Observation of the Historical Relationship between Regional Surface Ozone, Temperature and Power Plant NOx emissions in the Eastern U.S.

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Introduce: The *Climate Penalty Factor*

A simple metric combining:

Surface Ozone

and Temperature Change
Introduce: The *Climate Penalty Factor*

A simple metric combining:

- Emissions
- Surface Ozone
- and Temperature Change
“Warming of the climate system is unequivocal.”

Dr. R K Pachauri Chairman IPCC Press Presentation Saturday, 17 November 2007 Valencia, Spain

Models Say...

Global Mean Temperature

<table>
<thead>
<tr>
<th>Period</th>
<th>Rate °C per decade</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>0.177±0.052</td>
</tr>
<tr>
<td>50</td>
<td>0.128±0.026</td>
</tr>
<tr>
<td>100</td>
<td>0.074±0.018</td>
</tr>
<tr>
<td>150</td>
<td>0.045±0.012</td>
</tr>
</tbody>
</table>

IPCC, AR4, WG1, Ch. 3
A Climate Change Penalty Defined and Predicted

Can we separate the signals? If so, how? What does it mean?

Use a Model
Make some Predictions

(a) Temperature (2050 - 2000)

The Reality is more complicated: Emission Reductions Occurred at the Same time as the temperature was observed to warm.

Remember: IPCC reports temperatures went up in Eastern US And we see warming in the data...(coming soon)
So how can we tell what happened to “Background” Ozone? Step 1.

Chemically Coherent Receptor Regions
Derived from Rotated Principal Component Analysis

Rural, CASTNET, offers additional opportunities due to co-located meteorological observations
Observations: Mid-Atlantic Temperature and Ozone

Full distributions Inter-annual Variability: Difficult to see trends

Grouping Relative to Emission Changes Signals start to become apparent
Observations: Mid-Atlantic Temperature and Ozone

Temperature Went Up. Warming After 2002

Ozone Went Down After 2002
Ozone, Temperature and Emission Changes, Regionally, across the Eastern U.S.
Can we directly observe the influence of warming?

Mid-Atlantic Pre-2003 May-Sept. Hourly Ozone

YEAR ≤ 2002
Slope = 3.3 ppbv/°C
Looking deeper into the data: method

Ozone rises as temperature increases. The slope is defined to be the "climate penalty factor".
Mid-Atlantic

pre 2002: 3.3 ppbv/°C
post 2002: 2.2 ppbv/°C
Can we observe the influence of warming?

Climate Penalty Factors
- Consistent across the distribution
- AND across the power plant dominated receptor regions
Can we observe the influence of warming?

Reducing NO\textsubscript{x} emissions
Lowered Ozone over the entire distribution
And decreases the Climate Penalty Factor

The change in the climate penalty factor is remarkably consistent across receptors dominated by power plant emissions (separating the SW):

The average of 3.3 ppb/°C pre-2002
Drops to 2.2 ppb/°C after 2002

Bloomer et al., GRL 2009
Another way to think (possibly) about a Climate Change Penalty in Ozone air quality

Median Temperature increases about 0.5°C
Using Climate Penalty Factor of 2.2 (or 3.3) ppb/°C

 Leads to a Climate Change Penalty of 1.1 (or 1.7) ppb

Median Temperature warmed 0.68°C since pre-1999 implying a possible penalty of 1.5 to 2.3 ppb
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Median Temperature warmed 0.68°C since pre-1999 implying a possible penalty of 1.5 to 2.3 ppb
Possible Climate Change Penalty observed for Mid-Atlantic of between 1.1 and 2.3 ppb
Implications for a warming world

Temperatures already observed to be warming

Global NO$_2$ Observed from Space

IPCC, AR4, WG1, Ch. 3

Ozone is predicted to increase in areas with warming and especially where emissions are growing

Burrows et al., 2004.
http://www.esa.int/esaEO/SEM340NKPZD_index_0.html

Warming with growing precursor emissions
Large populations at risk of increased mortality and morbidity
Impacts upon radiative transfer...

Climate Penalty Factors
A useful tool (?)
Thank you!
I invite Questions and Discussion

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Implications of the Climate Change Penalty in Ozone Air Pollution

- A 2 ppb higher ozone is
  - About the same amount as the air quality improvement modeled for many non-attainment areas justifying the entire NO$_X$ SIP call
  - NO$_X$ SIP call annualized capital costs modeled to be about $2.1 billion per year (1997$)
- 2 ppb increase, across the population of the Eastern US, is from 8,000 to 16,000 additional premature deaths per year due to local climate change.
Can we directly observe the influence of warming?

Mid-Atlantic Post-2002 May-Sept. Hourly Ozone

YEAR > 2002
Slope = 2.5 ppbv/°C
r² = 0.1939
Additional Slide: CPF and how varies by region for different breakpoint years

Great Lakes

North East

South West

Mid-Atlantic
Northeast
pre 2002: 3.3 ppbv/°C
Northeast
pre 2002: 3.3 ppbv/°C
post 2002: 2.4 ppbv/°C
Great Lakes
pre 2002: 3.1 ppbv/°C
Great Lakes
pre 2002: 3.1 ppbv/°C
post 2002: 2.2 ppbv/°C
Southwest

pre 2002: 1.3 ppbv/°C
post 2002: 1.4 ppbv/°C