Climate Effects of Black Carbon Aerosols

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Acknowledgements:
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Intro

How well do models simulate BC?

BC radiative effects

BC effects on ice clouds

Conclusions

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.

### Absorbing aerosols

- **(b)**

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

- **(c)**

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

- **(d)**

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

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

- Vertical profiles of BC are shown for different models and pressure levels.
- The profiles are for HIPPO-1 (Jan 2009) and A-FORCE (Mar-Apr 2009) campaigns.
- The models include BCC, GISS-MATRIX, GISS-modelE, IMPACT, INCA, ECHAM5-HAM, OsloCTM2, GMI, and GOCART.
- The concentration of BC MMR (ng kg⁻¹) is plotted against pressure (hPa).

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

![Graphs showing BC and CO concentrations in the Arctic Atmosphere](image)

- **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
- Hygroscopcity
- CCN activity
- IN activity

Properties of other substances

- Refractive index
- Solubility
- Coating thickness

Extensive variables

- Number of BC particles
- Mass emission of BC
- 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

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

Mean = 15.43 mg[C] m⁻² yr⁻¹

(b) Burden

Mean = 0.82 mg[C] m⁻²

(c) Climate forcing

Mean = +0.45 W m⁻²

(d) Temperature response

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>
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<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>
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<tr>
<td>Combined liquid cloud</td>
<td>-0.2 (-0.61, 0.1)</td>
<td>Low</td>
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<tr>
<td>(semi-direct, albedo, and lifetime)</td>
<td></td>
<td></td>
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<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>
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<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>
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<tr>
<td>BC only</td>
<td>1.1 (0.17, 2.1)</td>
<td></td>
</tr>
<tr>
<td>BC + co-emitted species</td>
<td>-0.06 (-1.45, 1.29)</td>
<td></td>
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</tbody>
</table>

Bond et al., JGR (2013)
Heterogeneous freezing

$S_i$

water saturation

homogeneous freezing of cloud droplets

homogeneous freezing of solution droplets

deposition nucleation

condensation nucleation

immersion freezing

contact freezing

Hoose and Möhler, 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

\[ n_s \text{ in m}^{-2} \]

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

Temperature (°C)

Hyoose and M"ohler, ACP (2012)
Frozen fraction of droplets containing BC

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Intro

Ulrike Lohmann (IACETH)

BC climate effects

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Courtesy André Welti and Zamin Kanji (ETHZ)
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)