Impact of international shipping on aerosols and clouds – Simulations with ECHAM5/MADE

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Outline

1. Introduction
2. The model system ECHAM5/MADE
3. Impact of ship emissions on aerosols and clouds
4. Conclusions and Outlook
Introduction
Transport-related annual emissions (2000)

From Eyring et al. (JGR, 2005a)

Contribution of traffic to total anthropogenic CO₂ emissions

<table>
<thead>
<tr>
<th>Emission Type</th>
<th>Road Traffic</th>
<th>Aviation</th>
<th>Shipping</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ (Tg)</td>
<td>1122</td>
<td>178</td>
<td>222</td>
</tr>
<tr>
<td>NOₓ (Tg)</td>
<td>8.3</td>
<td>0.71</td>
<td>6.5</td>
</tr>
<tr>
<td>SO₂ (Tg)</td>
<td>2.2</td>
<td>0.075</td>
<td>6.0</td>
</tr>
<tr>
<td>PM₁₀ (Tg)</td>
<td>2.1</td>
<td>0.001</td>
<td>1.7</td>
</tr>
<tr>
<td>Fuel Consumption (Tg)</td>
<td>1320</td>
<td>207</td>
<td>280</td>
</tr>
</tbody>
</table>
Future ship emission scenarios until 2050
4 Demand Scenarios (GDP growth based on IPCC SRES Scenarios) & 4 Technology Scenarios

From Eyring et al. (JGR, 2005b)
Introduction

Why investigate the impact of shipping on aerosols and clouds?

• Shipping contributes significantly to total budget of transport-related emissions
• Currently one of the least regulated sources of anthropogenic emissions
• Rapid growth of ship traffic expected in the future
• Currently large uncertainties about overall impact of emissions from shipping on atmospheric composition and climate, in particular on aerosols and clouds
The model system ECHAM5/MADE
The model system ECHAM5/MADE (MESSy version)
Model setup

- **ECHAM5/MADE** (MESSy v1.1): horizontal resolution T42, 19 vertical layers
- model dynamics nudged to ECMWF reanalysis (1998-2004)
- chemistry (MECCA): tropospheric background chemistry ($\text{NO}_x$, $\text{HO}_x$, CH$_4$, CO, O$_3$) + sulfur (DMS, SO$_2$)
- emissions (**year 2000**):
  - trace gases except SO$_2$ and DMS: EDGARv3.2-FT2000 (Olivier et al., 2005)
  - DMS and sea salt: on-line calculation
  - SO$_2$ and aerosols except sea salt: AeroCom 2000 (Dentener et al., 2006)
- **3 model experiments**:
  - ship emissions from Eyring et al. (2005)
  - ship emissions from Dentener et al. (2006)
  - no ships
Emissions from international shipping
– Year 2000 –

<table>
<thead>
<tr>
<th>Gases</th>
<th>Aerosols</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO2 (TgS)</td>
<td>SO4 (TgS)</td>
</tr>
<tr>
<td>NOx (TgN)</td>
<td>BC (Tg)</td>
</tr>
<tr>
<td>CO (TgC)</td>
<td>POM (Tg)</td>
</tr>
</tbody>
</table>

- Eyring et al. (2005)
- Dentener et al. (2006), Olivier et al. (2005)
- Dentener et al. (2006)

Masking of Dentener et al. (2006) BC and POM ship emissions: $1^\circ\times1^\circ$ land-/seamask
⇒ aliasing at coast lines (BC, POM)
SO$_2$ emissions from international shipping
– Year 2000 –

Eyring et al. (2005), 5.9 Tg(S)/yr

Dentener et al. (2006), 3.9 Tg(S)/yr
Impact of ship emissions on aerosols
Total sulfate mass ($\mu g/m^3$) from international shipping
– climatological (1999-2004) annual averages –

Eyring et al. (2005) ships

Dentener et al. (2006) ships

Surface level

Zonal average

Total burden: 54.7 Gg (3.6%)

Total burden: 35.2 Gg (2.3%)
Contribition of shipping to total atmospheric burdens
– climatological (1999-2004) annual averages –

<table>
<thead>
<tr>
<th>Total atmospheric burdens (Tg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>compound</td>
</tr>
<tr>
<td>SO$_4$</td>
</tr>
<tr>
<td>NH$_4$</td>
</tr>
<tr>
<td>NO$_3$</td>
</tr>
<tr>
<td>H$_2$O</td>
</tr>
<tr>
<td>BC</td>
</tr>
<tr>
<td>POM</td>
</tr>
<tr>
<td>sea salt</td>
</tr>
<tr>
<td>mineral dust</td>
</tr>
</tbody>
</table>

Contribution of shipping (%)

- Eyring et al. (2005) ships
- Dentener et al. (2006) ships

Graph showing contributions of shipping for different compounds (SO$_4$, NH$_4$, NO$_3$, H$_2$O, BC, POM) for both Eyring et al. (2005) and Dentener et al. (2006) methods.
Impact of shipping: number size distribution

– climatological (1999-2004) annual averages –

surface layer, Atlantic Ocean (85°W...5°W, 15°N...60°N)

no ships

with ships (Eyring et al., 2005)
Impact of shipping: particle composition

- climatological (1999-2004) annual averages -

Surface layer, Atlantic Ocean (85°W...5°W, 15°N...60°N)

Aitken mode

- no ships
  - 51.2% SO$_4$
  - 20.4% NH$_4$
  - 16.7% NO$_3$
  - 7.8% POM
  - 4.0% dust

- with ships
  - 57.0% SO$_4$
  - 20.9% NH$_4$
  - 12.9% NO$_3$
  - 3.5% POM

Accumulation mode

- no ships
  - 23.9% SO$_4$
  - 4.5% NH$_4$
  - 12.6% NO$_3$
  - 35.5% POM

- with ships
  - 39.9% SO$_4$
  - 7.7% NH$_4$
  - 5.1% NO$_3$
  - 10.5% POM

Coarse mode

- no ships
  - 84.9% SO$_4$
  - 15.1% NH$_4$

- with ships
  - 84.9% SO$_4$
  - 15.1% NH$_4$

Concentrations (μg/m$^3$)

- no ships
  - 0.204 μg/m$^3$
  - 2.009 μg/m$^3$
  - 18.806 μg/m$^3$

- with ships
  - 0.238 μg/m$^3$
  - 2.412 μg/m$^3$
  - 18.841 μg/m$^3$
Impact of shipping: aerosol optical depth
– climatological (1999-2004) annual averages –

Δ aerosol optical depth (0.55 μm)

Δ clearsky TOA radiative flux (solar)

Changes in net clearsky fluxes
Eyring et al. (2005): -0.036 W/m²
Dentener et al. (2006): -0.013 W/m²
Impact of ship emissions on clouds
Impact of ship emissions on clouds
– climatological annual mean (1983-2004) of low cloud amount (ISCCP) –

- Regions of interest: Areas with frequent low maritime clouds and major shipping routes
  ⇒ West Coast of North America and South Africa, Northeastern Atlantic
- Impact limited to warm clouds in the lower troposphere (< 1.5 km)
  ⇒ no modification of ice clouds

ISCCP D2 MONTHLY MEANS AND CLIMATOLOGY:
http://isccp.giss.nasa.gov/products/browsed2.html
Conclusions

1. shipping contributes significantly to global aerosol burdens, e.g. SO$_4$: 3.6% (2.3%)

2. increase in aerosol optical depth above the oceans up to 10%
   ⇒ change in net clearsky TOA radiative fluxes:
   -0.036 W/m$^2$ (-0.019 W/m$^2$)

3. about 75% of changes in radiative fluxes (TOA) are related to changes in sulfur budget

4. impact on clouds limited to
   ⇒ low warm clouds (< 1.5 km)
   ⇒ no impact on ice clouds
   ⇒ West Coast of North America and South Africa, Northeastern Atlantic

• strong dependence of results on emission data sets
  ⇒ geographical distribution important
  ⇒ implies high uncertainties
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Outlook

Investigation of the effect of ship emissions on:

1. cloud microphysics
   ⇒ CDNC
   ⇒ LWC
   ⇒ effective cloud droplet radii

2. cloud properties
   ⇒ precipitation formation
   ⇒ cloud cover

3. radiation
   ⇒ cloud optical thickness
   ⇒ TOA cloud forcing