Ozone and methane changes and interactions Regional to global scales

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Tropospheric impact of NOx and CO emissions on ozone and methane

NO contribute to composition change/RF through:

Chemical formation of the secondary compound O_3

Reduction in CH_4 through reduced lifetime (enhanced OH)

Enhanced ozone production:

$$NO + HO_2 \rightarrow NO_2 + OH$$
$$NO_2 + \text{UV-light} \rightarrow NO + O$$
$$O + O_2 + M \rightarrow O_3 + M$$

Enhanced methane loss:

$$NO + HO_2 \rightarrow NO_2 + OH$$
$$CH_4 + OH \rightarrow CH_3 + H_2O$$

CO (and VOC) contribute to composition change/RF through:

Chemical formation of the secondary compound O_3

Enhanced CH_4 through increased lifetime (reduced OH)

Enhanced ozone production:

$CO + OH + O_2 \rightarrow CO_2 + HO_2$ (main loss reaction for CO and OH)

$NO + HO_2 \rightarrow NO_2 + OH$

$O + O_2 + M \rightarrow O_3 + M$

Enhanced methane production:

$CO + OH + O_2 \rightarrow CO_2 + HO_2$

$CH_4 + OH \rightarrow CH_3 + H_2O$

NO: Increased climate effect through O_3, reduced climate effect through methane

CO: Increased climate effect through O_3, increased climate effect methane methane

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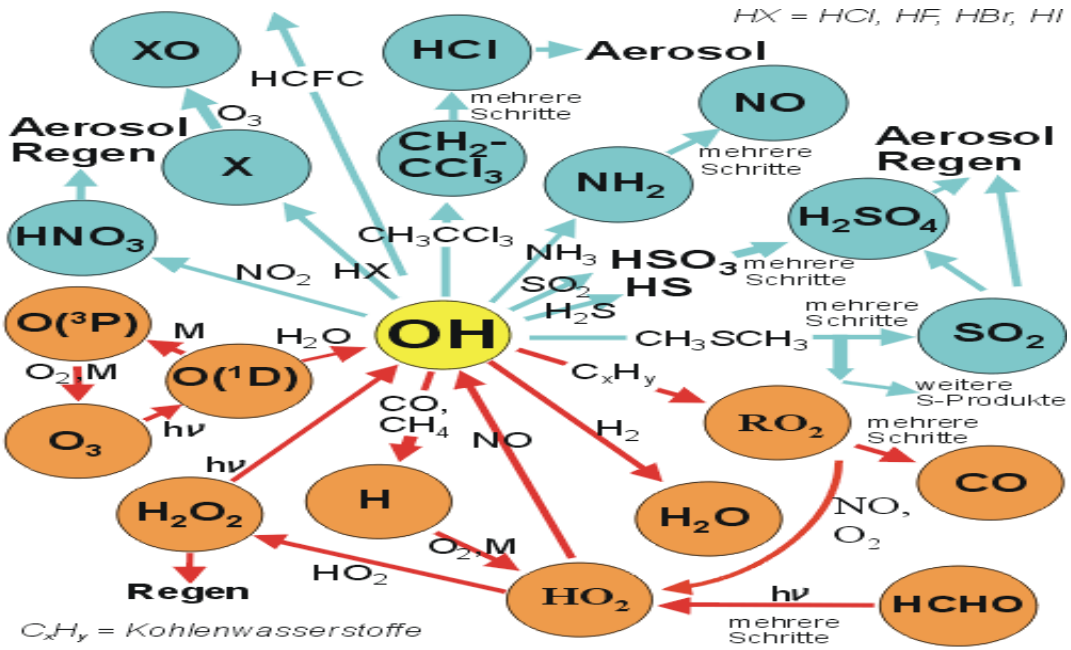
OH a key compound in atmospheric chemistry



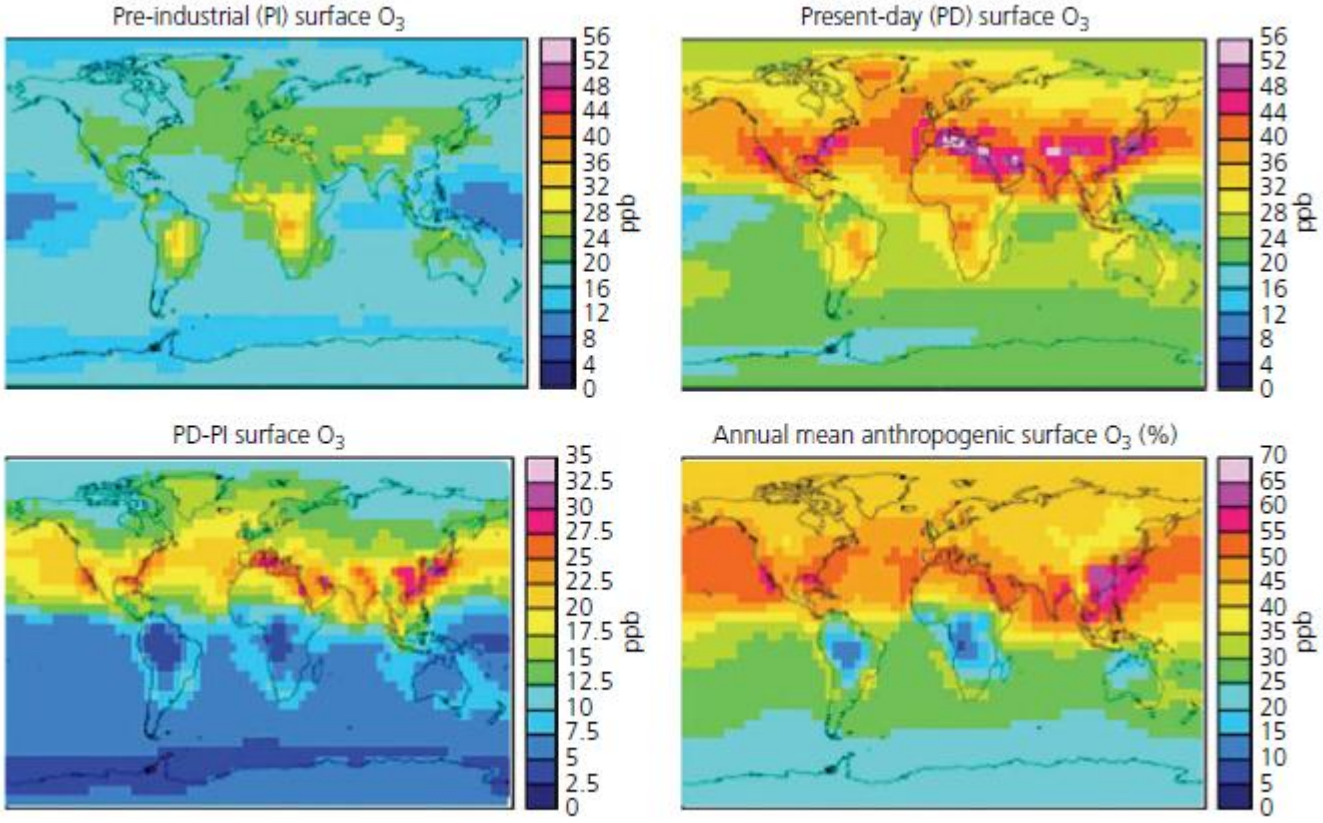
From W. CHAMEIDES and D.DAVIS, Chem. Eng. News 1982

Key chemical reactions involving the hydroxyl radical (OH)

More than 90 % of atmospheric methane (CH4) is lost through the reaction with OH:

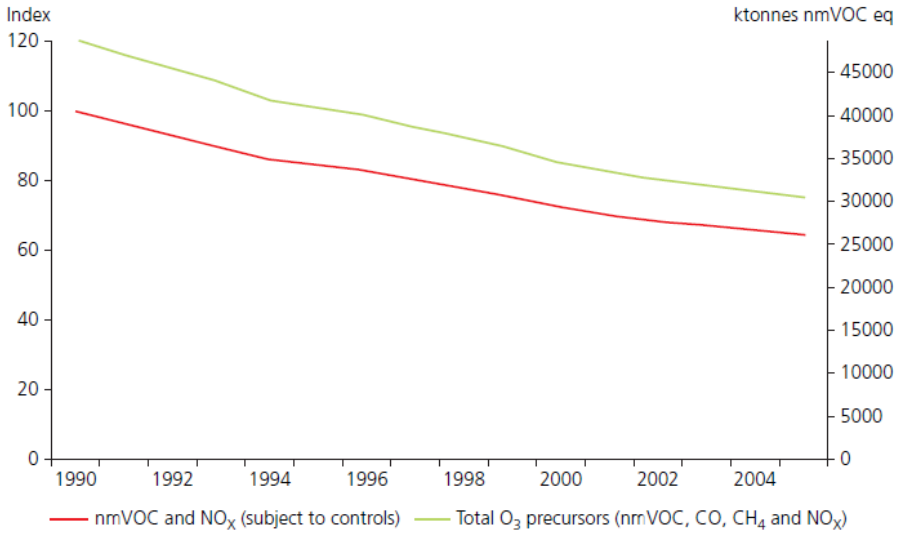
$$CH_4 + OH \rightarrow CH_3 + H_2O$$

Surface ozone distribution



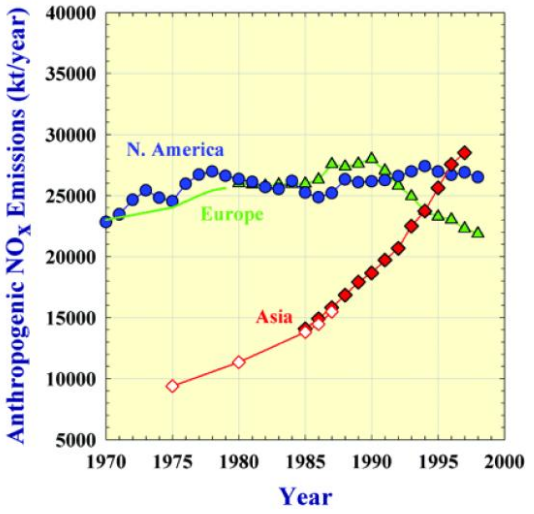
Modelled global changes in surface O3 concentrations between pre-industrial times and present day. Multi-model mean surface layer annual mean O3 (ppb) is presented. PI: pre-industrial, PD: present day, PD-PI: modelled increase in O3, and in % of annual mean O3 attributable to anthropogenic sources.

Trend and regional differencnes i pollution emissions



Emissions of O3 precursors in Europe (EEA-32 member countries) from 1990–2005

Source: EEA (2007)



Changes in anthropogenic NOx emissions in North America (United States and Canada), Europe (including Russia and the middle East), and Asia (East, Southeast, and South Asia).

Source: Akimoto, 2003

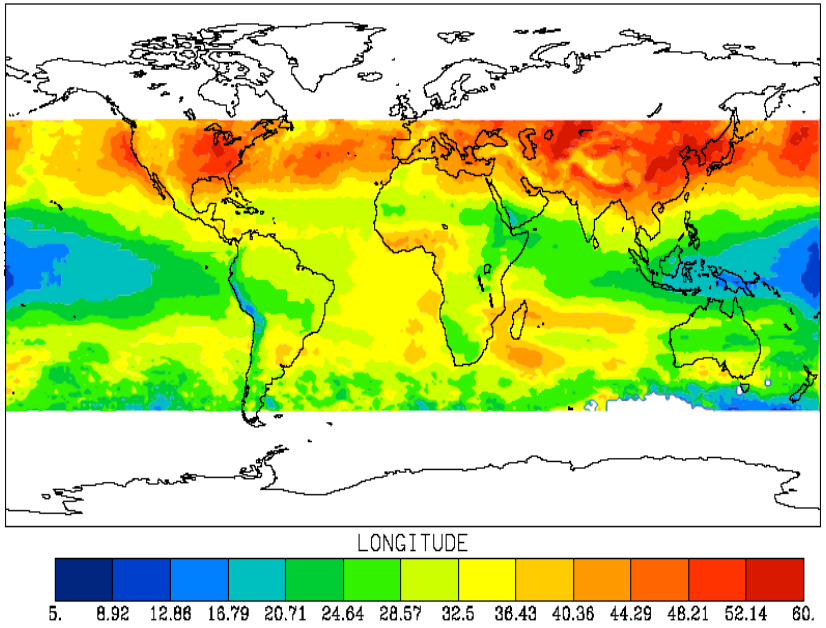
Tropospheric ozone column distribution

Question: How well can models represent values and patterns?

Tropospheric ozone residual

From Fishman (NASA, Langley)

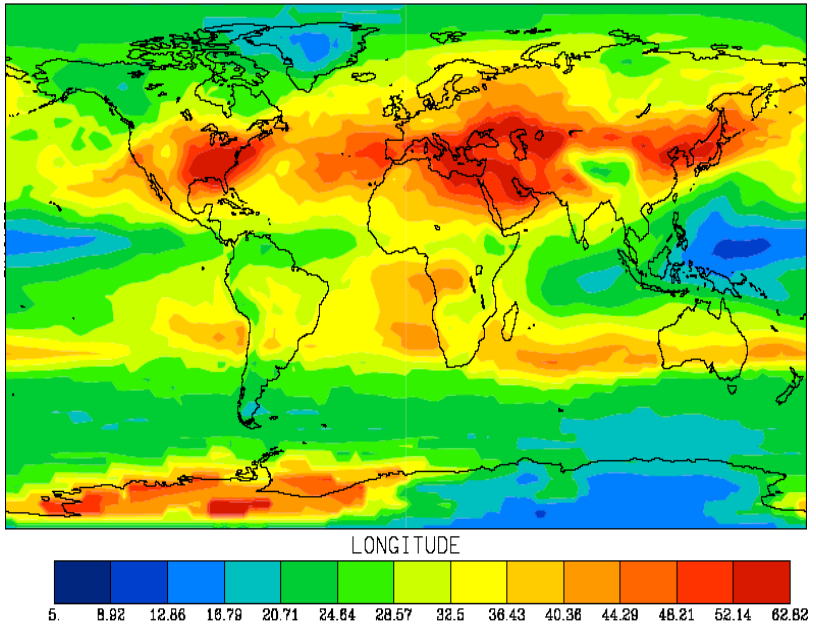
July 2000
Dobson units



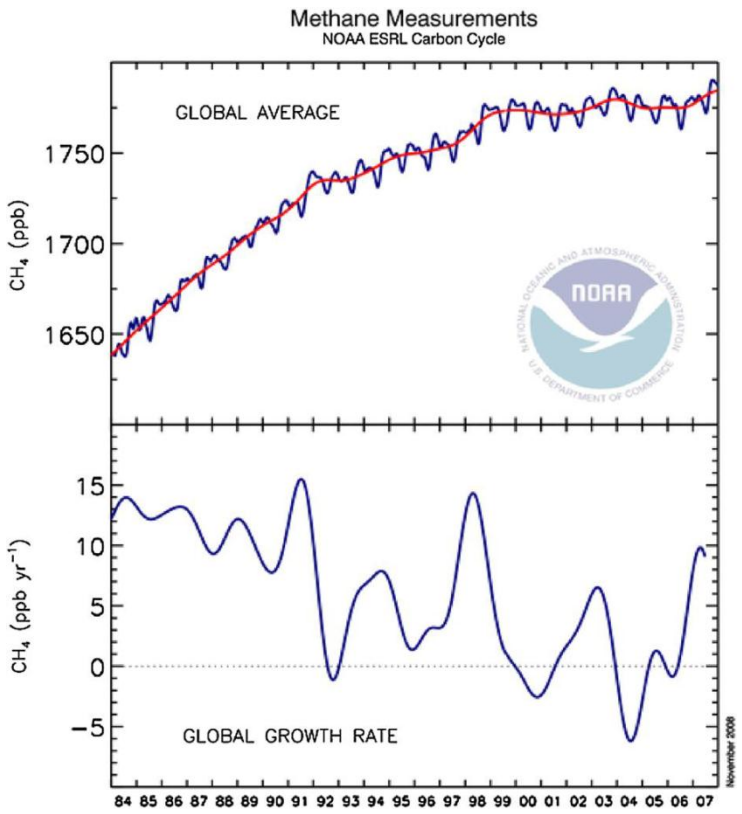
CTM2 Tropospheric column

From Dalsøren et al., 2006

Jul 2000
Dobson units

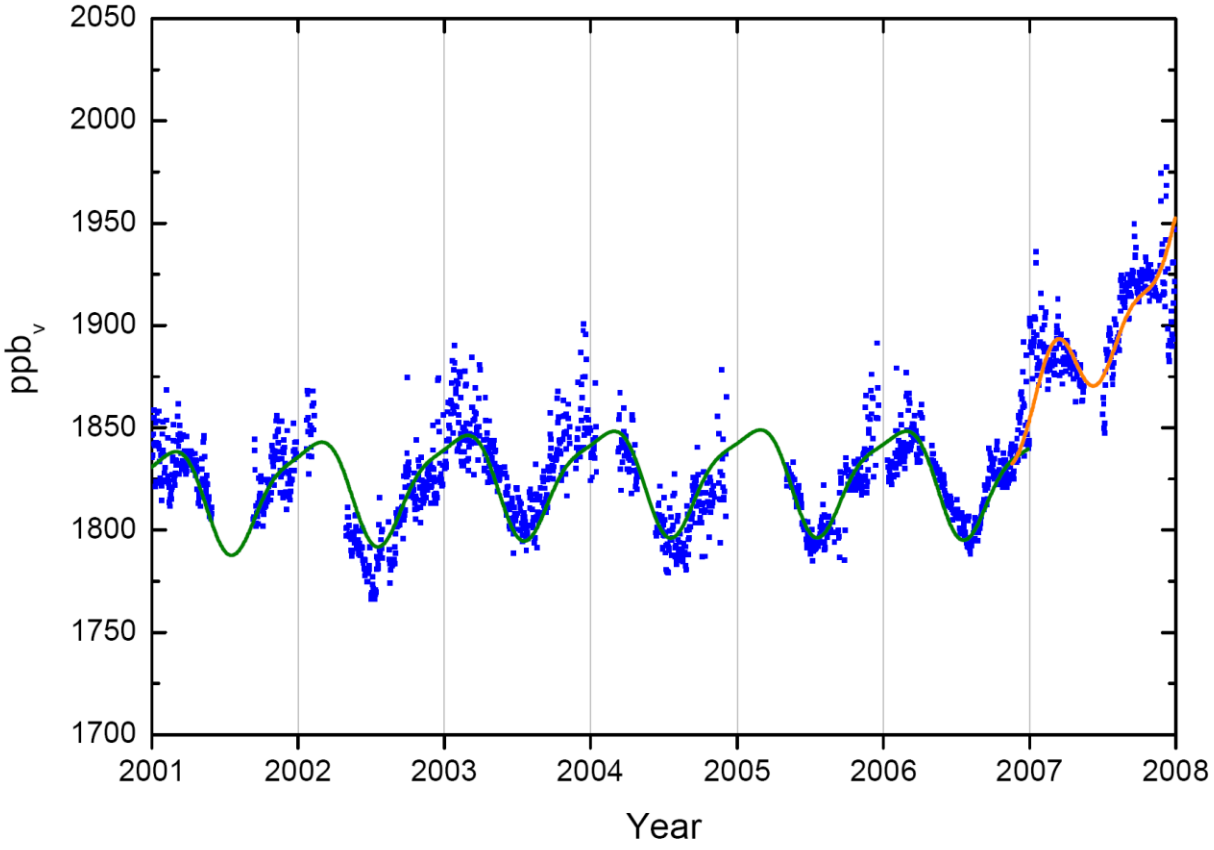


Global surface methane distribution



20 years of methane growth

Observations of methane for the period 2001-2007 at Zeppelin observatory, 79 deg. N



Significant methane increase in the Arctic after 2006

Emission from international shipping and aviation

- Land-based emissions have been reduced in many countries
- Emissions from international aviation and shipping are rapidly increasing
- Aviation contributes ~ 2% of global NOx emission
- International shipping Contributes ~15%, of global NOx emission

Large increases are expected

- Global passenger air travel, growth by 5% per year between 2000 and 2020
- European NOX emissions from shipping (32% of land-based NOX emissions) will exceed these sources by 2020

Ozone and methane perturbations by ship and aircraft

NOx emission from aircraft➔ increased O_3 :

- Occurs at cruise altitudes (in the UTLS region, 10 to 12 km) where ozone is an efficient climate gas
- At UTLS heights ozone has a long lifetime and is transported to Arctic latitudes
- Background NOx is important

NOx emission from ship➔ increased O3 and reduced CH_4:

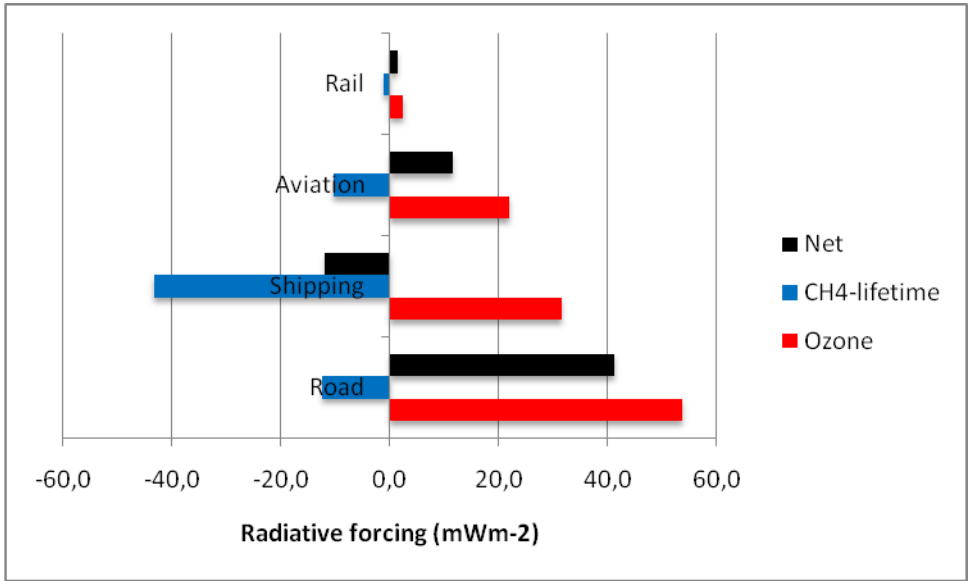
- Occurs in remote prestine regions with low background NOx

- Emission index for aircraft: $NO_2/CO > 1$
- Emission index for ship: $NO_2/CO >> 1$
- Surface emissions: $NO_2/CO << 1$

In particular ship emission have significant impact on OH (increase)

Impact from the transport sector

Estimate of radiative forcing for the different transport sectors



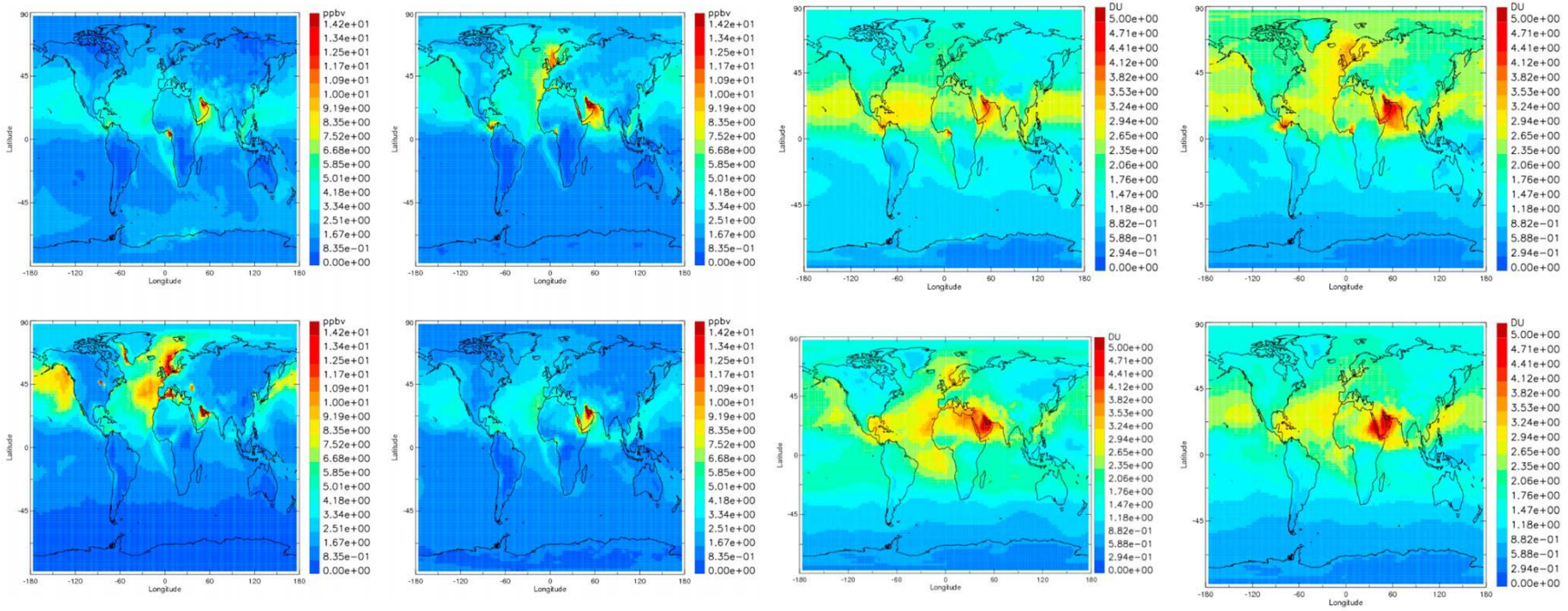
Fuglestvedt et al., 2008

Radiative forcing from CH_4 (changes in lifetime) and from O_3, and the corresponding net radiative forcing for four transport sectors from pre-industrial time to present due to NOx emissions.

Large differences between the sectors:

- Road transport large positive contribution
- Ship emission negative contribution
- Aircraft have noticeable positive and negative contributions

Impact of ship emission on tropospheric ozone

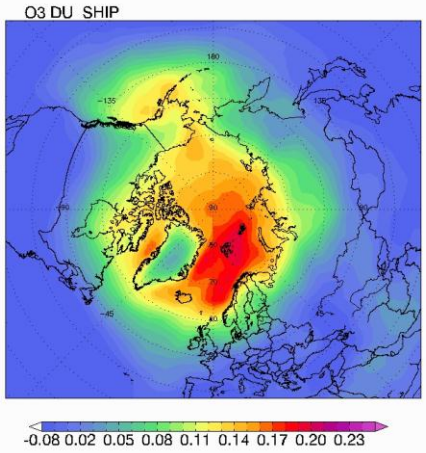


Surface (left) and column (right) ozone change due to year 2000 ship emissions for the months (top left) January, (top right) April, (bottom left) July and (bottom right) October.

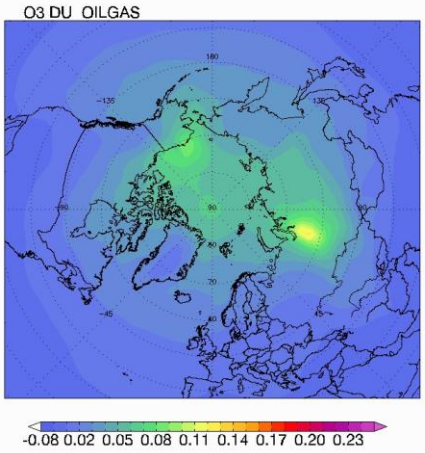
Max tropospheric column change from ship: 10 to 20 %.

Activity in the Arctic:
Current changes in tropospheric ozone columns and in methane

Shipping

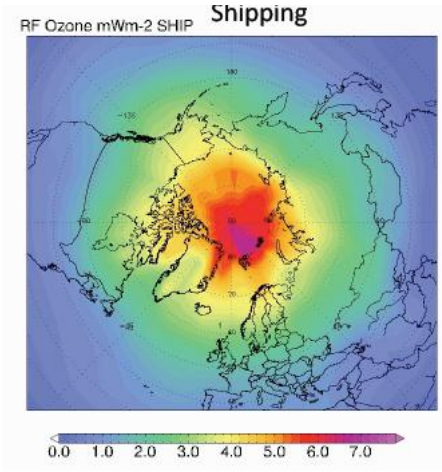


Oil and gas

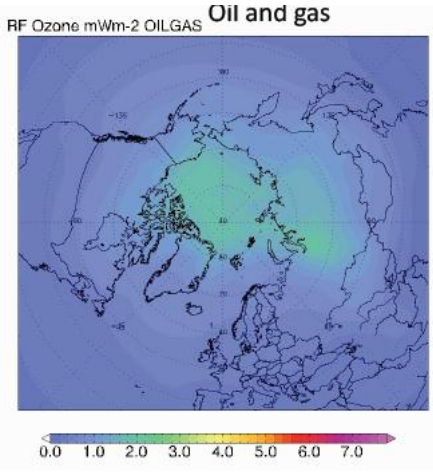


Max ozone column change from shipping ~ 1% of trop. column

Shipping

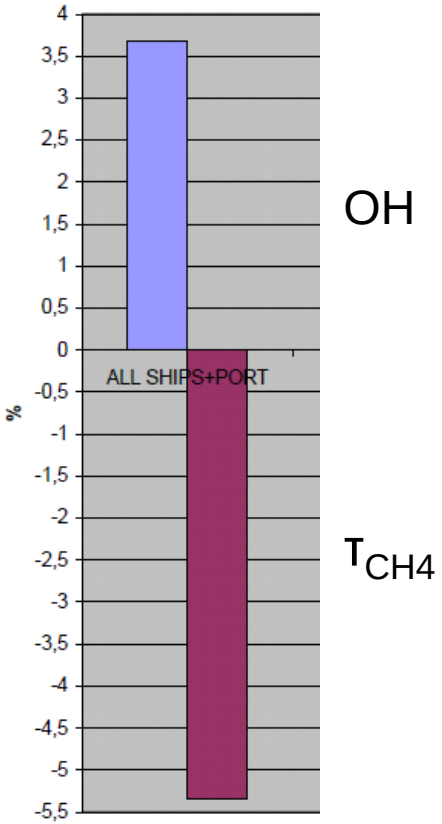


Oil and gas



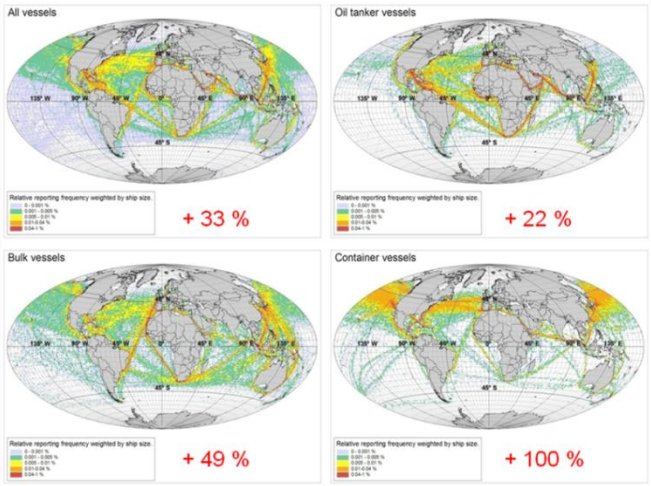
Radiative Forcing from ozone increases in mW/m²

Ship emission impact on methane lifetime



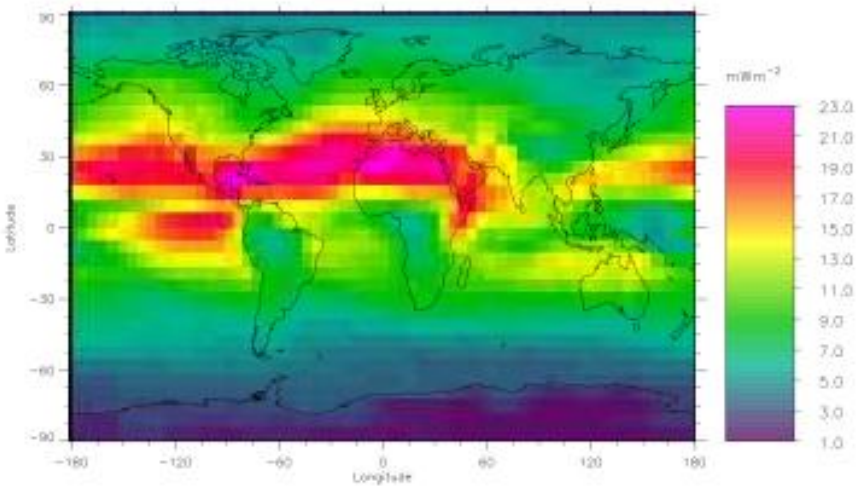
Changes in global average OH and CH_4 lifetime from ship emissions (2000)

Impacts of international ship traffic 2000-2007 on surface ozone and RF

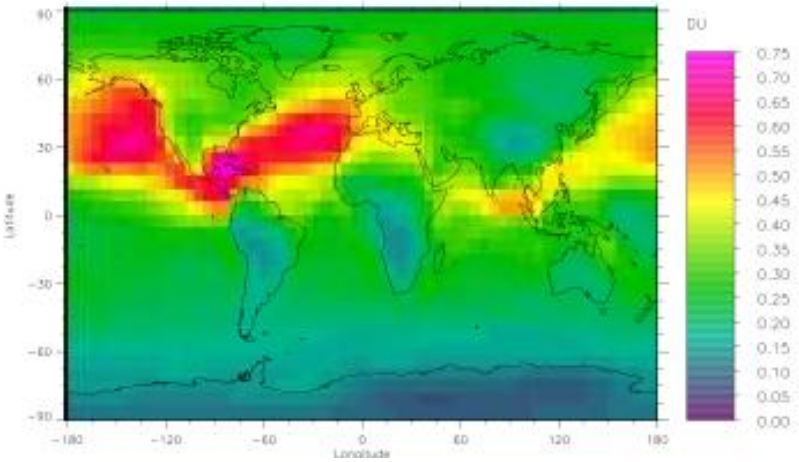


Pattern of vessel traffic densities for year 2001/2002 based on the AMVER (2005) data.

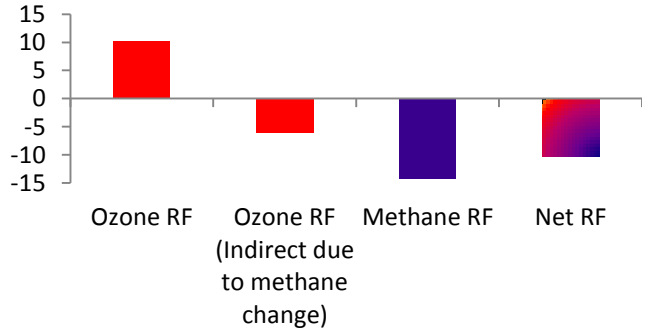
Red numbers denotes the estimated increase in emissions in the period 2000-2007.



Change in Radiative Forcing (RF)



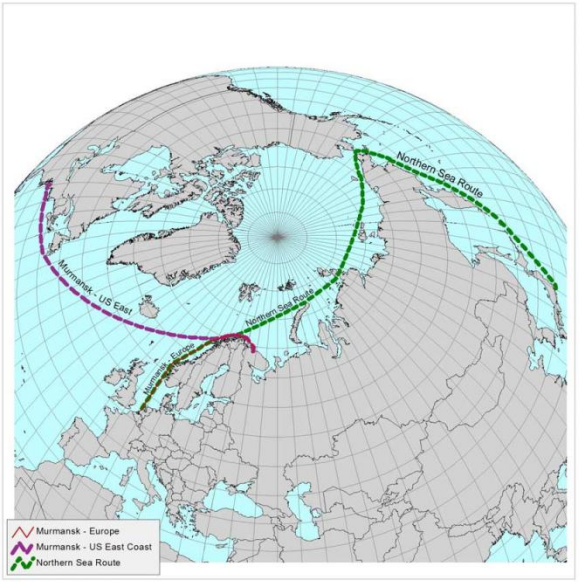
Change in tropospheric ozone column (DU)



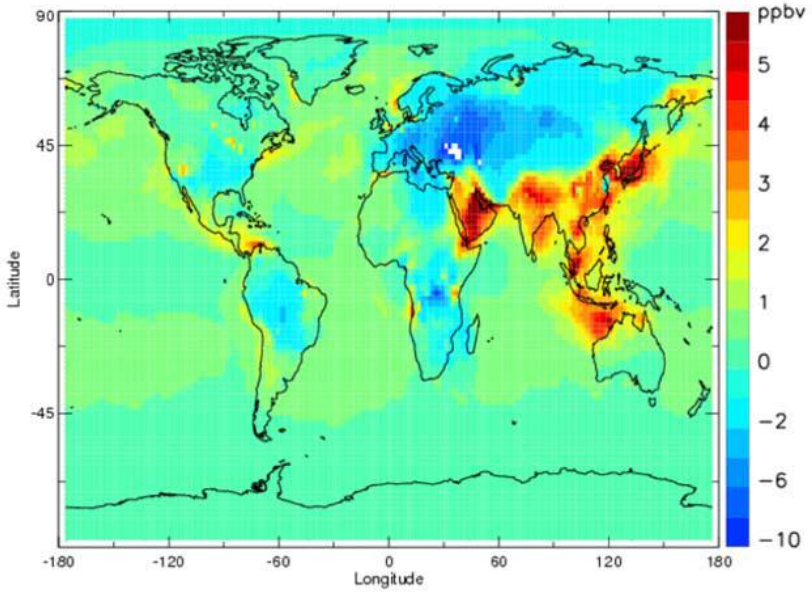
Radiative forcing (RF) of ozone and methane changes due to increasing ship emissions

Dalsøren et al. 2007

Impact of future sea transport



Northern Sea Route, expected oil trades and main ports for the tanker transport in 2015.



Ozone surface change from July 2000 to 2015 from a sensitivity study including both changes in ship emissions and land based anthropogenic sources.

Future chemical impact

- Issues:
  - Climate change
  - Air pollution
  - Interaction air pollution/climate
- Key compounds:
  - O_3, OH (CH_4)
- Processes related to:
  - Emission and emission scenarios (NOx, CO)
  - Regional and sectorwise processes
  - Modelling capability
  - Climate change (Atmospheric processes, emission, deposition)

Impact on chemically active climate gases in a warmer climate

Permafrost thawing with enhanced emission of CH_4

- Long term impact on global climate

Ozone increase during frequent high pressure systems

- Regional pollution

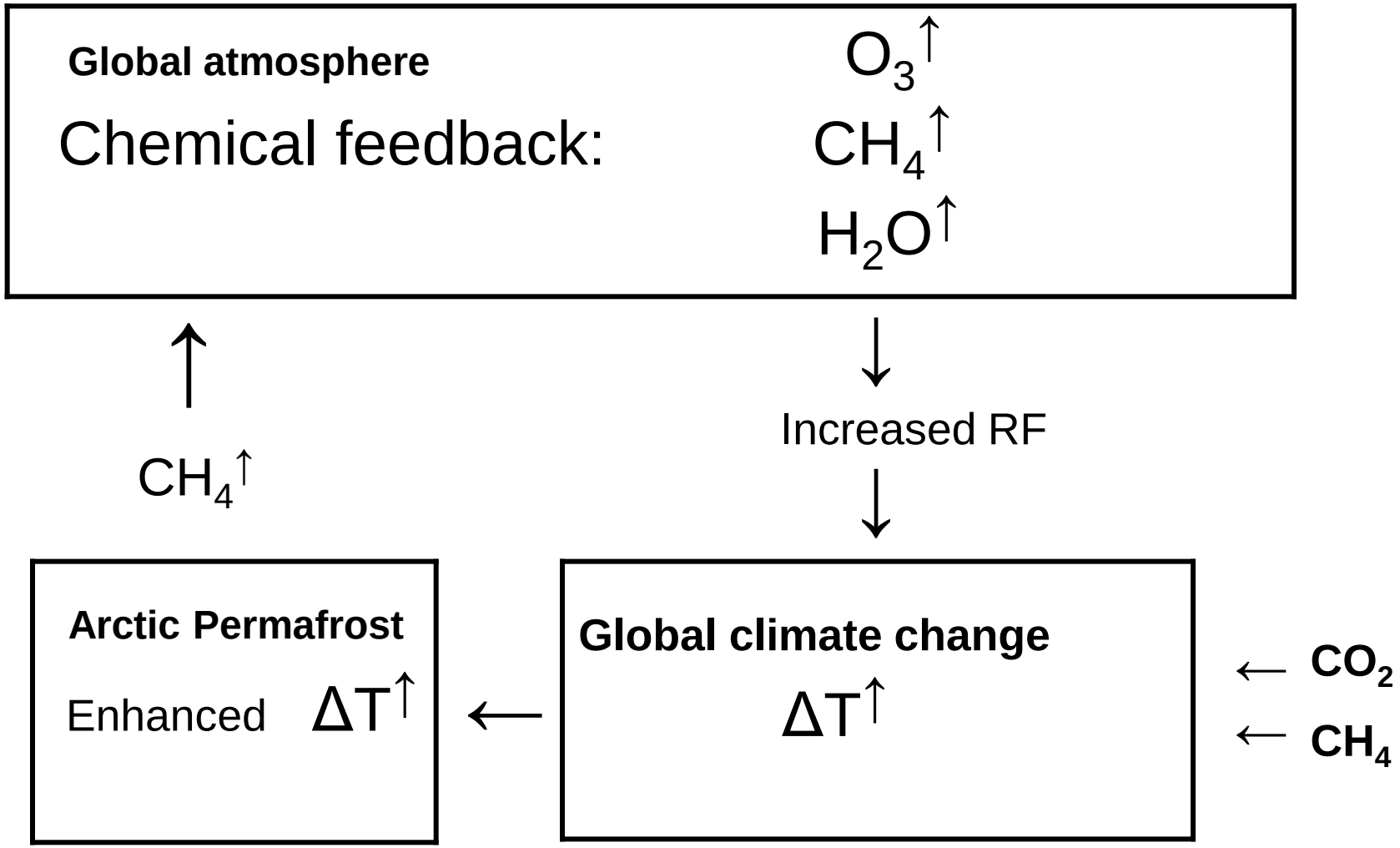
Warmer climate

- Enhanced permafrost thawing→ Release of greenhouse compounds (CH_4, CO_2)
- More severe pollution episodes (ozone, particles)
- Changes in emission of biogene compounds (isoprene, nitrogen oxides)
- Changes in atmospheric oxidation (increaced OH → reduced CH_4)

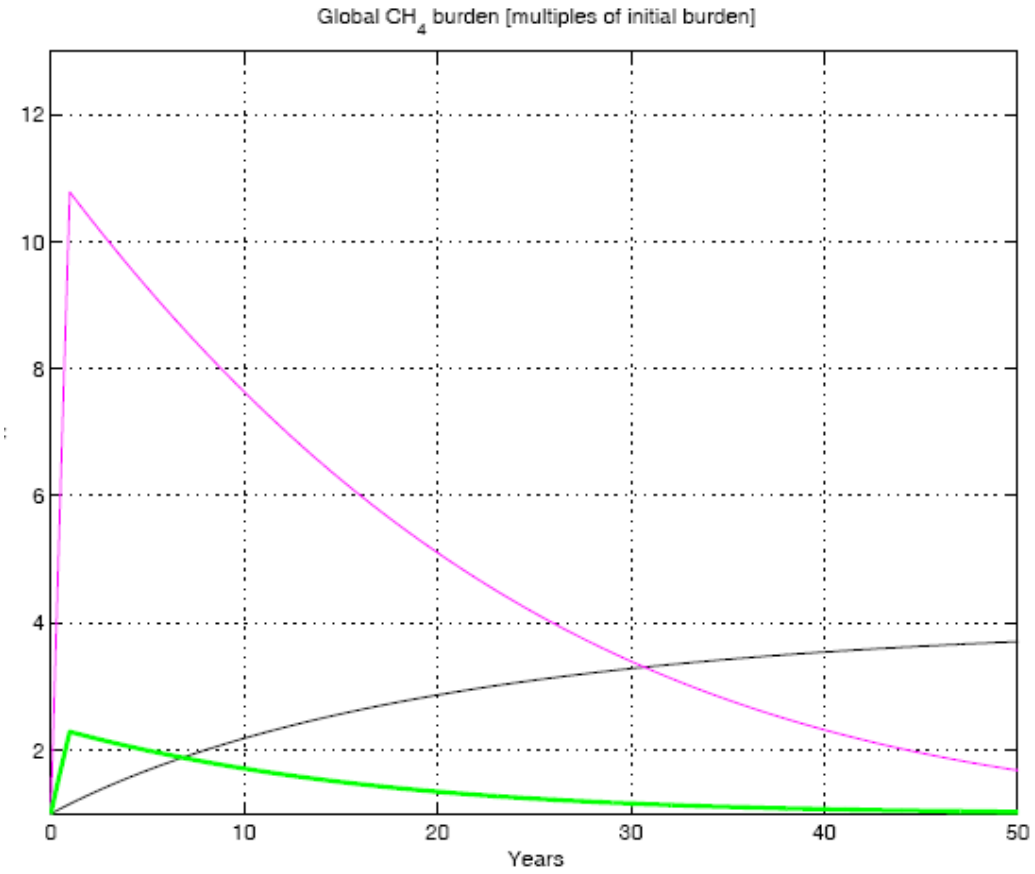
Atmospheric chemical changes non linear

- Not a 1 to 1 relation between release and atmospheric changes (CH_4 a factor 1.5)
- Formation of secondary compounds (O_3, sulfat) depends on precursors

Impact on climate from permafrost thawing



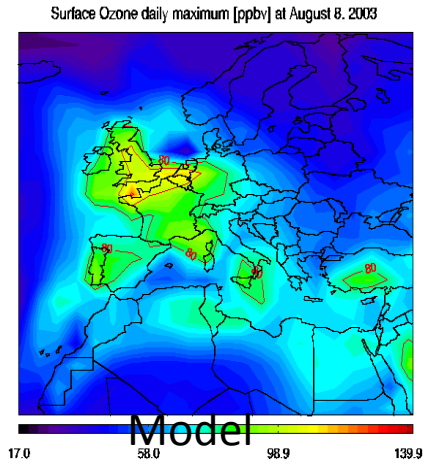
Methane emissions in the Arctic during permafrost thawing



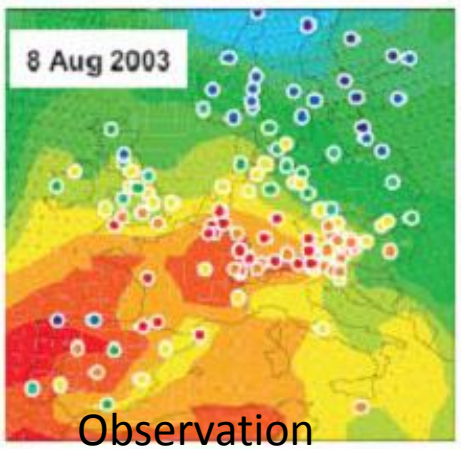
Max RF for a pulse of 5 Gt: 1.1 W/m^2

Global metane increase for pulses of 5 Gt (green), 50 Gt (lilac), and continous emission of 0.8 Gt/year (black**)**

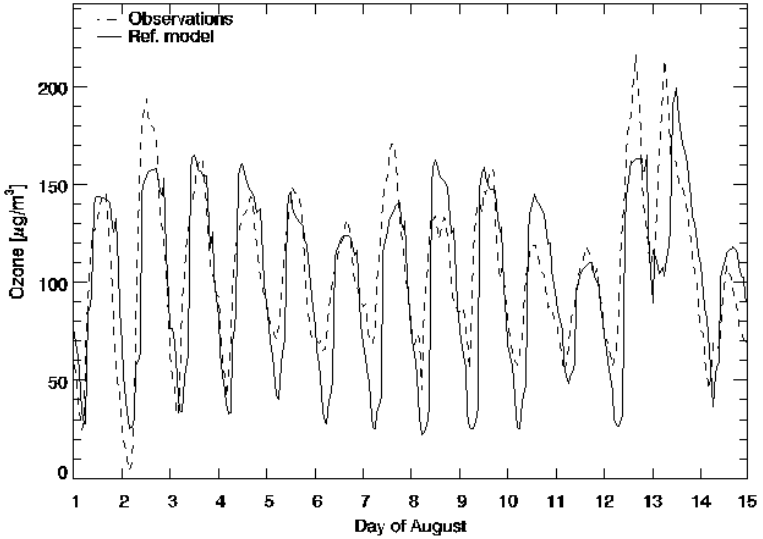
Possibel effect of a warmer climate:
Enhanced surface ozone during the August 2003 heat wave



Model



Observation



Extremely high surface ozone and paticle levels over Western Europe

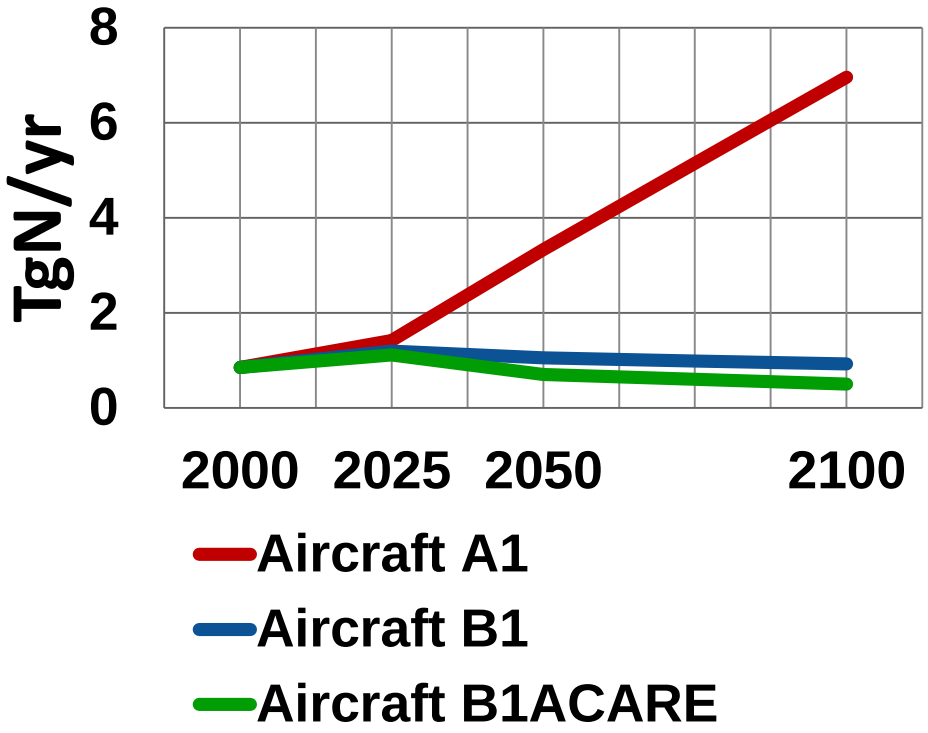
Enhanced mortality

More frequent during a future warmer climate?

Observed and modeled surface ozone for one European stations (in ppb)

Søvde (2008)

Large uncertainties with future scenarios: Aircraft NO_X emission scenarios ifrom the QUANTIFY project



Large differences in scenarios of future emissions

- Potential for significant emission reductions

Final comment on future studies of impact and adaptation of control measures

A key question for estimates of future impact is the adoption of realistic emission scenarios

- Even on a time scale of a few decades scenarios show a wide spread in the scenarios

Estimatees of climate contribution require studies of the compounds with highly different lifetimes

- Appropriate metricies need to be adopted

Several key compounds involved in climate change are affected by atmospheric chemistry

- The role of climate-chemistry interaction need to be better understood

Adaptation of control measures to reduce the climate impact require a sectorwise approach

- Sectors emit different compounds with different climate impact, and emissions occur in different regions