Contrail cirrus and their climate impact

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WakeNet3-Europe

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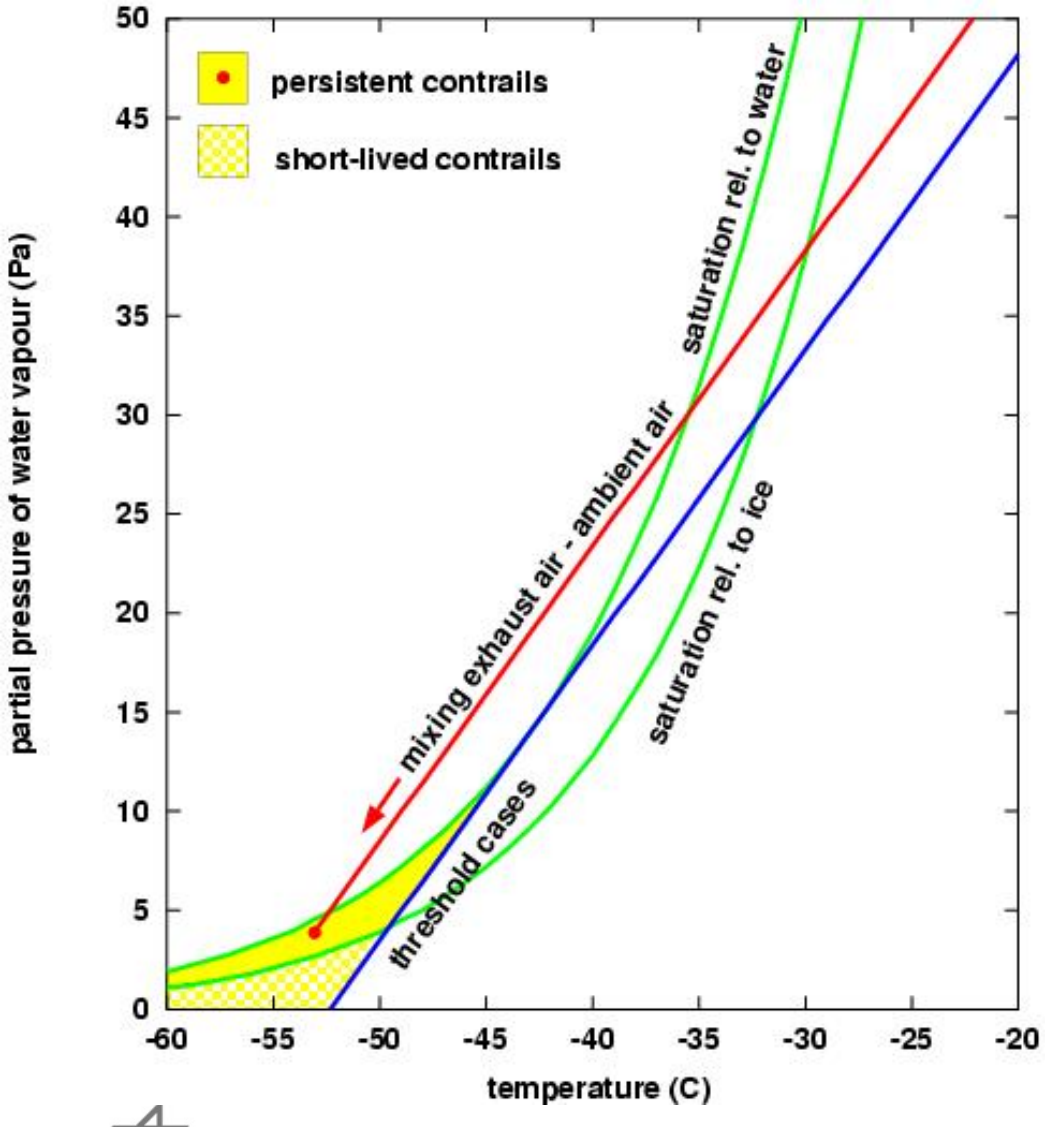
Contrail formation

Contrail formation



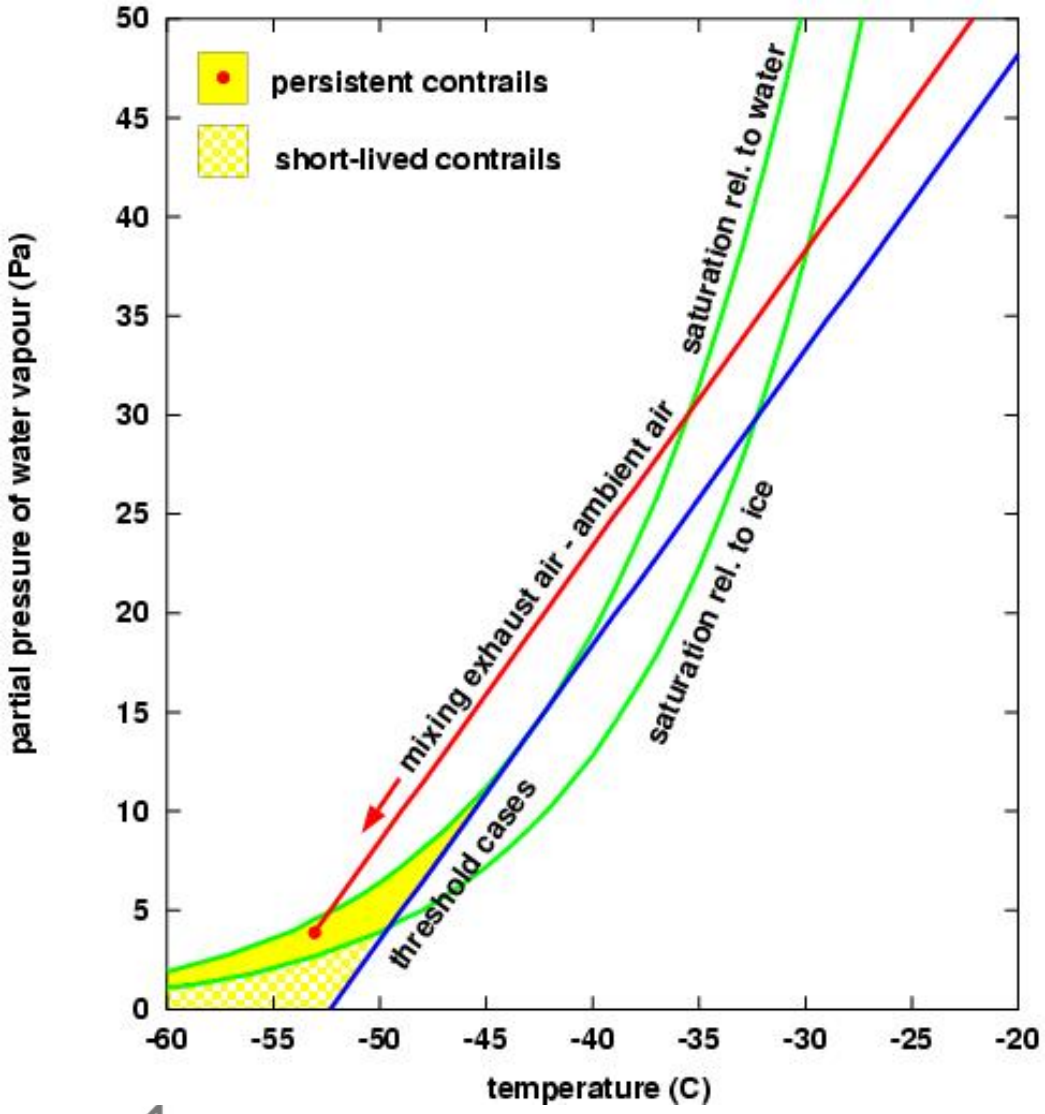
Aircraft engines emit under cruise conditions (per kg kerosene):
water vapour (1.25 kg),
soot particles (O(10^{15})),
heat (about 28 MJ), ...

Emissions mix isobarically with ambient air.
If water (super)saturation is temporarily reached

formation of condensation trail (contrail).

Schmidt (1941), Appleman (1953), Schumann (1996)

Contrail formation



Persistent contrails can form at slight ambient ice supersaturation whereas natural cirrus form only at high ice supersaturation

↓

Contrails and contrail cirrus can increase the cloud coverage substantially

↓

climate impact due to an increase in cloudiness

Vortex regime - LES simulations

surviving number fractions

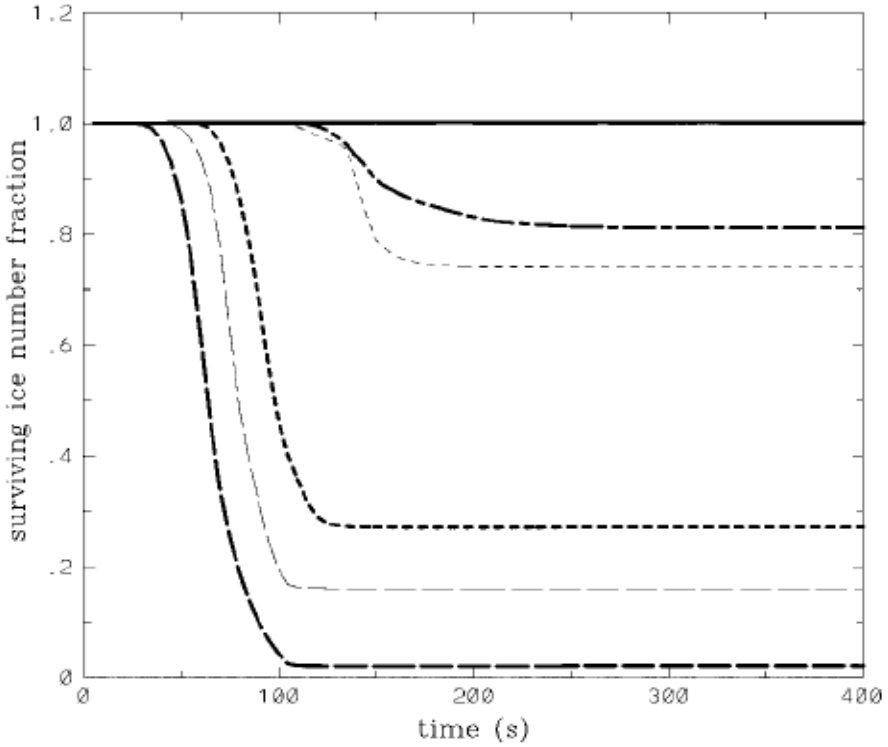


FIG. 7. Fraction of initial ice crystal number surviving vs time. Thick lines indicate B747 contrails, thin lines B737. Here RH_i = 130% (solid lines), RH_i = 120% (long-short dash), RH_i = 110% (short dash), and RH_i = 102% (long dash).

surviving ice mass

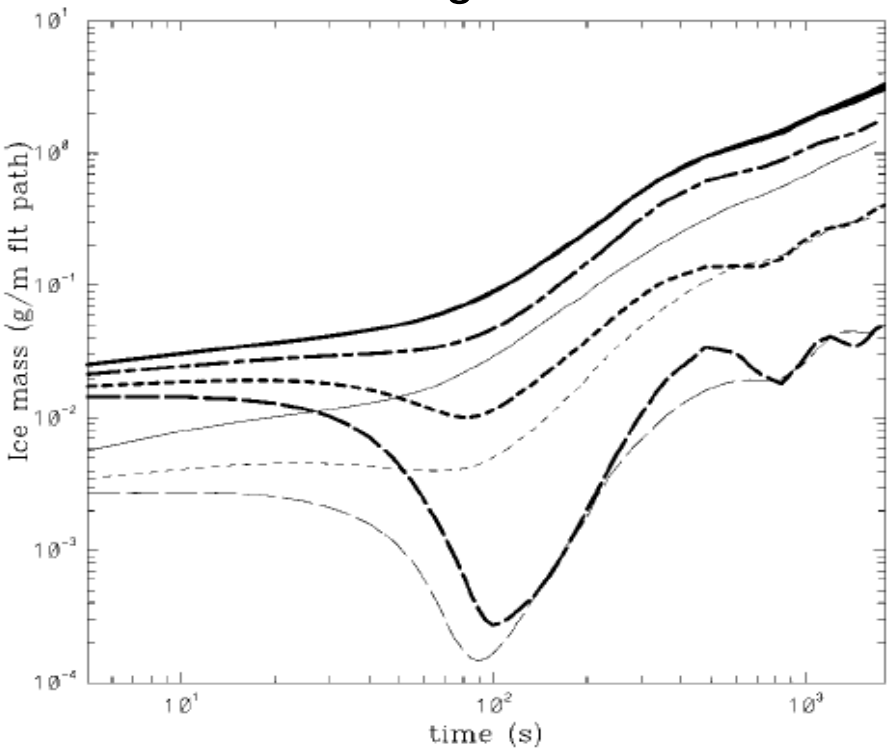


FIG. 8. Total contrail ice mass per length of flight path vs time. Line thickness and dash patterns as in Fig. 7.

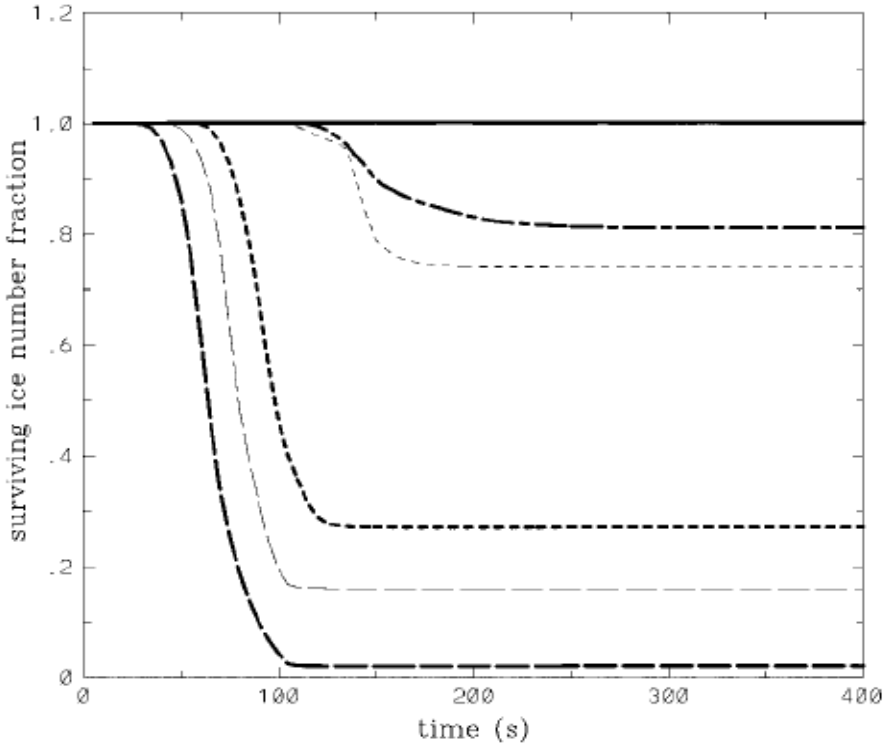
Lewellen and Lewellen, 2001

number concentration can be strongly reduced in vortex phase

fraction of ice particles surviving the vortex regime is a sensitive function of temperature, supersaturation, stratification, and aircraft type

Vortex regime - LES simulations

surviving number fractions



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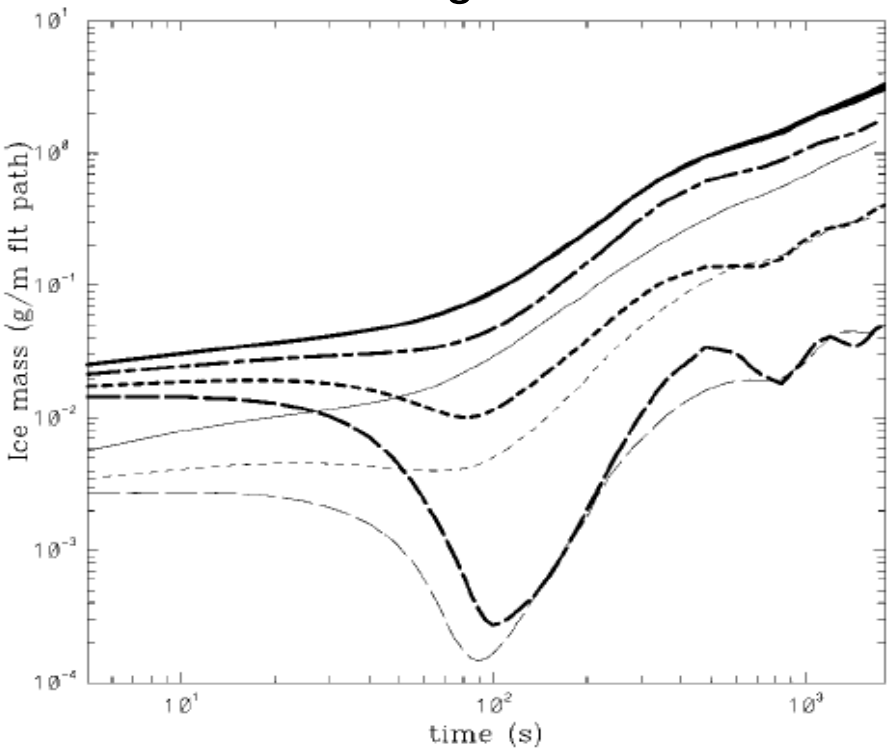

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Lewellen and Lewellen, 2001

number concentration can be strongly reduced in vortex phase - ice mass converge for different airplanes since ambient conditions are most important - optical properties of contrails change with time

Contrail lifetime is related to ambient relative humidity

Contrails are not persistent in air that is subsaturated relative to ice

strongly subsaturated

weakly subsaturated

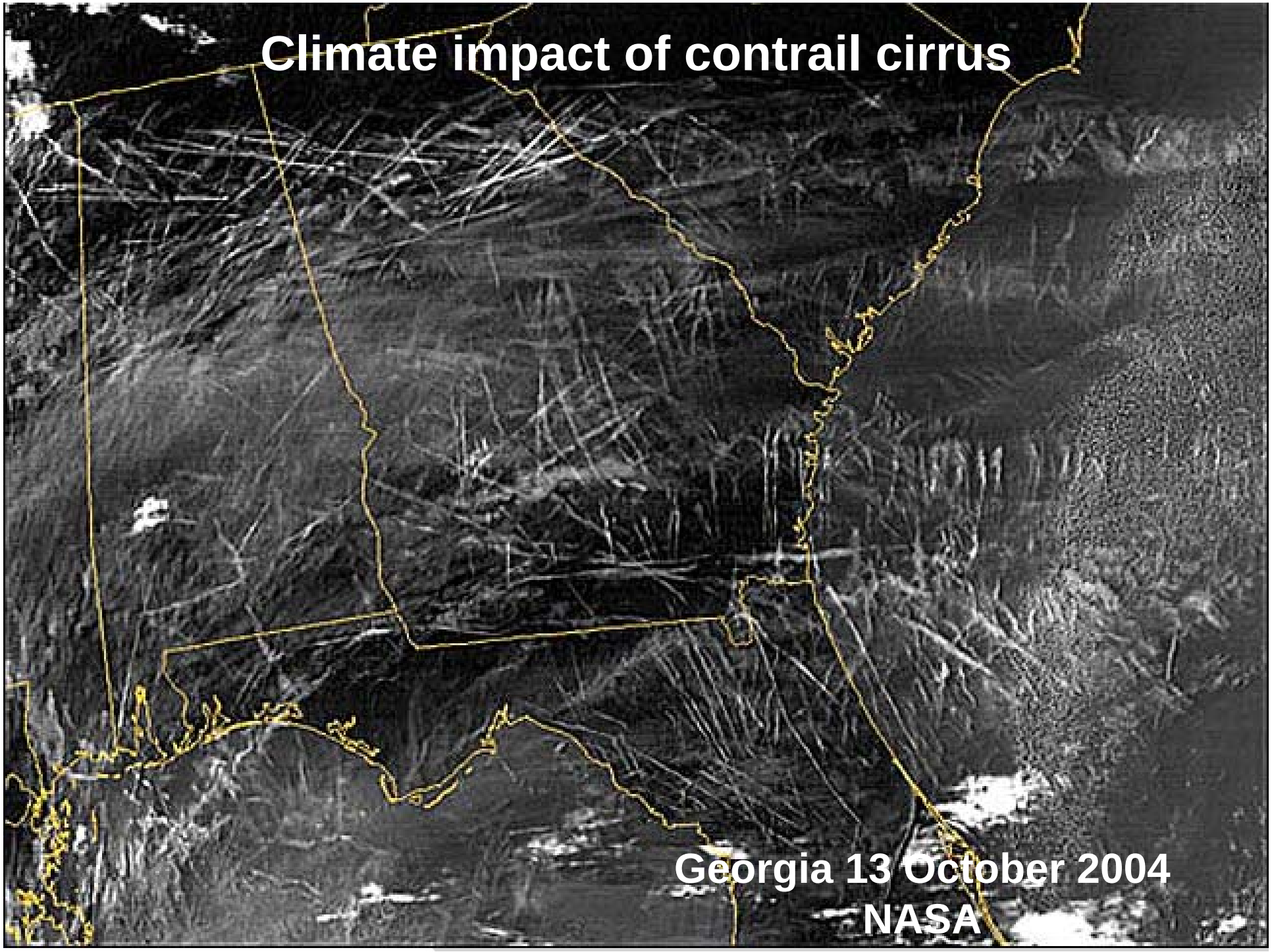
Contrail lifetime is related to ambient relative humidity

In ice supersaturated air contrails are persistent

weakly ice supersaturated - only ice in secondary wake is persistent

strongly ice supersaturated - ice in primary and secondary wake persistent


Line shaped contrails and contrail cirrus can increase coverage substantially. Satellite observations can show a line shaped contrail coverage of ~3-5% regionally.


Climate impact of contrail cirrus
Georgia 13 October 2004
NASA

Contrails in a climate model

	Contrail scale	GCM resolution
spatial:	10^2-10^4m	10^3km
temporal:	~2min (jet+vortex phase)	30 min

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- Simulation of persistent contrails only
- Simulation of statistical properties of contrail cirrus as for natural clouds (e.g. fractional coverage, grid mean IWC)
- properties of contrails after the vortex phase have to be parameterized depending on humidity, stability, temperature, air craft ... and can be used for initialization in a climate model

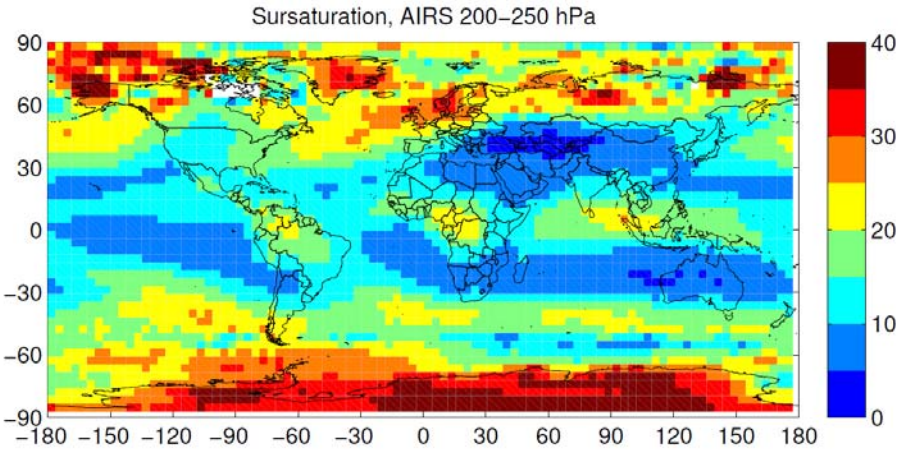
Contrail cirrus module in the ECHAM climate model

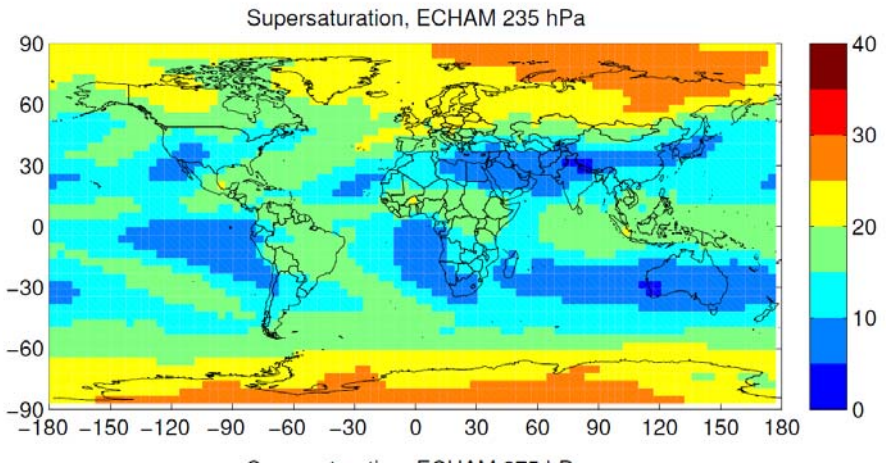
- Simulation of persistent contrails only
- Simulation of statistical properties of contrail cirrus as for natural clouds (e.g. fractional coverage, grid mean IWC)
- Parameterization of processes controlling contrail coverage and IWC (formation, advection, spreading, deposition, sublimation, precipitation)
- Contrail cirrus evolve in supersaturated area

Contrail cirrus life cycle and atmospheric feedbacks are simulated within the ECHAM climate model.

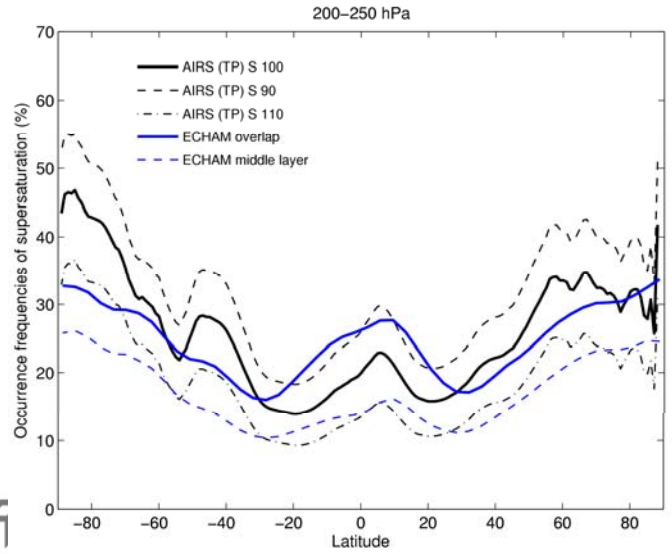
Burkhardt and Kärcher, JGR, 2009

Contrail cirrus simulation depends on the simulation of supersaturation frequency in climate models





Lamquin et al.



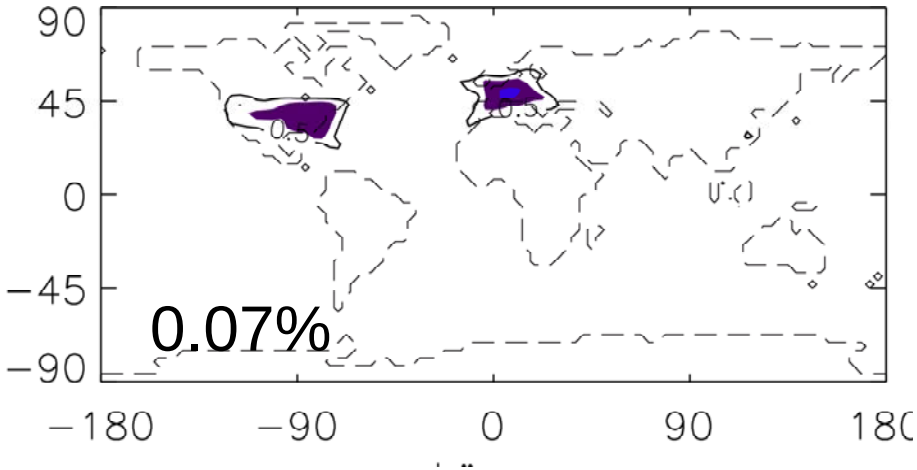
Parameterized supersaturation compares well with AIRS (troposphere only) estimates at the upper levels

Contrail cirrus coverage

(maximum random overlap)

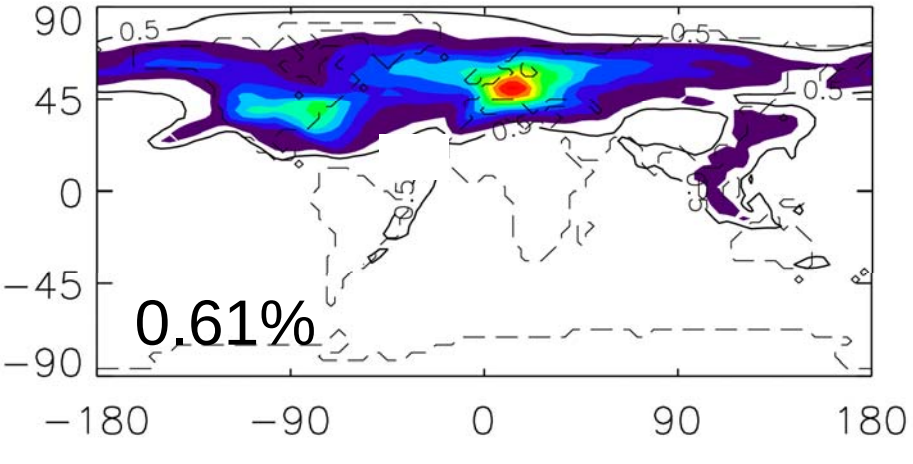
young contrails (< 5 hr)

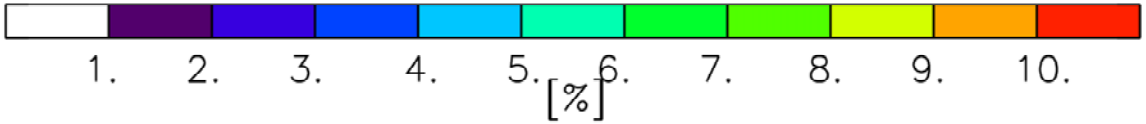
easy to distinguish from natural clouds



contrail cirrus (all ages)

hardly distinguishable from natural clouds

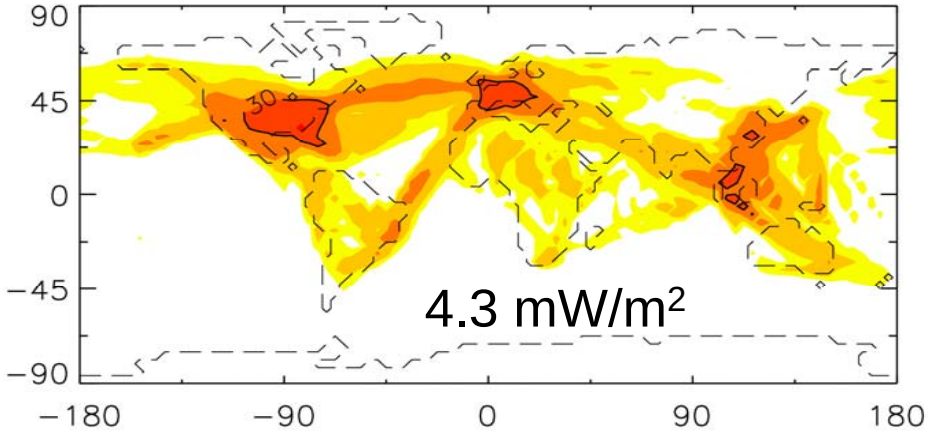




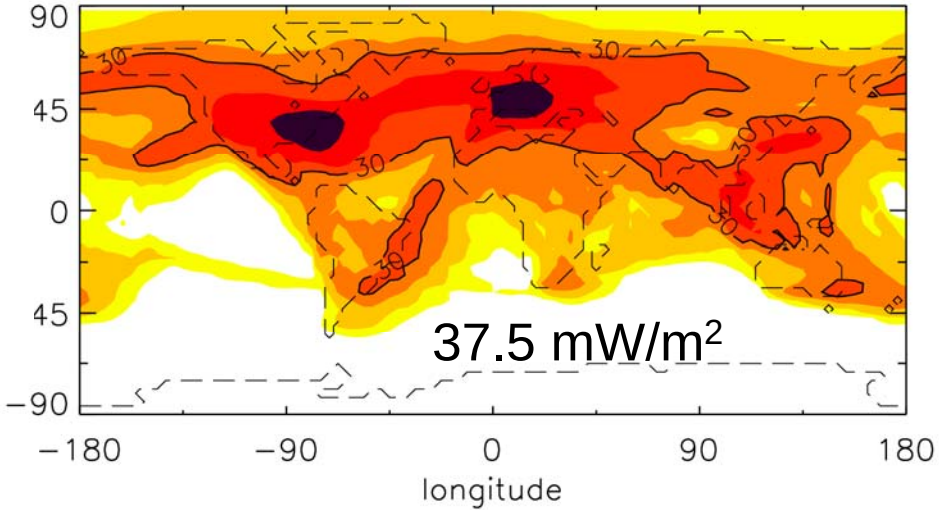
Contrail cirrus coverage strongly increased relative to young (line-shaped) contrail coverage - In the past only line shaped contrails and their climate impact were studied

Radiative forcing of young contrails and contrail cirrus

net RF young contrails



net RF contrail cirrus



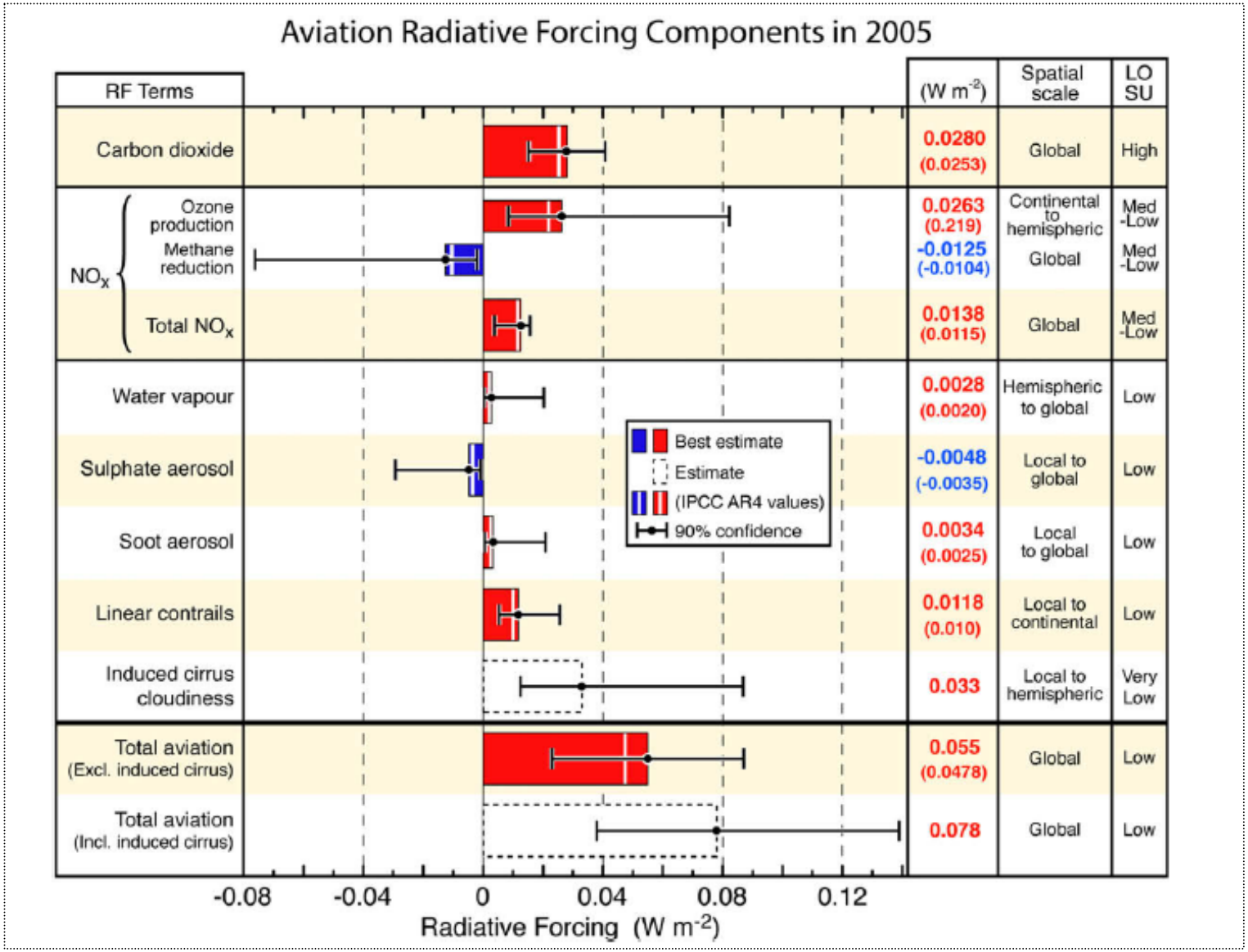
global radiative forcing (change of the radiation budget at the tropopause) due to

young contrails - 4.3 mW/m²

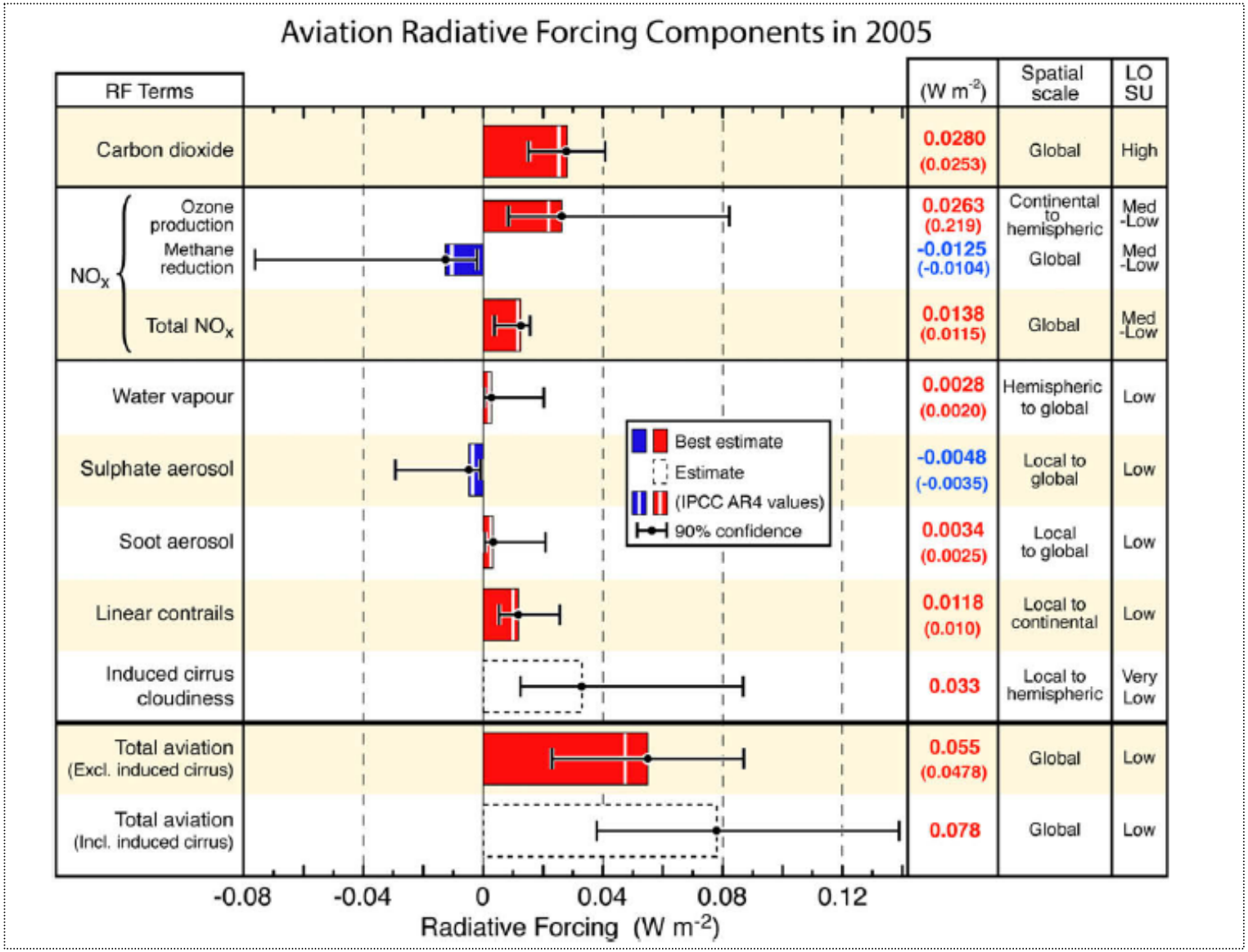
contrail cirrus - 37.5 mW/m²

BUT

natural cirrus coverage (and cloud RF) may be reduced due to changes in the humidity field



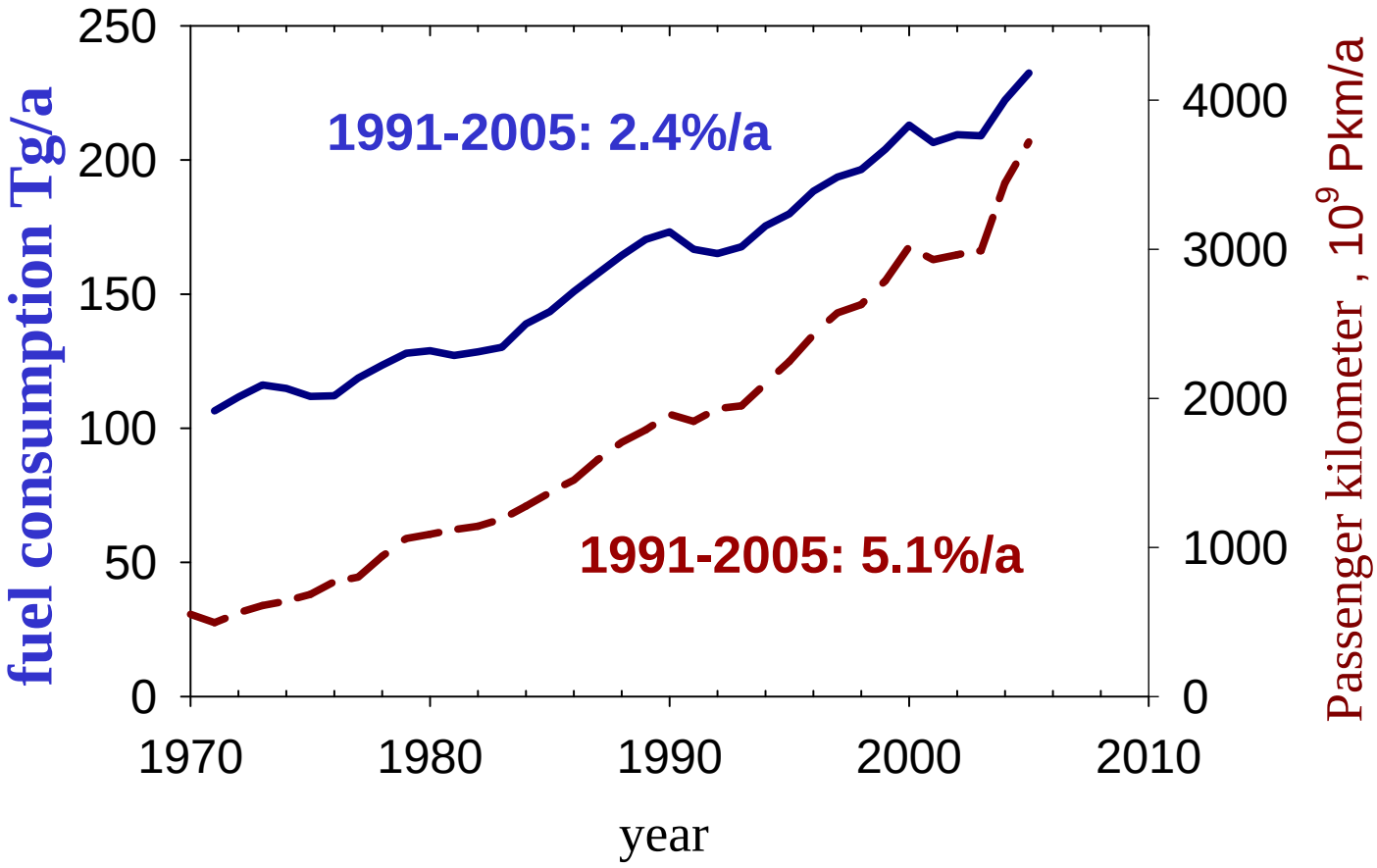
aviation RF currently 2-8% of climate change RF



aviation RF currently 2-8% of climate change RF

Contrail cirrus RF maybe largest component of aviation RF

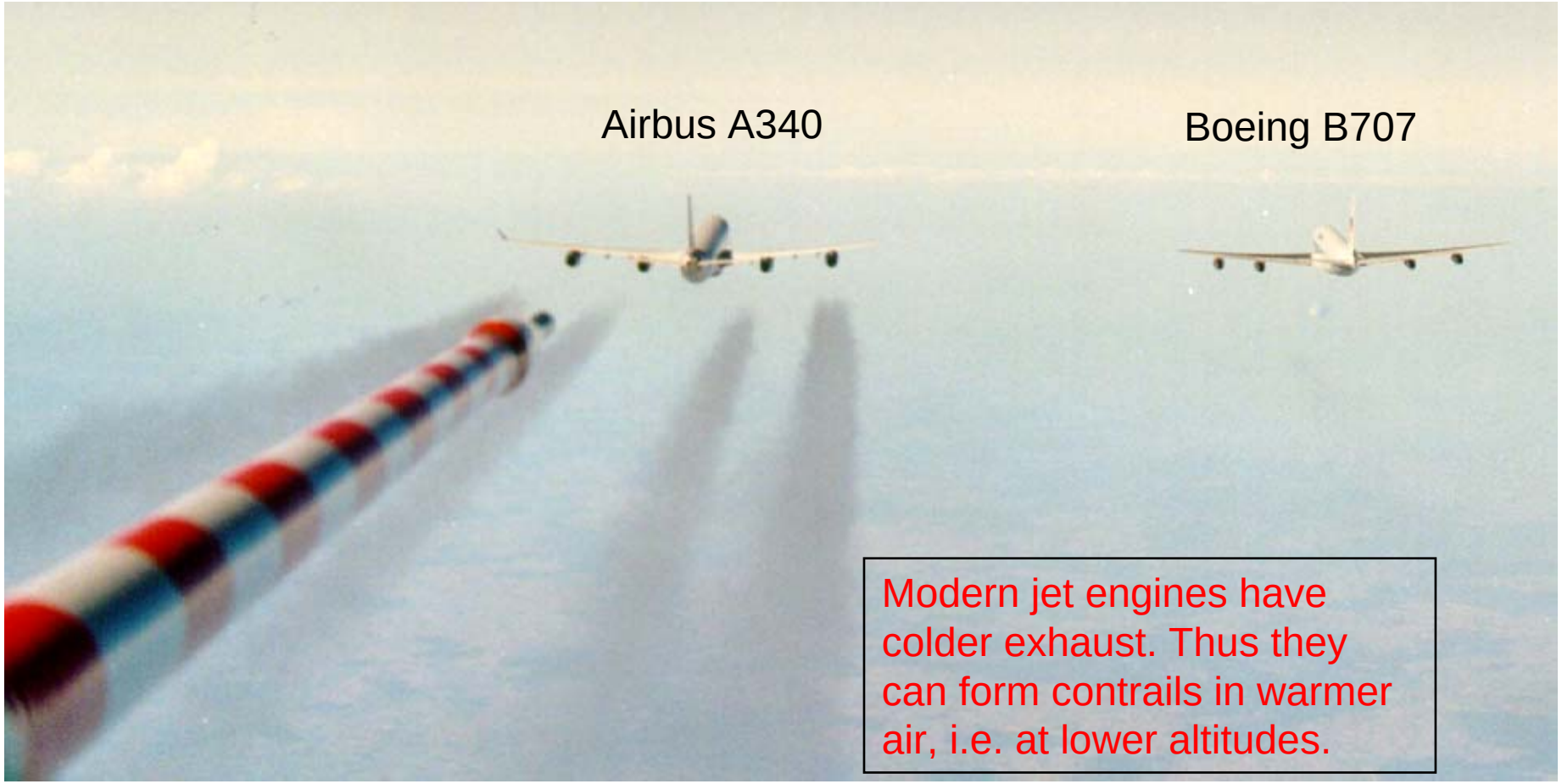
Projected growth of air traffic increases contrail climate forcing



As emissions of greenhouse gases are reduced, aviation is still growing and its part in climate change is getting more dominant

Contrails from modern and old aircraft

altitude 344 hft

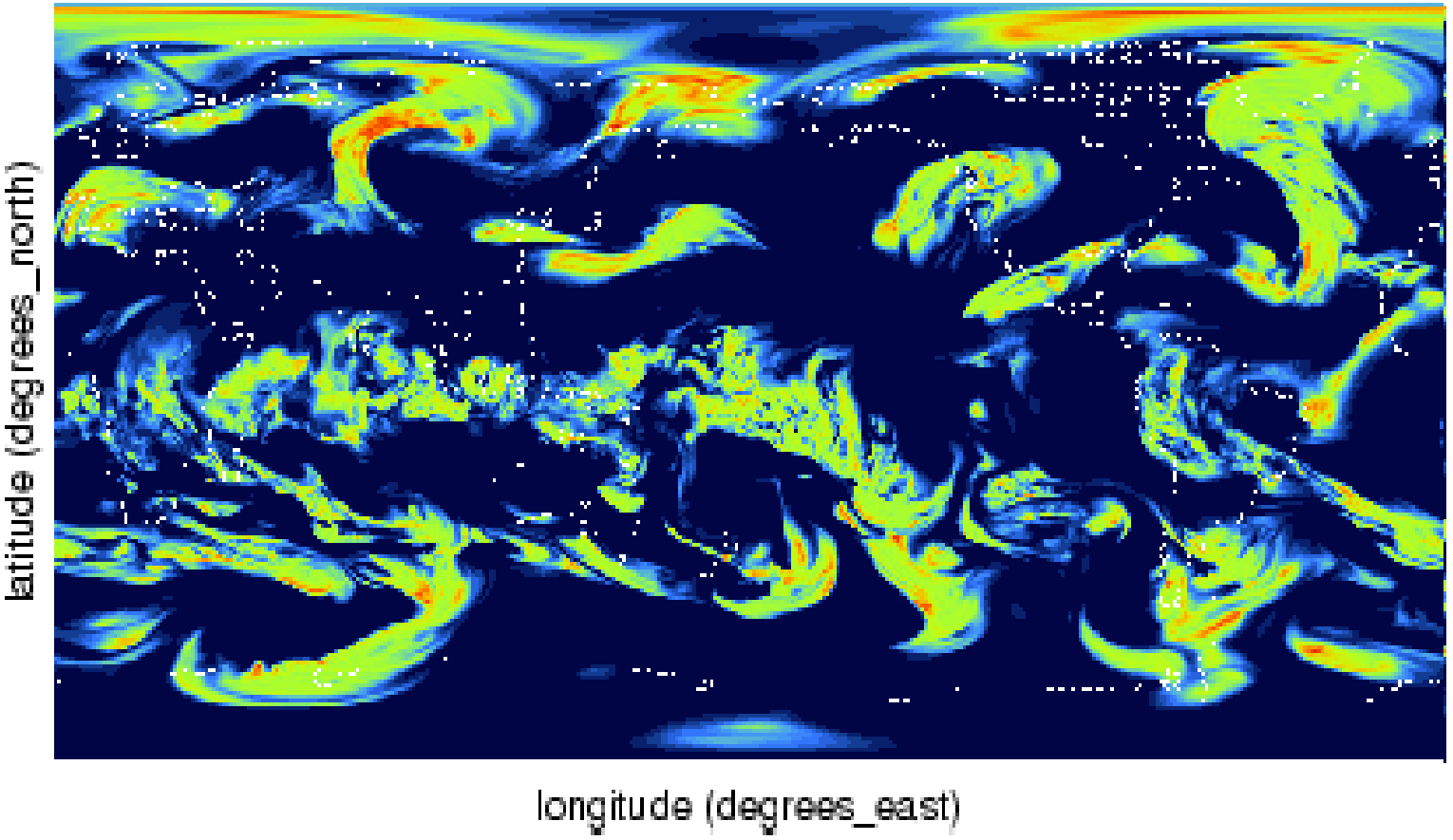


Schumann et al., 2000

$$\text{slope of mixing}_{\text{isobaric}} \propto \frac{1}{(1-\eta)}$$

η - propulsion efficiency

Predictability of ice supersaturation



Source: ECMWF-IFS

green/yellow/red: RHI > 100%

Problems: Data assimilation and validation

Summary

Aviation climate forcing estimated to be 2-8% of overall climate forcing

Initial properties of contrails determined in jet and vortex regime

First simulations of contrail cirrus coverage and radiative forcing

Our simulations confirm that contrail cirrus may be largest component in aviation climate forcing

Newly developed engines may increase the formation probability of contrails

Climate impact and in particular contrail cirrus climate impact may turn out to be a limiting factor for air traffic growth.