Climate Effects of Black Carbon Aerosols

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Acknowledgements:
Zamin Kanji and André Welti
How well do models simulate BC?

BC radiative effects

BC effects on ice clouds

Conclusions

Intro

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Extra

Bond et al., JGR (2013)
**Aerosol-radiation interactions**

**Scattering aerosols**

(a) Aerosols scatter solar radiation. Less solar radiation reaches the surface, which leads to a localised cooling.

(b) The atmospheric circulation and mixing processes spread the cooling regionally and in the vertical.

**Absorbing aerosols**

(c) Aerosols absorb solar radiation. This heats the aerosol layer but the surface, which receives less solar radiation, can cool locally.

(d) At the larger scale there is a net warming of the surface and atmosphere because the atmospheric circulation and mixing processes redistribute the thermal energy.

*IPCC, Fig. FAQ 7.2, (2013)*
Vertical profiles of BC

Fig. 7.15 (IPCC, 2013)
Transport to the Arctic

![Graph showing BC and CO concentrations in the Arctic atmosphere]

ARCTAS–A, Spring

**BC (ng/m³)**

- STD - $R^2 = 0.46$ - Mean bias (%) = 95.4
- NEW - $R^2 = 0.69$ - Mean bias (%) = 38.0

**CO (ppbv)**

- STD - $R^2 = 0.81$ - Mean bias (%) = 12.8
- NEW - $R^2 = 0.79$ - Mean bias (%) = 12.7

Bourgeois and Bey, JGR (2011)
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Properties of BC and BC-containing particles and their connections to climate models

Properties of BC:
- Refractive index
- Density
- Shape
- Size

Properties of BC-containing particles:
- Mass absorption cross-section
- Mass scattering cross-section
- Wet particle size
- Dry particle size

Properties of other substances:
- Refractive index
- Solubility
- Coating thickness

Extensive variables:
- Number of BC particles
- Mass concentration of BC
- Mass of added material

Total particle number

Atmospheric processes:
- Nucleation
- Coagulation
- Condensation, Oxidation

Arrow: Line of influence
Dashed shape: Difficult measurements made rarely and assumed to apply broadly
* Scattering properties include directional scattering

Needed to model direct forcing
Needed to model cloud changes

Bond et al., JGR (2013)
Aerosol radiative forcing 1750-2010

hatched: Aero-Com II models
solid: AR5 estimates

(IPCC, Fig. 7.18, 2013)
Black carbon diagnostics in the HadGEM1 climate model

(a) Emissions

(b) Burden

(c) Climate forcing

(d) Temperature response

Mean = 15.43 mg[C] m$^{-2}$ yr$^{-1}$

Mean = 0.82 mg[C] m$^{-2}$

Mean = +0.45 W m$^{-2}$

Mean = +0.28 K

Bond et al., JGR (2013)
Climate effects of black carbon emissions

The impact of BC on snow and ice causes additional warming in the Arctic region and contributes to snow/ice melting. **VERY LIKELY BUT MAGNITUDE UNCERTAIN**

BC in northern hemisphere mid-latitude snow leads to earlier springtime melt and reduces snow cover in some regions. **LIKELY BUT MAGNITUDE UNCERTAIN**

The warming caused by BC is concentrated in the northern hemisphere. **VERY LIKELY.**

Absorbing aerosols may have caused changes in precipitation patterns with largest effects likely to be in South Asia.

The hemispheric nature of the BC forcing causes a northward shift in the ITCZ. **LIKELY.**

Absorbing aerosols may cause circulation changes over the Tibetan Plateau and darkening of the snow. The importance of this for glacier melting is unknown.

Bond et al., JGR (2013)
### Global climate forcing of black carbon and co-emitted species in the industrial era (1750 - 2005)

<table>
<thead>
<tr>
<th>Climate forcing terms</th>
<th>Estimate (Uncertainty range)</th>
<th>LOSU</th>
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</thead>
<tbody>
<tr>
<td><strong>BC direct effects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmosphere absorption &amp; scattering</td>
<td>0.71 (0.08, 1.27)</td>
<td>Med</td>
</tr>
<tr>
<td><strong>BC cloud indirect effects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combined liquid cloud (semi-direct, albedo, and lifetime)</td>
<td>-0.2 (-0.61, 0.1)</td>
<td>Low</td>
</tr>
<tr>
<td>BC in cloud droplets</td>
<td>0.2 (-0.1, 0.9)</td>
<td>Very low</td>
</tr>
<tr>
<td>Mixed-phase cloud</td>
<td>0.18 (0, 0.36)</td>
<td>Very low</td>
</tr>
<tr>
<td>Ice cloud</td>
<td>0.0 (-0.4, 0.4)</td>
<td>Very low</td>
</tr>
<tr>
<td><strong>BC snow and sea ice effects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BC snowpack effective forcing</td>
<td>0.10 (0.014, 0.30)</td>
<td>Med</td>
</tr>
<tr>
<td>BC sea ice effective forcing</td>
<td>0.030 (0.012, 0.06)</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Total climate forcing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BC only</td>
<td>1.1 (0.17, 2.1)</td>
<td></td>
</tr>
<tr>
<td>BC + co-emitted species (BC-rich sources only)</td>
<td>-0.06 (-1.45, 1.29)</td>
<td></td>
</tr>
</tbody>
</table>

*Bond et al., JGR (2013)*
Heterogeneous freezing

Hoos and M"ohler, ACP (2012)
Compilation of freezing data on soot

(a) soot

(b) soot - negative results

Hoose and Möhler, ACP (2012)
Ice nucleation active surface site (INAS) density

**Immersion/condensation freezing**

- $n_s$ in m$^{-2}$
- $T$ in °C

- ATD
- desert dusts
- clay minerals
- dusts, BET surface area
- soot
- bacteria
- other bioaerosols

Hoose and Möhler, ACP (2012)
Frozen fraction of droplets containing BC

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Ulrike Lohmann (IACETH)  BC climate effects  ETH Zurich, June 24, 2014  14 / 16
Conclusions

BC as ice nuclei:

- BC nucleates ice only at rather cold temperatures
- The studies testing BC as an ice nuclei obtain conflicting results

Climate effects of BC:

- The total climate forcing of BC is positive, but could be close to zero if co-emitted species are considered as well
- The effect of BC on clouds seems to counteract its direct radiative effect, but they are much more uncertain
BC-rich sources comprise 99% of all BC emissions

- Top bar: direct forcing by aerosol and most gases and aerosol cryosphere forcing
- Middle bar: cloud effects and nitrate
- Bottom bar: net climate forcing by each emission source

Bond et al., JGR (2013)