Chemistry-climate interactions

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Stratospheric ozone and climate

- **greenhouse gases**
- halogen containing species
- chemical reactions and transport
- reactive species

**stratospheric water vapor increase**
- albedo changes (ice and snow cover)
- changes in dust/organic matter

**Stratospheric temperatures**
- upper stratosphere
- middle stratosphere
- lower stratosphere

**Surface temperatures with respect to ozone decrease in the:**
- upper stratosphere
- middle stratosphere
- lower stratosphere

**Stratospheric dynamics**

**Tropospheric dynamics**

**Tropospheric ozone**

**Surface UV-B**

**Biogenic production**

**ozone depletion**

**increased UV radiation**

**vulcanoes**

**solar activity**

### Stratospheric ozone changes and climate

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Impact of stratospheric ozone decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Impact</td>
</tr>
<tr>
<td>Stratospheric temperatures</td>
<td>Large</td>
</tr>
<tr>
<td>- upper stratosphere</td>
<td>Small</td>
</tr>
<tr>
<td>- middle stratosphere</td>
<td>Medium-to-large</td>
</tr>
<tr>
<td>- lower stratosphere</td>
<td></td>
</tr>
<tr>
<td>Surface temperatures with respect to ozone decrease in the:</td>
<td>Small</td>
</tr>
<tr>
<td>- upper stratosphere</td>
<td>Small</td>
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<td></td>
</tr>
<tr>
<td>Stratospheric dynamics</td>
<td>Medium-to-large</td>
</tr>
<tr>
<td>Tropospheric dynamics</td>
<td>Medium-to-large</td>
</tr>
<tr>
<td>Tropospheric ozone</td>
<td>Medium</td>
</tr>
<tr>
<td>Surface UV-B</td>
<td>Medium-to-large</td>
</tr>
<tr>
<td>Biogenic production</td>
<td>Medium-to-large</td>
</tr>
</tbody>
</table>
Changes in ozone

Assimilated GOME total ozone, KNMI fast delivery, 12 October 2000

GOA project: ozone hole

Assimilated GOME total ozone, KNMI fast delivery, 12 October 2000

Total ozone deviations from the pre-1980 level

Bodeker, NIWA assim data, Dobson, TOMS, GOME
Tropospheric Cl
Emissions stop in 2000
WMO scenario
Emissions at 2000 level

Inorganic chlorine inventory

- Total Column Abundance (10^16 molecules/cm²)


- CL₂, HCl, ClONO₂

Trop Cl, Strat Cl

ESA-ESRIN, Frascati, Rome, Italy

18th – 29th August 2003
Modelled temperature trends with imposed ozone trends

Observations
Effects of changes in climate on stratospheric ozone

9 Chemistry - Climate models, decadal averages, means and two standard deviations
- TOMS observations
Climate change

Hohenpeissenberg: ozone, tropopause height and temperature trends
Splitting of the ozone hole, climate effect?

Analysis 28-9-2002 9-day forecast 2001

NAO index (large scale climate variability N.Atlantic/ Europe)
Total Ozone in winter over Arosa
Climate impact of tropospheric ozone changes
Mean Tropospheric NO$_2$ 1996–2001

Vertical Column Density [$10^{15}$ molecules/cm$^2$]

Surface ozone over Harwell
– background
--- polluted air masses
Changes in radiative forcing due to tropospheric ozone increase from pre-industrial to present conditions.

Changes in modelled tropospheric ozone columns (DU) from 2000-2100.
Accumulated radiative forcing in Wm$^{-2}$ due to increase of greenhouse gases

2000-2050

2000-2100
Impact of climate change on tropospheric ozone
Climate effect on tropospheric ozone budget

- STE stratosphere-troposphere exchange
- NCP net photochemical production
- DEP surface deposition

Simulated zonal mean ozone concentrations and stratospheric ozone tracer, 1990

Changes between 1990 and 2090
<table>
<thead>
<tr>
<th>Process/activity</th>
<th>Impact on global tropospheric ozone resulting from climate change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human activity-fossil fuel related emissions</td>
<td>Small</td>
</tr>
<tr>
<td>Biomass burning</td>
<td>Medium to large</td>
</tr>
<tr>
<td>Soil NO₃</td>
<td>Medium</td>
</tr>
<tr>
<td>Lightning NO₂</td>
<td>Medium to large</td>
</tr>
<tr>
<td>Natural CH₄ emissions</td>
<td>Medium to Large</td>
</tr>
<tr>
<td>Natural VOC emissions</td>
<td>Medium to large</td>
</tr>
<tr>
<td>Oceanic emissions of sulphur containing gases</td>
<td>Small</td>
</tr>
<tr>
<td>Heterogeneous chemistry on sea-salt</td>
<td>Medium</td>
</tr>
<tr>
<td>Heterogeneous chemistry on mineral dust</td>
<td>Small-medium</td>
</tr>
<tr>
<td>Changes in dry deposition</td>
<td>Medium</td>
</tr>
<tr>
<td>Changes in wet deposition</td>
<td>Small-medium</td>
</tr>
<tr>
<td>Effect of meteorology on O₃ production and loss, humidity</td>
<td>Large</td>
</tr>
<tr>
<td>Climate induced changes in stratosphere-troposphere exchange</td>
<td>Large</td>
</tr>
<tr>
<td>Changes in weather patterns, transport</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

**Sensitivity of climate model ECHAM for experiments with CO₂ doubling**

- Model and experiments
- Control climate and (uniformly) doubled CO₂ climate
- Responses to non-uniform CO₂ doubling
Model:

- MA version of ECHAM4
- 39 layers, up to 0.01 hPa (80 km)
- horizontal resolution: T42 (~ 2.8° x 2.8°)
- Prescribed Sea Surface Temperature
- Prescribed O$_3$ fields
- 30-year equilibrium experiments, focus: DJF, NH

Experiments:

- C-run: control
  - 1x CO$_2$
  - 1x CO$_2$
  - Control climatology
- S-run
  - 2x CO$_2$
  - 1x CO$_2$
  - (~Control climatology)
- A-run
  - 2x CO$_2$
  - 2x CO$_2$
  - 2 x CO$_2$ climatology
- T-run
  - 1x CO$_2$
  - 2x CO$_2$
  - (~2 x CO$_2$ climatology)
1. Additivity \( R_a = R_t + R_s \)

2. Tropospheric zonal wind

Attributable to stratospheric CO₂ doubling!!!
Mainly Attributable to tropospheric CO$_2$ doubling!!
Doubling CO2 model experiment

- Non-uniform CO2 doubling experiments to improve insight in uniformly doubled CO2 climate change
- Strengthening of stratospheric residual circulation tropospheric CO2 doubling
- Increase of tropospheric NH westerlies stratospheric CO2 doubling
- CO2 doubling between 10-0.01 hPa induces significant tropospheric zonal wind changes

Conclusions
Climate-chemistry coupling important in
- Stratosphere
- Stratosphere-troposphere interface/coupling
- Troposphere
- Mesosphere
Outlook chemistry climate interactions

Challenging research field in strong development

• Detection and description interactions
• Simulation past climate/atmospheric composition with chemistry-climate models,
• Evaluation by confrontation with observations,
• Long term global monitoring, satellite data + ground-based + in situ + assimilation, integrated approach
• Forecasting future climate/atmospheric composition

References:
WMO Scientific Assessment of Ozone Depletion, 2002
IPCC Assessment Climate Change, 2001
EU Assessment of chemistry-climate interaction, 2003
SPARC
WMO, IGACO report, 2003
Sigmond, Siegmund and Kelder, Analysis of the coupling between stratosphere and surface zonal winds, 2003, Climate Dynamics, in press

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