Radiation-aerosol-atmosphere feedbacks on the regional scale

Max Bangert
Kristina Lundgren
Rayk Rinke
Bernhard Vogel
Heike Vogel

Institut für Meteorologie und Klimaforschung
# Global radiative forcing

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>RF values (W/m²)</th>
<th>Spatial scale</th>
<th>LOSU</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Long-lived greenhouse gases</strong></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><strong>Anthropogenic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ozone</td>
<td>-0.05 [-0.15 to 0.05]</td>
<td>Continental to global</td>
<td>Med</td>
</tr>
<tr>
<td>Stratospheric</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>0.07 [0.02 to 0.12]</td>
<td>Global</td>
<td>Low</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-Low</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-Low</td>
</tr>
<tr>
<td><strong>Total Aerosol</strong></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-Low</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><strong>Linear contrails</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.01 [0.003 to 0.03]</td>
<td>Continental</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Natural</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar irradiiance</td>
<td>0.12 [0.06 to 0.30]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Total net anthropogenic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.6 [0.6 to 2.4]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Radiative Forcing (W/m²)**
Weekly cycles of atmospheric variables?

- Mean temperature anomaly

- Anomaly of the accumulated yearly precipitation

- Anomaly daily temperature range

Bäumer and Vogel, 2007a
Weekly cycles of emissions, AOT, and PM10

Weekly cycle of AOT

Bäumer and Vogel, 2007b
Feedback processes
COSMO–ART (ART = Aerosols and Reactive Trace Gases)

Concept:

COSMO-ART is online coupled.

Identical methods are applied for all scalars as temperature, humidity, and concentrations of gases and aerosols to calculate the transport processes. This includes the treatment of deep convection (Tiedtke Scheme).

It has a modular structure.
Interaction of five modes:

- **Two modes** for $\text{SO}_4^{2-}$, $\text{NO}_3^-$, $\text{NH}_4^+$, $\text{H}_2\text{O}$, SOA, and soot internally mixed.

- **One mode** for pure soot.

- **Two modes** for $\text{SO}_4^{2-}$, $\text{NO}_3^-$, $\text{NH}_4^+$, $\text{H}_2\text{O}$, SOA, and soot internally mixed.

Source: homogeneous nucleation of $\text{H}_2\text{SO}_4$/water

Three modes for **mineral dust** particles + Three modes for **sea salt** particles + **Pollen**

**coagulation**
Optical Properties of the Aerosols

Refractive index of aerosols

Mie Calculations

Single scattering albedo ($\omega$), specific extinction coefficient ($b_s$), asymmetry parameter ($g$)

New Routine in COSMO-ART:
Computation of $\omega$, $b$, $g$ for prevailing aerosol concentration

$\omega$, $b$, $g$

Modified radiation in COSMO:
Substitution of climatological optical properties based on current aerosol concentrations in GRAALS

Emissions, Transport, Transformations, Sedimentation, Deposition

Size distribution, chemical composition of each mode

"Coating"
Feedback processes

Aerosol

Radiation
Gas phase
Dynamics
Humidity
Precipitation
Temperature
Clouds
Modellergebnisse

Simulation periods:
16.08.05 - 20.08.05 HC
28.08.05 - 01.09.05 LC

Simulation domain:
Europe
\( \Delta x, \Delta y: 14\text{km} \)

Input data:
Meteorology: ECMWF
Emission data (IER, Stuttgart)
Land use (JRC-IES, Ispra)

Run R: Reference
Run F: Feedback
Average over Three Days

Cloud cover

Aerosol mass

ΔT (F-R)

Cloud cover

Aerosol mass

ΔT in K

18.08.05

30.08.01.09.05

ΔT in K
Average over Three Days (Germany)

LC

HC

wet aerosol mass in $\mu g\ m^{-3}$ vs. $\Delta T$ in K

- LC diagram shows a scatter plot with wet aerosol mass on the y-axis and $\Delta T$ in K on the x-axis.
- HC diagram also shows a scatter plot with similar axes, but the distribution of data points appears to be different from LC.
## Average over Three Days (Germany)

<table>
<thead>
<tr>
<th></th>
<th>LC</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOT</td>
<td>0.172</td>
<td>0.590</td>
</tr>
<tr>
<td>$\Delta E_g$ in W m$^{-2}$</td>
<td>-5.43</td>
<td>-6.01</td>
</tr>
<tr>
<td>$\Delta T$ in K</td>
<td>-0.10</td>
<td>-0.08</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Episode</th>
<th>day</th>
<th>TR in K (run R)</th>
<th>TR in K (run F)</th>
<th>$\Delta$TR in K</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC</td>
<td>30.08.2005</td>
<td>7.63</td>
<td>7.53</td>
<td>-0.10</td>
</tr>
<tr>
<td></td>
<td>31.08.2005</td>
<td>10.13</td>
<td>9.98</td>
<td>-0.15</td>
</tr>
<tr>
<td></td>
<td>01.09.2005</td>
<td>11.42</td>
<td>11.25</td>
<td>-0.17</td>
</tr>
<tr>
<td>HC</td>
<td>18.08.2005</td>
<td>11.31</td>
<td>11.22</td>
<td>-0.09</td>
</tr>
<tr>
<td></td>
<td>19.08.2005</td>
<td>9.02</td>
<td>8.91</td>
<td>-0.11</td>
</tr>
<tr>
<td></td>
<td>20.08.2005</td>
<td>2.57</td>
<td>2.39</td>
<td>-0.18</td>
</tr>
</tbody>
</table>

**Observed average weekly cycles:** $\Delta T \approx 0.2$ K, $\Delta$TR $\approx 0.11$ K
Daily cycles of temperature south of Milan
Aerosols modify atmospheric radiation. This initializes feedback mechanisms that are currently neglected in operational weather forecast models.

As long as no clouds are present there is a close link of the spatial distribution of the aerosol and the spatial distribution of e.g. the temperature change.

When clouds are present the radiative effect of aerosols is superimposed by other processes and there is no linear relation between aerosol load and changes in temperature.

The simulated changes in temperature and temperature range for two three days episodes are in the same order of magnitude as the observed weekly cycles.

What is the role of the feedback between aerosol particles and cloud microphysics?
People behind COSMO-ART