CAM5 Estimates of Global Source-Receptor Relationships for Black Carbon under Present-day Emission Scenario

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The standard CAM5 is not correctly characterizing Arctic BC forcing (signatures are quite similar to other models; Koch et al. 2009); Systematic BC biases include:

- Over-prediction at high altitudes
- Under-prediction near surface
- Poor seasonal cycle

Contributing factors could be:

- Wet removal and BC aging (Liu et al., 2012; Wang et al., 2012)
- Eddy/circulation transports (Ma et al., 2012)
- Model resolution (Fast et al., 2012; Rasch et al., 2012)
- Inconsistencies in cloud micro-/macro-physics (Caldwell et al., 2012)
- Emissions (Wang et al., 2012)
Motivation and objective

- BC is an important forcing agent in the atmosphere (e.g., direct, indirect and semi-direct effects and associated feedbacks)

- BC in snow and ice can result in more rapid melting (e.g., Warren and Wiscombe, 1980), changing the coupled climate system through snow-albedo feedback (e.g., Flanner et al. 2007)

- Large uncertainties in BC emissions (Bond et al. 2004; Lamarque et al. 2010) and BC prediction by global models

- We use a tagging technique to establish global source-receptor relationships with a focus on the Arctic BC

- To assess climate impact of change in regional BC emissions
The tagging methods in CAM5

- **Simple method:**
  - Emissions divided by geographical regions and tagged by flavors
  - Mass tendencies of flavors are derived from those of the original variable, assuming that tendency is proportional to mass.
  - Flavors are explicitly advected
  - Easy to implement but cannot apply to species undergoing transformation

- **Explicit (brute-force) method:**
  - Do the same to emissions
  - Define a new variable for each of the tagged regions
  - Each variable experiences the same tendency calculations and advection
  - More straightforward and accurate, but more expensive
AR5 year 2000 BC emission (Lamarque et al., 2010)

**AS**: Asia (50-150E, 10-65N)

**AM**: N. America (60-130W, 15-65N)

**EU**: Europe (10W-50E, 35-65N)

**AF**: N. Africa (20W-50E, 0-35N)

**AR**: Arctic (66.5-90N)

**RW**: Rest of world

Global: 7.8 Tg/yr

AS: 3.0  EU: 0.83
AF: 0.99  AM: 0.63
AC: 0.008  ROW: 2.33
CAMS experiment

- 10-year 2-degree (1.9° x 2.5°) simulation
  - Fixed year 2000 SST
  - The 3-mode modal aerosols (MAM-3; Liu et al. 2012)
  - Improved cloud/precipitation scavenging (Wang et al. 2012)
  - AR5 year 2000 emissions (Lamarque et al. 2010)
Results: transport pathways of regional BC

Animation of daily-mean BC atmospheric column burden in January of yr-10
Results: transport pathways of regional BC

N. America

N. Africa

ROW

BC burden (µg m⁻²)

1.0E+04
5.0E+03
2.0E+03
1.0E+03
5.0E+02
3.0E+02
2.0E+02
1.0E+02
5.0E+01
1.0E+01
5.0E+00
Metrics to measure source-receptor relationship

- Contribution of source $i$ to burden in receptor region $j$
  \[ C_{i,j} = \left( \frac{B_i}{\sum B_i} \right)_j \]
  
  $(\sum B_i)_j$ represents the total burden in region $j$.

- Efficiency of source $i$ affecting receptor $j$
  \[ F_{i,j} = \frac{C_{i,j}}{E_i/\sum E_i} \]
  
  $\sum E_i$ represents global total emission rate.
Results: source attribution (ANN)
Relative contributions (colored) derived from the global distribution of source attribution for BC burden.
Arctic BC: seasonal variation of contributions
A different measure: the efficiency
## Results: source/receptor matrix for efficiency

<table>
<thead>
<tr>
<th>Burd (Gg):</th>
<th>24.39</th>
<th>5.66</th>
<th>16.90</th>
<th>5.78</th>
<th>0.97</th>
<th>42.09</th>
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<tbody>
<tr>
<td>RW</td>
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<td>0.0</td>
<td>0.5</td>
<td>0.1</td>
<td>0.2</td>
<td>2.3</td>
</tr>
<tr>
<td>AC</td>
<td>0.5</td>
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<td>0.1</td>
<td>1.7</td>
<td>47.6</td>
<td>0.5</td>
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<tr>
<td>AM</td>
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<td>0.4</td>
<td>0.1</td>
<td>10.1</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td>AF</td>
<td>0.3</td>
<td>0.3</td>
<td>5.1</td>
<td>0.2</td>
<td>0.2</td>
<td>1.4</td>
</tr>
<tr>
<td>EU</td>
<td>0.6</td>
<td>8.2</td>
<td>1.3</td>
<td>0.3</td>
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<td>0.2</td>
</tr>
<tr>
<td>AS</td>
<td>2.3</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>1.3</td>
<td>0.2</td>
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</table>

| Emis (Tg yr\(^{-1}\)):
<table>
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<tbody>
<tr>
<td>RW</td>
<td>2.333</td>
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<tr>
<td>AC</td>
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<tr>
<td>EU</td>
<td>0.834</td>
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<tr>
<td>AS</td>
<td>3.005</td>
</tr>
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</table>

Sensitivity of burden in the receptor region to per unit perturbation of emission in a source region.
We developed a regional aerosol source tagging technique in CAM5, which can be used to establish the quantitative aerosol source-receptor relationships and identify transport pathways.

In this particular study, it’s applied to a model version with improved aerosol vertical and long-range transport to focus on Arctic BC.

Under the AR5 yr2000 emission scenario, emission from Asia contributes the most to the Arctic BC, and then Europe and N. America; they affect different sectors in the Arctic.

The Arctic BC is most sensitive to emission uncertainties within the Arctic, and then Europe, Asia and N. America.

We are using this tool to study the impact of changes in regional BC emissions, as well as other aerosol species.