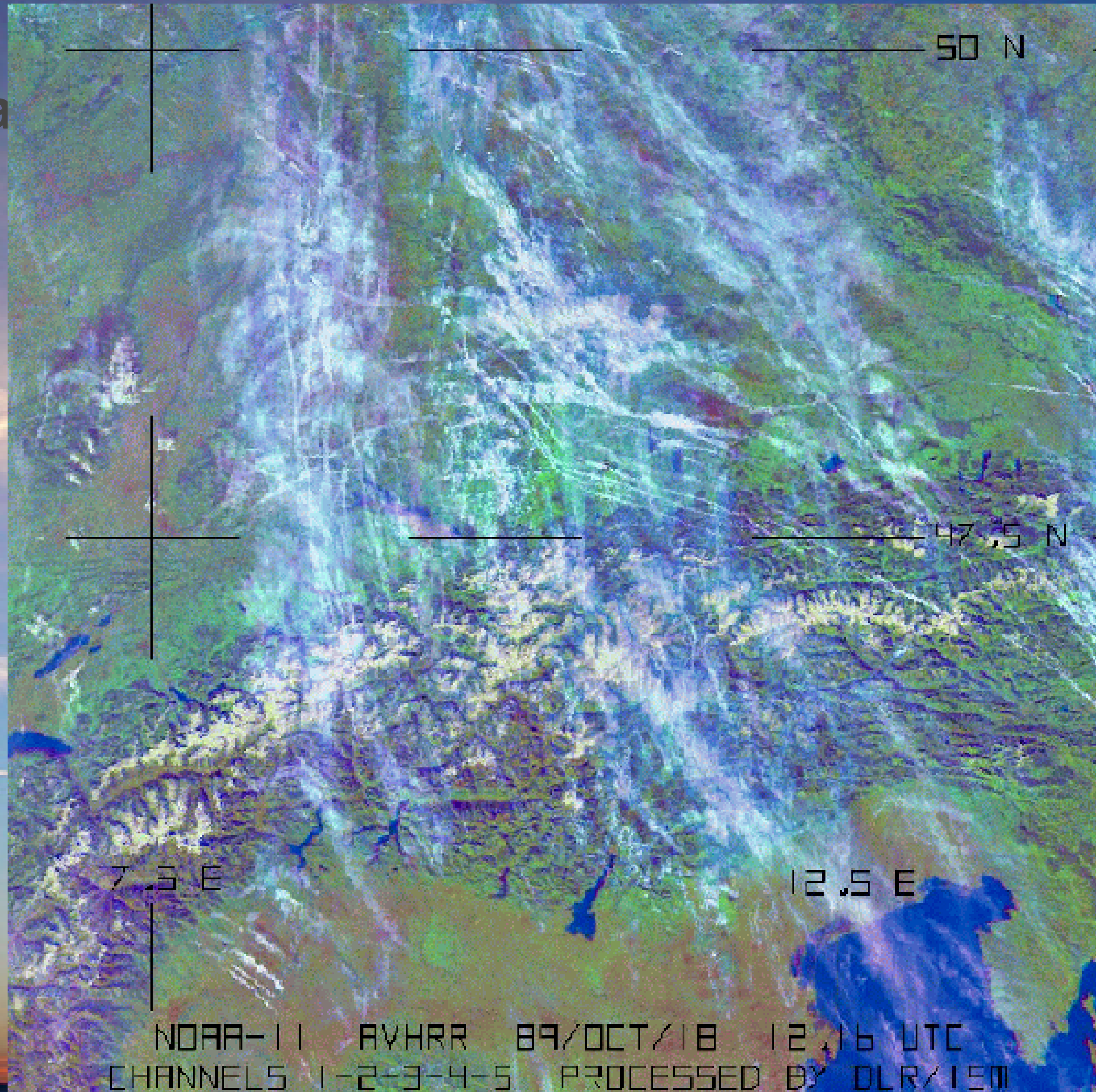
klimazwei
Risiken mindern · Chancen nutzen

UMWELTGERECHTE FLUGROUTENOPTIMIERUNG

Hermann Mannstein, Klaus Gierens, Kaspar Graf,
Ulrich Schumann, Margarita Vázquez-Navarro, Bernhard Mayer
(DLR)
Andreas Waibel, Stefanie Meilinger, (DLH)
Axel Seifert, and Carmen Köhler (DWD)

Contra


50 N
47,5 N
7,5 E
12,5 E
NOAA-11 AVHRR 89/OCT/18 12,16 UTC
CHANNELS 1-2-3-4-5 PROCESSED BY DLR/ISM

Kondensstreifen und Zirren

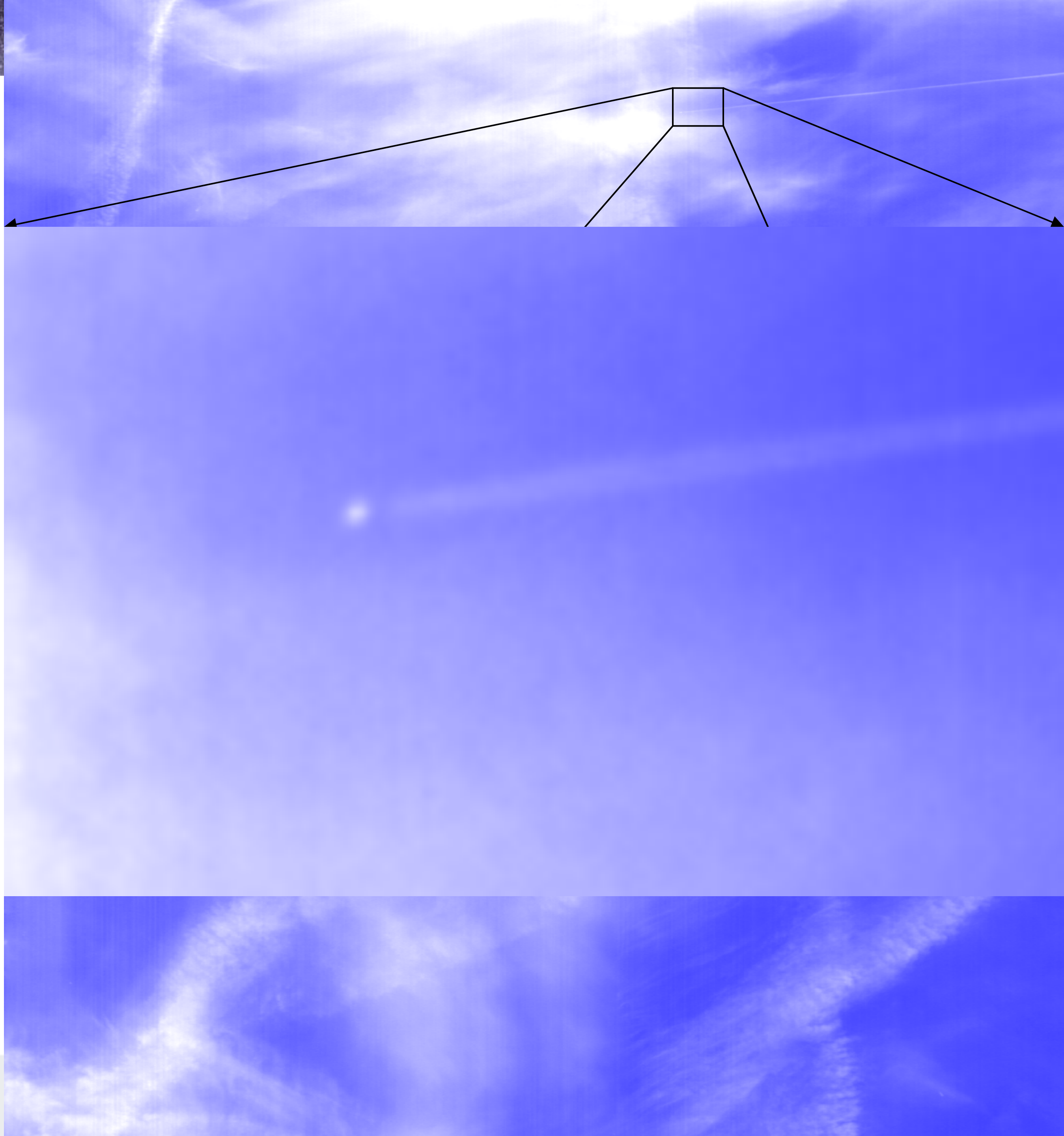
MOMS - 2P

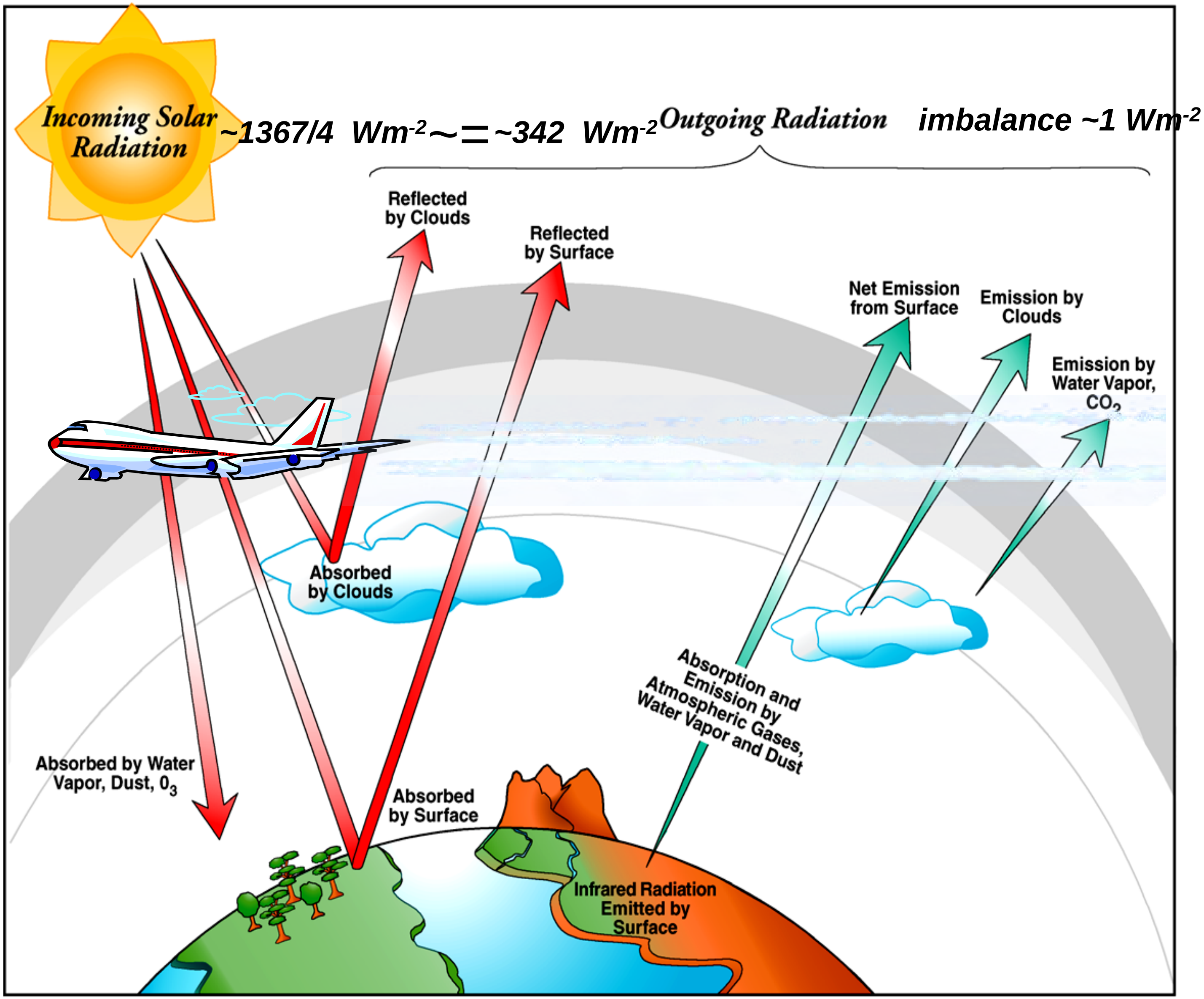
Priroda

May 8 1998

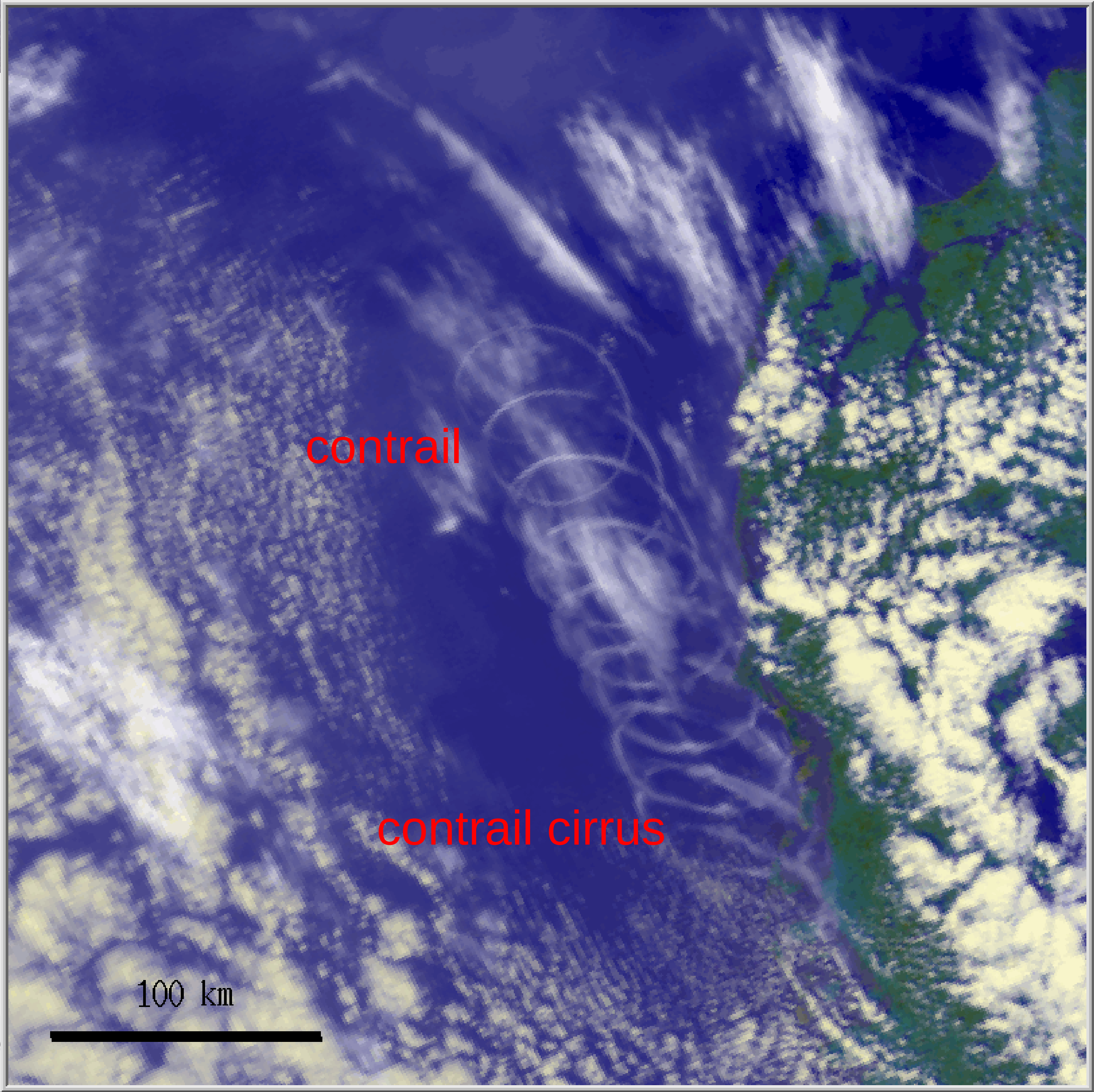
08:53 UT

49.4 N 2.9 W

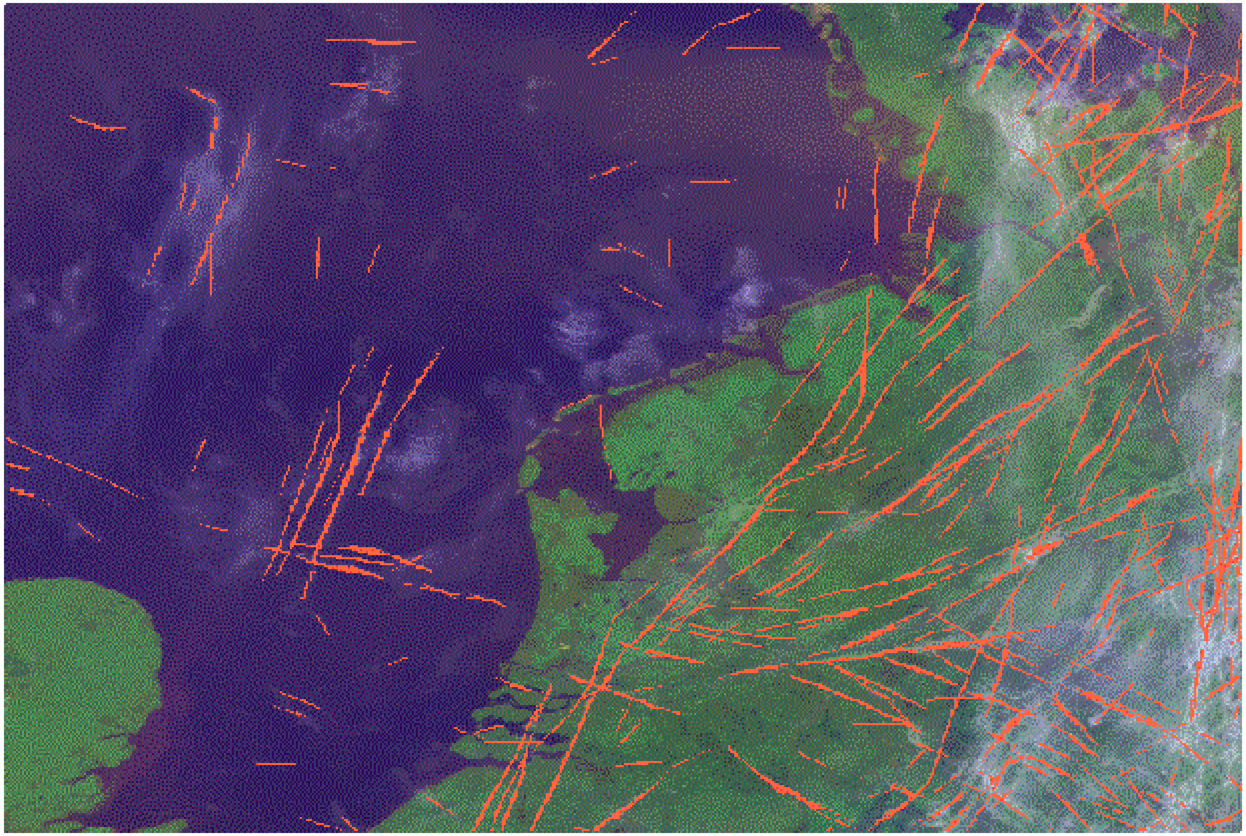



Incoming Solar Radiation
~1367/4 Wm-2 ~= ~342 Wm-2
Outgoing Radiation
imbalance ~1 Wm-2
Reflected by Clouds
Reflected by Surface
Net Emission from Surface
Emission by Clouds
Emission by Water Vapor, CO2
Absorbed by Clouds
Absorption and Emission by Atmospheric Gases, Water Vapor and Dust
Absorbed by Water Vapor, Dust, 03
Absorbed by Surface
Infrared Radiation Emitted by Surface

- NOAA 14 AVHRR
- May 22 1998 12:36
- ‘Corkscrew’ contrail
- ~1600km long,
- ~2.6 h old at the end



Kondensstreifenerkennung

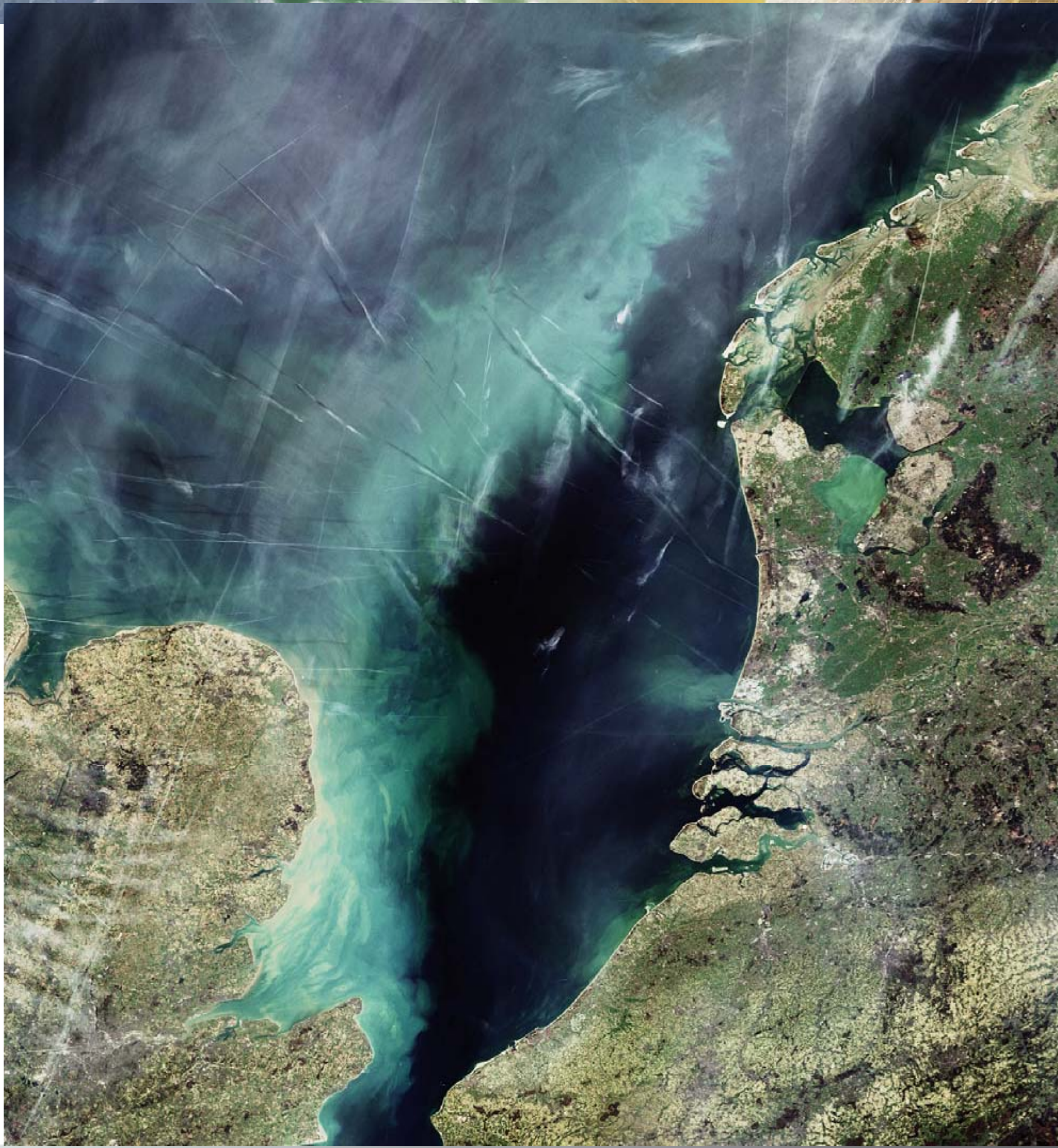


Contrails and Contrail-cirrus

Aircraft emit particles and water vapour. In cold air (T<–40°C) they produce contrails.

Contrails are persistent and may spread into contrail-cirrus when formed in ice-supersaturated regions (ISSR) in the upper troposphere.

Particles emitted by aviation can modify naturally formed clouds.



Atmospheric Environment 43 (2009) 3520–3537

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Aviation and global climate change in the 21st century

David S. Lee [a,*], David W. Fahey [b], Piers M. Forster [c], Peter J. Newton [d], Ron C.N. Wit [e], Ling L. Lim [a], Bethan Owen [a], Robert Sausen [f]

[a] *Dalton Research Institute, Manchester Metropolitan University, John Dalton Building, Chester Street, Manchester M1 5GD, United Kingdom*
[b] *NOAA Earth System Research Laboratory, Chemical Sciences Division, Boulder, CO, USA*
[c] *School of Earth and Environment, University of Leeds, Leeds LS2 9JT, United Kingdom*
[d] *Department for Business, Enterprise and Regulatory Reform, Aviation Directorate, United Kingdom*
[e] *Natuur en Milieu, Donkerstraat 17, Utrecht, The Netherlands*
[f] *Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany*

ARTICLE INFO

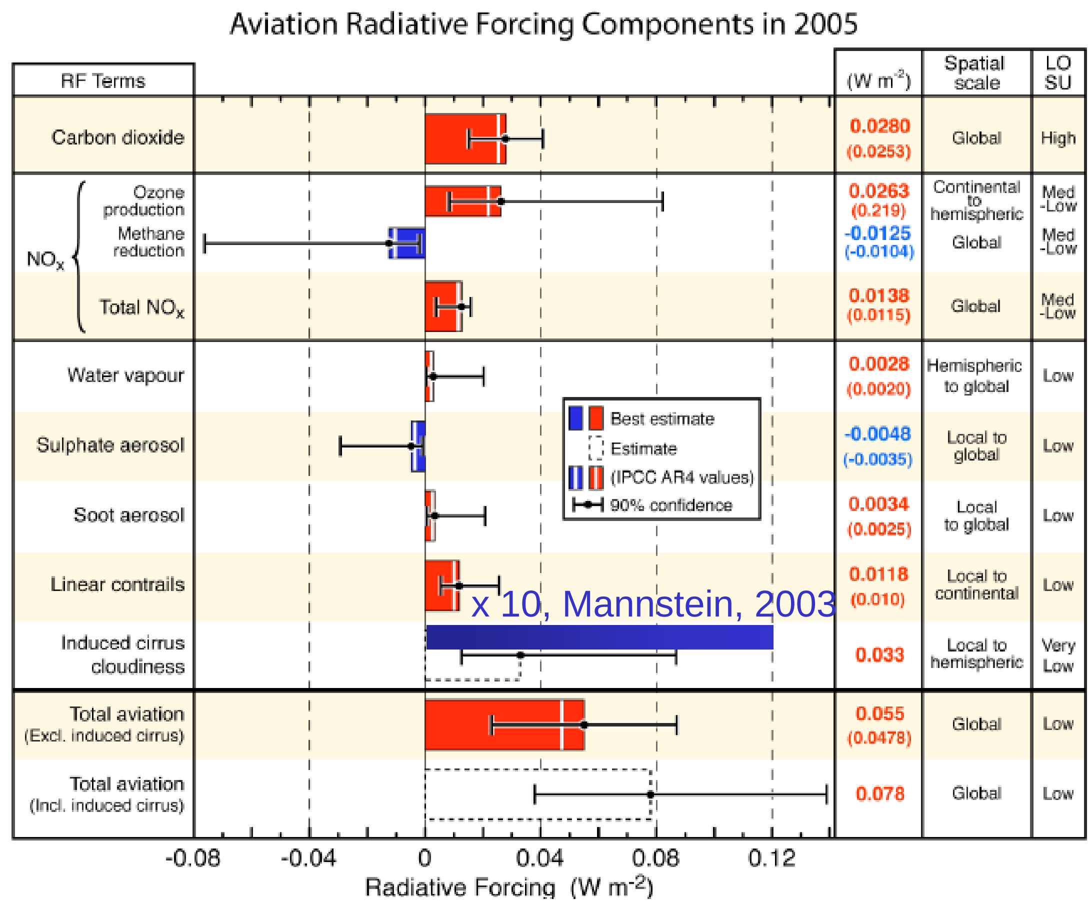
Article history:
Received 19 November 2008
Received in revised form
7 April 2009
Accepted 8 April 2009

ABSTRACT

Aviation emissions contribute to the radiative forcing (RF) of climate. Of importance are emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x), aerosols and their precursors (soot and sulphate), and increased cloudiness in the form of persistent linear contrails and induced-cirrus cloudiness. The recent Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) quantified

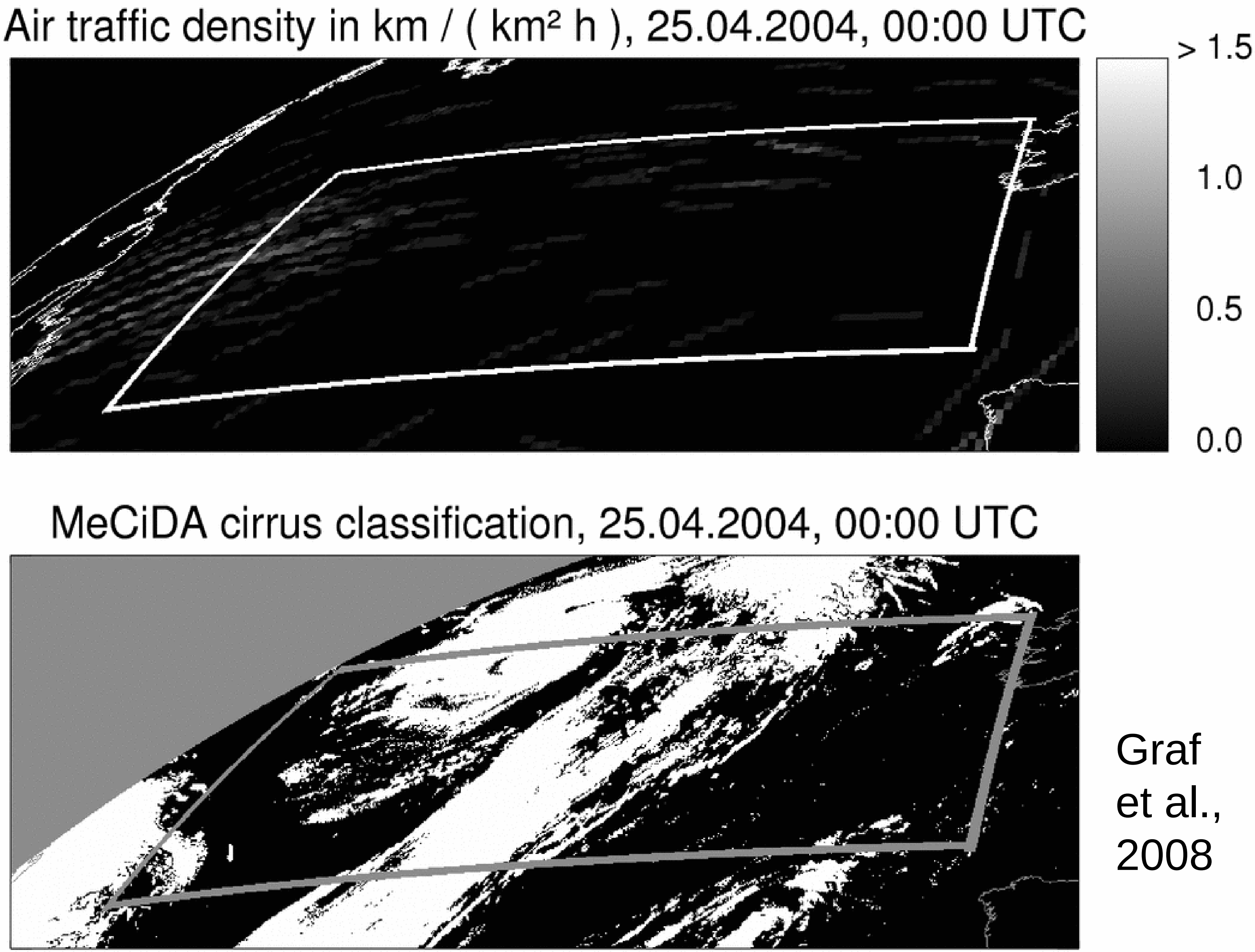
The new assessment:

Atmospheric Environment 43 (2009) 3520–3537



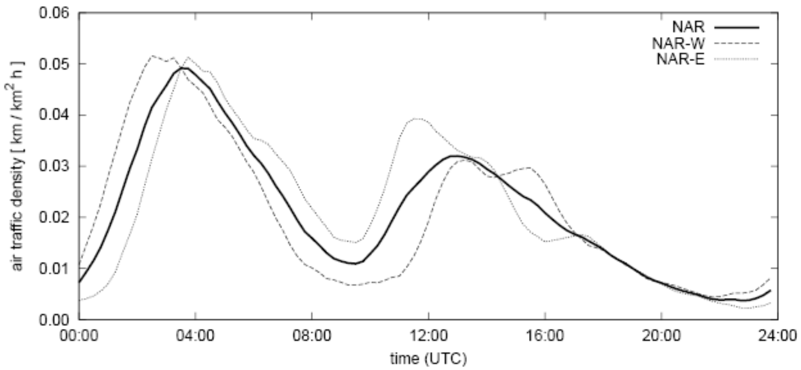
Aviation and global climate change in the 21st century

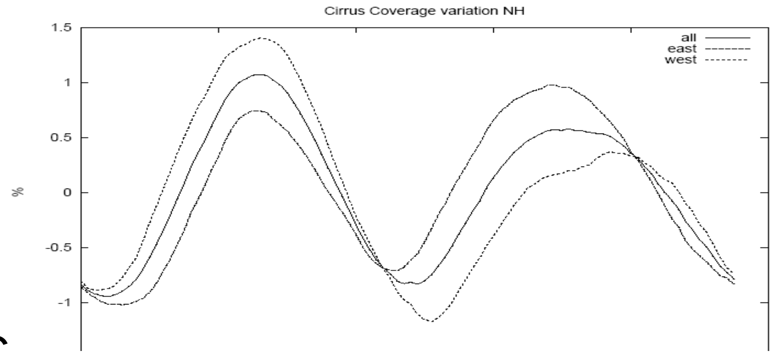
David S. Lee, David W. Fahey, Piers M. Forster, Peter J. Newton, Ron C.N. Wit, Ling L. Lim, Bethan Owen, Robert Sausen



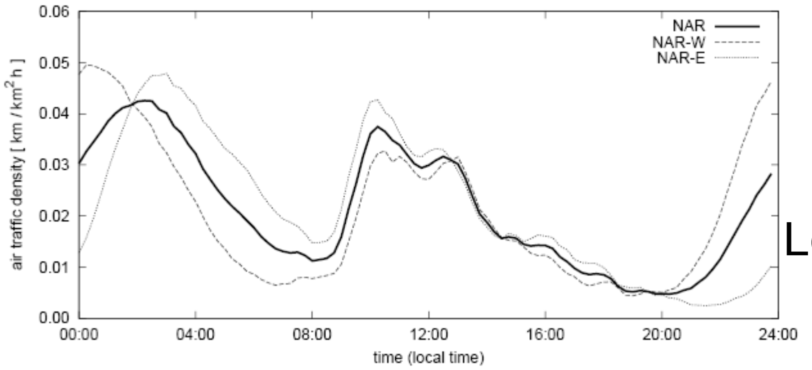
Graf et al., 2008

Correlation between air-traffic and cirrus coverage over the North Atlantic

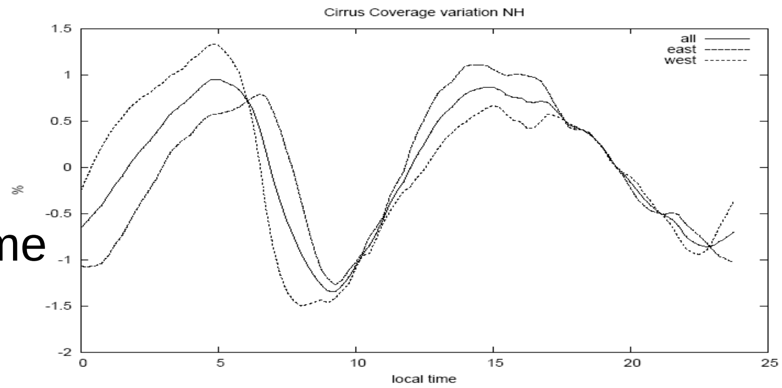




UTC



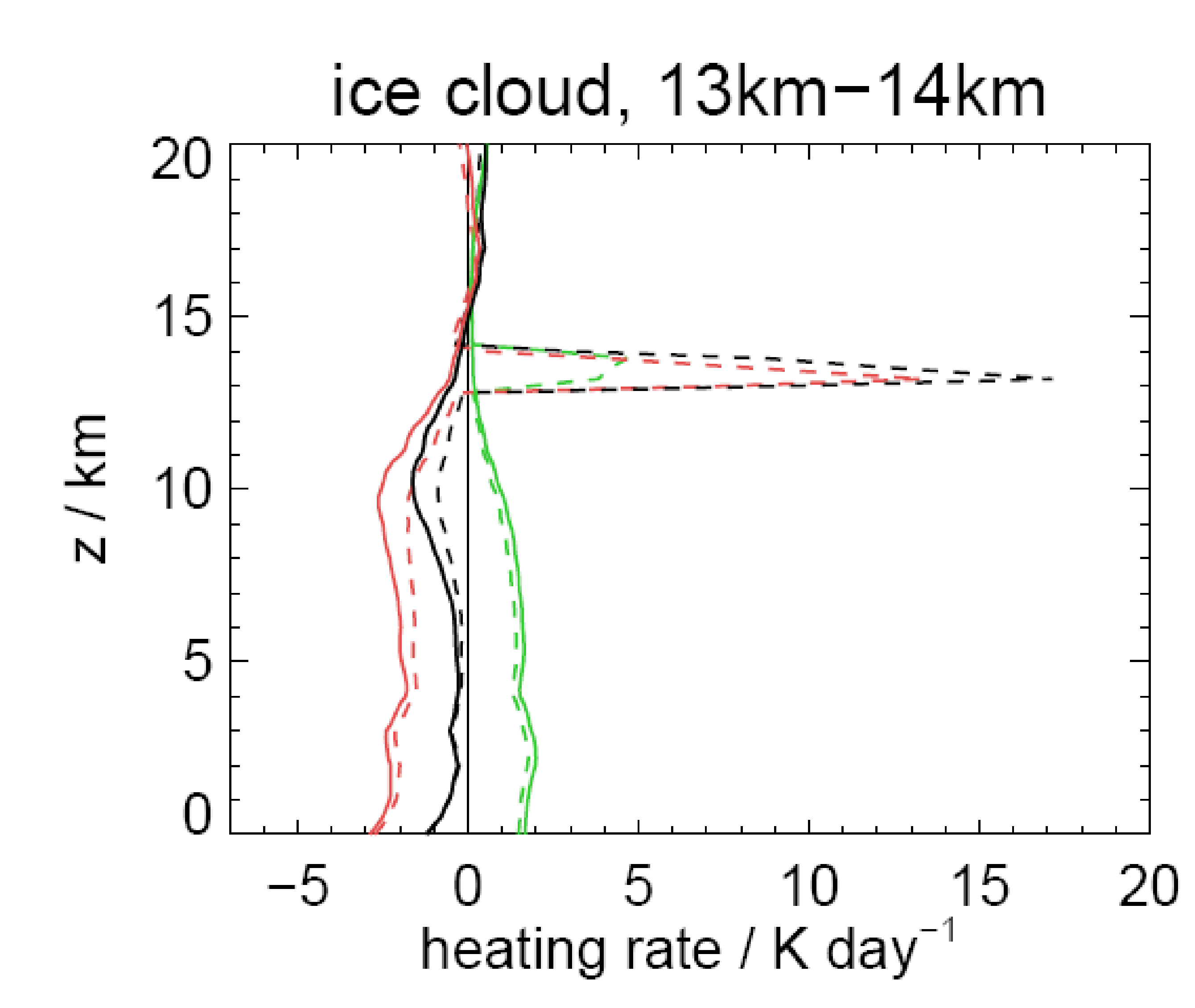
Local time



Air traffic density

Cirrus coverage deviation

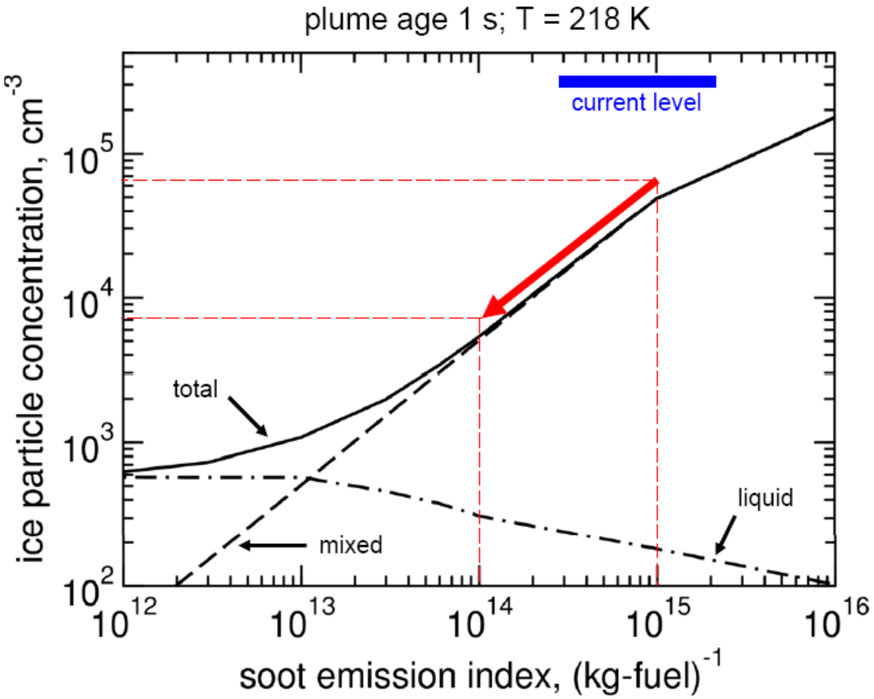
Warming and cooling aviation induced cloudiness



Contrail mitigation options

- Technical options
- Modification of contrail properties
- Operational options

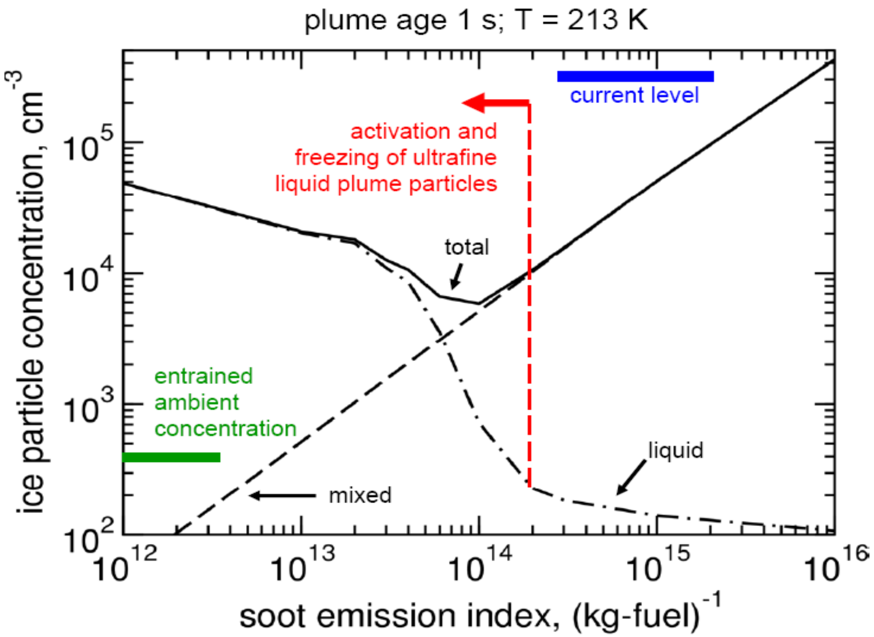
Making contrails optically thinner: soot reduction



Initial ice number controlled by soot number emission index.

Initial ice number is effective through whole contrail life span.

Reduction of soot makes contrail optically thinner and reduces its lifetime.



Soot reduction to very low levels does not help under cold conditions.

Kärcher and Yu, GRL, 2009

Contrail mitigation options

- Technical options
- Modification of contrail properties
- Operational options

What is ‚smart routing'?

Operational option: smart flight routing

- persistent contrail cirrus forms in ISSRs
- cruise level flights occur ≈ 15% in ISSRs
- contrails warm climate during night
- contrails warm or cool climate during day

⇒ avoid flight in ISSRs

⇒ avoid those contrails that induce warming

smart flight routing: aviation weather

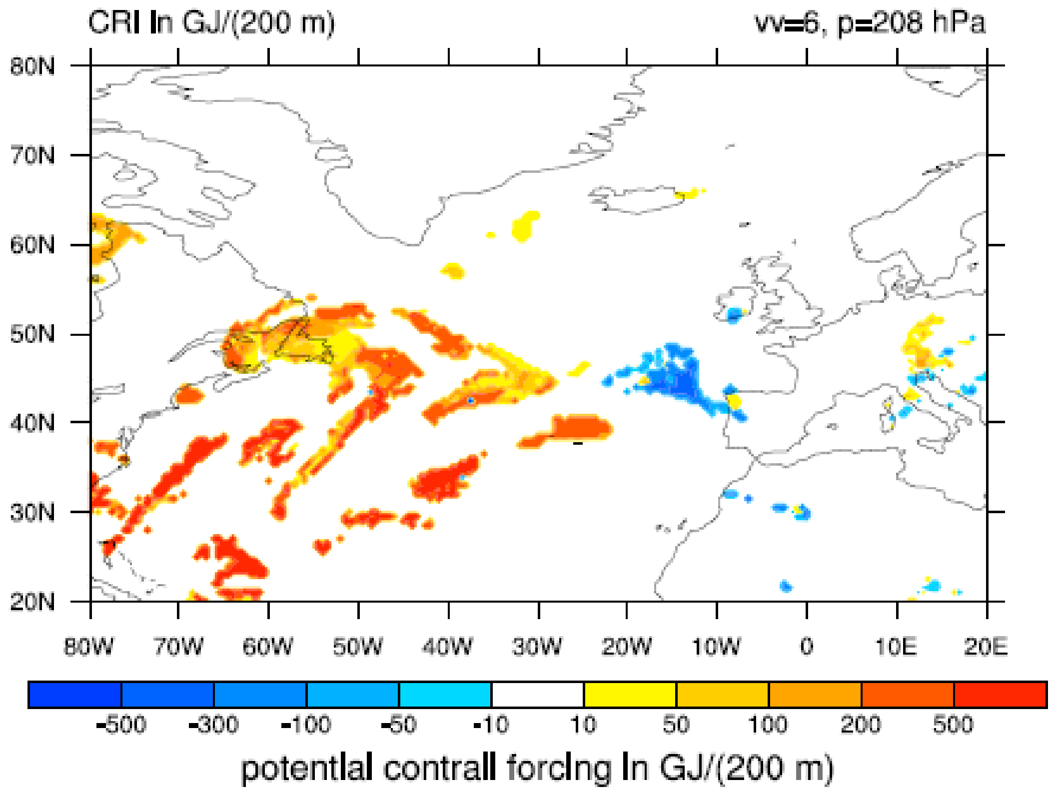
- needs a weather model that predicts ISSRs
- needs to test whether contrails can form under the given temperature and humidity conditions (Schmidt-Appleman criterion)
- may use further information (vertical wind speed, state of cloudiness)
- needs to implement method to compute potential contrail life-time integrated RF (metric to compare contrail climate effect to climate effect of fuel burn, CO_2 emission)
  - ideal: forward trajectories coupled to radiative transfer computations

$\Rightarrow$ contrail cost function for flight routing

German UFO project tests such a strategy

Warming and cooling aviation induced cloudiness

- Estimate of potential contrail forcing implemented into the GME of the DWD

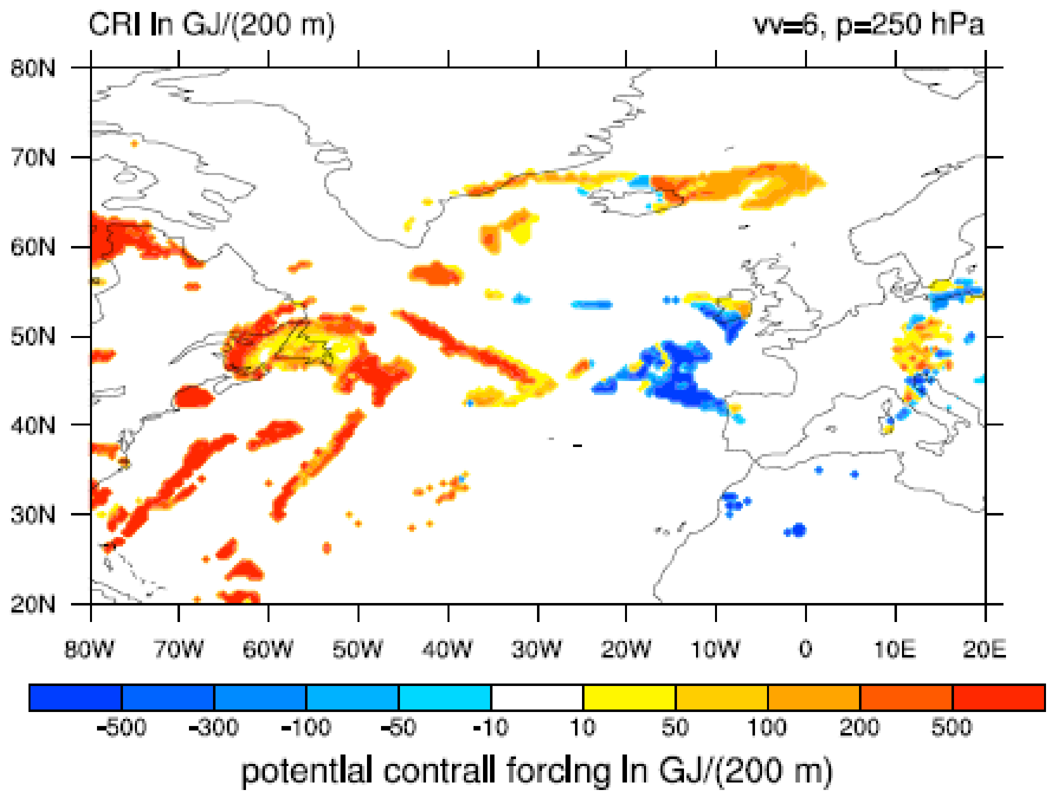


- FL 380

- Aug 15 2008, 0600 UTC

Warming and cooling aviation induced cloudiness

- Estimate of potential contrail forcing implemented into the GME of the DWD



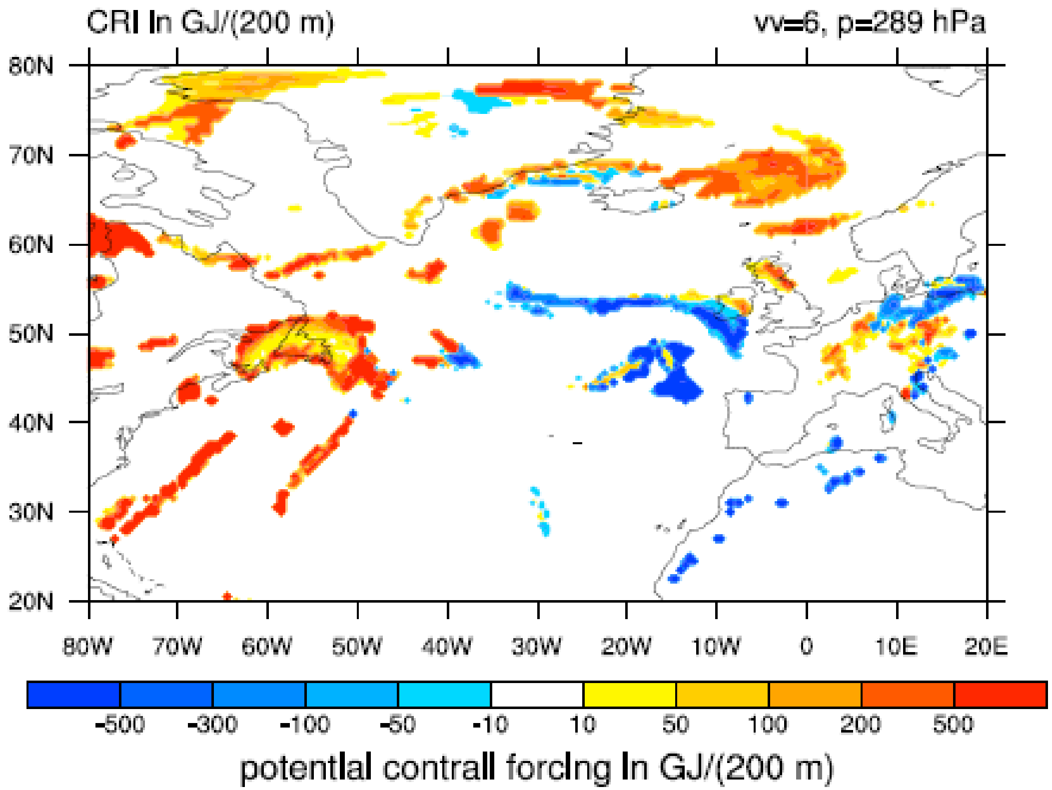
- FL 340

- Aug 15 2008, 0600 UTC

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

Warming and cooling aviation induced cloudiness

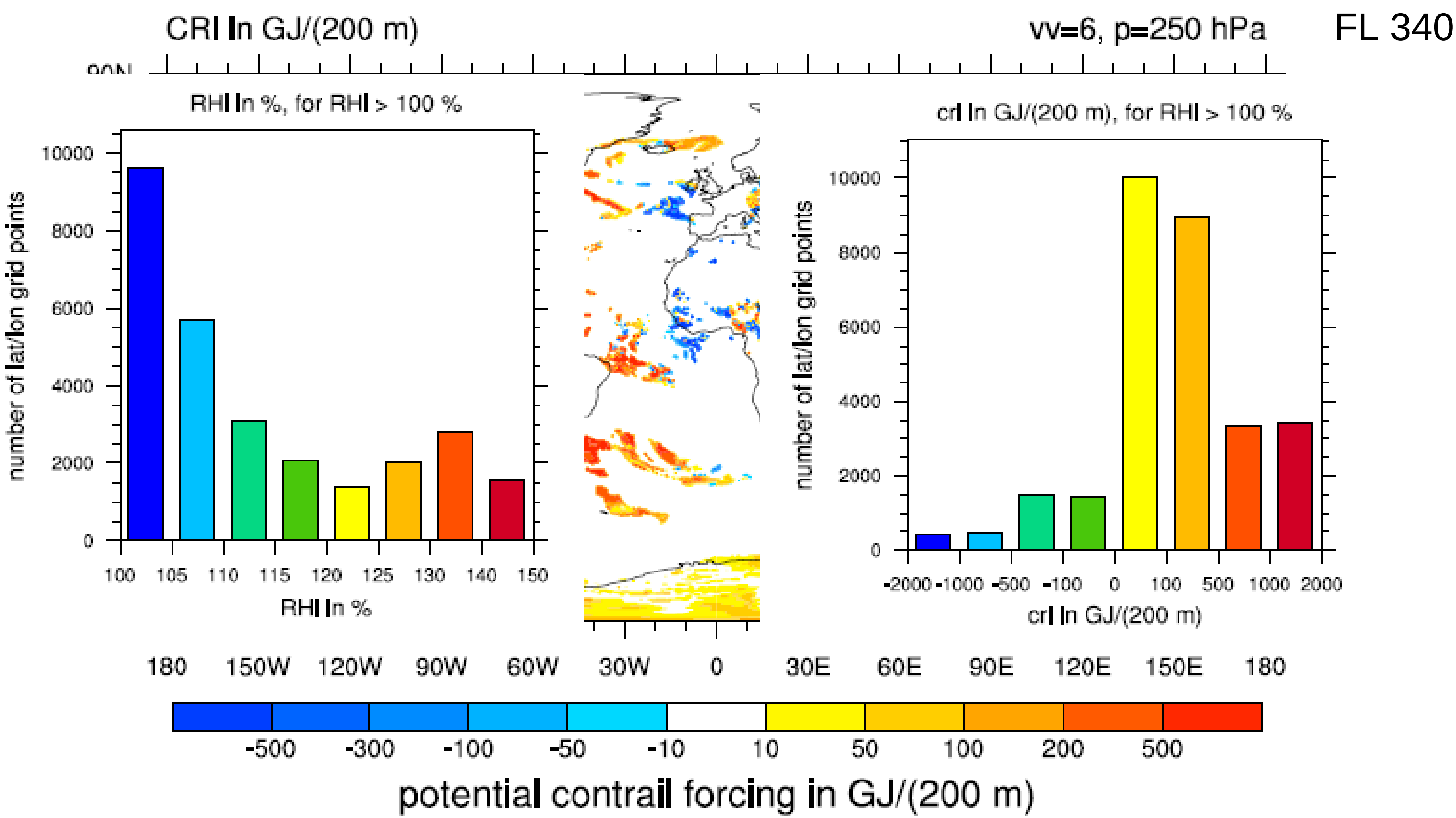
- Estimate of potential contrail forcing implemented into the GME of the DWD



- FL 310

- Aug 15 2008, 0600 UTC

Warming and cooling aviation induced cloudiness

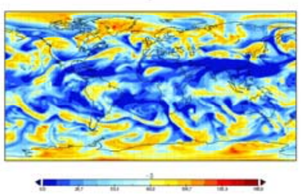


Environmentally compatible flight routing

- Optimization implemented at Lufthansa Systems LIDO OC

Lufthansa

DWD
RH [%]
T [K]
ΔE [GJ/SR]



DLR
ECMWF-based
RHice [%]
ΔE [GJ/SR]

Online
Offline

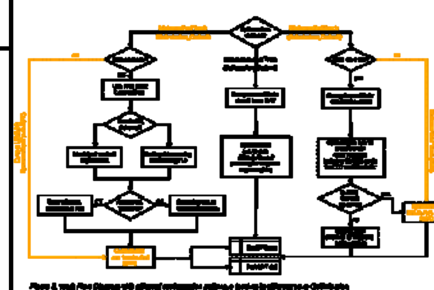
Flight Route Optimization with LIDO OC

INPUT DATA:
- **Online Weather**
- **Aeronautical Data:**
- **Contrail Forecast**

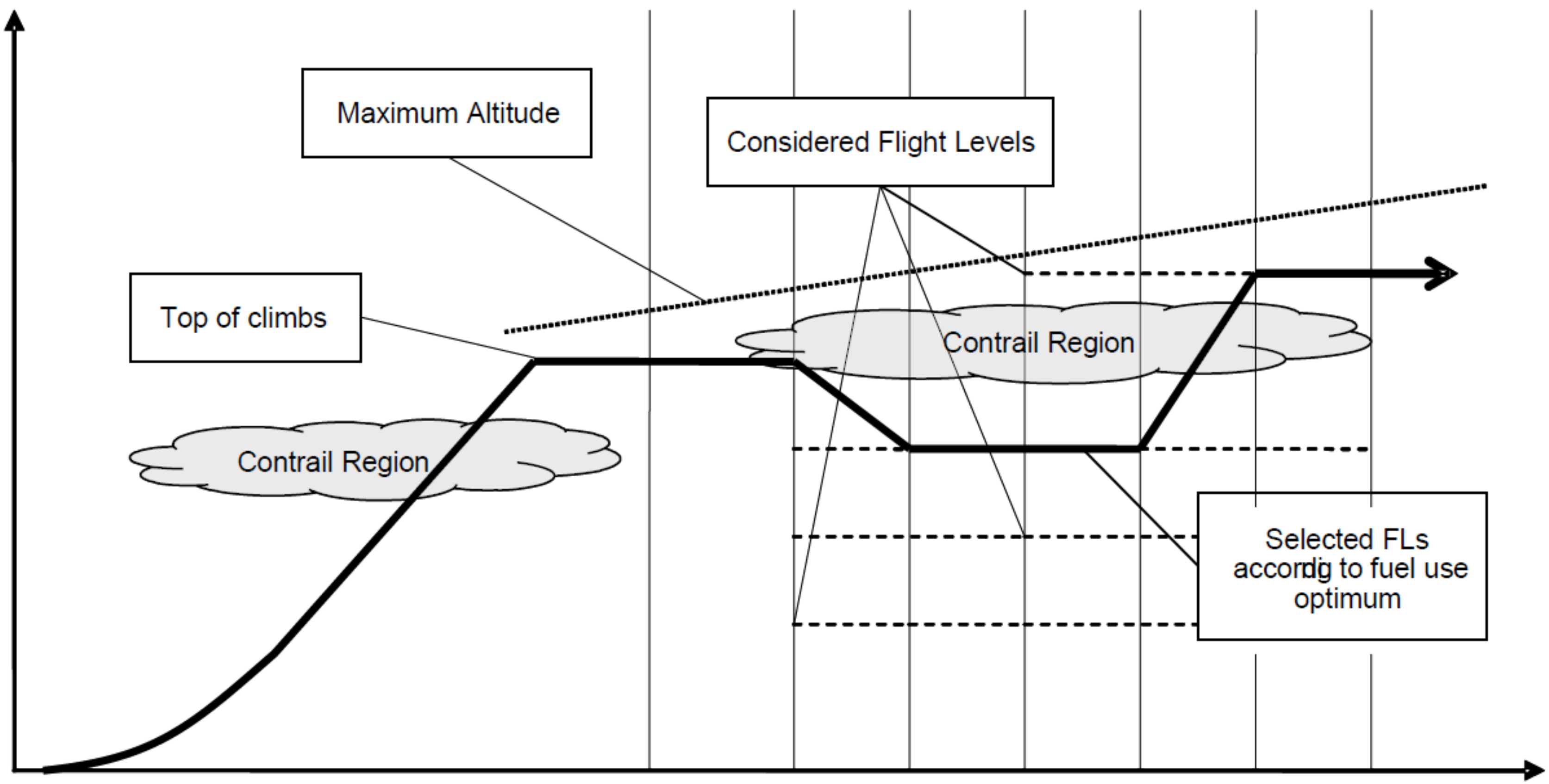
OPTIMIZER:
- **Existing Criteria**
- **UFO Algorithm**

UFO Algorithm

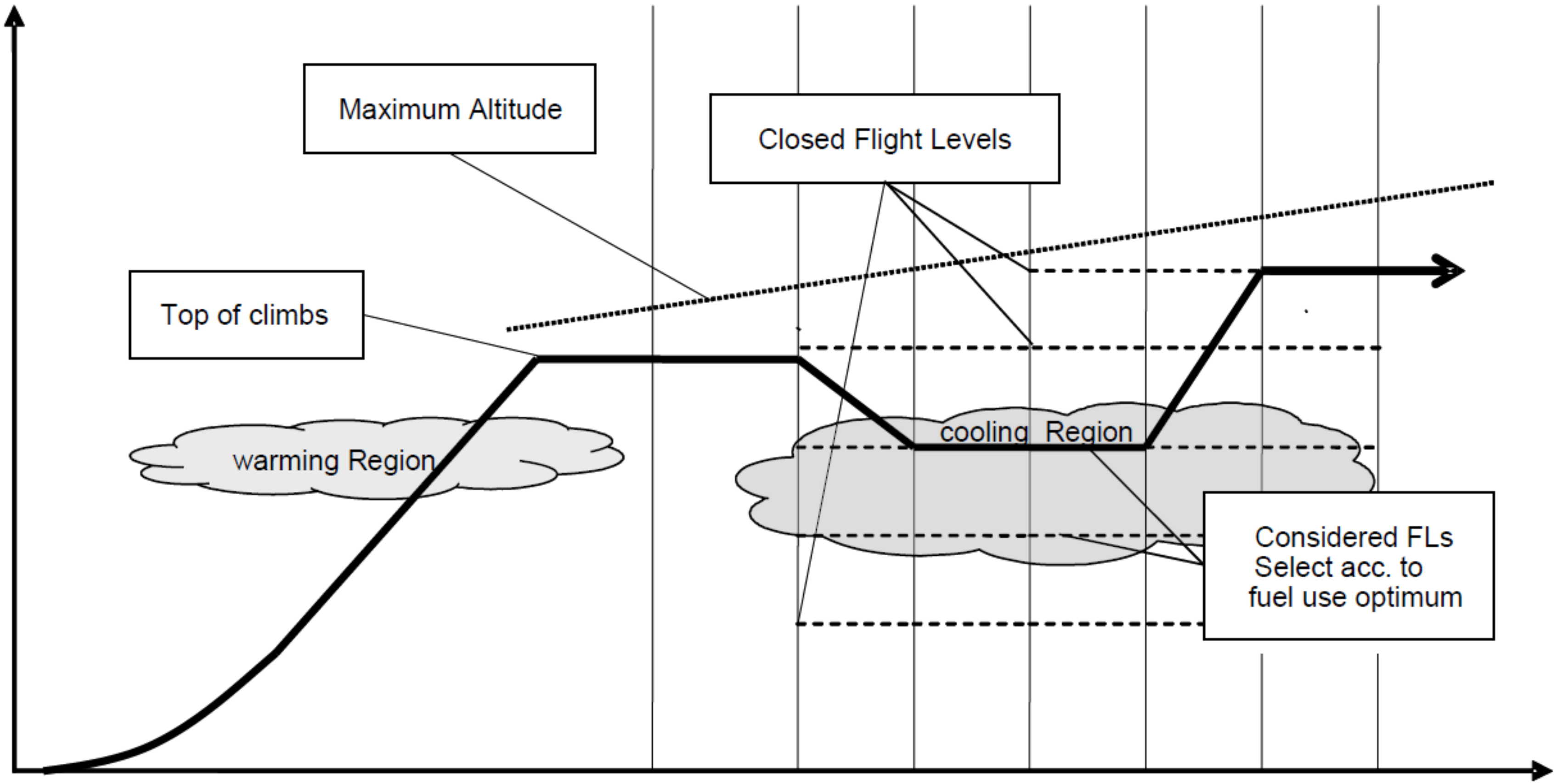
Contrail Avoidance
Climate Impact Optimization
Climate Cost Optimization



Routing example: avoiding contrail

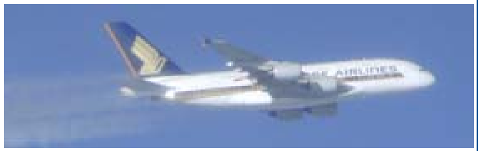


Routing example: enforcing cooling contrail

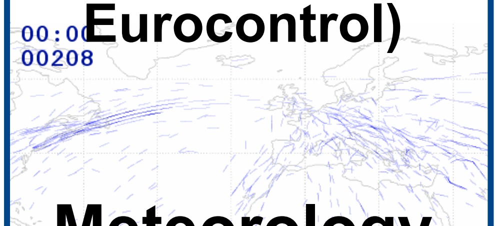


Contrail Cirrus Simulation and Prediction (CoCiP)

Input:
<u>Aircraft</u>
(BADA)

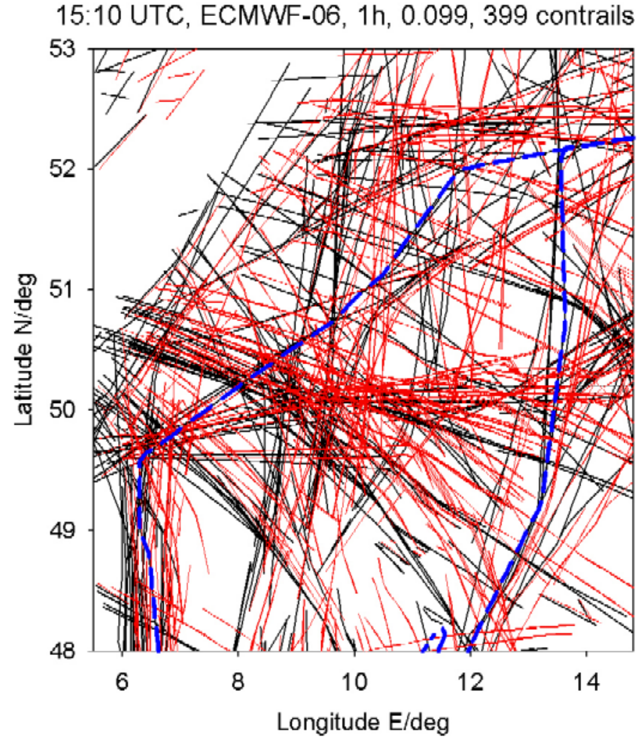


<u>Movements</u>
(ATM data, DFS, Eurocontrol)



<u>Meteorology</u>
(NWP results, ECMWF, DWD)

Contrail Cirrus Prediction Tool



- From regional to global
- Comparable to observations

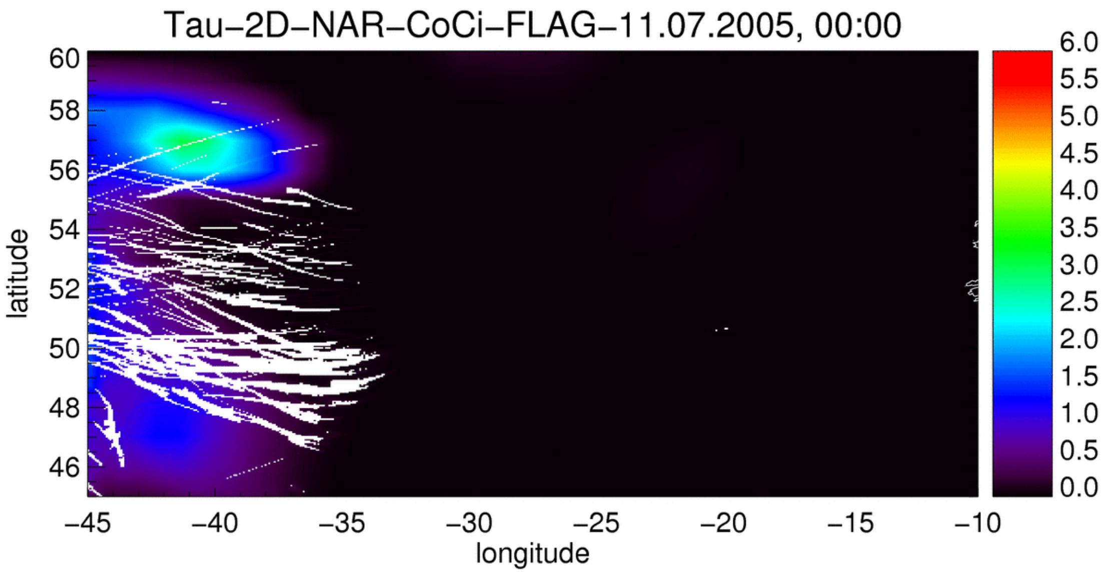
Output:
<u>Contrail</u>, life cycle, cover, radiation

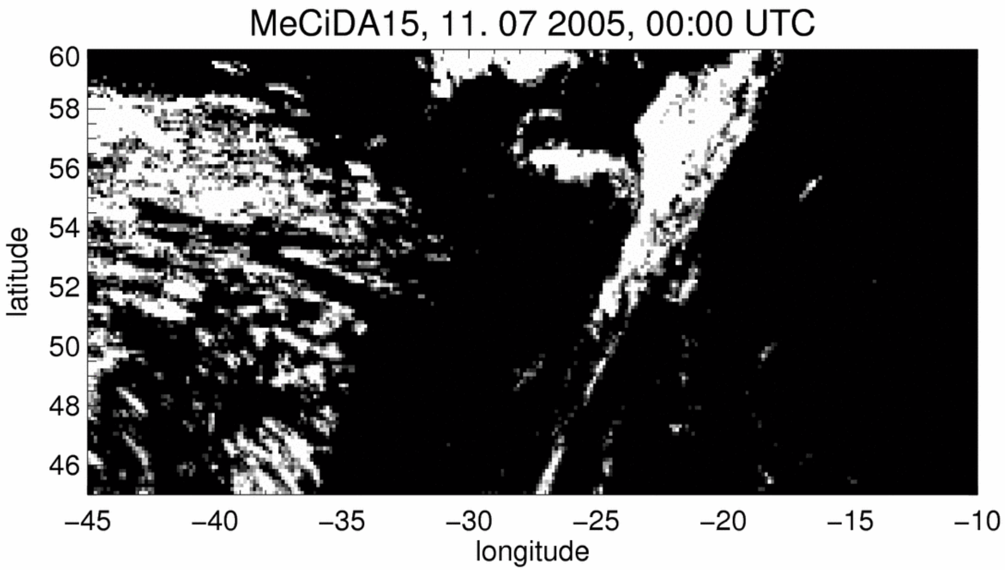
<u>Cirrus</u>

<u>Simulation</u>
(insitu, Lidar, Satellite)

<u>Sensitivity studies</u>

<u>Prediction</u>
<u>Climate impact</u>





North Atlantic Region (NAR)

Top:

Color scale: **cirrus cloud optical thickness** τ

white: $\tau_{Contrail} > 0.1$

Bottom:

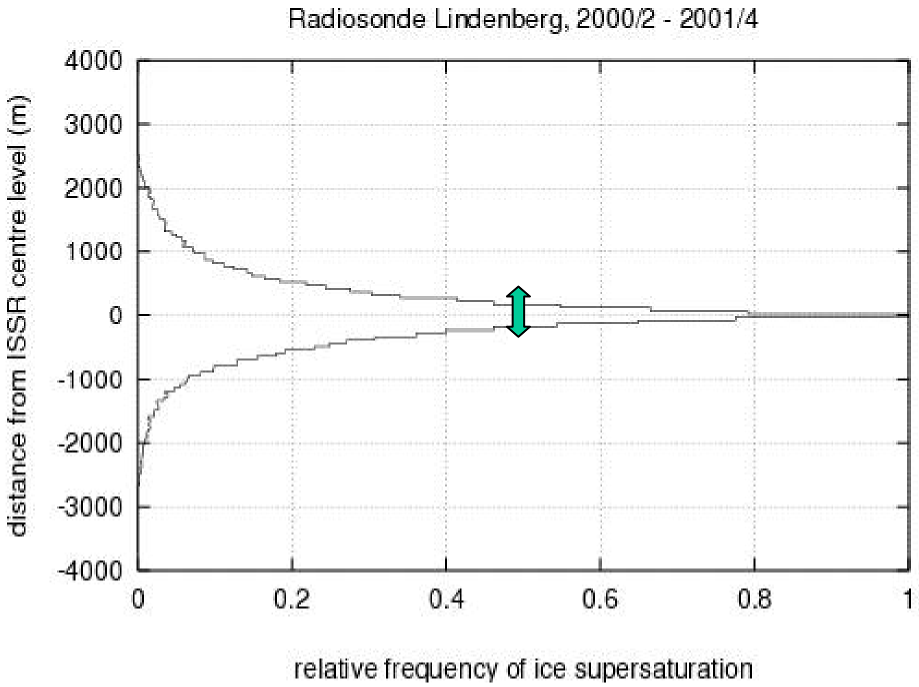
Meteosat (MSG)-MeCiDa observation derived cirrus cover (white)

Is it feasible?

- About 15 % of flight times occur in ISSRs
- ISSRs are shallow on average
- Contrails warm climate mostly during night and over bright surfaces
- Air traffic density is low over large regions

Most ISSRs are shallow

moderate flight level changes (±300 m) sufficient for avoidance of 50% ISSR

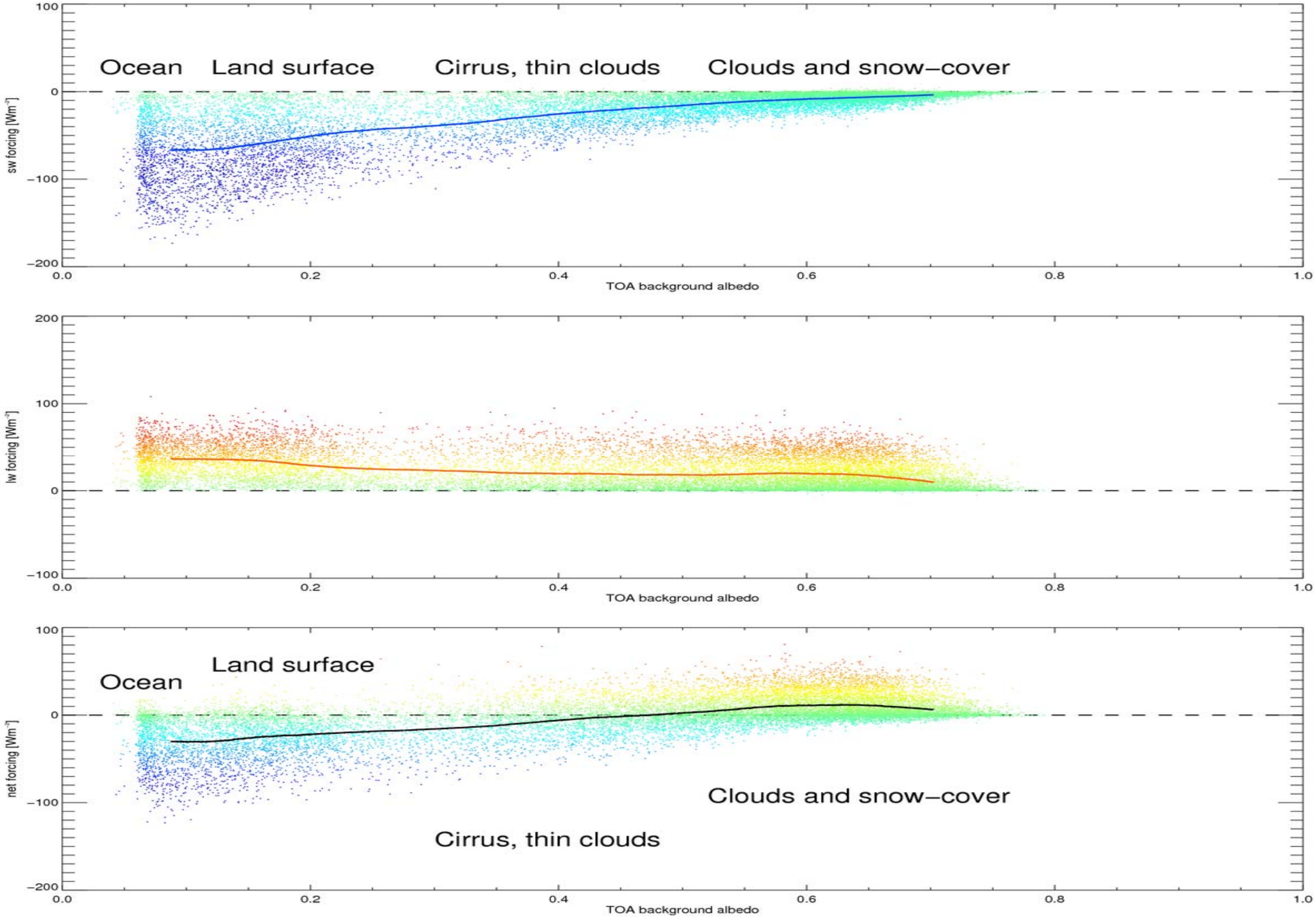


distribution of altitudes relative to ISSR centres over Lindenberg, Germany

Simulation of thin cirrus and contrail forcing (LibRadTran Mayer, 2009)

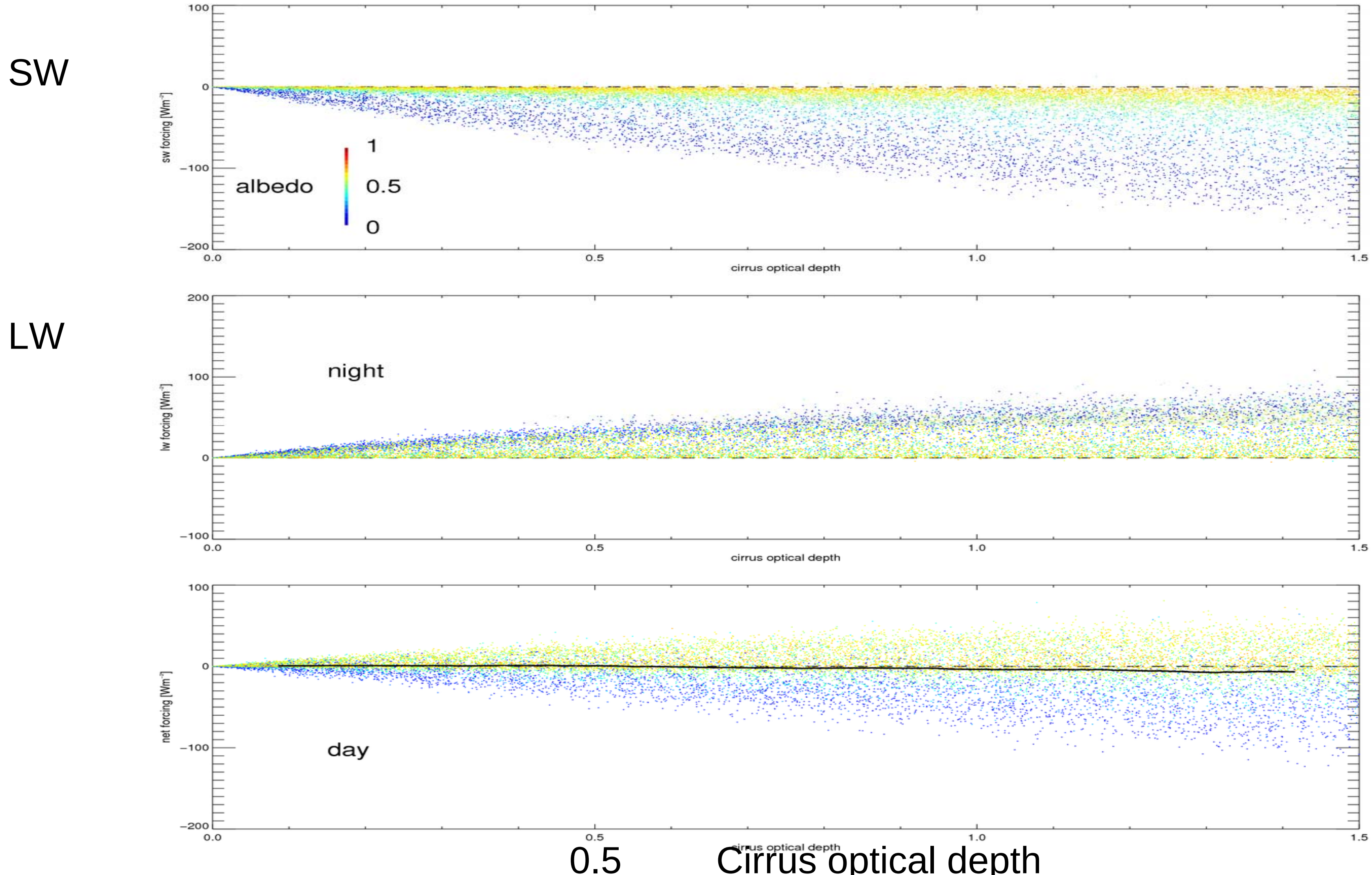
SW

LW

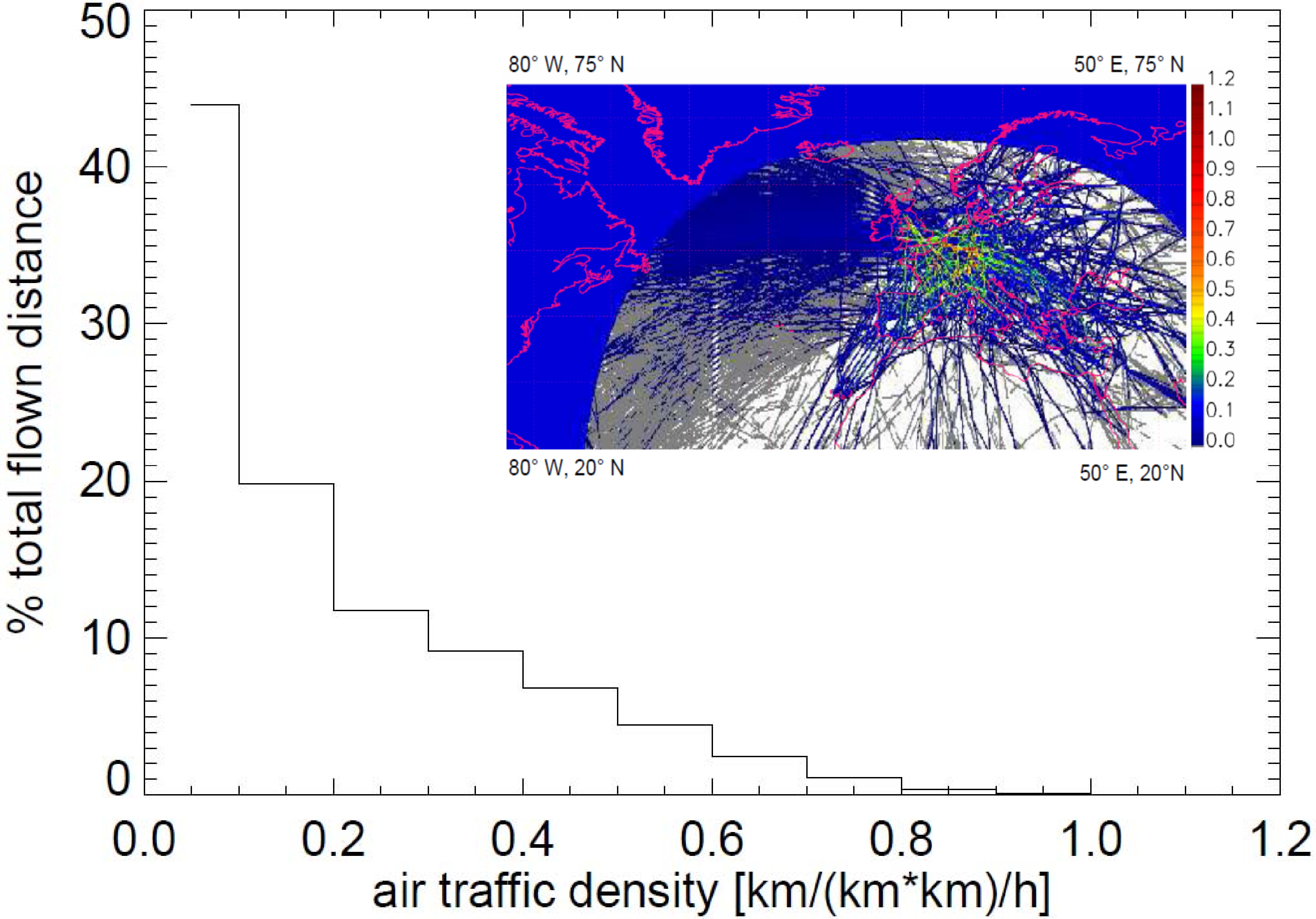


Background TOA albedo

Simulation of thin cirrus and contrail forcing (LibRadTran Mayer, 2009)



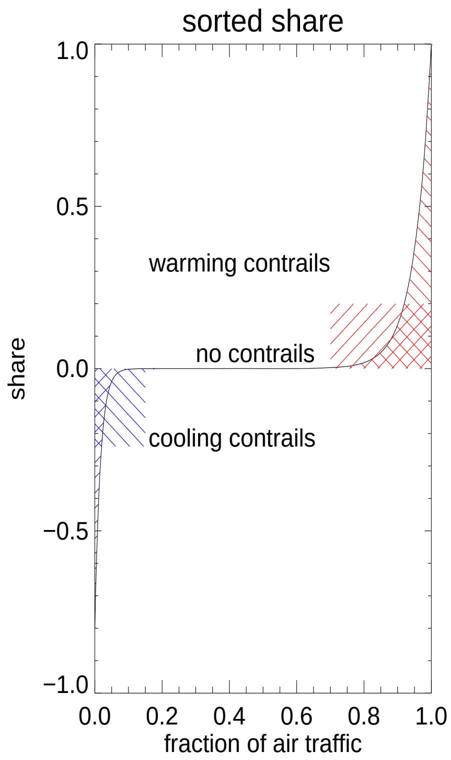
pdf of air traffic density

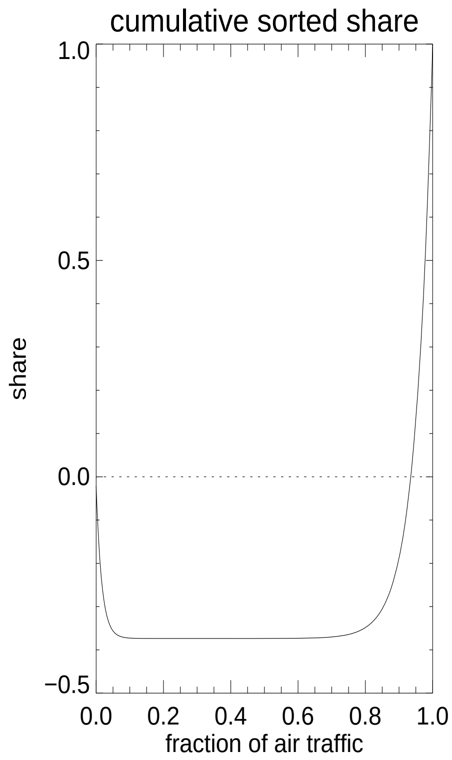


Source: Eurocontrol data, summer 2004, Europe and North Atlantic

Flying smart

- Avoid only those contrails that induce the greatest warming in the atmosphere.
- The lion‘s share of warming AIC radiative forcing is produced by a small fraction, perhaps 5% of the flown distance.
- If aviation puts the effort on „selective avoidance of warming contrails and cirrus“, the net AIC forcing can be reduced substantially.





⇒only a small fraction of flight distances has to be touched

Conclusions (1)

- Contrails and contrail cirrus appeared in the atmosphere a century ago. They are now almost an everyday phenomenon over regions with heavy air traffic.
- Although details remain uncertain, it seems clear that contrails and contrail cirrus add to the natural upper tropospheric cloudiness and to the greenhouse effect.
- The estimated net greenhouse effect of contrails and contrail cirrus is substantial compared to that of aviation gaseous emissions and will rise in future due to increasing demand for travel and airborne transport.
- Contrails and contrail cirrus may also induce further effects on (local) climate: reduced insolation, reduced daily temperature range.

Conc

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