Volcanic Ash Cloud Observations during Air Space Closure in Europe in April/May 2010

Ulrich Schumann

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in cooperation with Ludwig-Maximilians University Munich

100 JAHRE Luft- und Raumfahrtforschung in Deutschland

For details see

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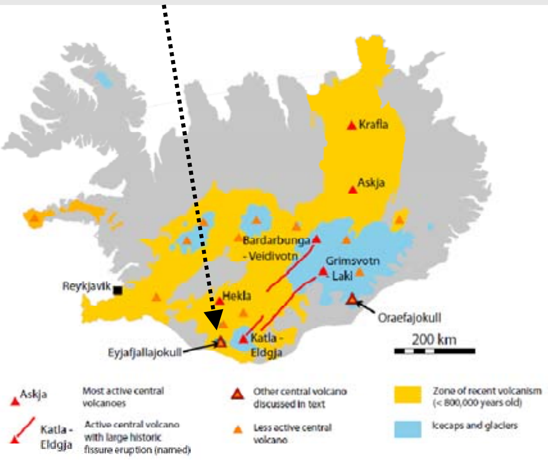
J.-F. Gayet, LaMP/CNRS, Clermont-Fd, France
K. Lieke, K. Kandler, M. Ebert, S. Weinbruch, TU Darmstadt
An Stohl, NILU Norway
J. Gasteiger, LMU Munich
H. Olafsson, Icelandic Met. Office, Reykjavik
and K. Sturm, Deutscher Wetterdienst, Offenbach, Germany

Airborne observations of the Eyjafjalla volcano ash cloud over Europe during air space closure in April and May 2010

Atmos. Chem. Phys. Disc. (2010, in press).

The Icelandic Volcanoes - Eyjafjallajökull

Historic volcanic record:
205 eruptive events, average of 20–25 eruptions / century.



The Eastern Volcanic Zone: 80% of historic eruptions.

Six most active volcanic systems in Iceland: Krafla, Askja, Bárdarbunga –Veidivötn, Grímsvötn, Hekla, and Katla.

(Thordarson & Larsen, 2007; Gudmundsson et al., 2008; Corrado Cimarelli)

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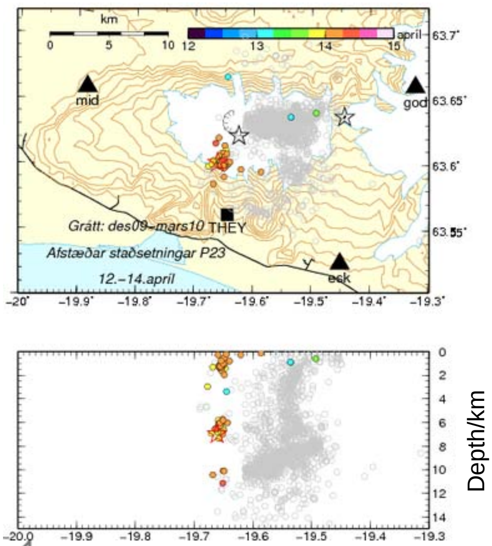
The Eyjafjallajökull eruption:

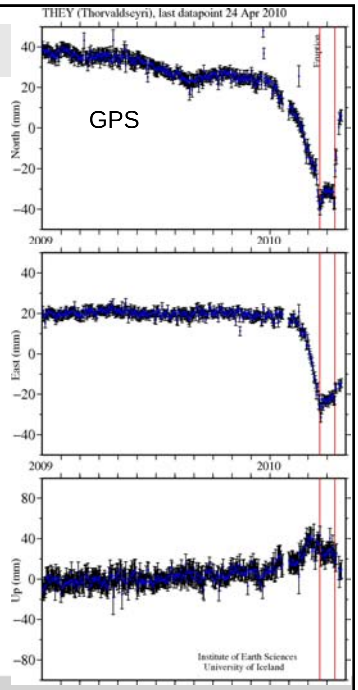
- April 2009: first seismic activities
- February - March 2010: large number of earth quakes
- 20 March 2010: first, short-term eruption, 4 – 7 km altitude
- 14 – 18 April: volcanic ash clouds reach up to 8 km height, flooding, ash layers

The Eyjafjallajökull eruption, first March 20, 2010

Precursors – April 12-15, 2010

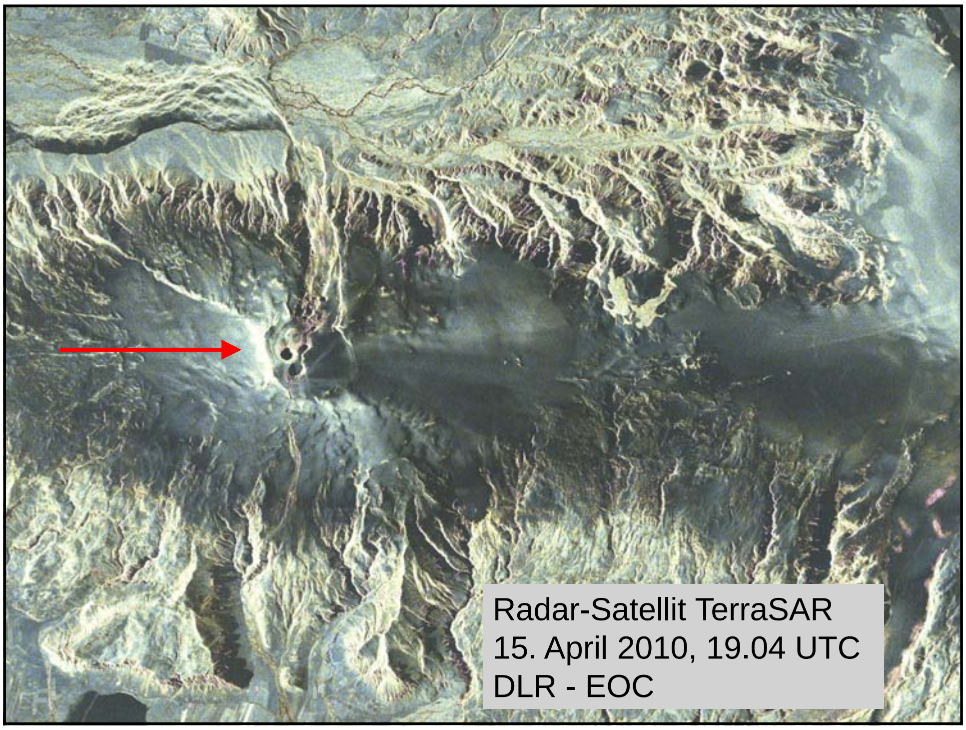
Seismicity





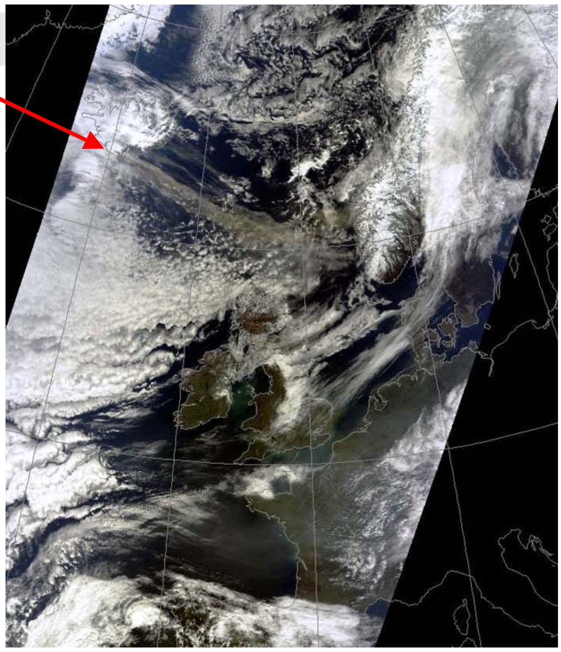
(IMO-IES, 2010)

14 April, starting 1 UTC: New Eruption



15 April: ash cloud

reaching Europe

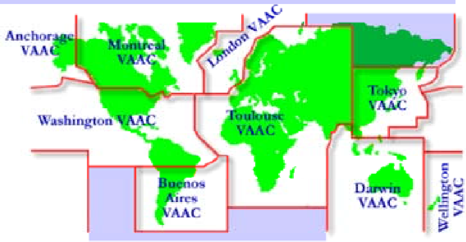


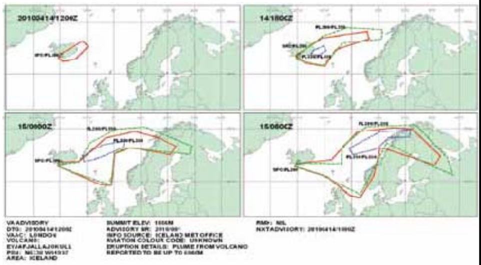
MODIS on NASA Terra
Satellite at 11.39 GMT
Thursday April 15, 2010

Volcanic Ash Advisory Centre (VAAC) at UK Met.Office

Met Office

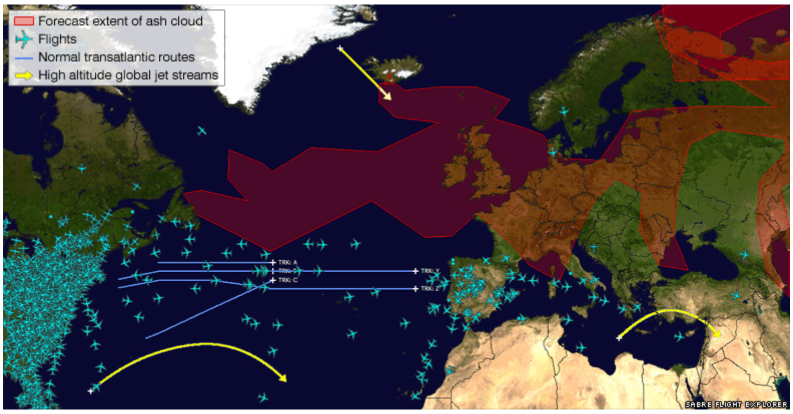
- London VAAC is the ICAO IAVWS designated centre for **volcanic eruptions** in the North-East Atlantic
- **Iceland** falls within this area of responsibility
- **ICAO Annex 3** *briefly* describes the responsibilities of a VAAC to include:
- Production of **advisories** detailing the spatial dispersion of VA
- **Running** (and/or **utilisation of** output from) NWP dispersion models
- **Monitoring** of observational data, especially satellite imagery for the presence of VA.





First VAAC advisory, 12 UTC April 14 2010

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



19 April 2010, 13:00 UTC

http://www.radarvirtuel.com/

taken from BBC: Iceland volcano in maps

April: 75 % of movements in 23 European countries suspended

May: 8000 flights cancelled

About 4 $\times 10^9$ € economic loss


Air-Berlin-Chef Joachim Hunold

Is Air Space Closure Justified?

VULKAN-ASCHE

Ist das Flugverbot berechtigt oder ein Skandal?

Flugverbot überEuropa: Berechtigt oder Skandal? – Air Berlin Chef Hunold erhebt Vorwürfe - News - Bild.de

Lufthansa: Es gab keine vulkanische Aschewolke

There was no volcanic ash cloud!?

Triebwerke von zehn Maschinen aschefrei

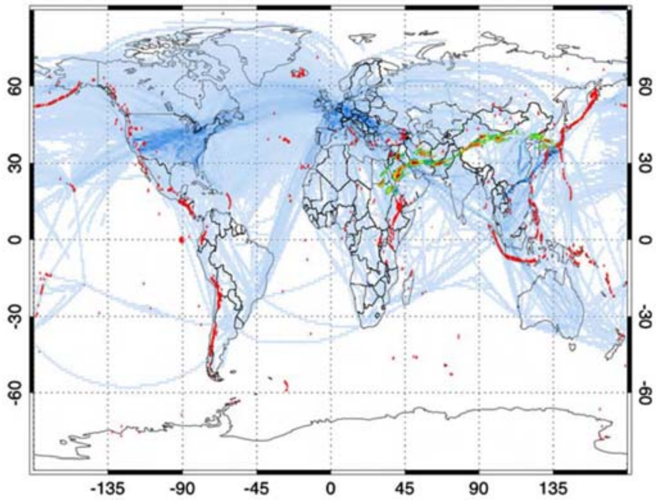
http://flugzeuge-flugzeugtechnik.suite101.de/article.cfm/es-gab-keine-vulkanische-aschewolke

ICAO: No flights in volcanic ash

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

Not the first case of volcano impact on aviation



Global air traffic and Volcanoes
A. J. Prata, Nat. Hazards (2008)

Red triangles: positions of Holocene and Historically listed volcanoes

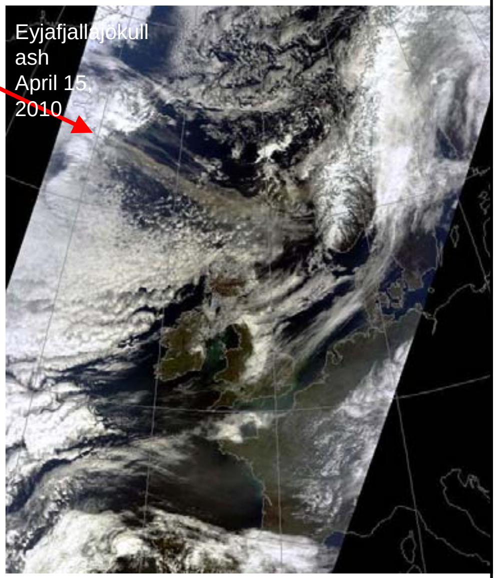
over 1,200 volcanoes

about 60 eruptions per year

More than 120 aircraft ash incidences

Some with total engine blowout (Redoubt 1989, Galunggung 1982)

Volcanic ash is similar to desert dust in many respect

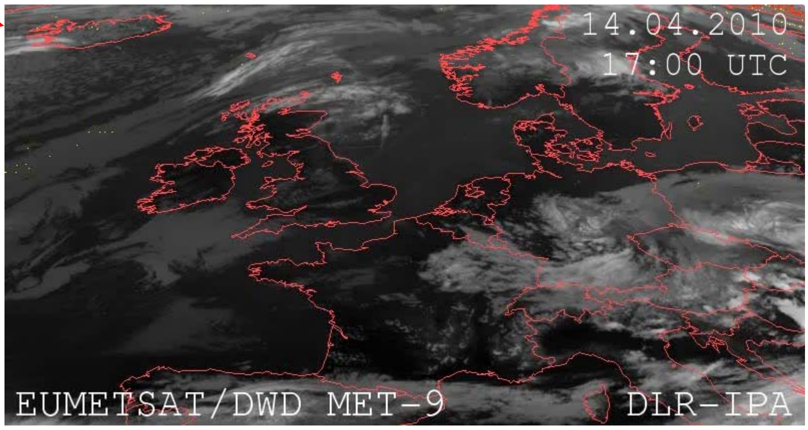


MODIS on NASA Terra Satellite,
11.39 GMT Thursday April 15, 2010

Quelle: NASA Earth Observatory

Volcano ash and SO_2 in geostationary satellite products

e.g. 14-17 April 2010



Extension of EUMETSAT dust product, using brightness temperature difference of channels 12 µm and 10.8 µm (Prata and Grant, 2001; Prata 2008)

processing and animation by K. Graf, DLR-IPA

Volcano ash and SO_2 in geostationary satellite products

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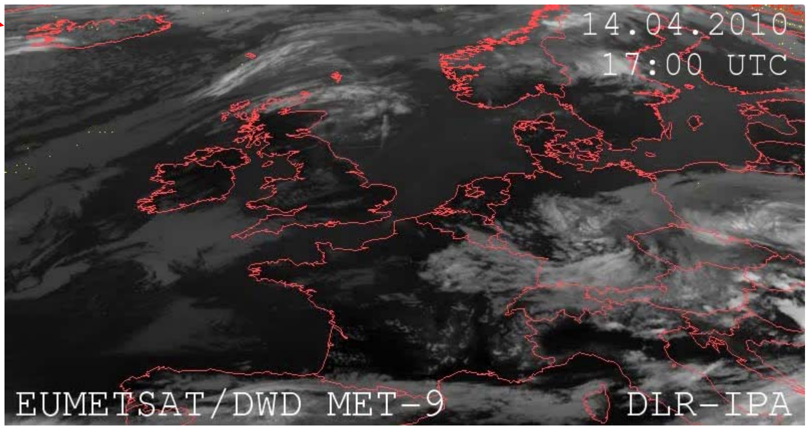

Extension of EUMETSAT dust product, using brightness temperature difference of channels 12 µm and 10.8 µm (Prata and Grant, 2001; Prata 2008)

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Volcano ash and SO_2 in geostationary satellite products

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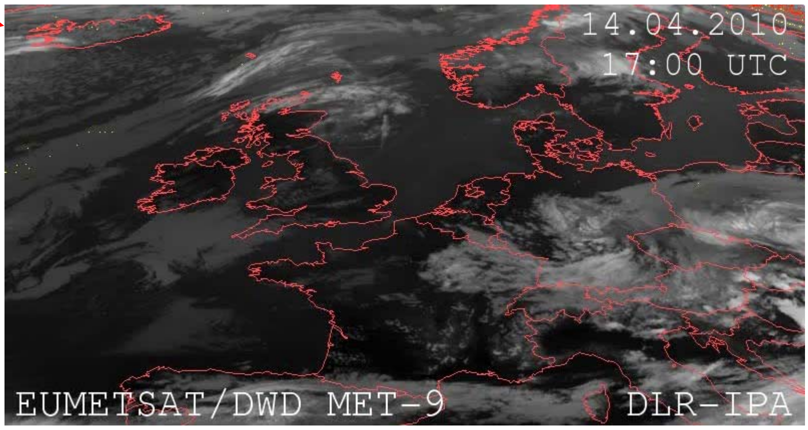

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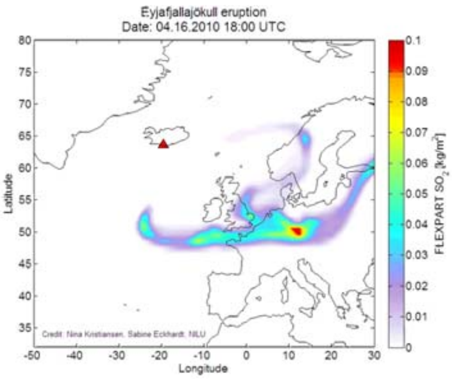
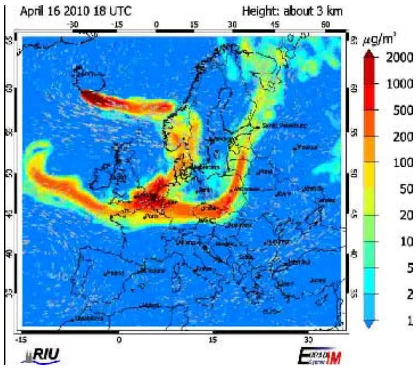
Public Model predictions: Friday, April 16, 18 UTC



Flexpart (SO_2 column)



EURAD (PM at 3 km)

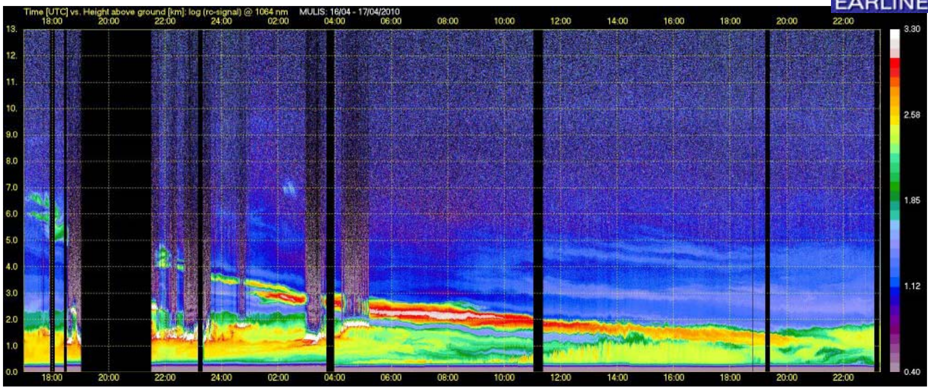
First academic model predictions available to public in internet:
April 15, 2010, 13:32 UTC (NILU, Flexpart)

European Lidar Network: EARLINET

EARLINET

Research Lidars, e.g. Univ. of Munich

EARLINET



17 0 6 12 18 24

plume age: ~28 h

-------------------------Saturday, April 17----------------------------

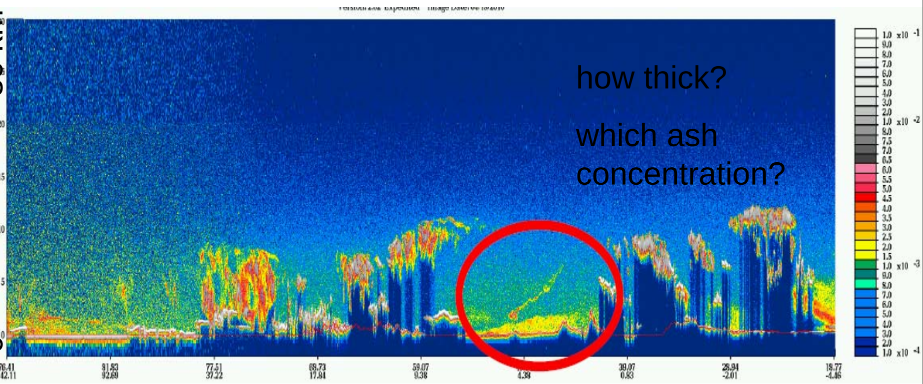
M. Wiegner, V. Freudenthaler, S. Groß et al.

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

FAKULTÄT FÜR PHYSIK METEOROLOGIE

MIM

CALIPSO Lidar, April 18, 2010

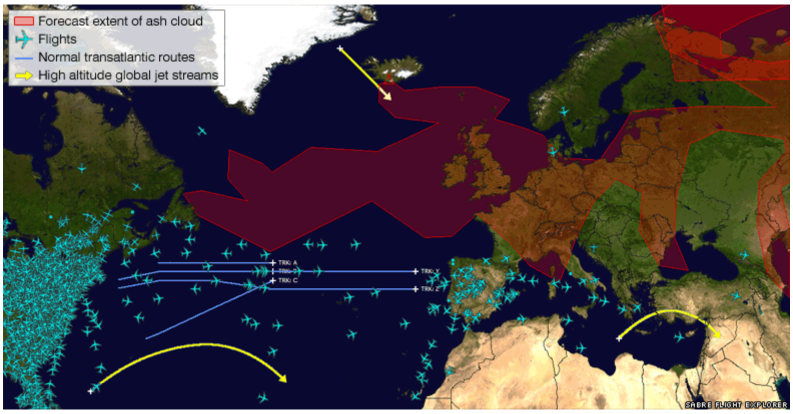


60 50 40 N

near 5 E

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation - CALIPSO:
a joint U.S. (NASA) and French (Centre National d'Etudes Spatiales/CNES) satellite mission

19 April, 13:00 UTC - Mid-European airspace closed

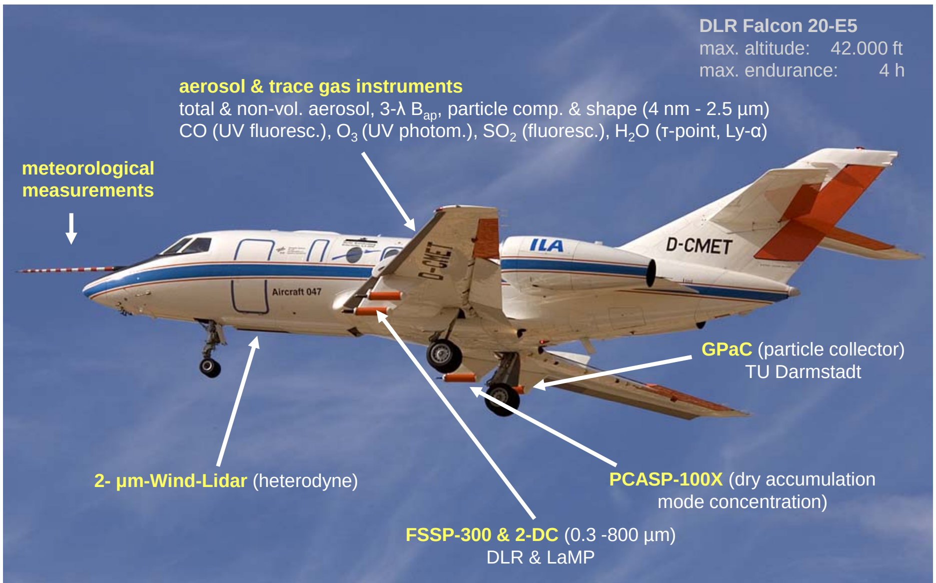


DLR-research aircraft
Falcon started at 14:10 UTC

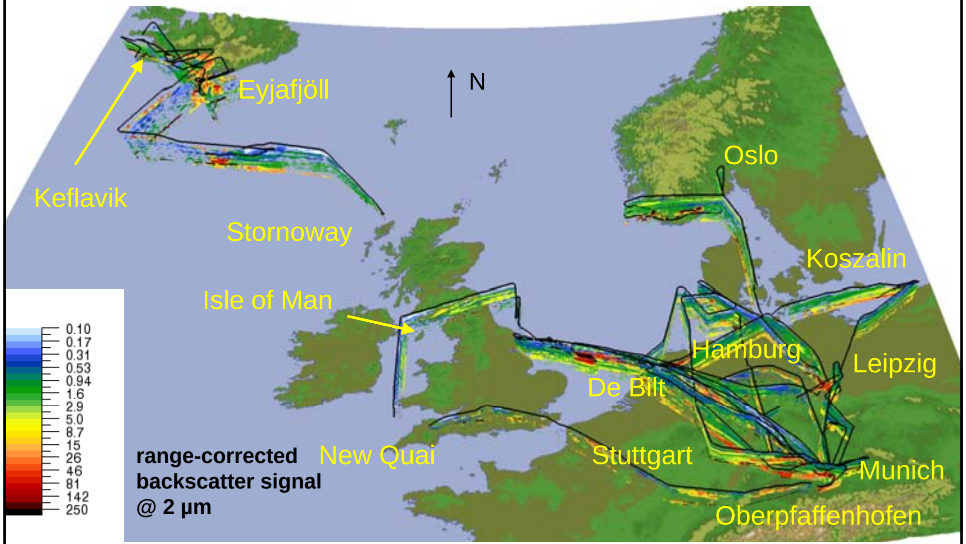
http://www.radarvirtuel.com/

taken from BBC: Iceland volcano in maps

DLR-Falcon instrumented research aircraft



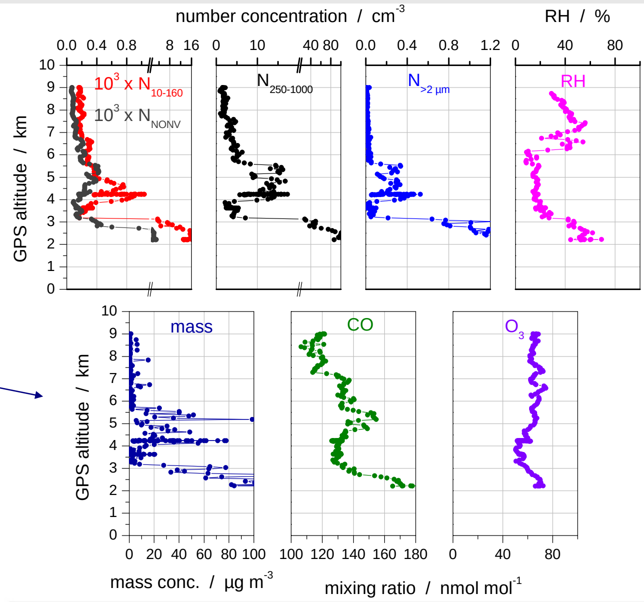
17 DLR Falcon flights, April 19 - May 18, 2010: OP - Iceland



OP –Keflavik: 2700 km

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

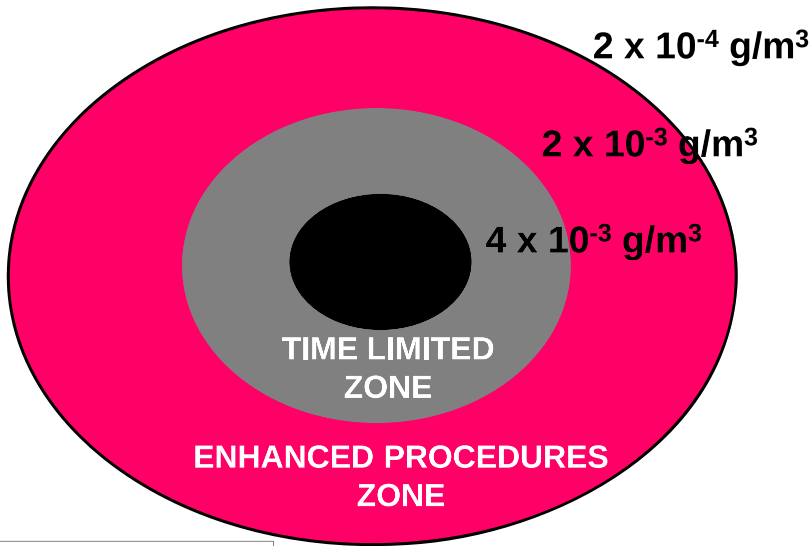
April 19: 4-5 days old ash layers with < 0.2 mg/m³ ash



ash concentration < 0.2 mg/m³, similar to desert dust

agreeing with gound-based Lidar

Since April 21, May 20: The “Three Zone” Approach



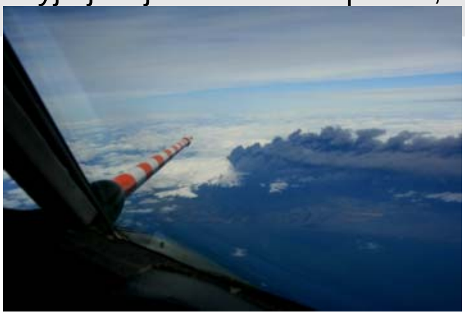
NORMAL OPERATIONS

(P. Kellegher, UK-CAA)

Eyjafjallajökull volcano plume, noon 1 May 2010

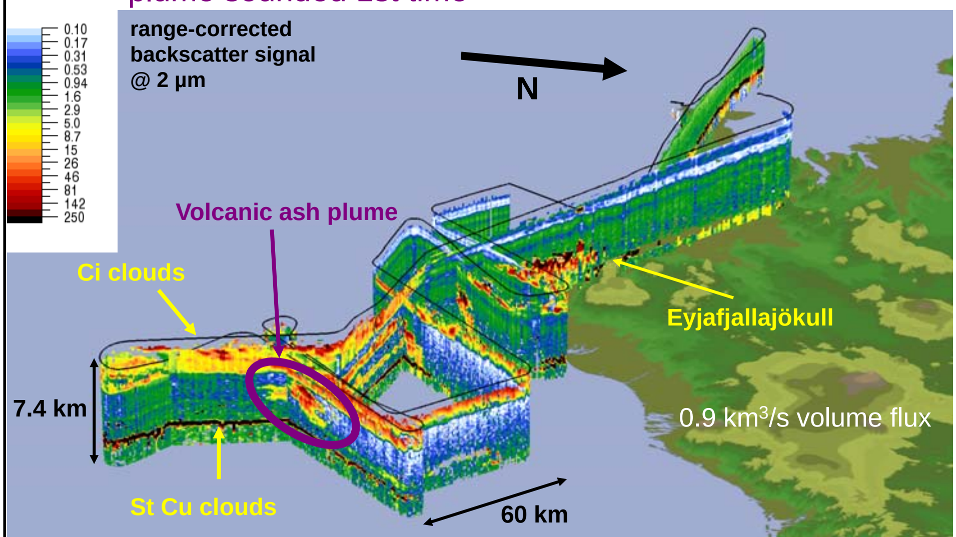
Eyjafjallajökull volcano plume, noon 1 May 2010

Eyjafjallajökull volcano plume, May 1, noon time



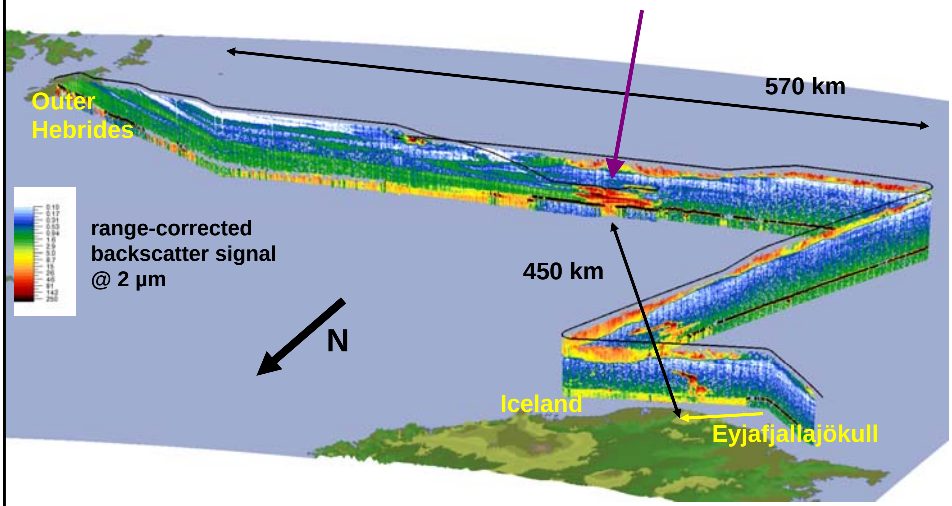

Plume and Keflavik (Iceland) soundings, May 1

plume sounded 1st time

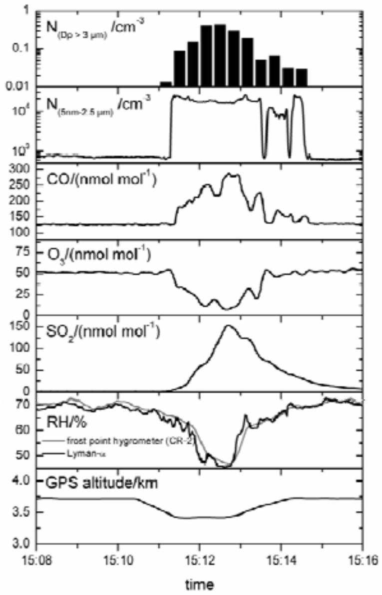


2 May 2010, North Atlantic near 60°N, 400 km from the source

May 2: measurements in top of ash plume at 60°N



May 2: 3 min measurements in top of ash plume at 60°N



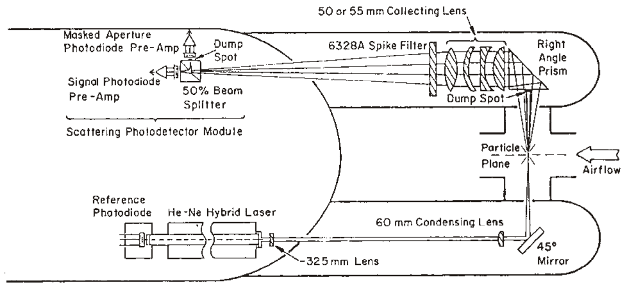
maximum ash mass concentration: 0.55 - 2.6 mg/m³

ash mass flux: 1800 kg/s

SO_2 is a strong plume indicator

Forward Scattering Spectrometer Probe

Counting and sizing of particles for diameters 0.3-20 µm



Light scattering at small and large particles

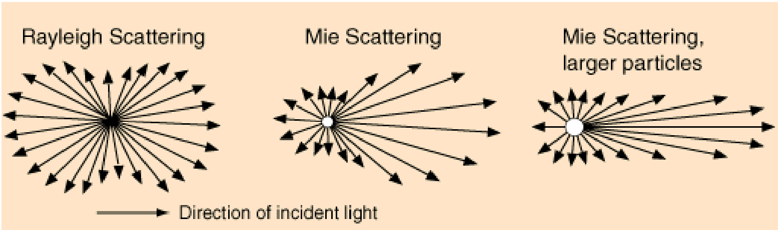
$\alpha = \frac{\pi D_p}{\lambda}$ ratio of particle size to wavelength of light

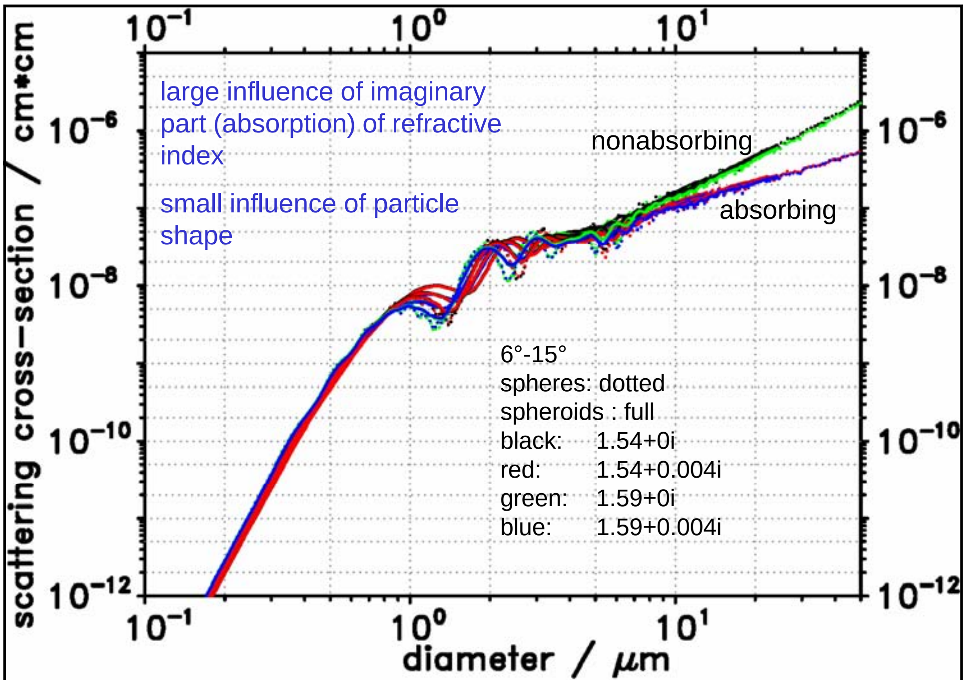
$\alpha \ll 1$ Rayleigh scattering regime

$\alpha \cong 1$ Mie scattering regime

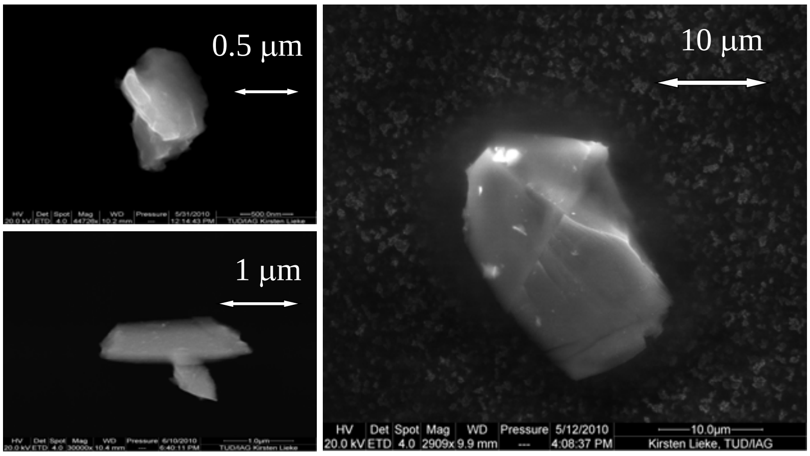
$\alpha \gg 1$ Geometrical optics regime

Scattering and absorption depends on particle size, particle shape and optical refractive index (real and imaginary parts)

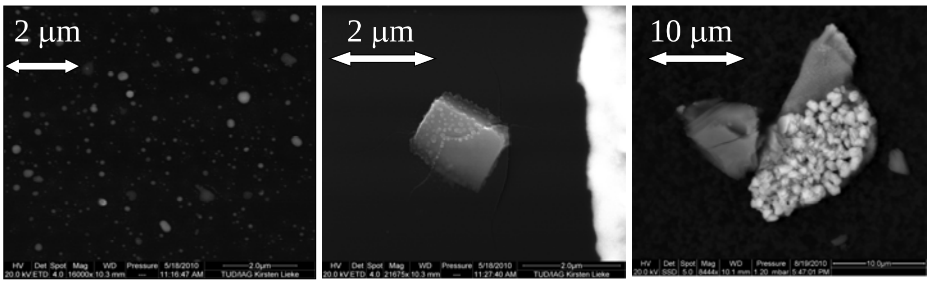




Particles collected inside the ash plume at 60°N, May 2

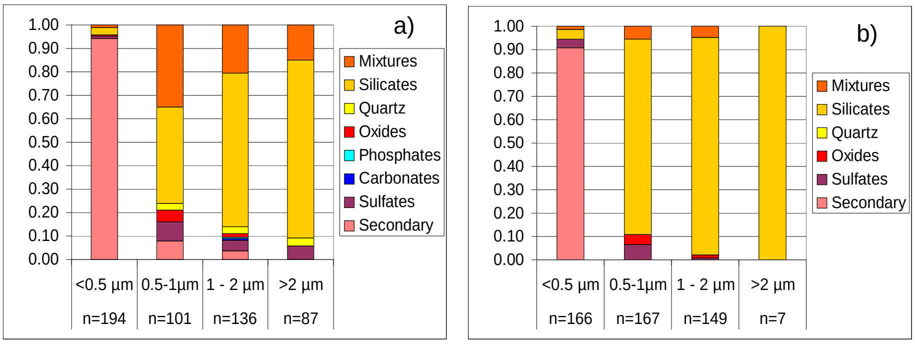


May 2, also found: ammonium sulfate, aggregates



Particle composition for a) 2 May and b) 17 May

size and age dependent!



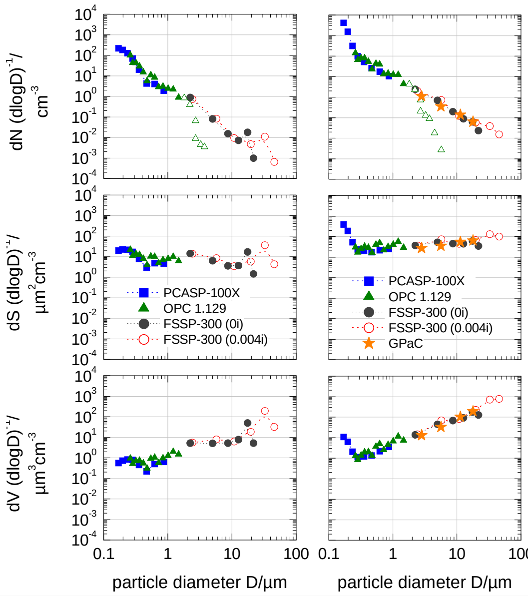
Particle properties derived from ESM analysis

Table 4. Number of investigated particles, measured two-dimensional aspect ratio and calculated density and complex refractive index values *m* for different particle size classes.

	2 May 2010				17 May 2010			
Size/µm	<0.5	0.5 - 1	1 - 2	>2	<0.5	0.5 - 1	1 - 2	>2
Number	194	101	136	87	165	166	149	7
Aspect ratio	1.9	2.2	2	2.1	1.8	2.1	2.1	2.
density	1.8	2.6	2.7	2.7	1.7	2.8	2.7	2.7
m (630 nm)	1.53 + 0.001i	1.60 + 0.004i	1.58 + 0.002i	1.56 + 0.001i	1.55 + 0.001i	1.59 + 0.003i	1.57 + 0.001i	–
m (2 µm)	1.50 + 2×10^{-6} i	1.56 + 40×10^{-6} i	1.55 + 20×10^{-6} i	1.54 + 10×10^{-6} i	1.53 + 7×10^{-6} i	1.56 + 20×10^{-6} i	1.55 + 10×10^{-6} i	–

Size distributions

19 April (left)
2 May (right)



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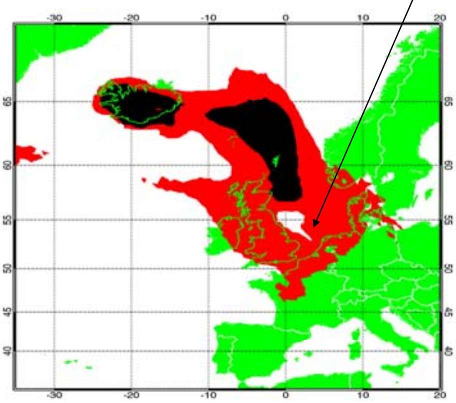
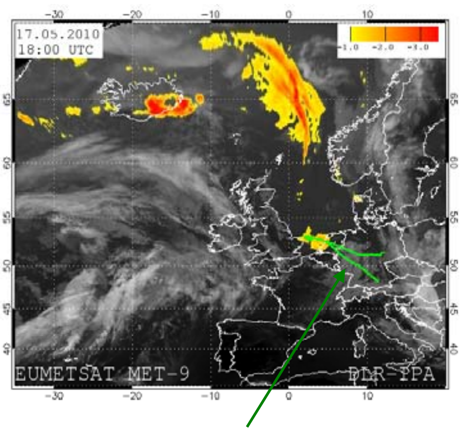
One hour Falcon flight in 2 km layer with 0.2-0.5 mg/m³ ash

VAAC



18 UTC 17 May 2010

Meteosat-VA Product by DLR



Falcon flight path

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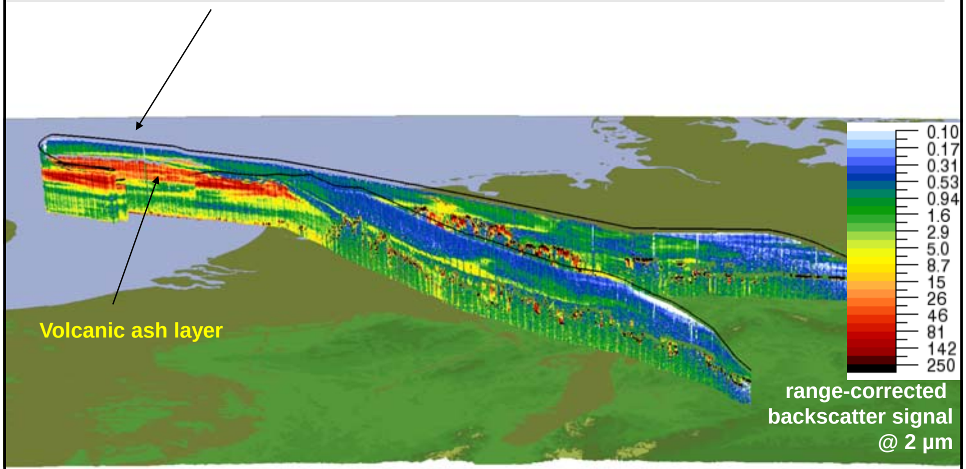
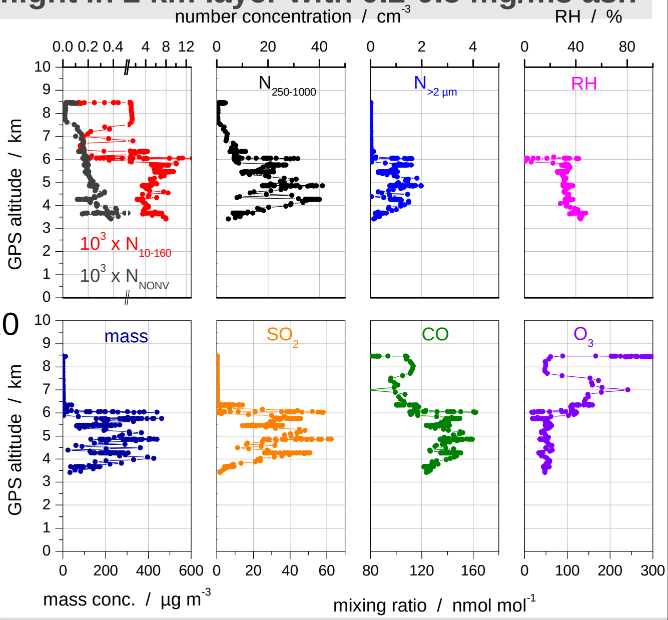
One hour Falcon flight in 2 km layer with 0.2-0.5 mg/m3 ash



18 UTC 17 May 2010

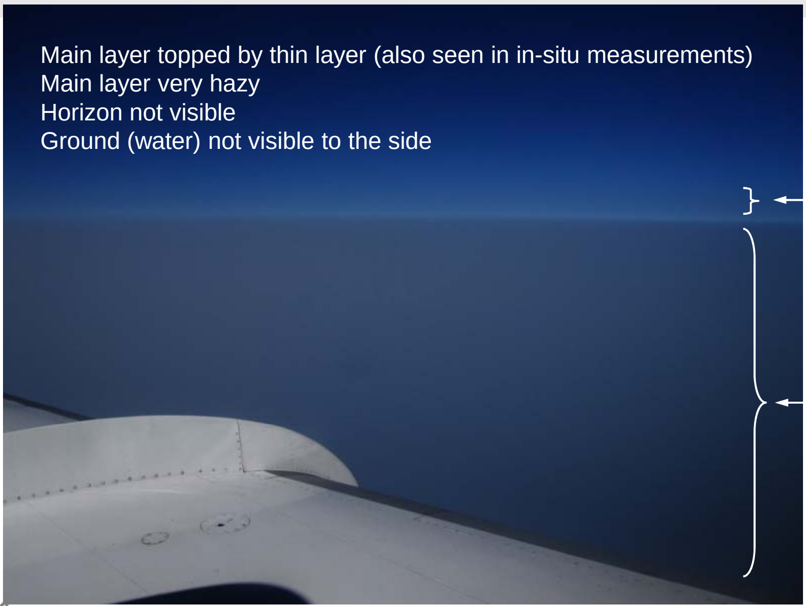
One hour Falcon flight in 2 km layer with 0.2-0.5 mg/m3 ash

18 UTC 17 May 2010



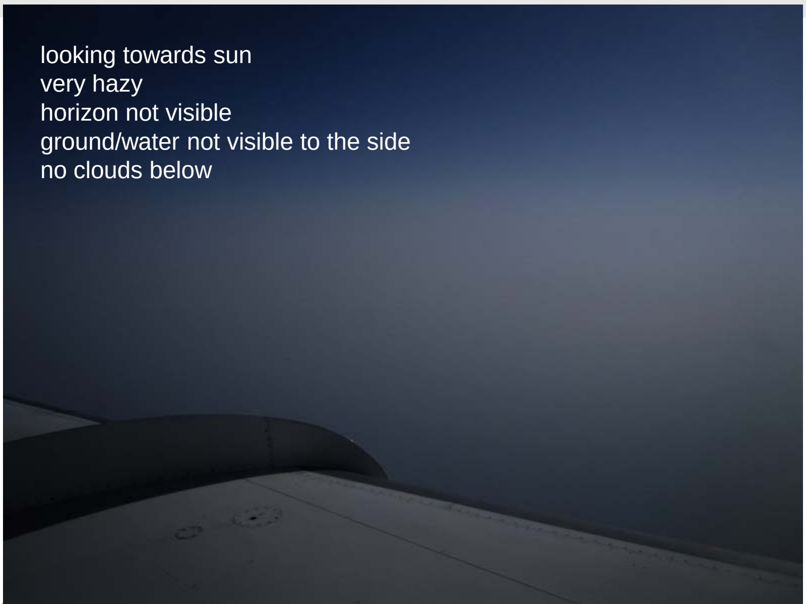
ash mass and SO_2 concentrations are correlated

Just above volcanic ash layer



17-May-2010, 15:54 UT, 6.4 km altitude, North Sea area

Inside volcanic ash layer at 5.5 km altitude

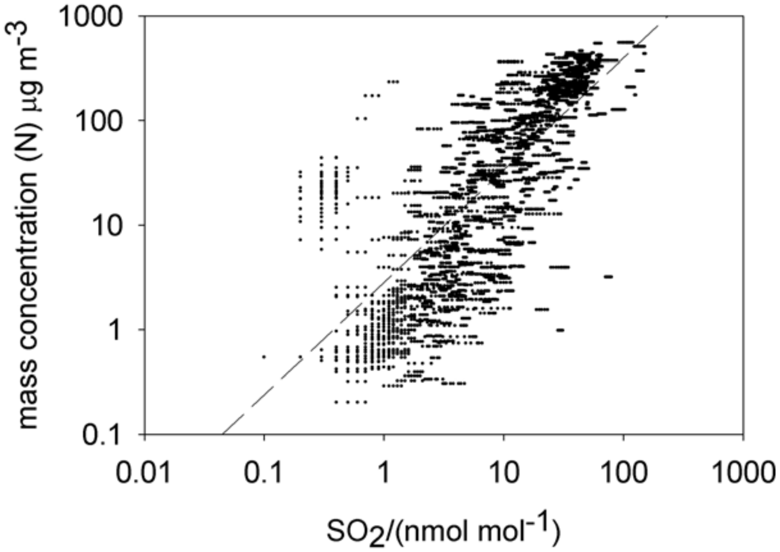


17-May-2010, 16:10 UT, 5.5 km altitude, North Sea area

Below volcanic ash layer at 2.7 km altitude

17-May-2010, 16:35 UT, 2.7 km altitude, North Sea area

SO_2 and ash mass concentrations are well correlated



Individual flight Activities (nationally and with EUFAR)

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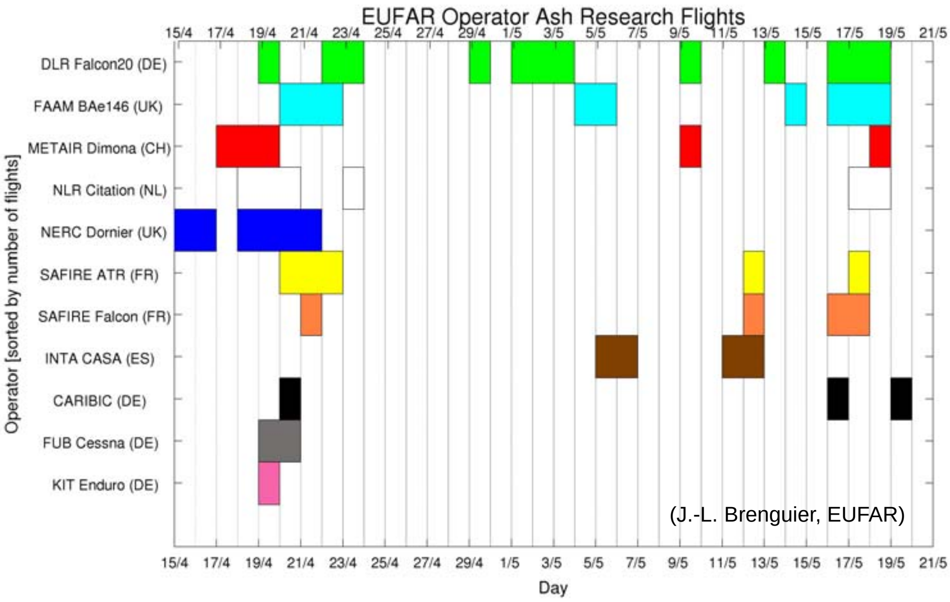
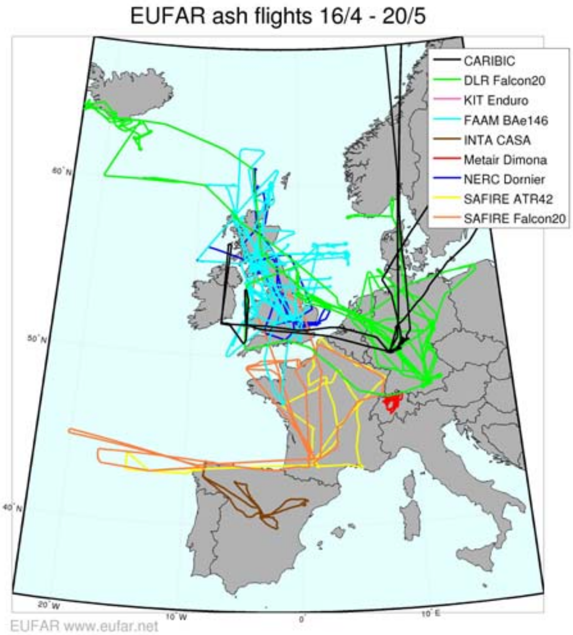
DLR Institute of Atmospheric Physics 55

Aircraft Activities, within a few days





Aircraft activities covered Europe

(J.-L. Brenguier, EUFAR)

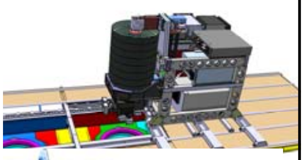
Future: Airbus A340-600, Falcon, HALO, Lidar, MSG

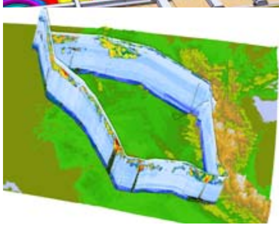
1. Insitu instruments on Airbus

Instrument	Measurement technique	Measurement par	
CAS	Light scattering	Particle and cloud distributions from µm, particle shape (discrimination be water and ice), liq content from 0.01	
UHSAS-A	Light scattering	Particle from 60 nm to 1 µm	under wing or fuselage
OPC	Light scattering	Size distribution fr to 1 µm	
CPCs	Condensation	Integral particle concentration (fine	
PSAP	Filter transmission	Ensemble absorpt	
SP2	Single-particle incandescence	Black carbon mas size of scattering	
SO_2 probe	Pulsed UV fluorescence	SO_2 mixing ratio	

n rack
n rack
n rack
n rack

2. High resolution spectral Lidar measurements





3. Accompanying Falcon measurements

Major findings

- Airborne observations (in-situ and with Lidar; besides ground based Lidar and satellite data) were essential for assessing volcanic ash load and plume source properties over Europe
- Ash was found at places as predicted by the VAAC
- Central Europe: ash mass concentration mostly below 2 mg/m^3
- Ash plumes with >0.5 mg/m3 are often detectable by crew observers and Meteosat ash product (outside thick clouds)
- Concentration similar to desert dust outbreaks
- Ash mass concentration difficult to measure and particle measurements alone could lead to false alarm frequently
- SO_2 can be used to identify dangerous ash plumes.
- The data are now being used to test/improve VAAC prediction model
- Lidar, satellite, and airborne data and VAAC model predictions should be integrated into risk assessment information systems.

Conclusions

- Largest impact of volcanoes on dense air traffic region since 1945
- Eyjafjallajökull was exceptional in its fine ash content, duration, altitude, and ambient wind field transporting to Central Europe
- Aviation was not well prepared; Thresholds for safe operation were missing in spite of discussions since at least 1991.
- VAAC was mainly relying on model and satellite observations
- Today, we are slightly better prepared (threshold, communication system, knowledge, models, observations)
- ICAO: International Airworthiness Task Force & Scientific Advisory Group on Volcanic Ash: started in July/August 2010
- Open: Decision making by governments or operators?
- Needed: Central information system for crisis situation
- No major research program funding available so far