen deposition estimates are important for biogeochemical cycling calculations performed by ecosystem models to simulate ecosystem degradation and recovery. Due to the lack of available monitoring data, creating these estimates is a high priority for water and soil chemistry modeling of nutrient loading, soil acidification, and eutrophication.

In collaboration with the atmospheric measurement community, we have conducted work to advance nitrogen air-surface exchange (dry deposition and evasion from soil and vegetation surfaces) modeling of ammonia and the treatment of coarse-mode nitrate chemistry in the Community Multiscale Air Quality (CMAQ) model. This process has included the following steps: (1) Develop testable hypotheses from the literature, in the form of new modules or routines for CMAQ. (2) Assist in the design of the field campaign needed to collect measurements of the parameters required to further develop these algorithms and to conduct robust evaluations of them. (3) Use the resulting field measurements to refine and evaluate the model algorithms for the development of an operational model.

Atmospheric loadings of mercury to sensitive ecosystems can lead to methylation and bioaccumulation, adversely affecting wildlife and becoming a vector for human exposure to methylmercury. The transport of mercury in the environment exhibits bidirectional surface exchange, similar to ammonia, and a bidirectional surface exchange model of mercury has been developed and is being used to assist in the design of field experiments to improve modeled air-surface exchange algorithms following the methodology of the refinements made to the bidirectional ammonia exchange algorithms.

Field experiments were planned and executed in collaboration with modeling and instrumentation communities. The resulting data are being used in various ways: (1) They have been applied to evaluate the dynamic gas-to-particle mass transfer treatment in CMAQ (Tampa BRACE field campaign); (2) they are being applied to develop and test the CMAQ bidirectional NH_3 surface exchange algorithms (NH_3 flux intercomparison studies at Lillington and Duke Forest, NC, in collaboration with EPA/NRMRL); and (3) they will be applied to develop bidirectional mercury exchange algorithms (collaboration with the University of Connecticut's Department of Marine Sciences). Collaborative work between EPA/AMAD scientists and measurement communities has resulted in the collection of variables needed for robust model evaluation, the development of improved mechanistic air-surface exchange model algorithms, and a productive transfer of knowledge between the two communities. The advanced model algorithms that resulted have improved CMAQ and maintained its functionality at the state-of-the-science for ecosystem applications.

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Linking CMAQ to Watershed/Estuarine Models (5.2)

Donna Schwede, Ellen Cooter, Robin Dennis and Jonathan Pleim

Collaborators: Randy Bruins (NERL/EERD); Betsy Smith, Vasu Kilaru, and John Iiames (NERL/ESD); Mary Ann Bitz (Argonne National Laboratory); Limei Ran (UNC at Chapel Hill); Melanie Wilson (Computer Sciences Corporation); Paul Stacey (CT Department of Environmental Protection); Miao-Li Chang (MD Department of the Environment)

The key environmental issue addressed by this research is the improved estimation of ecosystem exposure to air pollutants. Atmospheric wet and dry deposition can be important nonpoint-source contributors to total pollutant loadings to water bodies, through both direct deposition to water bodies and deposition to watersheds with subsequent transport into water bodies, leading to harmful effects on ecosystems. Acidification of lakes and streams, caused primarily by atmospheric deposition of sulfur and reactive nitrogen, drives a number of adverse effects in aquatic and terrestrial ecosystems; these include reductions in species diversity, increased vulnerability of forest species to pests and diseases, and shifts in species composition. Atmospheric deposition of reactive nitrogen can be an important source of unintended fertilization, leading to eutrophication in coastal ecosystems. For exposure to occur, the stressor and the receptor must come together at the same time and in the same place, followed by uptake. Other ORD Laboratories perform research to quantify the uptake process. AMAD research is improving estimates of stressor exposure through improved characterization of wet and dry nitrogen deposition on ecosystem-relevant temporal and spatial scales, through incorporation of more detailed vegetation-class location and extent information into the CMAQ model, and through the development of land-cover-specific deposition estimates.

Examples of products and tools developed through this research are presented. The first example is the Watershed Deposition Tool (WDT), which allocates CMAQ gridded deposition results to HUCs (hydrological units) or other user-defined polygons; these can then be used for Total Maximum Daily Load (TMDL) and other nonpoint-source watershed analyses. Next, an example from a new National Land Cover Database (NLCD 2001) illustrates our improved ability to identify the location and extent of aggregate vegetation classes. Adoption of these new data increases CMAQ model consistency with watershed model inputs, and improves our ability to address issues of interest to the ecosystem services research community. Ecosystem services include products such as clean air, clean water, productive soils and generation of food and fiber for which there is a human demand and to which an economic value can be assigned. Finally, we present an example of vegetation-specific deposition results generated through application of a mosaic modeling approach.

AMAD is advancing the modeling science as well as building the tools and databases needed to facilitate the linkage of CMAQ to watershed and estuarine models, although further work is needed to implement, test, and evaluate these advances. Ongoing interaction with clients and cross-laboratory collaboration ensure that research outputs will support management decisions leading to more positive ecosystem health and service outcomes.

Providing Guidance and Advice to the Ecosystem Management Community Using CMAQ as a Laboratory (5.3)

Robin Dennis, Prakash Bhave, Rohit Mathur, and Christopher Nolte

Collaborators: Lewis Linker and Gary Shenk (Chesapeake Bay Program), Christie Gordon (National Park Service), Jack Cosby (Univ. of Virginia), Holly Greening (Tampa Bay Estuary Program), Noreen Poor (Univ. of South Florida)

Atmospheric deposition of sulfur and nitrogen is a key contributor to ecosystem exposure and degradation, causing acidification of lakes and streams and eutrophication of coastal systems. Reductions in atmospheric deposition of sulfur and oxidized nitrogen due to human-health-driven regulations in the 1990 Clean Air Act Amendments (termed the Clean Air Act (CAA)) are expected to significantly benefit efforts to improve water quality. However, water quality managers are not taking advantage of information on anticipated deposition reductions in developing their management plans. Managers need to understand what to expect from atmospheric emissions and deposition. This understanding must come from an air quality model utilized as a laboratory; it cannot come from measurements. The goal is to bring air quality into ecosystem management through regional air quality modeling and to facilitate the air-ecosystem linkage. Through identification of basic management questions, we define what research and tool developments for the air quality modeling system are needed to make the linkage functional and the air-ecosystem modeling applicable and useful.

Our approach is to collaborate with select, motivated air-water partners who are willing to work together to provide a test laboratory with the atmospheric model to explore, assess, and apply improved techniques to advance water quality management goals and test linkage approaches. We develop an understanding of the needs of the water quality managers through real-world experience/participation with model applications. We then design model analyses and sensitivity studies to identify and direct what atmospheric science needs to deliver. Results help provide answers to nearly universal questions uncovered in the course of the application studies: How much is depositing? Who and where is the deposition from? How much will deposition change due to air quality regulations in the face of population and economic growth? Guidance on several fronts has been developed. For example:

- Local solutions are not very effective.
- Long-range transport dominates, so regional approaches are necessary.
- The uncertainty in ammonia emissions/concentrations is very important.
- CAA reductions are expected to be significant.

Air deposition reductions are now a vital component of Chesapeake Bay Program's restoration efforts. Critical air deposition information has also been provided to the Tampa Bay Estuary Program to address its Total Maximum Daily Load (TMDL) needs and assessment goals. Our efforts have opened the door for water quality managers to include air deposition and make their management plans more efficient and effective. The work has paved the way for using CMAQ in national NO_x-SO_x regulatory assessments to protect ecosystems, and for using CMAQ in U.S. critical loads analyses.

Using CMAQ in Managing Mercury Deposition to Sensitive Ecosystems (5.4)

Russell Bullock and Jesse Bash

Collaborators: Matt Landis, Tad Kleindienst, Ed Edney (NERL/HEASD); Thomas Braverman (EPA OAQPS); Dwight Atkinson (EPA Office of Water); Tom Atkeson, Bob Stevens (Florida DEP); Alexey Ryaboshapko, Oleg Travnikov (Meteorological Synthesizing Center – East); Ashu Dastoor, Didier Davignon (Meteorological Service of Canada); Christian Seigneur, Kristen Lohman, Krish Vijayaraghavan (Atmospheric and Environmental Research, Inc.); Noelle Selin (Harvard Univ., currently at MIT); Rokjin Park (Harvard Univ., currently at Seoul National Univ.); Gopal Sistla, Kevin Civerolo, Jia-Yeong Ku (New York State Department of Environmental Conservation); Thomas Myers (ICF International); Robert Mason (Univ. of Connecticut); Steve Brooks, Winston Luke, Tilden Myers (NOAA Air Resources Laboratory)

The Clean Air Act Amendments of 1990 recognized mercury as an important atmospheric pollutant, and directed EPA to study its environmental behavior and promulgate appropriate emission rules to mitigate mercury-related health risks to humans and wildlife. Mercury is a naturally occurring element. However, its concentrations in air, water, soil, and biota have been significantly increased by human activities. Mercury has been extracted from geologic formations and used for many industrial and scientific purposes where some loss to the environment is unavoidable. Mercury is also found in fossil fuels, especially coal. Combustion of these fuels is a major source of mercury to the atmosphere. Atmospheric deposition is the primary source of the mercury found in most sensitive aquatic systems. In the early 1990's, AMAD began to develop atmospheric mercury modeling based on a Lagrangian-type model framework, and the results were reported in EPA's Mercury Study Report to Congress in 1997. Since then, the behavior of atmospheric mercury has been found to be more complex and better suited to Eulerian-type models, like the Community Multiscale Air Quality (CMAQ) model. In 2002, the CMAQ model was first adapted to simulate mercury in three separate species: gaseous elemental mercury (GEM), reactive gaseous mercury (RGM), and particulate mercury. These remain the only species of mercury resolvable by currently deployable atmospheric monitoring technology. However, the treatment of aqueous-phase mercury chemistry in CMAQ does include compound-specific reactions based on the latest laboratory results. As research findings on the chemistry of atmospheric mercury are published, the CMAQ model is being updated to reflect any new or revised information. Updated CMAQ simulations are then used to inform the research community of the scientific uncertainties to which the model is most sensitive, to guide future research endeavors. Once deposited from the atmosphere, mercury can be re-emitted from water, soil, and vegetation. The latest version of the CMAQ mercury model treats this recycling process as a bidirectional mercury exchange. Truly natural emissions of mercury do occur, but re-emission of deposited mercury involves both natural mercury and anthropogenic mercury. In fact, fully two-thirds of all mercury currently being deposited from the atmosphere is believed to be anthropogenic. A two-film resistance model was recently added to the CMAQ mercury model so that truly natural mercury emissions can be treated separately from the recycling process.

The CMAQ mercury model was used in the development of EPA's Clean Air Mercury Rule. It has also been applied in two mercury model intercomparison studies, one in Europe and one in North America. The second study demonstrated the importance of intercontinental transport and the need for accurate air concentration data at the regional model boundaries. This research is intended to provide regulatory authorities with the most accurate modeling tool possible for predicting the effectiveness of proposed domestic regulation of mercury emissions.

10.5 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.

Improving Atmospheric Deposition Processes in CMAQ for Ecosystem Applications (5.1)

Arnold, J.R., W.T. Luke., Nitric Acid and the Origin and Size Segregation of Aerosol Nitrate Aloft During BRACE 2002, *Atmospheric Environment*, 2007, 41:4227-4241. (Arnold was a member of AMAD during this study.)

Bash, J.O., Miller, D.R., A relaxed eddy accumulation system for measuring surface fluxes of mercury, *Journal of Atmospheric and Oceanic Technology*, 2008, 25(2), 244-257

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April 2006 : “Uncertainty Assessment of CMAQ Dry Deposition Predictions” Robin L. Dennis
April 2008: “Relative Responsibility Assessment of Sectors and States: Oxidized Nitrogen Deposition in 2020 (final numbers)” Robin L. Dennis
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From NPS to Robin Dennis (Shenandoah study)
From Chesapeake Bay on CMAQ usefulness to process

Holly Greening to Larry Reiter on usefulness of CMAQ results
Peer Reviewed Chapter in Process of being published as part of NARSTO Multipollutant Assessment; Chapter 8 by Christian Seigneur and Robin L. Dennis on Air Quality Modeling needs to support multipollutant accountability and critical load assessments.

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