Pollution-Climate Interactions during the 20th Century

Dorothy Koch

Columbia University
NASA Goddard Institute for Space Studies

Alumni Conference, G&G Department, Yale University   November 7, 2009
Koch, D., A spreading drop plume model for Venus. 


20th century
Surface Air Temperature
Long-lived GHG changes

Observed global temperature trend
IPCC AR4 Ch3

Hansen and Sato, 2004
Where might we be headed?

Climate models needed...

You are here

CO2 Change

You are here

Hansen et al, 2007
But climate models are uncertain...

1. **Climate sensitivity**: warming amount per forcing change
2. **Cloud response**: Cloud cover change due to warming
3. **Ocean CO$_2$ and heat uptake** have delayed warming
4. Aerosols have cooled/warmed, affected clouds and probably affected climate sensitivity
Aerosol Sources; Air Quality Impacts

- Transport
- Residential
- Biomass burning
- Power
- Industry
Aerosol Climate Effects

1. **Direct effect**: scatter and absorb incoming solar radiation. Sulfate, nitrate, organic carbon scatter. Black carbon (BC) also absorbs. (Ozone also warming)

2. **Indirect cloud effect**: Aerosol pollution makes clouds brighter and longer-lived. Cooling.

3. **BC-snow-darkening effect**: BC deposited on snow promotes melting. Warming
Model sensitivity

- Kiehl (2007) showed that AR4 climate models have smaller forcing if climate more sensitive...
Model sensitivity

• And most of the forcing difference is from aerosols
Global, Centennial View!!

But aerosols vary temporally and spatially as regions industrialize and then address air quality.

IPCC AR4 Ch2
Greenland ice core records
McConnell et al., 2007
North American pollution changes
Black carbon fossil-, bio-fuel emission inventory

Bond et al., 2006

North America
Europe
Southeast Asia
Total
Our coupled chemistry-climate experiments

- Transient climate experiments, from 1890 to 2000.
- GISS GCM coupled to deep ocean, with aerosols-ozone-chemistry are FULLY INTERACTIVE with the climate.
- Aerosol-cloud indirect and BC-snow-albedo effects are fully interactive. (This is actually very tricky... the indirect effect in a transient model with a deep ocean has a powerful cooling effect beginning mid-century.)
- We do multiple experiments to isolate aerosol effects.
- We performed “pollution reduction” experiments.
Aerosol Optical Depth changes

Century

1890s-1990s
2.69 [2.26]
Aerosol Optical Depth changes

<table>
<thead>
<tr>
<th>Century</th>
<th>Early</th>
<th>Middle</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>1890s-1990s</td>
<td>2.69 [2.26]</td>
<td>0.50 [0.31]</td>
<td>1.61 [1.67]</td>
</tr>
<tr>
<td>1890s-1940s</td>
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<tr>
<td>1940s-1980s</td>
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The maps show the distribution and changes in aerosol optical depth over different time periods, with color gradients indicating the magnitude of change.
Surface radiation changes
“Dimming/brightening”

Observed

Wild et al., 2005, Science 308
SULFATE top-of-atmosphere forcing changes

1890s-1990s: -0.62 [-0.20]
1890s-1940s: -0.12 [-0.04]
1940s-1970s: -0.30 [-0.11]
1970s-1990s: -0.21 [-0.05] Global [Arctic]
Sulfate vs Black Carbon TOA forcing changes

1890s-1990s
-0.62 [-0.20]

1890s-1940s
-0.12 [-0.04]

1940s-1970s
-0.30 [-0.11]

1970s-1990s
-0.21 [-0.05]

Global [Arctic]
### TOA forcing changes

<table>
<thead>
<tr>
<th></th>
<th>1890s-1990s</th>
<th>1890s-1940s</th>
<th>1940s-1970s</th>
<th>1970s-1990s</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO4</td>
<td>-0.62 [-0.20]</td>
<td>-0.12 [-0.04]</td>
<td>-0.30 [-0.11]</td>
<td>-0.21 [-0.05]</td>
</tr>
<tr>
<td>BC</td>
<td>0.32 [0.12]</td>
<td>0.13 [0.17]</td>
<td>0.07 [-0.08]</td>
<td>0.12 [0.03]</td>
</tr>
<tr>
<td>Aer</td>
<td>-0.53 [-0.12]</td>
<td>-0.05 [0.11]</td>
<td>-0.28 [-0.19]</td>
<td>-0.20 [-0.04]</td>
</tr>
</tbody>
</table>
Observed Surface Air Temperature (SAT) changes

Δ century          warmer          neutral          warmer

GISS observed temperature analysis
Observed Surface Air Temperature changes

Indirect effect is too cooling near the end of the century
Aerosol effects on Surface Air Temperature (SAT) changes

<table>
<thead>
<tr>
<th>Time Period</th>
<th>All Effects</th>
<th>Indirect Effect</th>
<th>BC-albedo Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1890s-1990s</td>
<td>0.28 [0.96]</td>
<td>-0.34 [-0.49]</td>
<td>-0.03 [0.20]</td>
</tr>
<tr>
<td>1890s-1940s</td>
<td>0.35 [0.73]</td>
<td>-0.11 [-0.11]</td>
<td>-0.01 [0.18]</td>
</tr>
<tr>
<td>1940s-1970s</td>
<td>-0.01 [0.05]</td>
<td>-0.13 [-0.28]</td>
<td>0.003 [0.19]</td>
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<tr>
<td>1970s-1990s</td>
<td>-0.06 [0.18]</td>
<td>-0.10 [-0.10]</td>
<td>-0.02 [-0.17]</td>
</tr>
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</table>
Indirect Effect helps the tropical vertical $\Delta T$

Without the indirect effect, tropical upper troposphere warms too much, like AR4 models.

With indirect effect warming is uniform, as observed.

Radiosonde, satellite data indicate uniform warming with altitude in the tropics for end of century.
Should we reduce Black Carbon pollution to cool climate?

**TROMSØ DECLARATION**

On the occasion of the Sixth Ministerial Meeting of

The Arctic Council

The 29th of April, 2009, Tromsø, Norway

**Note** the role that shorter-lived climate forcers such as black carbon, methane and tropospheric ozone precursors may play in Arctic climate change, and **recognize** that reductions of emissions have the potential to slow the rate of Arctic snow, sea ice and sheet ice melting in the near-term,
A policy-relevant summary of black carbon climate science and appropriate emission control strategies
PROJECT SURYA
Mitigation of Global and Regional Climate Change

Buying the planet time by reducing black carbon, methane and ozone
(Part I)
Black Carbon
A Review and Policy Recommendations

Authors
Karon Bice, Andrew El, Bilal Habib,
Pamela Heymans, Robert Kopp, Juan Nogues,
Frank Norcross, Margaret Sweitzer-Hamilton, Alex Whitworth

Project Advisor
Denise Mauzerall, Associate Professor of Public and International Affairs, Woodrow Wilson School
“Mitigation” Studies 1970-2000

Starting in 1970, branch 3 cases and compare with standard run.

**Cooling experiments:**
1. Pollution BC = 0 (-0.3 W/m²)
2. Long-lived GHGs at 1970 levels (-1 W/m²)

**Warming Experiment:**
3. Pollution sulfur = 0 (+0.4 W/m²)
Temperature changes for mitigation experiments
Cloud changes affect temperature changes

BC →

GHG=1970

Sulfur →

SAT

cloud cover
Conclusions

1. Aerosols during the 20th century climate:
   a) 1900-1950: Coal burning from Europe/North America ➔ Black Carbon, warmed and contributed to increased Arctic ice/snow melt.
   b) 1950-1980: Oil/gas from Europe/North America ➔ Sulfate ➔ dimming and reduced climate warming

2. IN OUR MODEL, BC reduction is less effective cooling strategy than GHG reductions because of cloud responses. Climate/hydrologic responses (not just radiative forcing) need careful consideration in mitigation strategies!
20th century forcing changes

- BC
- SO4, scattering
- O3 (SW)
- LL GHG

1890 to 1990
Another view of forcing changes

- 1970 to 2000
- 1940 to 1970
- 1890 to 1940
- 1890 to 1990

BC
SO4, scattering
O3 (SW)
LL GHG

-1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3

-1 0 0.5 1 1.5 2 2.5 3
Surface Air Temperature (SAT) trend without indirect effect

Modeled SAT

Observed SAT
SAT trend with the indirect effect

Climate warmed OK at first
SAT trend with the indirect effect

Then climate went COLD!!!!
We weakened the indirect effect. Other models are having a similar experience as they prepare for AR5. These climate experiments are an excellent challenge for the indirect effect, the most uncertain and maybe most important aerosol effect.