Particle emissions and contrails

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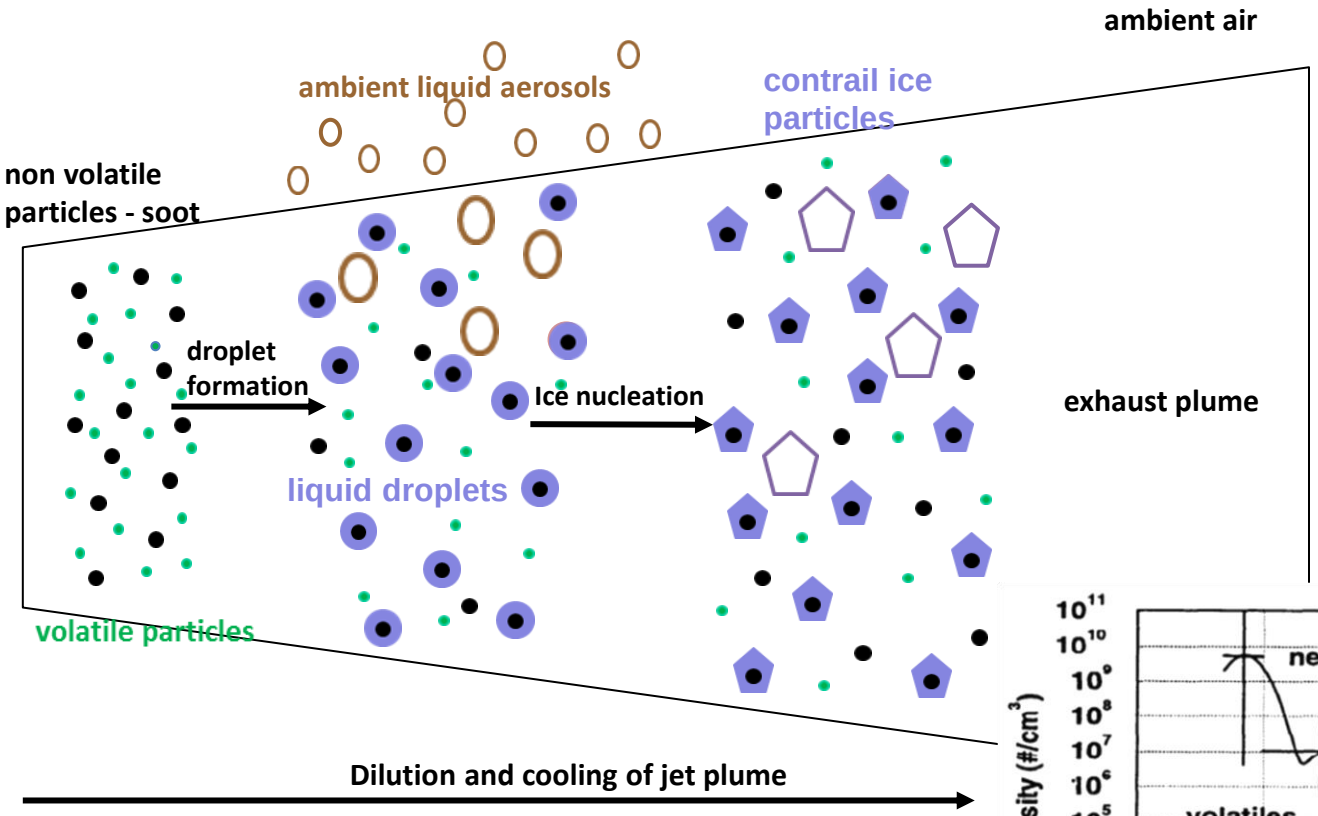
Beyond CO^2 – Biofuel, Brussles, 25 April 2013

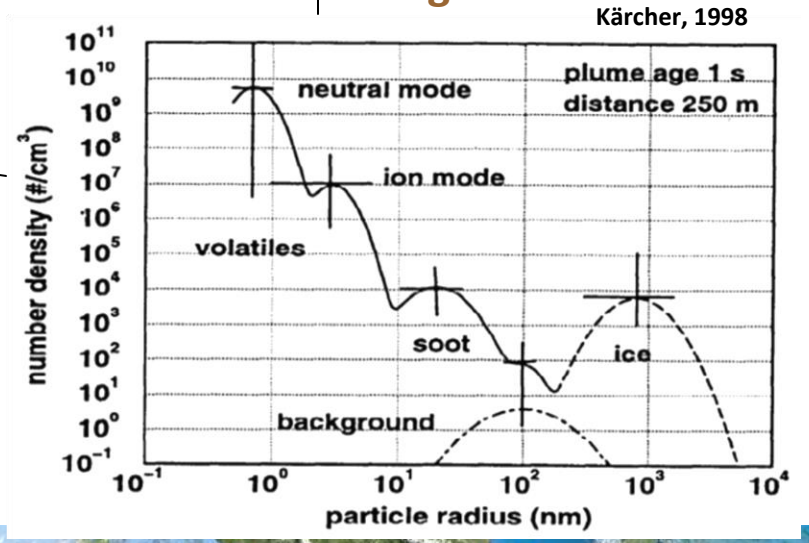
Formation of ice crystals in an aircraft plume



Volatile particles – H_2SO_4, soluble organics, ion-cluster

Ambient aerosols – mainly H_2SO_4 and soluble organics

Kärcher, 1998



Number density and particle radii of aerosols and ice crystals

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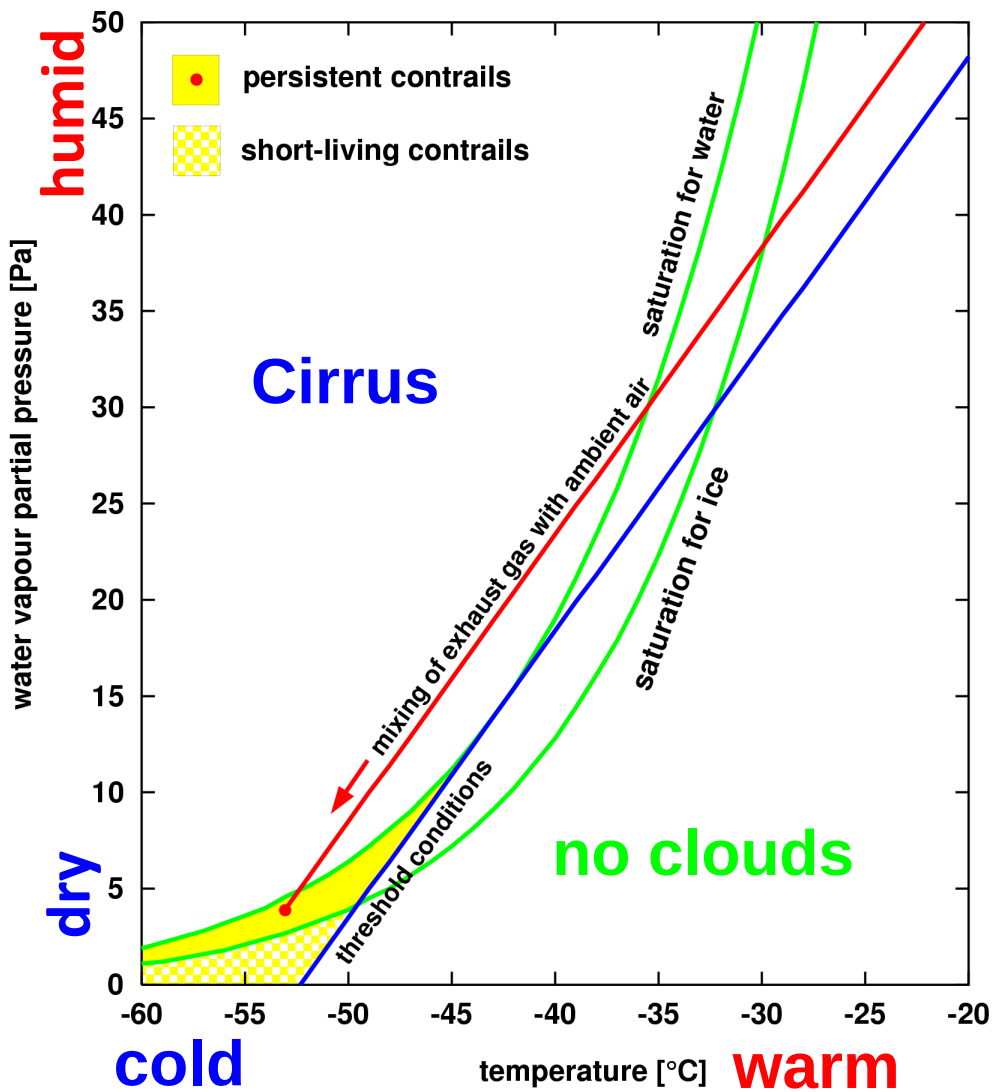
How do contrails form?

Formation depends on

Atmospheric condition
Temperature/Humidity

Too dry/warm
⇒ No contrails

Too humid/cold
⇒ Cirrus already exists



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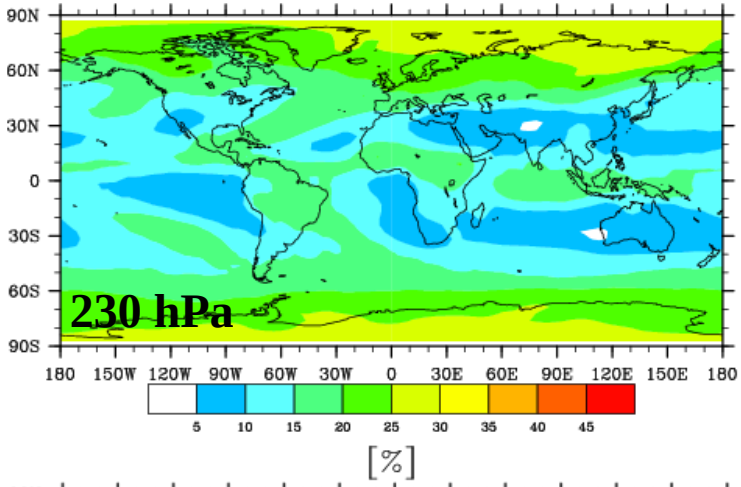
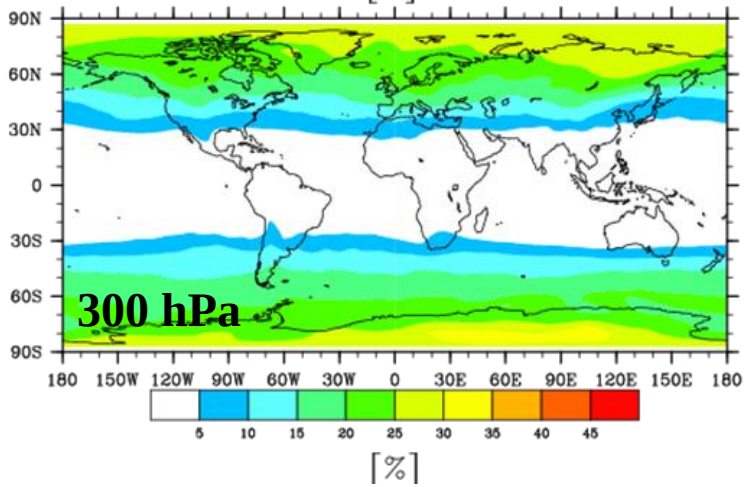
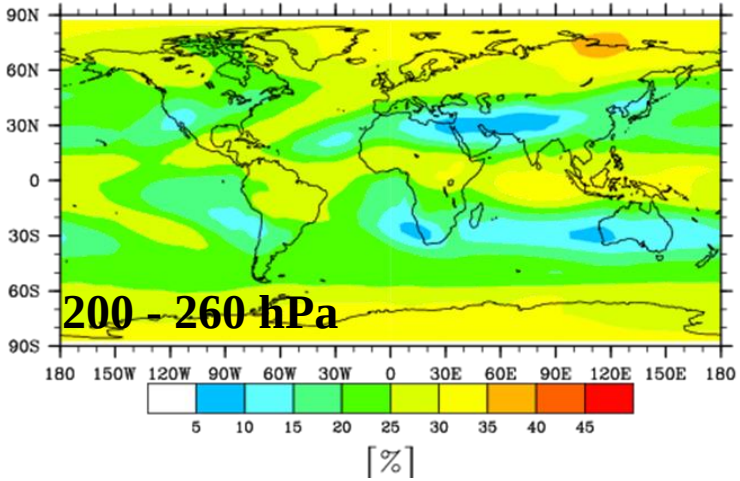
Contrail formation probability and persistence

Contrail formation probability





Ice supersaturation - persistence



No contrails are formed in 300 hPa in the tropics. In extratropics contrail formation possible over much of the upper troposphere. Contrails persist in ice supersaturated areas. Contrail persistence lowest in subtropics.

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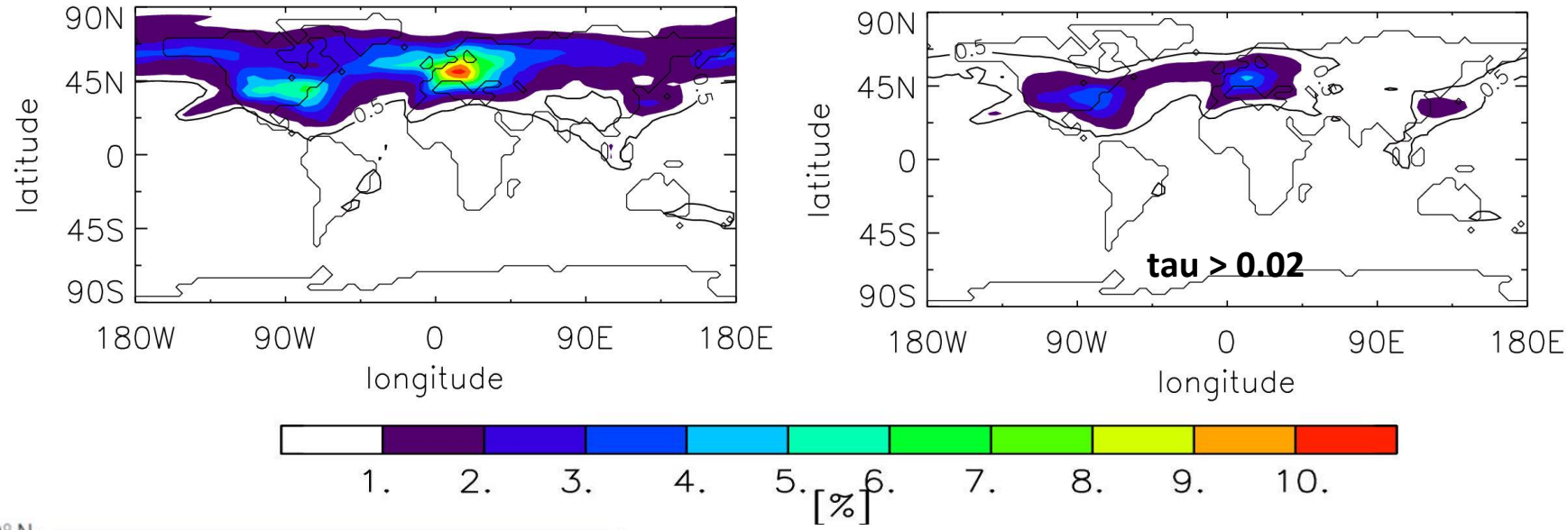
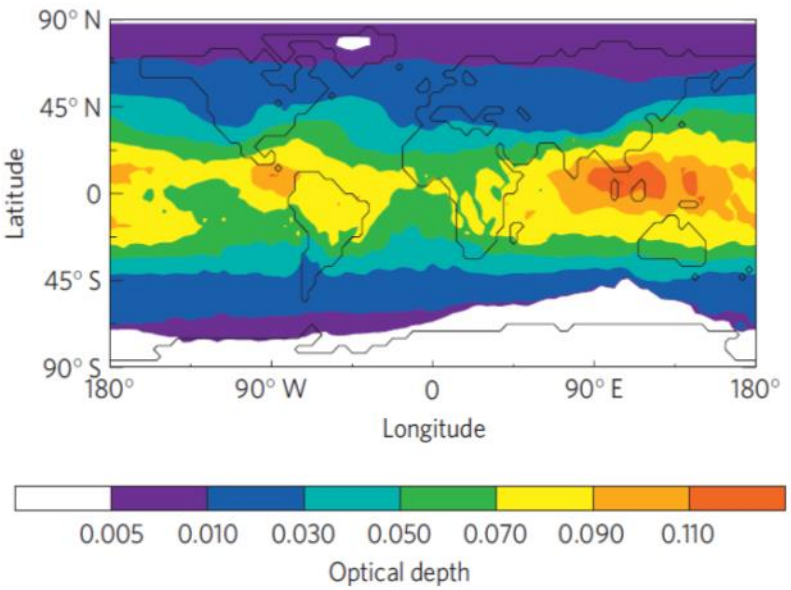
Contrail cirrus coverage and optical depth for current air fleet



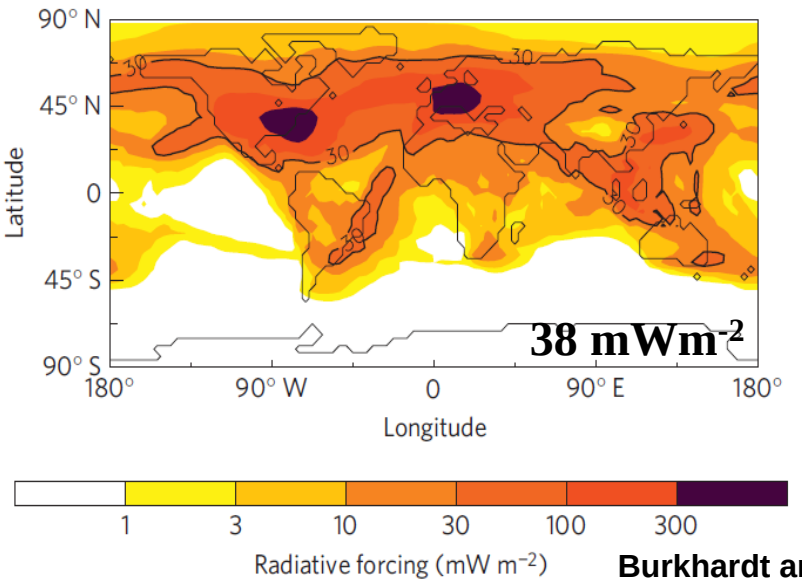


Large contrail cirrus coverage over Europe and the East Coast of the US.

Large optical depth over tropics →Contrail cirrus have larger radiative impact over tropics/subtropics than in the extratropics.

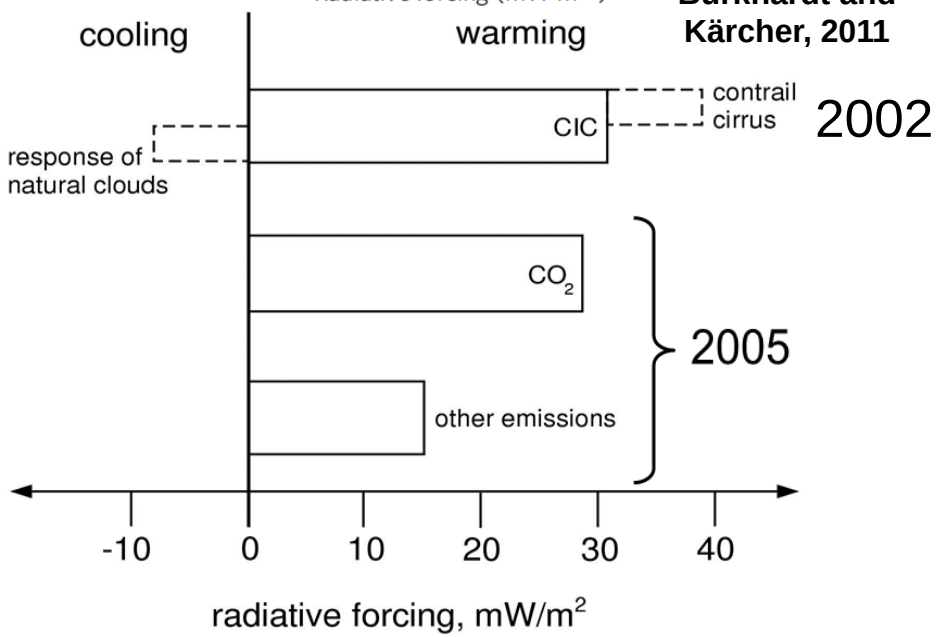
Burkhardt and Kärcher, 2011

Contrail cirrus radiative forcing and feedback natural clouds



Burkhardt and Kärcher, 2011

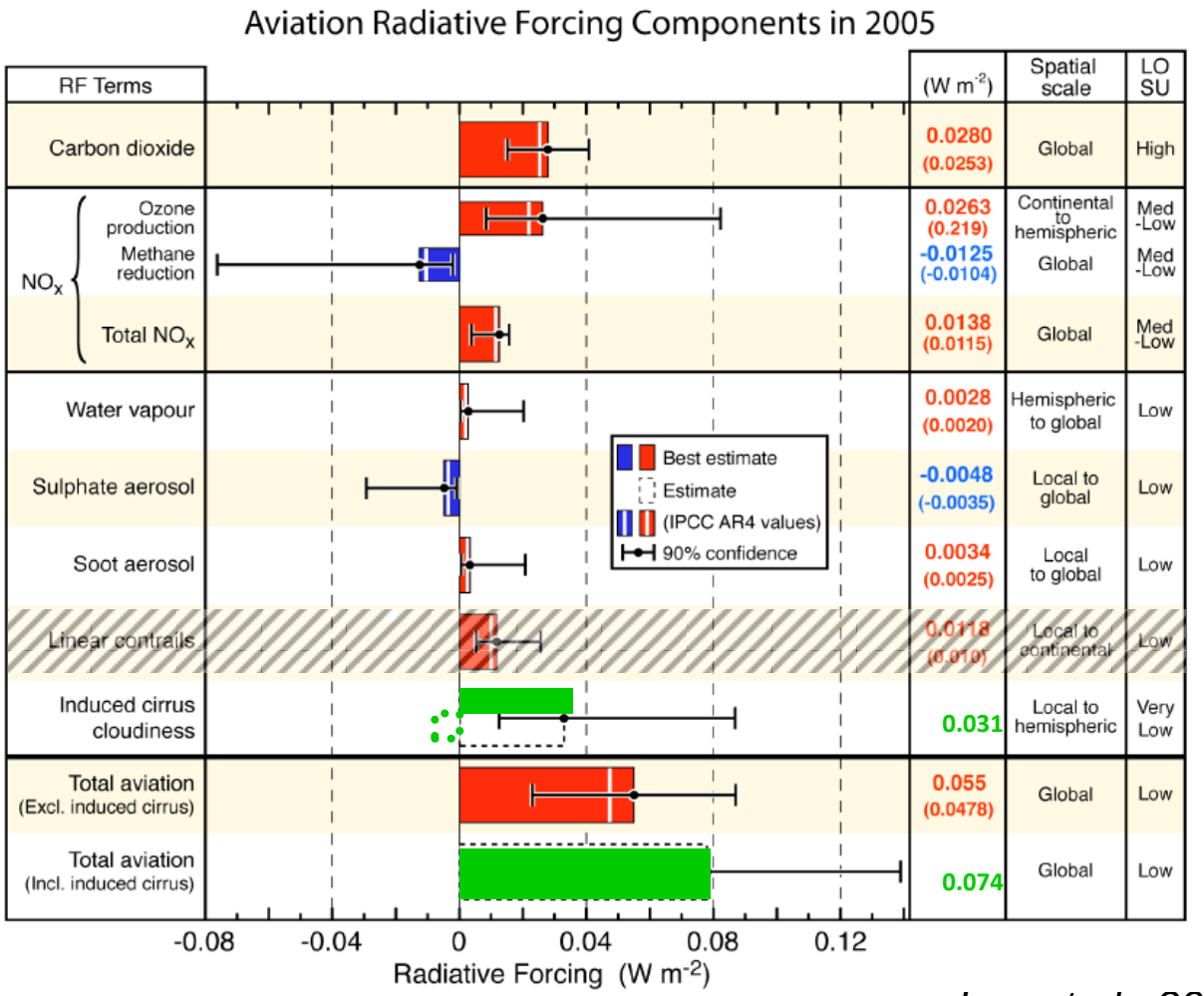
Net radiative forcing (balance between long wave and short wave changes) ~ 38 mW/m² and exceeds over Europe and the USA 0.3 Wm^{-2} and over parts of south east Asia 0.1 Wm^{-2}



Net radiative forcing due to reduction in natural cirrus coverage ~ - 7 mW/m² partly compensates the radiative forcing due to contrail cirrus.

Short life time of contrail cirrus make them ideal aim for mitigation efforts

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., 2010

updated with Burkhardt&Kärcher, 2011 (for 2002 air traffic)

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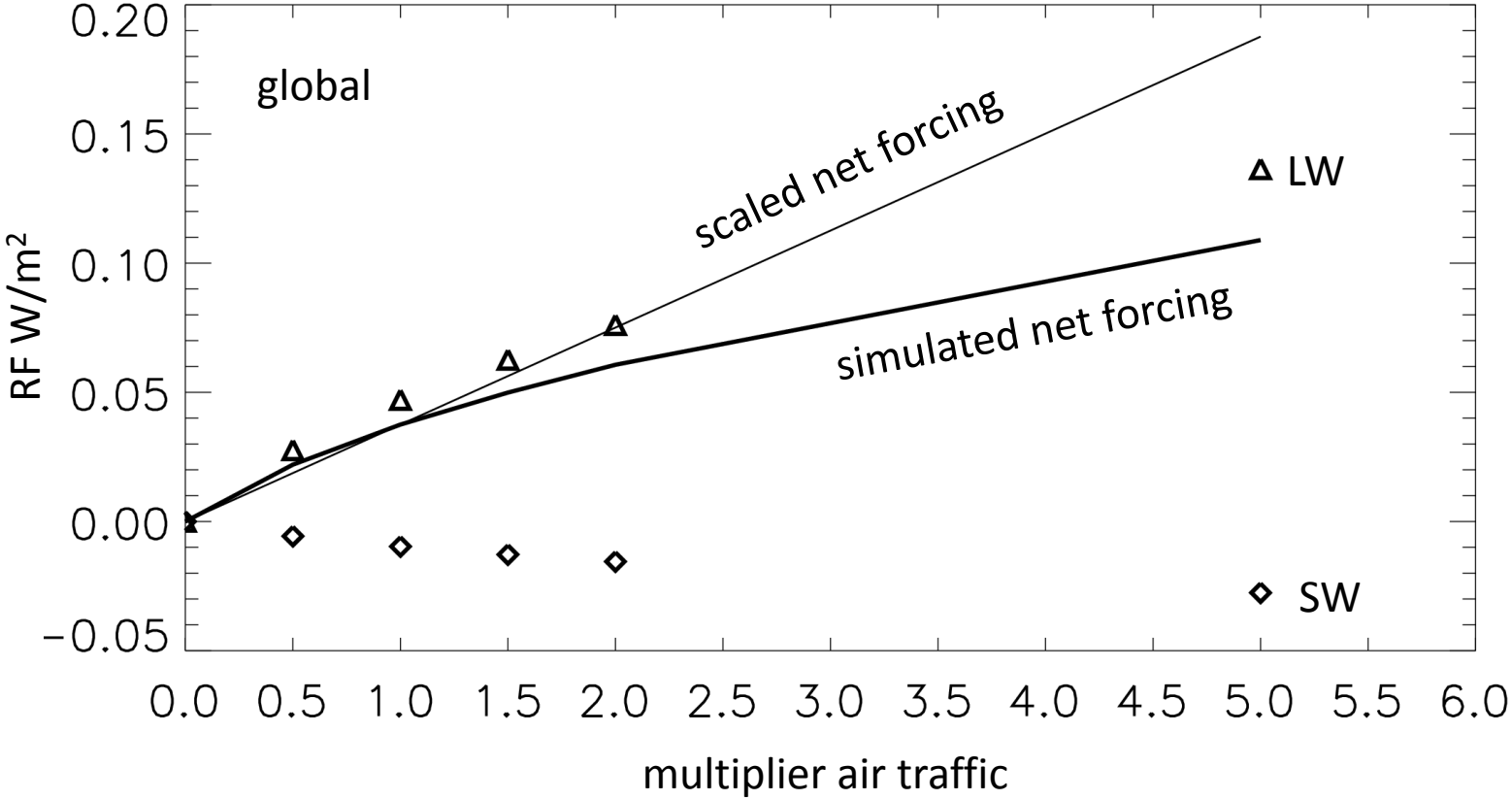
Increase in global mean contrail cirrus radiative forcing with air traffic



Global contrail cirrus radiative forcing does not increase linearly with air traffic due to saturation in well travelled areas.

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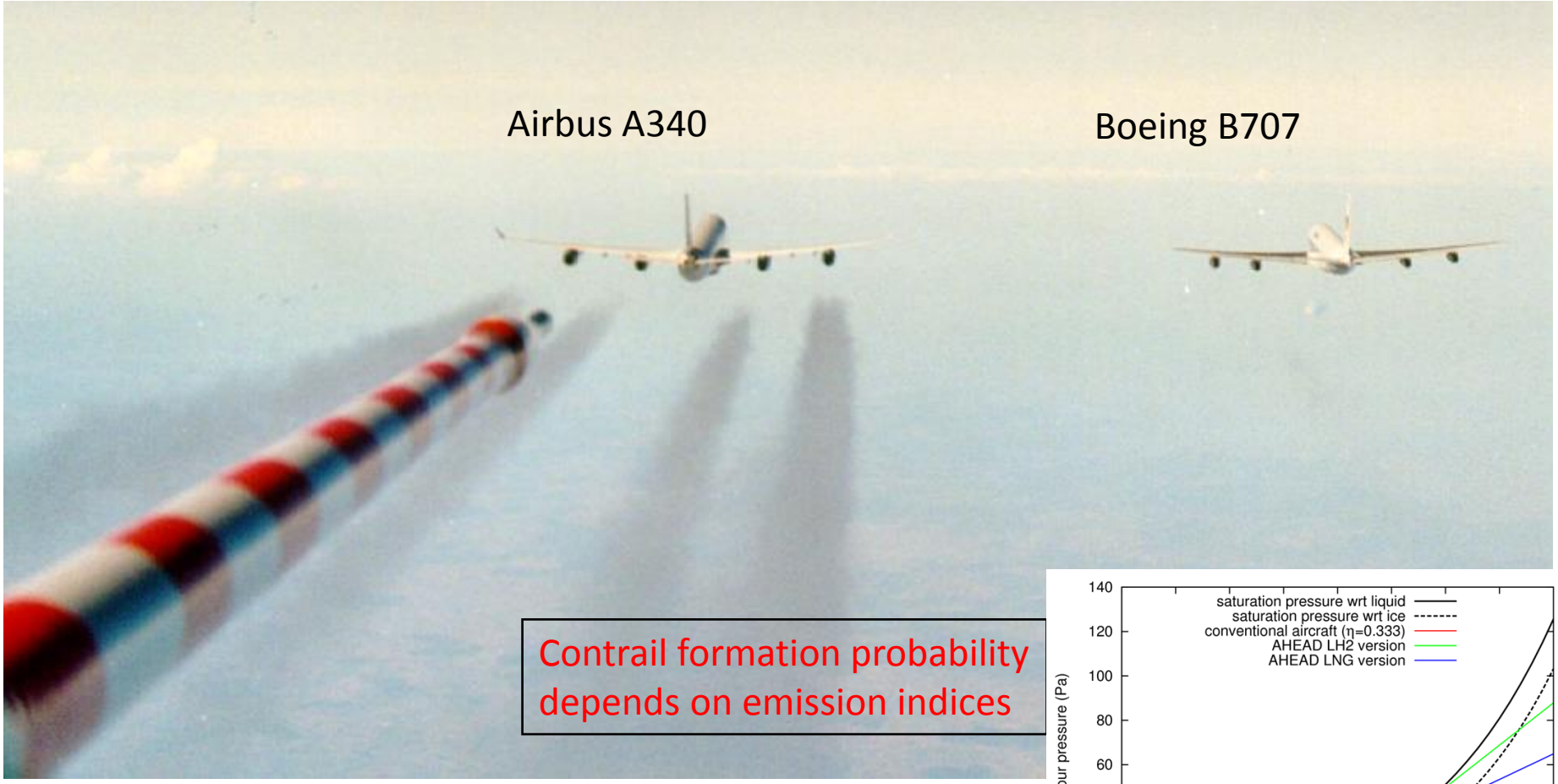
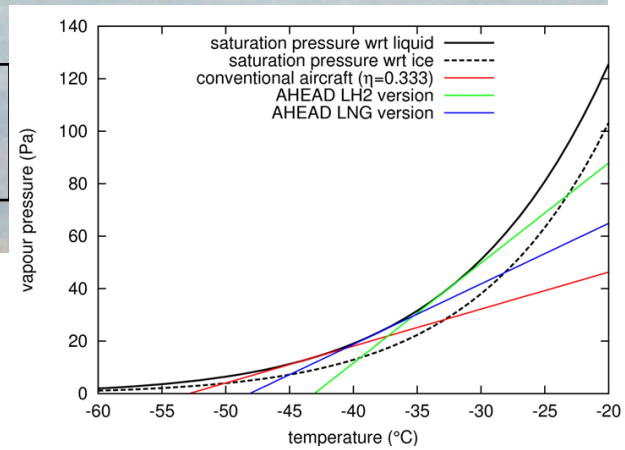
Change in formation conditions

altitude 344 hft



Contrail formation probability depends on emission indices



Schumann et al., 2002

$$G \propto \frac{EI_{H_2O}}{(1-\eta)\cdot Q}$$

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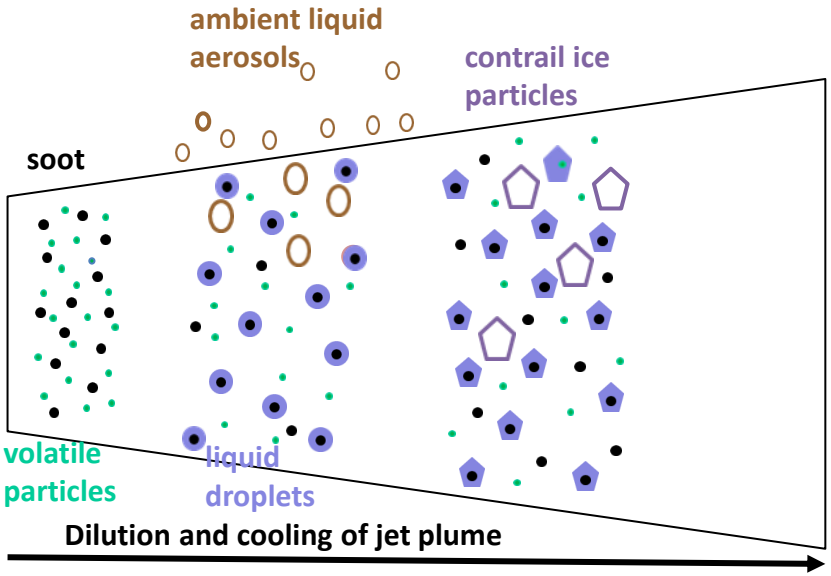
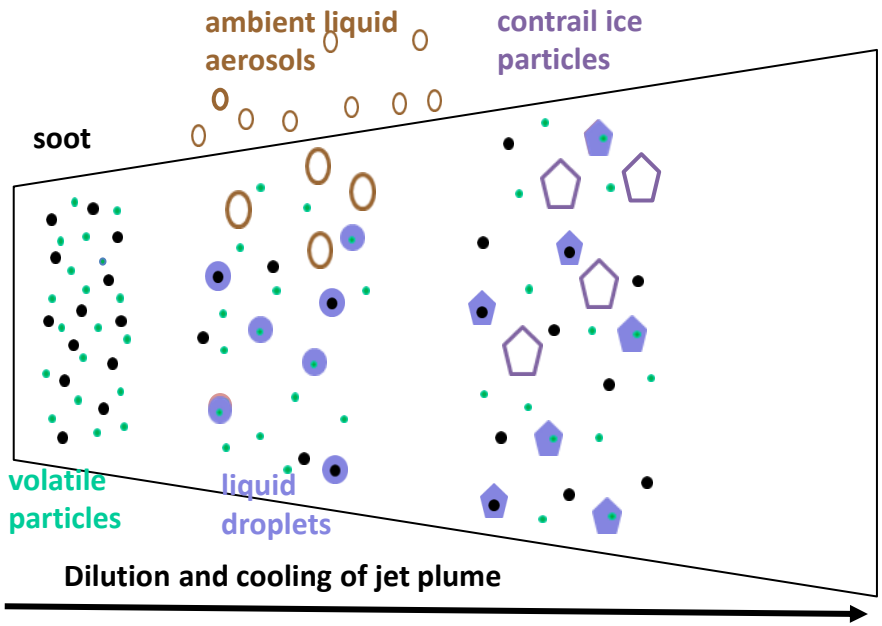
Effect of changes in particle emissions

Soot-rich regime



Soot-poor regime



In soot-poor regime droplets / ice crystals are also formed on ambient and volatile plume particles particularly at low temperatures

fewer aerosols → fewer ice crystals →decreased albedo
→ larger sedimentation → lower ice water content → lower rad. effects
→ larger ice crystals → shorter life time
→smaller contrail radiative forcing?

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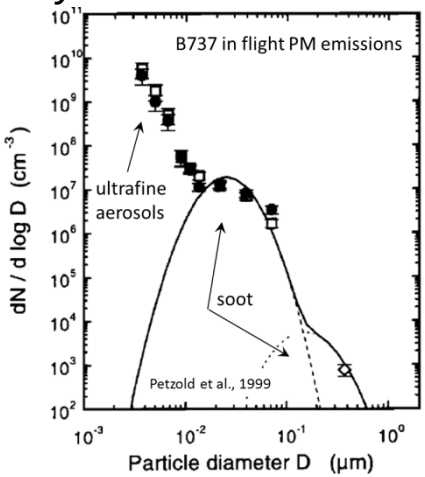
In-situ Measurements

- Ground-based engine tests
  - Investigation of fuel effects on emissions characteristic
  - Comparison of fuel-effects on emissions from real engine and DLR spray-burner



ECLIF – Emission and Climate impact of alternative fuels – planned DLR project / NASA

- Airborne campaigns
  - Investigation of fuel effects on emissions in flight
  - Characterization of exhaust composition in young plumes relevant to ice formation
  - Microphysical properties of contrail ice crystals and ice precursor particles (soot etc.)

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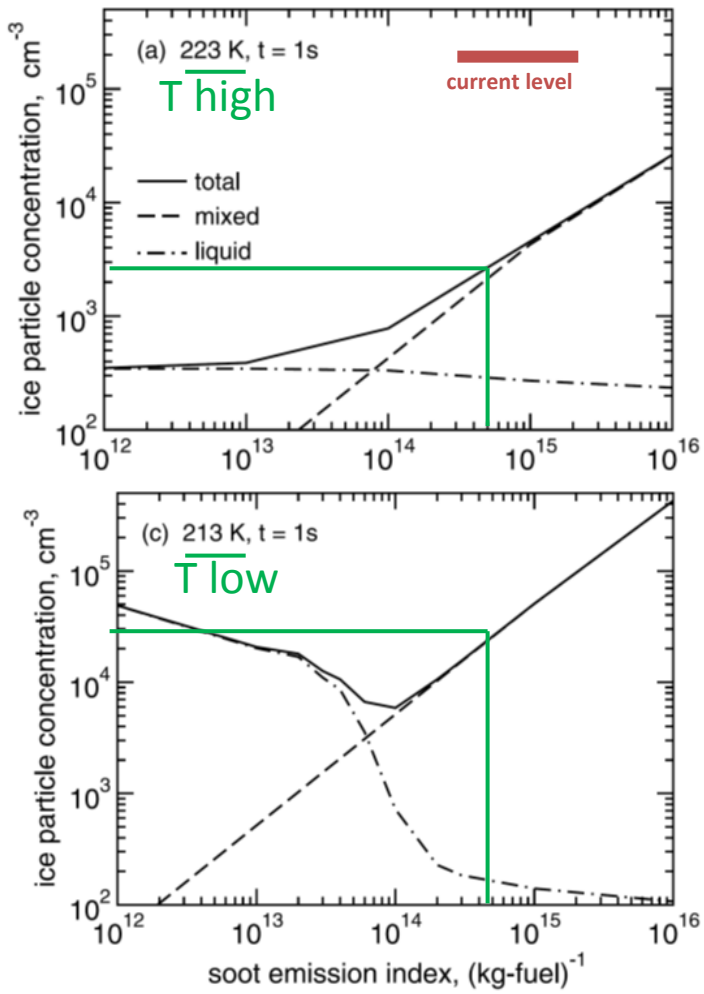
Change in soot emissions:
Effect on ice particle concentrations in contrails



Kärcher and Yu, 2009

Initial ice crystal number controlled by soot number emission index.

At lower temperatures (higher flight levels) more ice crystals form at constant soot emissions

Decrease in soot emissions
-> more entrained background liquid aerosol particles (mainly sulfuric acid and organics) freeze

At low temperatures liquid plume particles (sulfuric acid, nitric acid and low volatile, soluable organics) freeze additionally

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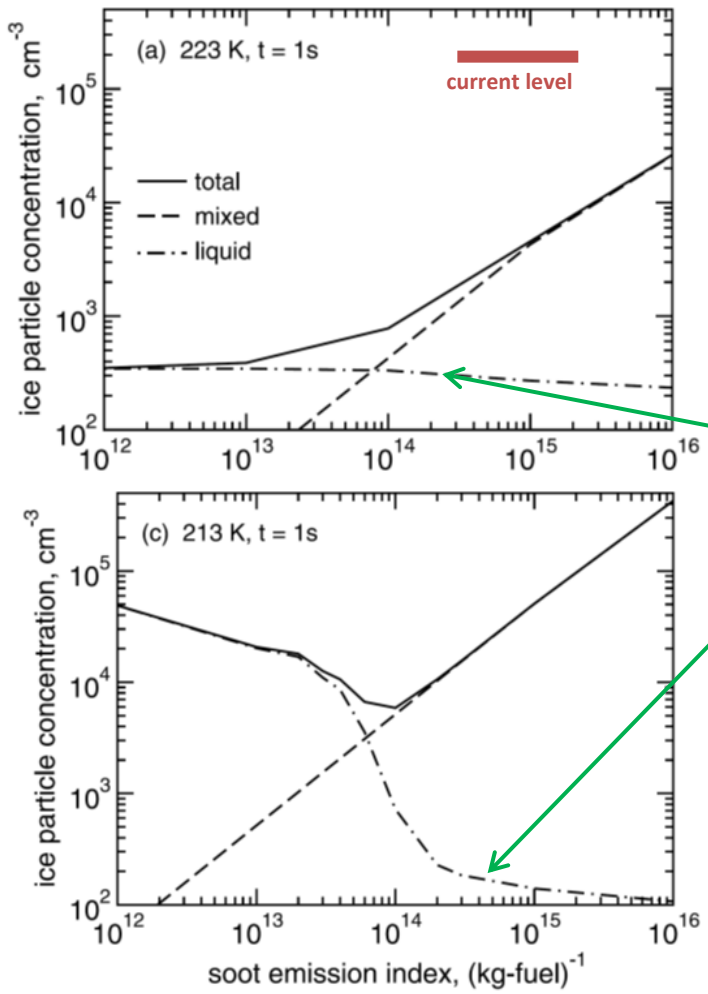

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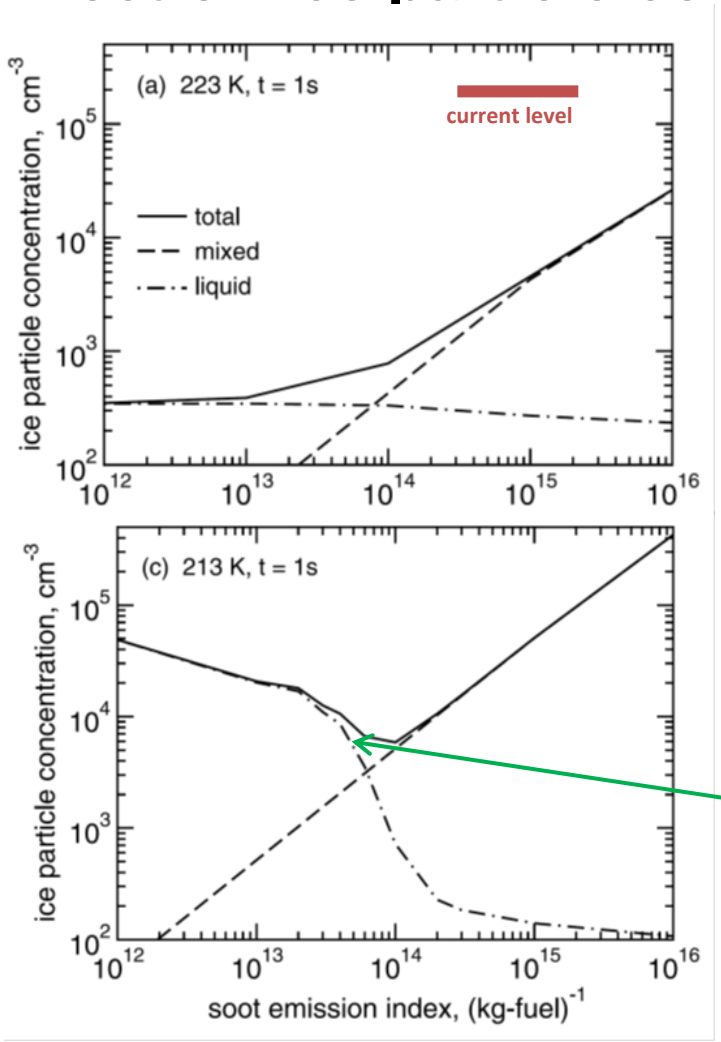

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A reduction in soot emissions can lead at low temperature to increases in ice particle number concentrations as long as fuel contains sulfur (and maybe condensable organics).

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Conclusions

- **Soot, ultrafine plume particles and ambient aerosol particles can act as ice nuclei within an exhaust plume forming contrails**

- **Contrail cirrus (originating from line shaped contrails) are largest radiative forcing component from air traffic – increases with air traffic limited due to saturation behavior**

- **Soot emissions control over a large range contrail ice particle concentrations and therefore contrail optical depth and possibly life time**

- **Characterization of emissions on ground and during flight necessary in order to estimate impact of contrail changes due to emissions**

- **At low temperatures in soot-poor regimes smaller particles, such as volatile plume particles and ambient aerosols, nucleate forming ice crystals**

- **Impact of soot reductions on contrail cirrus radiative forcing needs to be studied – model under development**

- **Caution: In order to evaluate climate impact of biofuels all radiative forcing components and the whole biofuel life cycle including the response of the regional climate to land use changes have to be evaluated**