Long-Term Air Quality Simulations Over the Northeast: Model Performance and Potential Applications for Health Impact Analyses

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Introduction

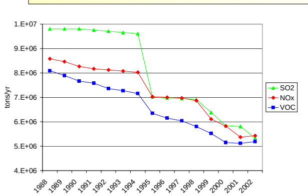
- Objective: Characterize the linkages between climate variability, air quality, and public health over New York State for the time period from 1988 to 2002
- Need: Spatially and temporally dense characterization of meteorology (temperature, humidity) and air quality (O_3, $PM_{2.5}$) over the entire time period for epidemiological time series analysis
- Some of the Challenges:
  - Spatial and temporal sparsity of observations (density of monitoring network, sampling schedule for $PM_{2.5}$ and PM_{10}, lack of $PM_{2.5}$ observations up to about 1999
  - Establishing associations between ambient conditions and health data (morbidity, mortality)
- Add grid-based meteorological and air quality models (MM5 and CMAQ) to provide additional information

Approach and Datasets

- Three alternative exposure datasets for ambient climate and air quality will be compared in health impact analysis:
  - Method 1: Use values from the closest monitor for health impact analysis
  - Method 2: Perform spatial interpolation (kriging) of observations and quantify associated uncertainties
  - Method 3: Integrate monitoring data with MM5/CMAQ simulations for 1988 - 2002
- Observational databases:
  - Hourly meteorological surface observations from NCAR's TDL dataset
  - O_3 concentrations 1988 – 2002 from AQS
  - Weekly average SO_4 measurements at 8 rural CASTNet sites in the modeling domain 1989 – 2002
  - 24-hr average speciated and total $PM_{2.5}$ concentrations every 3rd day at 5 rural IMPROVE monitors 1993 – 2002
  - 24-hr average speciated and total $PM_{2.5}$ concentrations every 3rd day at ~30 rural and urban IMPROVE and STN monitors 2000 – 2002
- Model simulations:
  - MM5: 36 km/12 km modeling with data assimilation
  - Emissions
    - Inventories: NEI Online ("NEON") OAQPS/EMAD: County/SCC-level emissions for 1990 and 1996-2002
    - Processed by SMOKE
  - CMAQ 36 km Eastern U.S. / 12 km NYS and surrounding states: full gas phase and aerosol modules

Emission Summaries 1988 - 2002

Domain-Total Annual Total Emissions of NO_x, VOC, and SO_2



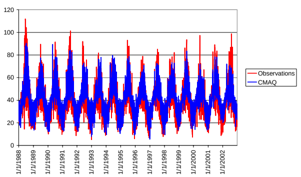
- Substantial reductions in SO2 emissions from power plants starting in 1995
- Continuous reductions of NO_x and VOC emissions, to a large extent driven by mobile source reductions

Annual total anthropogenic emissions over the 12 km modeling domain processed by SMOKE for 1990 and 2000. All emissions are shown in kilotons.

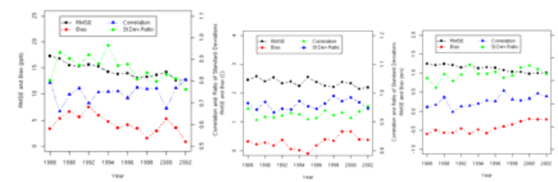
		NO_x	VOC	CO	SO_2	NH_3	$PM_{2.5}$
Area + Nonroad	1990	1,933	3,580	10,379	1,018	502	790
	2000	1,757	3,353	11,627	691	513	661
Mobile	1990	2,895	2,877	31,924	67	42	77
	2000	2,180	1,461	18,190	65	68	41
Point	1990	3,443	1,209	7,743	8,725	15	172
	2000	1,884	334	1,190	5,088	11	328

Model Performance for Meteorological Variables and Ozone

Example: Time Series of Daily Maximum 1-hr O_3 Averaged Over New York State Monitors, 1988 - 2002



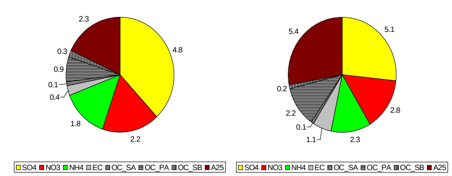
Performance Statistics for O3, Temperature, and Wind Speed Calculated Separately for Each Summer



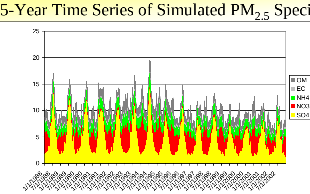
- The modeling system captures seasonal and synoptic fluctuations while underestimating interannual variability
- The range of evaluation metrics is similar to other studies reported in the literature
- Model performance exhibits interannual variability

Model Results and Evaluation for $PM_{2.5}$

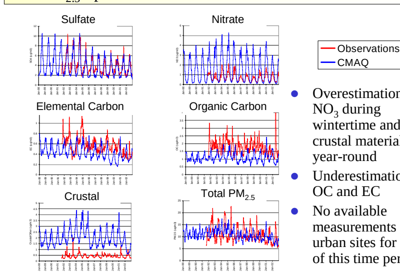
Simulated Rural (left) vs. Urban (right) Contrasts in $PM_{2.5}$ Composition



15-Year Time Series of Simulated $PM_{2.5}$ Species

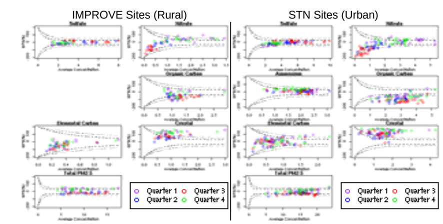


Comparison of Simulated and Observed Seasonal Time Series of $PM_{2.5}$ Species at Five Rural IMPROVE Sites 1993 - 2002



- Overestimation of NO_3 during wintertime and crustal material year-round
- Underestimation of OC and EC
- No available measurements at urban sites for most of this time period

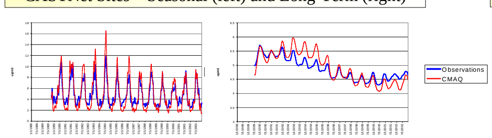
Mean Fractional Bias vs. Average Observed Concentration by $PM_{2.5}$ Species and Quarter, 2000 - 2002



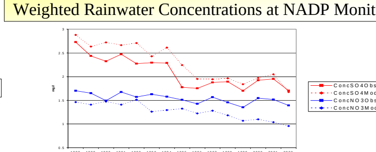
- Overestimation of crustal material more pronounced at urban locations
- Underestimation of organic carbon more pronounced at urban locations

Response to Emission Controls During the Simulation Period

CMAQ and Observed SO_4 Concentrations at 8 Rural CASTNet Sites – Seasonal (left) and Long-Term (right)



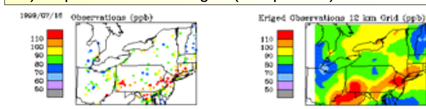
CMAQ and Observed Annual Average Precipitation-Weighted Rainwater Concentrations at NADP Monitors



- Comparison against long-term records of weekly dry-deposition PM2.5 sulfate measurements at six rural CASTNet sites in the modeling domain generally shows good agreement
- CMAQ appears to capture the effect of SO2 emission reductions on sulfate wet deposition; need for further investigation of nitrate wet deposition

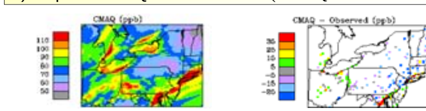
Integrated Use of Observations and Model Simulations for Air Quality Characterization in Support of Health Impact Analyses

1) Maps of Raw and Kriged (Interpolated) Observations



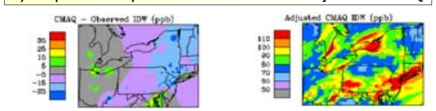
- Spatial interpolation of observations through kriging – often too smooth

2) Maps of CMAQ and Model Bias (CMAQ minus Observed)



- CMAQ gridded fields of O_3 and $PM_{2.5}$ – more spatial structure than interpolated observations, but subject to biases

3) Maps of Interpolated Bias and Bias-Adjusted CMAQ



- For each day, compute the difference between point observations and CMAQ at the location of all monitors and interpolate these location-specific differences to the 12-km CMAQ grid using inverse distance weighting
- Add the interpolated gridded "bias fields" to the gridded CMAQ fields
- Product: daily gridded maps of daily maximum 1-hr and 8-hr ozone for each day during April – October, 1988 – 2002
- The approach for $PM_{2.5}$ is under development and will need to take into account spatially-varying season- and component-specific model errors determined for recent time periods since only very limited observations are available for earlier time periods

Summary and Outlook

- Long-term simulations for ozone and $PM_{2.5}$ over the Northeastern U.S. have been performed with the MM5/SMOKE/CMAQ system
- For $PM_{2.5}$, comparison against the limited measurements available during the simulation time period indicates best model performance for SO_4, general underpredictions of OC, and overpredictions of crustal material
- Comparisons of simulated SO_4 concentrations and wet deposition against limited available measurements indicate that CMAQ captures the effect of the Title IV SO_2 reductions
- Potential use for health analyses:
  - Need for data integration and CMAQ post-processing
  - Need to perform health impact studies to assess the utility of modeling runs vs. simpler interpolation approaches
  - Additional tools are needed to characterize local-scale phenomena and personal exposure

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