Source Impact Forecasting

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Georgia Institute of Technology
Motivation

• Air quality forecasting is an integral part of air quality management, especially for dynamic management.
  – Source specific information, valuable for dynamic management, are missing from operational air quality forecasting practice.

• Improving forecasting accuracy will involve:
  – More accurate emissions
    • Emission inventories are typically at least 4 years behind and “growth factors” are outdated
  – Wildland fire are becoming increasingly important contributors to PM and ozone.
Objective

• To provide information that can better assist dynamic air quality management

  – Forecast source impacts, in addition to air quality, to provide extra information that may be valuable for dynamic air quality management

  – Improve air quality and source impact forecasting accuracy using near real time measurements through dynamic adjustments of emissions inventories
Current Hi-Res Forecasting System

Hi-Res Modeling Domains

- Based on SMOKE, WRF and CMAQ models
- Forecasting ozone and PM$_{2.5}$ since 2006
- 48-hour forecast at 4-km resolution for Georgia and 12-km for most of Eastern US
- Used by GA EPD assisting their AQI forecasts for Atlanta, Columbus and Macon
- Potentially useful for other states
Hi-Res performance during 2006-2013 ozone seasons for Metro Atlanta

Ozone

PM$_{2.5}$

<table>
<thead>
<tr>
<th></th>
<th>2006-2008</th>
<th>2009-2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>MNB</td>
<td>20%</td>
<td>-10%</td>
</tr>
<tr>
<td>MNE</td>
<td>25%</td>
<td>32%</td>
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</tbody>
</table>

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Newly Built Hi-Res2 Forecasting System

Forecasting Air Quality for CONUS
(https://forecast.ce.gatech.edu open since November 28th)

- Updated base emissions to 2011NEI
- WRF3.6.1 and CMAQv5.02 used
- 72-hour forecasts at 4-km resolution for Georgia and surrounding states, 12-km for most of Eastern states and 36-km for the rest of CONUS

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Forecasting Source Impacts at 4-km for Georgia (https://forecast.ce.gatech.edu open since November 28th)
Brute Force vs. DDM-3D and HDDM-3D

\[ S^{(1)} = \frac{\partial C}{\partial \varepsilon} \]

\[ S^{(2)} = \frac{\partial^2 C}{\partial \varepsilon^2} \]

\[ S^{(1)} \approx \frac{C_B - C_A}{\Delta \varepsilon} \]
Uncertainties in emissions degrade both air quality and source impacts forecasting
Currently working with PM$_{2.5}$ measurements at ~20 sites in Georgia

An emissions and air quality auto-correction system utilizing near real-time satellite and surface observations

- Minimizes the differences between forecasted and observed concentrations
- Minimal adjustment to source emissions
- Uses impacts of emission sources calculated by CMAQ-DDM-3D
  - Source impacts can be used for dynamic air quality management (e.g., traffic and fires)
Inverse Model Formulation

• Solve for \( R_j \) that minimizes \( \chi^2 \)

\[
\chi^2 = \sum_{i=1}^{N} \left[ \frac{\left( c_i^{\text{obs}} - c_i^{\text{sim}} - \sum_{j=1}^{J} S_{i,j} (R_j - 1) \right)^2}{\sigma_{c_i^{\text{obs}}}^2} \right] + \Gamma \sum_{j=1}^{J} \frac{(\ln(R_j))^2}{\sigma_{\ln R_j}^2}
\]

- \( \chi_{Ci}^2 \): Remaining Error
- \( \chi_{Rj}^2 \): Amount of Change in Source Strengths

DDM-3D calculated sensitivity of concentration \( i \) to source \( j \) emissions

emission adjustment ratio

weight

L-BFGS algorithm is used for the optimization (R package nloptr)
Example of selecting appropriate $\Gamma$

L-curve plot
Offline Test 1: week1 Dec.1-7, 2013 & week2 Dec. 08-14, 2013

<table>
<thead>
<tr>
<th>Dec. 1-7, 2013</th>
<th>Area</th>
<th>On-road</th>
<th>Non-road</th>
<th>Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjustment</td>
<td>0.17</td>
<td>0.83</td>
<td>0.85</td>
<td>0.97</td>
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</table>

**without emissions adjustments**

Dec. 11, 2013 PM$_{2.5}$ Concentration

**with emissions adjustments**

Dec. 11, 2013 PM$_{2.5}$ Concentration

<table>
<thead>
<tr>
<th>Dec. 8-14, 2013</th>
<th>Obs (ug/m$^3$)</th>
<th>Sim (ug/m$^3$)</th>
<th>NFE</th>
<th>NFB</th>
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</thead>
<tbody>
<tr>
<td>Original</td>
<td>4.64</td>
<td>10.04</td>
<td>86%</td>
<td>85%</td>
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<tr>
<td>Emis adjusted</td>
<td>&quot;</td>
<td>5.62</td>
<td>54%</td>
<td>39%</td>
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### Jul. 6-12, 2011

<table>
<thead>
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<th>Area</th>
<th>On-road</th>
<th>Non-road</th>
<th>Point</th>
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</thead>
<tbody>
<tr>
<td>Adjustment</td>
<td>3.34</td>
<td>1.09</td>
<td>1.46</td>
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</table>

**without emissions adjustments**

**Jul. 15, 2011 PM$_{2.5}$ Concentration**

**with emissions adjustments**

**Jul. 15, 2011 PM$_{2.5}$ Concentration**

### Jul. 13-19, 2011

<table>
<thead>
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<th>Obs (ug/m$^3$)</th>
<th>Sim (ug/m$^3$)</th>
<th>NFE</th>
<th>NFB</th>
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</thead>
<tbody>
<tr>
<td>Original</td>
<td>14.39</td>
<td>8.67</td>
<td>54%</td>
</tr>
<tr>
<td>Emis adjusted</td>
<td>&quot;</td>
<td>14.92</td>
<td>44%</td>
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</table>
Concluding Remarks

- Hi-Res2 operational with source impact forecasting
  - New in air quality forecasting practice
  - Supports dynamic air quality management through providing source specific information
  - Currently for traffic and power plant emissions only, can add more
  - Fire emission impact forecasts underway for dynamic prescribed-burn management (Talat’s talk, next)

- Hi-Res2 operational with dynamic emissions adjustments
  - Online performance evaluation is underway
  - Dynamic emissions adjustment significantly improves PM forecast accuracy in off-line testing
  - Expansion to include other species measurements underway
  - Improved approach to assimilating AOD and PM measurements underway (Utilizing data-fused fields)
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