Using Linked Global and Regional Models to Simulate U.S. Air Quality in the Year 2050

Chris Nolte
NOAA/ARL/ASMD and EPA/ORD/AMD
Research Triangle Park, North Carolina

EPA Region 9 Workshop
Impacts of Climate Change on Air Quality in the Pacific Southwest
October 11, 2007
Coauthors

Alice Gilliland  NOAA/EPA
Christian Hogrefe  SUNY Albany
Loretta Mickley  Harvard University
Climate Impacts on Regional Air Quality (CIRAQ)

Research Problem:
Air quality is known to be sensitive to meteorological conditions. How might future climate conditions affect air quality (ozone, particulate matter) under current and future emission scenarios?

Why examine this issue?

• Air quality management decisions are presently made assuming current climate conditions (yet controls can be implemented over several decades).
• If future climate differs substantially, there is an additional layer of uncertainty when looking at future controls scenarios.
• Modeling potential influences of future climate on air quality is a first step towards introducing climate as a consideration in air quality management.
CIRAQ Modeling Approach: Regional-scale meteorology and air quality predictions via ‘downscaling’

- Global scale climate and chemistry modeling
  - GISS II’ GCM
  - IPCC A1B scenario
  - Mickley et al. (2004)

- Downscaling via MM5 regional climate model
  - Boundary conditions every 6 h from GCM
  - No assimilation of observations
  - Criteria: consistency with global model
  - “1999-2003” and “2048-2052” i.e., climatological runs, intended to capture interannual variability.
  - Leung and Gustafson (2005)
Chemical Transport Modeling (CTM)

Air Quality modeling with CMAQ v4.5

- 5 year simulations for current and future climate
- SAPRC chemical mechanism, 36km×36km, Cont. U.S. domain
- No feedbacks from aerosols and ozone on meteorology!
- **Current simulation:** 2001 EPA National Emission Inventory
- **Future simulation #1:** 2001 emissions, except isoprene and mobile source emissions vary with meteorology (isolate climate)
- **Future simulation #2:** Anthropogenic emissions of VOCs, NO\(_x\), and SO\(_2\) scaled according to A1B scenario for developed nations

Chemical boundary conditions (BCs)

- Harvard tropospheric ozone chemistry module (coupled to GISS II’ A1B): *Loretta Mickley, Daniel Jacob*
- Aerosol BCs provided by Carnegie Mellon University model (same GISS II’ GCM): *Peter Adams, Pavan Racherla*
- Monthly averaged BCs capture long-term changes, not intercontinental transport of episodic pollution
# Emission Scaling Factors for Future Simulation #2

<table>
<thead>
<tr>
<th>Species</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO\textsubscript{x}</td>
<td>0.52</td>
</tr>
<tr>
<td>SO\textsubscript{2}</td>
<td>0.37</td>
</tr>
<tr>
<td>VOCs</td>
<td>0.79</td>
</tr>
<tr>
<td>CO</td>
<td>1.5</td>
</tr>
<tr>
<td>Primary PM</td>
<td>1 (unchanged)</td>
</tr>
<tr>
<td>NH\textsubscript{3}</td>
<td>1 (unchanged)</td>
</tr>
</tbody>
</table>
Change in mean summer 8-h max O3

Climate change only

Changed climate and emissions
Change in 95th percentile summer 8-h max O3

Climate change only

Changed climate and emissions

RESEARCH & DEVELOPMENT
Building a scientific foundation for sound environmental decisions
Change in mean Sept-Oct 8-h max O3

Climate change only

Changed climate and emissions
Change in summer 8-h max O3
CH4 increased from 1.85 to 2.40 ppm
Conclusions from CIRAQ ozone simulations

- Effect of climate change on ozone concentrations is smaller than the effect of planned emission changes, which are highly uncertain.
- Predictions suggest future climate could cause ozone increases between 2-5 ppb in Eastern U.S. and Texas.
- Need to consider increasing global methane concentrations alongside climate change.
- Interannual variations require multi-year assessment.
- Substantial positive bias in model predicted ozone under current climate, influenced by:
  - Meteorological uncertainties from RCM approach
  - Chemical mechanism uncertainties
Evaluations of CIRAQ PM Predictions for Current Climate

• IMPROVE monitoring network
  ▪ 24-h samples collected every third day

• Subsequent maps show 5-year seasonally averaged model bias (CMAQ – observations) in $\mu$g m$^{-3}$.
Model Bias—PM$_{2.5}$
Model Bias—SO$_4$ and NO$_3$

**SO$_4$**

- Summer
- Winter

**NO$_3$**

- Summer
- Winter

µg m$^{-3}$
Model Bias—OC and soil dust

**OC**

Summer

Winter

**Soil**

Summer

Winter
Current/Future Comparison

- Plots show 5-year seasonally averaged differences between future and current simulations
  - FUT1 – 2001 NEI
  - FUT2 – emissions scaled according to A1B scenario for OECD.

<table>
<thead>
<tr>
<th>Species</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO\textsubscript{x}</td>
<td>0.52</td>
</tr>
<tr>
<td>SO\textsubscript{2}</td>
<td>0.37</td>
</tr>
<tr>
<td>VOCs</td>
<td>0.79</td>
</tr>
<tr>
<td>CO</td>
<td>1.5</td>
</tr>
<tr>
<td>PM</td>
<td>1 (unchanged)</td>
</tr>
<tr>
<td>NH\textsubscript{3}</td>
<td>1 (unchanged)</td>
</tr>
</tbody>
</table>
Changes in biogenic SOA
Summary

• Over prediction of current PM$_{2.5}$ driven by too much dust (unspeciated PM) in the emission inventory.
• Organic carbon is under predicted, especially during the summer.
• SO$_4$ and NO$_3$ predictions are generally better, though biases exist for certain regions and seasons.
• PM concentrations in the eastern U.S. are predicted to decrease by 1-3 $\mu$g m$^{-3}$ if emissions are unchanged, and by 2-8 $\mu$g m$^{-3}$ under the A1B emissions scenario.
Future Work

• Explore meteorological factors driving FUT1 – CURR differences
  ▪ Changes to deposition due to differing precipitation and wind speeds
  ▪ Changes in chemical boundary conditions from global model
  ▪ Ventilation: changes in wind speeds and/or PBL heights
  ▪ Increased cloudiness causing enhanced SO2 oxidation?

• Assess extent of interannual variability in PM predictions
Future Work

NOAA FY10 Gap Analysis for Climate and AQ

NOAA GFDL-ARL
Global to Regional Modeling Strategy

- GFDL’s AM3 global climate & chemistry model
- ARL’s integrated WRF-CMAQ
- Linking the above global and regional models
  - Provides capability to downscale variety of climate scenarios for air quality sensitivity
  - Provides consistent treatment of future scenarios for chemistry and climate from global model
  - Radiative feedbacks from emission scenarios and future air quality
  - Offers tools to study interactions between climate and air quality more comprehensively
Developing Integrated Model for Climate - Air Quality Interactions

- Global Climate Model
  - Climate downscaling
  - Regional Meteorological Model
  - Radiative Feedback of Aerosols
  - Natural and Anthropogenic Emissions
  - Regional Air Quality Model
    - Gas phase and aerosol species
    - Transport and Diffusion
    - Chemical Transformation
    - Deposition (wet and dry)
    - Cloud processes
Acknowledgments

Pacific Northwest National Laboratory
   Ruby Leung

Carnegie Mellon University
   Pavan Racherla, Peter Adams

NOAA/EPA
   Ellen Cooter, Rob Gilliam, Bill Benjey

Harvard University
   Daniel Jacob

Computer Sciences Corporation
   Ruen Tang, Allan Beidler

Email: nolte.chris@epa.gov

Disclaimer: A portion of the research presented here was performed under the Memorandum of Understanding between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and under agreement number DW13921548. This work constitutes a contribution to the NOAA Air Quality Program. Although it has been reviewed by EPA and NOAA and approved for publication, it does not necessarily reflect their policies or views.
How significant is the change in 5-yr averages relative to year-to-year variability?