Impact of Potential Future Climate Change on Regional Ozone and Fine Particulate Matter Levels in the USA
(A Joint Research Project of Georgia Tech, NESCAUM, and MIT)

Chair’s Air Pollution Seminar
California Air Resources Board
Sacramento, CA, January 10, 2007

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Acknowledgements

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Who we are

- NESCAUM (Northeast States for Coordinated Air Use Management)
- The Clean Air Association of the Northeast States
- A nonprofit organization founded in 1967 to assist the New England states in developing air pollution policy, technical, and management programs.
Who we are (cont.)

- Our Members include:
  - ME, NH, VT, MA, RI, CT, NY and NJ
NESCAUM Mission

• The five elements:

  – Provide technical assistance to the member States
  – Provide policy guidance and strategic advice to the States
  – Represent States in various national forums
  – Identify and explore emerging issues and programs that will be important to the States in the coming years
  – Provide a forum for the States to work together to resolve regional problems
An Example of NESCAUM’s Role: Climate Change Programs with Regional and National Scope

Multi-State Climate Registry

- NESCAUM is helping to coordinate efforts to develop high-quality GHG emissions data and information systems:
  - **Mission**: Provide companies and organizations with opportunity to document early action, demonstrate environmental leadership, and identify GHG risks and opportunities
  - **Benefits**: Program will support multiple state/regional climate policy goals (mandatory and voluntary), leverage state resources, facilitate linkages between programs, and promote transparency and accountability
  - **Goals**: Registry will ensure consistency between reporting programs, help establish common currency, and establish high level of environmental integrity in emissions accounting and reporting
  - **Participating States**: More than 30 eastern, midwestern, and western states engaged in registry development process

**Contact**: Heather Kaplan, Climate Policy Analyst, hkaplan@nescaum.org
Regional GHG Initiative (RGGI)

- NESCAUM served as Resource Panelist to RGGI State Working Group
- Supported analysis on potential economic impacts of RGGI in the northeast (REMI)
- Supported states through the RGGI model rule public comment process
- Currently providing analytical and other support to individual states in implementing RGGI

[Map showing RGGI States (as of Jan 2007)]
The 2001 NRC Report Notes:

- Our ability to understand observed changes in global air quality and to accurately predict future changes will depend strongly on answering two important questions:
  - How can global air quality change affect, and in turn be affected by, global climate change?
  - How is global air quality affected by the international and intercontinental transport of air pollutants?
“Scientific” Scales of Air Pollution

- Air Pollution is a “Mixture” of Scales
  - **Local** (CO, ozone, SO$_2$, PM, mercury);
  - **Regional** (ozone, PM, NO$_x$, mercury, acid deposition, regional haze)
  - **Global** (CFCs, CO$_2$, mercury, methane, “background” ozone)

- CO$_2$ is global, but has local and regional impacts
Recent Events

• **November 29, 2006: In the US Supreme Court (Oral Arguments): Massachusetts, et al., v. EPA, et al.**

• The key questions: Is CO₂ a pollutant under the Clean Air Act and does EPA have the authority to regulate it? Does the State of Massachusetts have “standing”?

• Justice Scalia: I thought that the standing requires imminent harm. If you have not been harmed already, you have to show the harm is imminent. Is this harm imminent?

• Mr. Milkey (attorney for Mass.): It is, Your Honor. We have shown that the sea levels are already occurring (“rising”) from the current amounts of greenhouse gases in the air, and that it means it is only going to get worse as the ---

• Justice Scalia: When? I mean when is the predicted cataclysm?

• Mr. Milkey: Your Honor, it is not so much a cataclysm as ongoing harm. The harm does not suddenly spring up in the Year 2100, it plays out continuously over time. And even to the extent you focus on harms that occur in the future, there is nothing conjectural about that. Once these gases are emitted into the air, and they stay a long time, the laws of physics take over.
Recent Events (Cont.)

• Later on, Mr. Milkey: Your Honor, first of all, I do think we have special standing. For example, here it is uncontested that greenhouse gases are going to make [the] ozone problem worse, which makes it harder for us to comply with our existing Clean Air Act responsibilities.

• A Point to Note: The word “Uncertainty” appears twenty three times in the oral arguments. As in: “the studies that are being developed to reduce the uncertainty,” in the area of global warming (Chief Justice Roberts); “there will always be scientific uncertainty,” (Mr. Milkey); “those are two very different levels of uncertainty,” (Chief Justice Roberts), referring to lead emissions from vehicles and impact of CO₂ on global warming; “..now is not the time [for EPA to] to exercise such authority, in light of the substantial scientific uncertainty surrounding global climate change and the ongoing studies designed to address those uncertainties,” (Mr. Garre, U.S. Department of Justice), and so on.
It is the mark of an instructed mind to rest satisfied with the degree of precision which the nature of the subject permits and not to seek an exactness where only an approximation of the truth is possible -- Aristotle
Consider a Spherical Cow
A Course in Environmental Problem Solving
JOHN HARTE
Regional future O₃ and PM₂.₅ levels & components over US

Historic period: summer 2000, 2001 (full year), summer 2002

Future climate: summer 2049, 2050 (full year), summer 2051

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Modeling approach

GCM: Global Climate Model
EI: Emission Inventory

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Downscaling meteorology (GISS-GCM) using MM5
Global and Regional Climate Models*

GISS GCM: grid spacing = 4º x 5º
9 levels
output every 6 hours

MM5 Domain 1: dx = 108 km
67x109 points
output hourly

MM5 Domain 2: dx = 36 km
115x169 points
output hourly

Leung and Gustafson (2005),
Numerical Experiments

- **Global climate simulations**
  - GISS includes CO and BC tracers and a “qflux ocean” boundary condition
  - A transient simulation was performed for 1950 - 2052
  - The A1B SRES scenario for greenhouse gases was assumed for the future (2000 – 2052) and observed greenhouse gas concentrations were used for 1950-2000

- **Regional climate simulations**
  - One simulation driven by NCEP/NCAR reanalysis for 1990-2000 for model evaluation
  - The base case driven by GISS: 1995-2005 (includes 2000-02)
  - A future case driven by GISS: 2045-2055 (includes 2049-51)
Emissions

 EI (Historic) -> SMOKE -> MCIP
 EI (FUTURE) -> SMOKE

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Emissions

Emissions inventories:

      Canada: Environment Canada 2000
      Mexico: U.S. EPA’s 1999 BRAVO

2050: IPCC-A1B emissions scenario and CAIR 2020
Projection of Future Emissions

* Develop 2050 Emission Inventory
  - Target year: Year 2050, Annual
  - Format: SMOKE-ready
  - Sector: Anthropogenic only
  - Geographical domain: US/CAN/MX
  - Projection approach:
    Two-stage approach when national projections are available

* In support of modeling
  - Did not create new future energy/emissions scenarios
IPCC SRES Scenarios (Global CO2 & SO2)

Source: IPCC

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Basic Strategy
Future-year EI development

• Obtain the best available future EI data possible
• Fill-up gaps from near/certain future to distant/uncertain future

Example: Use EPA projection until 2020 and use IPCC scenario from 2020-2050
# Comparison of existing “future-EI” development approaches

<table>
<thead>
<tr>
<th>Name</th>
<th>Base Year</th>
<th>Future Years</th>
<th>Geographical Domain</th>
<th>Scenario</th>
<th>Source sectors</th>
<th>Chemical species</th>
<th>Model</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPA CAIR</td>
<td>2001</td>
<td>2010/2015/2020</td>
<td>Continental US</td>
<td>EPA BASE/CAIR</td>
<td>EGU$s, non-EGU$s</td>
<td>NOx, VOC$s, CO, NH$_3$, SO$_2$, PM</td>
<td>IPM/EGAS/NMIM</td>
<td>Yes</td>
</tr>
<tr>
<td>EPA CSI</td>
<td>1996</td>
<td>2010/2020</td>
<td>Continental US</td>
<td>EPA BASE/CSI</td>
<td>EGU$s, Non-EGU$s</td>
<td>NOx, VOC$s, CO, NH$_3$, SO$_2$, PM</td>
<td>IPM/EGAS</td>
<td>Yes</td>
</tr>
<tr>
<td>RPOs</td>
<td>2002</td>
<td>2009/2018</td>
<td>Continental US</td>
<td>OTB/OTW</td>
<td>EGU$s$ &amp; non-EGU$s$</td>
<td>NOx, VOC$s$, CO, NH$_3$, SO$_2$, PM</td>
<td>IPM/EGAS</td>
<td>Partly</td>
</tr>
<tr>
<td>SAMI</td>
<td>1990</td>
<td>2040(~/10yrs)</td>
<td>38 States + DC</td>
<td>OTB/OTW/BWC/BB</td>
<td>EGU$s$ &amp; non-EGU$s$</td>
<td>NOx, VOC$s$, CO, NH$_3$, SO$_2$, PM</td>
<td>SAMI</td>
<td>No</td>
</tr>
<tr>
<td>RIVM*</td>
<td>1995</td>
<td><del>2100(</del>/yr)</td>
<td>World (17 regions)</td>
<td>IPCC SRES(A1, B1, A2, B2)</td>
<td>Energy sector/fuel combination</td>
<td>CO$_2$, CH$_4$, N$_2$O, CO, NO$_x$, SO$_2$, NMVOC</td>
<td>IMAGE</td>
<td>Yes</td>
</tr>
<tr>
<td>NESCAUM/EPA</td>
<td>1999</td>
<td><del>2029+ (</del>/3yrs)</td>
<td>Units(EGUs), States(NE), Country</td>
<td>BAU, RGGI</td>
<td>Energy sector/fuel combination</td>
<td>NOx, VOC$s$, CO, NH$_3$, SO$_2$, PM</td>
<td>MARKAL</td>
<td>2007</td>
</tr>
</tbody>
</table>

- **Pros**
- **Cons**
- **Both**

- **RIVM**: Netherlands’s National Institute for Public Health and the Environment
- **IMAGE**: Integrated Model to Assess the Global Environment
WorldScan (economy model), and PHOENIX (population model) feed the basic information on economic and demographic developments for 17 world regions into three linked subsystems (EIS, TES, and AOS*).

*EIS (Energy-Industry System), TES (Terrestrial Environment System), AOS (Atmospheric Ocean System)
Air Quality

Brute Force (BF):
$S = \frac{\Delta C}{\Delta E}$

Decoupled Direct Method (DDM):
$S = \frac{\partial C}{\partial E}$

For sensitivity: DDM

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Nescaum
Baseline Evaluation

Temperature

A general under prediction in temperatures

Better performance during summer months and worst during fall, caused by the high mesoscale variability during seasonal transition.
Baseline Evaluation

**O₃**

![O₃ Diagram](image)

**PM₂.₅**

![PM₂.₅ Diagram](image)
METEOROLOGY

Are historic and future years representative?
Surface Temperature Distribution
Surface Temperature Distribution

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Surface Temperature Distribution

![Graph showing surface temperature distribution with CDF (Cumulative Distribution Function) for different years. The graphs display the cumulative percentage of temperature values up to a certain temperature level, with data points for 2000, 2001, 2002, 2049, 2050, and 2051. The x-axis represents temperature in Kelvin (K), ranging from 260 to 310, and the y-axis represents CDF values from 0 to 1. The graphs indicate a slight increase in temperature distribution over the years.]
Combined Temperature Distribution

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Temperature (Spatial Distribution)

2000
Layer 1 TAd

2001

2002
Layer 1 TAf

Layer 1 TAj

Layer 1 TAl

Layer 1 TAk

January 3, 2001 1:00:00
Min= 268.8 at (42,130), Max= 300.9 at (105,1)

January 1, 2050 2:00:00
Min= 269.9 at (42,130), Max= 301.6 at (106,1)

January 1, 2051 6:00:00
Min= 268.8 at (42,130), Max= 300.9 at (178,1)

2050

2051

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Humidity

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Regional Emissions: Projections

Year 2001
Year 2050

Present and future years NOx emissions by state and by source types

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Emissions Projections

2050 – 2001:
- NOx: -50%
- VOC’s: +2%
- PM2.5: -10%
- SO2: -50%
- NH3: +7%

2050np – 2001:
- VOC’s: +15%

np (non-projected): Emission Inventory 2001, Climate 2050
Future Emissions (CANADA)

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Future Emissions (Mexico)

1999

2050

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## Changes (in percent) in pollutants concentrations for future compared to historic values

<table>
<thead>
<tr>
<th></th>
<th>M8hO₃ (%)</th>
<th>PM₂.₅ (%)</th>
<th>SO₄ (%)</th>
<th>NO₃ (%)</th>
<th>NH₄ (%)</th>
<th>OC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summers</td>
<td>Summers</td>
<td>Summers</td>
<td>Summers</td>
<td>Summers</td>
<td>Summers</td>
</tr>
<tr>
<td>West</td>
<td>-11.6</td>
<td>0.9</td>
<td>-15.7</td>
<td>-2.0</td>
<td>-32.2</td>
<td>-72.8</td>
</tr>
<tr>
<td>Plains</td>
<td>-15.8</td>
<td>-0.1</td>
<td>-34.3</td>
<td>-12.1</td>
<td>-48.7</td>
<td>-46.4</td>
</tr>
<tr>
<td>Midwest</td>
<td>-24.4</td>
<td>-2.5</td>
<td>-37.1</td>
<td>-18.4</td>
<td>-52.6</td>
<td>-68.5</td>
</tr>
<tr>
<td>Northeast</td>
<td>-20.2</td>
<td>2.8</td>
<td>-41.2</td>
<td>-1.7</td>
<td>-56.7</td>
<td>-79.3</td>
</tr>
<tr>
<td>Southeast</td>
<td>-27.9</td>
<td>0.3</td>
<td>-45.2</td>
<td>-14.3</td>
<td>-60.5</td>
<td>-77.1</td>
</tr>
<tr>
<td>US</td>
<td>-18.9</td>
<td>0.0</td>
<td>-35.9</td>
<td>-9.9</td>
<td>-52.6</td>
<td>-65.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>2050</th>
<th>2050np</th>
<th>2050</th>
<th>2050np</th>
<th>2050</th>
<th>2050np</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>-9.2</td>
<td>0.9</td>
<td>-23.4</td>
<td>1.1</td>
<td>-30.8</td>
<td>6.2</td>
</tr>
</tbody>
</table>

np: Emission Inventory 2001, Climate 2050

---

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## Regional and local (cities) predicted maximum eight-hour O₃ (M₈hO₃) concentration characteristics

<table>
<thead>
<tr>
<th>Region / City</th>
<th>M₈hO₃ (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>summers 2000-2002</td>
</tr>
<tr>
<td></td>
<td>Region</td>
</tr>
<tr>
<td>99.5% # of days over 80 ppb</td>
<td>Peak value</td>
</tr>
<tr>
<td>West / Los Angeles</td>
<td>65</td>
</tr>
<tr>
<td>Plains / Houston</td>
<td>72</td>
</tr>
<tr>
<td>Midwest / Chicago</td>
<td>89</td>
</tr>
<tr>
<td>NorthEast / New York</td>
<td>84</td>
</tr>
<tr>
<td>SouthEast / Atlanta</td>
<td>94</td>
</tr>
</tbody>
</table>

np: Emission Inventory 2001, Climate 2050
Sensitivity of Ozone to Climate and Emission Controls

O$_3$ to NOx _anthropogenic

O$_3$ to VOC _anthropogenic

O$_3$ to VOC _biogenic
PM$_{2.5}$

**US**

**Southeast**

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Uncertainty Analysis of Results

Modeling approach

Meteorological data derived based on climatic change runs using MIT’s Integrated Global System Model (IGSM) for future years

Remapping

IGSM GCM
GISS GCM

Temperature and Humidity

Intermediate Meteorology

MM5

CMAQ-DDM

SMOKE

GISS GCM
IGSM GCM

Intermediate Meteorology

MM5

MCIP

CMAQ-DDM

SMOKE

MM5

MCIP

Meteorological data derived based on climatic change runs using MIT’s Integrated Global System Model (IGSM) for future years.
Summer 2050 average temperature
Summer 2050 average humidity
Summer 2050 average PM2.5

Sun

M_{2.5}

lower – middle

upper – middle
What is the uncertainty in some mega-cities?

<table>
<thead>
<tr>
<th>Region / City</th>
<th>Region</th>
<th>City</th>
<th>Region</th>
<th>City</th>
<th>Region</th>
<th>City</th>
</tr>
</thead>
<tbody>
<tr>
<td>West / Los Angeles</td>
<td>99.5%</td>
<td>82</td>
<td>99.5%</td>
<td>82</td>
<td>99.5%</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td># of days over 80 ppb</td>
<td>2</td>
<td># of days over 80 ppb</td>
<td>6</td>
<td># of days over 80 ppb</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Peak value</td>
<td>82</td>
<td>Peak value</td>
<td>84</td>
<td>Peak value</td>
<td>91</td>
</tr>
<tr>
<td>Plains / Houston</td>
<td>99.5%</td>
<td>82</td>
<td>99.5%</td>
<td>82</td>
<td>99.5%</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td># of days over 80 ppb</td>
<td>5</td>
<td># of days over 80 ppb</td>
<td>10</td>
<td># of days over 80 ppb</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Peak value</td>
<td>87</td>
<td>Peak value</td>
<td>90</td>
<td>Peak value</td>
<td>98</td>
</tr>
<tr>
<td>Midwest / Chicago</td>
<td>99.5%</td>
<td>84</td>
<td>99.5%</td>
<td>84</td>
<td>99.5%</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td># of days over 80 ppb</td>
<td>3</td>
<td># of days over 80 ppb</td>
<td>4</td>
<td># of days over 80 ppb</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Peak value</td>
<td>87</td>
<td>Peak value</td>
<td>89</td>
<td>Peak value</td>
<td>97</td>
</tr>
<tr>
<td>Northeast / New York</td>
<td>99.5%</td>
<td>84</td>
<td>99.5%</td>
<td>84</td>
<td>99.5%</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td># of days over 80 ppb</td>
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<td># of days over 80 ppb</td>
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<td>0</td>
</tr>
<tr>
<td></td>
<td>Peak value</td>
<td>68</td>
<td>Peak value</td>
<td>70</td>
<td>Peak value</td>
<td>74</td>
</tr>
<tr>
<td>Southeast / Atlanta</td>
<td>99.5%</td>
<td>85</td>
<td>99.5%</td>
<td>85</td>
<td>99.5%</td>
<td>86</td>
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<tr>
<td></td>
<td># of days over 80 ppb</td>
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<td># of days over 80 ppb</td>
<td>0</td>
<td># of days over 80 ppb</td>
<td>2</td>
</tr>
<tr>
<td></td>
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<td>75</td>
<td>Peak value</td>
<td>78</td>
<td>Peak value</td>
<td>85</td>
</tr>
</tbody>
</table>
Conclusions

- Combining the effect of emission changes and climate change, future O$_3$ and PM$_{2.5}$ concentrations over U.S. are expected to be lower but the effects are more pronounced for regional PM$_{2.5}$ concentrations.

- Organic carbon could become the most important PM$_{2.5}$ component.

- Regionally, the Eastern U.S. shows more benefits than the rest of the regions.

- The contribution of anthropogenic NOx emissions to O$_3$ formation is more important than VOCs. Reductions in anthropogenic NOx emissions will continue to be effective for reducing regional ozone concentrations.

- Uncertainties of predicted O$_3$ and PM$_{2.5}$ concentrations due to climate change are larger in the “high-extreme” meteorology case.

- Uncertainties of predicted O$_3$ and PM$_{2.5}$ concentrations due to climate change are regional in nature: Plains have higher uncertainties than elsewhere because temperature predictions are more uncertain there.

- Emission controls have larger impact than climate change.