SLCF and the Arctic

Science update and preliminary results from recent modeling assessing black carbon effects on the Arctic from different regions and different sources

Terje Berntsen
UiO/CICERO

Geneva 13. September 2010
Activities under the AMAP expert group

- Focus on Black Carbon aerosols
- Modelling experiments to quantify impacts in terms of radiative forcing from emissions in different regions and sectors
- Batch A: 25 combinations of regions and sectors have been identified

**Status:**
- Two models have performed the simulations
  - CESM (NCAR Earth system model) at Univ. of Michigan (Mark Flanner)
  - Oslo CTM2 at University of Oslo/CICERO (Karianne Ødemark and Terje Berntsen)
- Preliminary analysis of direct radiative forcing have been performed
- Analysis of radiative forcing due to deposition on snow and ice is not yet available
- A third model – GISS model (Koch/Unger) will do the simulations
## Batch A

<table>
<thead>
<tr>
<th>Regions/ Sectors</th>
<th>US</th>
<th>Canada</th>
<th>Russia</th>
<th>Scandinavia</th>
<th>ROW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>M,O</td>
<td>M,O</td>
<td>M,O</td>
<td>M,O</td>
<td>M</td>
</tr>
<tr>
<td>Transport</td>
<td>M,O</td>
<td>M,O</td>
<td>M,O</td>
<td>M,O</td>
<td>M</td>
</tr>
<tr>
<td>Agriculture</td>
<td>M,O</td>
<td>M,O</td>
<td>M,O</td>
<td>M,O</td>
<td>M</td>
</tr>
<tr>
<td>Industry/ power/waste</td>
<td>M,O</td>
<td>M,O</td>
<td>M,O</td>
<td>M,O</td>
<td>M</td>
</tr>
<tr>
<td>Grass+forest</td>
<td>M,O</td>
<td>M,O</td>
<td>M,O</td>
<td>M,O</td>
<td>M</td>
</tr>
</tbody>
</table>
Model: NCAR Community Earth System Model 1.0, resolution: 1.9 x 2.5 degrees


Aerosols: Bulk aerosol model (Rasch et al, 2001), no indirect cloud forcing in these runs

Sea-ice aerosol effect: Briegleb and Light (2007)

Snow aerosol effect: SNICAR (Flanner et al, 2007, 2009)

Model length: 14 month run (2 month spinup + one full year) for emissions from each region and sector

Emissions: Lamarque et al, ACP, 2010

Instantaneous direct radiative forcing calculated within atmospheric, snow, and sea-ice components
Models/setup UiO/CICERO

- Oslo CTM2, offline global chemistry transport model,
- Resolution: T42 (2.8°x2.8°), 40 vertical layers below 10 hPa
- Aerosols: Bulk scheme with modified aging times based on more detailed microphysical models (M7, Vignati et al., JGR)
- Radiative forcing: Derived from burden changes calculated by the Oslo CTM2 and normalized RF fields
  \[ nRF(BC\_column, \text{lat}, \text{long}, \text{month}) \]
- Emissions: Lamarque et al, 2010
- BC in snow (land and sea ice). Simple snow-column budget module
Emissions of BC (Gg/yr) from sectors and regions

Emission Transport (Gg/yr)

Emission energy+industrial+waste (Gg/yr)

Emission domestic (Gg/yr)

Emission Grass+forest (Gg/yr)
Ranking of sources (regions and sectors) contribution to RF 60°-90°N

Univ. of Michigan

C: Canada
S: Scandinavia
R: Russia
W: ROW
US: United States

Radiative Forcing (mWm⁻²)

Total RF 60-90 N: 79 mWm⁻²

RF (direct) 60°-90°N (mWm⁻²)
Why do the models differ?

Emissions (equal)

- Burden change
  - Radiative Forcing
- Burden change
  - Radiative Forcing

• Burden Change:
  - Atmospheric transport and mixing
  - "Aging" (Conversion from hydrophobic to hydrophilic form)
  - Deposition

• Radiative forcing
  - Optical properties
  - Location of BC relative to clouds
  - Surface albedo
Source region potential

Shindell et al., ACP, 2008
RF per unit burden change 60-90 N

C: Canada
S: Scandinavia
R: Russia
W: ROW
US: United States
Does it matter where the forcing is located?

Response Region: Arctic

Figure 5.1 Summary graphic of BC indirect effects on clouds.

Bond et al., in prep.
Preliminary conclusions

• Most of "Batch A" simulations have been carried out by two models – some diagnostics pending (most important RF due to BC on snow).

• Contribution to direct RF north of 60°N have been analyzed.

• Ranking of sources largely robust between the models, absolute levels approx. a factor of 2 different.

• Emissions from "Rest of the World" and wildfires are most important for radiative forcing north of 60°N.

• Apart from that, Domestic (Russia) and Transport (US) are the most important sources.

• In terms of RF per unit of emissions, Scandinavian sources are most effective.

• Potentially important forcing mechanism and regional climate feedbacks are NOT included in this analysis.
Important factors towards identification of regions and sectors for cost-effective mitigation of Black Carbon aerosols

- Absolute level of impact (here Radiative Forcing)
- Impact normalized to emission (e.g. Wm$^{-2}$/Tg(yr)$^{-1}$)

Other factors not discussed here:
- Changes in co-emitted species
- Mitigation costs
- Feasibility (Technologically and politically)
Ranking of sources (ROW and grass+forest removed) contribution to RF 60°-90°N.

Univ. of Oslo

RF (direct) 60-90N mWm-2
Other activities on understanding BC impacts on the climate

• "Bounding BC" initiative (Bond, Fahey, Forster ++)
  - Focus on quantifications (with uncertainties) of the effects of all possible processes where BC interacts with climate. Draft due soon.

• BC activity under EMEP/CLRTAP
  - Focus country specific contribution to direct radiative forcing by BC aerosols
  - Dedicated model simulations with the EMEP model at met.no (M. Gauss ++) with input on forcing efficiencies from CICERO (G. Myhre) → input to the GAINS model at IIASA

• UNEP assessment of BC
Historical (1850–2000) gridded anthropogenic and biomass burning emissions of reactive gases and aerosols: methodology and application

<table>
<thead>
<tr>
<th>Species</th>
<th>EDGAR-HYDE EDGAR</th>
<th>RETRO</th>
<th>Smith et al.</th>
<th>Bond et al.</th>
<th>Junker and Liouesse</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOₓ</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NMVOC</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Historical Global BC Emissions (Tg/yr)

- **1850**
- **1870**
- **1890**
- **1910**
- **1930**
- **1950**
- **1970**
- **1990**
- **2010**
Emissions in "Rest of the World"

Emission ROW (Gg/yr)

- Transport
- Grass + Forest
- Energy + Industrial + Waste
- Domestic
- Agricultural
Climate impacts of soot aerosols in the Norwegian Earth System Model (NorESM)

Alf Kirkevåg, Trond Iversen,
Jens Boldingh Debernard, Øyvind Seland, Mats Bentsen,
Corinna Hoose, Jón Egill Kristjánsson,
Mark Flanner, Steve Ghan, Phil Rasch

Acknowledgement:
National Center for Atmospheric Research, NCAR
Pacific Northwest National Laboratory, PNNL

IPY-Oslo Science conference, Lillestrøm, June 10'th 2010
Light-absorption by soot and mineral dust on snow and sea-ice is included in NorESM

In the land model (CLM4 from NCAR):
The SNow, ICe, and Aerosol Radiative (SNICAR) model (Flanner et al., 2007; 2009)
  • grain-size dep. snow aging
  • aerosol deposition (BC, DU)
  • meltwater scavenging of aerosol
  • look-up tables for optical parameters
  • multilayer radiative transfer in the snow

In the sea-ice model (CICE4 from NCAR):
(Holland et al., 2010, draft in preparation)
  • aerosol deposition (BC, DU)
  • BC and DU impact on snow albedo through CICE’s own radiation transfer module
Simulations – all fully coupled:

1. CTRL 68 years:
   Year 2000 aerosol emissions and GHG concentrations

2. noBCdep 68 years:
   As CTRL, but no effects of BC deposition on snow and sea-ice albedo

3. noBC 68 years:
   As CTRL, but BC aerosols excluded (entirely)

Global near 2m temperature (K)

(JRA25 reanalysis 1979-2004)

years 39-68 used in analysis
Response of all BC: **CTRL - noBC**

- **Temp.** Increased air temperature at 2m height (°C)
- **albedo** Increased surface albedo (fraction)

**Snow cover**
Increased land-surface snow-cover (fraction)

- 0.17
- 0.0007

**Sea-ice cover**
Increased sea-ice cover (fraction)

- 0.0013
- 0.0011
**Response:** NH winter mid-tropospheric flow (500hPa)

**NorESM:**
CTRL - noBC:
Response to all BC

**Reference:** flow-regimes from re-analysed data (Corti et al, 1999; Nature)

**ClusterB**
PNA-; NAO+ (NCEP Re-analysis)
Figure 4.2: Calculated RF due to BC and POC caused by emissions from EU27 countries (upper panels) and all EMEP countries (lower panels) (Wm$^{-2}$).
Norm. RF (direct) 60°-90°N (mWm⁻²/Tg/yr)

domestic (S)
energy+industrial+waste (S)
transport (S)
agricultural (S)
domestic (R)
energy+industrial+waste (R)
transport (R)
agricultural (C)
agricultural (R)
energy+industrial+waste (C)
domestic (C)
transport (C)
agricultural (US)
energy+industrial+waste (US)
domestic (US)
transport (US)