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

Robin Dennis, Prakash Bhave, Rohit Mathur and Christopher Nolte

2009 AMAD Peer Review: Session 5
Linking Air Quality and Ecosystem Health

Environmental Issue

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. Excess nitrogen (N) loading from deposition is an issue for National Estuary Programs and Total Maximum Daily Load (TMDL) assessments. Increasing N deposition is an issue for western ecosystems. Increased N deposition will be a biofuels issue. Acidification issues continue as ecological recovery is slower than expected. Tipping points (critical loads) for ecosystems are being explored as a tool for eco-system management, where atmospheric deposition is the key source of exposure. Climate change is expected to change exposure to stressors and delivery of atmospheric deposition. Often, however, ecosystem managers do not include deposition reductions due the human health-related Clean Air Act (CAA) controls in their management plans, lowering their cost-effectiveness. Managers need to under-stand where to look and what to expect from atmospheric emissions and their control. This understanding cannot come from measurements but must come from an air quality model utilized as a numerical laboratory.

Research Objectives

- Bring air quality into ecosystem management by facilitating the air-ecosystem linkage.
- Identify management questions to help define atmospheric research and tool development needed to make air-ecosystem model linkage functional and air modeling useful.
- Use the model as a laboratory to better understand and illuminate the functioning of the air quality and deposition system and develop credibility in the model predictions.
- Apply the atmospheric model at relevant temporal and spatial scales to assess current and future atmospheric deposition.

Modeling Approach

- Work with select, motivated air-water partners to provide a test laboratory with the atmospheric models to explore and assess improved techniques to advance water quality management goals and test linkage approaches.
- Develop an understanding of the needs of the water quality managers through real world experience/participation with model applications and design special analyses and sensitivity studies to address management questions.
- Work with conceptual models, sensitivity studies and special model versions to illuminate and understand the functioning of the system, provide sought-after answers, and identify the most relevant uncertainties/issues.
- Provide regional atmospheric model simulations at relevant spatial and temporal scales to assess current and future atmospheric deposition, associated with CAA regulations, to support water quality modeling analyses.

Results and Discussion

- **Three major management questions recur:**

  Who and where is the deposition from;

  How much is depositing, especially dry deposition, and

  How much will it change in the future, accounting for growth.

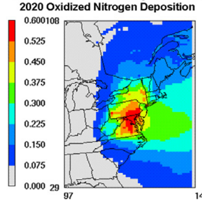
- **Local sources are not dominant for oxidized-nitrogen.**

For Chesapeake Bay, projected 2020 NO_X emissions from the 6 Bay states (taking political boundaries instead of watershed boundaries) explain roughly 50% of the 2020 deposition to the Chesapeake Bay watershed. Water-shed NO_X emissions explain about 35% of watershed deposition.

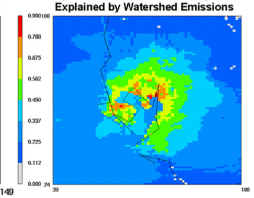
For Tampa Bay, NO_X emissions from within the watershed account for 40 to 50% of the oxidized-nitrogen deposition to the Tampa Bay watershed.

State Contribution	
Delaware	1.2%
Maryland	7.9%
New York	4.6%
Pennsylvania	16.4%
Virginia	14.9%
West Virginia	4.6%
TOTAL	49.6%

Relative Influence of 6 Bay States on 2020 Oxidized Nitrogen Deposition

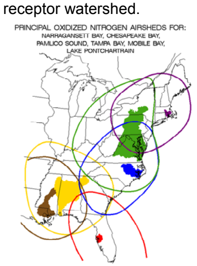


Tampa Fraction of Total Ox-N Deposition Explained by Watershed Emissions



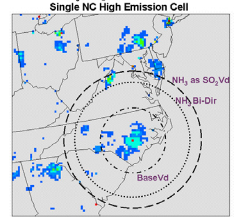
- **Long-range transport is very important**

Airsheds are very large compared to estuaries, watersheds and national parks. For NOx emissions the range of influence is multi-state leading to airsheds that are multi-state in size. This is also true for NH_3 emissions, which is counter to conventional wisdom in the ecological community. The airshed is defined as the domain from which emissions would account for a significant majority of the deposition to the receptor watershed.



Like Colors Match Airshed to Watershed

NH_3 Range of Influence: Single NC High Emission Cell

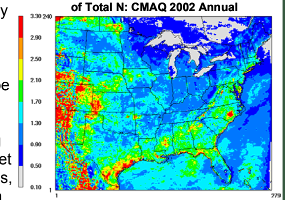


Uncertainty in NH_3 deposition velocity greatly affects area of influence of NH_3 emissions: Current uni-directional CMAQ=BaseVd; Bi-Dir=bidirectional flux; Lower limit equates NH_3 and SO_2 deposition velocity

- **Dry deposition is important to estimate**

Dry deposition typically is greater than wet dep-osition and is not simply correlated to wet. Dry deposition needs to be estimated on its own. However, this cannot be done using monitoring data because many of the species composing the total-nitrogen budget are not measured. Thus, the model, which has a complete budget, is an important source of dry deposition.

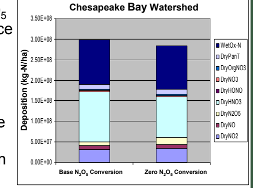
CMAQ Simulated Ratio of Dry Deposition to Wet Deposition of Total N: CMAQ 2002 Annual



- **CMAQ helps identify key uncertainties**

The uncertainty in the hetero-geneous conversion of N_2O_5 to HNO_3 was examined since it impacts HNO_3 concentra-tions and deposition. How-ever, this uncertainty has a minor impact on oxidized nitrogen deposition because the deposition pathways among the oxidized nitrogen species rebalance. While zeroing out this conversion reduces HNO_3 and aNO_3^- deposition by 18% and 26%, total oxidized nitrogen is only reduced by 6%. The model is needed to understand this.

Total Oxidized-N Deposition to Chesapeake Bay Watershed

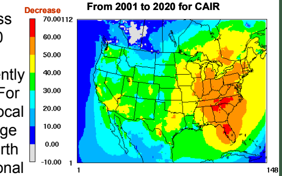


However, the ammonia deposition uncertainty, associated with incorporation of bi-directional exchange (i.e., deposition and/or surface release), is important.

- **Clean Air Act driven reductions are expected to be significant.**

Oxidized-nitrogen depo-sition is expected to be cut roughly in half across the eastern US by 2020 by the Clean Air Inter-state Rule (CAIR), recently vacated by the courts. For Tampa Bay stringent, local controls on two very large power plants is one-fourth as effective as the national CAIR regulations that would have affected all of Florida.

CMAQ Simulation of the Decrease in Total Oxidized-Nitrogen Deposition From 2001 to 2020 for CAIR



- **There are nonlinearities in the system that play off sulfur against nitrogen**

Reductions in SO_2 emissions will reduce sulfate which will cause a release of ammonia that will not be picked up by nitrate, hence increasing ammonia deposition without changing ammonia emissions.

Conclusions

- Solely local solutions are not very efficient/effective. Within-watershed emissions typically account for much less than half of the total deposition.
- Regional or national approaches to reducing atmospheric deposition will be the most effective.
- Uncertainties in NH_3 deposition are important. Reduced-N deposition is expected to dominate oxidized-N by about 2020.
- Dry deposition is very important and the model represents the best means to estimate it.
- Need to provide an interface that requires little knowledge of atmospheric models (e.g., the WDT: see Poster 5.2).
- The mismatch of spatial/temporal scales and the need for calibrated water quality model paradigms makes linking air and water models difficult (see Poster 5.2).
- Management questions require answers from a model.

Future Directions

- Work on nitrogen and precipitation budgets: reduce biases. Work on new science, e.g., NH_3 bi-directional exchange.
- Extend tool capabilities: CMAQ DDM-3D (to other species) and Watershed Deposition Tool (WDT).
- Extend research to air-ecosystem linkages for national critical load mapping (terrestrial and aquatic).
- Investigate the impact of climate change on deposition.
- Extend applications to ORD's Ecosystem Services Research Program to contribute to ecosystem services assessments (e.g., biofuels).
- Investigate combining monitoring and model data into a single deposition field for assessments.

Impact

- Air deposition reductions are now a vital component of Chesapeake Bay Program's restoration efforts.
- Critical air deposition information was provided to Tampa Bay Estuary Program to address its TMDL assessment goal attainment.
- Opened the door for water quality managers to include air deposition and make their management plans more efficient.
- Paved the way to use CMAQ in national NO_X-SO_X regulatory assessments to protect ecosystems.
- Paved the way to use CMAQ for US critical loads analyses.

Contributors/Collaborators

Lewis Linker and Gary Shenk, Chesapeake Bay Program
Christie Gordon, National Park Service
Jack Cosby, University of Virginia
Holly Greening, Tampa Bay Estuary Program
Noreen Poor, University of South Florida