Volcanic, Weather and Climate Effects on Air Transport

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Content:

- Volcanic ash hazard avoidance by improved ash detection methods, e.g. the Eyjafjallajökull eruption in Iceland, 2010
- Improved traffic guidance around weather hazards based on nowcasting
- Mitigation of climate effects by route optimization using new prediction tools

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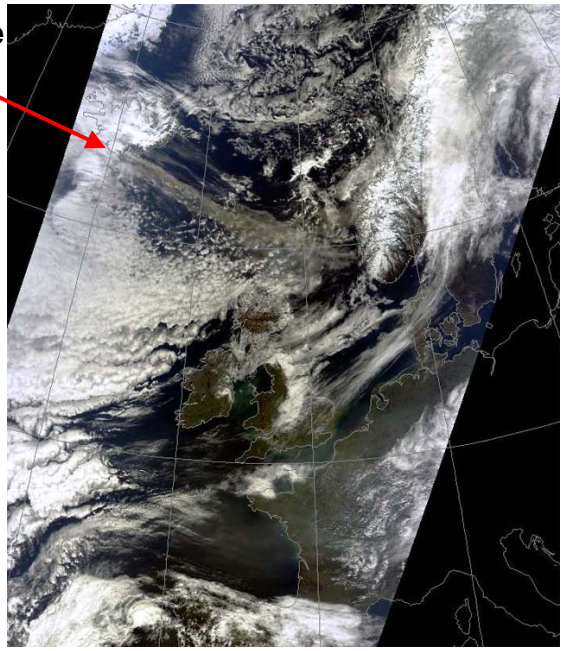
0100 UTC 14 April 2010: Eyjafjallajökull volcano eruption

No 3

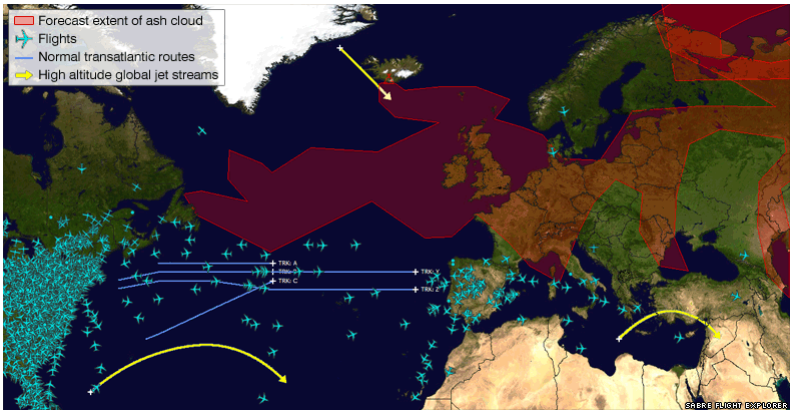
Noon 15 April: ash plume reaches Europe



MODIS on NASA Terra Satellite at 11.39 GMT Thursday April 15, 2010

No 4

16-21 April 2010: 75 % of mid-European airspace closed



-19 April 2010, 13:00 UTC

-http://www.radarvirtuel.com/

-April: 75 % of movements in 23 European countries suspended

-May: further 8000 flights cancelled

-About 4 $\times 10^9$ € economic loss

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The closure of the airspace in 2010 was the logical consequence of ICAO's "*zero-tolerance" rule*

Thomas J. Grindle (NASA Dryden Flight Research Center), Frank W. Burcham jr., AS&M/NC uit ICAO Journal, nr. 2 2002

Even minor volcanic ash encounters can cause major damage to aircraft

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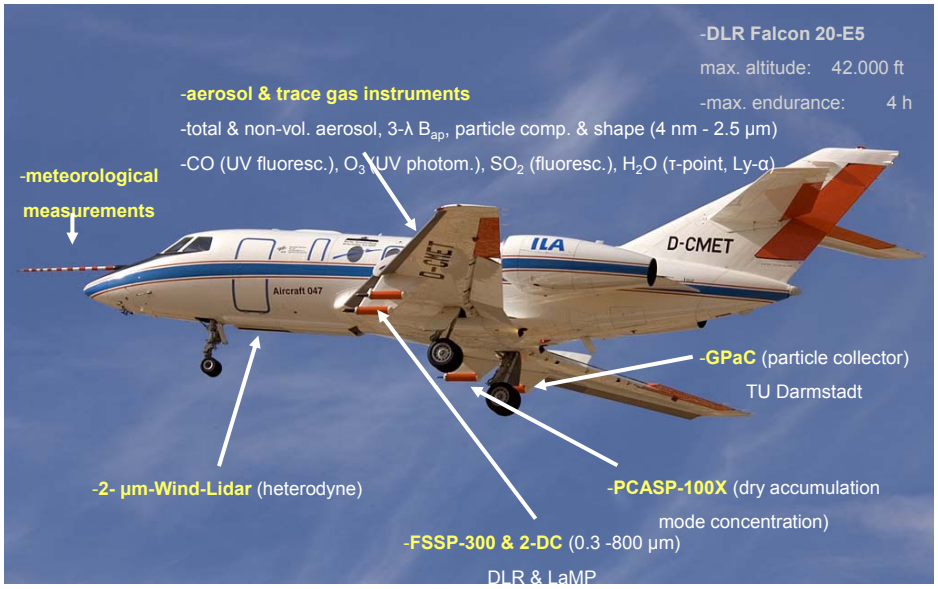
19 April–18 May: research flights with DLR „Falcon" aircraft



(Schumann et al., 2011)

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Ash layer (4-5 days old) just visible over Leipzig, 19 April 2010

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Eyjafjallajökull volcano plume, noon 1 May 2010

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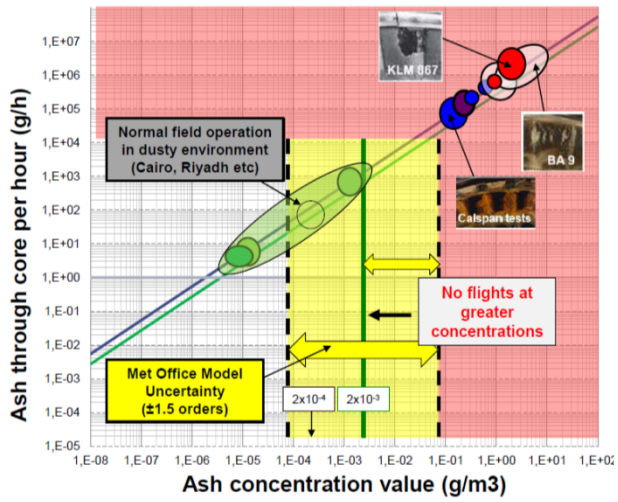
To avoid further massive disruption of air traffic:

The Safe to Fly – Chart: 17th May 2010



Ash mass concentration limit of 2 mg/m^3

Helpful for orientation and for formalizing decision processes, but not generally approved

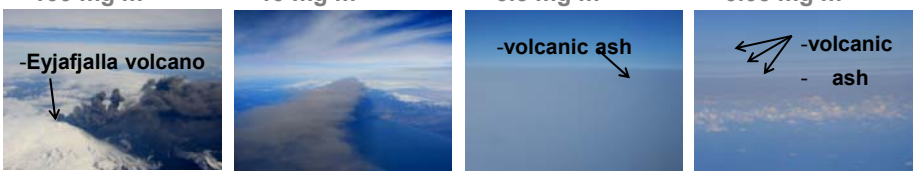
Ash mass concentration is difficult to predict and to measure in the atmosphere.

For ICAO's position see Andrew Tupper's talk.

Rolls-Royce proprietary data 15th & 16th September 2010

Current avoidance guidance:
“Visible volcanic ash” is to be avoided
- What is visible ash?

> 100 mg m^{-3}	> 10 mg m^{-3}	~ 0.5 mg m^{-3}	< 0.05 mg m^{-3}



-increasing distance from the volcano

-„ash cloud" -„ash layer" -„thin filaments"

(Weinzierl et al., 2012)

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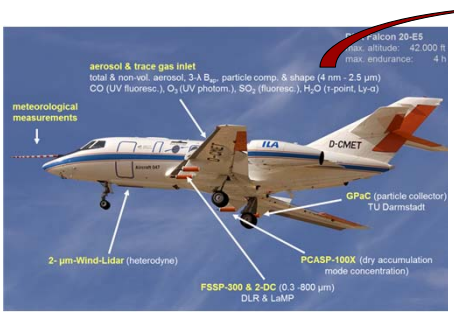
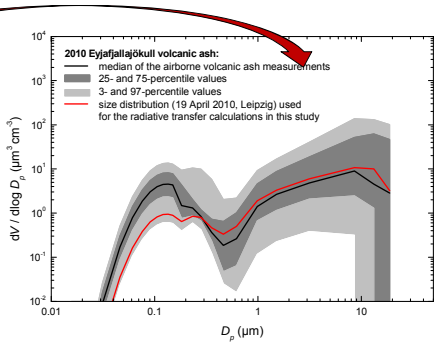
Visibility depends on particle properties, which we derived from our measurements





- Size spectrum
- Wavelength dependent aerosol refractive index
- Particle shapes
- Data from flights in Sahara Dust and tropical biomass burning plumes (SAMUM1/2, 2006,2008) and in the Eyjafjalla ash clouds

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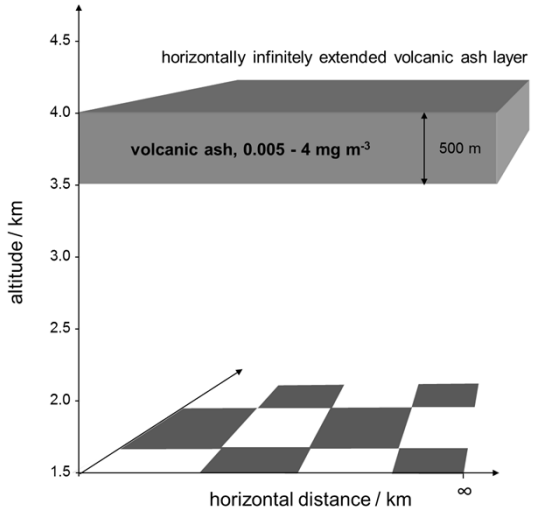
Visibility simulation with 3d radiation transfer code



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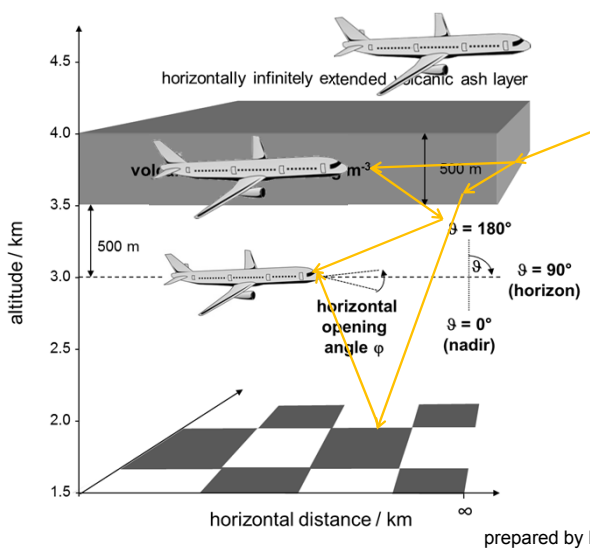
Visibility simulation with 3d radiation transfer code



$-sza = 75°$

Method: MYSTIC:

Monte Carlo code for the physically correct tracing of photons in cloudy atmospheres

Emde & Mayer (2007),

Buras & Mayer (2011) etc.

prepared by Daniel Sauer, see Weinzierl et al. (2012)

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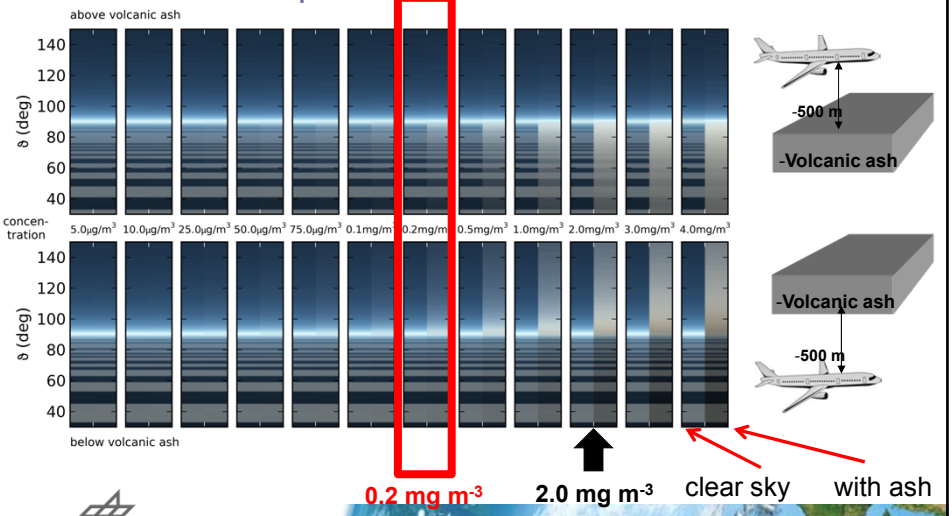
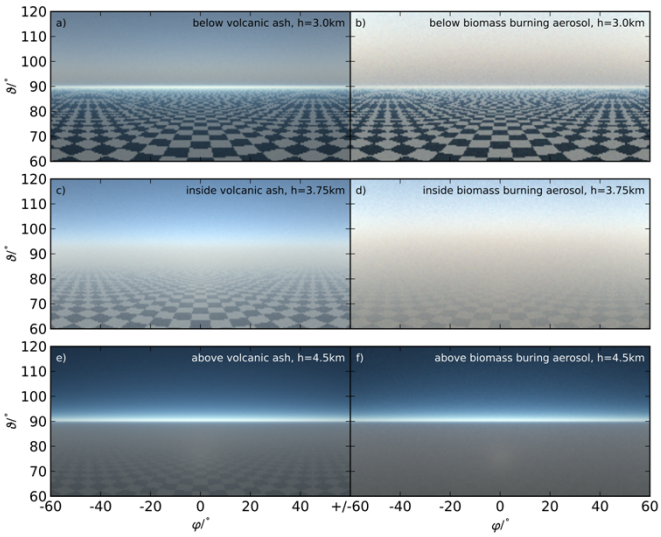
What is the lowest detectable concentration?

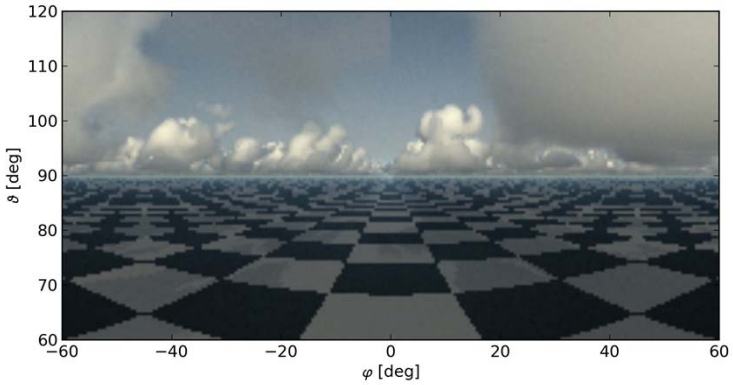
-View from the cockpit of an aircraft simulated with MYSTIC



Can one distinguish volcanic ash from desert dust or biomass burning aerosol? No!

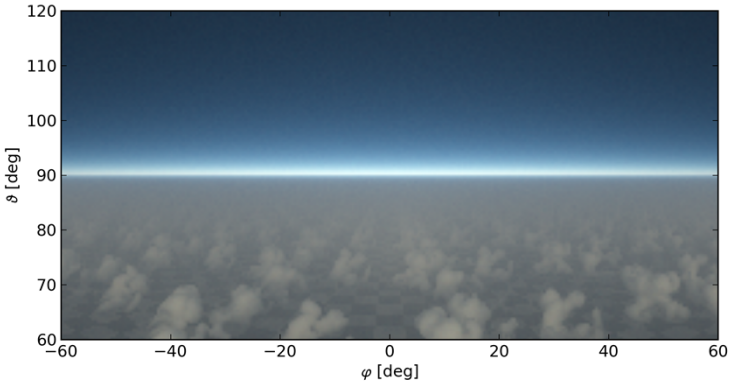


What if there are clouds?



Aircraft at 1 km altitude, below the ash and clouds,
ash hardly visible discernible

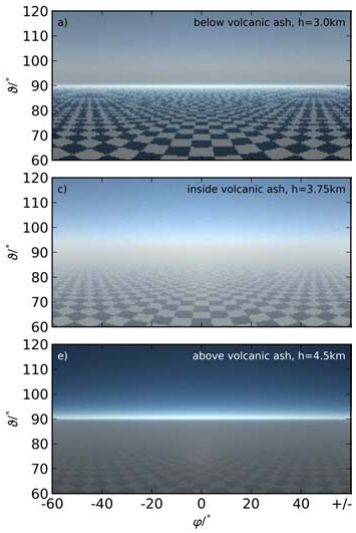
What if there are clouds?



Aircraft at 5.5 km altitude, above ash and clouds

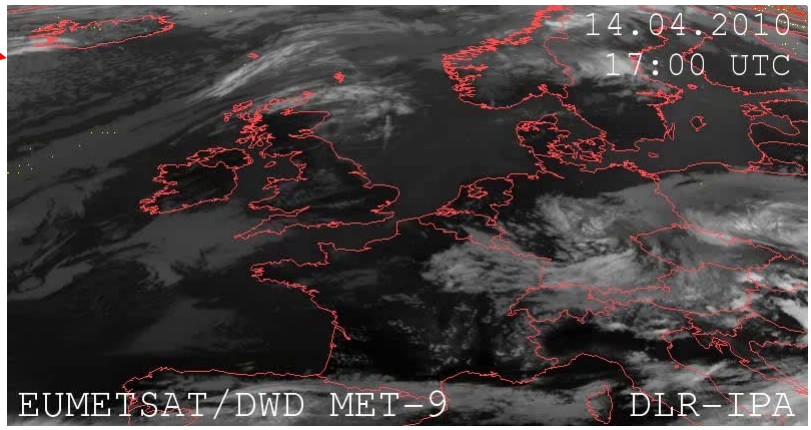
Visibility study results

- Ash layers visible for mass concentrations > 0.2-0.5 mg m^{-3} and > 500 m thickness
- Ash cannot be visually discriminated from desert dust or biomass aerosol
- Visual appearance does not allow to discriminate low from potentially dangerous mass concentrations
- Visibility is restricted to daylight and non-cloudy conditions
- Further methods required to detect visible or discernible ash



Visibility in Satellite Infrared data - METEOSAT SEVIRI

Example: initial Eyjafjallajökull period 14-17 April 2010

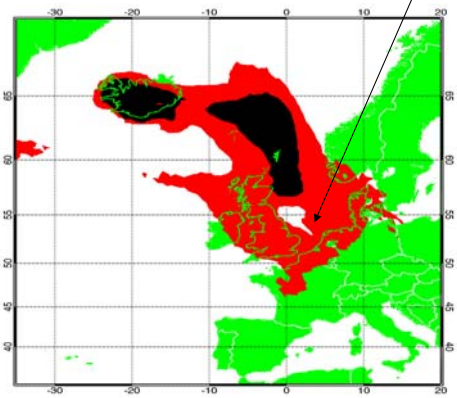


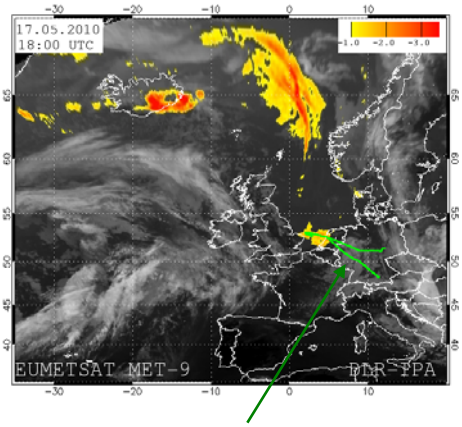
prepared by K. Graf, DLR, an improved EUMETSAT dust product, using brightness temperature difference of channels 12 µm, 10.8 µm, and 8 µm (following Prata and Grant, 2001; Prata 2008)

Validation test case Eyjafjallajökull of 17 May 2010

VAAC

Meteosat-VA Product of DLR





18 UTC 17 May 2010

Falcon flight path

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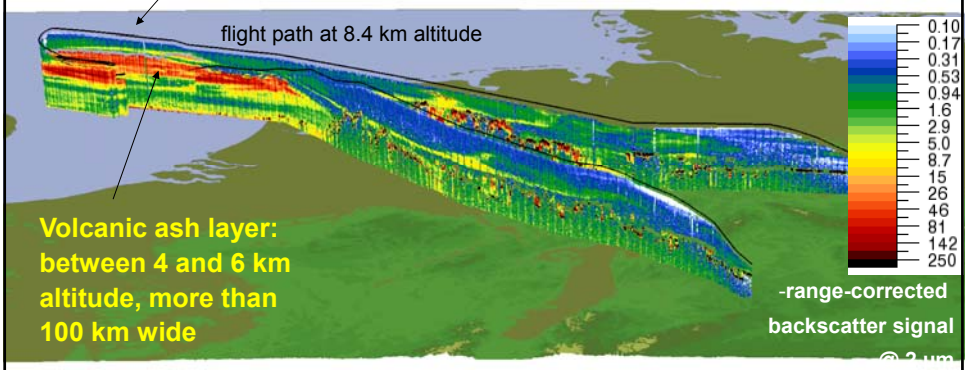
Falcon with 2-µm Lidar, detects ash layer over the North Sea



18 UTC 17 May 2010

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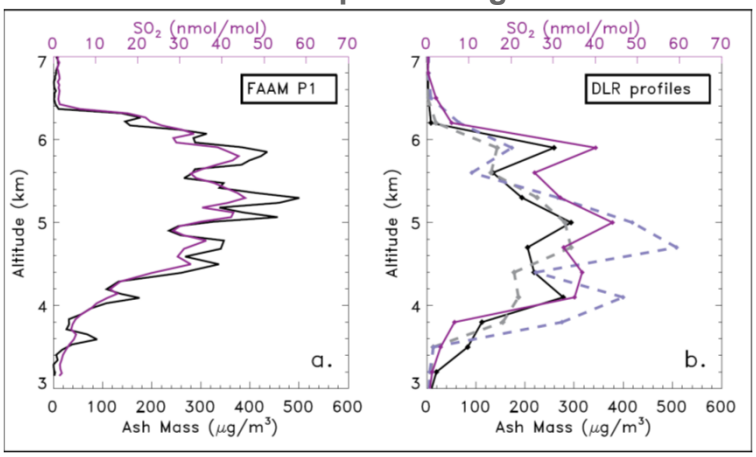
In-situ measurements (DLR Falcon and UK FAAM): ash mass concentration up to 0.5 mg/m³



18 UTC 17 May 2010

(Turnbull et al. JGR, 2012, Schumann et al., 2011)

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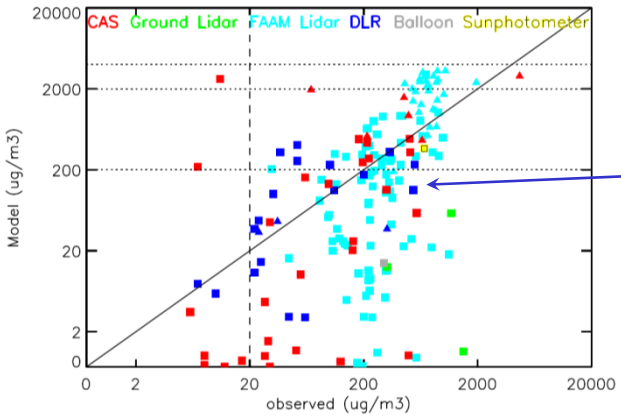
Difficult to predict because of strong sensitivity to meteorology (wind etc.) and eruption plume data details

Comparison VAAC-NAME-Model with observations



DLR Falcon

-> about factor 3-30 uncertainty

Webster et al. (JGR, 2012)

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Possibly repeating event.
Eruption of Grimsvötn, Iceland 21 May 2011

Source: dpa Picture-Alliance GmbH, Trickl et al., ACPD 2012

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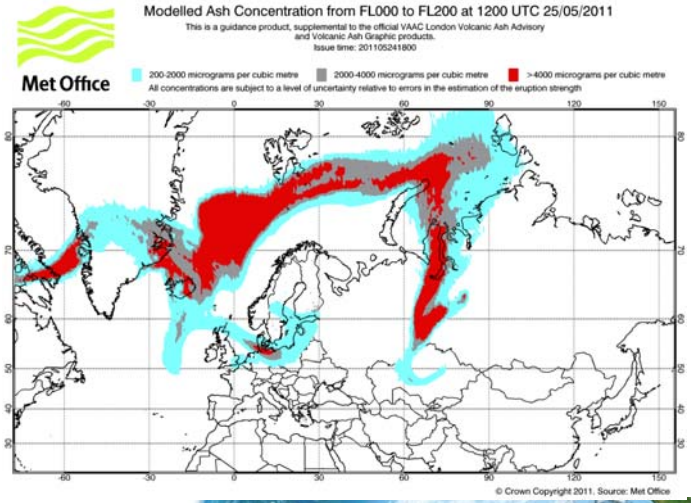
VAAC-NAME-model prediction of >4 mg/m³ (red zone)
(as of 18UTC 24 May for 12 UTC 25 May 2011)
-> Northern Germany airspace gets closed



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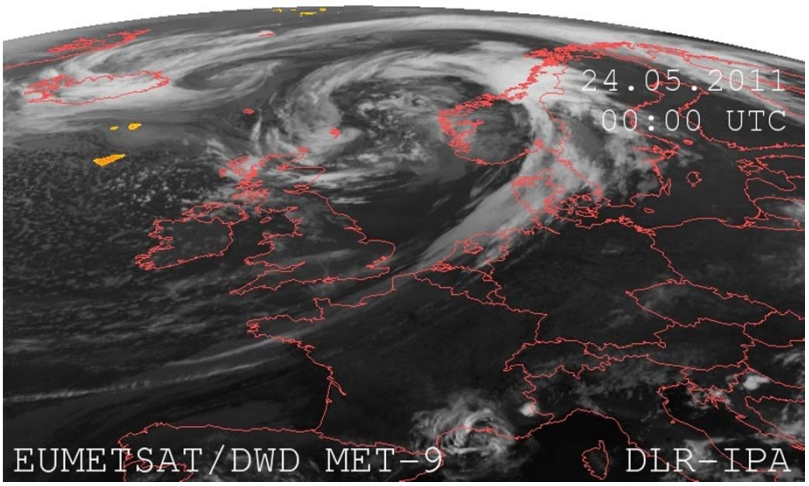
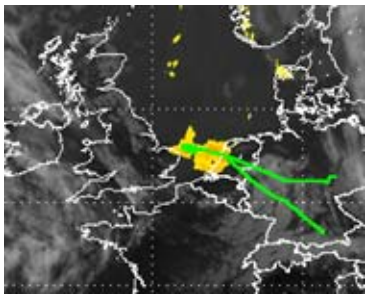
METEOSAT shows ash moving from Scotland to Norway on 24 May 2011. No indication for transport towards Germany



Future development

- Safe aviation requires reliable tools to predict and detect regions with ash loads exceeding certain thresholds.
- For efficient aviation, one also needs reliable tools to predict and identify regions free of dangerous ash loads.
- IR satellite data from geostationary satellites such as Meteosat (in the future also GOES R) provide observations which can be used – with further development - to identify the presence or the non-presence of ash clouds, their column density and altitude
- ATM procedures have to be developed that make optimal use of such data



Weather hazards (Thunderstorms, winter weather, aircraft iceing, volcano ash clouds, etc.,)

- Chaotic nature limits deterministic predictability from 10 min to a few h
- Nowcasting required (extrapolation of observed movements)
- Requires online data transfer from ground to cockpit
- Crucial for ATM efficiency and safety (see AF 447 case)

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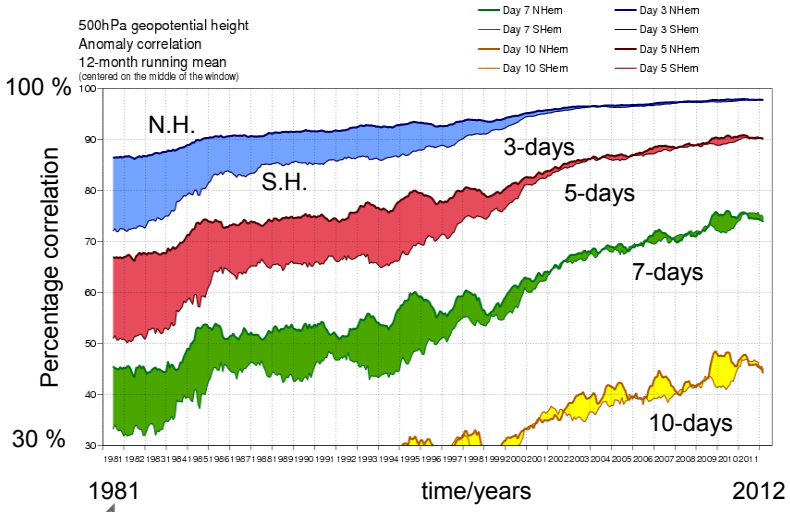
Remarkable progress in medium range weather prediction, e.g., at the European Center ECMWF: to be used for ATM



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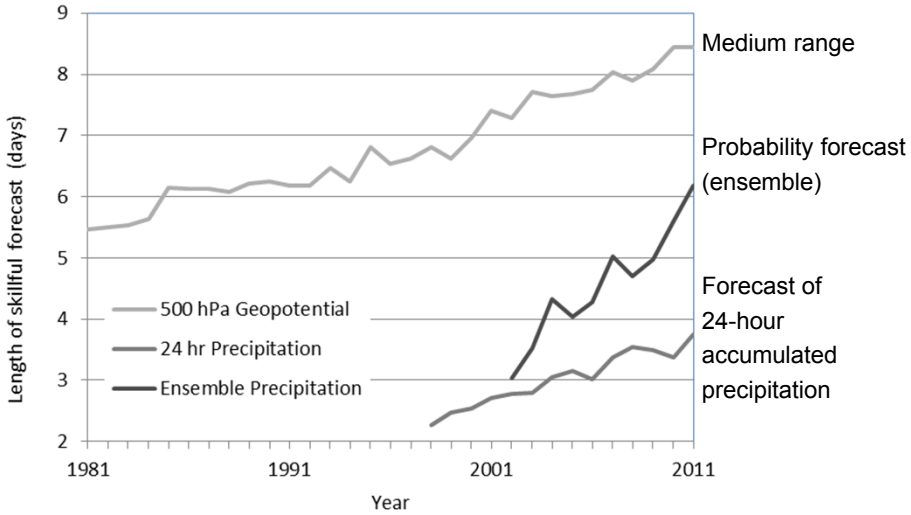
Small-scale and unstable weather processes are far more difficult to predict. -> nowcasting methods required



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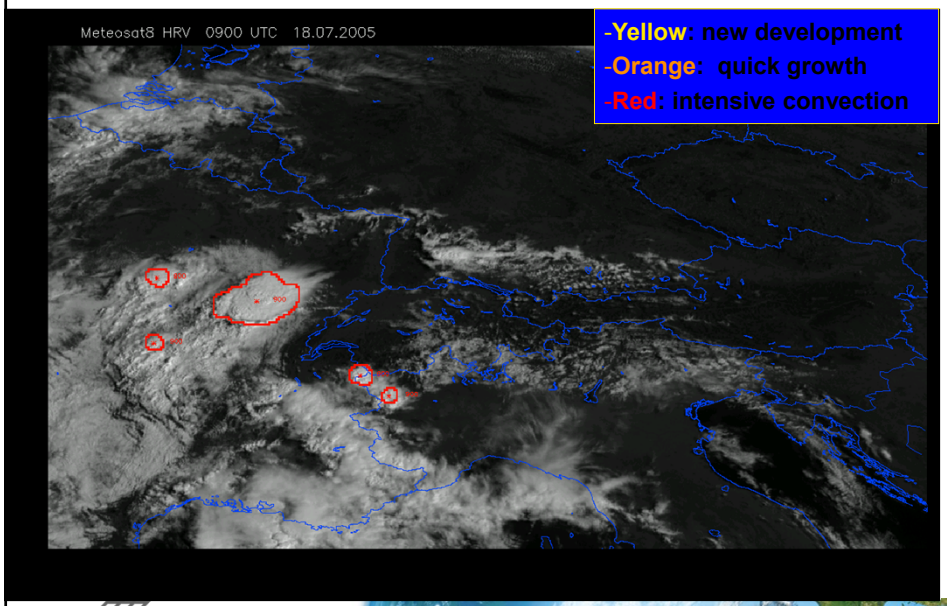
Weather hazards, e.g. thunderstorms, in METEOSAT



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Climate optimized air transport

- Aviation impacts climate by carbon dioxide emissions, nitrogen oxides, contrails and cloud changes
- Presently a relatively small effect (5 %, possibly 2-14 %)
- Importance grows with time, traffic, progress in other sectors, and approach of climate thresholds (2 K limit)
- Contrails have larger climate impact than CO_2 from past aviation
- Contrails offer mitigation options

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Contrails spread in humid air masses, they warm or cool

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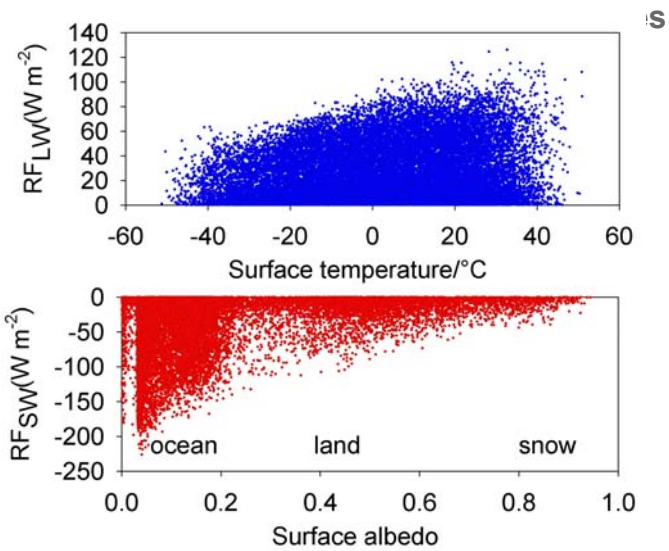
Contrails warm or cool depending on day time and underground



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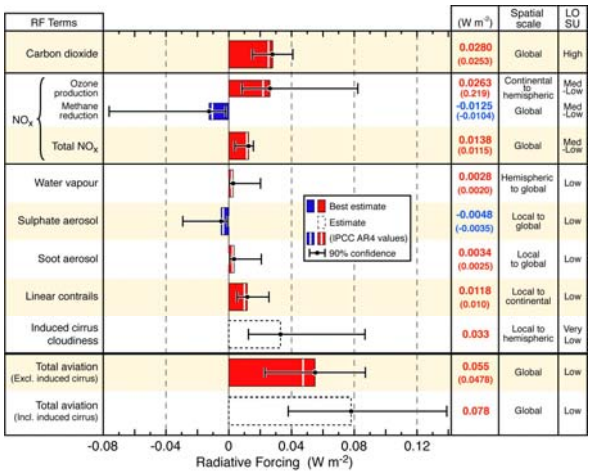
Radiative forcing by Aviation: state of the art (Lee et al., 2009)



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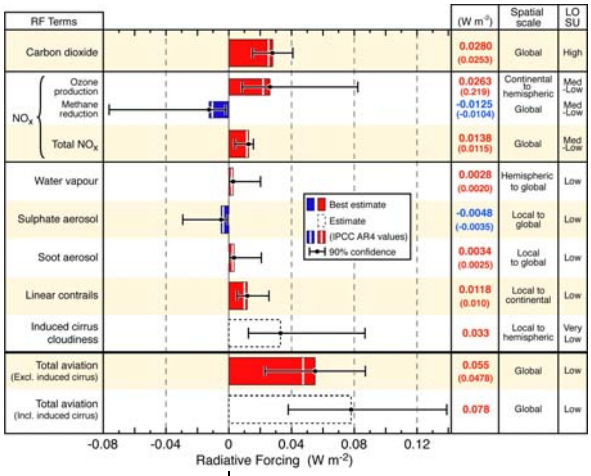
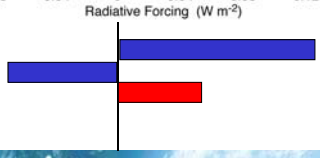
Radiative forcing by Aviation/Contrail Cirrus



(Burkhardt & Kärcher, 2011; Schumann & Graf, 2012)

Contrail cirrus global mean



Longwave
Shortwave
net effect

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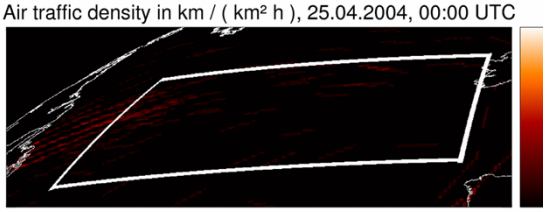
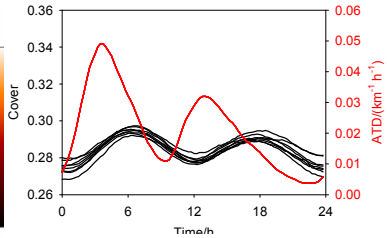
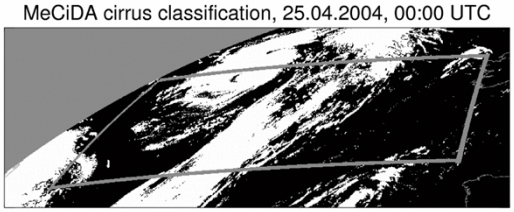
Contrail cirrus cover and RF from observations and models

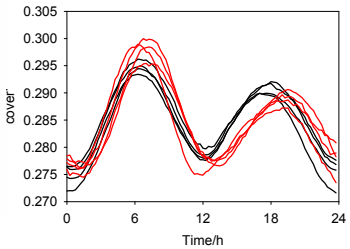
Air traffic density in km / (km² h), 25.04.2004, 00:00 UTC





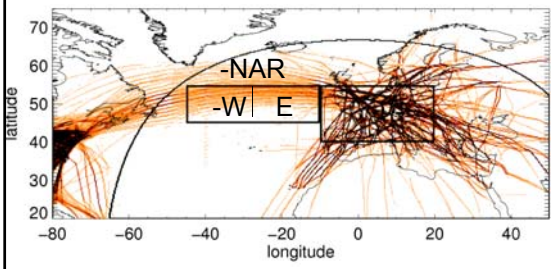
MeCiDA cirrus classification, 25.04.2004, 00:00 UTC

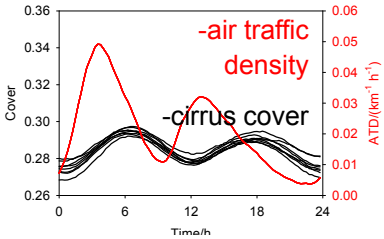


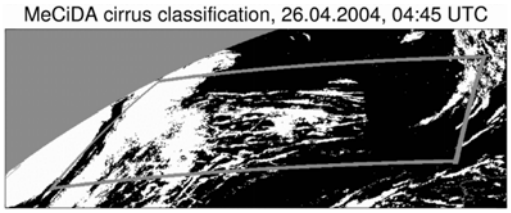


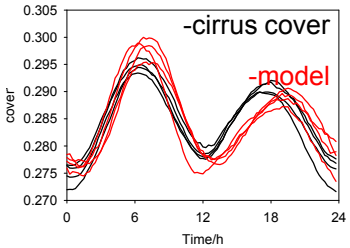
Graf, Schumann et al. (GRL; 2012); Schumann and Graf (JGR, 2012, submitted)

Contrail cirrus cover and RF from observations and models









Graf, Schumann et al. (GRL; 2012); Schumann and Graf (JGR, 2012, submitted)

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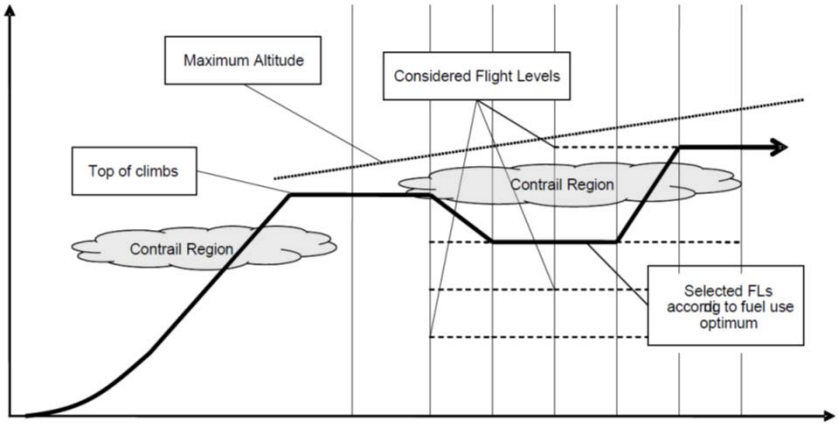
Route optimisation: avoid contrails



(Mannstein, Meilinger-Lufthansa, 2001)

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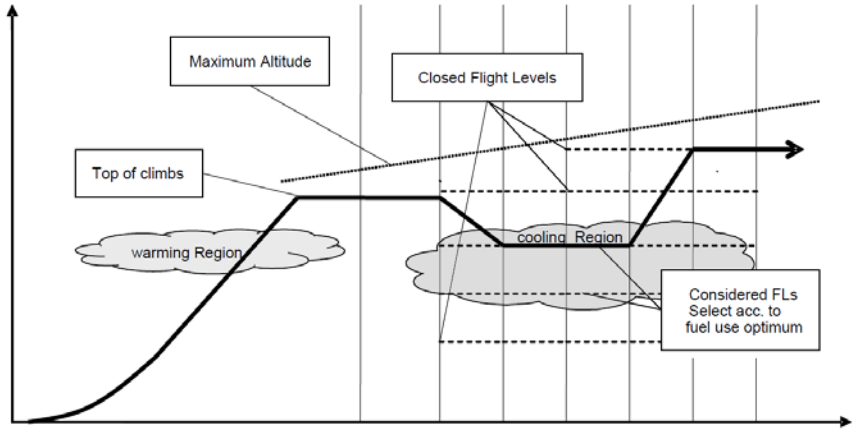
Better: avoid warming contrails but enforce cooling contrails



(Mannstein, Meilinger-Lufthansa, 2001)

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Contrail Cirrus Simulation and Prediction Model (CoCiP)

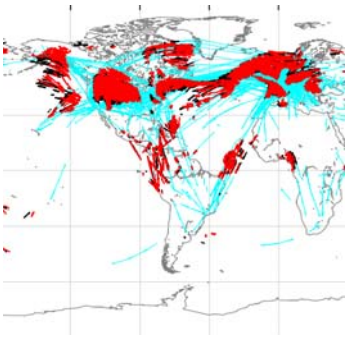
-Input:

-**Aircraft (BADA)**

-**Movements (FAA 2006)**

-**Meteorology (ECMWF)**

-**Contrail Cirrus Prediction Tool**



- From regional to global
- Comparable to observations

-Output:

-**Contrail,**

-**life cycle,**

-**cover, radiation**

-**Cirrus**

-**Simulation (insitu, Lidar, MSG, Modis)**

-**Sensitivity studies**

-**Prediction & Mitigation**

(Schumann, 2012)

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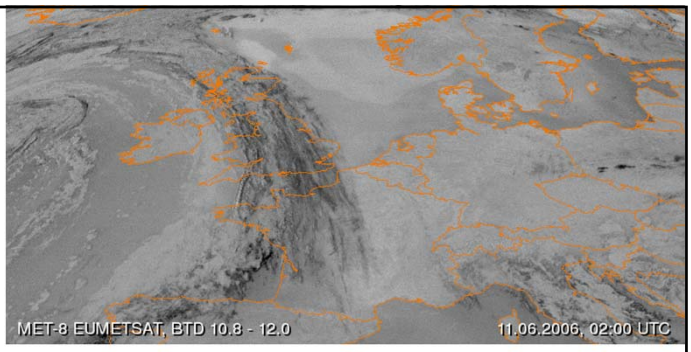
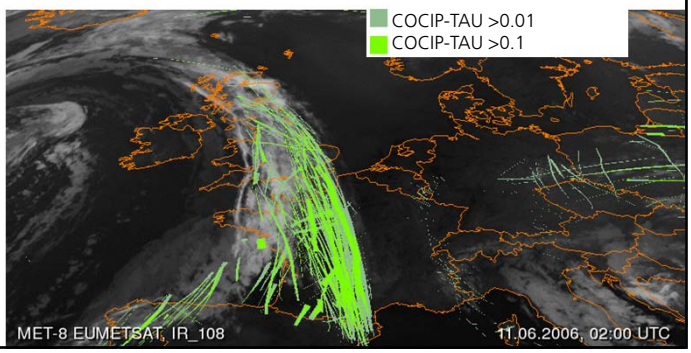
Contrails are predictable

-Top: cirrus (black) observations

-Bottom prediction over IR BT observations

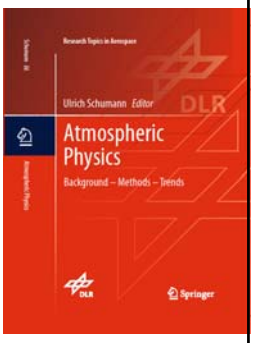
-Input used:
-3-days weather forecast data (ECMWF)
-and (historic) air traffic data (FAA ACCRI)





Conclusions

- Volcanic, weather and climate effects have common: impact on aviation
- Safety, efficiency and climate sustainability have in common that they require an efficient air transport system
- In particular they require an intelligent air traffic management (ATM) in close connection with weather/hazard/climate predicition to minimize the impact of disruptive events and find cost and climate optimal routing



- New results on ash visibility and contrail predictability
- Satellite methods required for identification of not only critical regions but also regions that are free of hazards

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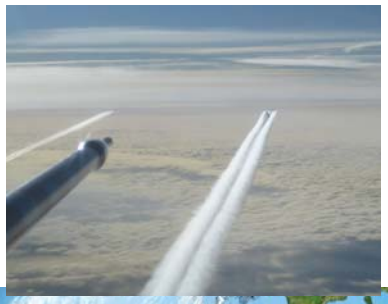
- I thank the ICAS committee for invitation



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