Development of REMSAD emissions tagging scheme in support of MANE-VU contribution assessment

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ABSTRACT

The Mid-Atlantic/Northeast Visibility Union (MANE-VU) Technical Support Committee (TSC) has adopted a weight of evidence approach that relies on several independent methods for attributing visibility impairment to different sources and source regions. These include Eulerian source models, Lagrangian source dispersion models, as well a variety of data analysis techniques including source apportionment models, back trajectory calculations, and the use of monitoring and inventory data. The Regional Modeling System for Aerosols and Deposition (REMSAD) is the one of eight techniques used in a weight of evidence approach. NorthEast States for Coordinated Air Use Management (NESCAUM: a partner agency within MANE-VU) has developed emissions tagging techniques for application in air quality impact analyses using the tagging scheme incorporated into REMSAD version 7.10 and higher. NESCAUM has modeled year 2002 base year RPO emissions inventories processed for a 12km eastern domain. For this work, all sources in a region (State, generally) were tagged to evaluate the impact of each state on sulfur over Class I areas in MANE-VU and adjacent areas. This paper presents NESCAUM's emission source tagging scheme and annual SMOKE/REMSAD results.

INTRODUCTION

Regional haze State Implementation Plans (SIPs) due in April 2008 must include a contribution assessment and pollution apportionment analysis as part of the long-term emissions management strategy for meeting visibility improvement objectives in Class I areas subject to federal haze regulations. In order to adequately determine the degree to which emissions sources located in particular geographic regions or areas are contributing to visibility impairment at Class I areas within the Mid-Atlantic/Northeast Visibility Union (MANE-VU) region, the MANE-VU Technical Support Committee (TSC) has adopted a weight of evidence approach that relies on several independent methods for attributing visibility impairment to different sources and source regions. These include Eulerian source models, Lagrangian source dispersion models, as well a variety of data analysis techniques including source apportionment models, back trajectory calculations, and the use of monitoring and inventory data. The Regional Modeling System for Aerosols and Deposition (REMSAD) is the one of eight techniques used in a weight of evidence approach. NorthEast States for Coordinated Air Use Management (NESCAUM: a partner agency within MANE-VU) has developed emissions tagging techniques for application in air quality impact analyses using the tagging scheme incorporated into REMSAD version 7.10 and higher. In general, these emissions tagging schemes can be used to assess source contributions in various ways including: (1) by source size and susceptibility to transport (e.g. large elevated sources vs. small, low-level sources); (2) by sectors/types (e.g. by SCCs or by point, area, or mobile source categories); (3) by regions (e.g. by country/state/county); or (4) by combinations (e.g. largest electricity generating unit (EGU) in a specific state). We had applied the combination of (2) and (3) for our Mercury modeling work to identify contribution from two northeast regions, rest of US, Canada, and out of domain for EGUs, MWC/MWIs, SSIs, Other Point sources, and non point sources (Graham et al., 2006). For Regional Haze SIP modeling, we tag total (i.e. non-sectoral) emissions from 26 individual states, CENRAP states in the modeling domain, and three domain boundaries. From this emissions tagging scheme and subsequent air quality modeling, we estimate each state's and out-of region's contribution to ambient sulfate concentrations in several Class-I areas. This paper describes the approaches and results from our SIP modeling.

APPROACH

Modeling Platform

Regional Scale Air Quality Modeling is being conducted by NESCAUM with two primary modeling systems based on the Community Multi-scale Air Quality modeling system (CMAQ; Byun and Ching, 1999) and the Regional Modeling System for Aerosols and Deposition (REMSAD; SAI, 2002). CMAQ was developed by USEPA, while REMSAD was developed by ICF Consulting/Systems Applications International (ICF/SAI) with USEPA support. REMSAD has been peer reviewed (Seigneur et al., 1999) and used by EPA for regulatory applications (http://www.epa.gov/clearskies/air_quality_tech.html) to study ambient concentrations and deposition of sulfate and other PM species. REMSAD V7.10 and more recent versions have capabilities that allow model tags of sulfur species (up to 11 tags), nitrogen (up to 2 tags), mercury (up to 24 tags), and cadmium (up to 10 tags) to identify the impact of specific tagged species. For the regional haze modeling study, a whole year of MM5 generated meteorological data for 2002 was provided by University of Maryland (UMD) and used to drive annual CMAQ and REMSAD modeling. Our modeling efforts were focused on a 12-km Eastern U.S. domain (see Domain 2 in Figure 1.) consistent with the Regional Planning Organization (RPO) projection national domain. This domain covers the Northeast region including northeastern, central and southeastern US as well as Southeastern Canada with 12km resolution. It extends from 66°W~94°W in longitude and 29°N~50°N in latitude with 172X172 grid cells, and has 22 vertical layers. For both domains, the same Lambert-Conformal map projection is used in MM5 and CMAQ.

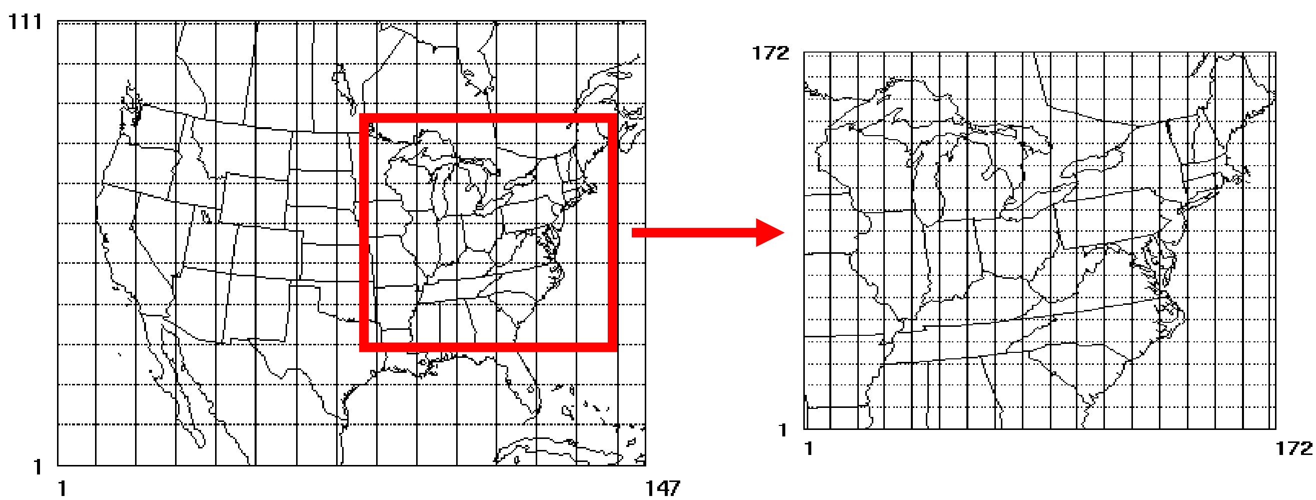


Figure 1. Modeling domains used in NESCAUM air quality modeling studies.
(a) Domain 1: 36km National US domain with location of 12km domain highlighted;
(b) Domain 2: 12km Northeast US domain. The gridline interval shown represents 10 cells.

The initial concentrations and boundary conditions were generated using the same concentration profile provided by an annual CMAQ 36km domain run. The approach is to use similar model inputs to allow comparison of REMSAD with CMAQ to better understand differences between the two models. Due to the simplified chemical mechanism (i.e. Micro CB-IV), REMSAD may not simulate atmospheric chemistry as well as CMAQ. However, advantages such as the tagging feature, faster modeling, and reasonable correspondence with measurements for many species, make REMSAD an important tool for MANE-VU.

Emission Processing and Tagging

Emission scenarios are simulated using the Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System Version 2.1. The emission processing for CMAQ for the 36km national domain and 12km Eastern domain (Domain 2) was performed by New York State Department of Environmental Conservation (NYSDEC) using SMOKE v2.1 compiled on a Red Hat 9.0 Linux operating system with the Portland group Fortran compiler version 5.1. The 2002 static emission inventory, CEM data, and surrogates are based on the 2002 Regional Planning Organization (RPO) data. Biogenic emissions were calculated using BEIS3 with BELD3 data. Mobile source emissions were processed using MOBILE 6. The updated Canadian inventory for 2000 and 1999 Mexican inventory were used for processing. The emission inputs used for emissions tagging for REMSAD processing were primarily the same as the input described above for CMAQ. Some differences, however, exist because of emissions updates and the necessity of simplified emissions processing to compensate for the added complexity introduced by tagging, say, no CEM data used and pre-calculated onroad mobile data use. Since REMSAD is a simpler model than CMAQ but provides plausible longer term (> monthly) output for impact analysis, using a simpler emissions processing approach may be reasonable. Also, we tagged anthropogenic emissions only (i.e. no tag for biogenic, dust, fire emissions).

NESCAUM has taken the additional step of processing source emission files such that the model input is formatted to take advantage of REMSAD's tagging capabilities. This includes; 1) developing and applying in-house emissions tagging software to the above mentioned EI, 2) modifying SMOKE to process this tagged emissions. Thus, each of all combustion and industrial process emissions sources in over 26 eastern states have been tagged according to state of origin, providing an estimate of the contribution those sources in each state make toward simulated sulfate concentrations at Eastern receptor sites. Moreover, boundary conditions were tagged to assess out-of-domain impact. Due to the limitation of number of tags, we had to do three annual runs of SMOKE/REMSAD with different tag groups. The tagging scheme employed for this analysis is shown in Figure 2.

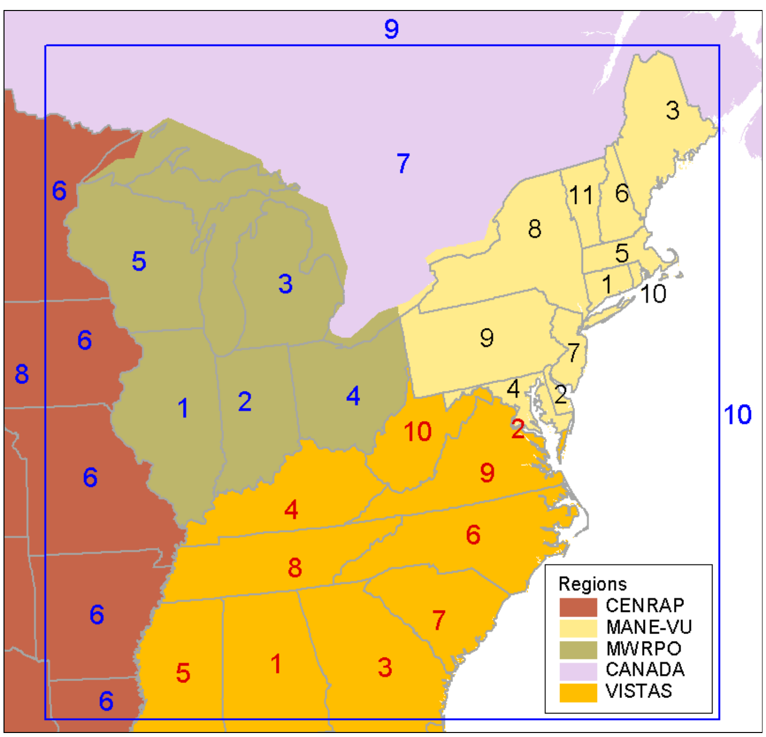


Figure 2. Tagging map for REMSAD modeling. Sulfur species from anthropogenic emission sources are tagged by states with 3 tag groups. Color of numbers represents tag groups (black : group1, red : group2, and blue : group3). Tag group 3 also includes boundary conditions.

RESULTS AND DISCUSSION

Tagged emissions and model performance

Figure 3 and Figure 4 show the gridded SO_2 emissions with tags in our 12km modeling domain and some examples of annual average REMSAD sulfate concentrations by selected Northeast States, respectively. Figure 4 illustrates the spatial distribution of the REMSAD simulated tagged emissions concentration fields. These fields are strongest in their own state and generally have the largest outside state impact toward the northeast.

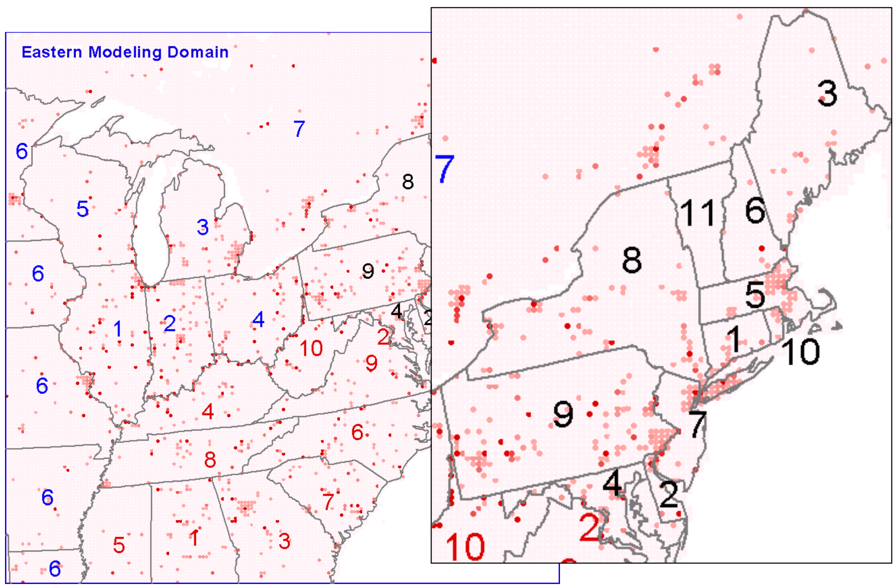


Figure 3. Gridded SO_2 emissions distribution and tag numbers.

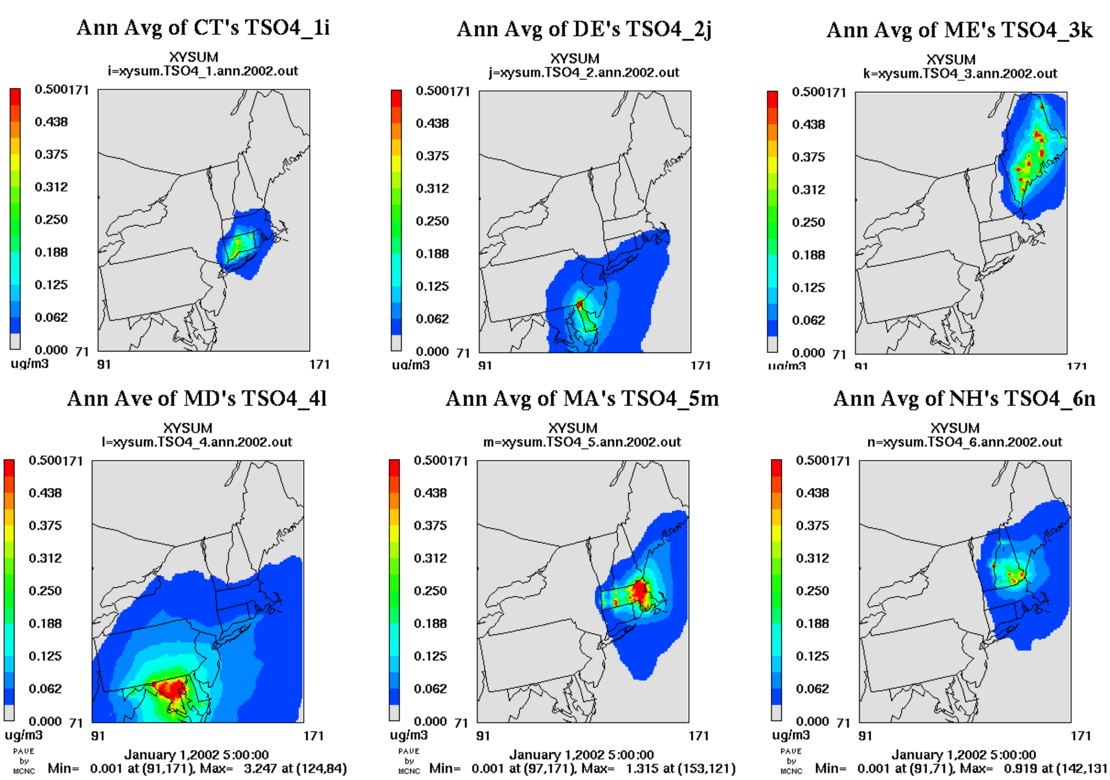


Figure 4. Sample sulfate depositions by states.

A spatial performance evaluation of REMSAD simulations for sulfate on the 12km northeast US domain for the year 2002 was conducted through comparison with IMPROVE/STN measurements, as illustrated in Figure 5. These comparisons are inexact because the discrete measurements represent irregular areas whereas model outputs represent a uniform gridded concentration field. This approach, however, does provide a first order examination of measurement and modeling results, which is appropriate for an annual averaged analysis. In general, REMSAD's simulation field is well matched with measurement data. Figure 6 shows the comparison of paired 24-hourly surface sulfate concentrations between five different air quality model results (including REMSAD) and IMPROVE measurements during the year 2002. For LyeBrook, which is a Class-I area in Vermont, the two CMAQ model runs show the best performance in terms of slope, intercept and coefficient of determination (r^2). The REMSAD result shows the 2nd best performance with the two Calpuff results matching least to measurements. This trend remains similar for Shenandoah. Along with EPA's previous evaluation (Timin B. et al., 2002), REMSAD performs reasonably well for longer term sulfate simulation.

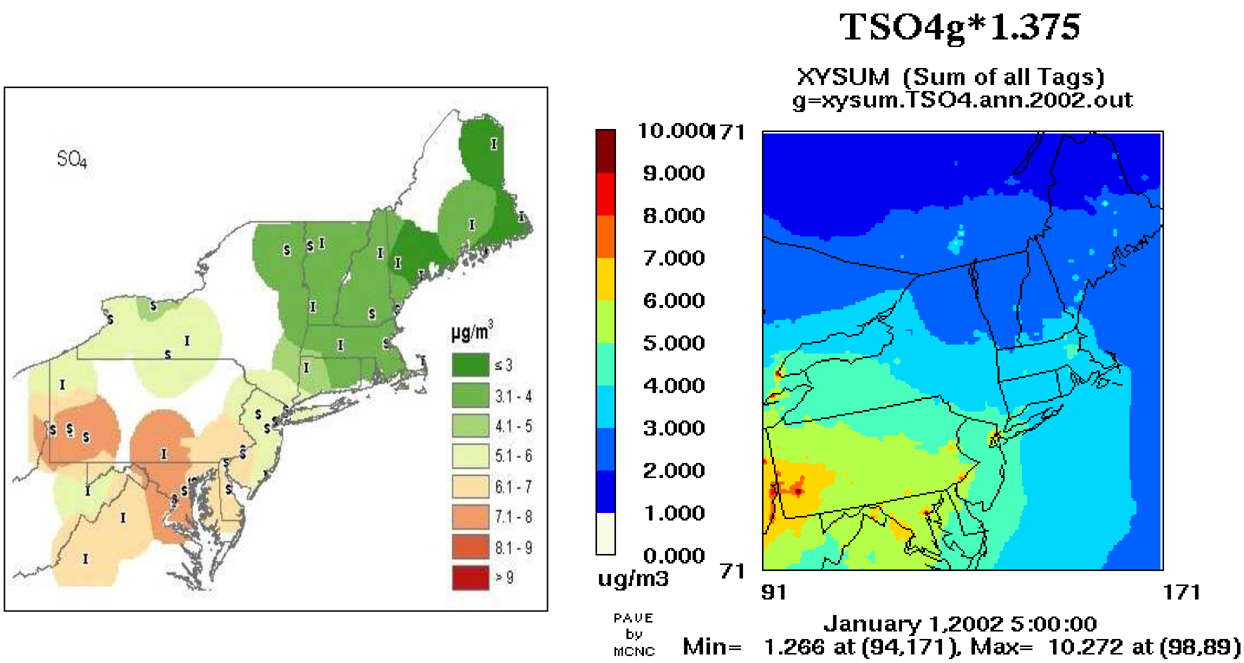


Figure 5. Sulfate concentrations from IMPROVE/STN measurements and REMSAD model.

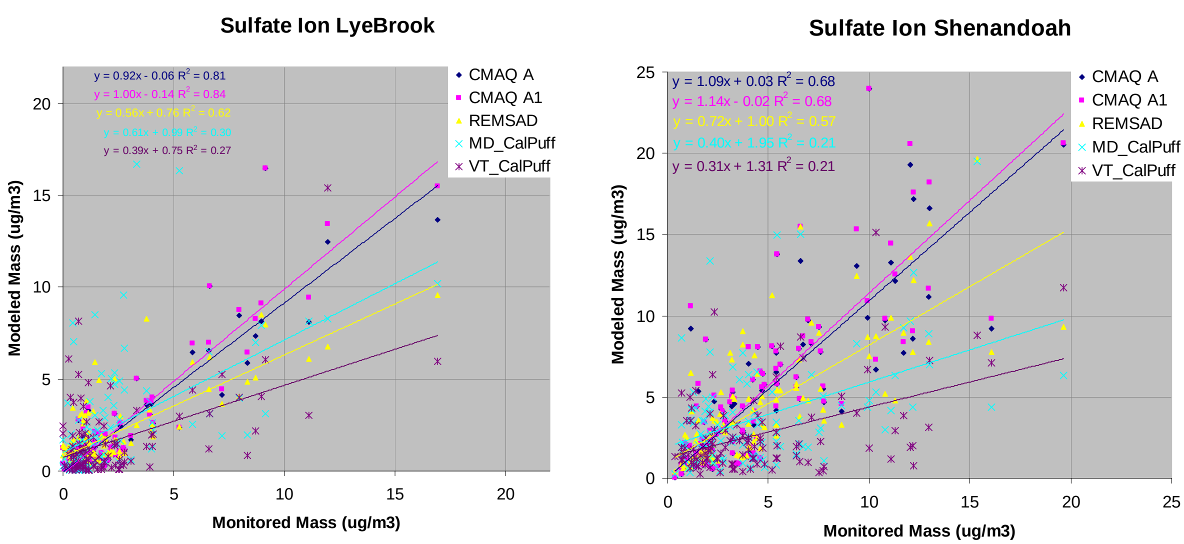


Figure 6. Intercomparison of measurement and model data for 5 different annual model simulations.

Contribution assessment

In addition to the REMSAD tagged sulfur modeling, NESCAUM and its MANE-VU partners performed other analysis techniques to assess states' impact on PM levels over the Northeast US (e.g. CalPuff modeling, Percent Upwind, and Q/D analysis). Figure 7 shows modeling results of state and region/country specific contributions to PM sulfate in the Brigantine, NJ Class I area from five different contribution assessment techniques. In general, the four different techniques show similar contribution of sulfate to Brigantine Class I area. The analysis reveals about 35% of sulfate coming from in-region sources, 40% coming from adjacent RPO regions (i.e. MRPO and VISTAS) and 10% is from CENRAP (in-domain) and Canada. Pennsylvania, New York, New Jersey, and Maryland are the major in-region states that affect Brigantine. The "Other" tag from REMSAD, which explains non-tagged emissions and boundary conditions (about ~16% of total contribution), was normalized then included in other relative contribution analysis techniques because only REMSAD predicted those impacts.

Figure 8 show monthly contributions by four different class I areas in the Northeast region. The contribution of "Other" and MANE-VU region are relatively big in Acadia (in Maine) because it is located at the Northeast boundary of the modeling domain. The concentration amounts are generally strong in the Summer months (i.e. June, July, and August) from all the regions with the relative contribution of MRPO and VISTAS higher than other seasons, likely due to stronger westerly/southwesterly winds in summer. The "Other" and MANE-VU regions' contributions are still relatively big at LyeBrook (in Vermont) but MRPO and VISTAS' contributions are more significant than in Acadia's case because Vermont is closer to those regions. The monthly concentration shows a similar pattern to that from Acadia. For Brigantine (in New Jersey), MANE-VU's contribution remains biggest, followed by VISTAS, "Other", and MRPO. The monthly contribution from "Other" tag decreases after June in contrast to MRPO's. The VISTAS and MRPO's contributions are relatively large at Shenandoah (in Virginia) due to their proximity.

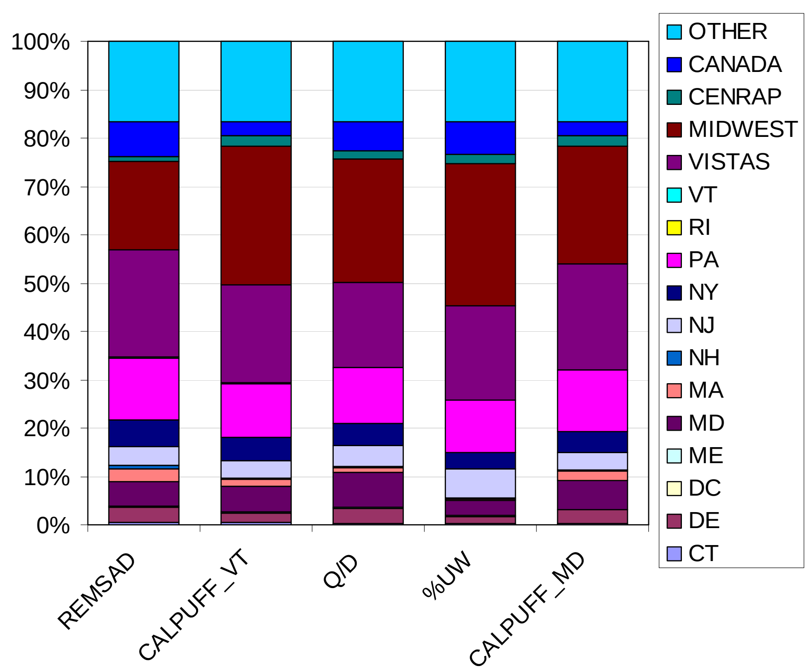
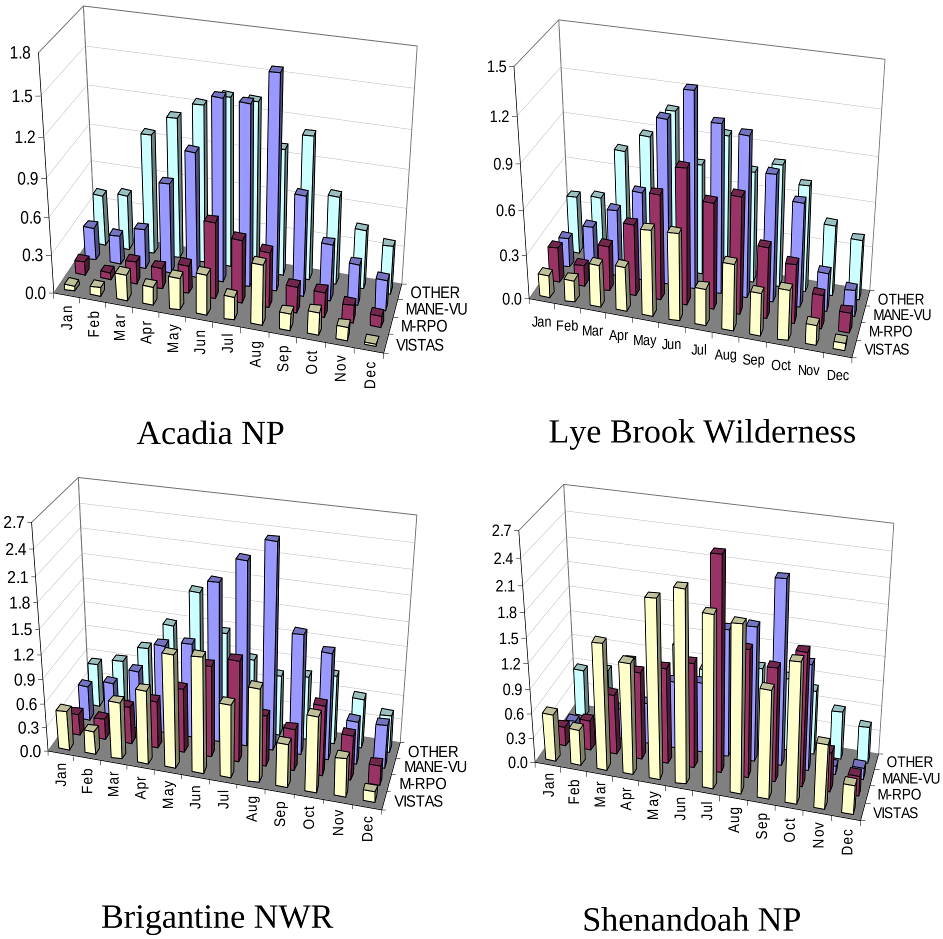


Figure 7. Contribution of tagged sources by different apportionment methods – Brigantine sulfate.



Acadia NP

Lye Brook Wilderness

Brigantine NWR

Shenandoah NP

Figure 8. Contribution of tagged sources for different Class-I areas in Northeast (monthly average sulfate concentration).

ON-GOING AND FUTURE WORK

In collaboration with the University of New Hampshire (UNH), NESCAUM is conducting mercury tagging, emissions processing (SMOKE), and air quality modeling (REMSAD and CMAQ) for the Northeast Center for Atmospheric Science and Policy (NCASP) project funded by NOAA. We plan to use the Community Multi-Scale Air Quality - mercury model (CMAQ-Hg) to conduct a rigorous evaluation of the performance of CMAQ, using data from AIRMAP and this program, for mercury in addition to a suite of EPA standard air pollutants. In addition, a more complete understanding of the relative contributions of local versus more distant speciated Hg emission sources will be calculated using Hg source tagging tools in the REMSAD model to apportion total calculated deposition. The REMSAD-derived apportionment factors can then be applied in a relative sense to the CMAQ-calculated and directly observed values while EPA is developing Hg tagging code within CMAQ itself (anticipated to be available some time next year).

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REMSAD website http://www.remsad.com

KEY WORDS

Emissions Inventory
SMOKE
REMSAD
Tagging
Contribution Assessment
Air Quality Modeling