More and different clouds from transport

Klaus Gierens

Deutsches Zentrum für Luft- und Raumfahrt (DLR)
Institut für Physik der Atmosphäre
Oberpfaffenhofen, Germany

Transport Emissions: The Climate Challenge
Results from IP QUANTIFY and SSA ATTICA
Brussels, 24 June 2010

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Acknowledgements

Veronika Eyring and the ATTICA ships team

David Lee and the ATTICA aviation team

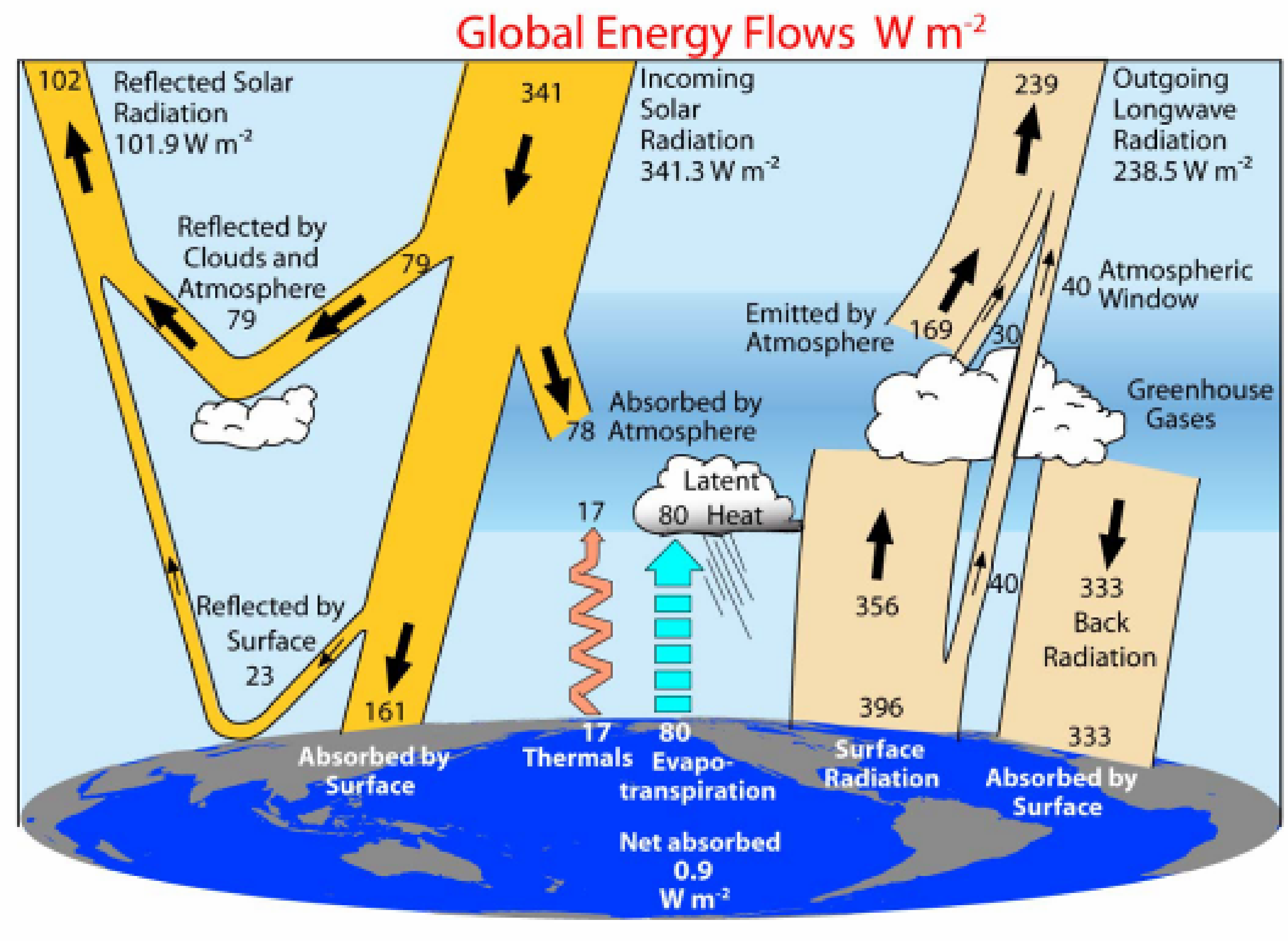
Kaspar Graf, Hermann Mannstein, Ulrich Schumann

Christos Zerefos, Kostas Eleftheratos

Mathias Schreier, Andy Sayer, Don Grainger

Contents

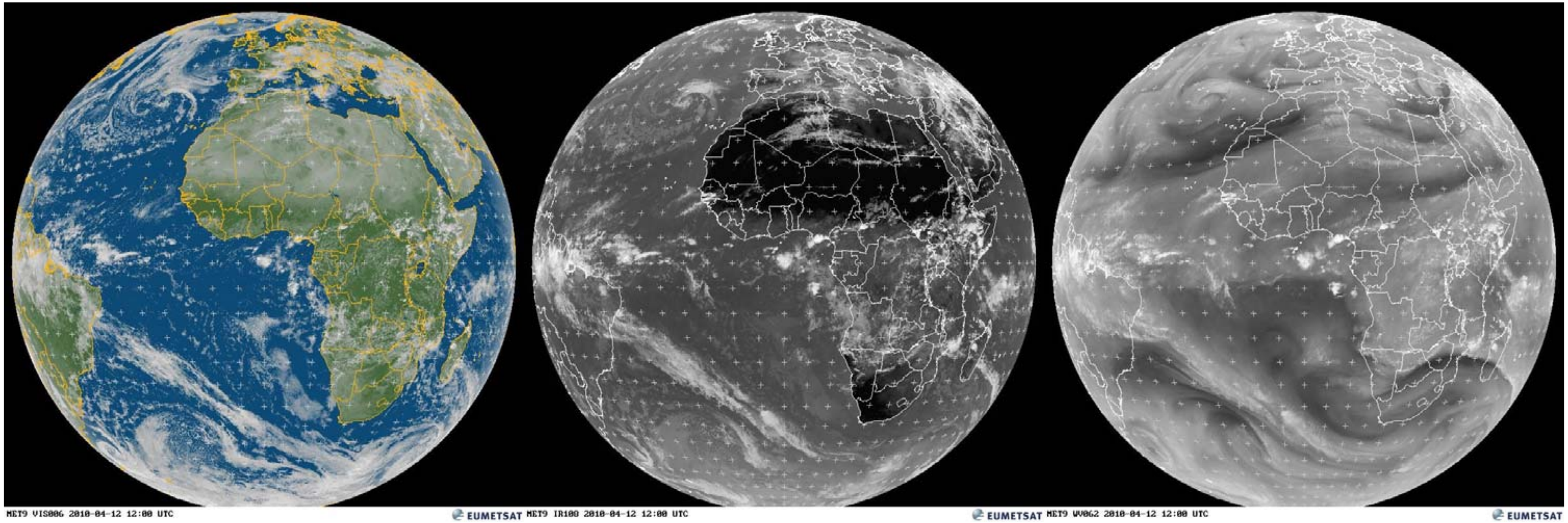
Climate: Dynamical equilibrium between energy inflow and outflow



Trenberth et al., 2009: Earth's Annual Global Mean Energy Budget

Clouds

visible light | IR window | water vapour

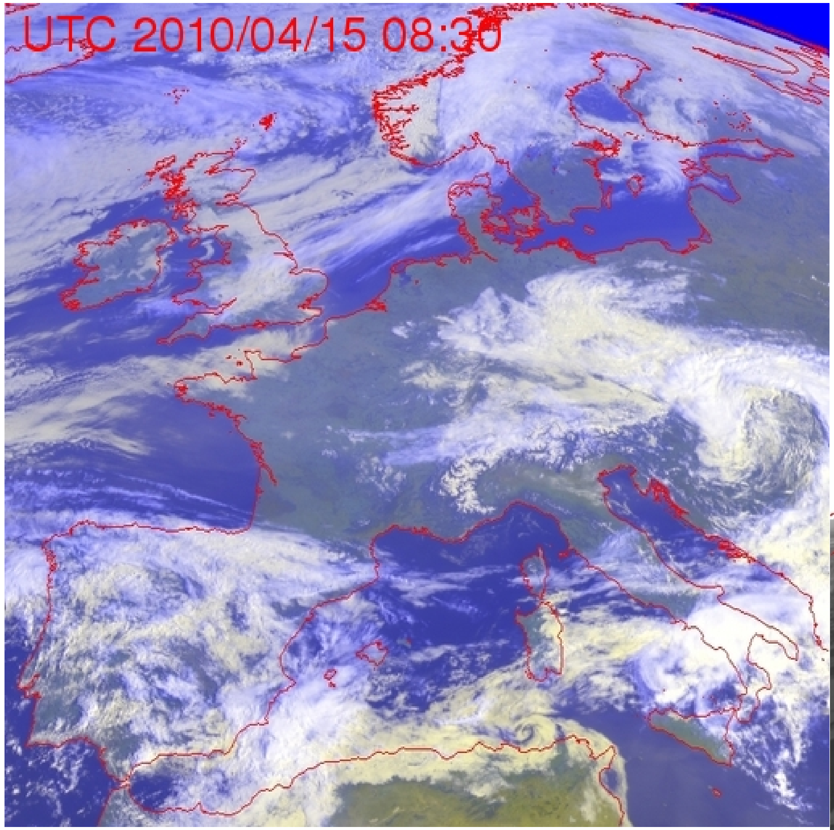


Eumetsat image gallery

Clouds interact strongly with both solar and terrestrial radiation, as evidenced by their clear visibility on such satellite images (contrast).

Systematic cloud changes therefore impact the radiative equilibrium.

Climate warming and cooling by clouds

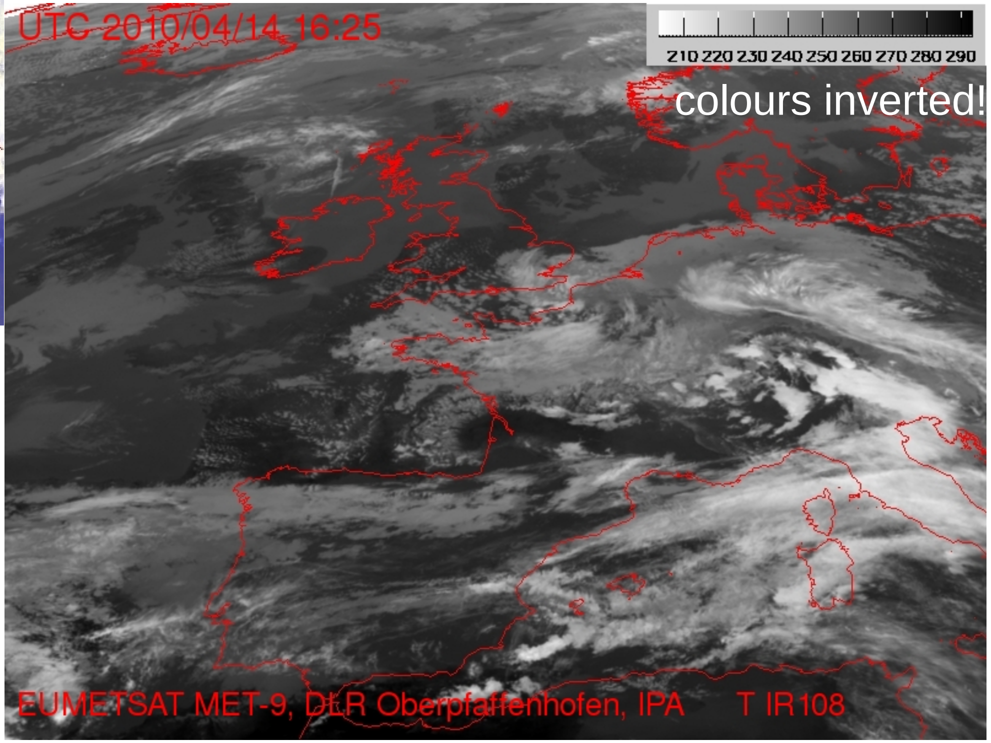


reflection: cooling

Cirrus clouds both cool and heat the atmosphere, and the total can be positive or negative.

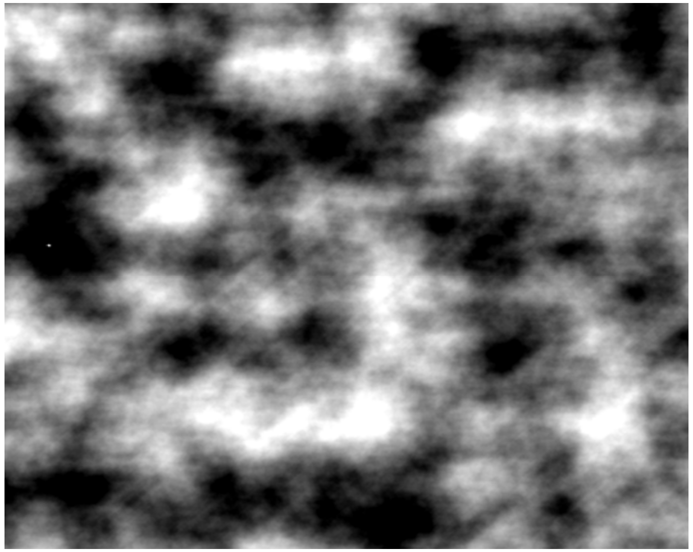
Uncertainties arise from subtracting large positive and negative values.

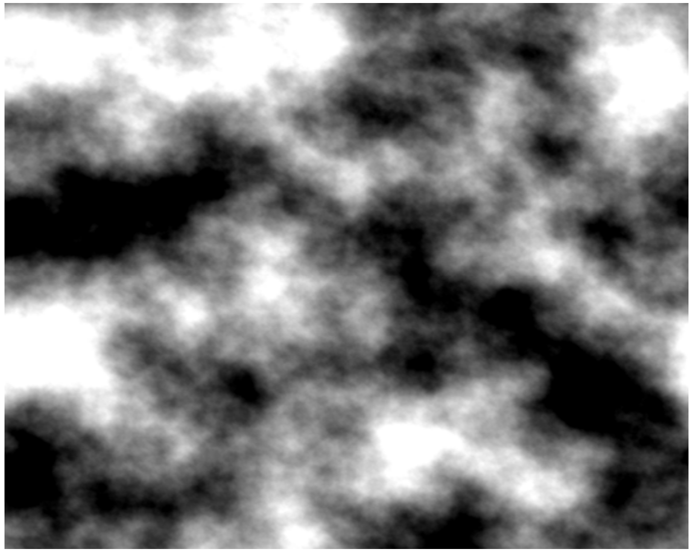
trapping: heating

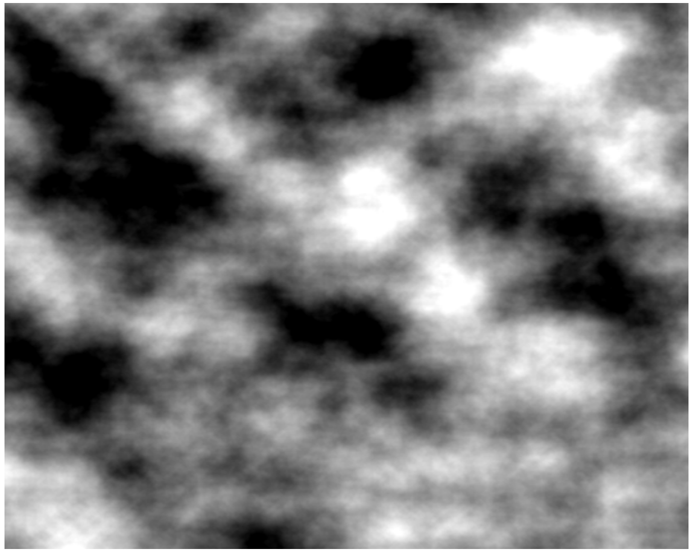


QUANTIFY

Detection of cloud changes is difficult ...



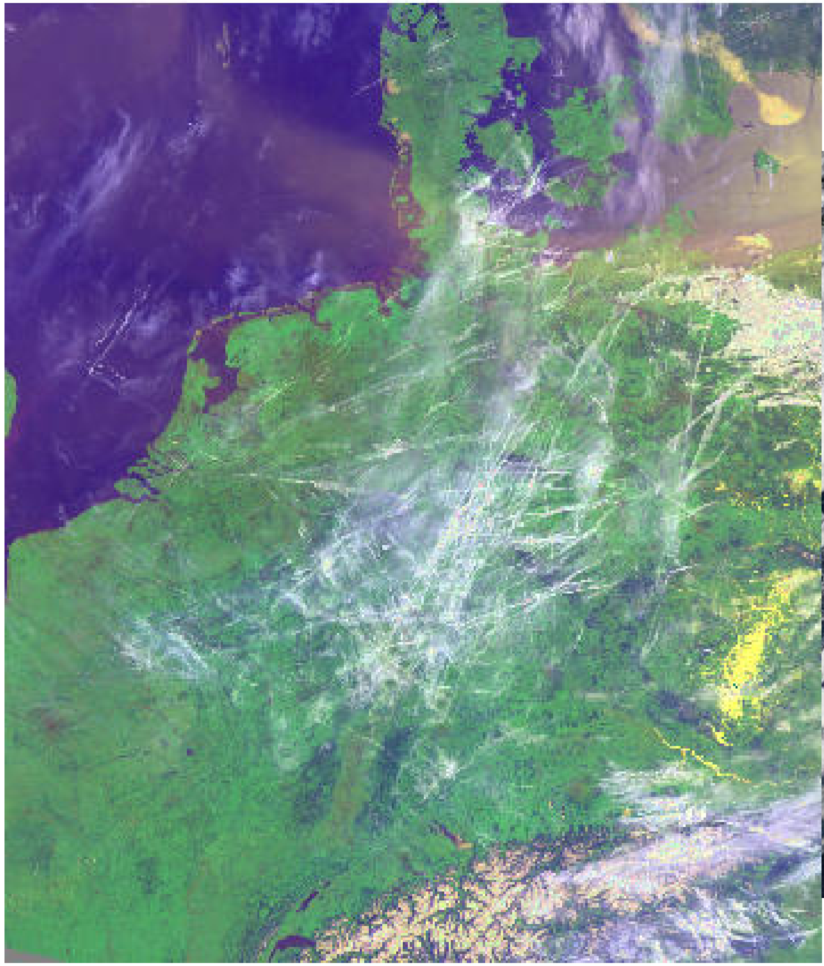


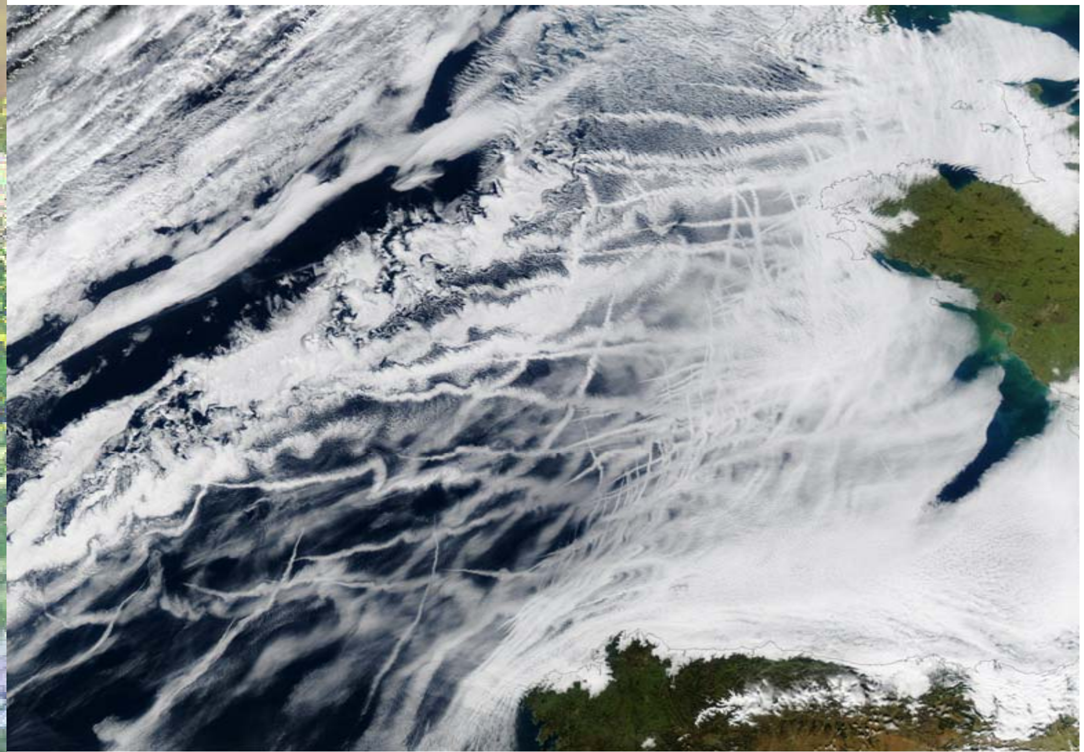


no two clouds are equal. Therefore to detect systematic cloud changes is a question of statistics with interpretation aid from theoretical cloud physics.

As it is statistics, it implies uncertainties.

... unless they appear as contrails and ship tracks





Contrails and ship tracks are easily detectable due to their particular line shape.
Even automatic detection and tracking methods work.

How can clouds be altered?

Ingredients for cloud formation:

- high relative humidity (saturation and supersaturation)
- appropriate aerosol particles which act as condensation and ice nuclei.

Particles are present in the natural atmosphere in copious numbers.

Anthropogenic particle emissions change composition (chemical composition, surface structure) and number concentration of the aerosol.

⇒ Cloud formation where no natural cloud would form (contrails, some ship tracks)

⇒ Modification of natural cloud formation processes ⇒ clouds with different microphysical and optical properties

Contrail formation

Contrail formation is like breathing in cold air:

Mixing of hot and moist exhaust gases with sufficiently cold ambient air can lead to transient water (super)saturation ⇒ condensation on exhaust and entrained ambient particles ⇒ freezing ⇒ contrail

Contrails can persist for hours in ice-supersaturated airmasses.

Aerodynamic contrail formation

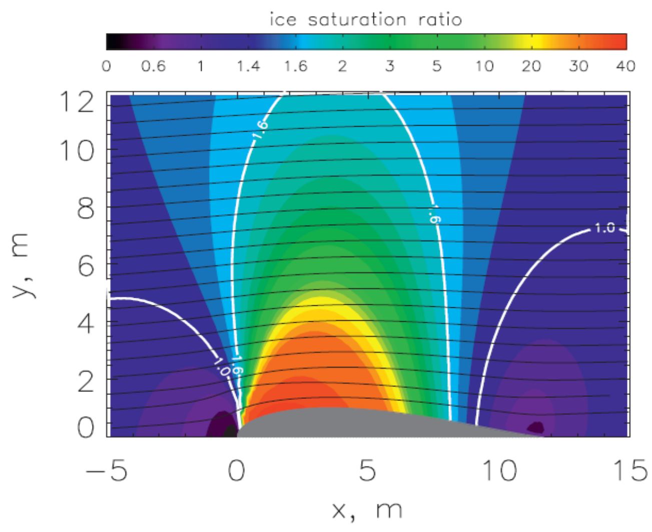
Pressure drop around wings

leads to strong cooling of the air

leads to very high values of supersaturation for some milliseconds

leads to condensation and freezing on aerosol particles in the air flow

Phenomenon is rarely observable under cruise flight conditions



Dieter Klatt, D-Oldenburg

Formation of ship tracks: natural aerosol

Normal conditions over the sea: small numbers of sea salt and sulphate aerosol

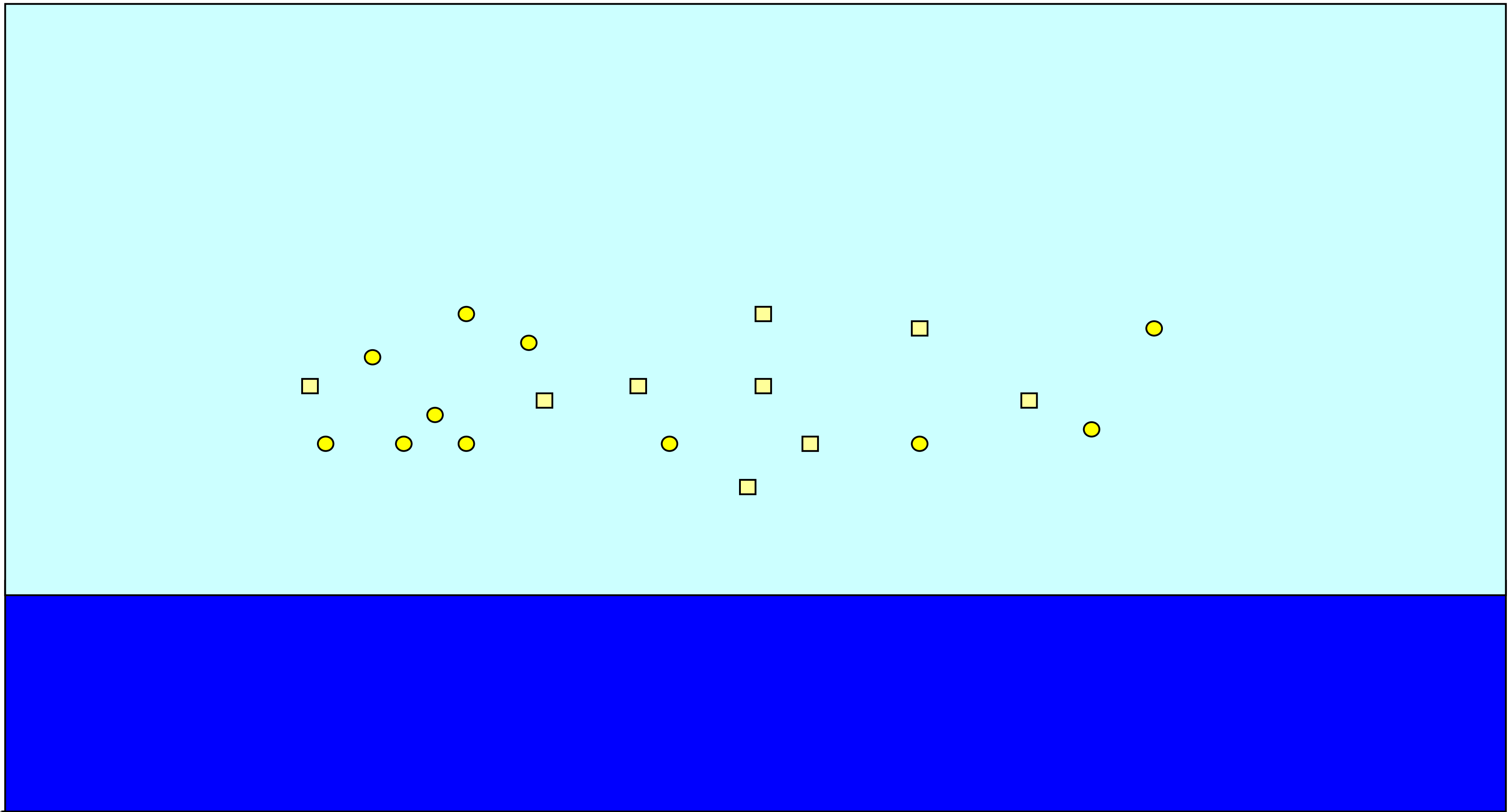
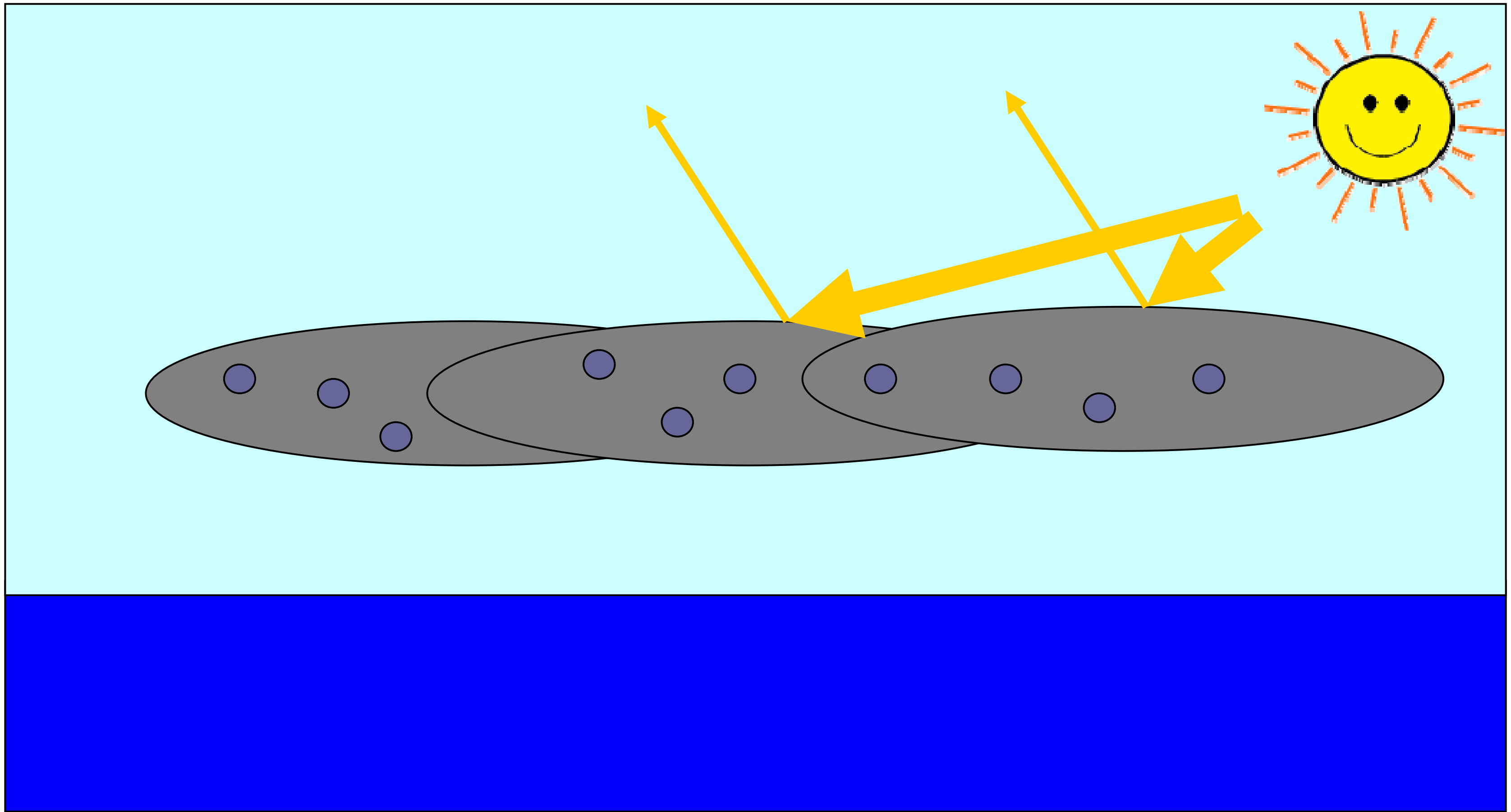


Illustration courtesy of M. Schreier, Univ. Bremen

Formation of ship tracks: cloud formation

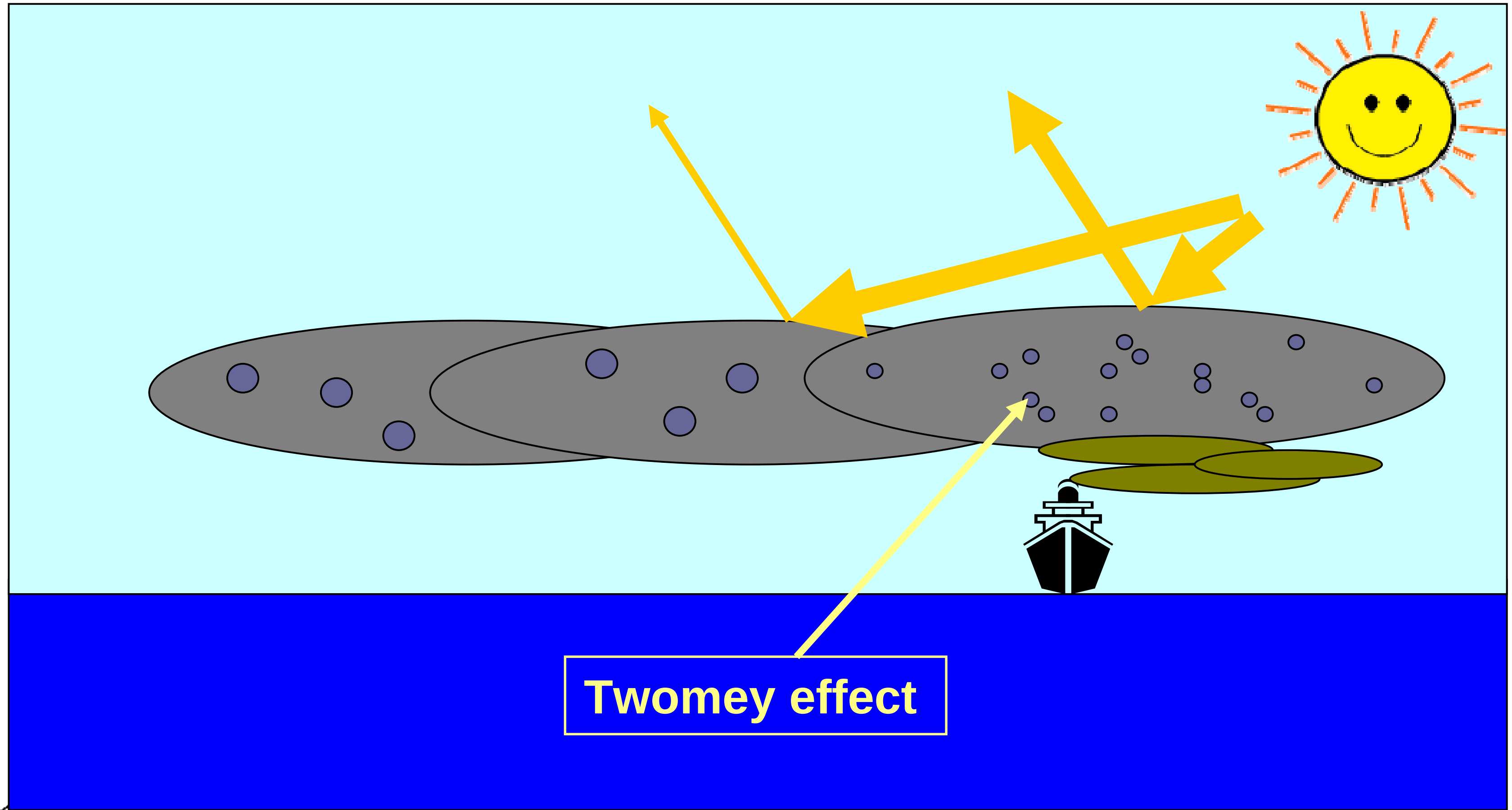
small number of condensation nuclei to form droplets

⇒ small number of big cloud droplets



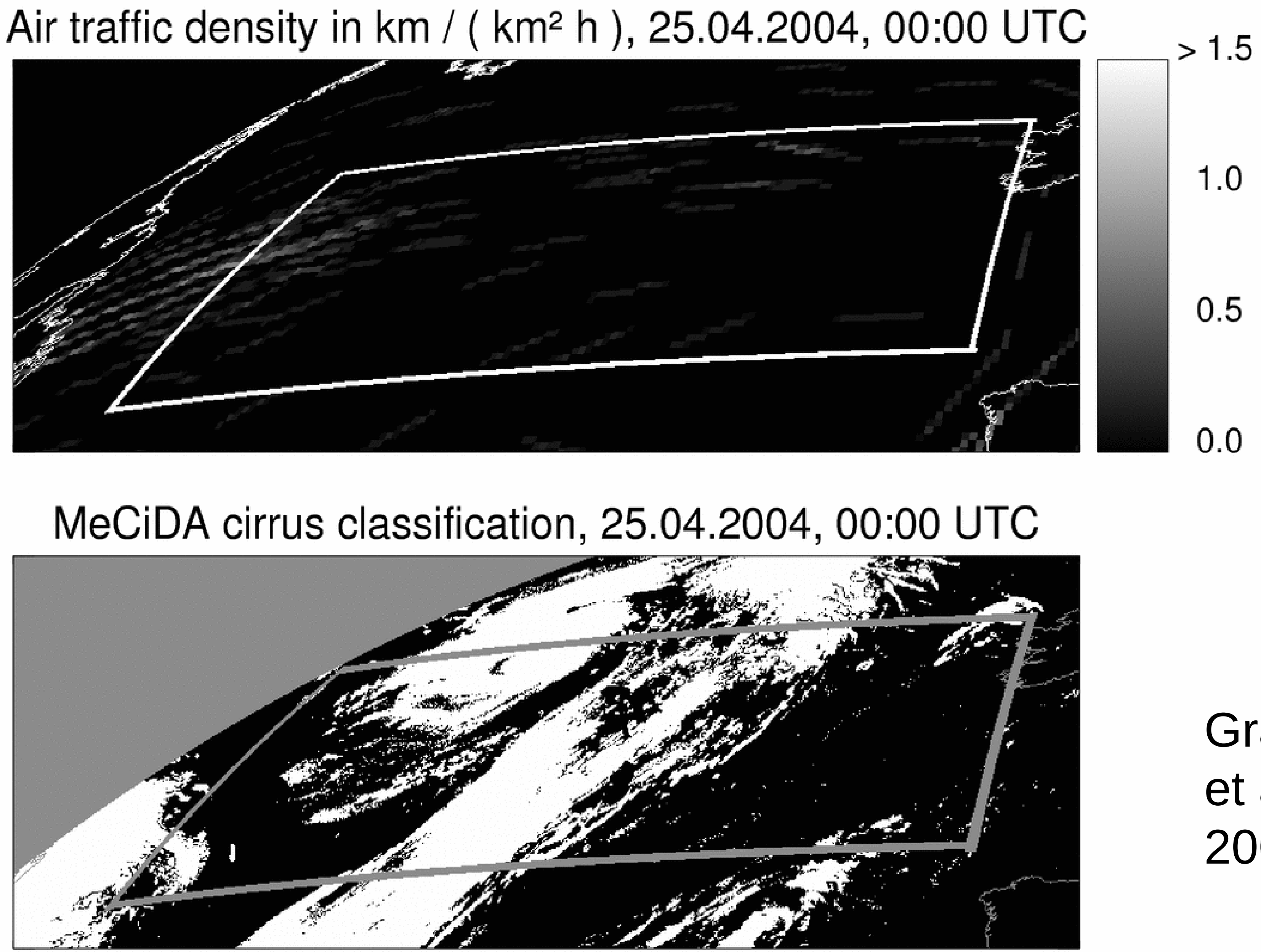
Formation of ship tracks: Twomey effect

addition of aerosol particles from ship exhaust ⇒ more condensation nuclei ⇒ large number of small cloud droplets ⇒ higher reflectivity



QUANTIFY

Manifestations of cloud changes induced by air traffic



Graf et al., 2008

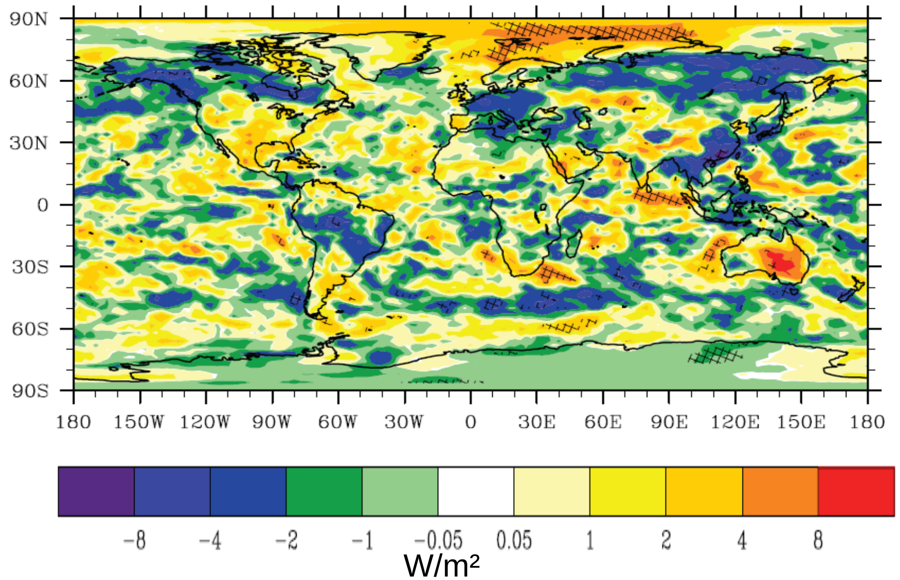
Large scale aviation impact on cirrus clouds: Optical and microphysical properties

Aviation influence is expected to

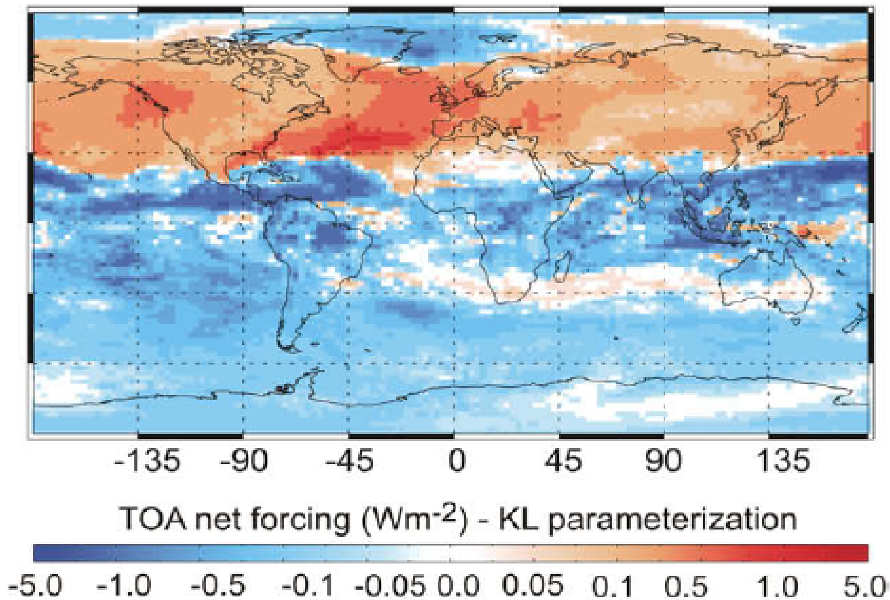
- decrease ice crystal numbers in clouds formed in clean environments
- increase ice crystal numbers in clouds formed in polluted environments

Either cooling or warming can result, depending on predominating conditions. Only two numerical studies so far with inconclusive results

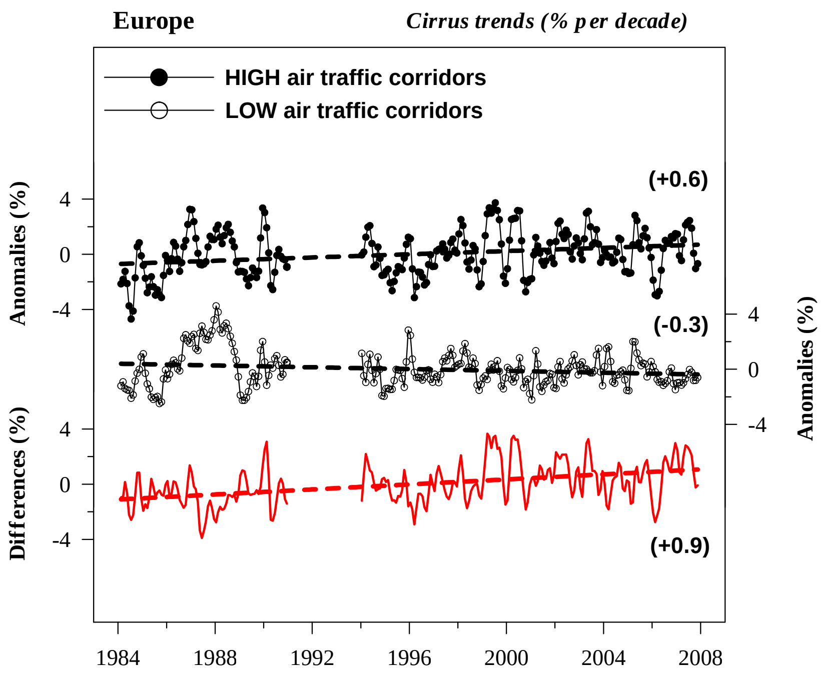
Liu, Penner, Wang 2009

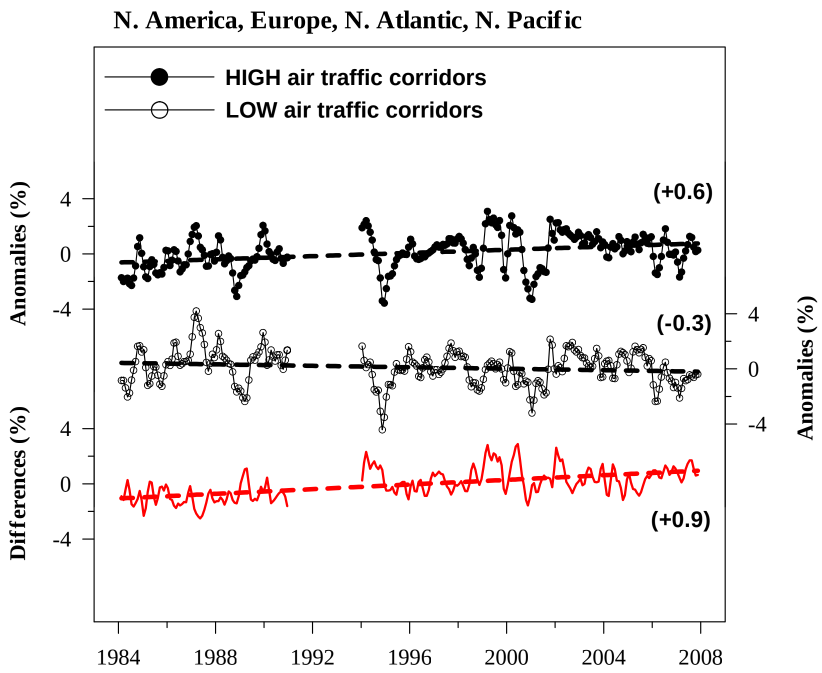


Penner, Chen, Wang, Liu, 2009



Large scale aviation impact on cirrus clouds: Coverage changes (trend analyses)





Zerefos & Eleftheratos, recent results:
In all cases the differences have a positive trend which could be considered in favour of a pattern that is imposed by increasing of miles travelled by aviation in the past 20 years

Manifestations of cloud changes induced by ship traffic

Ship tracks (observations)

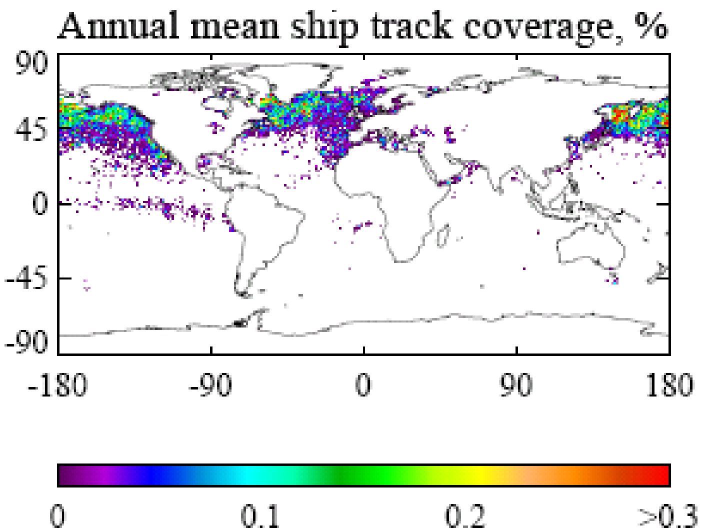
selective phenomenon

smaller droplets (incr. reflectivity)

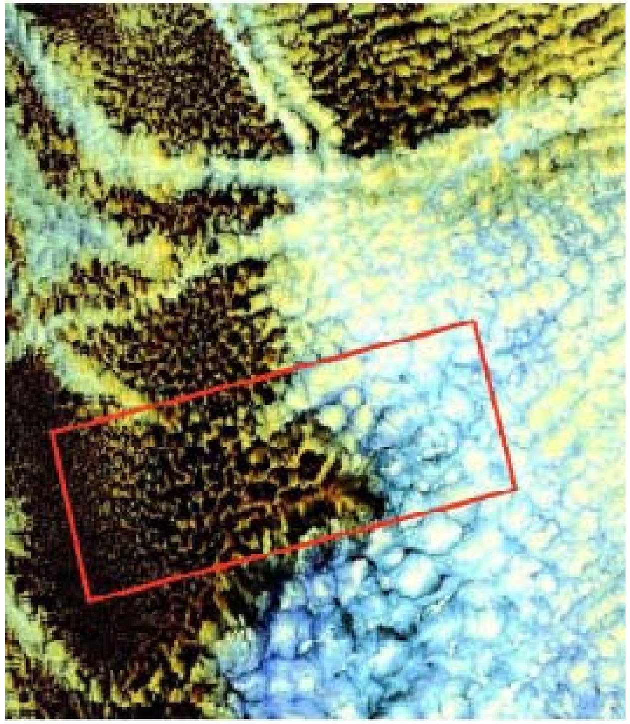
reduced drizzle formation

increased lifetime

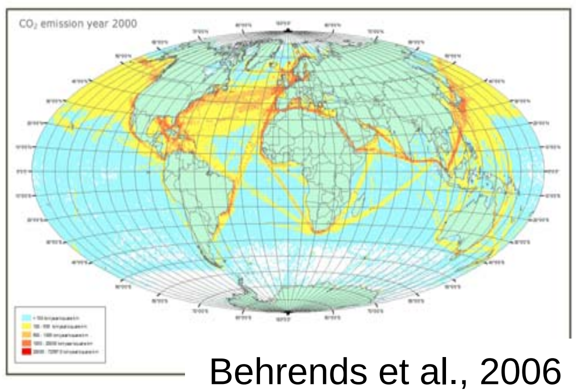
≈ 300 km long, ≈ 10 km wide



Sayer and Grainger, 2010



Rosenfeld et al. 2006

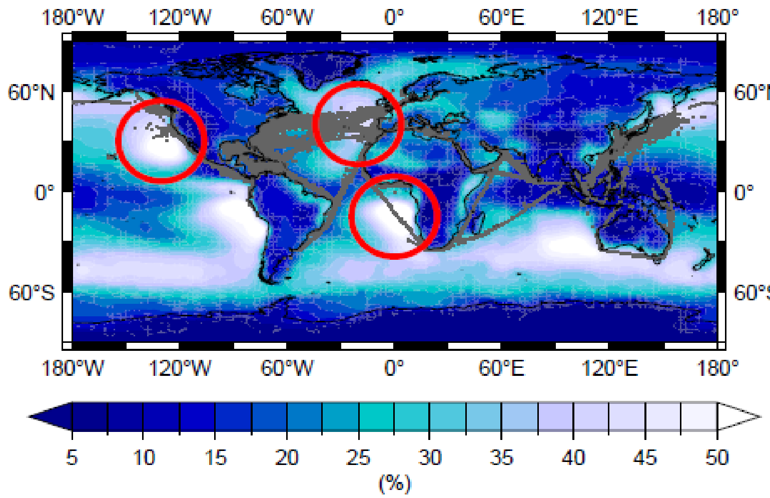


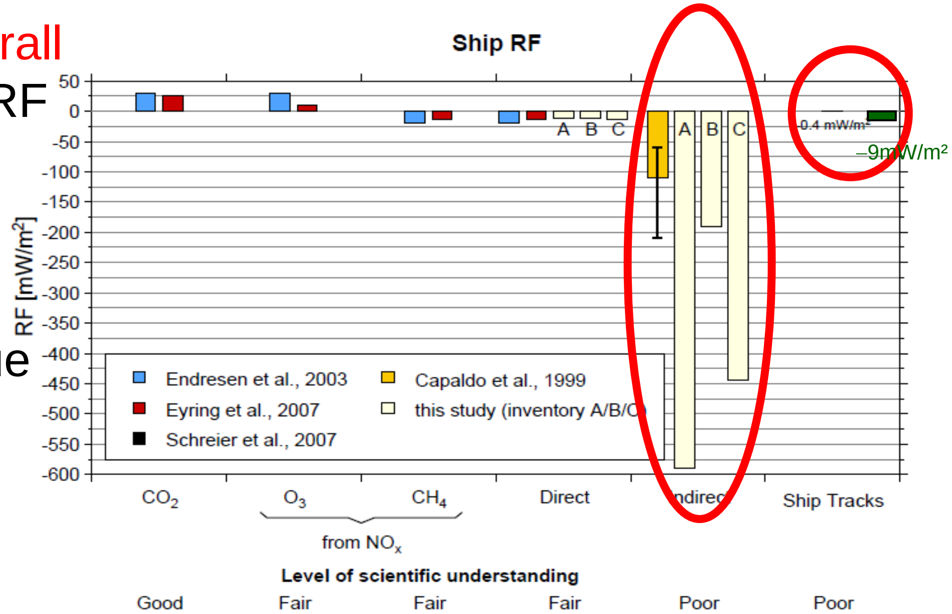
Behrends et al., 2006

Larger scale ship effects on clouds

Results from numerical modelling:

- Regions with a frequent high amount of low clouds above the ocean are susceptible to effects from ship emissions.
- Ship emissions cause 5-30% increased droplet concentration
- increased reflectivity, causes strong overall cooling effect, very uncertain (2005 RF range: –0.737 to –0.047 W m^{-2})
- small IR effect, because affected clouds are close to surface
- ship tracks RF much smaller than RF due to large scale effects





Lauer et al. 2007, Sayer and Grainger 2010

Summary

Traffic particulate emissions modify the atmosphere's aerosol content and aerosol properties (chemistry, surface structures)

Consequences visible to everybody are contrails and ship tracks. Linear contrails warm and ship tracks cool climate (RF about a few mW/m^2).

Wider reaching effects from aviation are contrail cirrus (warming: a few $\times$ 10 mW/m^2) and indirect cloud effects on cirrus from aircraft soot (soot cirrus: size and sign of the effect currently uncertain).

Wider reaching effects from ships are indirect cloud effects on low level clouds (increased reflectivity) which potentially cause strong cooling.

Although we think to know the working principles, many process details are still unknown or uncertain.

The quantification of the effects through measurement and modelling is quite difficult and very many measurements are needed: still large uncertainties.