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

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Impacts of Climate Change on Air Quality in the Pacific Southwest
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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\textsubscript{x}, and SO\textsubscript{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>
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<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>
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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
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 μg m$^{-3}$.
Model Bias—PM$_{2.5}$

Summer (JJA)  
Winter (DJF)
**Model Bias—SO$_4$ and NO$_3$**

**SO$_4$**
- Summer
- Winter

**NO$_3$**
- Summer
- Winter
Model Bias—OC and soil dust

OC

Summer

Winter

soil

Summer

Winter

μg m⁻³

μg m⁻³
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.

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Changes in PM2.5
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

Regional Meteorological Model

Climate downscaling

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
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How significant is the change in 5-yr averages relative to year-to-year variability?