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On the direct effects of anthropogenic aerosols on European climate with RegCM3

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On the direct effects of anthropogenic aerosols on European climate with RegCM3

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Aerosol direct and indirect effects
Radiative Forcing Components

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>RF values (W m⁻²)</th>
<th>Spatial scale</th>
<th>LOSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-lived greenhouse gases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>1.66 [1.49 to 1.83]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>N₂O</td>
<td>0.48 [0.43 to 0.53]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.16 [0.14 to 0.18]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Halocarbons</td>
<td>0.34 [0.31 to 0.37]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Ozone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stratospheric</td>
<td>-0.05 [-0.15 to 0.05]</td>
<td>Continental to global</td>
<td>Med</td>
</tr>
<tr>
<td>Tropospheric</td>
<td>0.35 [0.25 to 0.65]</td>
<td>Continental to global</td>
<td>Med</td>
</tr>
<tr>
<td>Stratospheric water vapour from CH₄</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface albedo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land use</td>
<td>-0.2 [-0.4 to 0.0]</td>
<td>Local to continental</td>
<td>Med</td>
</tr>
<tr>
<td>Black carbon on snow</td>
<td>0.1 [0.0 to 0.2]</td>
<td>Local to continental</td>
<td>Med</td>
</tr>
<tr>
<td>Total Aerosol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct effect</td>
<td>-0.5 [-0.9 to 0.1]</td>
<td>Continental to global</td>
<td>Med</td>
</tr>
<tr>
<td>Cloud albedo effect</td>
<td>-0.7 [-1.8 to 0.3]</td>
<td>Continental to global</td>
<td>Low</td>
</tr>
<tr>
<td>Linear contrails</td>
<td>0.01 [0.003 to 0.03]</td>
<td>Continental</td>
<td>Low</td>
</tr>
<tr>
<td>Solar irradiance</td>
<td>0.12 [0.06 to 0.30]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td>Total net anthropogenic</td>
<td>1.6 [0.6 to 2.4]</td>
<td>Global</td>
<td>Low</td>
</tr>
</tbody>
</table>

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Aerosols in RegCM3

- General approach ↔ Tracer model / RegCM3
  (from Giorgi et al., 2002; Qian et al., 2001)

\[
\frac{\partial \chi}{\partial t} = -\mathbf{V} \cdot \nabla \chi + F_H + F_V + T_{CUM} + S_{\chi} - R_{w,ls} - R_{w,cum} - D_{dep} + \sum Q_p - Q_l
\]

Transport
Primary Emissions
Removal terms
Physico – chemical transformations

Strongly dependent on the nature of the tracer

- Particles and chemical species considered (“anthropogenic compounds”)

SO$_2$ ↔ SO$_4^{2-}$
BC (soot)

6 Tracers

Hydrophilic
Hydrophobic

Hydrophilic
Hydrophobic
RegCM3/aerosol simulations

Two 12-year RegCM3/aerosol simulations were performed for the period 1996-2007:

a) The control run (Crun) with the chemical tracers only being transported

b) The aerosol feedback run (AFrun) including the direct aerosol feedback on the shortwave radiation

**Lateral boundary conditions:** NCEP-DOE AMIP-II Reanalysis dataset

**Domain:** European domain with 50 km x 50 km resolution (18 layers up to 50 hPa)
Radiative forcing

- **Autumn**
  - Mean(96–07) Rad Forcing SRF Fb Aut (SON)

- **Winter**
  - Mean(96–07) Rad Forcing SRF Fb Win (DJF)

- **Spring**
  - Mean(96–07) Rad Forcing SRF Fb Spr (MAM)

- **Summer**
  - Mean(96–07) Rad Forcing SRF Fb Sum (JJA)
AOD values

autumn

Mean AOD 1996–2007 Aut (SON) Fb

winter

Mean AOD 1996–2007 Win (DJF) Fb

spring

Mean AOD 1996–2007 Spr (MAM) Fb

summer

Mean AOD 1996–2007 Sum (JJA) Fb
Geopotential Height differences AFrun-Crun at 500 hPa over 1996-2007

Zonal wind differences AFrun-Crun at 500 hPa over 1996-2007

Meridional wind differences AFrun-Crun at 500 hPa over 1996-2007
Summer 2001
Summer 2000
Anomalies of summer 2000 from the summer climatic mean over the period 1961-1996 for a) near surface air temperature and b) wind speed at 300 hPa. The contour lines denote the mean values of summer 2000.
Seasonal mean fields in summer for the year 2000 of the difference AFrun-Crun RegCM3 aerosol simulations due to aerosol feedback in a) total column fractional cloud cover (%) and b) surface absorbed solar radiation (W/m²).
Seasonal mean fields in summer for the year 2000 of the difference AFrun-Crun RegCM3/aerosol simulations due to aerosol feedback in zonal wind at 500 hPa (a) and 300 hPa (b). The units are in m/s.
Mean summer (for the year 2000) meridional cross sections averaged over the longitudinal zone 20°E-30°E of the difference AFRun-Crun RegCM3/aerosol simulations due to aerosol feedback in a) air temperature (°C), b) zonal wind (m/s), c) vertical wind (10⁻⁵ hPa/s) and d) cloud fraction (dimensionless).
Key points

• The direct effect of anthropogenic aerosols induces a small near surface temperature differences (decreases) for the overall period 1996-2007 with the largest effects seen in spring and summer when RF values are more negative.

• The pattern of the regional aerosol induced changes of the near surface temperature is mainly arisen through the aerosol induced changes of the atmospheric circulation and is not spatially collocated with the pattern of the aerosol induced surface radiative forcing.

• A common feature in the aerosol induced changes in atmospheric circulation for spring and summer is a small decrease of the westerly zonal wind in the latitudinal belt 45° N-55° N.

• Greater near surface temperature differences seen from year to year as the aerosol radiative forcing interacts in a complex way with the specific atmospheric circulation patterns of each year. The effect on circulation patterns becomes moderate in the long-term mean.

• A southward shift of the subtropical jet stream seems to play a dominant role for the decrease in near surface air temperature over Southeastern Europe and the Balkan Peninsula for summer 2000.
Thanks for your attention
Aerosols processes

- **Transport of tracers**
  
  Advection / diffusion ↔ Cloud mmr (mm5 options)

- **Convective transport**
  
  Simple mixing hypothesis

- **Wet removal by large scale rainfall:**

  \[ R_{w,ls} = \chi f_{sol} (\chi) \frac{1 - \exp \left( - \Delta t / \tau_{w,ls} \right)}{\Delta t} \]

  (Giorgi et al., 1989)

- **Wet removal by cumulus convective rainfall:**

  \[ R_{w,cum} = \chi f_{cum} f_{sol} (\chi) \frac{1 - \exp \left( - \Delta t / \tau_{w,cum} \right)}{\Delta t} \]

  \[ \tau_{w,cum} \sim 20\text{min} \]

- **Dry deposition:** prescribed deposition velocities (nature tracer / surface)
Aerosols processes

- **Sulfur Aerosol Model** (Kasibhalta et al., 1997, Qian et al., 2001)
  
  Gas phase:
  \[ SO_2 + OH \rightarrow SO_4^{2-} + HO_2 \]
  
  Aqueous phase:
  \[ HSO_3^- + H_2O_2 \rightarrow SO_4^{2-} + 2H^+ + HO_2 \]

  [OH] : constant profile + diurnal evolution (max for cosθ = 1)

- **Aging of carbon aerosol** (Cooke et al., 1999)

  Simple approach:

  \[ \tau_{\text{aging}} = 1.15 \text{ days} \]

  Deposition (dry, wet)  Optical properties  CCN
Carbon aerosol (Lioussse et al., 1996)

- **BC**
- \( \text{OC}_{\text{tot}} = \text{OC}_{\text{prim}} + \text{OC}_{\text{sec}} \)

**Fossil fuel**: 1995, 1 deg, annual

**Biomass burning**: 80-90’s
3.75*5 deg, monthly
  - Forest
  - Savanna
  - Agriculture
  - Cleaning
  - Domestic fires

**Injection height**

**Emission factors method**

- **Hydrophobicity at the emission**

<table>
<thead>
<tr>
<th></th>
<th>BC</th>
<th>( \text{OC}_{\text{tot}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>😞</td>
<td>80 %</td>
</tr>
<tr>
<td>Savanna</td>
<td>😞</td>
<td>50 %</td>
</tr>
<tr>
<td>Agric.</td>
<td>😞</td>
<td>50 %</td>
</tr>
<tr>
<td>Cleaning</td>
<td>😞</td>
<td>20 %</td>
</tr>
<tr>
<td>Domestic fires</td>
<td>😞</td>
<td>50 %</td>
</tr>
</tbody>
</table>
Figure 2. a) Anthropogenic emission of a) SO2 (in 10-9 kg m-2 s-1) and b) the sum of black and organic carbon (in 10-12 kg m-2 s-1). Seasonal mean fields in summer of the year 2000 of c) the aerosol optical depth and d) the surface radiative forcing (in W/m2) due to anthropogenic aerosols (carbonaceous particles and sulphates) obtained from the RegCM3/aerosol simulations.