When can we expect the science to be sufficiently robust to provide an acceptable basis for regulation? – contrail / cirrus

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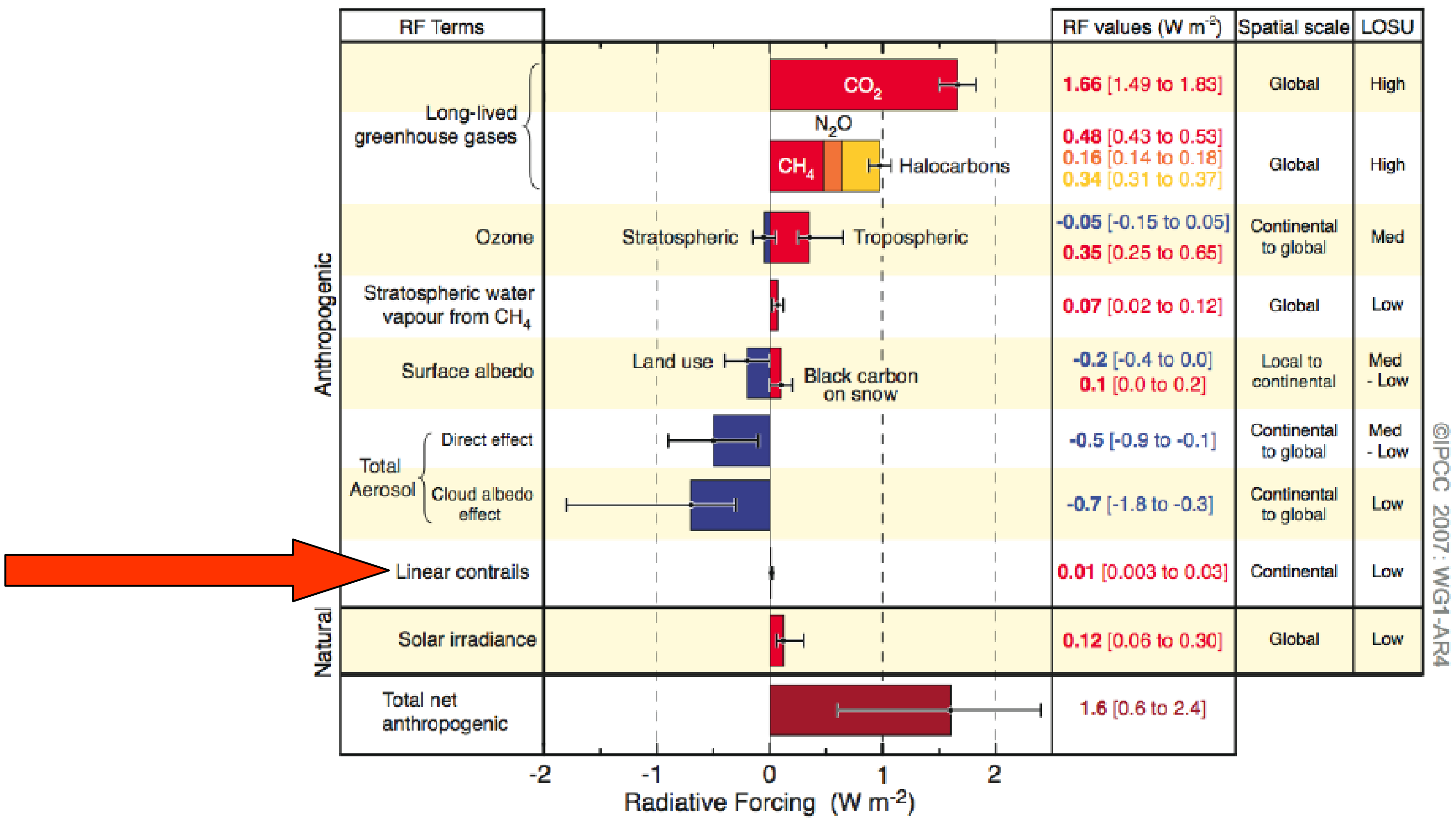
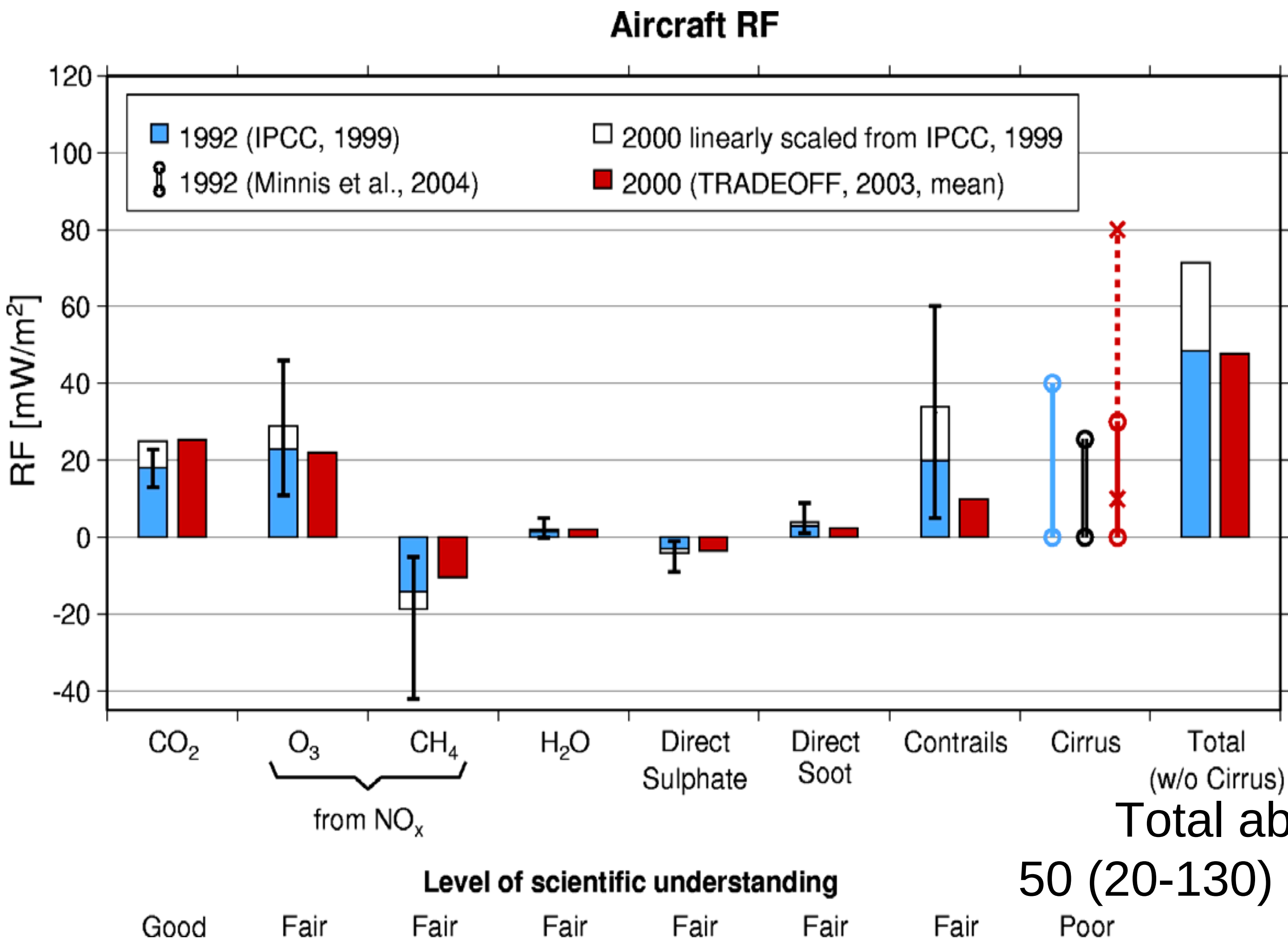
Radiative Forcing Components



Intergovernmental Panel on Climate Change, 2007 WG1 Summary for policy makers, http://www.ipcc.ch/WG1_SPM_17Apr07.pdf

Radiative forcing until 2000 from Global Aviation



Total about
50 (20-130) mW m^{-2}

(Sausen et al., TRADEOFF,2005)

Aviation contribution to global climate change

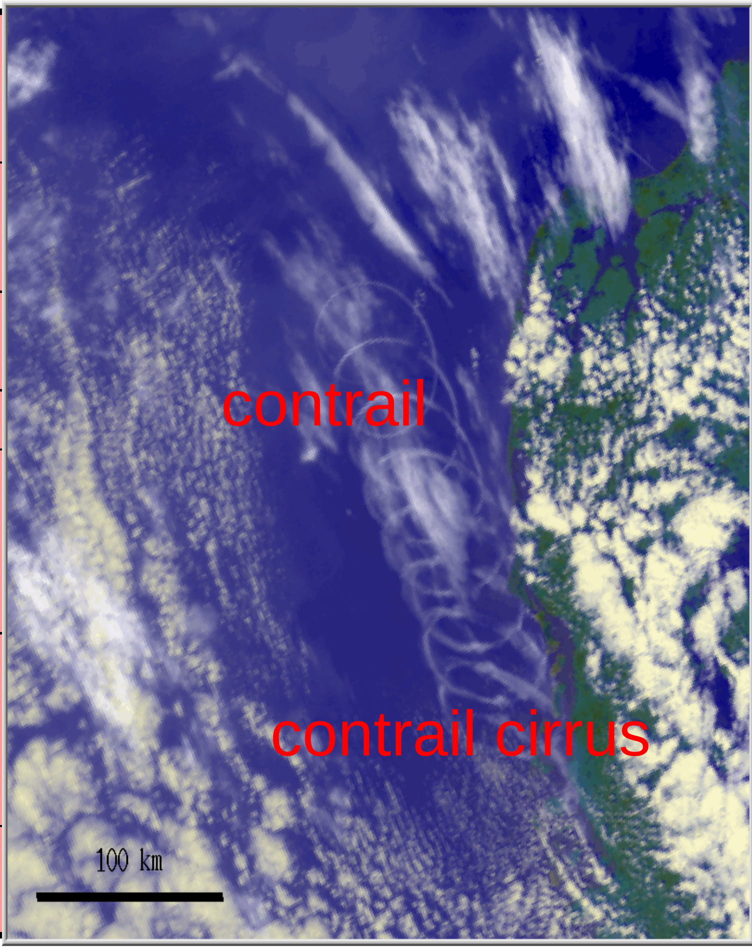
Contribution to	Absolute contribution	Total anthropogenic contribution	Relative contribution
CO_2 emissions	550-700 Tg/a	30700 Tg/a	1.8-2.3 %
CO_2 concentration increase	1-1.5 μmol/mol	100 μmol/mol	1-1.5%
Radiative forcing	0.05 W/m^2 (0.02-0.13 W/m^2)	1.6 W/m^2 (0.6 – 2.4 W/m^2)	3 % (2-8 %) (1-22 %)
Global mean warming	0.02-0.03°C	0.76°C	3-4 %

Large uncertainty mainly because of unknown contrail cirrus contributions

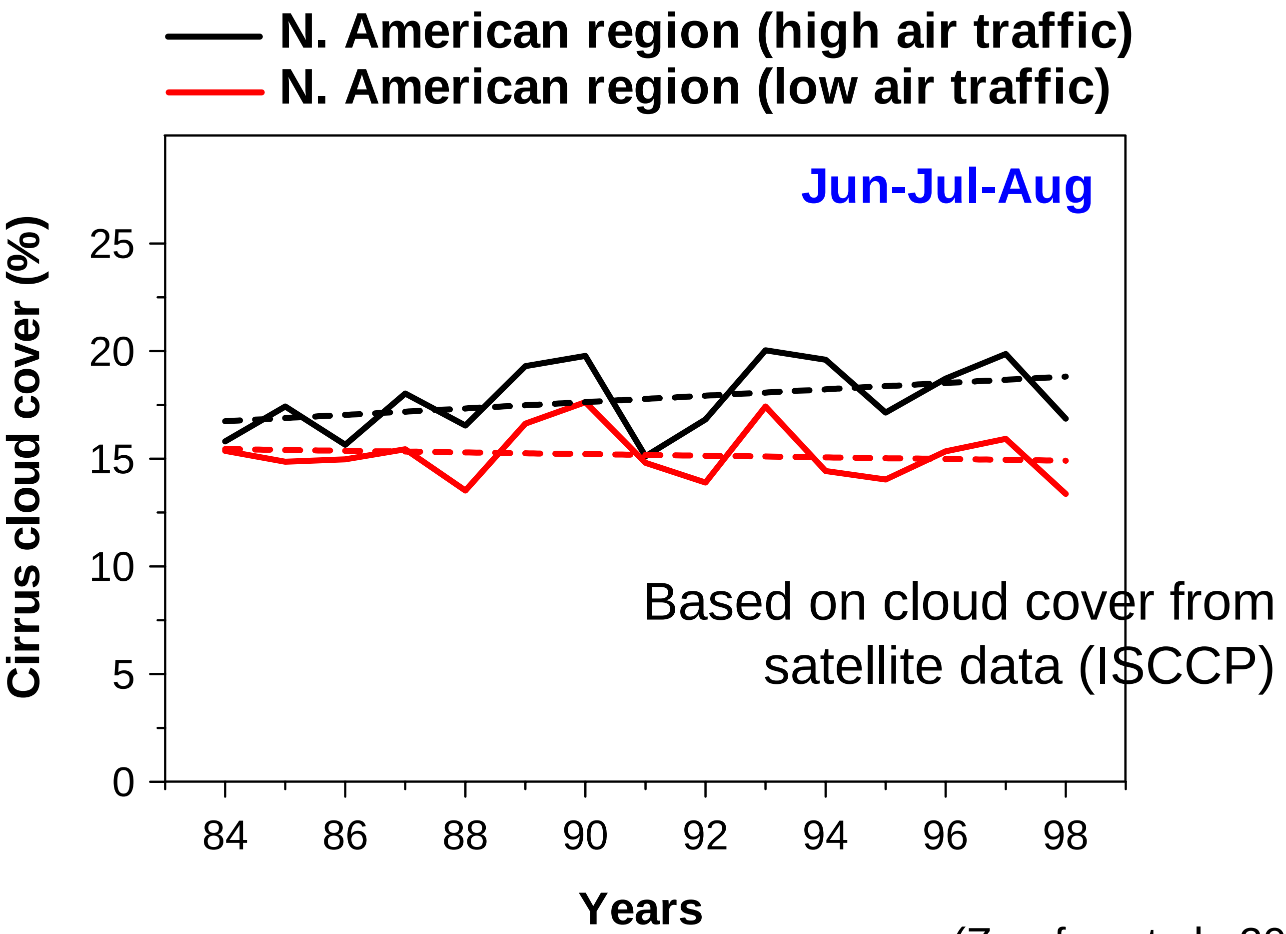
Sausen and Schumann (2000), Sausen et al. (2005), IPCC (2007), IEA (2007)

Linear Contrails vs. Contrail Cirrus

shape	linear flight path	fuzzy flight path + wind shear & sedimentation
width	< 2- 5 km subsidence of wake vortex	>2 km sedimentation of ice Crystals
particle size	<10µm (< 1 µm at 1 min)	> 10µm
age	usually < 1 h	usually > 1 h
conditions of ambient air	Schumann - Schmidt-Appleman criterion (cold)	super-saturated with respect to ice (ISSR)
detection	visual analysis contrail detection algorithm ~ 1 km resolution	looks like natural cirrus correlation of cirrus coverage or cirrus coverage trends with air traffic
climate model	yes	no



Cirrus Cloud Cover seems to be increasing, possibly by 2%/decade



(Zerefos et al., 2003)

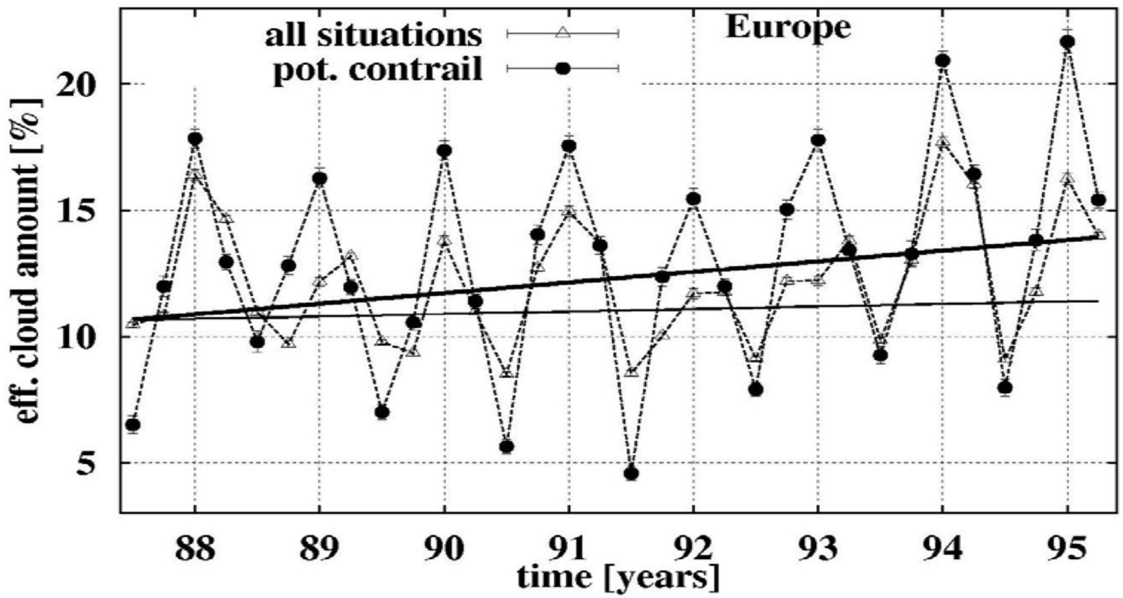
Reassessment with help of Meteosat data (Stordal et al., 2005):

0.28 (0.08-0.47) % global mean cover of aviation induced cirrus cover in 2004.

RF = 30 (10-80) mW/m²

assuming contrail-cirrus to be optically thin

TOVS satellite data suggest 10 times smaller cirrus trends: 0.2%/decade, and only where contrails form



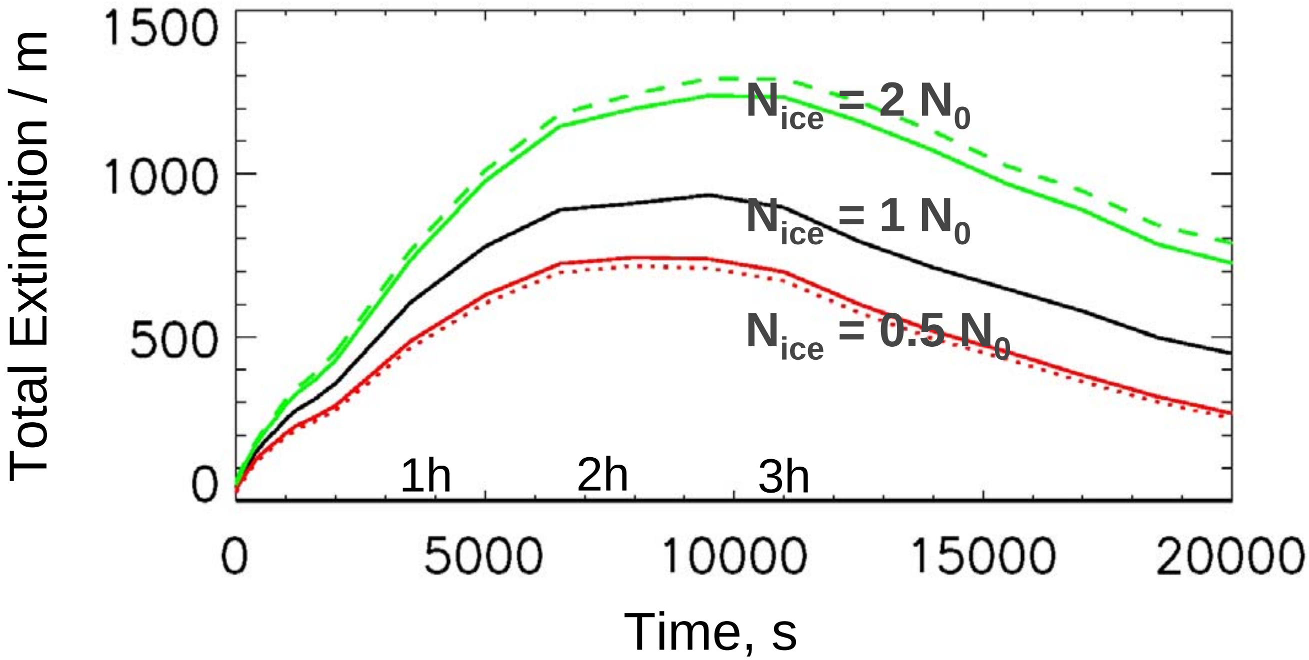
Data from TOVS satellite data

No trend for cirrus in general.

Positive trend of cirrus cover for atmospheric situations favorable for contrail formation

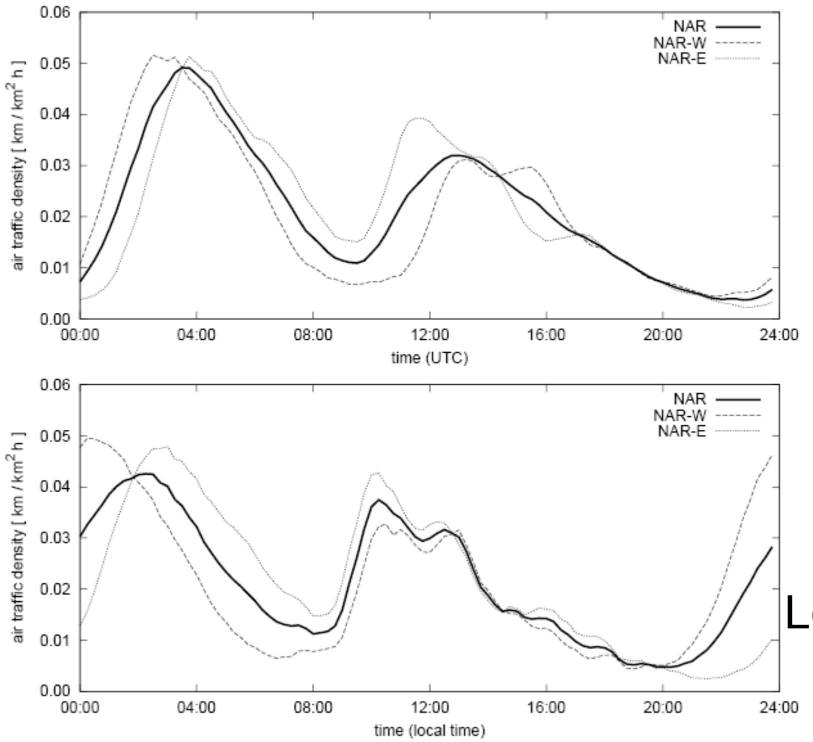
(Stubenrauch und Schumann, 2005)

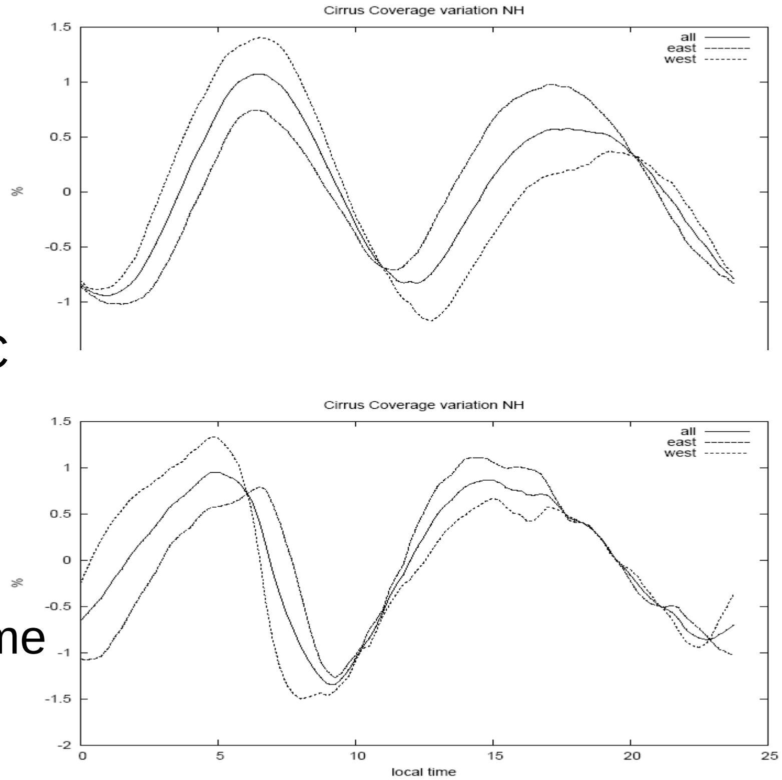
The total extinction (product of width and optical depth) depends on initial number of ice particles



(Unterstraßer, 2008)

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





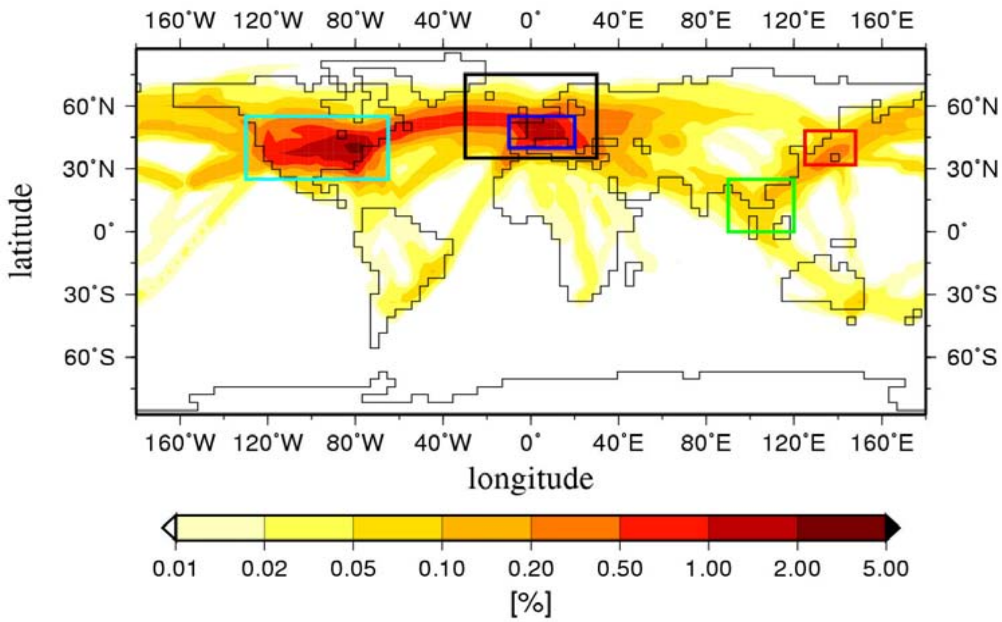
UTC

Local time

Air traffic density

Cirrus coverage deviation

Global line-shaped contrail cover can be estimated from meteorological and traffic data up to factor 2



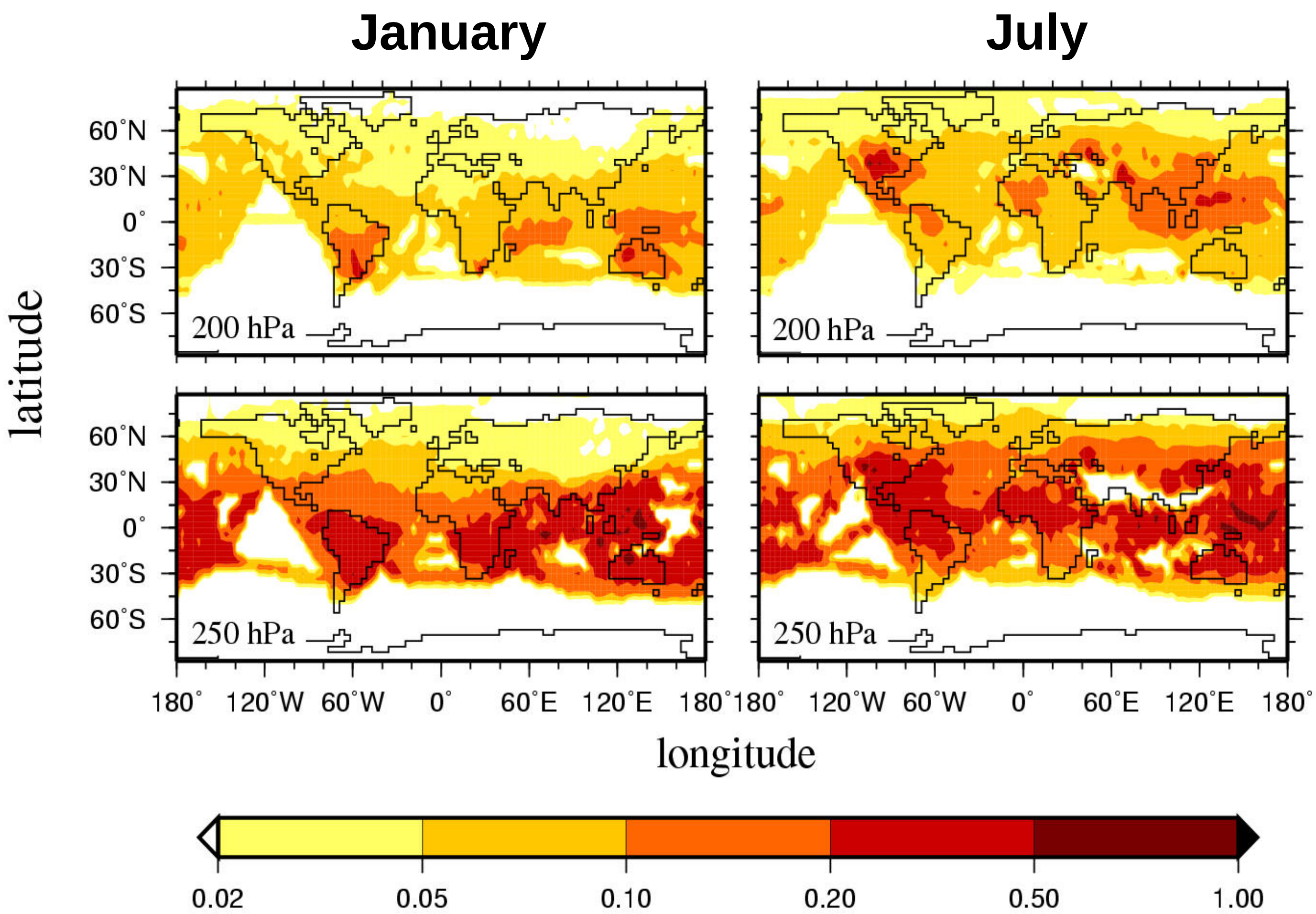
Annual mean contrail cover for traffic of 1992

Comparison to observed line-shaped cover

(Marquart et al., 2004)

Region	Model (1992)	observation
Bakan et al. (1994)	0.37	0.37
Europe, Meyer et al. (2002a)	0.83	0.50 (1996)
USA, Minnis et al. (2000)	0.61	1.30 (1993)
Japan, Meyer et al. (2007)	0.17	0.25 (1998)
Thailand, Meyer et al. (2007)	0.06	0.13 (1998)
World	0.06	

The optical thickness of line-shaped contrails depends on the amount of water available for ice formation

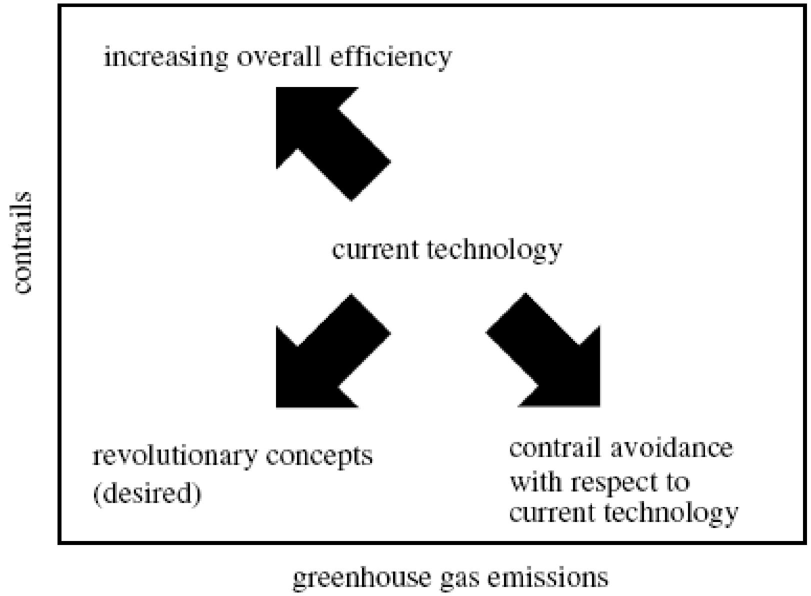


$\tau_{mean} \cong 0.1$ (?)

(Marquart et al., 2003)

Mitigation options

- **Revolutionary technology**
  - "Novel Engine Concept to Suppress Contrail and Cirrus Cloud Formation,"
  - Condensing the water/ice within the engine
- **Fuel additives**
  - Unlikely to find a coating for the soot, which enhances the critical water saturation ratio
  - The Schmidt-Appleman criterion is not the limiting factor for contrail cirrus, it's the super saturation with respect to ice!

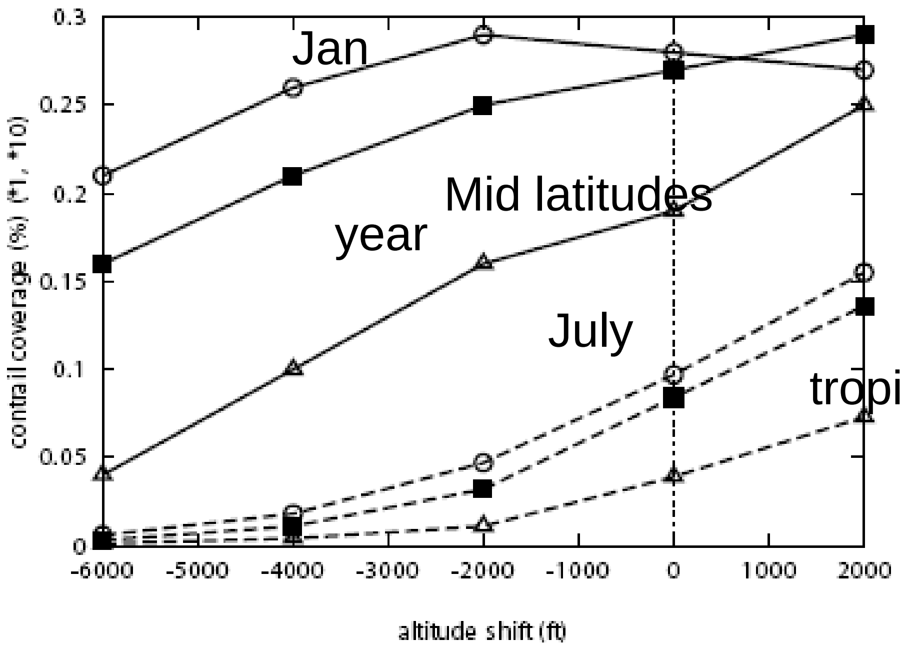


F. Noppel∗ and R. Singh: Overview on Contrail and Cirrus Cloud Avoidance Technology, JOURNAL OF AIRCRAFT, 2007

K. Gierens: Are fuel additives a viable contrail mitigation option? Atmospheric Environment, 2007

Mitigation options

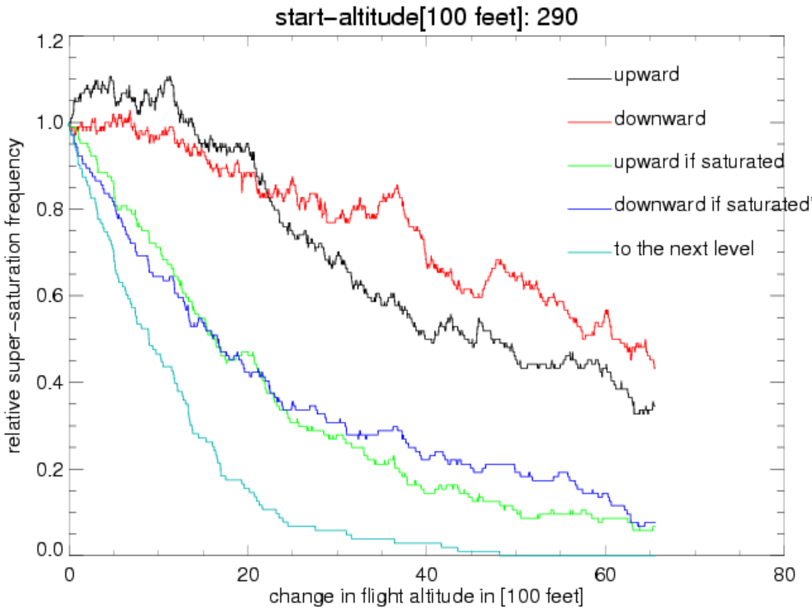
- **Flying higher**
  - Stratosphere:
  - Sub-optimal for current fleet
  - Uncertain effects due to enhanced life time of soot, ozone chemistry
- **Flying lower**
  - Reduced air space
  - Sub-optimal for current fleet



K. Gierens,Ling Limb and K.Eleftheratos:A Review of Various Strategies for Contrail Avoidance, *The Open Atmospheric Science Journal,* 2008

Mitigation options: Flying smart

- **Flight planning**
  - Ice super saturated regions are usually shallow and have limited size
  - Optimize routing (selection of fligth level)
  - Good forcast of moisture is necessary
  - Avoid ‚warming contrails‘
    - at night,
    - over bright surface



Mannstein H, Spichtinger P, Gierens K. A note on how to avoid contrail cirrus. Transp Res Part D 2005; 10: 421-26.

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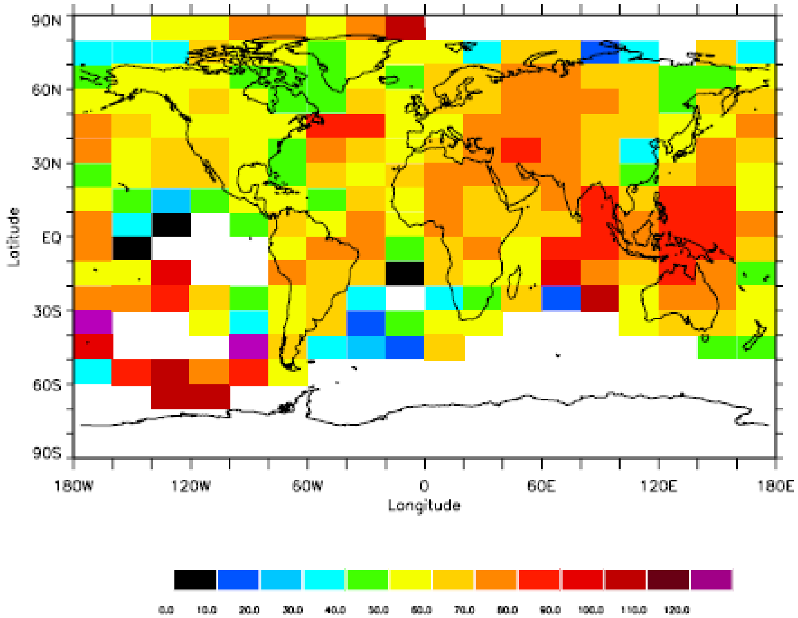

Fig. 5. Percentage contribution of flights during local night time to the annual mean diurnal mean contrail radiative forcing. Contributions less than 50% are indicated by striped boxes, contributions higher than 50% by solidly filled boxes.

Stuber and Forster, ACP, 2007

Mannstein H, Spichtinger P, Gierens K. A note on how to avoid contrail cirrus. Transp Res Part D 2005; 10: 421-26.

Mitigation options: Flying smart

N. Stuber, P. Forster, G. Rädel, K.Shine, Nature, 2006

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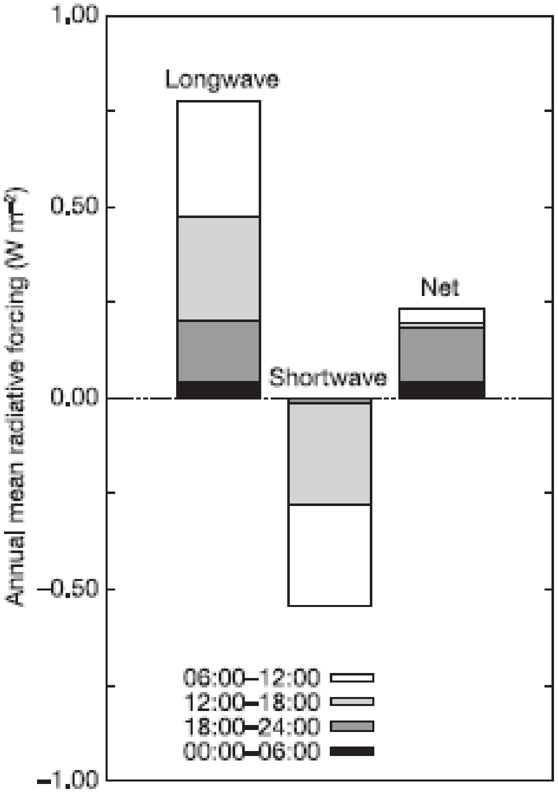


Figure 2 | Annual mean longwave, shortwave, and net radiative forcing due to persistent contrails over Herstmonceux. The contributions of flights occurring during different time periods to the diurnal mean values are indicated by differently shaded bars.

Mannstein H, Spichtinger P, Gierens K. A note on how to avoid contrail cirrus. Transp Res Part D 2005; 10: 421-26.

Mitigation options: Flying smart

- **Flight operation**
  - Avoid ‚warming contrails'
    - at night,
    - over bright surface

Only one contrail

- instead of many ?

Mannstein H, Spichtinger P, Gierens K. A note on how to avoid contrail cirrus. Transp Res Part D 2005; 10: 421-26.

Metrics – comparison of different emissions

'the global annual mean surface temperature increase should not exceed 2°C above pre-industrial levels'
http://europa.eu/bulletin/en/200503/i1010.htm

- **Radiative forcing –**
  - historical data

▪ Keith Shine -> next talk

- **Global warming potential**

$$\mathrm{AGWP}^{\mathrm{x}}(H) = \int_0^H A_{\mathrm{x}} \exp\left(-\frac{t}{\alpha_{\mathrm{x}}}\right) \mathrm{d}t = A_{\mathrm{x}} \alpha_{\mathrm{x}} \left[1 - \exp\left(-\frac{H}{\alpha_{\mathrm{x}}}\right)\right]$$

- **Global temperature change potential**
  - Shine et a. Phil. Trans. R. Soc. A (2007) 365, 1903–1914

$$\mathrm{AGTP}^{\mathrm{x}}_{\mathrm{P}}(H) = \frac{A_{\mathrm{x}}}{C(\tau^{-1} - \alpha_{\mathrm{x}}^{-1})} \left[\exp\left(-\frac{H}{\alpha_{\mathrm{x}}}\right) - \exp\left(-\frac{H}{\tau}\right)\right]$$

Integrated radiative forcing of airtraffic induced cirrus

'backside of the envelope, calculation:

1 kg jet fuel -> chemical energy content (43.1 MJ) -> +0.043 GJoule

1 kg jet fuel -> CO_2 effect, life time ~ 100 Jahre -> +1 GJoule

A very efficient aircraft might travel ~200 m/kg fuel

200m of thick contrail cirrus, 4 km wide, 2h life time at night -> +300 GJoule

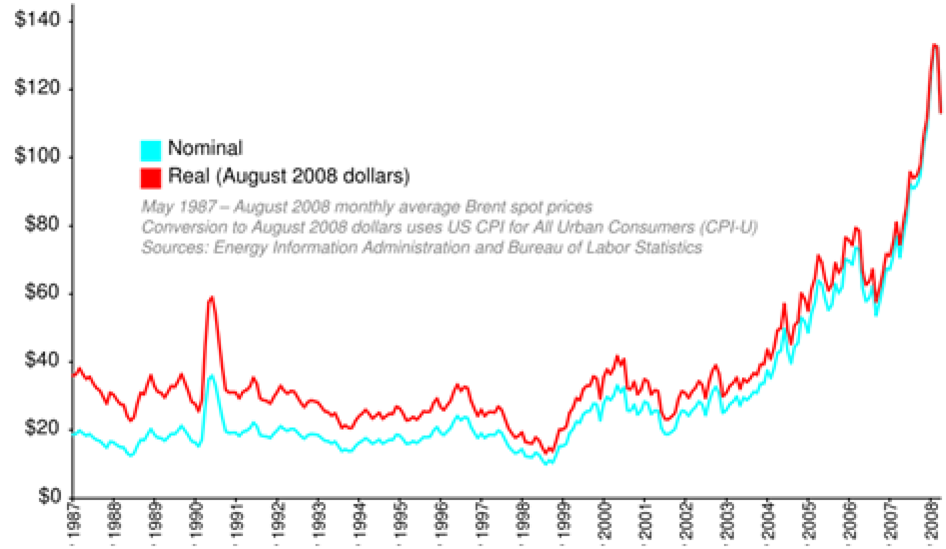
The same during daytime over cloudless ocean -> -200 GJoule

Estimated mean over all flights? -> ~1 GJoule

Regulations for CO_2?

- The fuel market does it:
- „Peak oil“ ?

- Crude oil (Brent) spot prices



Jet fuel price (IATA)

12 Sep 08	Share in World Index	cts/gal	$/bbl	$/mt	Index Value 2000= 100	vs. 1 week ago	vs. 1 month ago	vs.1 yr ago
Jet Fuel Price	**100%**	**334.3**	**140.4**	**1106.1**	**383.8**	**6.8%**	**2.4%**	**48.4%**
Asia & Oceania	22%	290.7	122.1	964.4	348.8	-2.1%	-10.3%	32.0%
Europe & CIS	28%	311.6	130.9	1031.1	352.5	-1.4%	-6.8%	38.3%
Middle East & Africa	7%	291.8	122.5	966.8	366.0	-1.8%	-9.1%	34.0%
North America	39%	369.2	155.1	1223.6	412.3	16.3%	15.7%	61.3%
Latin & Central America	4%	467.5	196.4	1512.0	544.0	28.3%	28.7%	103.3%

From http://www.iata.org/whatwedo/economics/fuel_monitor/price_analysis.htm

Which regulations for AIC are possible?

- Factor (1.7?) on CO_2 emissions used in the emission trading system
  - Simple, but <u>no incentive</u> for reduction of AIC!
  - Large uncertainty: 1 – 4, mainly due to uncertain total AIC, but also NO_x
  - The factor will still be uncertain in 2012, (airtraffic -> ETS)
- Penalty on production of contrails and contrail cirrus
  - Survaillance extremely difficult (‚contrails' project EUROCONTROL/ESA)
- Bonus for useful actions (financed by revenues from the ETS)
  - Contrail avoidance
  - Support of RTD:
  - Measurement of moisture (supersaturation) on route (AMDAR)
  - Monitoring of contrails (on-board rear looking camera)

When can we expect the science to be sufficiently robust to provide an acceptable basis for regulation?

- **Now!**
  - If the available fossil fuel (coal, oil, gas) will be burned anyway only non-CO_2 effects can be influenced by regulations
    -> “geo-engineering”
  - Warming contrails and contrail cirrus can and should be avoided
  - Research and technical development has to be accelerated now in order to reach the ACARE goals
  - More emphasis on contrails/contrail cirrus (ACARE did not even mention them)
  - Also soot may have an impact on cirrus
  - Support by air traffic industry is essential

When can we expect the science to be sufficiently robust to provide an acceptable basis for regulation?

- **In 2-4 years (2012)**
  - Results of EU-IP QUANTIFY and OMEGA will be available:
  - Optimization of flight routes: avoidance of AIC vs. additional fuel (German Ministry of Education and Research funded project “Environmentally compatible flight route optimization” with DLR, Lufthansa, DWD and DFS)
  - The uncertainty of the factor will still be considerable

- **In 8-10 years:**
  - A large, international project is necessary to reduce the uncertainties in the non-CO_2 effects.