

Aviation and climate change: Options for mitigation

Ulrich Schumann
DLR, Institute of Atmospheric Physics,
Oberpfaffenhofen, Germany



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



Content

- **Climate change and contribution from aviation?**
(Results from EU projects such as AERONET, TRADEOFF, AERO2k, QUANTIFY, SCOUT-O3, etc.)
- **European Vision: realistic and sufficient?**
- **Mitigation options?**
 - **Flying lower?**
 - **Flying higher?**
 - **Flying around?**
 - **Flying earlier?**
- **What should be done next?**

Climate change from aviation?

- Evidence for anthropogenic climate change is increasing (e.g. Climate J., 2005) and acknowledged at G8 summit 2005
- New assessments of emissions for 2.6 times larger traffic over 20 years predict growth in CO₂ and NO_x (EU-project AERO2K)
- New assessment of RF from CO₂, NO_x, contrails (Sausen et al. , Meteor. Z., 2005). - Contrail-cirrus still not included
- New findings on cirrus trends (Minnis et al., 2004, Zerefos et al., 2004, Stordal et al., 2005; Stubenrauch and Schumann, 2005)
- Correlation between air traffic and cirrus: 10 time more cirrus than contrails, large radiative forcing (Mannstein and Schumann, Meteor. Z., 2005; Krebs, Mannstein et al., ESA-CONTRAILS project, 2006)
- Impact of line-shaped contrails on climate change computed small (Ponater et al., GRL, 2005)
- Soot impact on cirrus potentially large (Hendricks et al., GRL, 2005)
- Many new findings on chemistry and physics of the UTLS region (IGAC Newsletter 32, 2005) call for new assessment



European Vision for 2020

- Five-fold reduction in accidents
- Halving perceived aircraft noise
- **50% cut in CO₂ emission per passenger-km**
- **80% cut in NOx emissions**
- Air traffic system capable to handle 16 million flights/year
- 99% of all flights within 15 minutes of timetable compared to 2000.

Realistic and sufficient?



Mitigation options?

- **Technology: Reduction goals of emissions declared in terms of mass per ASK and in the year 2020 compared to the technology of 2000**
- **Reductions are feasible but come to slow**
- **CO₂: Instead of 50 %, perhaps a 20 % reduction might be reached until 2020**
- **NO_x: Instead of 80 %, perhaps a 40 % reduction might be reached until 2020**
- **Soot: No reduction goal set (cirrus-climate and airport problem!)**
- **Contrails: No reduction goal set (cirrus-climate problem!)**
- **New option for mitigation by changed ATM: flying lower or higher or around humid regions or earlier during the day**
- **Strong increases in fuel prices (crude oil price increased by 40 % in the last 2 years) may driver quicker technology development**



Flying lower?

- is presently favored in the public "green" discussion
- has potential to reduce contrails
- significant only if altitude is reduced by an order 6000 feet (2 km)
- increases fuel consumption and hence CO₂ emissions (unless using turboprops)
- increases travel time
- increases air space congestion
- reduces travel comfort (turbulence etc.)
- increases cost per ticket


- not attractive for passengers/air liners
- unlikely to come for long-distance flights

Flying higher?

- "Dreamliner" B 787 reaches 13 km, A340 12 km
- appears to be counter-intuitive in view of negative image of supersonic transport
- Flying higher, by say 1 km, will not enlarge the "ozone hole"
- Has the potential to reduce contrails, contrail cirrus
- May have a minor impact on O₃; needs to be assessed in more detail
- May reduce climate impact for long distance extratropical flights
- Not recommended for short range traffic and tropical traffic
- Requires stronger and lighter aircraft structure and adjusted aerodynamics
- May reduce fuel consumption, CO₂ emissions, reduce travel time, congestion, turbulence, ticket price, and should be attractive for industry therefore
- Requires a dedicated research project of industry and academia.

Flying around?

- **Routing traffic around ice supersaturated regions by proper weather prediction and ATM may be far more effective than flying lower**
- **Has the potential to reduce contrails, and contrail cirrus**
- **Requires better weather prediction models (progressing)**
- **in particular better prediction of regions with humidity above ice-supersaturation and with upward motion**
- **Needs onboard observation of humidity with online data transfer to weather services**
- **Requires a more flexible ATM**
- **Is attractive in particular for flights in all regions and for all distances**
- **Extra fuel costs may be smaller than gains from route optimization**
- **Makes ATM more complex**
- **Requires research and development**



Flying earlier? more during morning time and less during night?

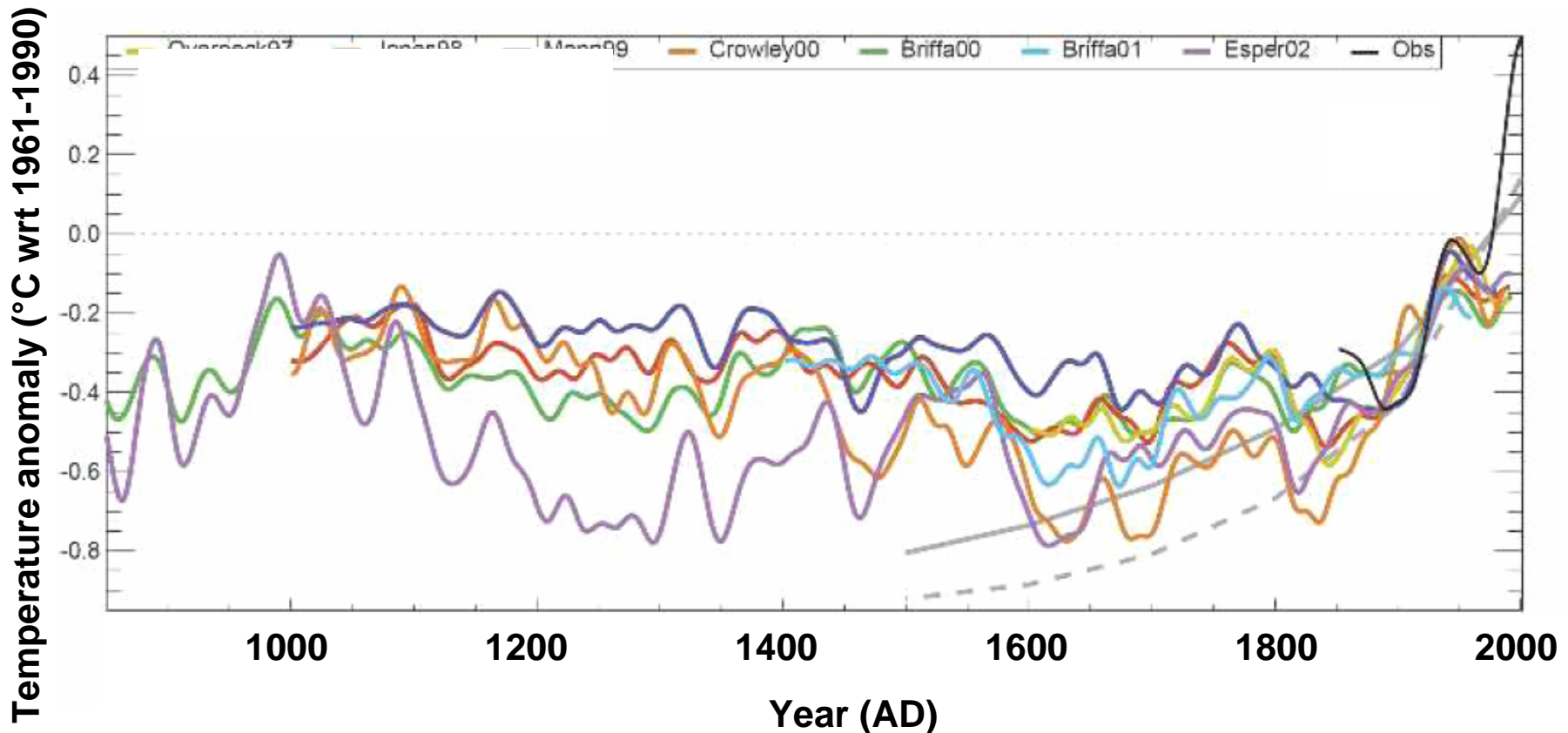
- **Contrail cirrus cools during day (in particular in the morning)**
- **Contrail cirrus warms during night**
- **Hence: shift traffic peaks into morning and noon time**
- **Will not come alone, but may require regulation (fee in proportion to climate impact of contrail cirrus)**
- **Climate impact reduction may be larger than from any other means**



What should be done next?

- **Start a new major research project: "Fly higher?"**
- **Assess technology options for higher and lower flight altitudes**
- **Assess ATM options for flying lower, around, higher or earlier**
- **Assess ozone and climate impact of flying higher**

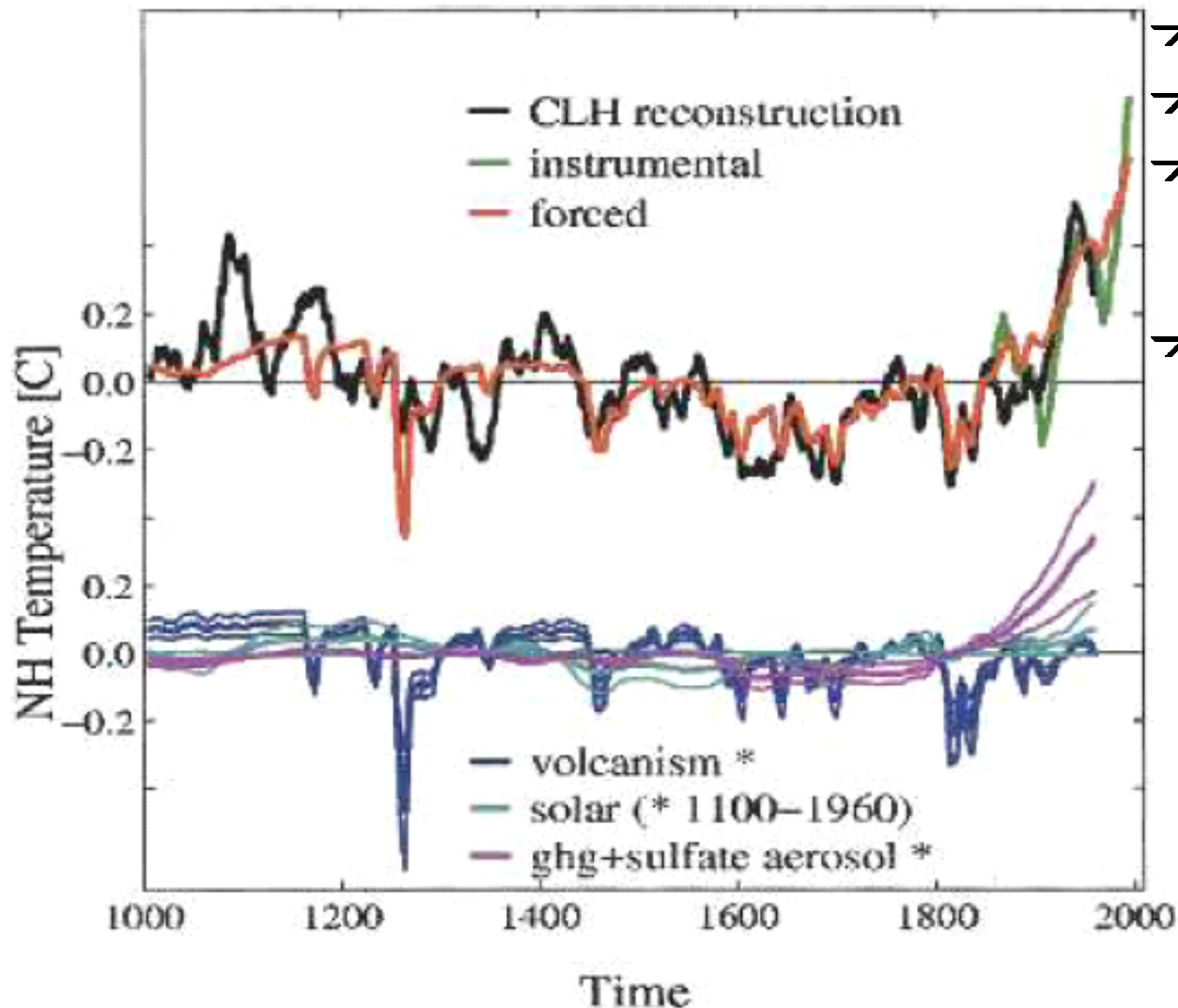
Global warming since 1950 exceeds natural millennium variability



(The International Ad Hoc Detection and Attribution Group, J. Clim., 2005)



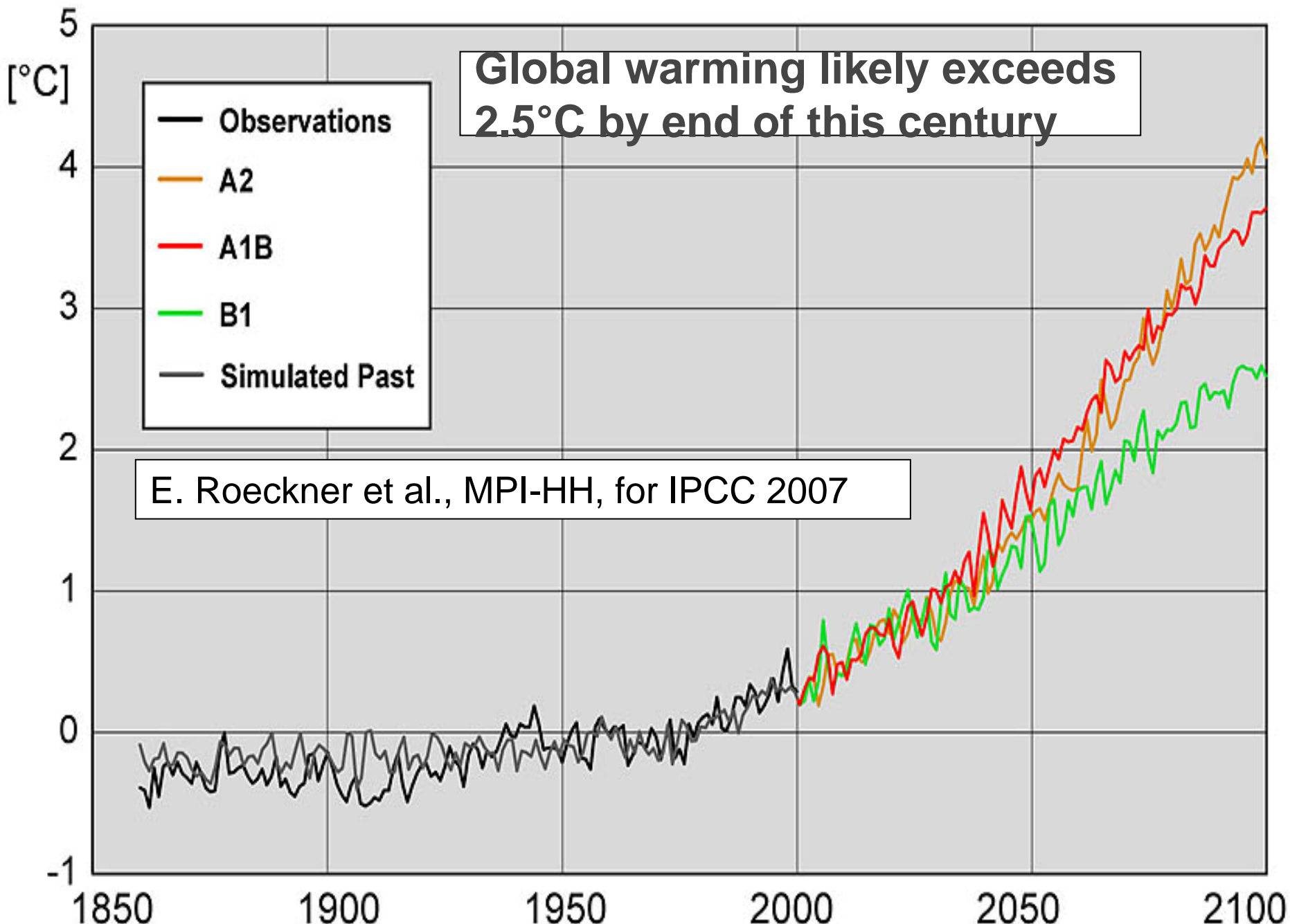
CO₂ + aerosol changes explain most of the observed warming



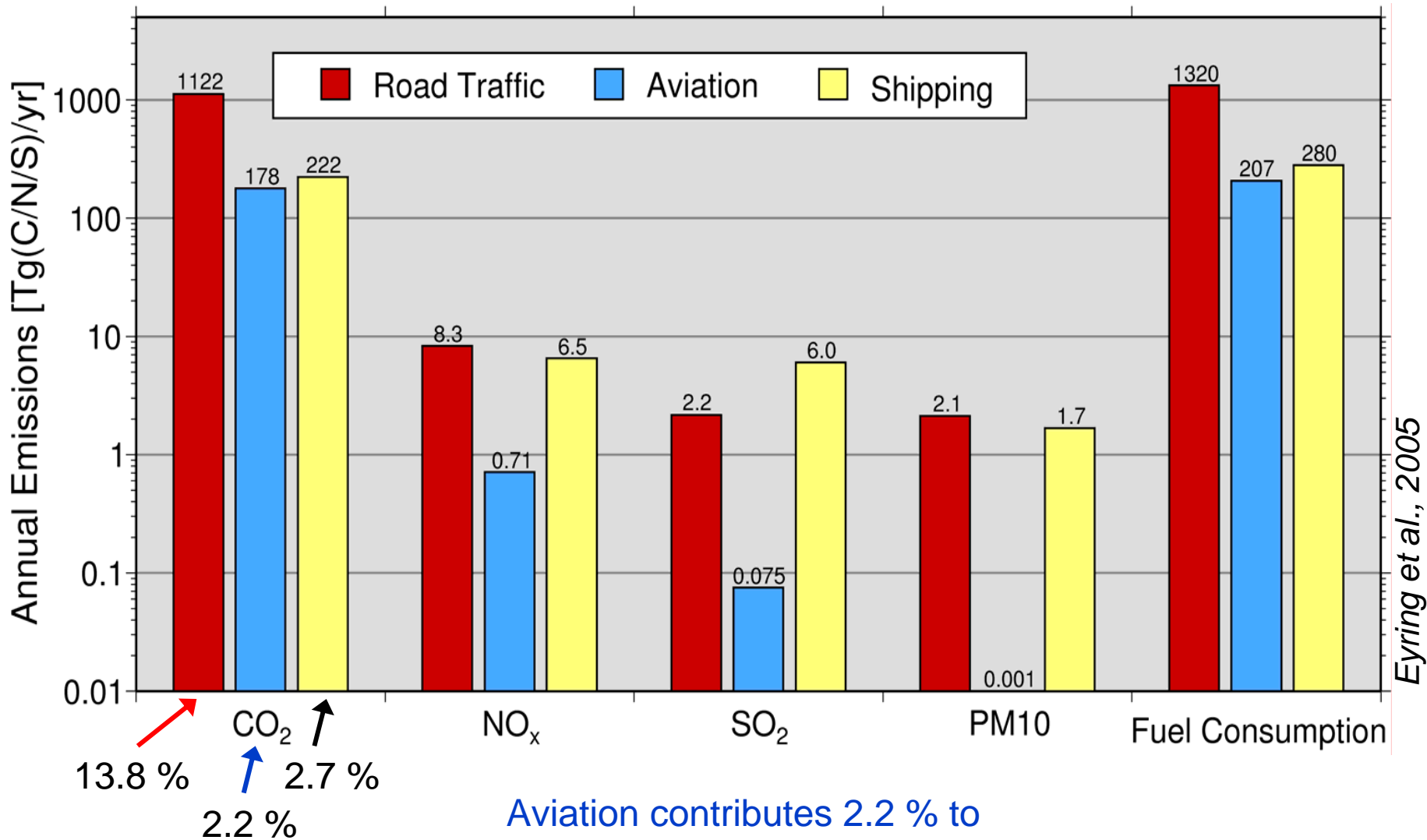
- Paleoreconstruction
- instrumental record
- best combination of solar, volcanic, and anthropogenic forcing
- (bottom) Contribution from various forcings

(The International Ad Hoc Detection and Attribution Group, J. Clim., 2005)

IPCC SRES Scenarios: Temperature Change relative to 1961-1990



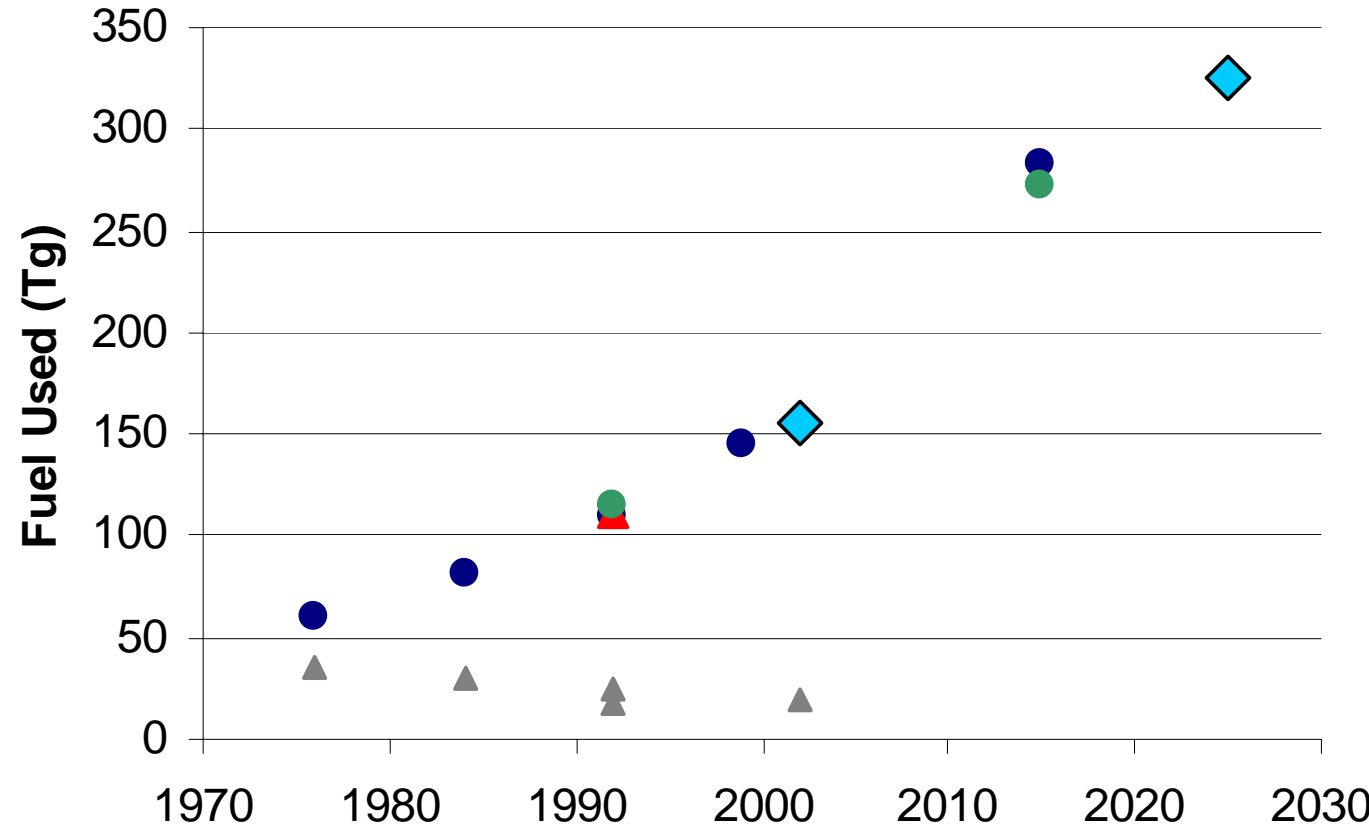
Emissions from various traffic modes, year 2000



Eyring et al., 2005

Aviation Fuel trends

assumed:
 $\text{PKM}(2025) = 2.6 \times \text{PKM}(2002)$

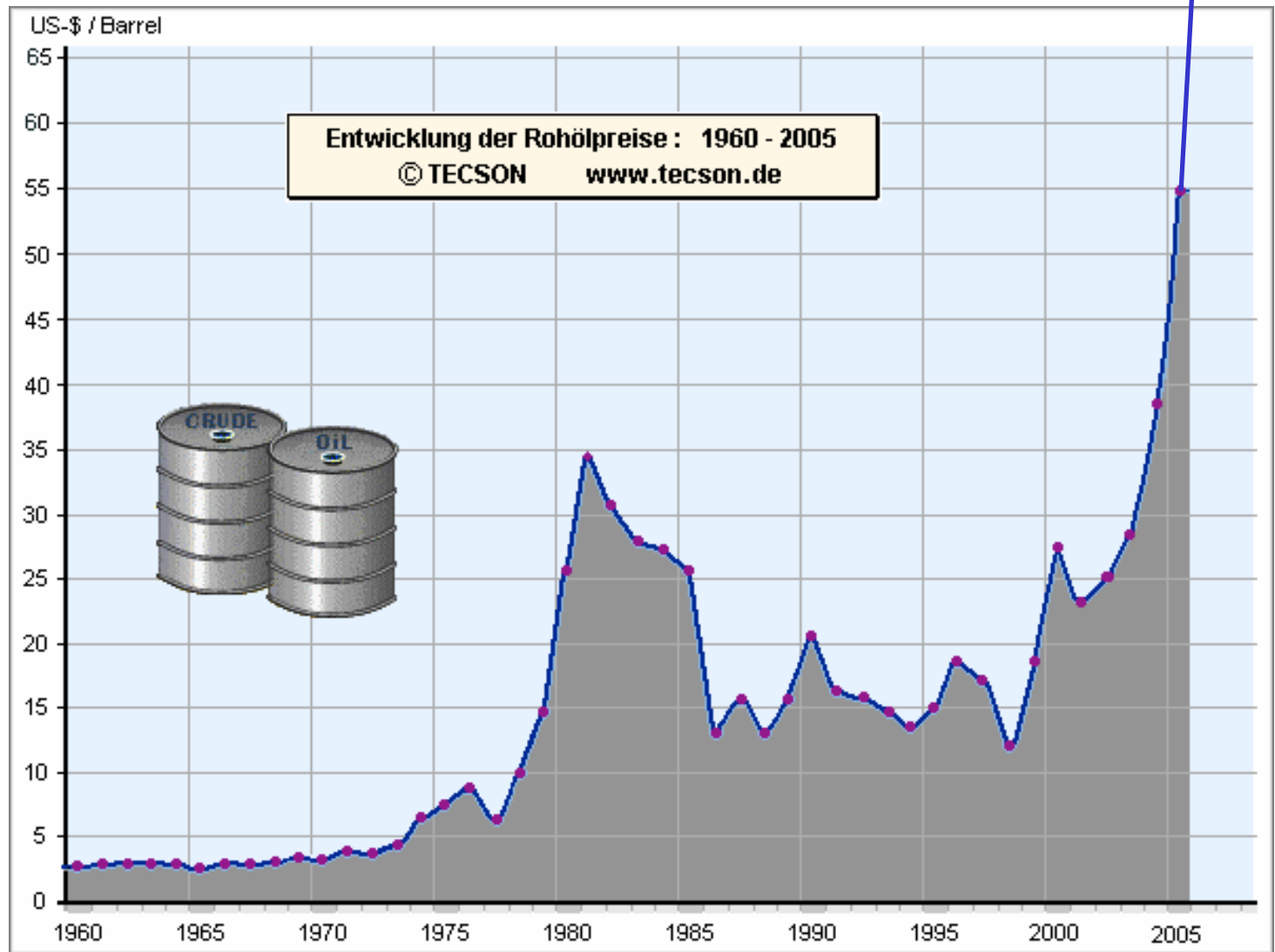


- NASA
- ▲ DLR
- ANCAT
- ◆ AERO2K
- ▲ Military

Computed reduction of specific fuel consumption: 20 %.
 Needed: 60 %

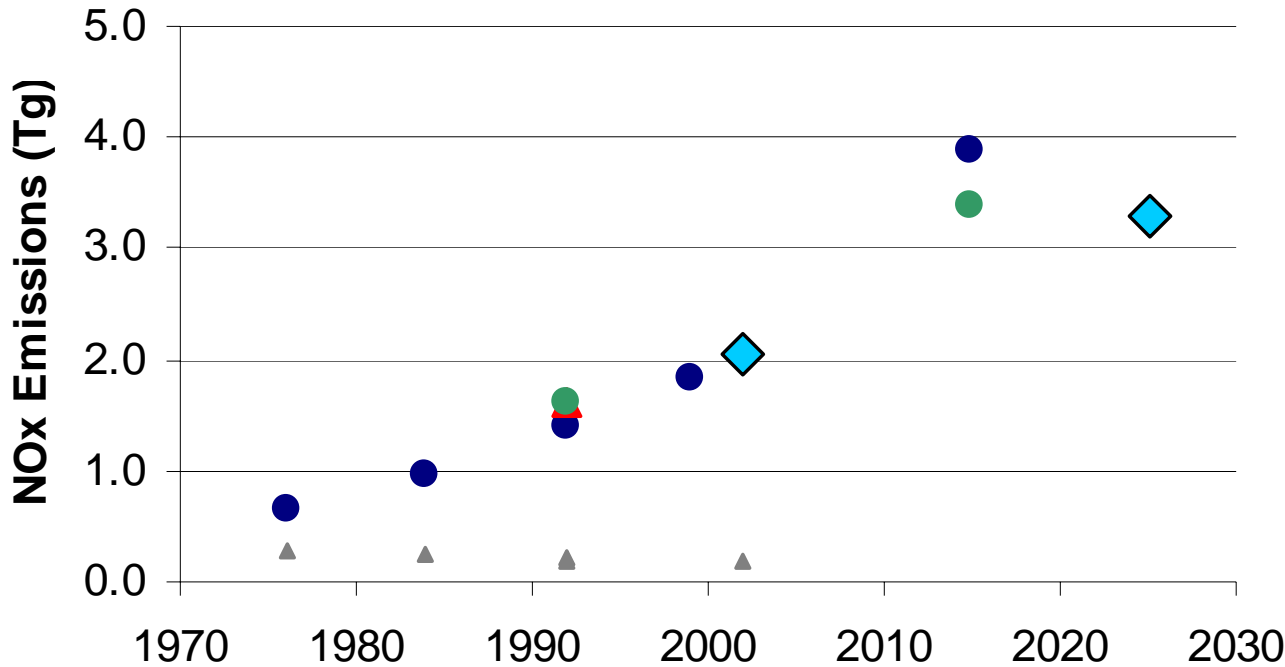
C. J. Eyers et al., **AERO2k** Global Aviation Emissions Inventories for 2002 and 2025, May 2005

Crude-Oil Price Trends



Aviation NOx emission trends

assumed:
 $\text{PKM}(2025) = 2.6 \times \text{PKM}(2002)$

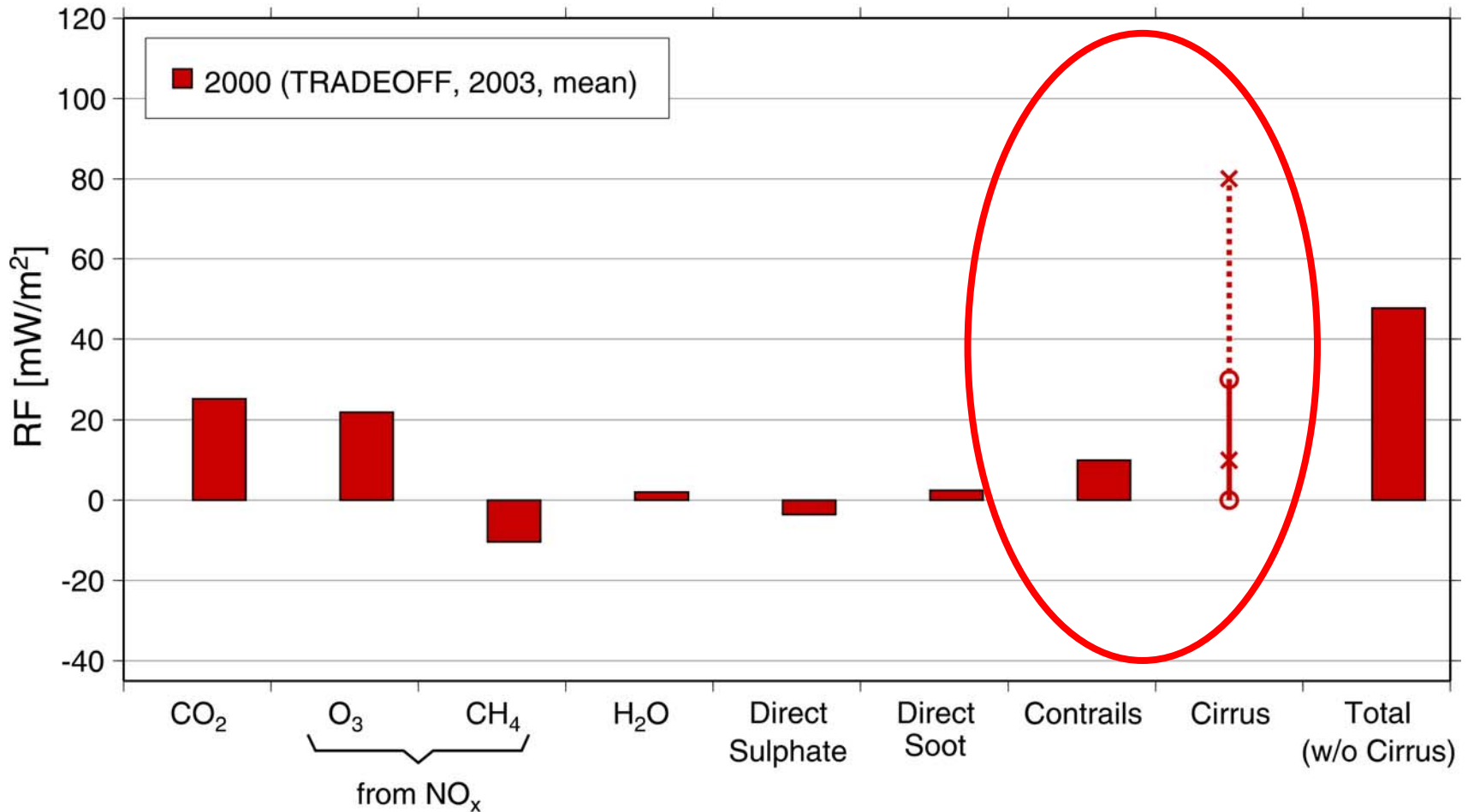


Computed reduction of specific NO_x emission: 38 %.
 Needed 60 %.

C. J. Eyers et al., AERO2k Global Aviation Emissions Inventories for 2002 and 2025, May 2005, EU-project funded by the CEC

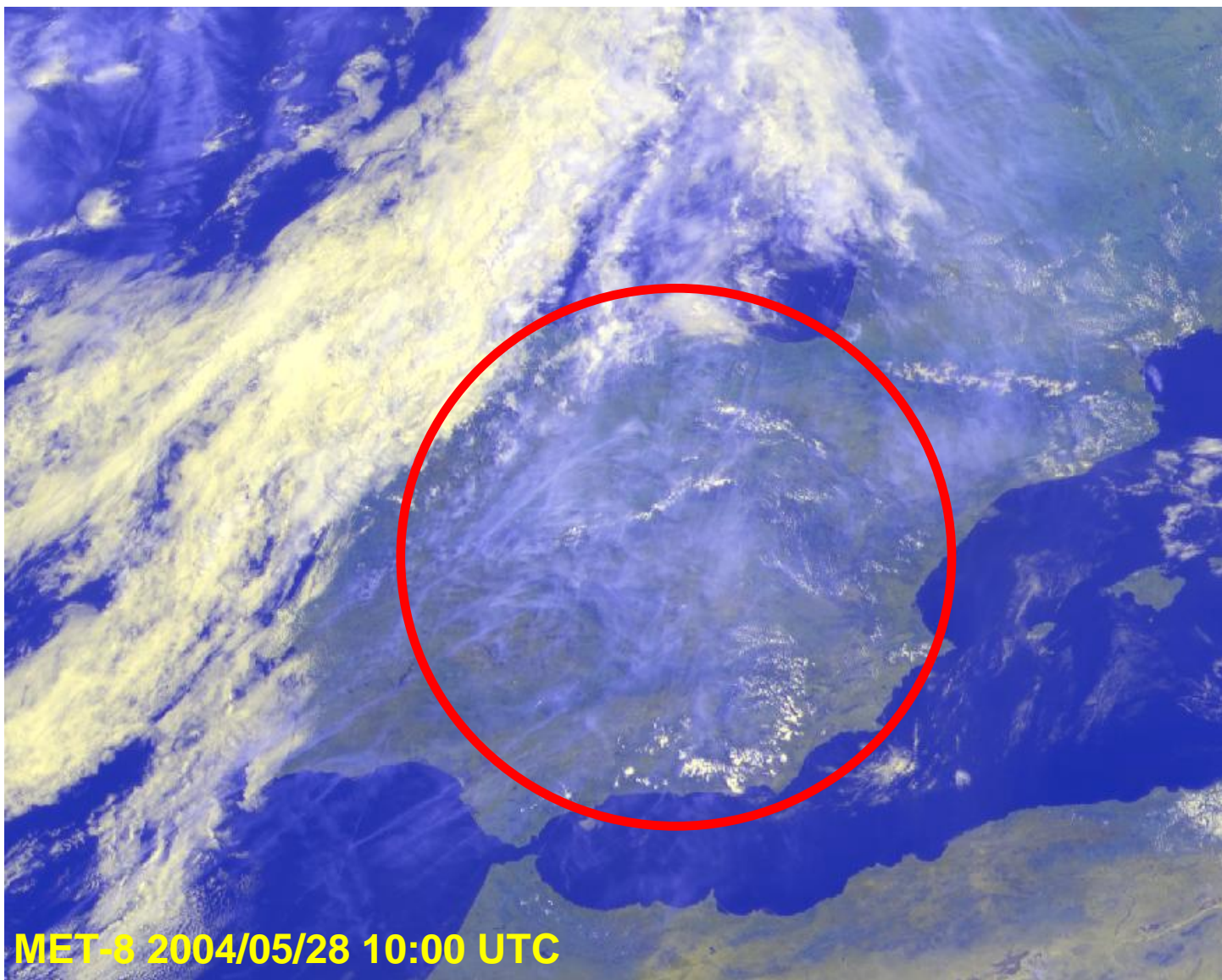
Radiative Forcing induced by Aviation for 2000 - new assessment from TRADEOFF (Sausen et al., 2005)

Aircraft RF



Sausen et al., 2005





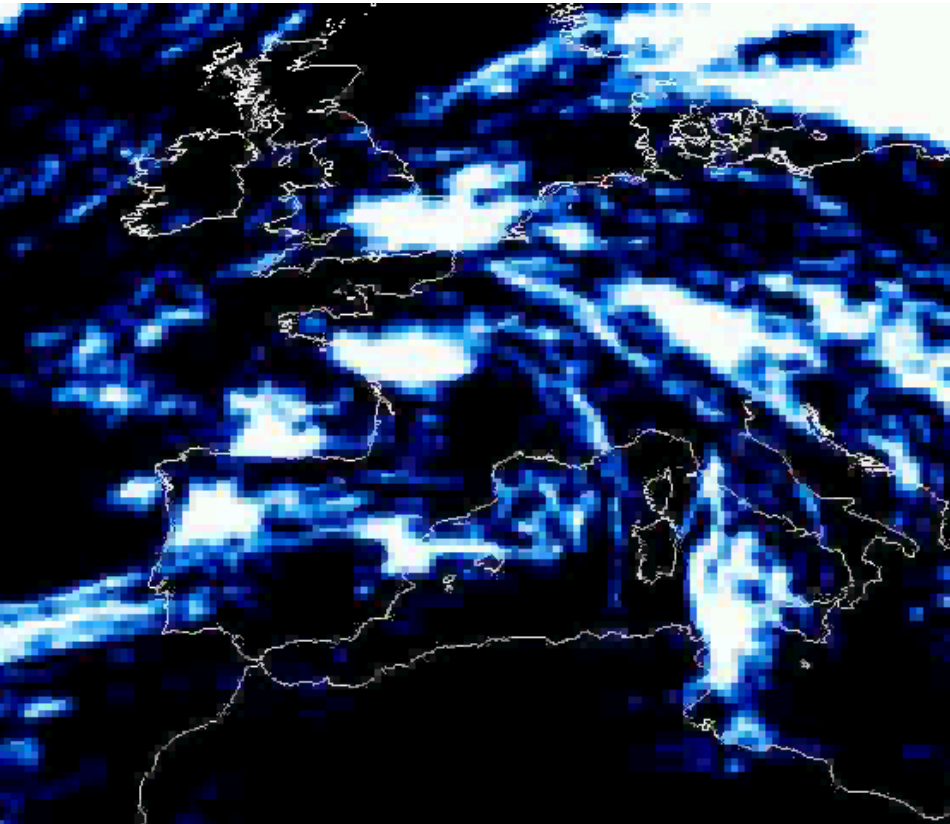
MET-8 2004/05/28 10:00 UTC



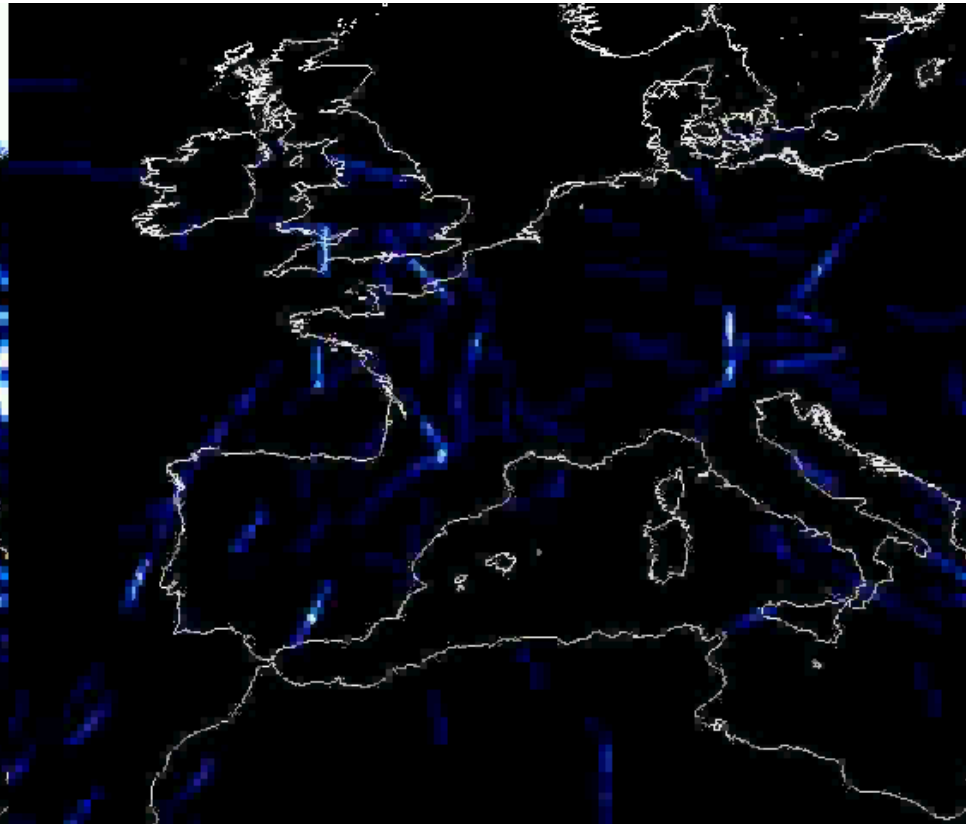
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U. Schumann, Aerodays 2006,
Vienna, 19-21 June 19

Cirrus cover (Meteosat)

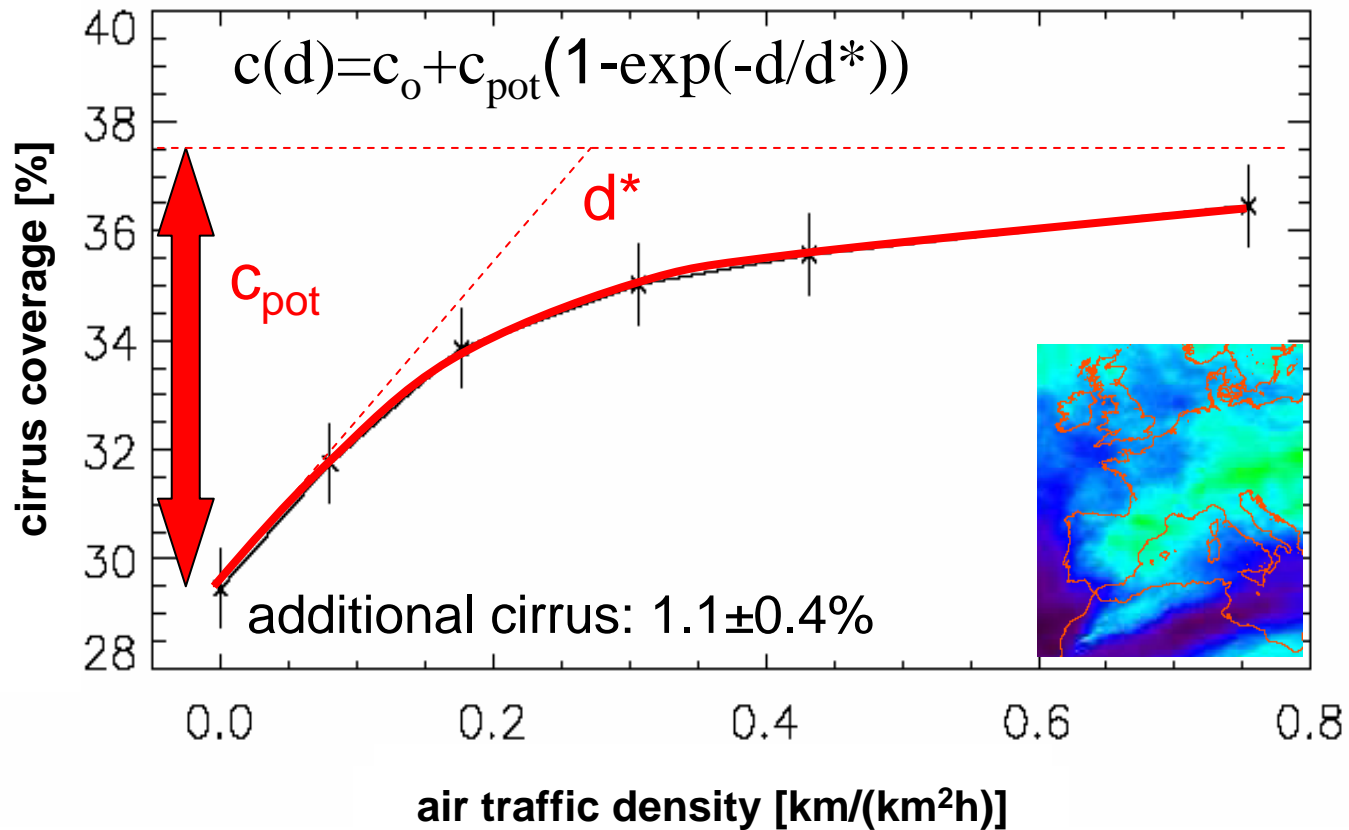


Air Traffic Density (Eurocontrol; flight levels: 200 hfeet - 450 hfeet)



15W - 20E, 30N - 60N, 0.25° x 0.25°

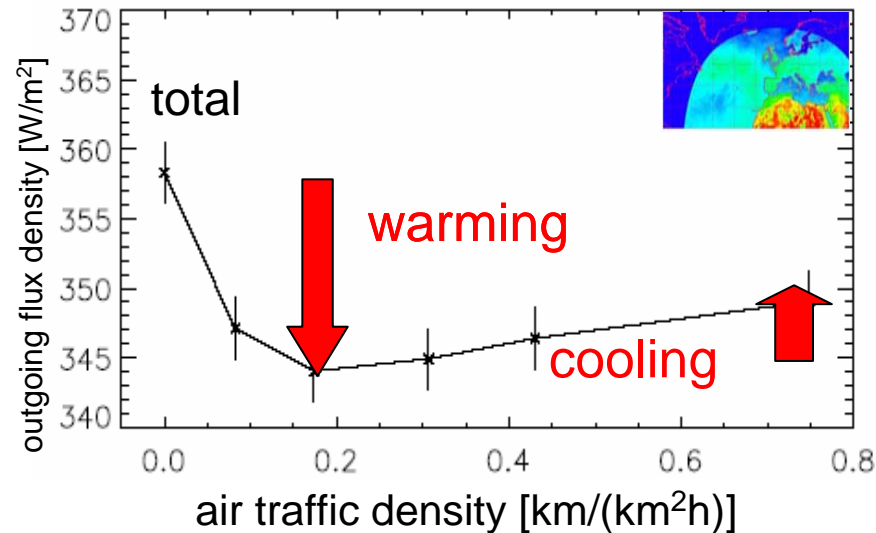
cirrus coverage vs. air traffic density Feb - Dec 2004



Outgoing flux density Feb-Dec 2004 vs. air traffic density

difference w/o air traffic

$$1.1 \pm 0.6 \text{ Wm}^{-2}$$

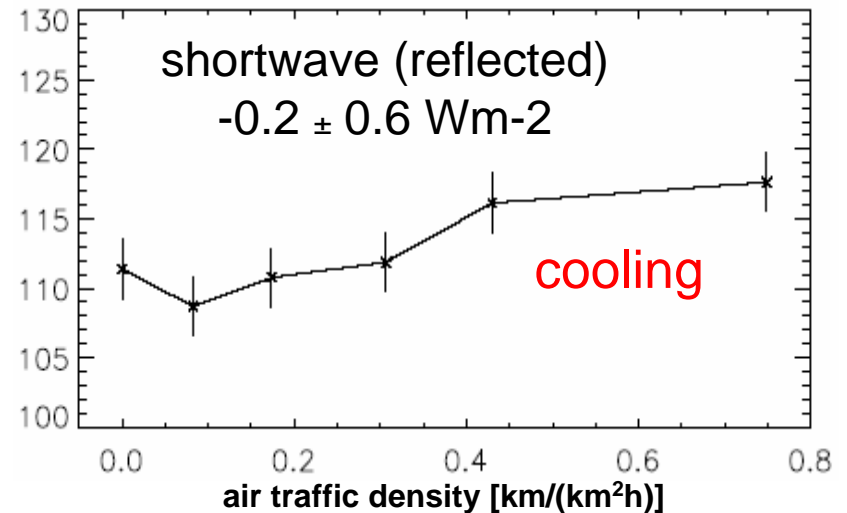
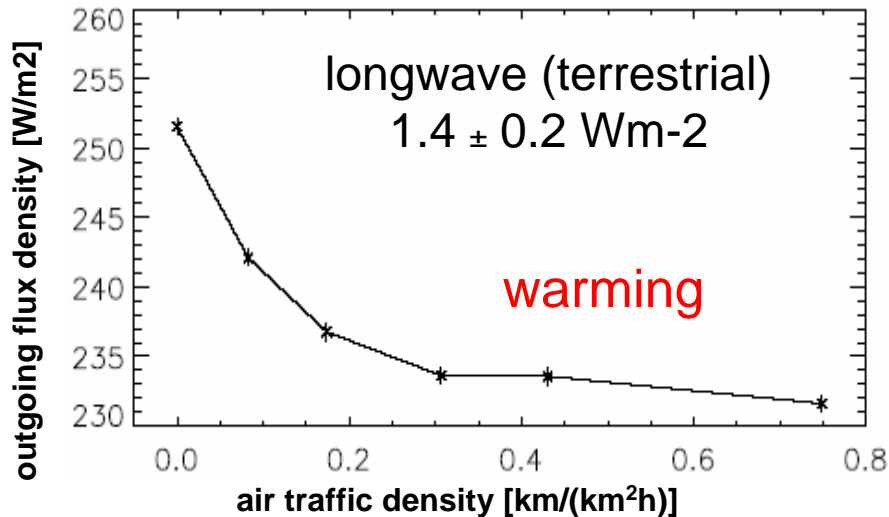


30% of global air traffic
8% of global area
global estimate:

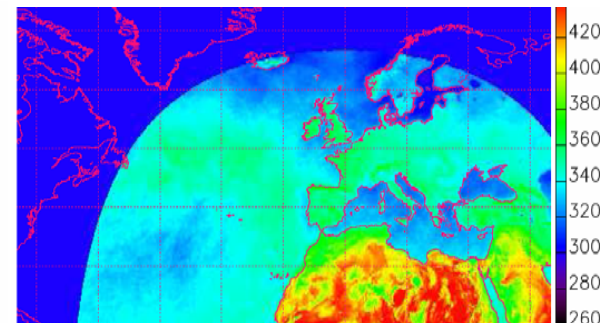
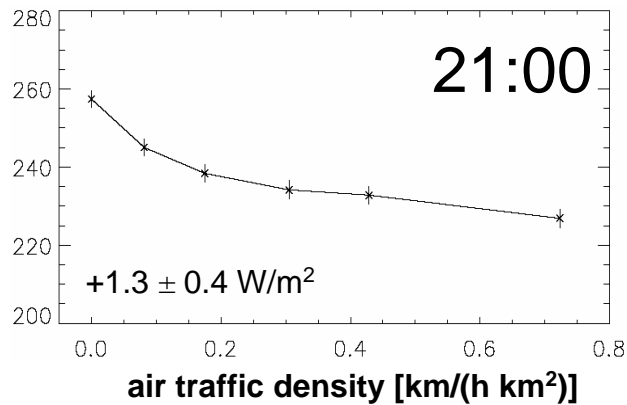
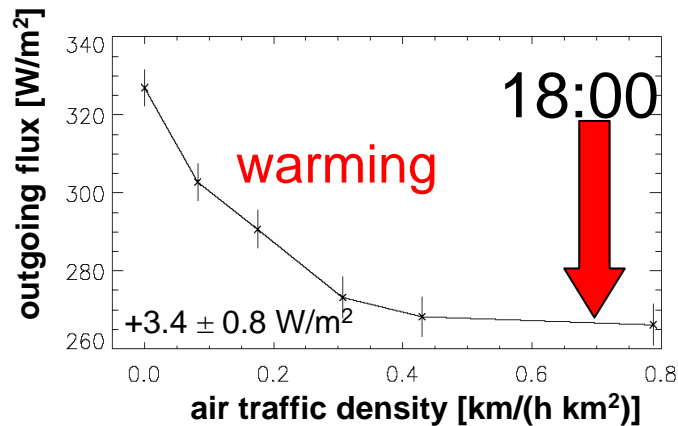
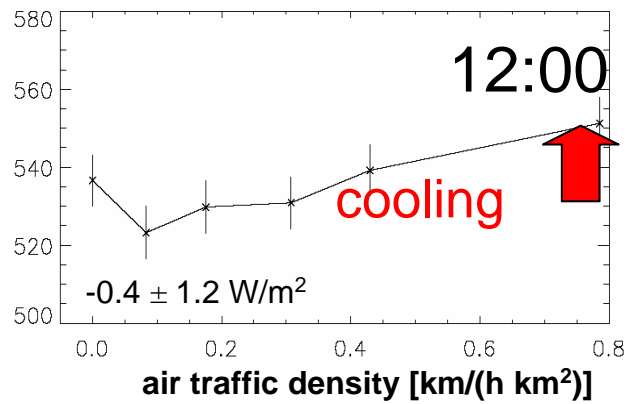
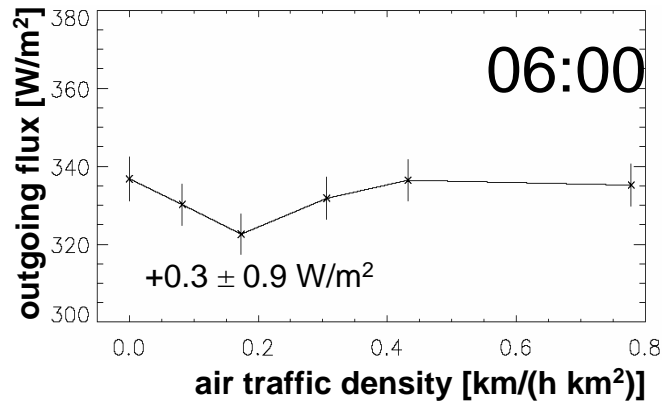
$$0.3 \pm 0.3 \text{ Wm}^{-2}$$

$$0.4 \pm 0.1 \text{ Wm}^{-2} \text{ (LW)}$$

$$-0.1 \pm 0.3 \text{ Wm}^{-2} \text{ (SW)}$$

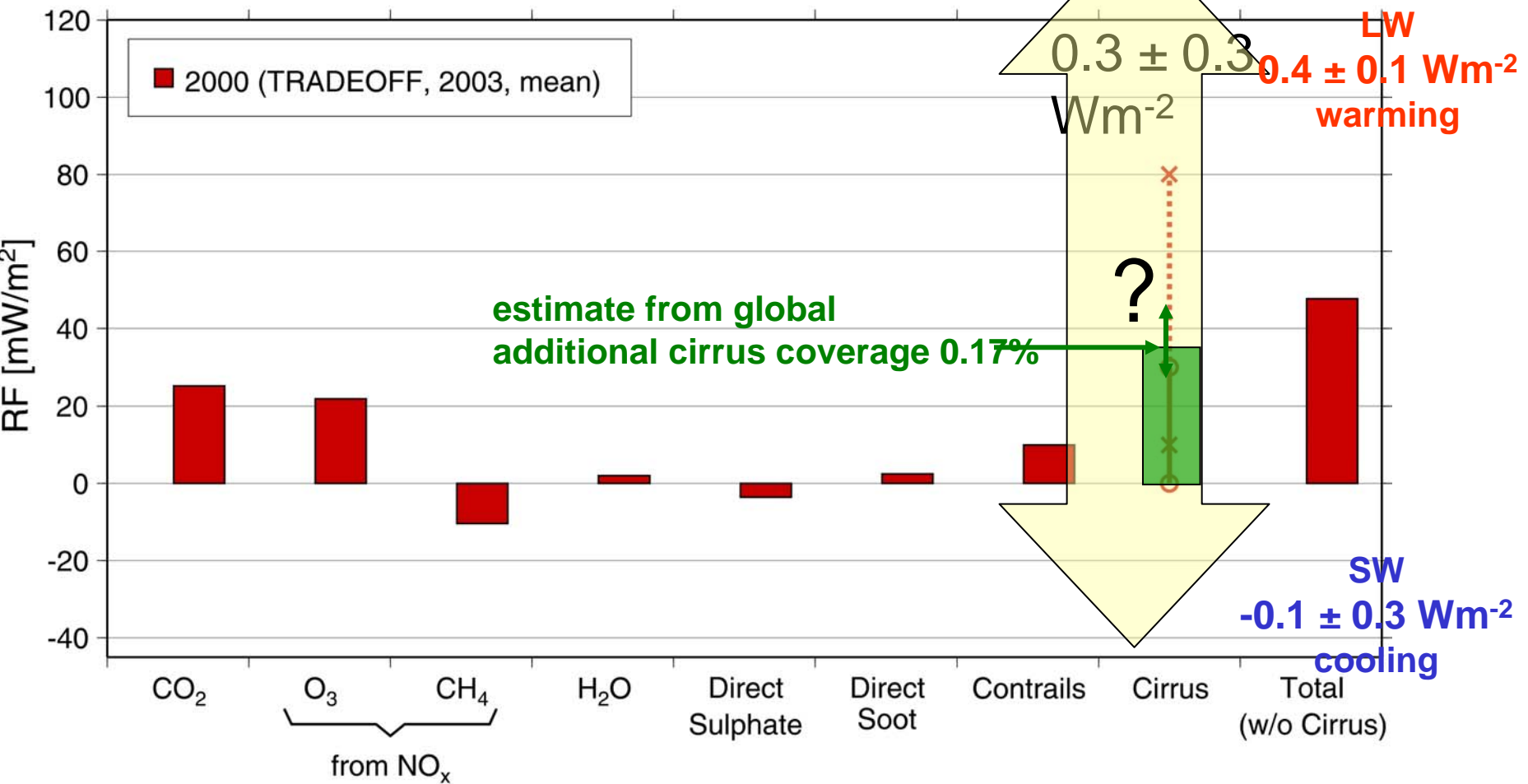


Diurnal variation





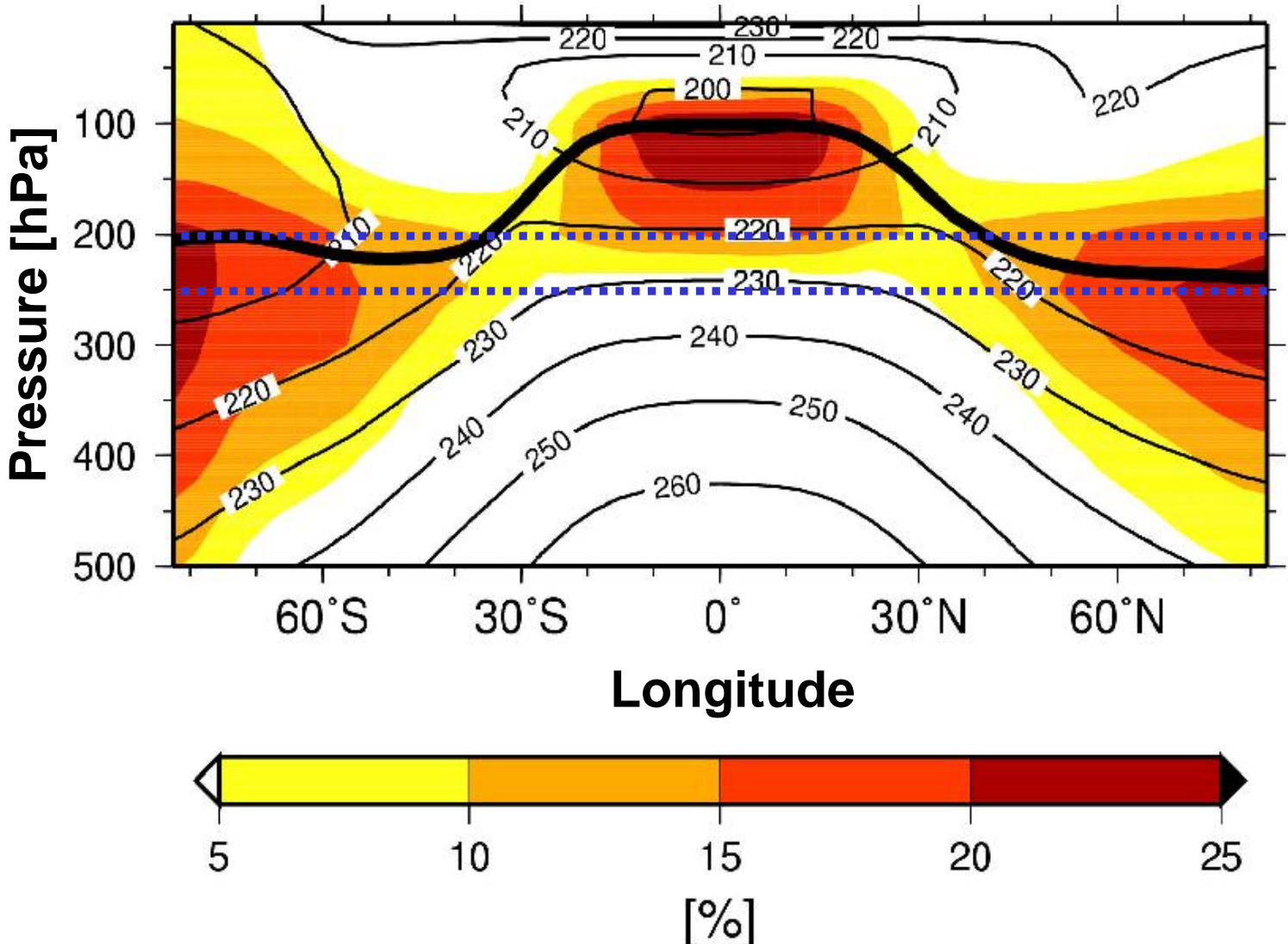
Aircraft RF





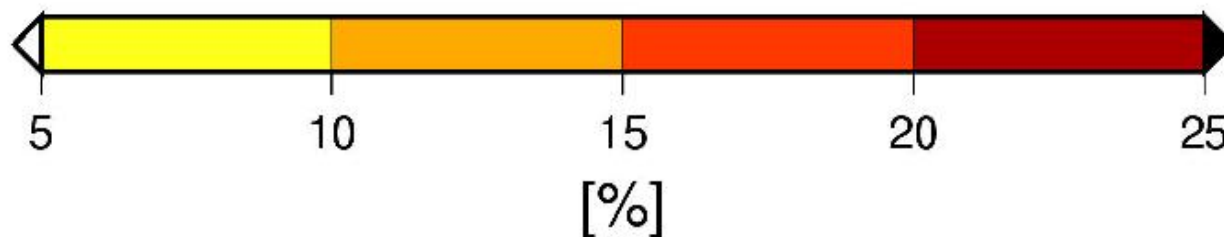
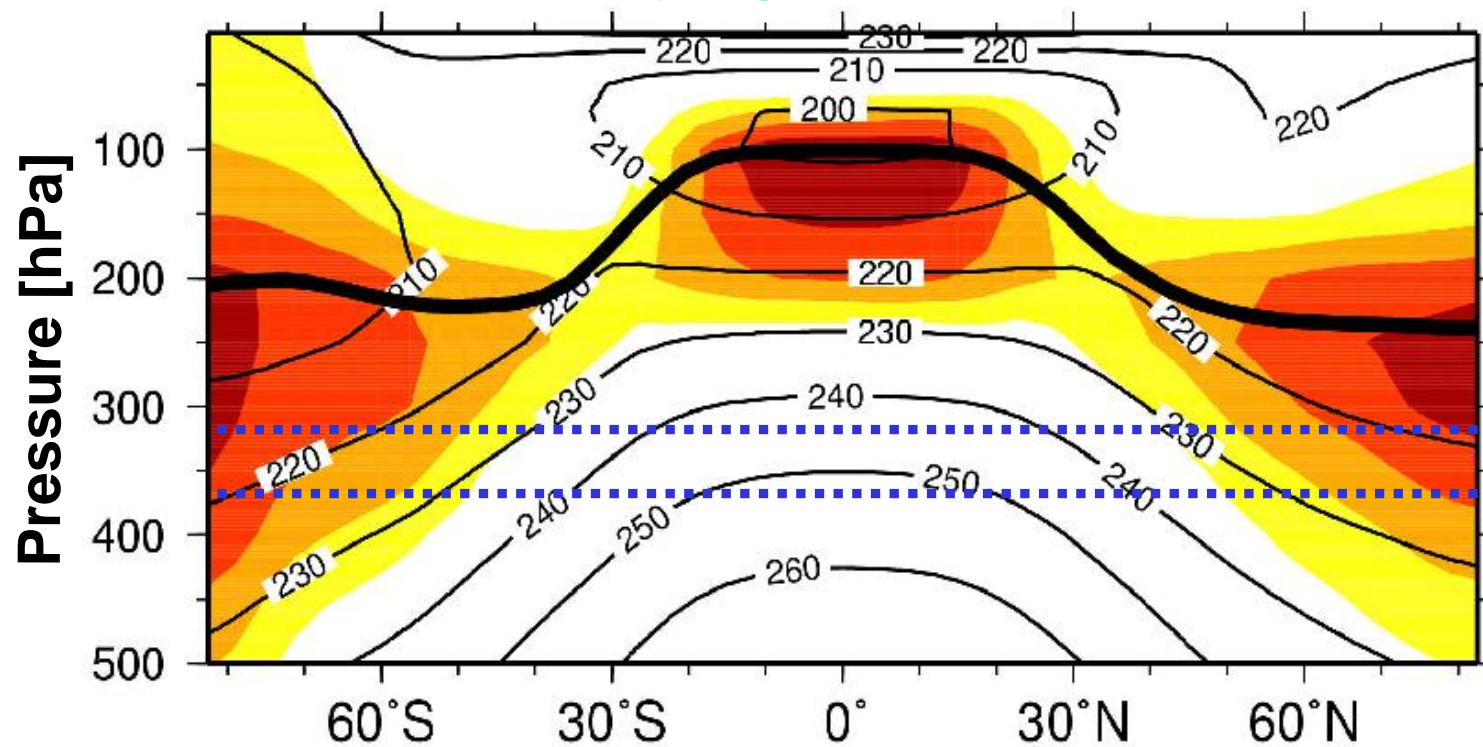
Mitigation options?

Frequency of contrail forming (humid and cold) air masses



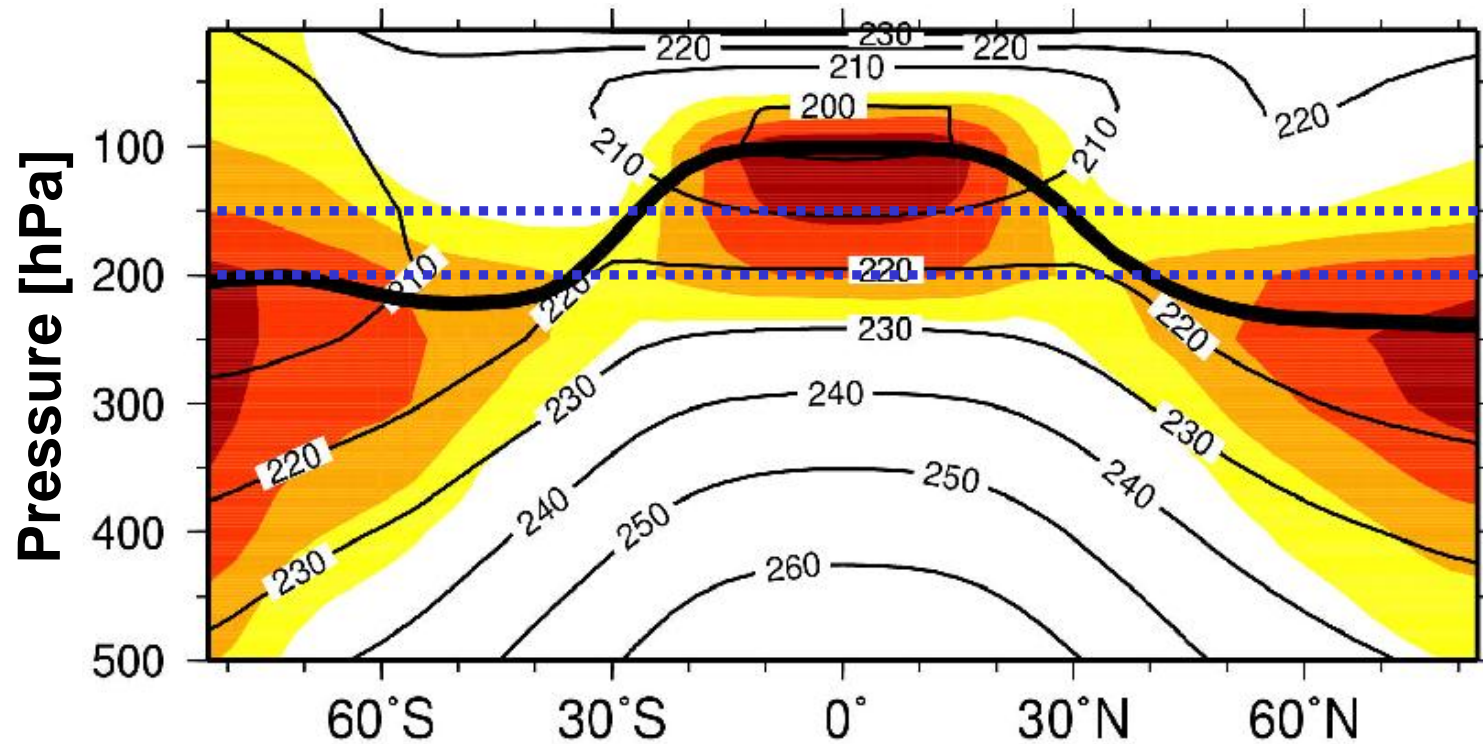
Frequency of contrail forming air masses

Flying lower?

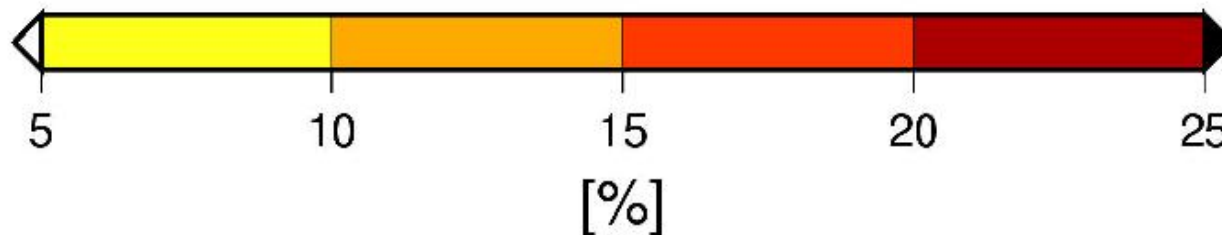


Frequency of contrail forming air masses

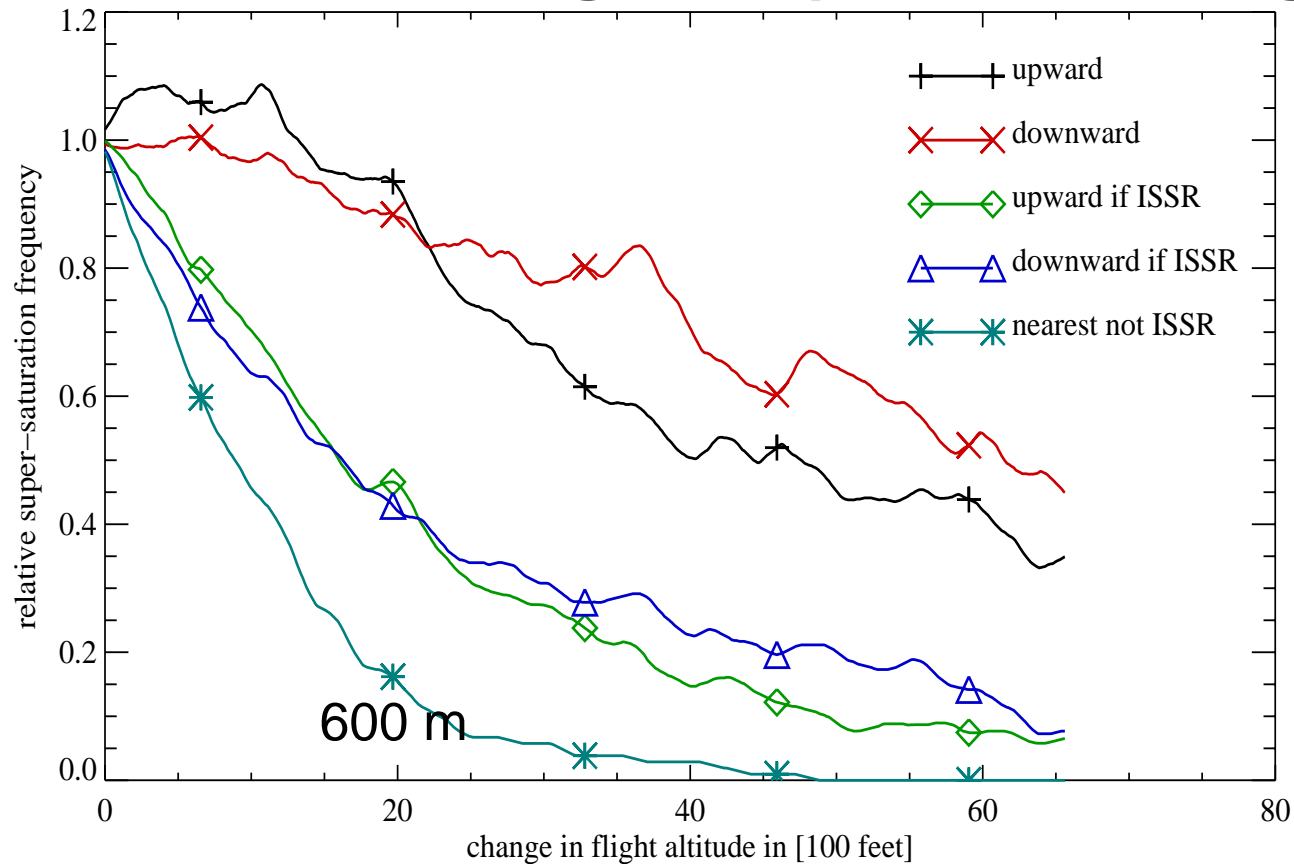
Flying higher?



Longitude



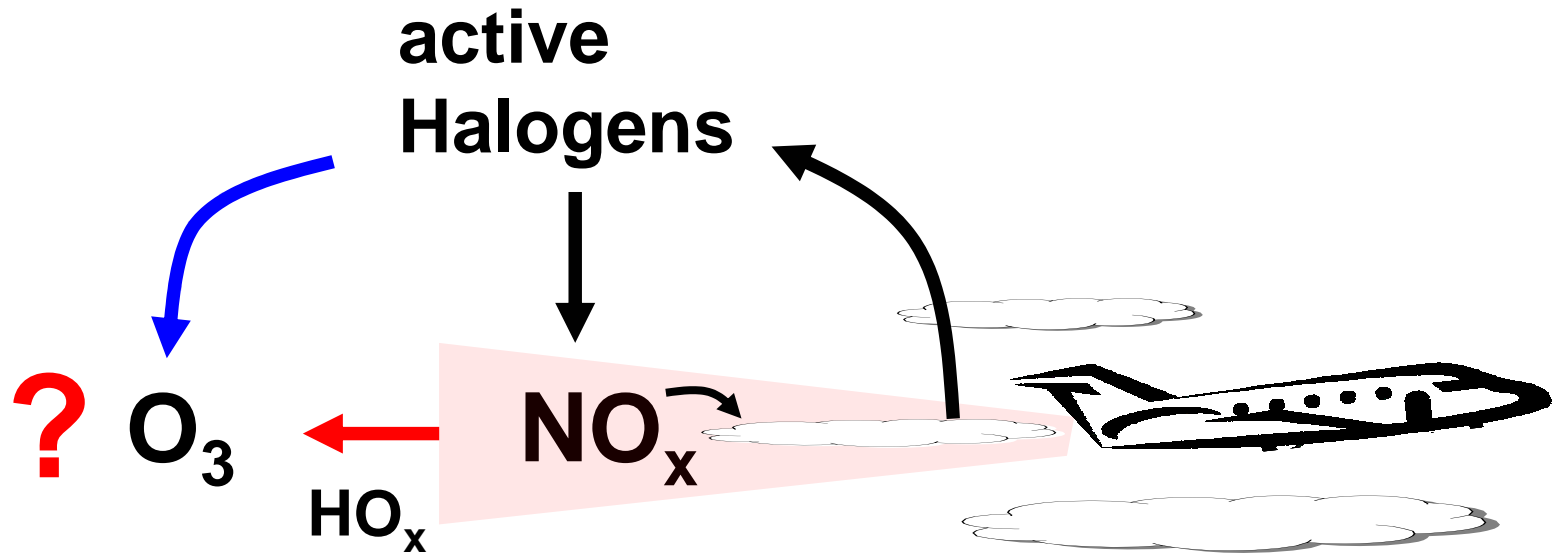
Avoiding contrails by small altitude changes avoiding ice supersaturated regions (ISSR)



Contrail cirrus can be avoided by flying outside ice-supersaturated regions, i.e., either a little lower or higher or around such regions

Mannstein, Spichtinger and Gierens,
Transp. Res., D 10, 421–426, 2005.

Ozone change due to flying higher?



Flying higher:

- longer residence times
- higher O_3 concentrations
- higher halogen loading
- NO_x emissions increase O_3
- and binds activated halogens
- contrail-cirrus activates halogens
- and binds NO_y



What should be done next?

- **Start a new major research project: "Fly higher?"**
- **Assess technology options for higher and lower flight altitudes**
- **Assess ATM options for flying lower, around, higher or earlier**
- **Assess ozone, cloudiness and climate impact of flying higher**

