Climate impact of contrail and contrail cirrus

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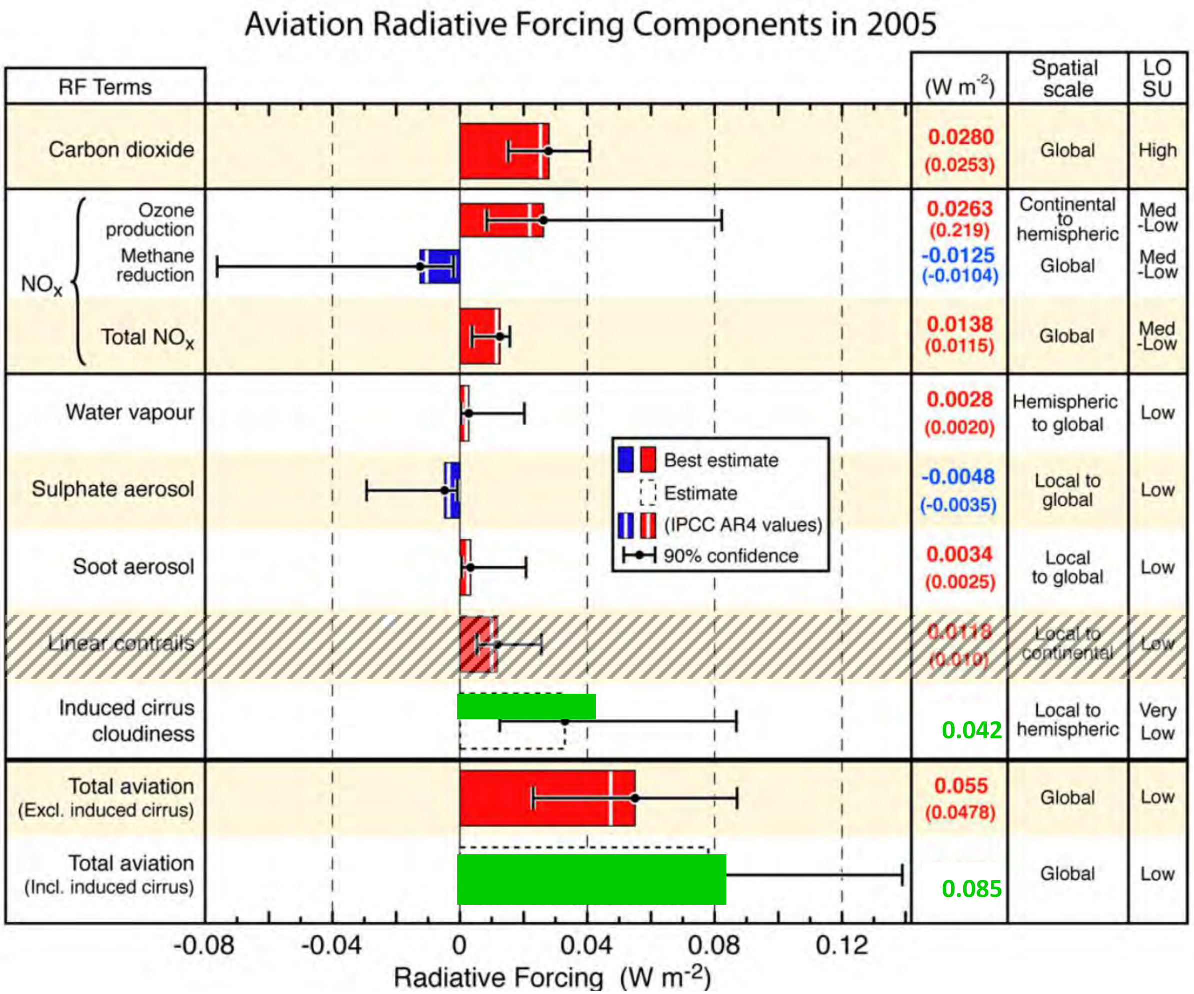
Climate impact of current air traffic (2005)



Main contributors:
Contrails
CO_2
NO_x

3.5-5.0% of warming attributed to air traffic

Lee et al., 2009

updated with Burkhardt&Kärcher, 2011 (for 2002 air traffic)
Schumann et al., 2015: 63 mW/m2
Chen et al., 2012

Contrail Cirrus in a climate model

ECHAM 5 - German community climate model

CCMod - Simulation of a new cloud class: persistent contrail cirrus

- prognostic treatment of contrail cirrus volume, cover and length (V, B, L), IWC (q) and ice crystal number concentration (n)
- microphysical 2-moment-scheme
- formation when Schmidt-Appleman criterion exceeded
- persistence in cloud-free ice supersaturated areas
- simulation of contrail cirrus life cycle and atmospheric feedbacks
- stratosphere adjusted radiative forcing

Bock and Burkhardt, JGR, 2016a

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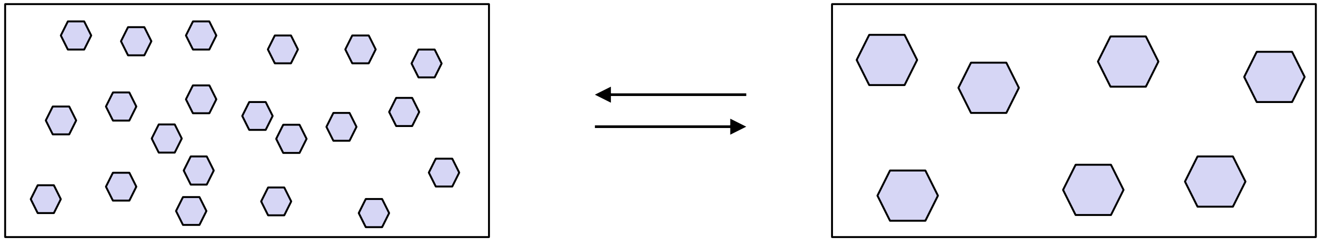
Introduction of microphysical 2-moment-scheme



many small crystals | few big crystals

Allows the simulation of many tiny ice crystals within contrails

→decreased sedimentation → increased ice water content

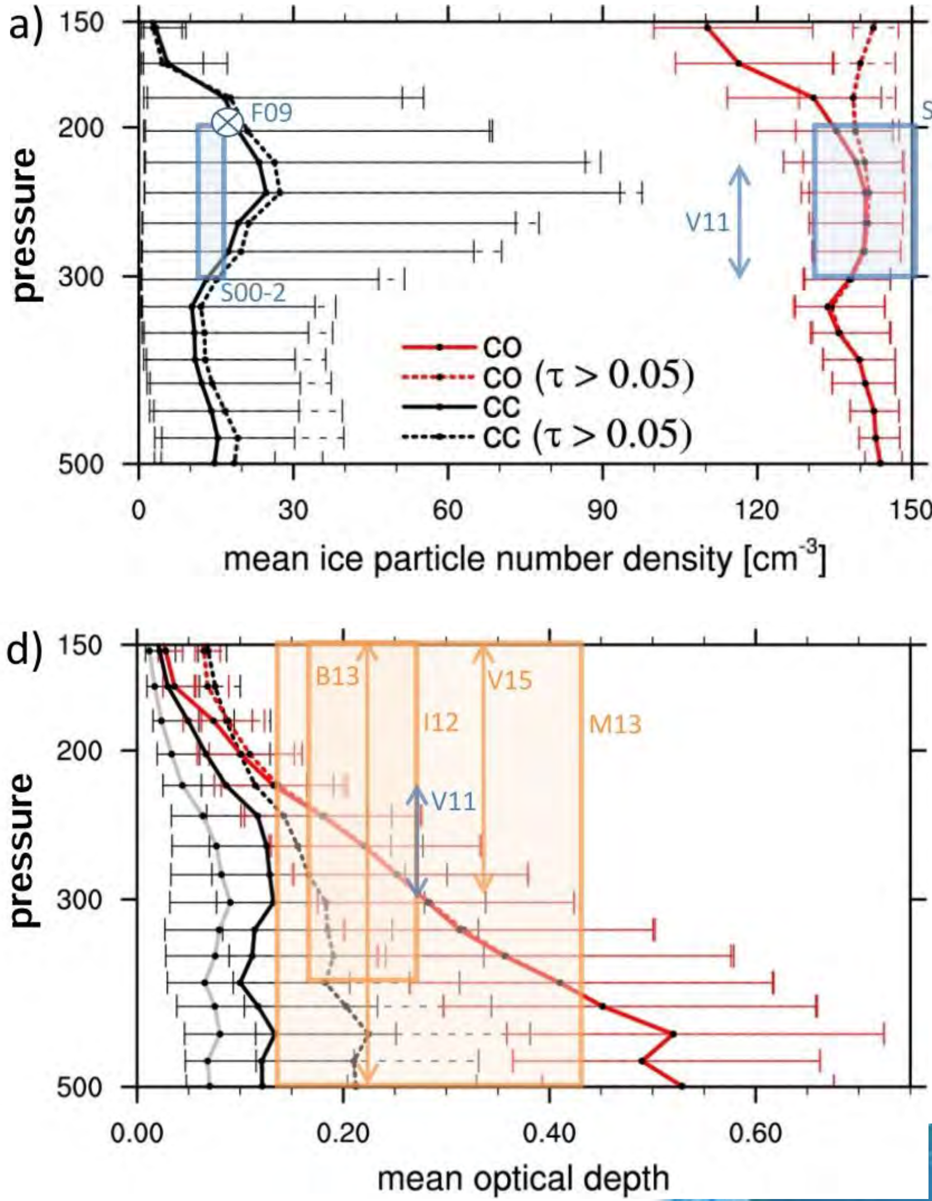
→ RF larger

→increased life time → RF larger

→increased albedo → RF smaller

Dependency on initial ice crystal number could be investigated (soot effect)

Microphysical properties of contrail and contrail cirrus



In situ measurements of mainly very young contrails:
S00 - Schröder et al. (2000);
F09 - Febvre et al. (2009);
V11 - Voigt et al. (2011)

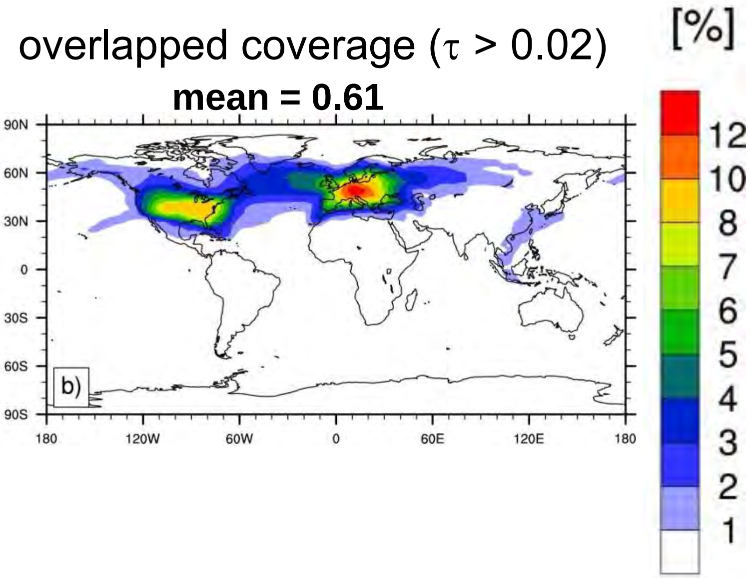
satellite measurements of line-shaped contrails:
I12 - Iwabuchi et al. (2012);
M13 - Minnis et al. (2013);
B13 - Bedka et al. (2013);
V15 - Vazquez-Navarro et al. (2015)

Results: Coverage and optical Depth 2002 (AERO2k)

ECHAM5-CCMod

overlapped coverage (τ > 0.02)

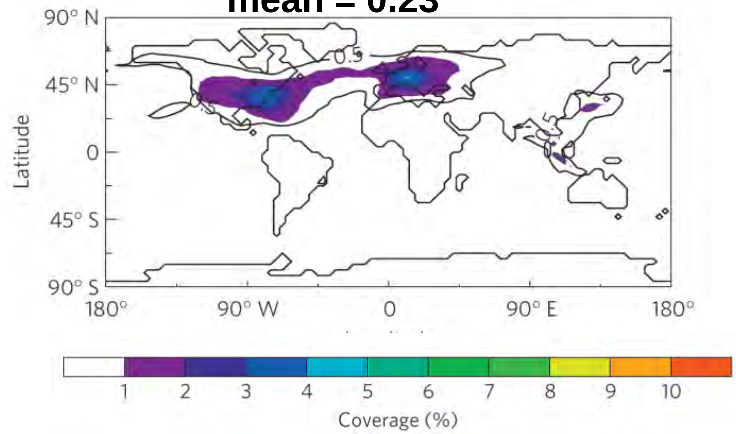
mean = 0.61



ECHAM4-CCMod

overlapped coverage (τ > 0.02)

mean = 0.23



Burkhardt und Kärcher, 2011

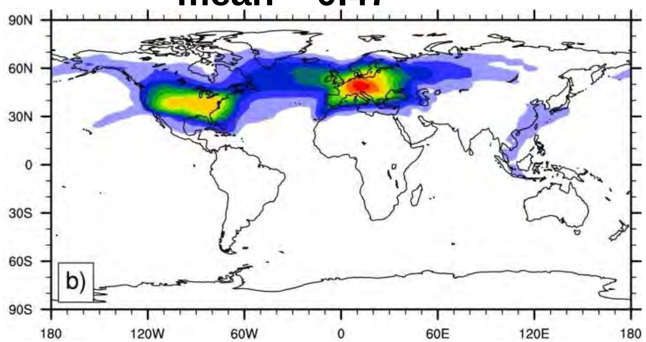
→ **global mean of optical thicker contrails 2.6 times larger**

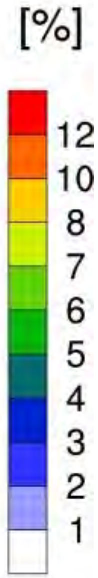
Results: Coverage and optical Depth 2002 (AERO2k)

ECHAM5-CCMod

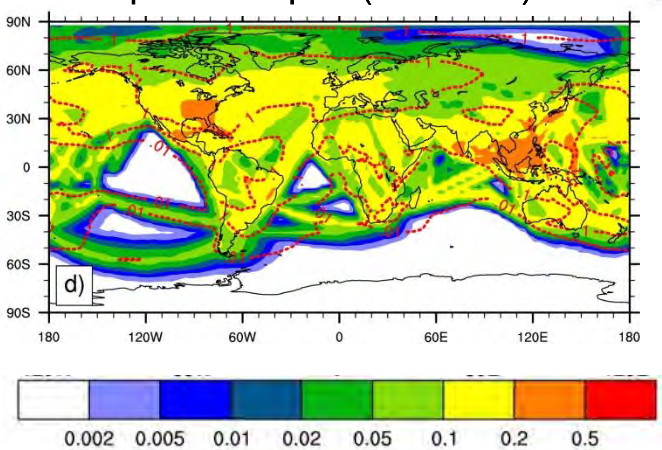
overlapped coverage (τ > 0.02)

mean = 0.47





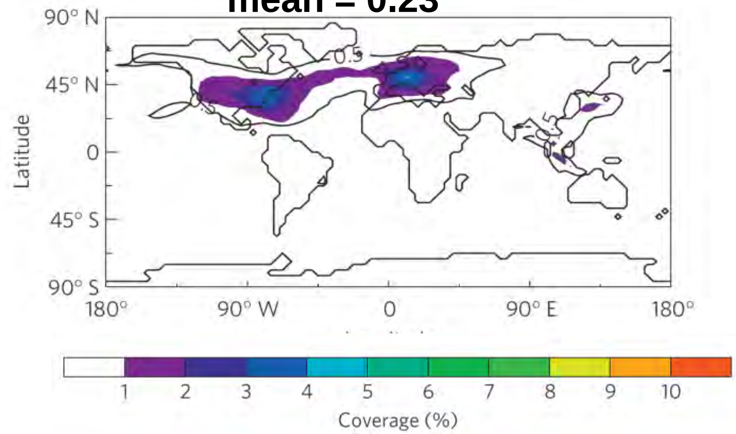
optical depth (240hPa)



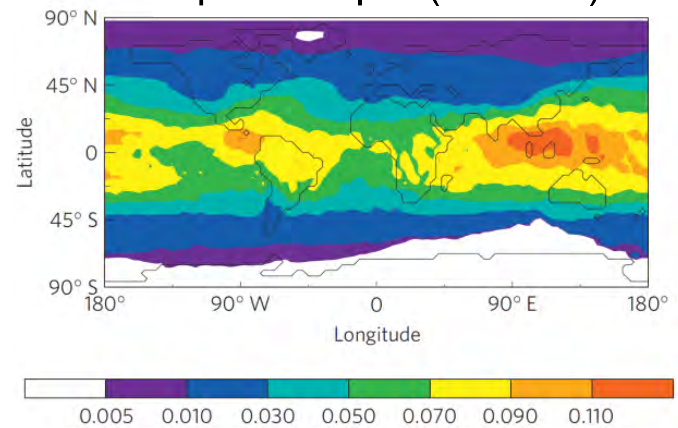
ECHAM4-CCMod

overlapped coverage (τ > 0.02)

mean = 0.23



optical depth (250hPa)

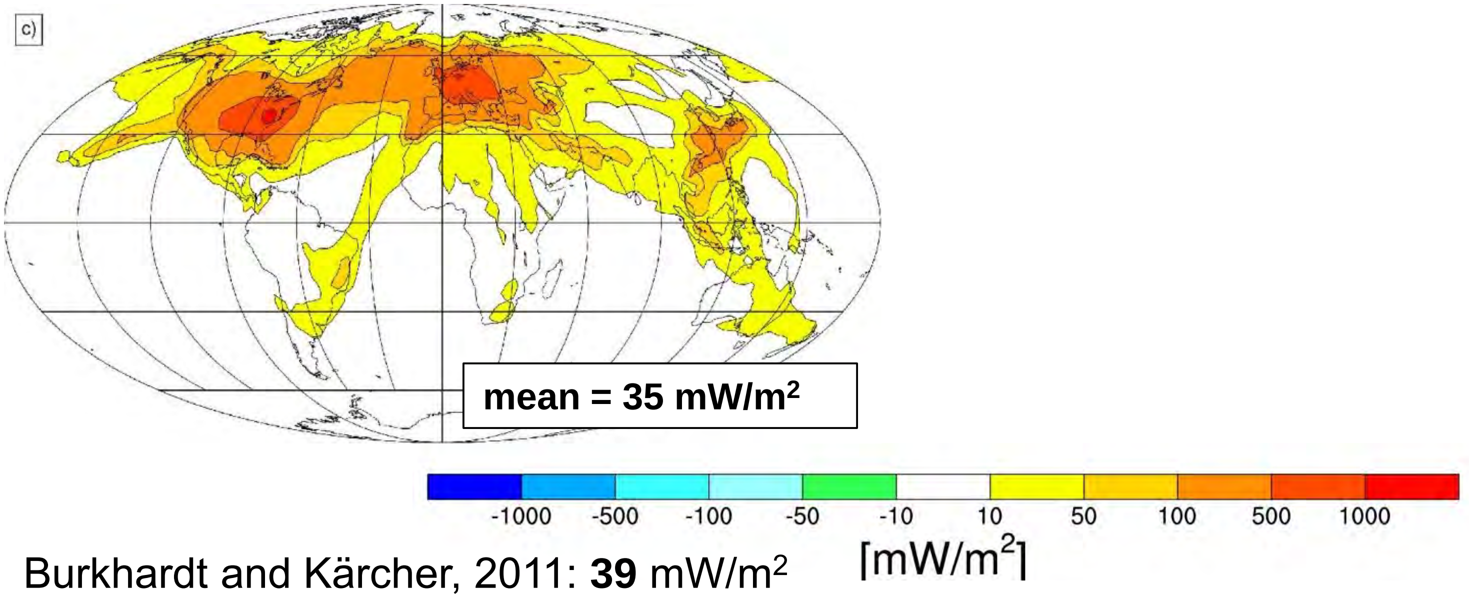


Burkhardt und Kärcher, 2011

→ larger optical depth especially in main flight regions

Results: Radiative forcing

AERO2k 2002



Burkhardt and Kärcher, 2011: **39** mW/m²
(31 mW/m² with feedback on natural cirrus)

→ global results agree well, but larger optical depth and larger compensation of longwave by shortwave RF countervail in the new model version

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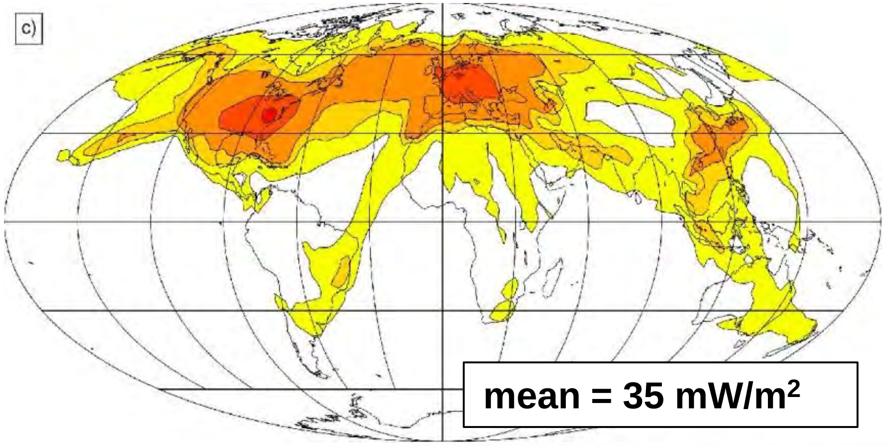
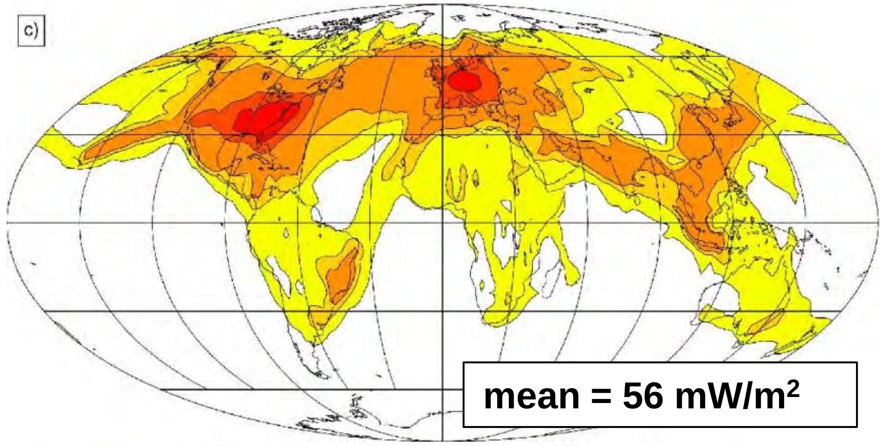
Results: Radiative forcing

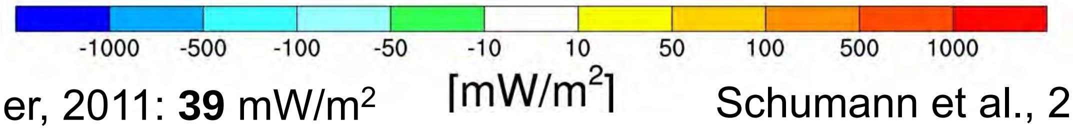
Bock and Burkhardt, JGR, 2016b

AERO2k 2002



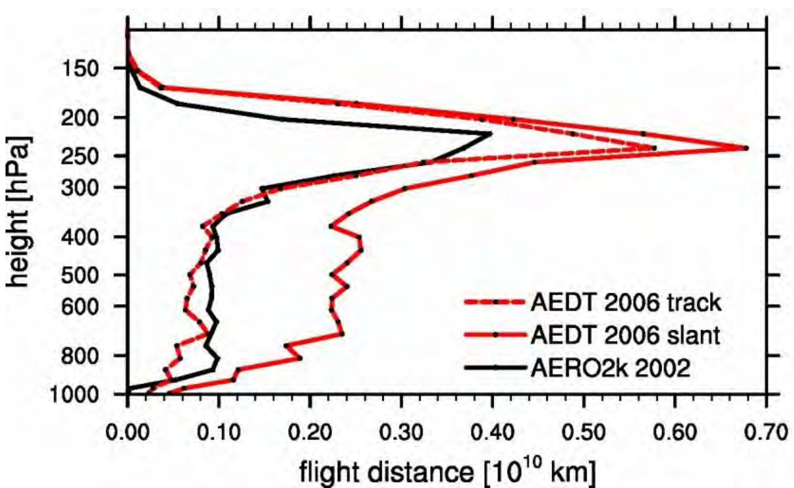
AEDT 2006





Burkhardt and Kärcher, 2011: **39** mW/m²
(31 mW/m² with feedback on natural cirrus)

Schumann et al., 2015: **63** mW/m²
Chen et al., 2012: **13** mW/m²
Burkhardt (REACT4C): **45** mW/m²

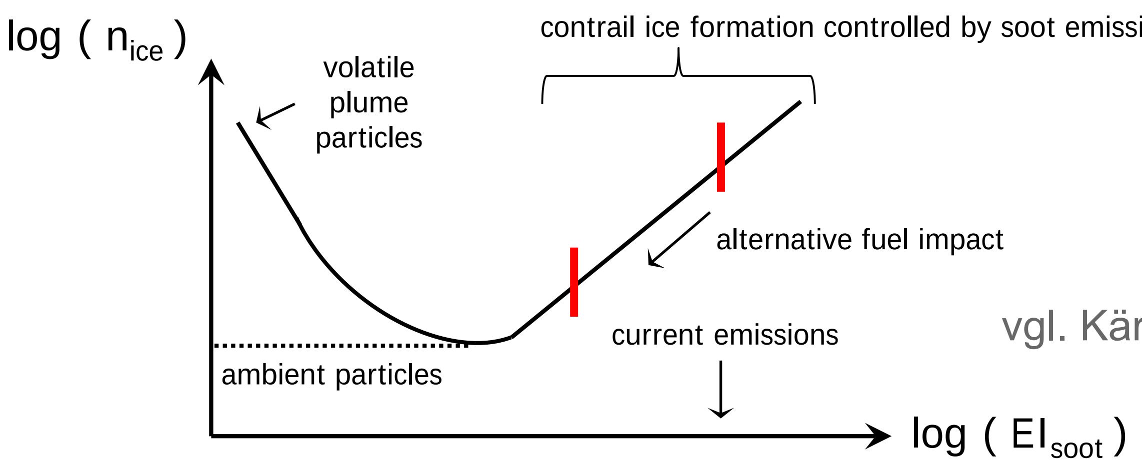


→ **large differences of inventories, especially in high altitudes, leads to strong increase of RF**

AERO2k: $3.28 \cdot 10^{10}$ flight-km
AEDT 2006 slant: $6.82 \cdot 10^{10}$ flight-km
AEDT 2006 track: $3.82 \cdot 10^{10}$ flight-km

Reducing soot emissions

- Use of alternative aviation fuels may reduce soot emissions by mass and number
- Reduction in soot number emission index, EI_{soot}
  → reduction in initial ice crystal number concentration, n_{ice}



vgl. Kärcher and Yu, 2009

- experiments to sensitivity of contrail cirrus RF on initial ice crystal number

Mitigation study

alternative fuel → Change in soot number emissions

↓

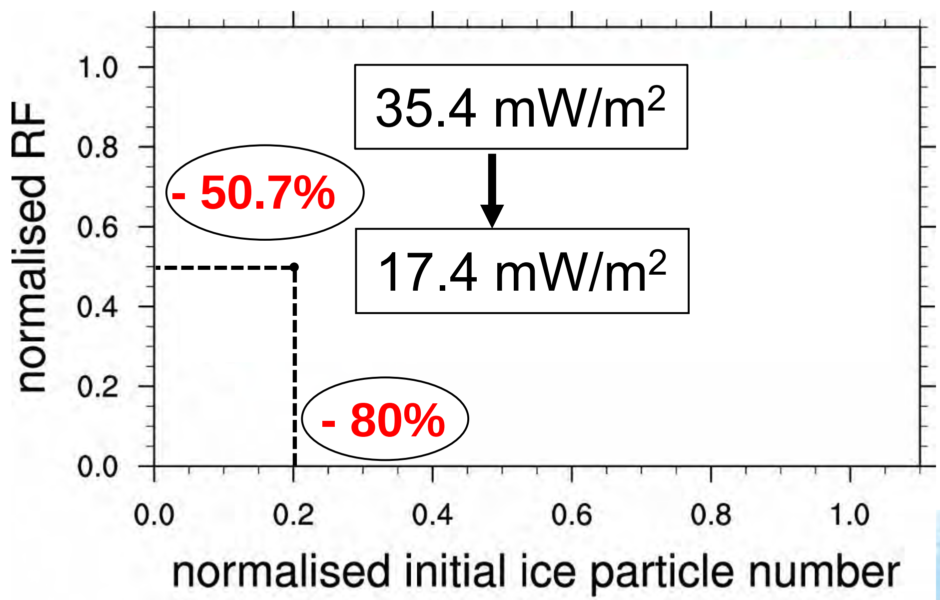
Change in initial ice crystal number of contrail

- 80%

↓

Change in microphysical und optical properties of contrail cirrus

→ Change in life time and climate impact of contrail cirrus



- → **contrail cirrus life times and optical depth are significantly reduced**
- → **leading to a strong decrease in the climate impact of contrail cirrus**

Mitigation study

alternative fuel → Change in soot number emissions

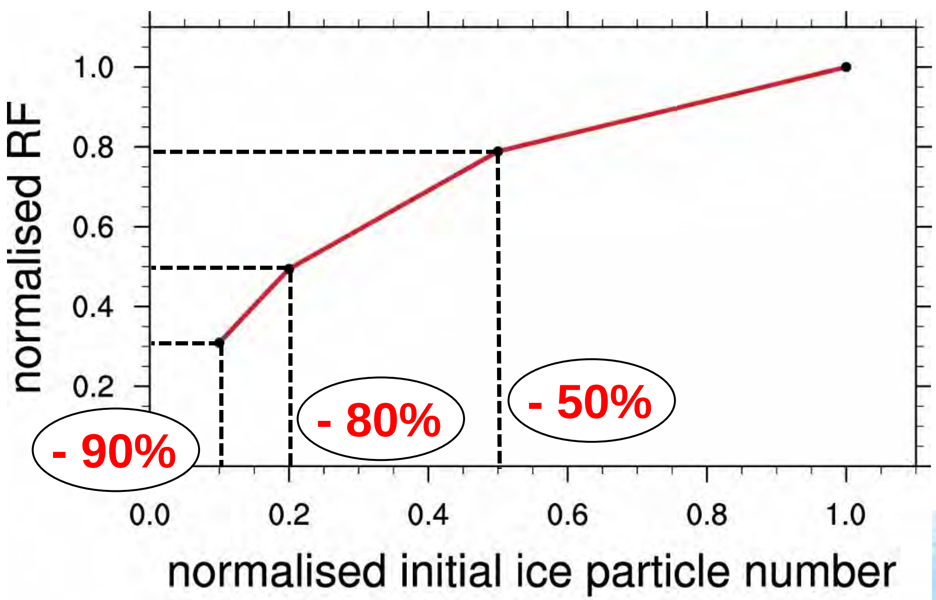
↓

Change in initial ice crystal number of contrail

↓

Change in microphysical und optical properties of contrail cirrus

→ Change in life time and climate impact of contrail cirrus



→ **nonlinearly dependency of RF on initial ice crystal concentration**

Aviation Scenarios

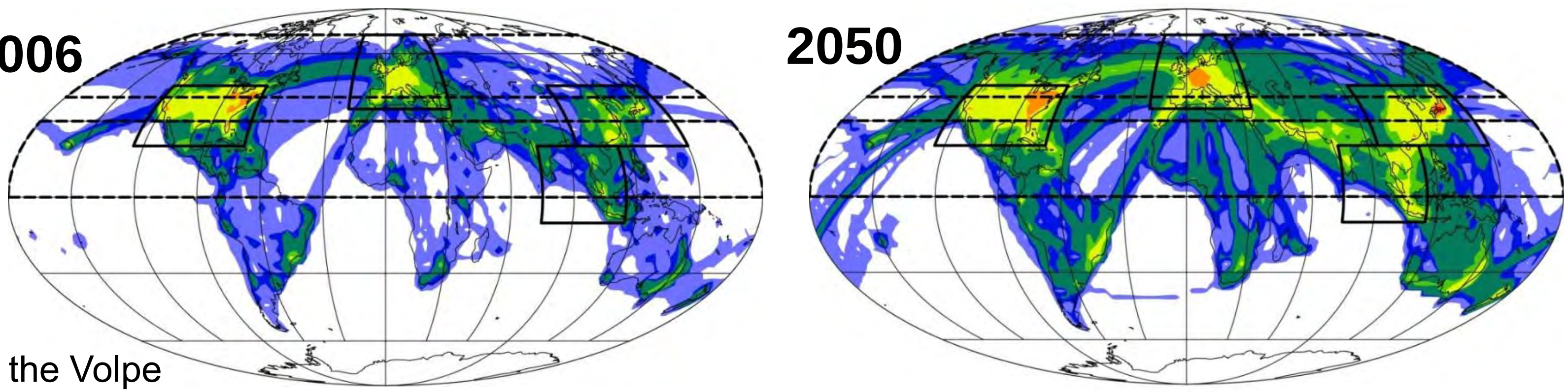
2006

2006 Plus
- increased air traffic volume

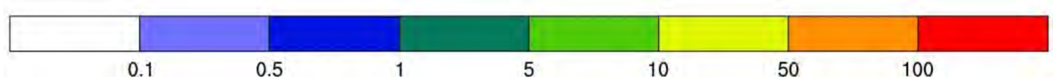
2050 Baseline
- increased air traffic volume
- climate change

2050 Scenario1
- increased air traffic volume
- climate change
- improvement in fuel efficiency
- reduction of soot emission

2006 **2050**



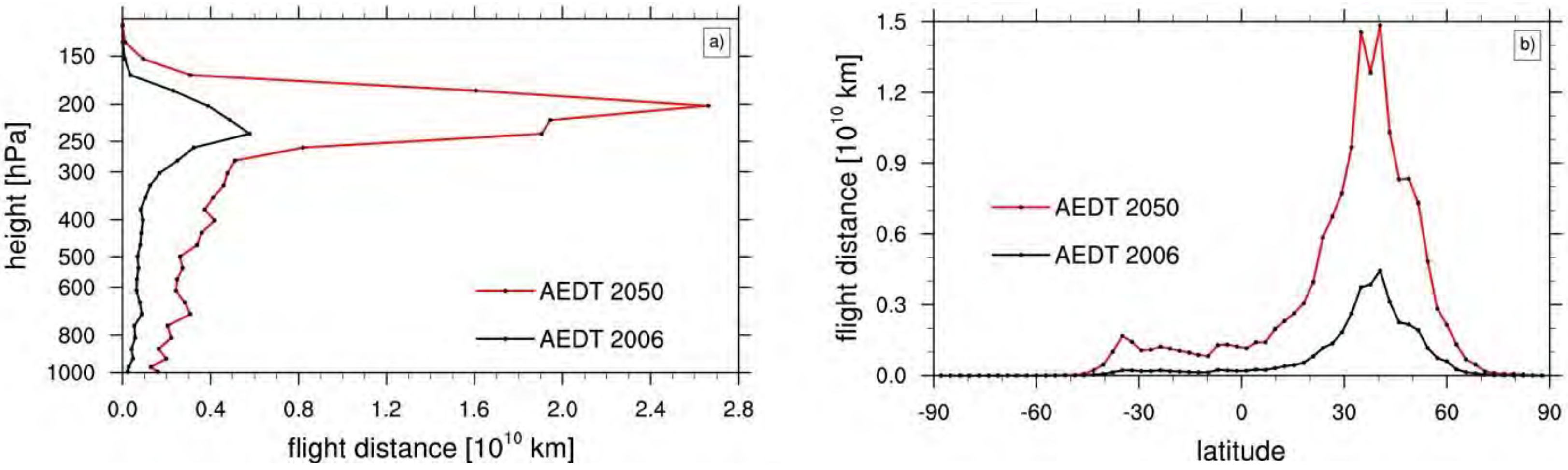
→ developed at the Volpe National Transportation Centre using the U.S. Federal Aviation Administration (FAA) Aviation Environmental Design Tool (AEDT)



[10^7 km/m^2 s^{-1}]

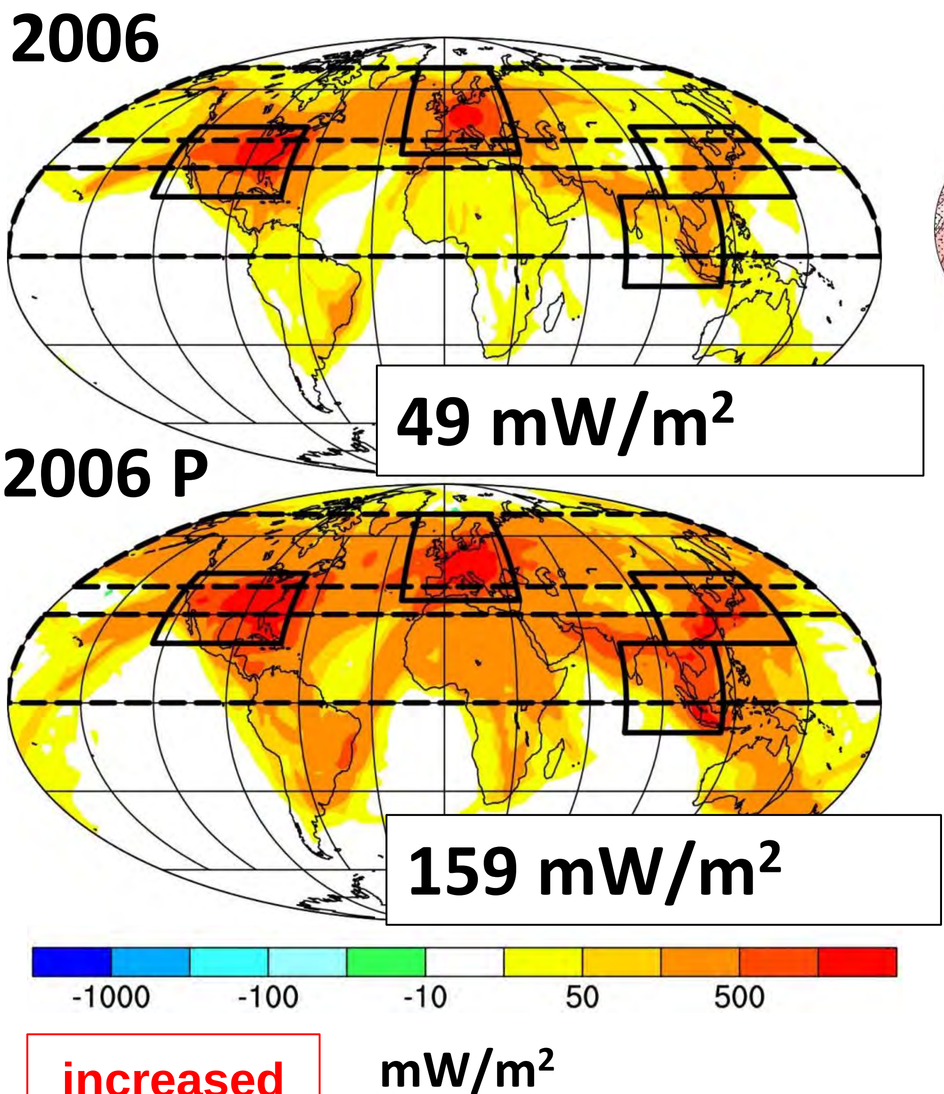
Flight density

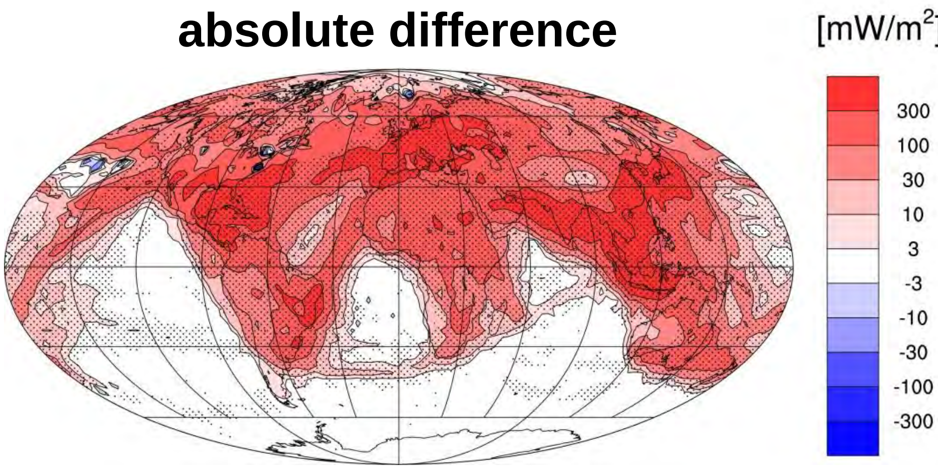
Inventories: flight distance (Track distance)



In 2006 air traffic largest at ~240 hPa.
In 2050 air traffic predicted to be largest at ~200 hPa.

Radiative Forcing





increases in air traffic volume

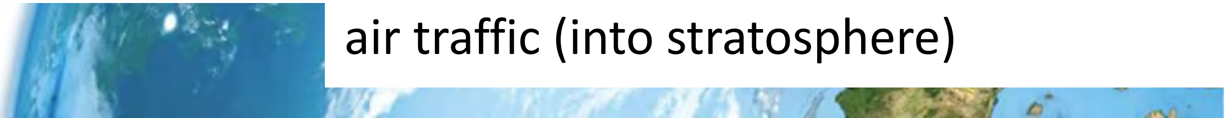
+ shift to higher altitudes

→ large increase in contrail cirrus RF

increased air traffic

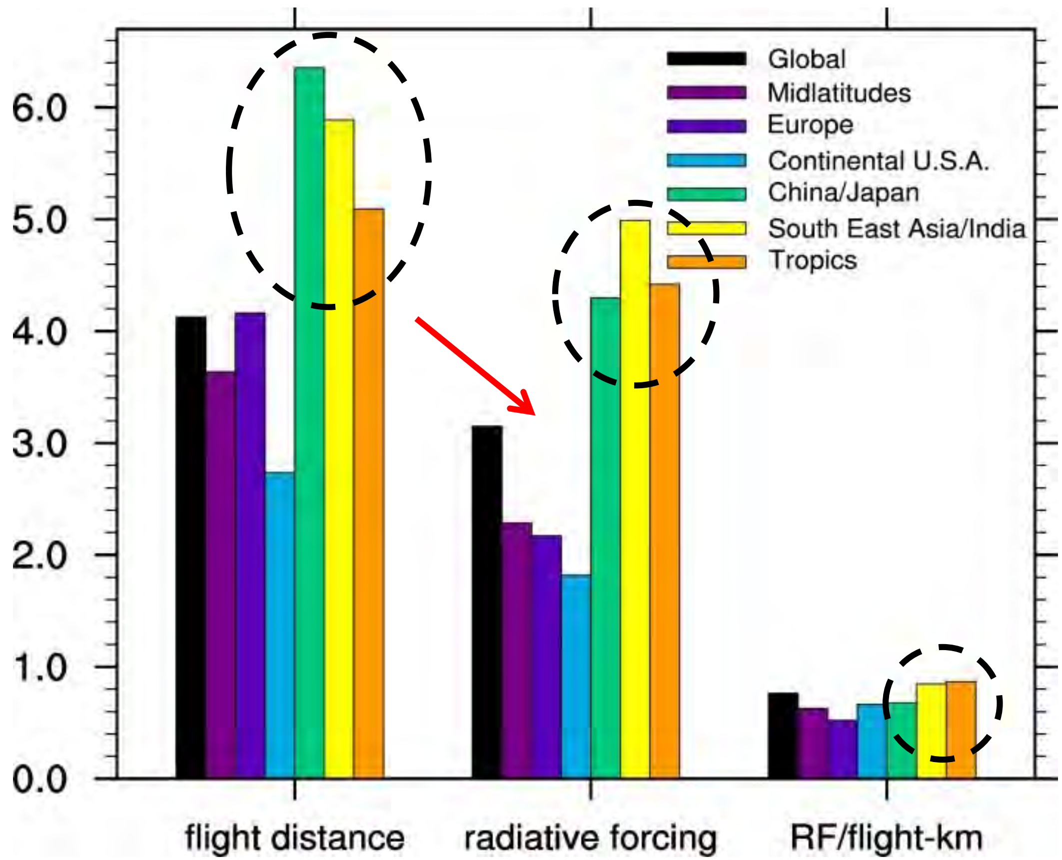
tropics: upwards shift of air traffic
→ larger probability of contrail formation

midlatitudes: increased air traffic partly compensated by upwards shift of air traffic (into stratosphere)

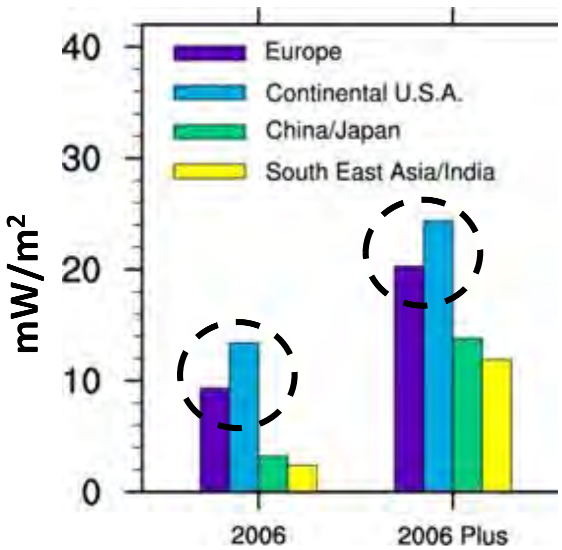


Increase of flight volume + shift of level with max. flight volume

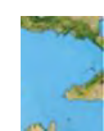
Factor of change (2006 → 2006 Plus)



Absolute RF

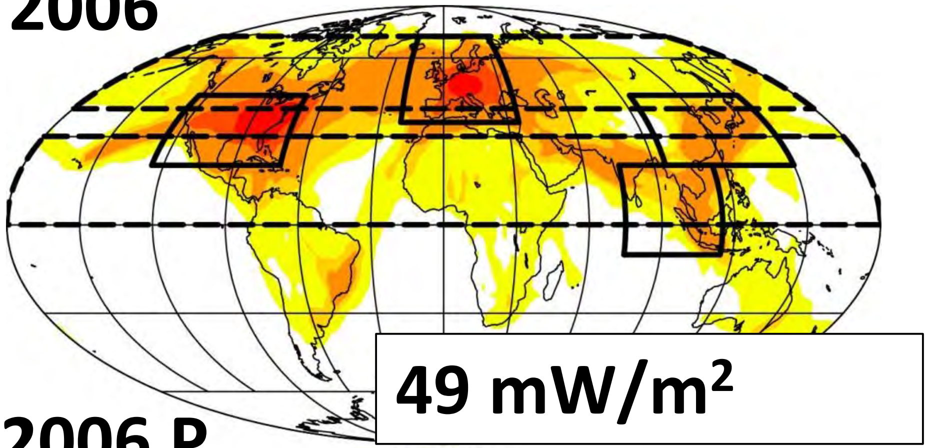


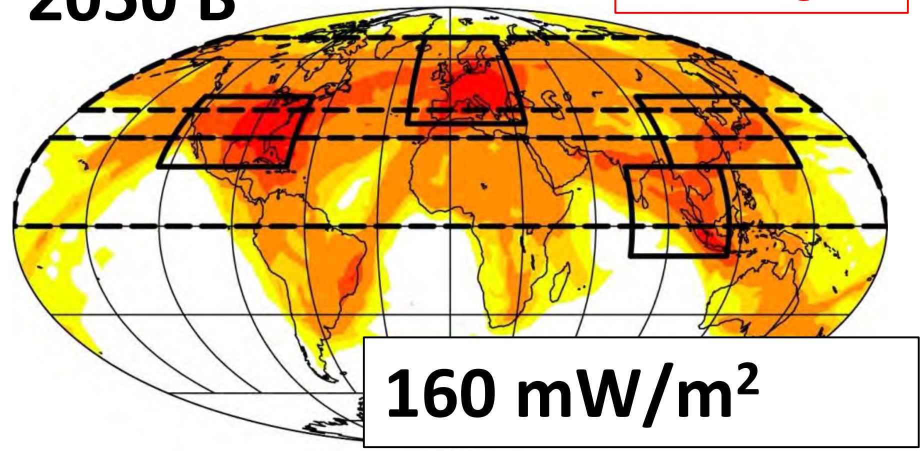
- increase in contrail cirrus RF less than the increase in flight distance
- stronger relative increase of air traffic and contrail cirrus RF in the Tropics

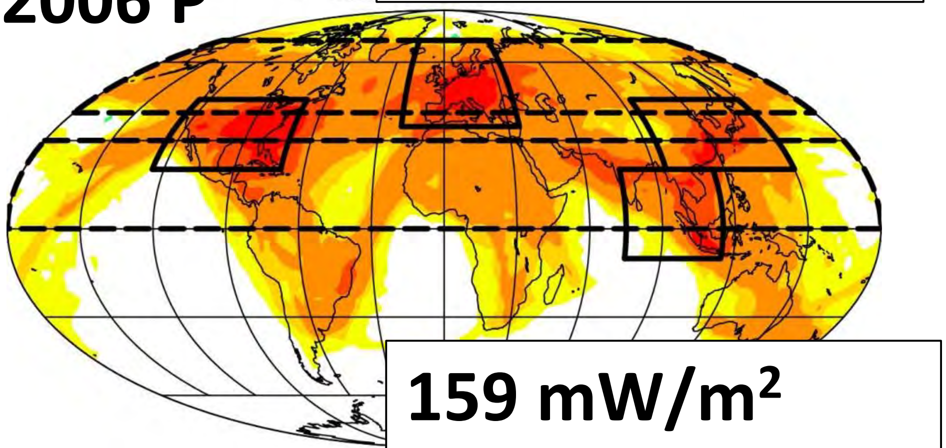


Radiative Forcing

climate change

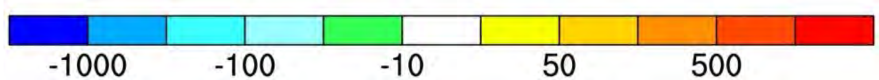






→ due to climate change (RCP6.0) contrail cirrus RF for the year 2050 is increased slightly (no significance)

increased air traffic



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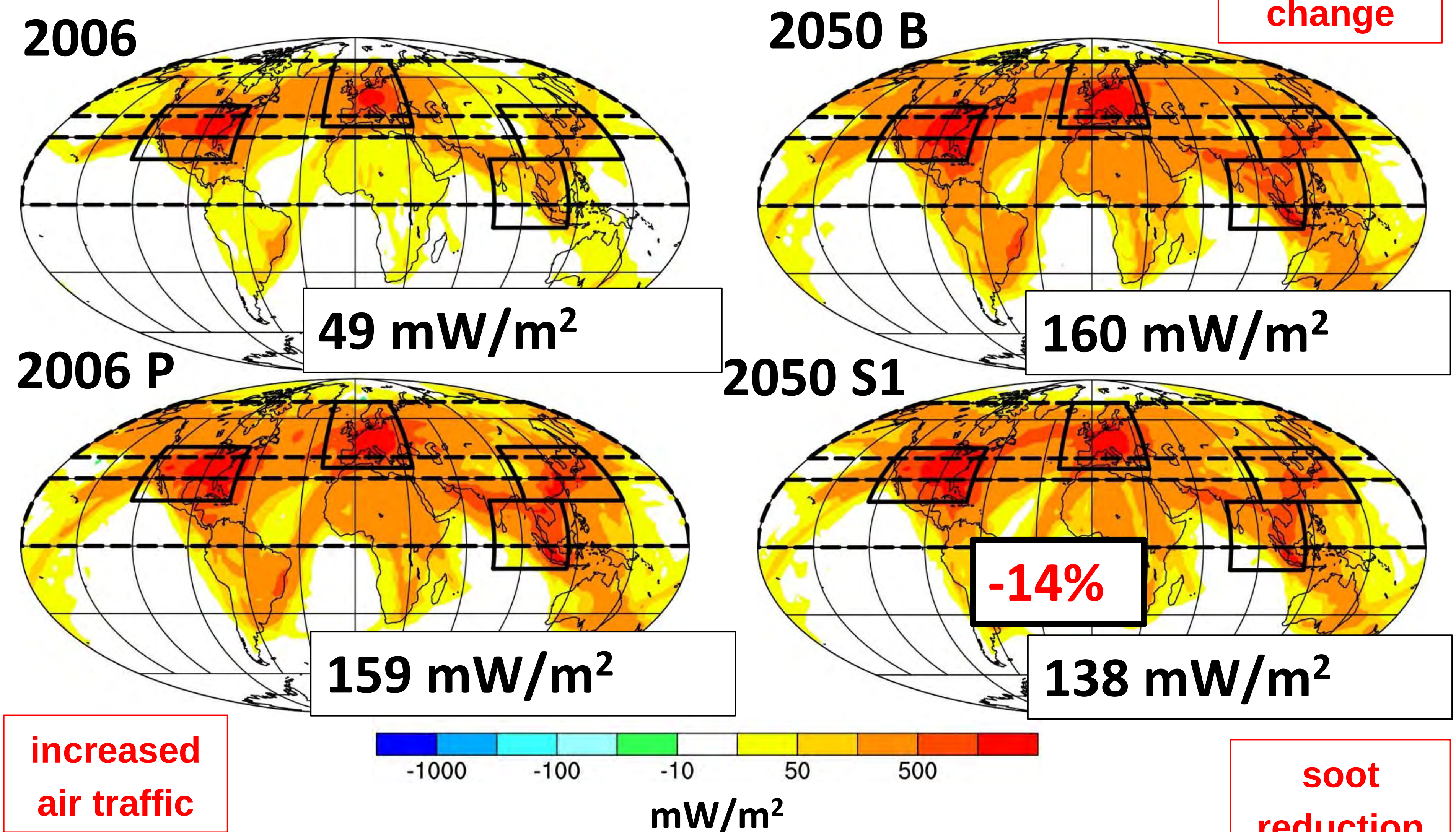
Radiative Forcing

climate change



increased air traffic

soot reduction

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Conclusion

→ After introducing **contrail ice crystal number** in the climate model: better representation of microphysical processes and better knowledge of microphysical and optical properties of contrail cirrus

→ Global results agree well, but **larger optical depth** and larger compensation of longwave by shortwave RF compensate in the new model version

→ Strong increase of RF from inventory AERO2k 2002 to AEDT 2006

→ **Initial ice crystal number** strongly affects the microphysical and optical properties of contrail cirrus

- lower soot emission ⇒ smaller contrail optical depth RF ↘
- nonlinear dependence of contrail cirrus RF on soot emissions

Future scenarios:

→ Strong increase of RF due to **larger air traffic volume** (sceanrio 2050) cannot be compensated by other processes

→ **Changing flight level** strongly effects contrail formation

higher flight level ⇒ midlatitudes: less contrails RF ↘

tropics: more contrails RF ↗

→ **Climate change** has a very small impact on contrail cirrus RF

Thanks for your attention!