Climate Impact of Aviation: Issues and present Assessment

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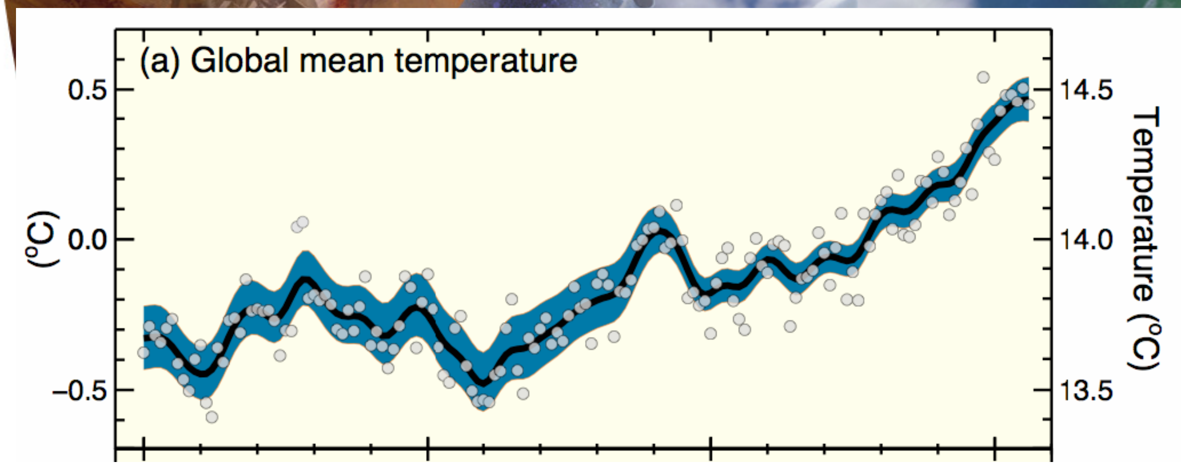
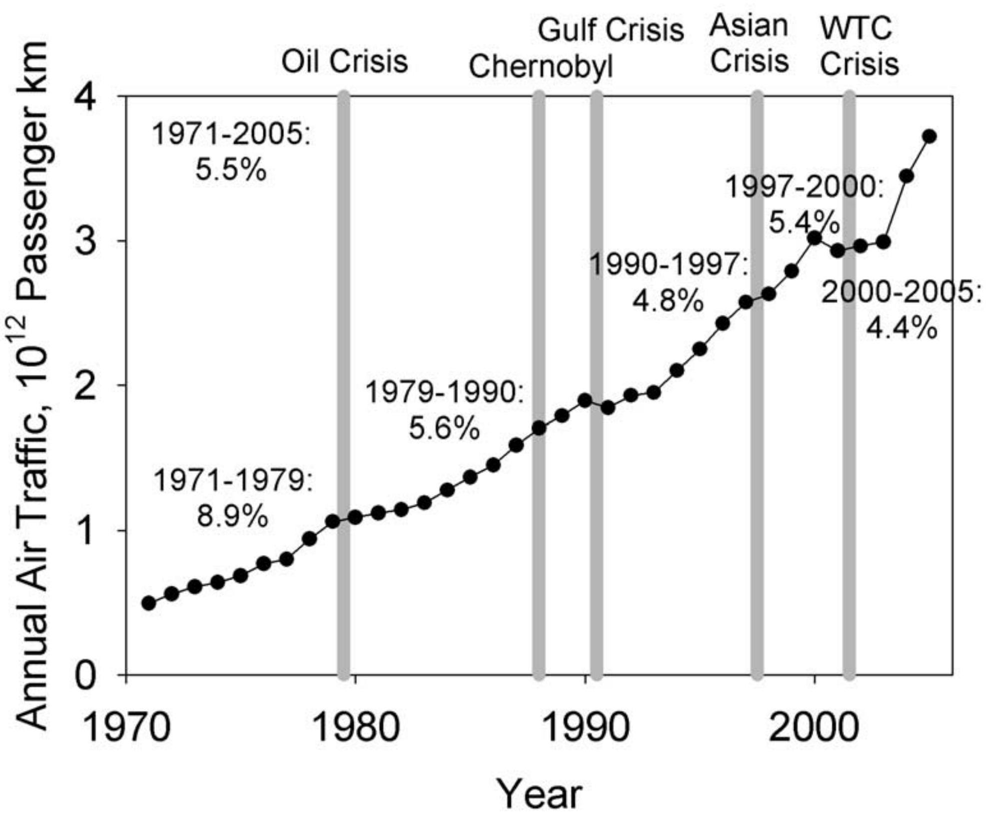




Introduction

This presentation is based on research since 1992, IPCC (1999, 2007), and several DLR, EU and EU/US projects

Issue: What is the aviation contribution to climate change

Previous talk (IPCC result):

- **Global warming is a reality**
- **Climate protection requires considerable reductions in greenhouse gas emissions from all sources within a few decades**

Climate Impact of Aviation

Global aviation contributes to climate change by emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x), water vapour, particles, contrails and cirrus changes.

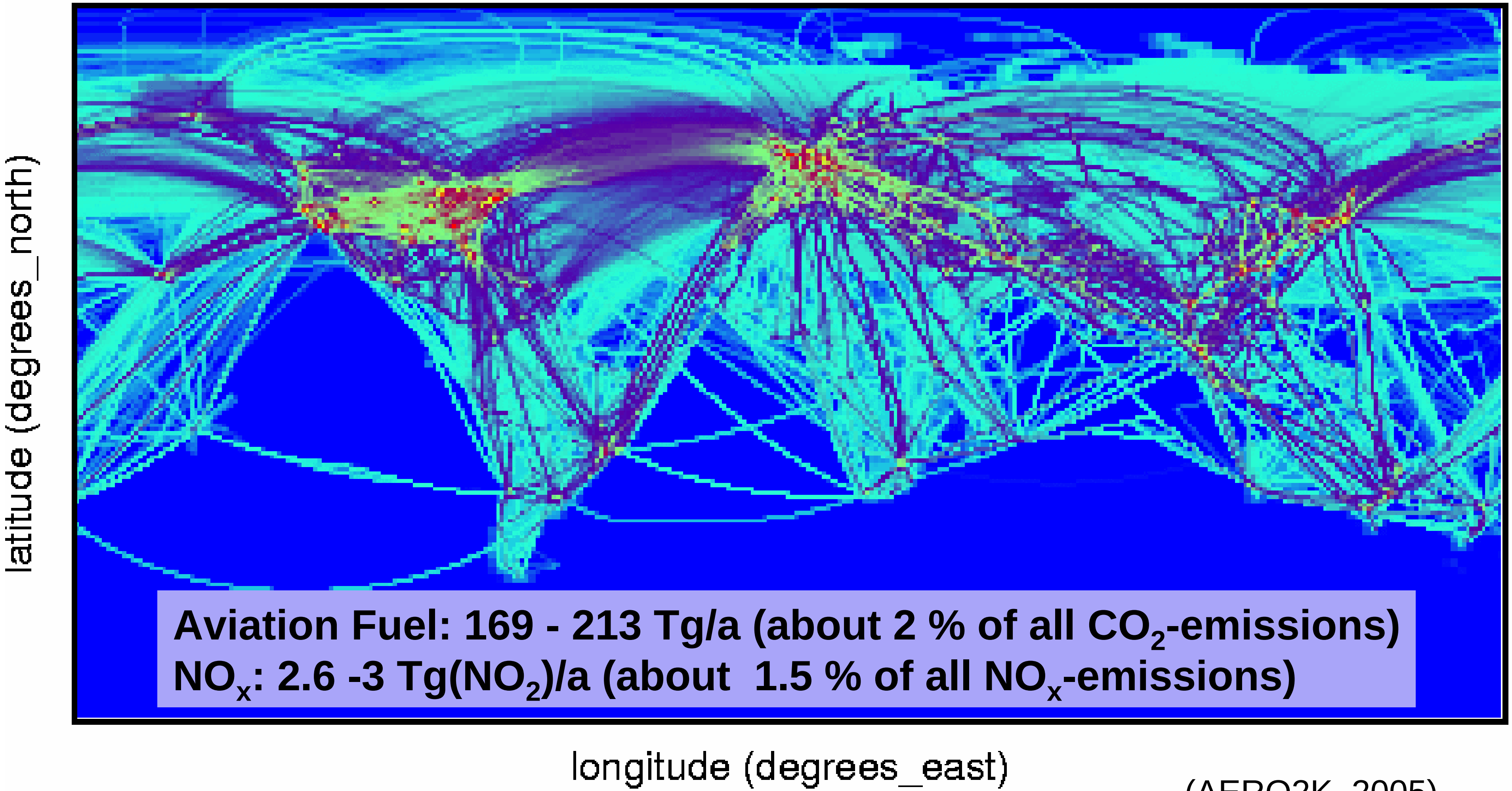
Carbon dioxide is the most important greenhouse gas. Its effect is independent of the altitude at which the emission occurs.

Nitrogen oxides from aviation at subsonic cruise altitudes enhance ozone formation and reduce methane; both are greenhouse gases.

Water vapour and particles (soot etc.) emitted at altitudes near the tropopause can induce contrails and cirrus cloud formation, likely enhancing the greenhouse effect.

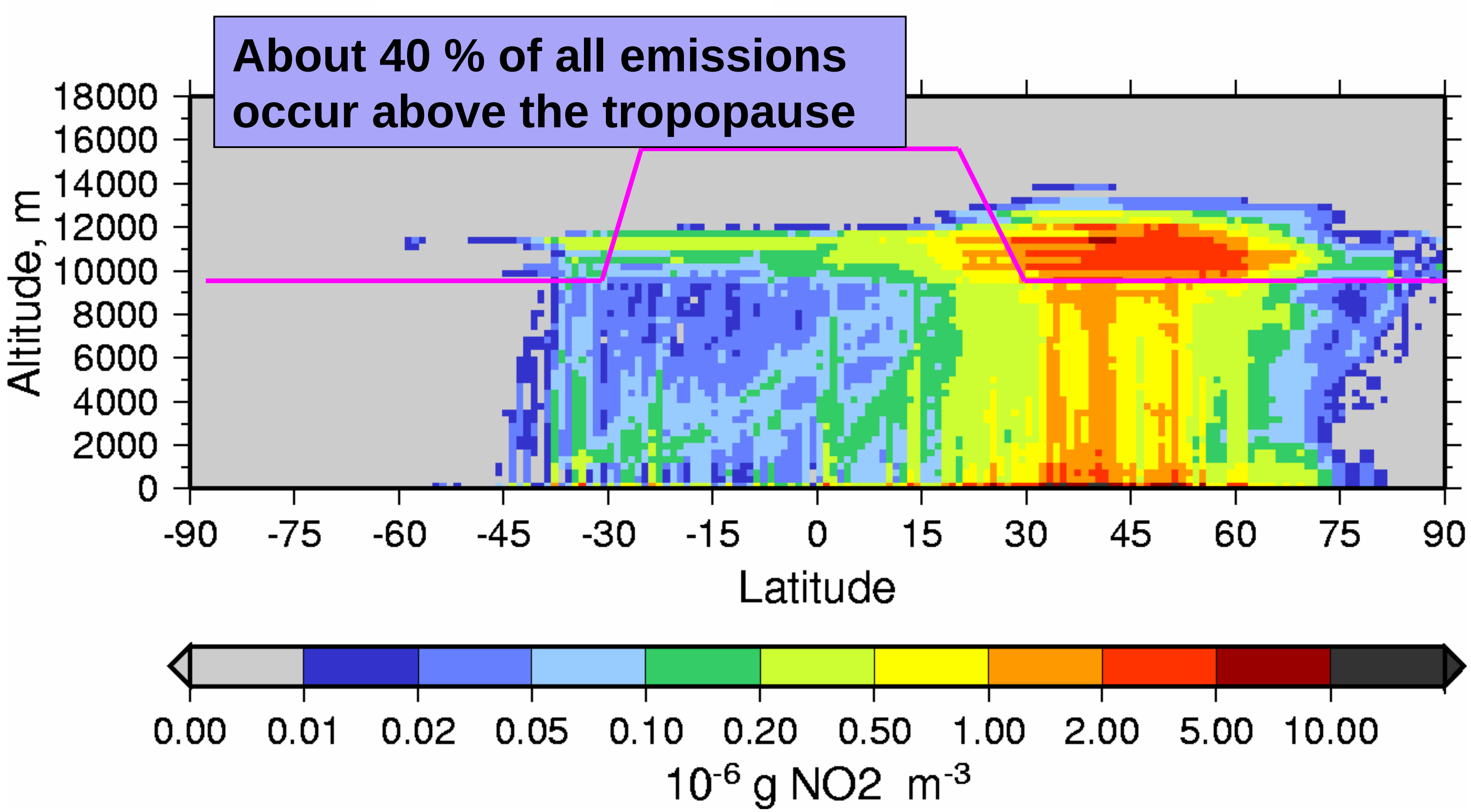
Because of different lifetimes (CO_2: order 60 years, NO_x and H2O: order 1 week, contrails: order hours) the impact depends on the periods and scenarios considered

Global distribution of aviation emissions



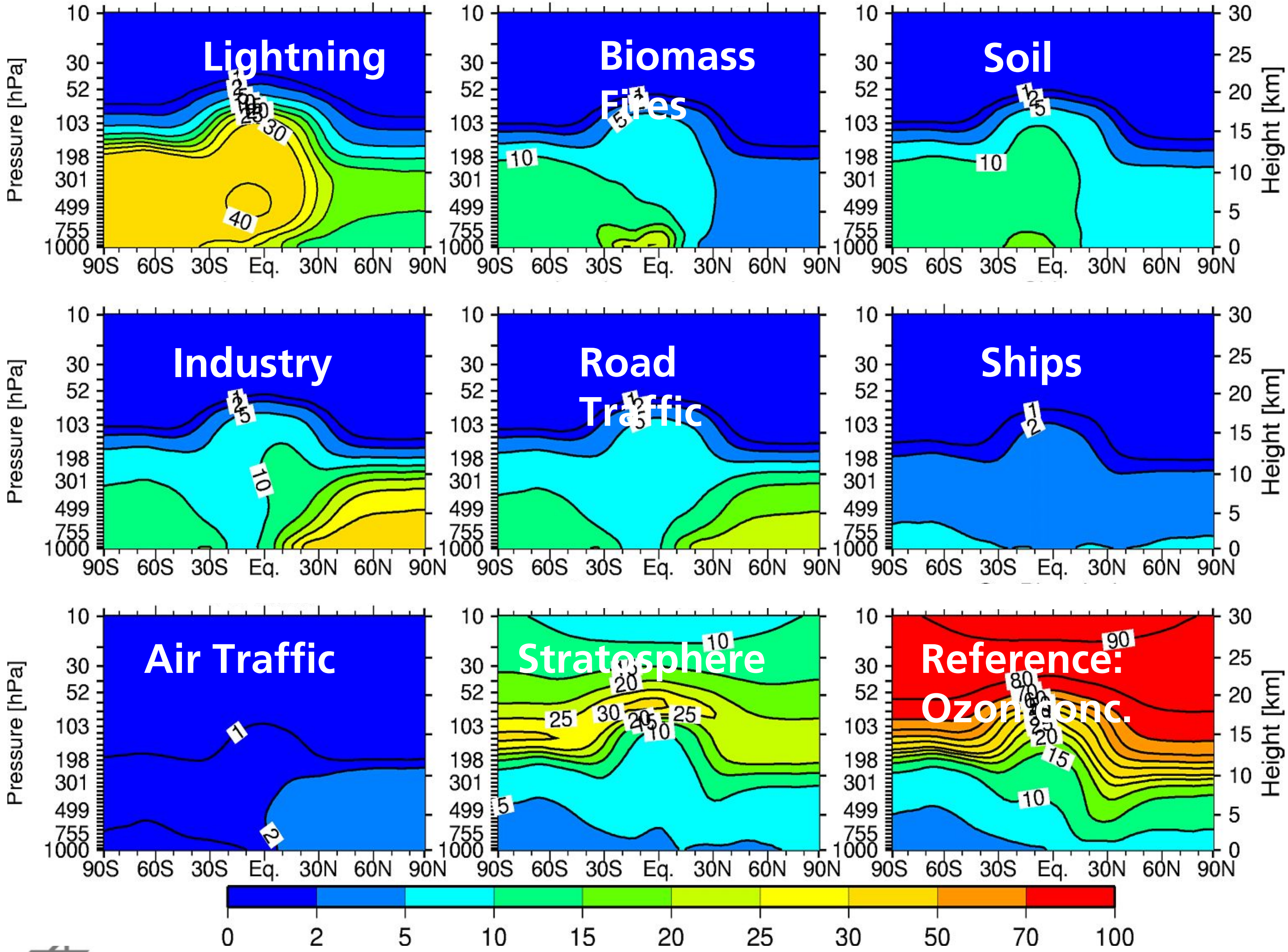
(AERO2K, 2005)

Vertical Distribution of Aircraft Emissions and Tropopause



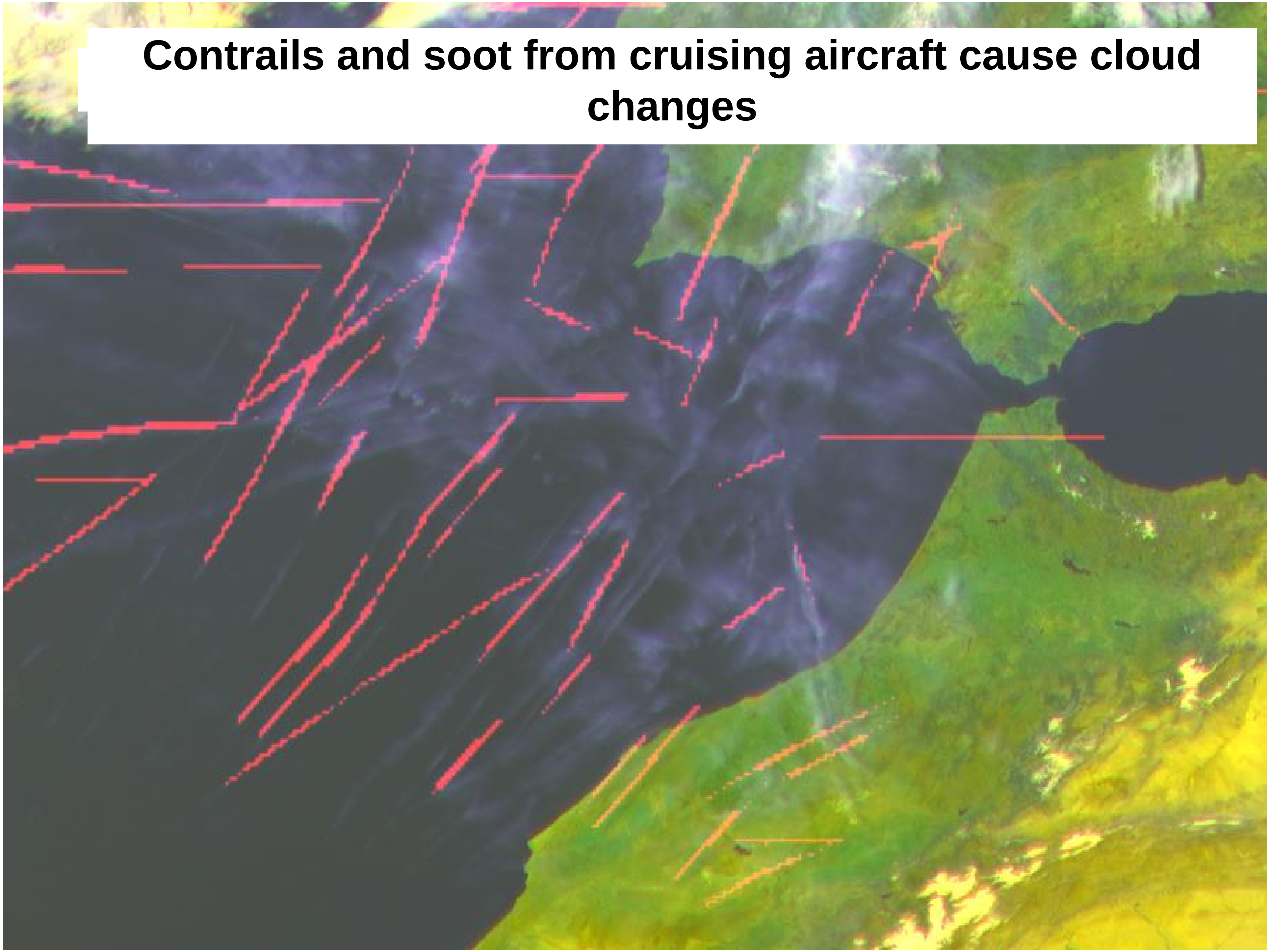
(AERO2K, 2005)

O_3-contribution (%) from aviation and other NOx sources



(Grewe, DLR, 2007)

Contrails and soot from cruising aircraft cause cloud changes



Contrails and soot from cruising aircraft cause cloud changes

Contrails are caused by water vapor emissions from aircraft flying in cold and humid air masses

Contrails evolve into “contrail cirrus” in humid air masses

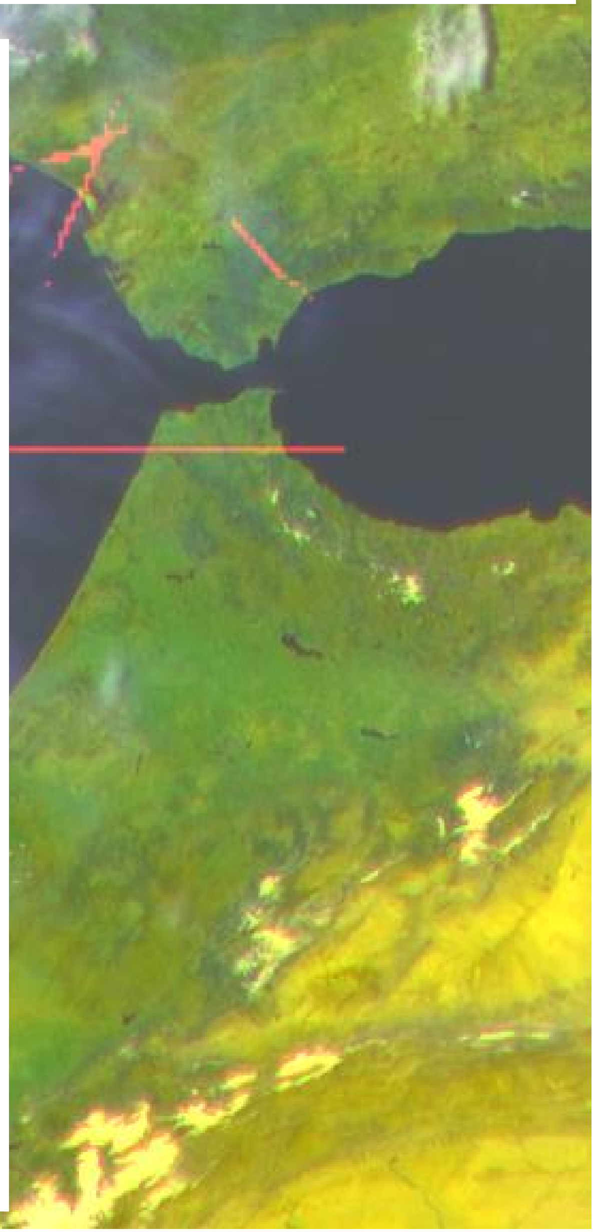
Soot and other particles change contrails and cirrus properties and may cause cirrus far away from air routes (“soot cirrus”)

Line-shaped contrails are detectable from space

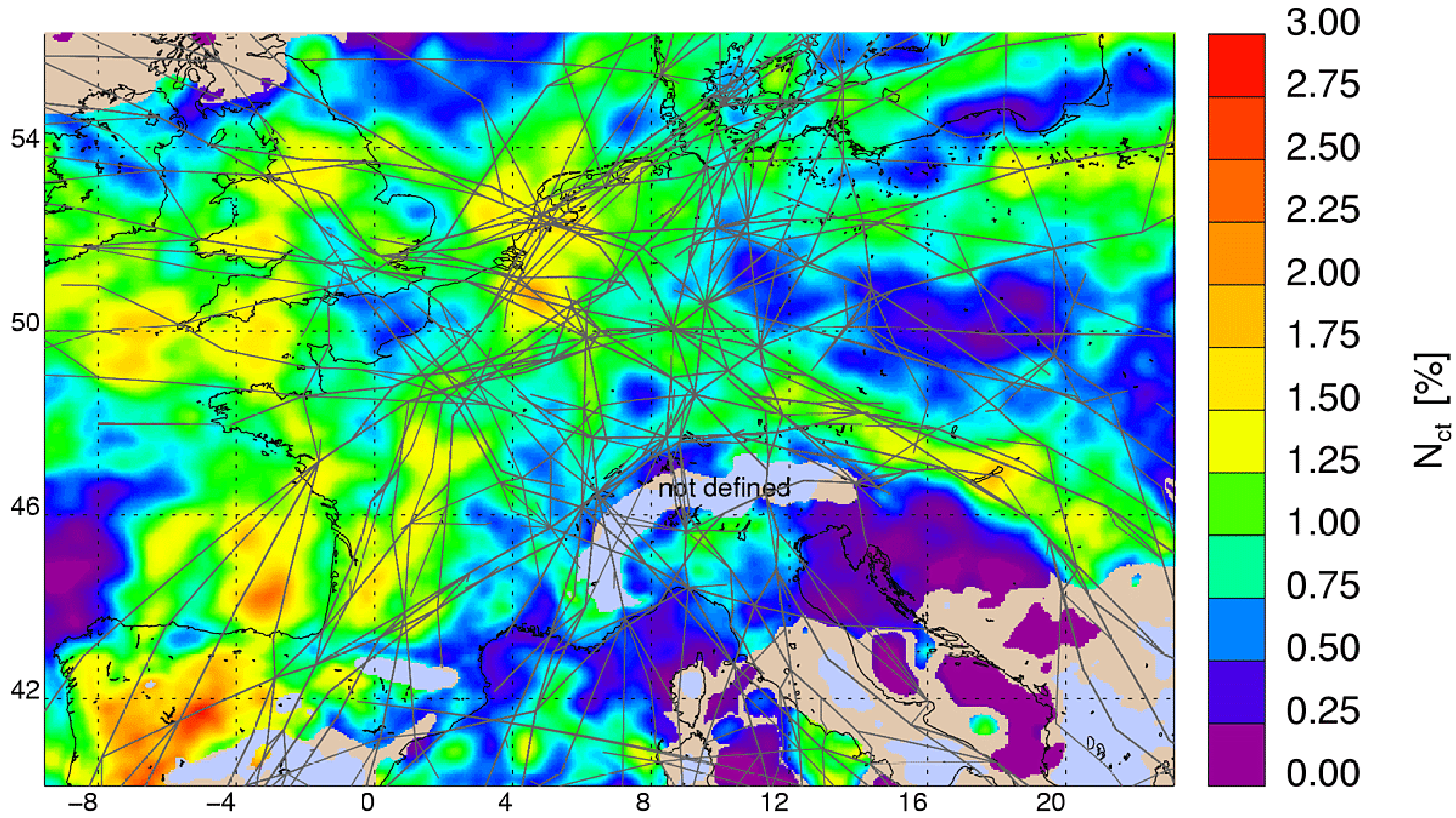
The total cirrus change is estimated with still large uncertainty

Cirrus and contrails heat during night

They heat or cool during day

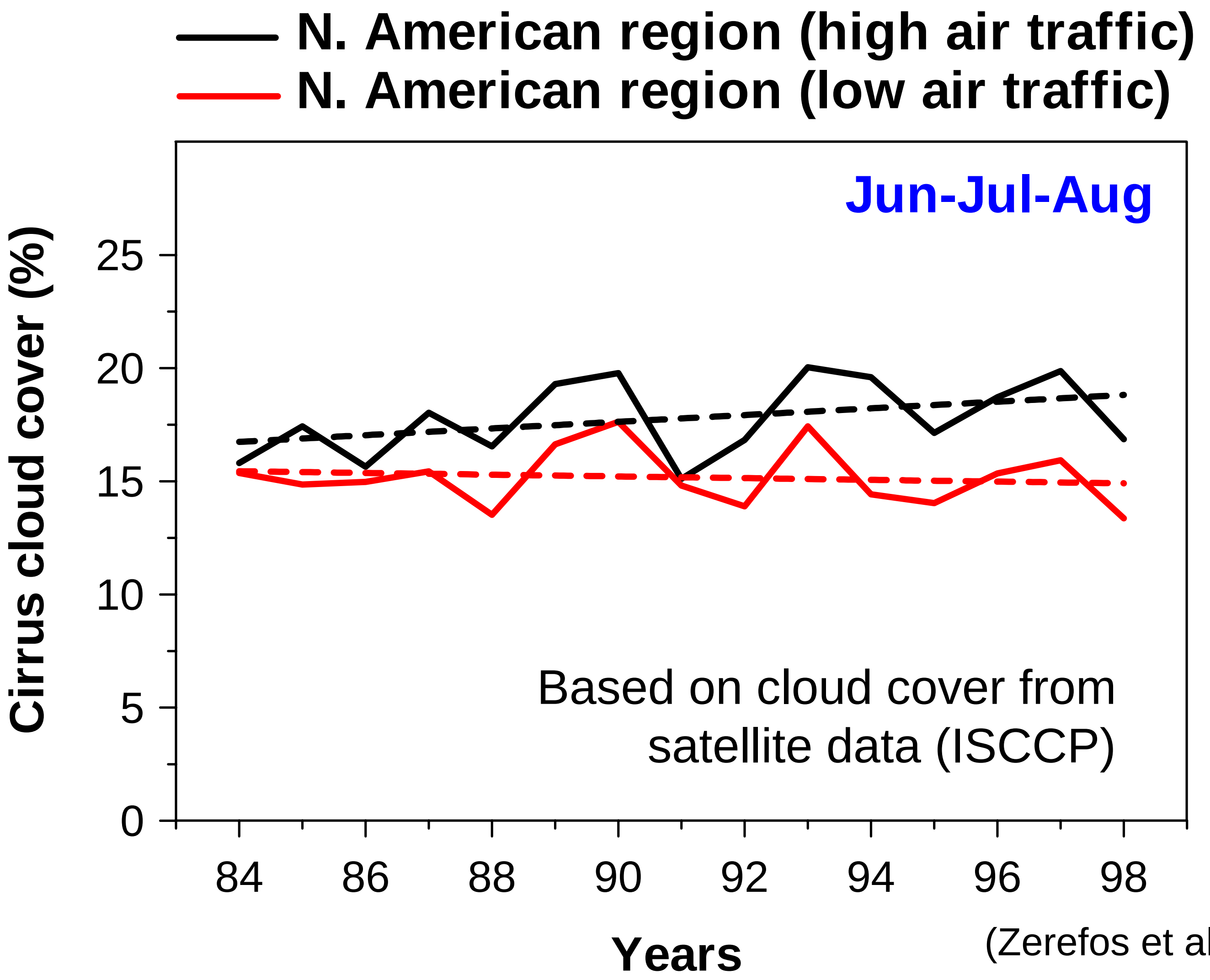


Line-shaped contrail cover: 0.5 % of Europe



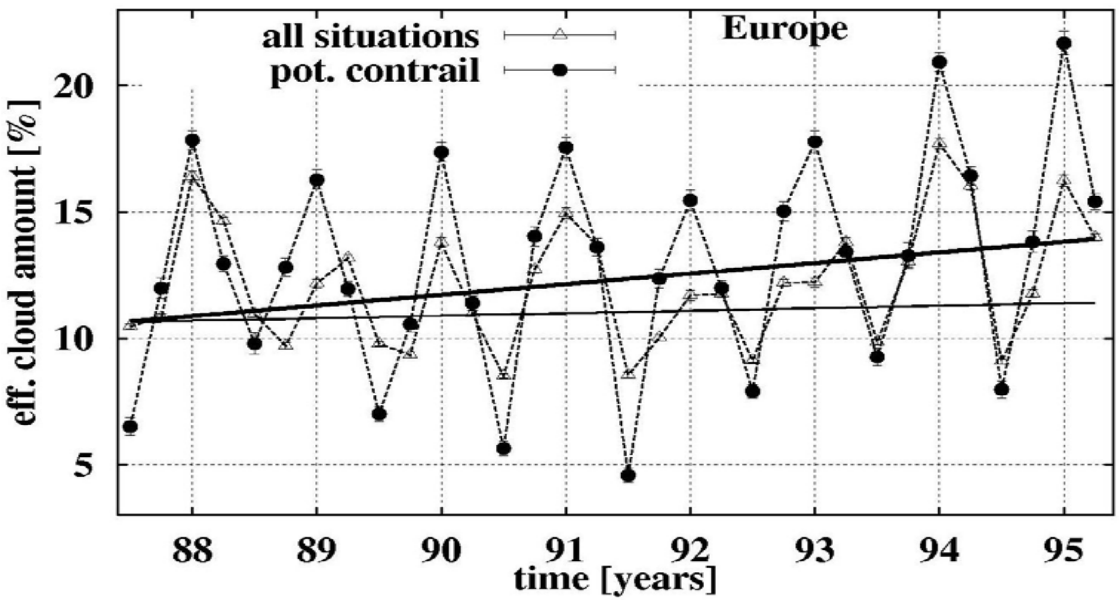
(Meyer et al., DLR, 2002, 2007)

Cirrus Cloud Cover Trends from Satellite Data: 2%/decade



(Zerefos et al., 2003)

Contrail Cirrus Trends from Satellite Data: 0.2%/decade



Data from TOVS satellite data

No trend for cirrus in all situations

Positive trend of cirrus cover for atmospheric situations favorable for contrail formation

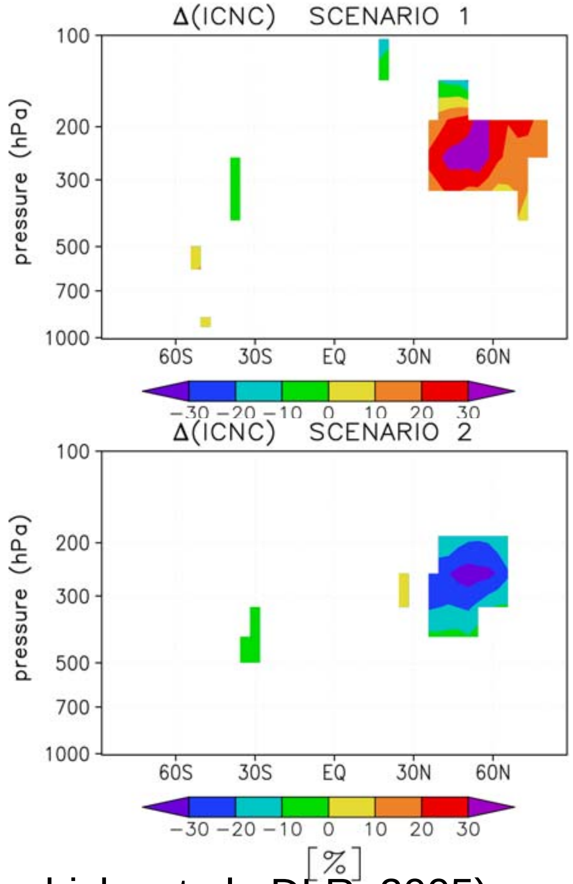
(Stubenrauch und Schumann, 2005)

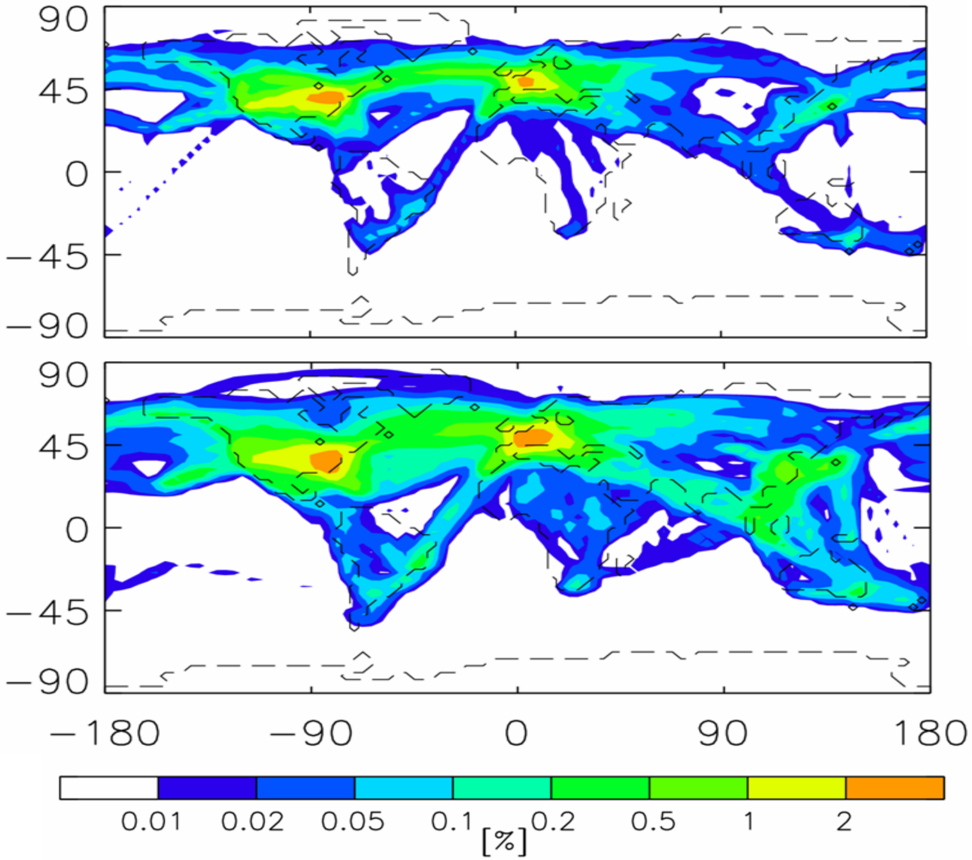
Soot impact and contrail-cirrus formation modeled

Soot impact on cirrus for two extreme nucleation models

Fresh and aged contrail cirrus

homogeneous - heterogeneous

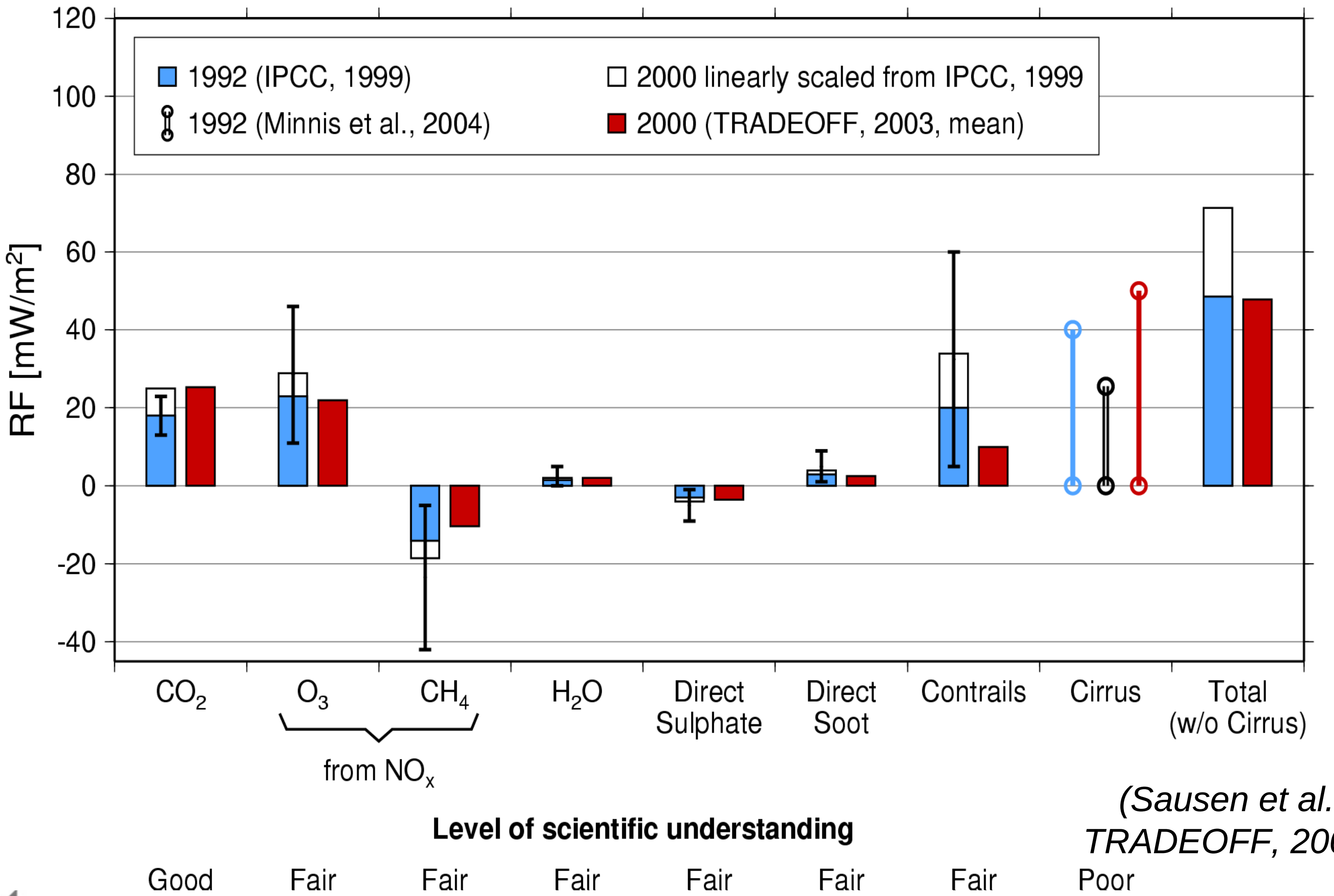




(Hendricks et al., DLR, 2005)

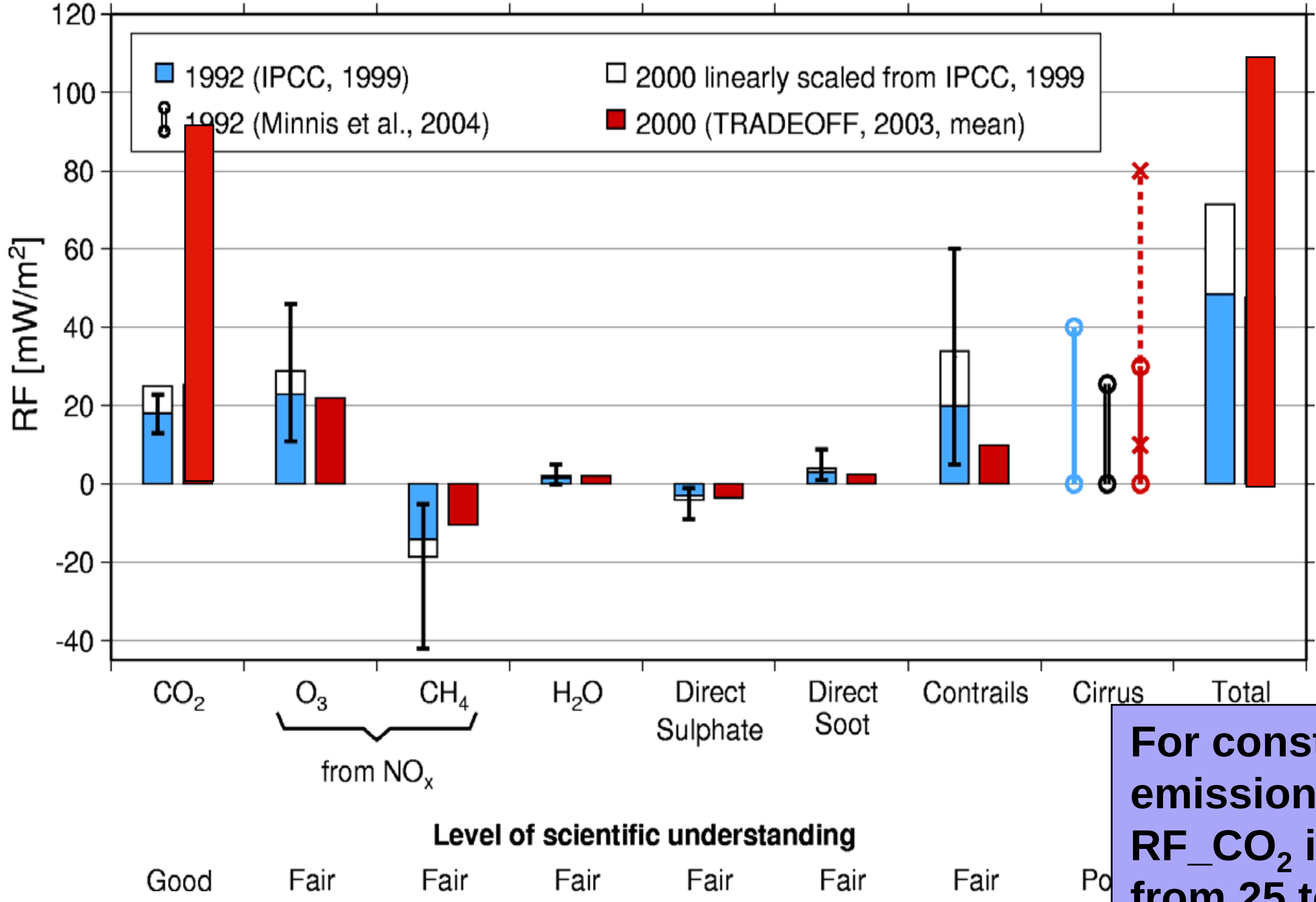
(Burkhardt & Kärcher, DLR, in preparation)

Radiative Forcing until 2000 from Global Aviation



(Sausen et al., TRADEOFF, 2005)

Radiative Forcing until 2100 for constant emissions



For constant aviation emissions:
RF_CO_2 increases from 25 to 90 mW m^{-2} (Forster et al., 2006)

Radiative Forcing and Temperature Change induced by Aviation

Global aviation contributed to Radiative Forcing so far about 0.05 W/m^2.

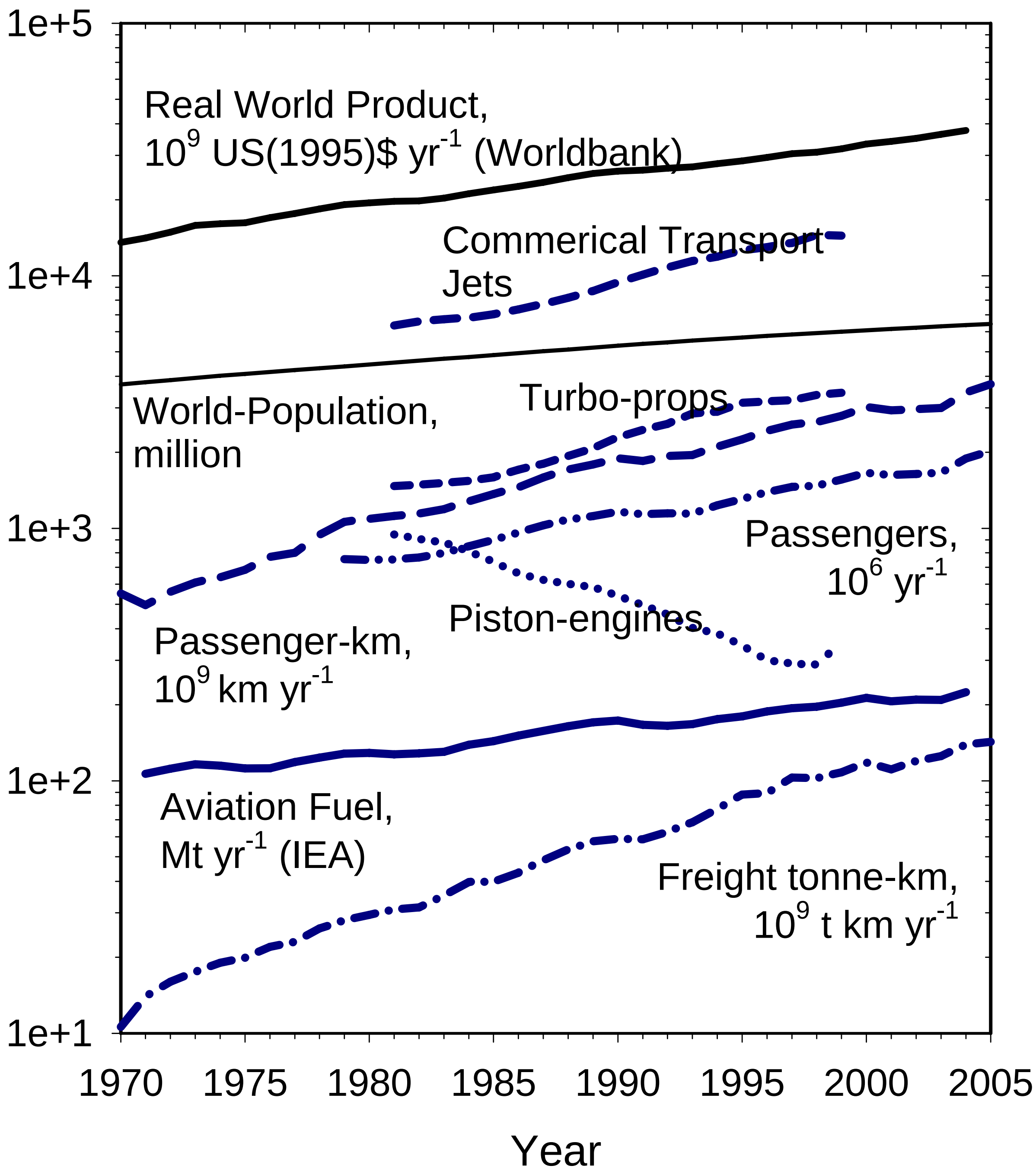
These are about 3 % of the total radiative forcing from all anthropogenic effects as assessed in IPCC (2007).

Global aviation contributed to the observed global warming of 0.7°C about 0.03°C (ca. 4 %).

Very little uncertainty on aviation CO_2 impact. CO_2 emissions reduction has highest priority in the long term.

The largest uncertainty comes from aviation contributions to changes in cirrus clouds, which are not included in the total therefore.

Including the presently know uncertainties, the aviation contribution is estimated within the range 2 to 8 %.



Trends

1991-2004:

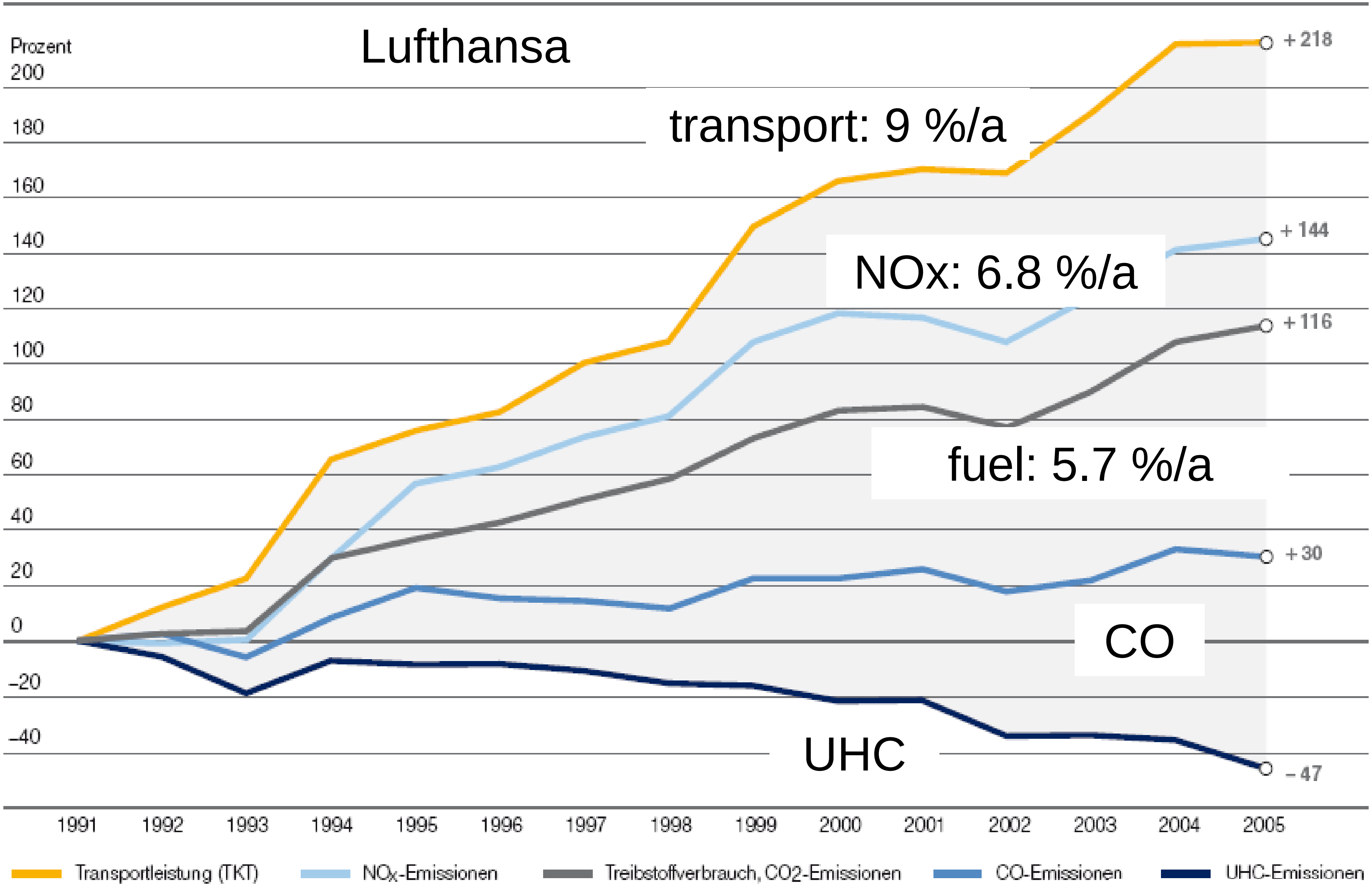
Passenger-km: 4.6 %/a

Freight-km: 6.4 %/a

Kerosene: 2.1 %/a

(Schumann, 2007)

Entkopplung von Transportleistung und Umweltbelastung
Veränderung gegenüber 1991 in Prozent, Angaben für die Flotte des Lufthansa-Konzerns



(Lufthansa, 2006)

Trends

Aviation fuel consumption (CO_2 emissions) grew globally by 2-3 % per year from 1990 – 2004.

Aviation NOx emissions grew by 4-5 %/year from 1990 – 2004.

For the near future, further growth of global fuel consumption and global emissions of CO2 and NOx is to be expected.

Scenarios of civil aviation CO_2 emissions in 2050 show a potential increase by factors 3.3 - 5 (see David Lee)

If aviation emissions continue to grow while other emissions get reduced, the relative importance of aviation contributions grows

CO_2 emissions reduction has highest priority in the long term.

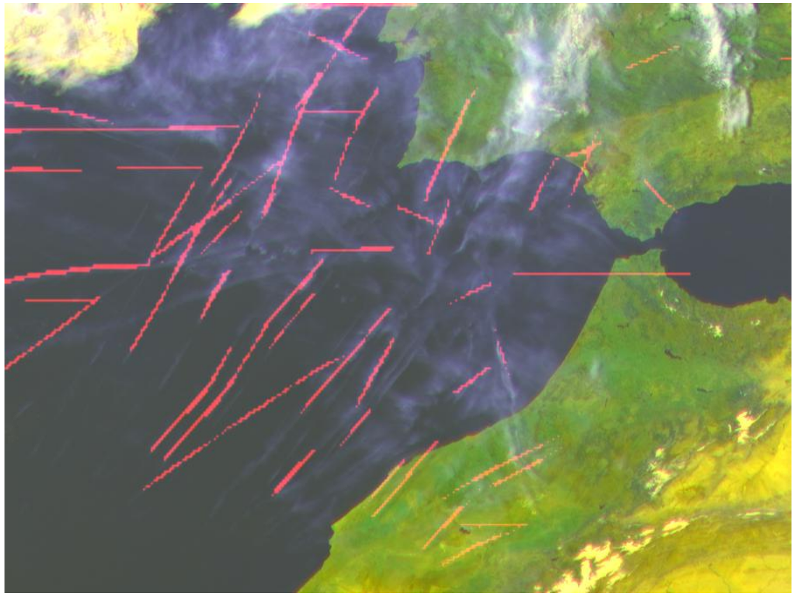
Reductions of NOx and contrails has largest impact on climate mitigation at short term.

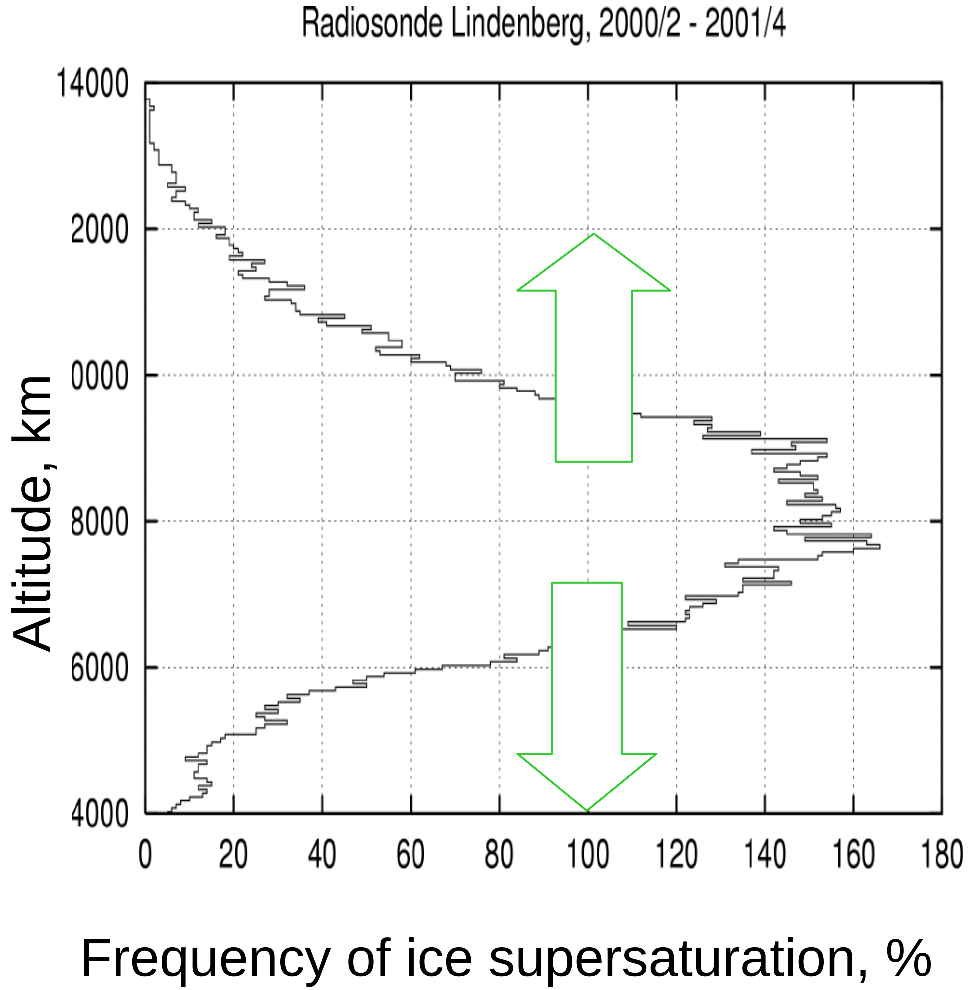
What can be done to avoid contrails?

Improved engines to not reduce contrails

(Photo and explanation: Schumann, *Aerosp. Sci. Techn*. 2000)

Fly higher or fly lower?



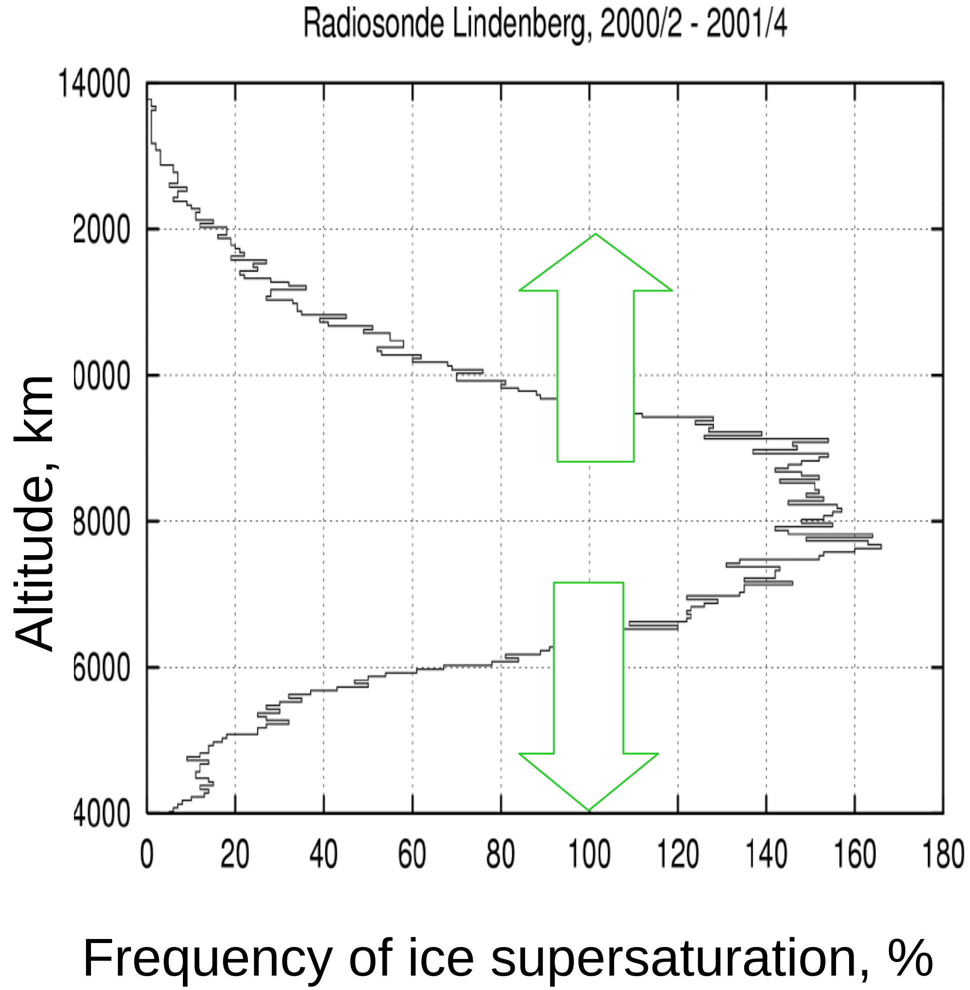


(Spichtinger et al., DLR, 2003)

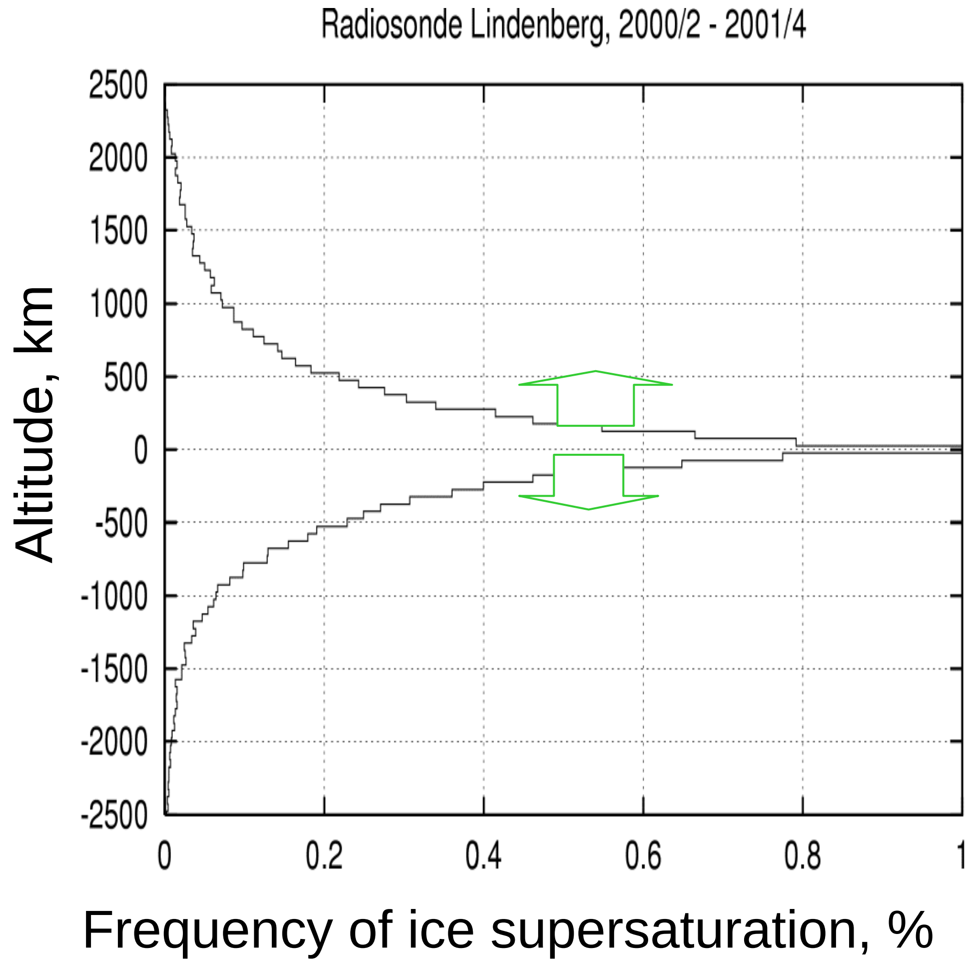
Fly higher or fly lower?

Vertical distribution of all ice-supersaturated regions

Required altitude change: 2 km



Fly higher or fly lower?



Vertical distribution of individual ice-supersaturated regions

Required altitude change: 300 m

Conclusions

The aviation share in CO_2 emissions is presently about 2 %

CO_2 is the most important greenhouse gas. Its effect is independent of the emission altitude. Its radiative forcing is well assessed.

NOx from aviation enhance O_3 and reduceCH_4. The radiative forcing has been assessed with fair certainty.

Water vapour and particles (soot etc.) emitted in cold and humid air induce contrails and cirrus clouds. Contrail cirrus may form largest RF-contribution.

The aviation share in radiative forcing is presently 3 % (range 2-8%)

The relative importance of short-lived (NO_x, contrails) and long-lived (CO_2) emissions depends on the scenario and choice of timescale

Possible mitigation options include: aircraft/engine with less emissions, fuel saving operation, contrail-avoiding routing

Reducing short-lived emissions (NOx, soot, contrails) may be more effective for climate mitigation than reducing long-lived effects (CO_2).