Volcanic ash layers over Europe - Airborne observations with the DLR-Falcon research aircraft in April/May 2010

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+ many more partners (IPA, FB, CNRS/LaMP, TU Darmstadt, IfT Leipzig, LMU München, NILU, Uni. Iceland, DWD, VAAC, DFS, LBA, KNMI, etc.)

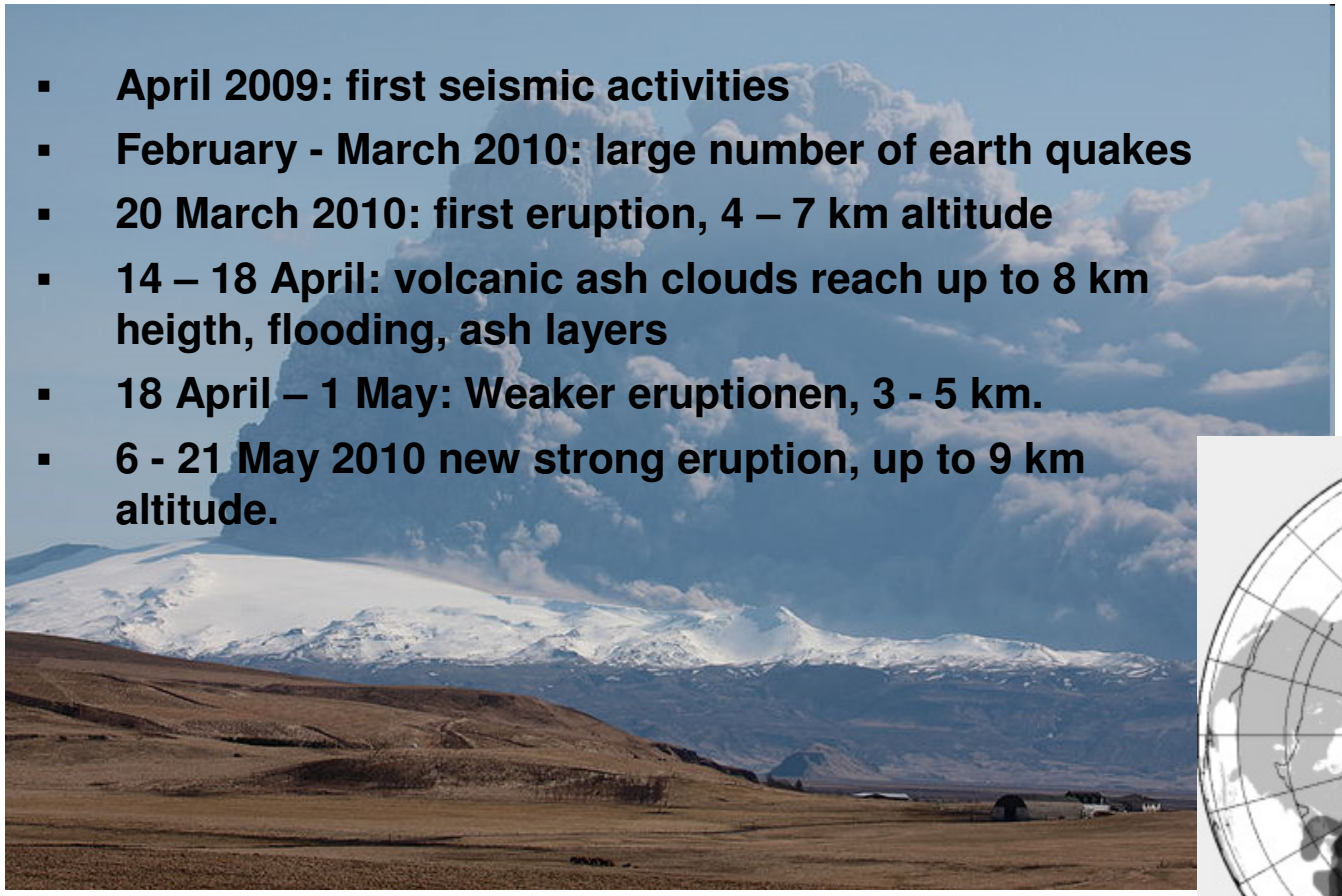
Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Institut für Physik der Atmosphäre
in cooperation with Ludwig-Maximilians University Munich

100 JAHRE Luft- und Raumfahrtforschung in Deutschland

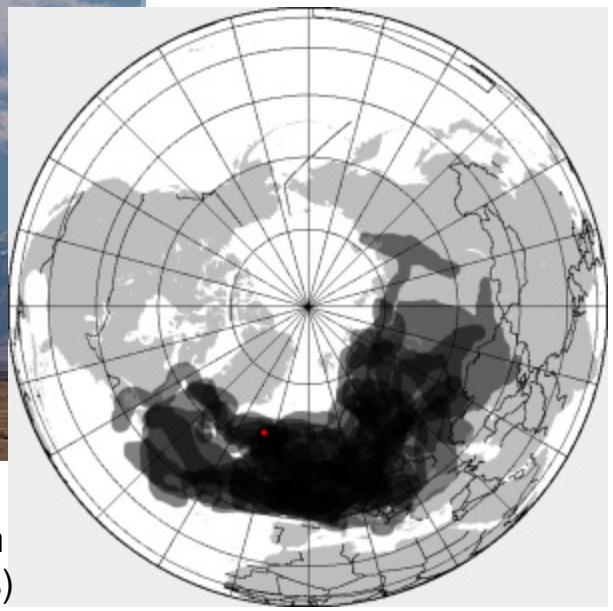
Eyjafjallajökull .... pronounced ['ɛɪja,fjatl̥a.jœkʏtl̥]

Eruption occurred (below ice) on early morning of 14 April 2010



- **April 2009: first seismic activities**
- **February - March 2010: large number of earth quakes**
- **20 March 2010: first eruption, 4 – 7 km altitude**
- **14 – 18 April: volcanic ash clouds reach up to 8 km heigth, flooding, ash layers**
- **18 April – 1 May: Weaker eruptionen, 3 - 5 km.**
- **6 - 21 May 2010 new strong eruption, up to 9 km altitude.**

http://en.wikipedia.org/wiki/Air_travel_disruption_after_the_2010_Eyjafjallajökull_eruption



Distribution of ash
(composite map of first 10 days)

Hazards for aviation

1) **Sand-blast effect**: cockpit windows ,
   wing aerodynamic, large particles only.
2) **Jet engines**, documented from 300 up to 1000
   distance from source:
   - Silicate melts already at < 1000 °C,
   - Erosion at engine fans,
   - Closure of ventilation holes (overheating),
   - Lack of oxygen in the engine (blow out).
3) **Sensor**: altimeter and airspeed indicator can get clogged.

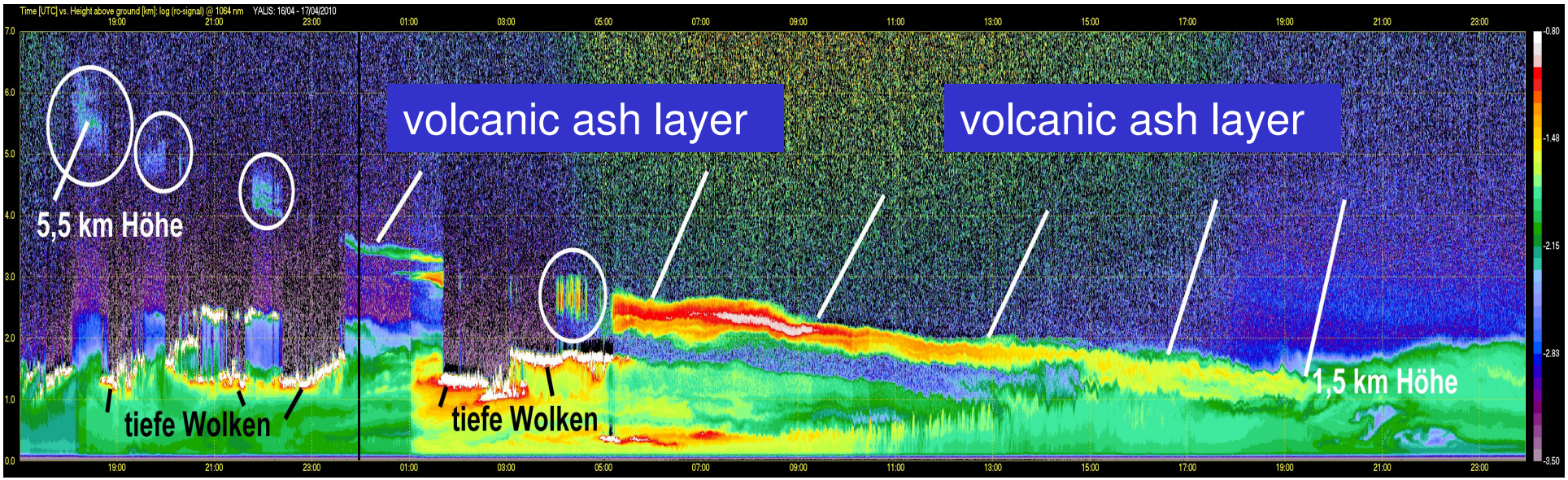
Problem: real hazard depends on ash concentration, engine type, flight attitude, ...!

April 2010: No threshold values for safe airtraffic available

Lidar measurements performed by the Univ. of Munich

(LMU-MIM, at Munich-Maisach; **plume age: ~28 h**)

0-7 km altitude above sea level



18 0 6 12 18 24

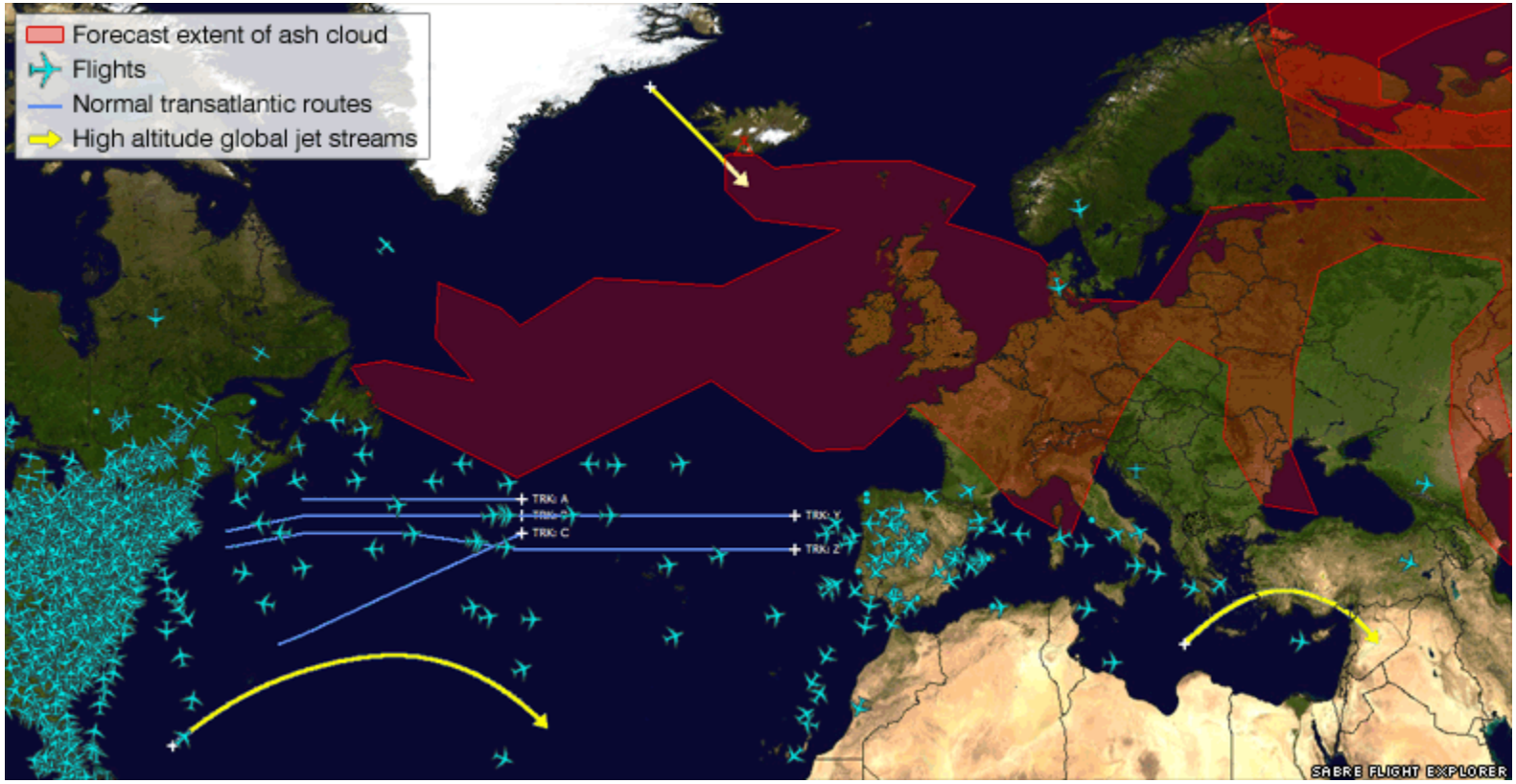
The measurments shown start on April 16 (18 MESZ) and end on April 17 (24 MESZ).

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

(V. Freudenthaler, S. Groß, M. Wiegner, B. Mayer)

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

DLR-Falcon started at 14:11 UTC



http://www.radarvirtuel.com/

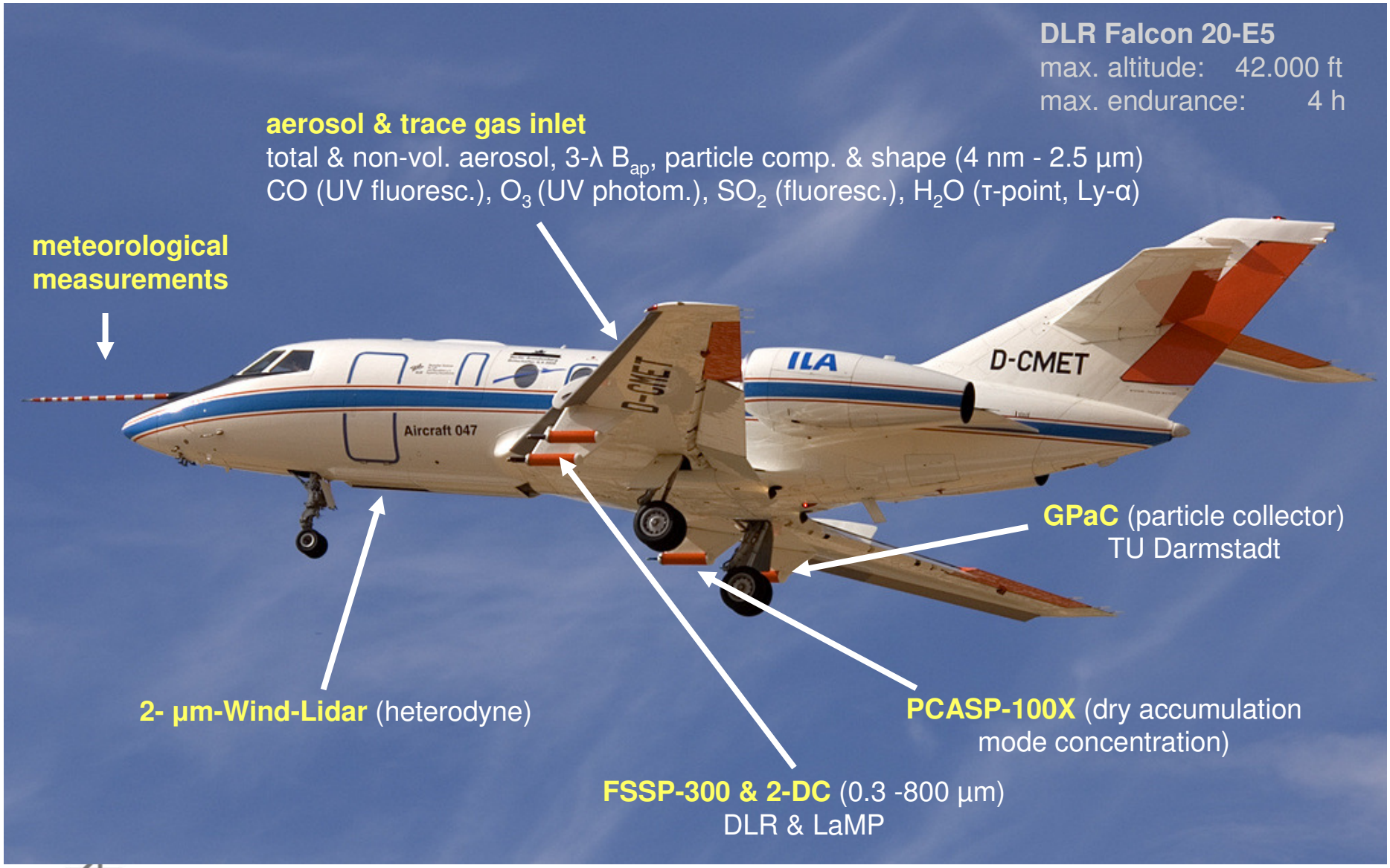
taken from BBC: Iceland volcano in maps

Objectives: Operational & scientific

- Closure of airspace justified or exaggerated?
- Quality of forecasts?
- Comparable to Saharan dust?
- Engine ash load thresholds?
- How to improve the ICAO-VAAC-DWD-DFS-BMVBS decision processes

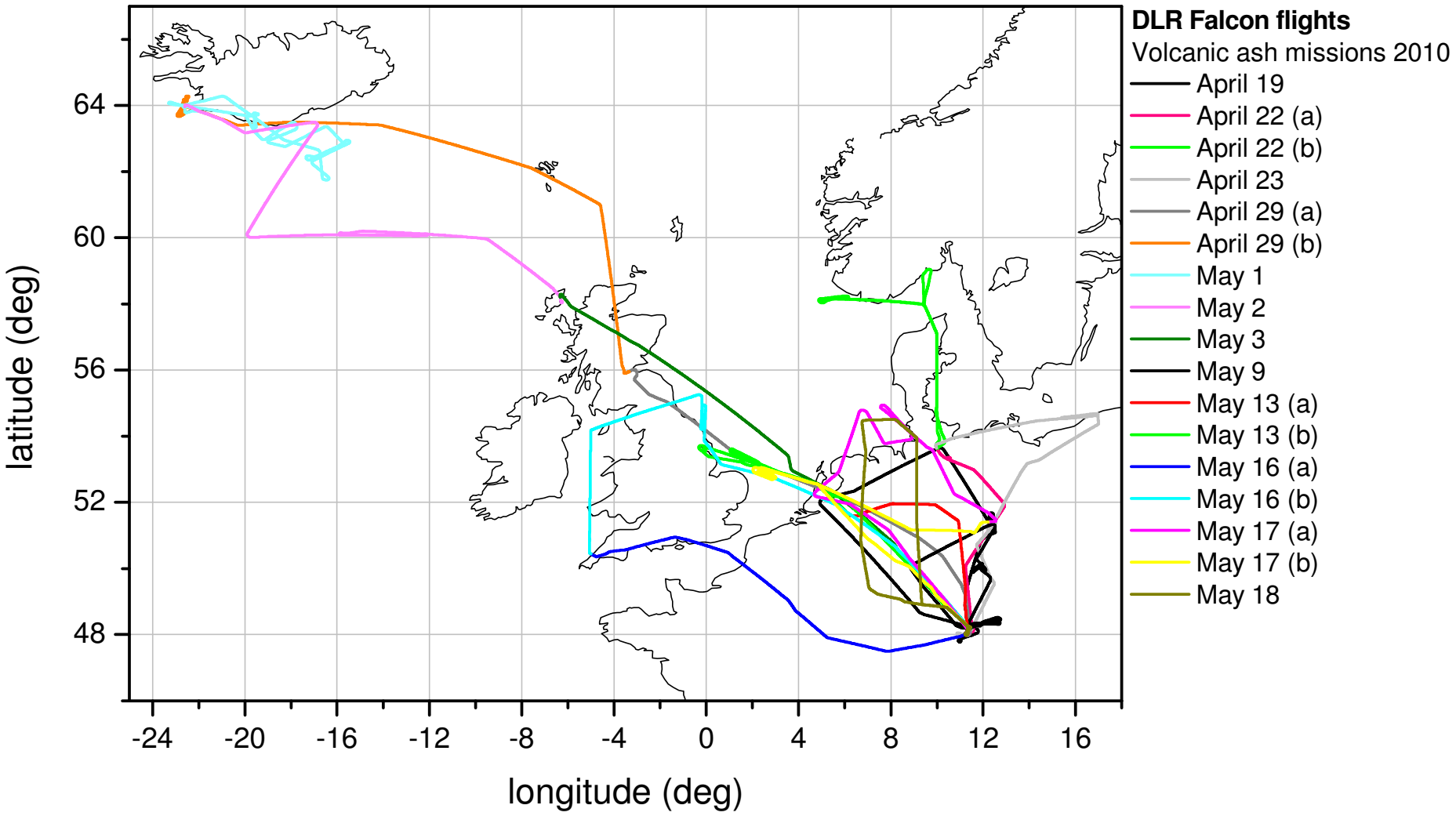
- What do the lidar and satellite instruments see?
- Volcanic source (mass, particle sizes, chemistry)
- Particle numbers and sizes, and mass concentration
- Chemical plume composition

Falcon 20E D-CMET, DLR Oberpfaffenhofen (seit 1976)

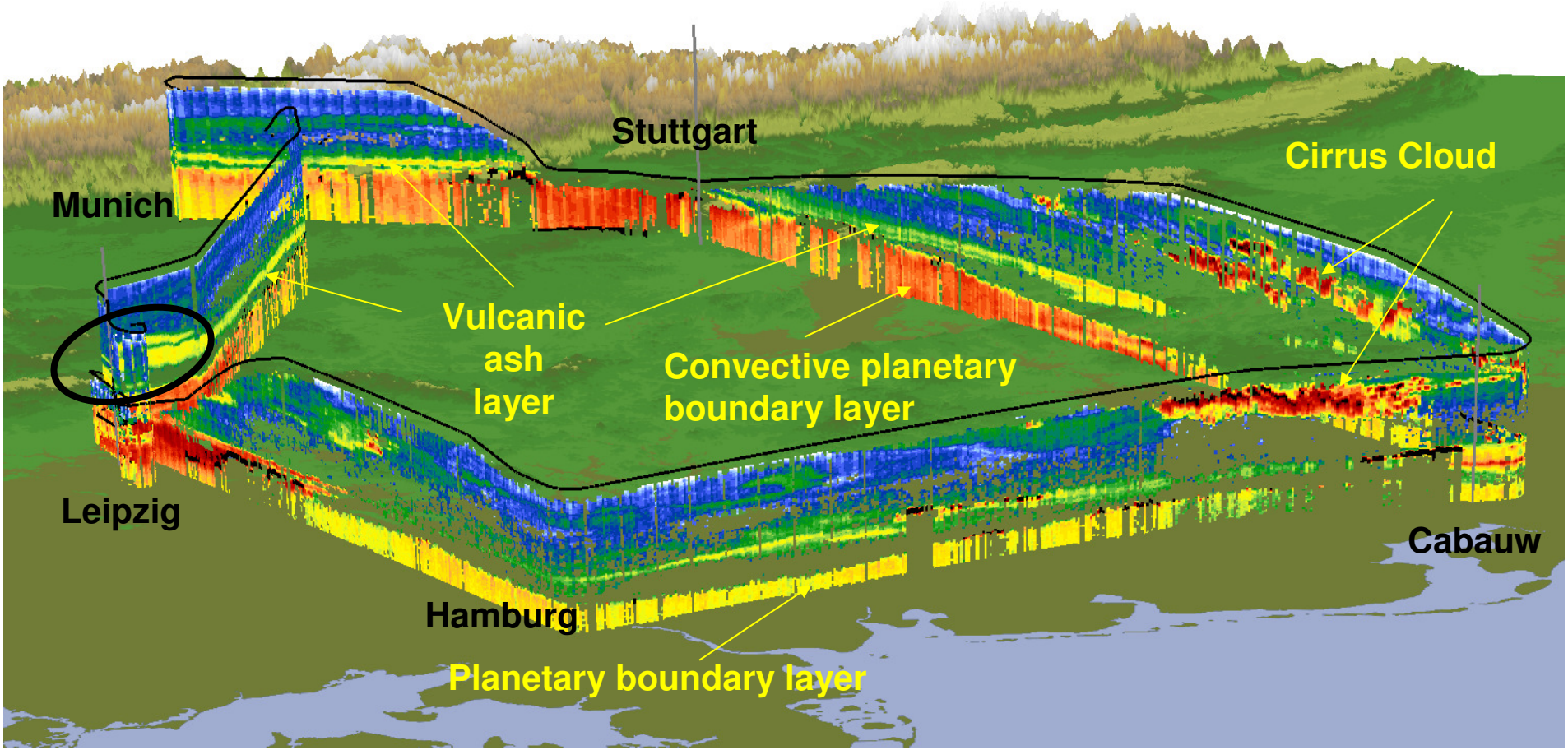


Weekend April 16-18, 2010: integration of the instruments

Map with flight tracks of all DLR Falcon flights

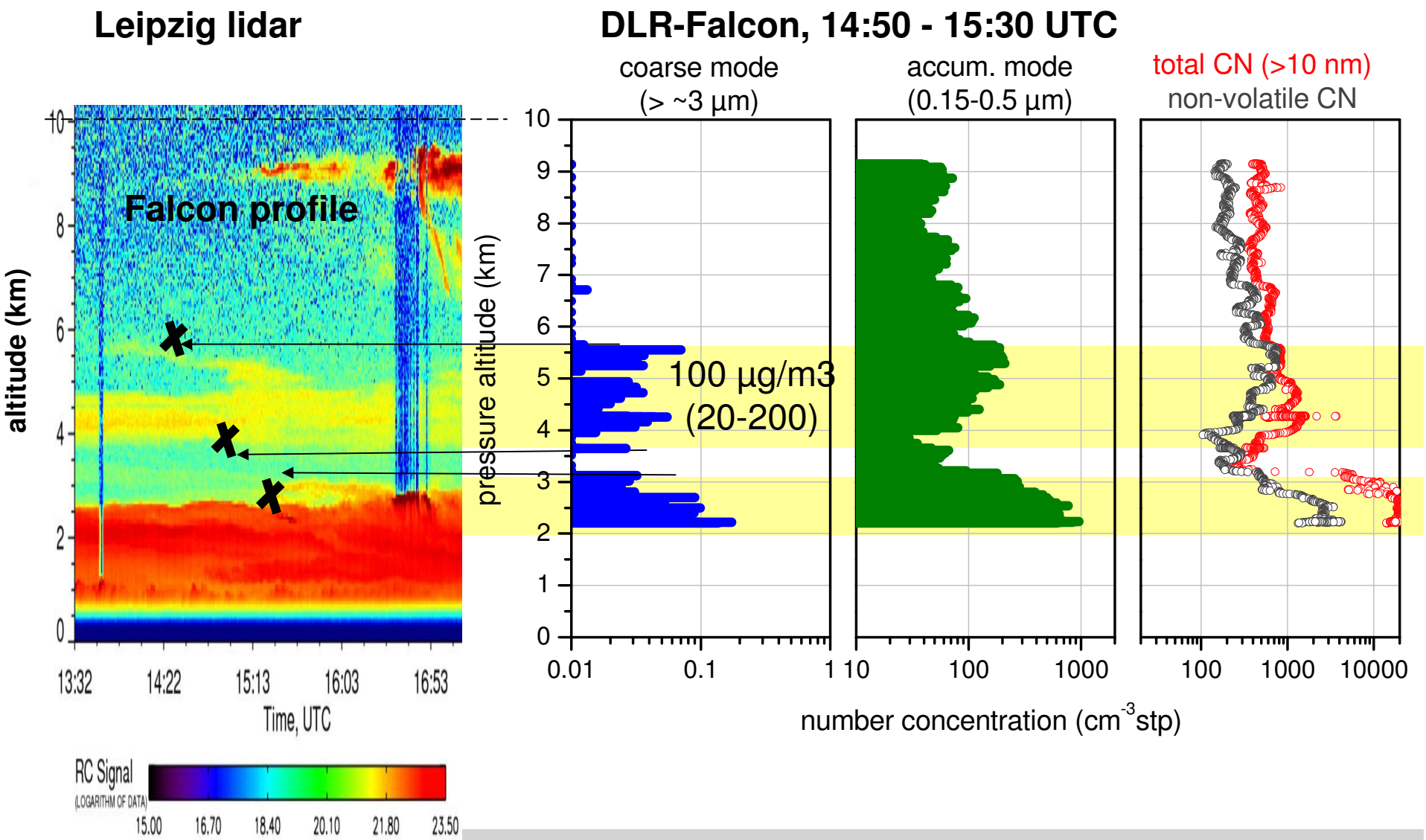


April 19, 2010 - lidar results



Vulcanic ash layer over Leipzig, April 19, 2010, 15:00 UTC

19 April 2010: vertical profile measurements over Leipzig



(Ift Leipzig: A. Ansmann, M. Tesche, P. Seifert et al.)

Eyjafjallajökull volcano plume, 29 April, late afternoon time

Eyjafjallajökull volcano plume, May 1, noon time

Eyjafjallajökull volcano plume, May 1, noon time

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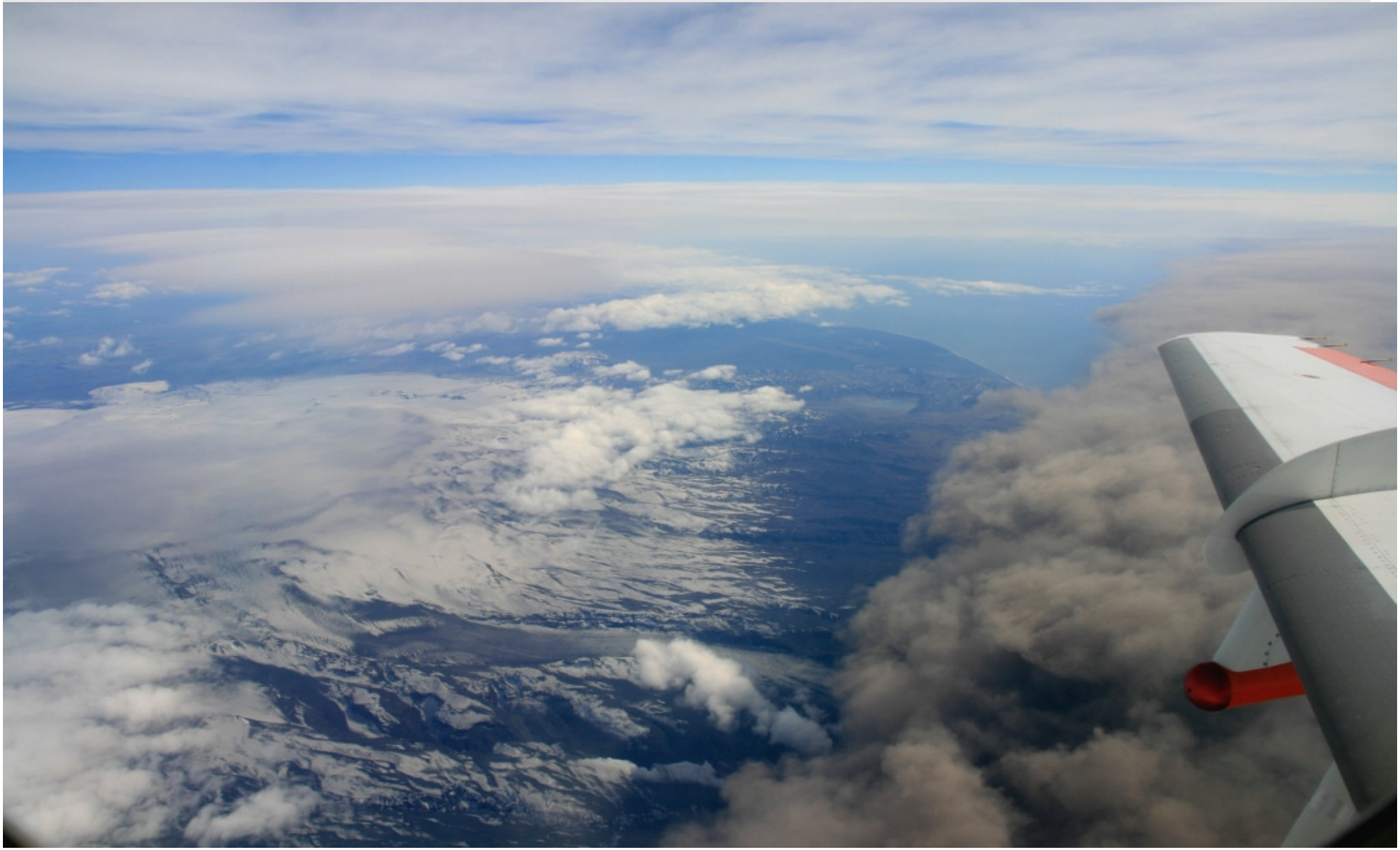
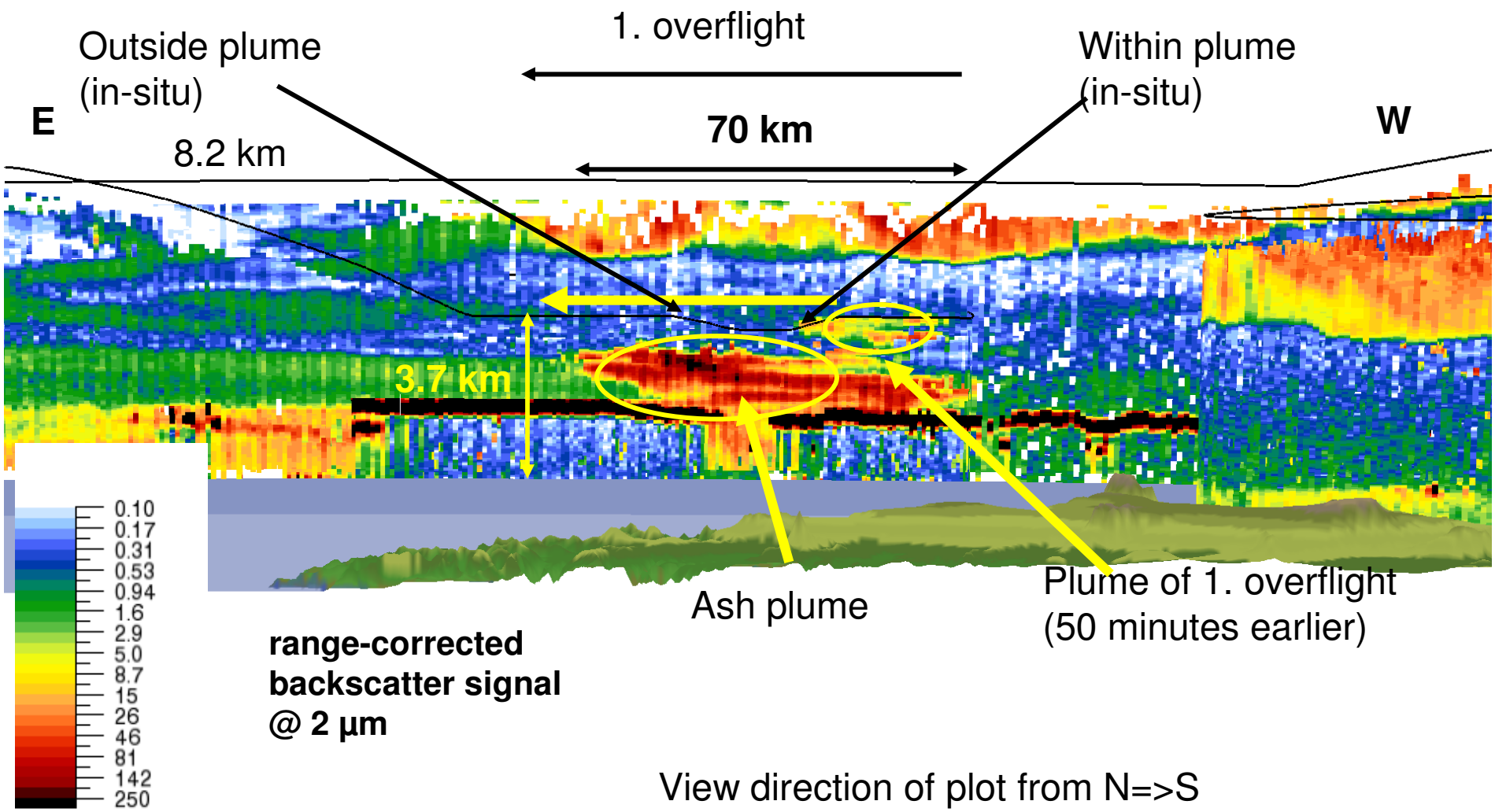
Eyjafjallajökull volcano plume, May 1, noon time



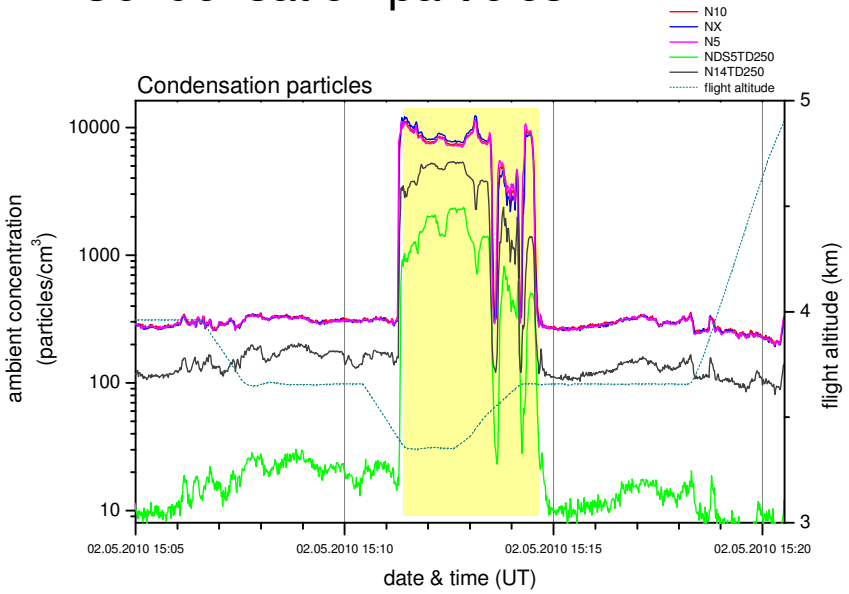
Eyjafjallajökull volcano plume, May 1, noon time

May 2, 15 UTC: North Atlantic, 450 km dist., 60 N, age 7 h

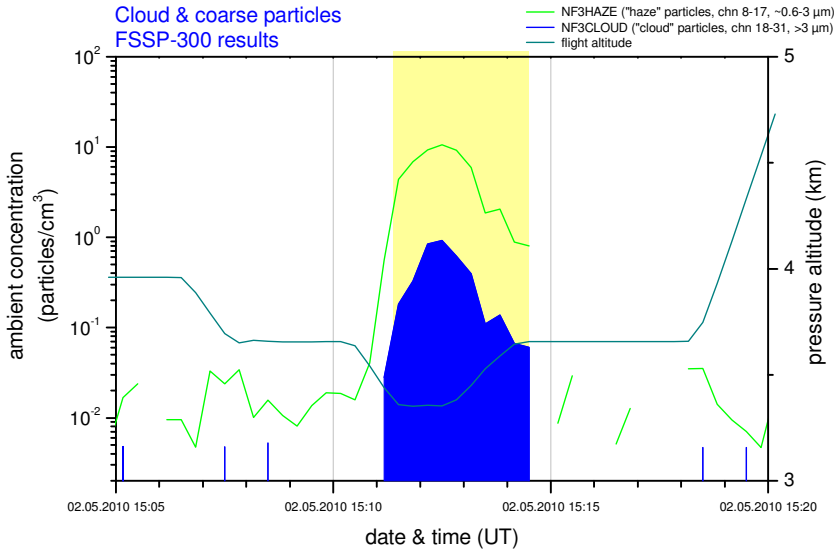


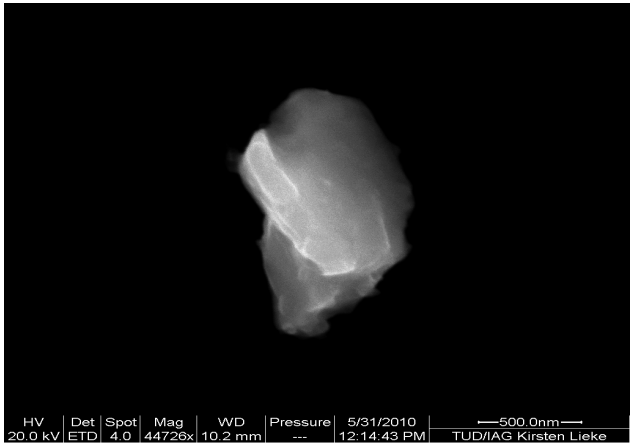
Aerosol properties in top of volcanic plume

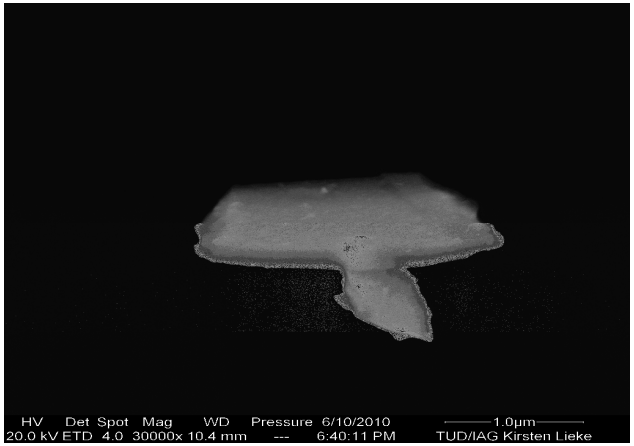
Condensation particles



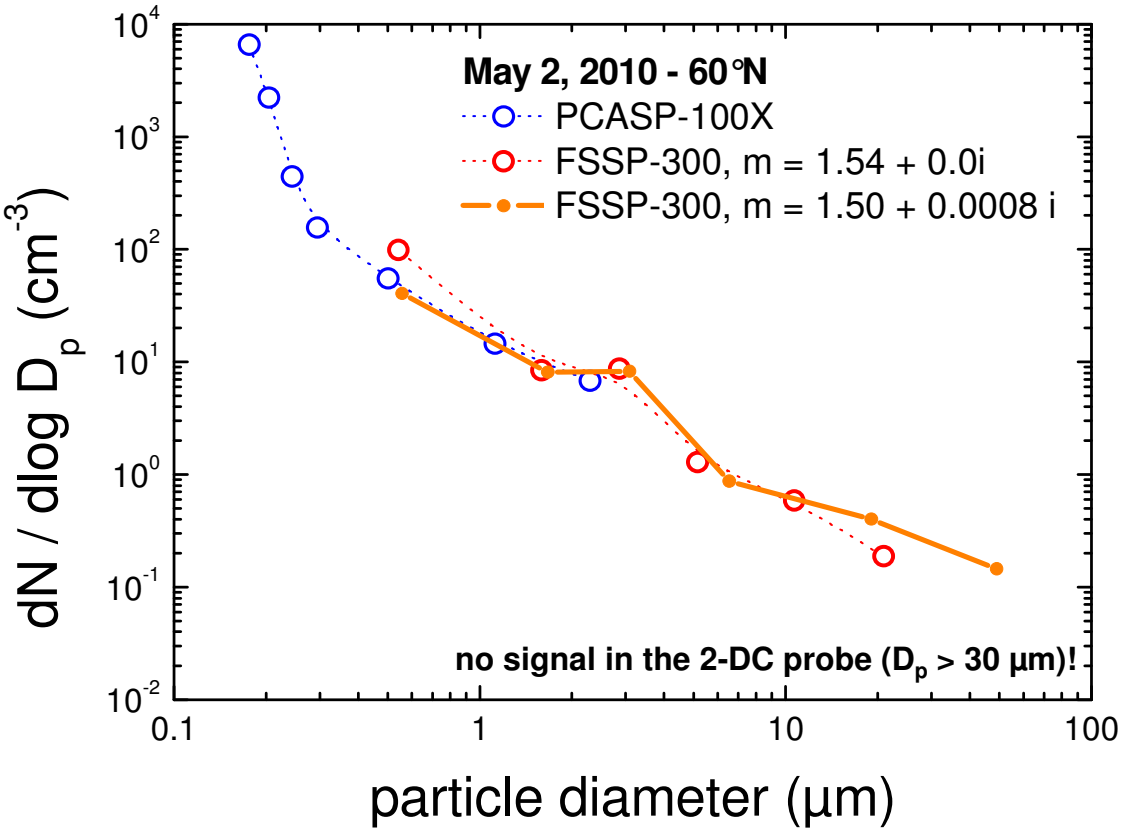
Coarse mode aerosol

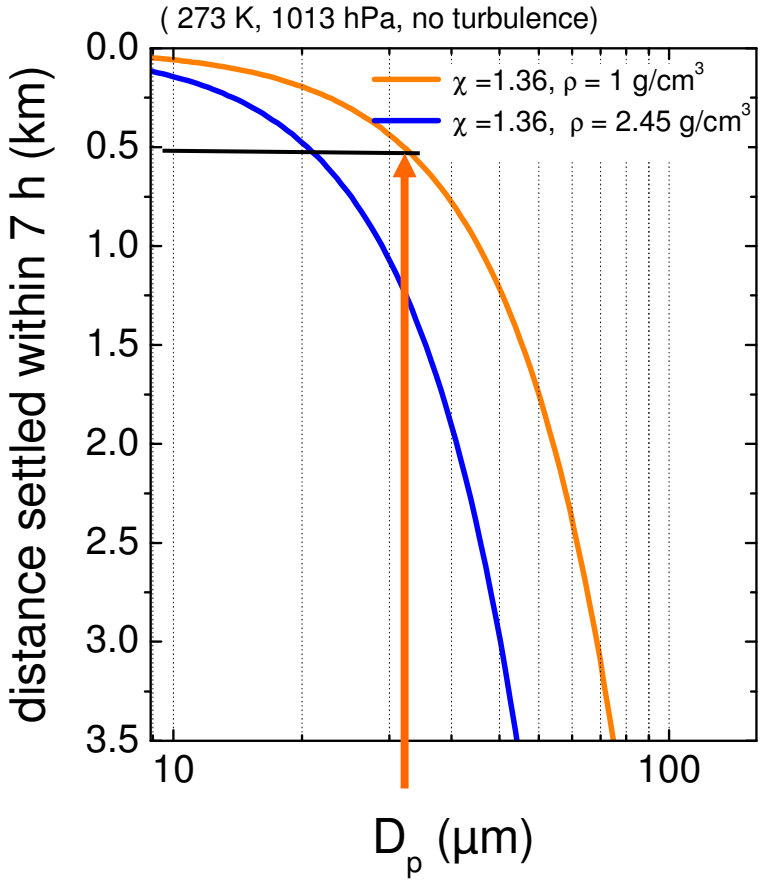






Mass concentrations in the plume over the North Atlantic



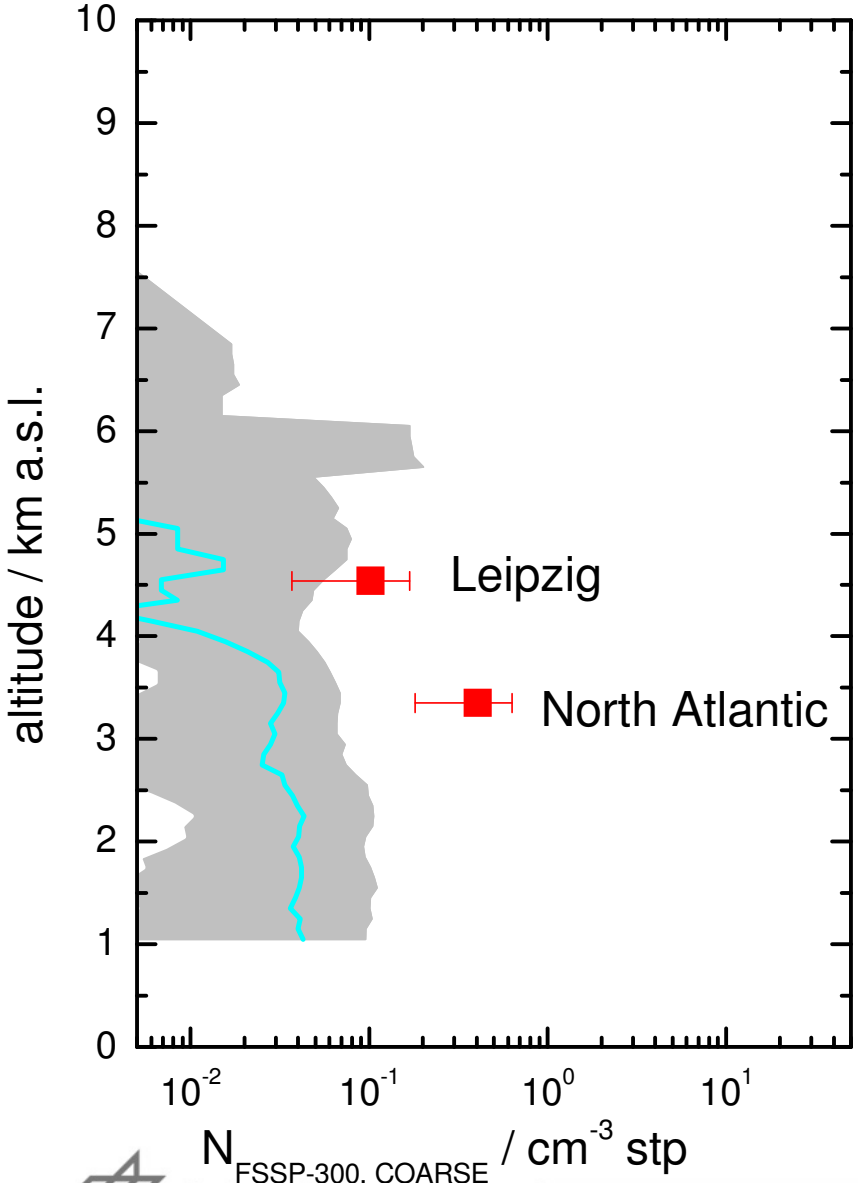


m = 1.54 + 0i	
PM2.5	30 µg/m³
FSSP-300 "total"	1200 µg/m³
D_{eff} 7 µm	preliminary!

m = 1.50 + 0.008i	
PM2.5	30 µg/m³
FSSP-300 "total"	10000 µg/m³
D_{eff} 26 µm	preliminary!

...assuming a particle density of 3 g/cm^{-3}

Comparison with Saharan dust (SAMUM-1, 2006, 17 flights)



Aerosol-optical depth (AOD, @532)

Munich

17.04. (plume age: 3 days):	0.8
19.04. (plume age: 5 days):	0.4

Leipzig

17.04. (plume age: 3 days):	1.0
19.04. (plume age: 5 days):	0.5

For comparison:

Sahara, SAMUM-1:	0.4 - 0.6

Further DLR Falcon flights

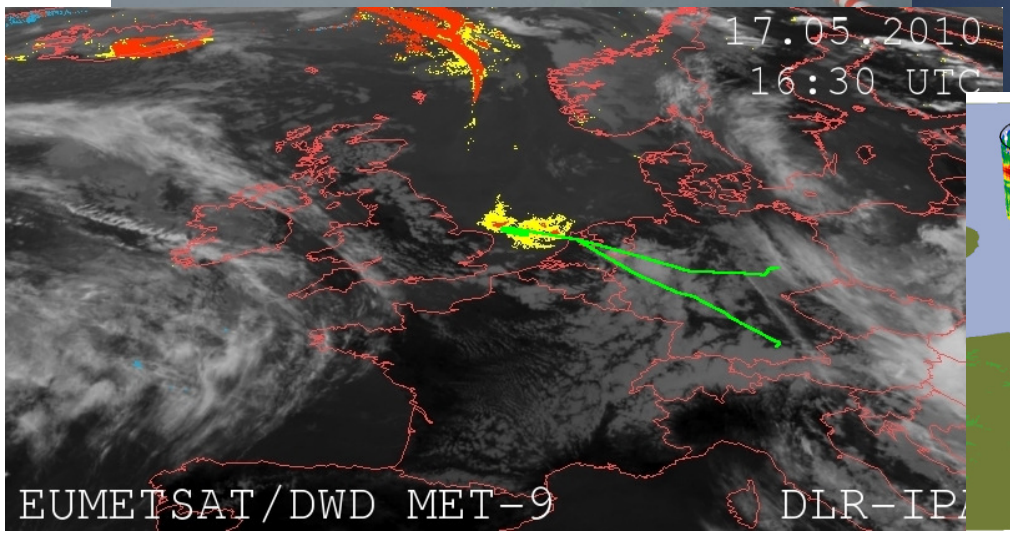
May 9: Southern Germany: < 10 µg/m³

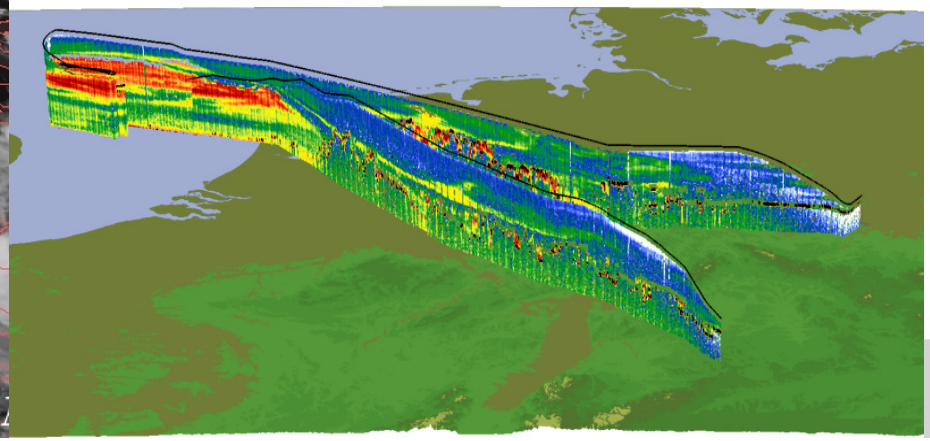
volcanic ash

May 13: English Channel: MSG detected thin ash cloud < 30 µg/m³, without VAAC warning

May 16: England and North Sea: thick volcanic ash plume > 2000 µg/m3

May 17: North Sea VA 450 µg/m3, observed also by MSG and Lidar Cabauw





Conclusions (science & operations)

- 17 Falcon flights April 19 - May 18, 2010
- Satellite data, ground based Lidar, model predictions
- Many scientific results
- Particles diameters up to 30 µm (mainly silicate, ammonia sulfate, more Na, K than in Saharan dust)
- Mass loading: 100 µg/m^3 Leipzig , >3000 µg/m^3 North Atlantic, England
- One hour of flight in 450 µg/m^3 without engine damage
- SO_2: 4 – 200 nmol/mol

- Mid-European airspace closure justified until Sat. April 17; then ageing of ash load
- Southern German airspace closure May 9 (6 days aged VA): questionable
- Closure over UK, May 16, 1-2 days aged plume: fully justified
- Keflavik/Iceland free of ash as predicted on April 19 - May 2
- Quality of forecasts reliable enough for aviation
- Fresh and heavy VA is well predictable, but >3 days aged VA: far more difficult
- Improved linking between operations and academia needed
- Continue operations of the DLR Falcon as Emergency Aircraft

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

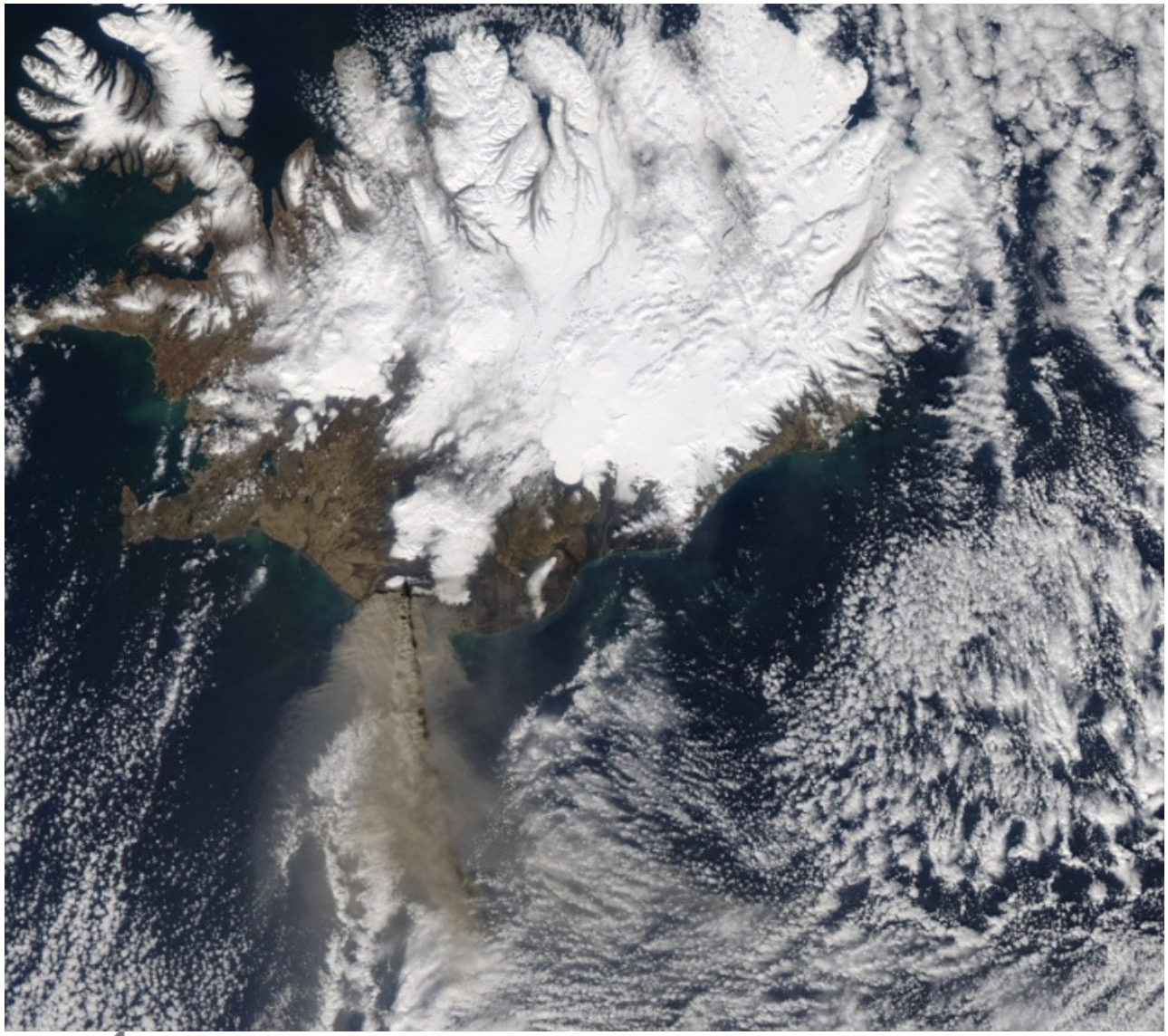

Thank you for your interest!

Backup

Summary of all flights

Date	Flight ID	Take-off time (UTC)	Landing time (UTC)	Mission objective
19 April 2010	#100419a	14:12:02	17:54:50	Aged ash plume over Germany & NL (air space in Europe largely closed)
22 April 2010	#100422a	14:14:14	15:35:09	Lidar survey over Germany
	#100422b	17:12:55	20:29:30	Aged ash plume south of Norway (embedded in clouds)
23 April 2010	#100423a	11:45:56	14:57:46	Aged ash plume over Germany, Poland & Baltic Sea
29 April 2010	#100429a	12:00:10	14:09:06	Ferry flight (to Edinburgh)
	#100429b	15:39:59	18:28:50	Flight to Iceland with lidar survey of ash plume and in-situ profiling at Keflavik airport
1 May 2010	#100501a	10:50:29	14:05:03	Lidar survey of fresh ash plume near volcano and in-situ profiling at Keflavik airport
2 May 2010	#100502a	12:58:36	16:17:57	Return flight with in-situ measurement in the top of the fresh plume over the North Atlantic
3 May 2010	#100503a	11:04:40	13:31:27	Ferry flight to Oberpfaffenhofen
9 May 2010	#100509a	14:26:52	18:01:24	Aged ash plume over Germany (Munich airport & air space closed for ~6 hours)
13 May 2010	#100513a	10:06:25	11:20:04	Ferry flight to Niederrhein
	#100513b	12:44:26	15:49:47	Aged ash plume north of English Channel
16 May 2010	#100516a	09:11:17	11:07:31	Ferry flight to Newquay (UK)
	#100516b	12:34:50	16:01:16	Aged ash plume over Irish Sea and northern England (UK air space partly closed)
17 May 2010	#100517a	10:38:47	13:29:50	Aged ash plumes over Germany, NL & North Sea
	#100517b	14:36:54	17:57:00	Aged dense ash plume over North Sea, extensive in situ measurement
18 May 2010	#100518a	07:25:32	10:34:56	Aged ash plume survey over Germany & North Sea (German air space closure was under consideration)

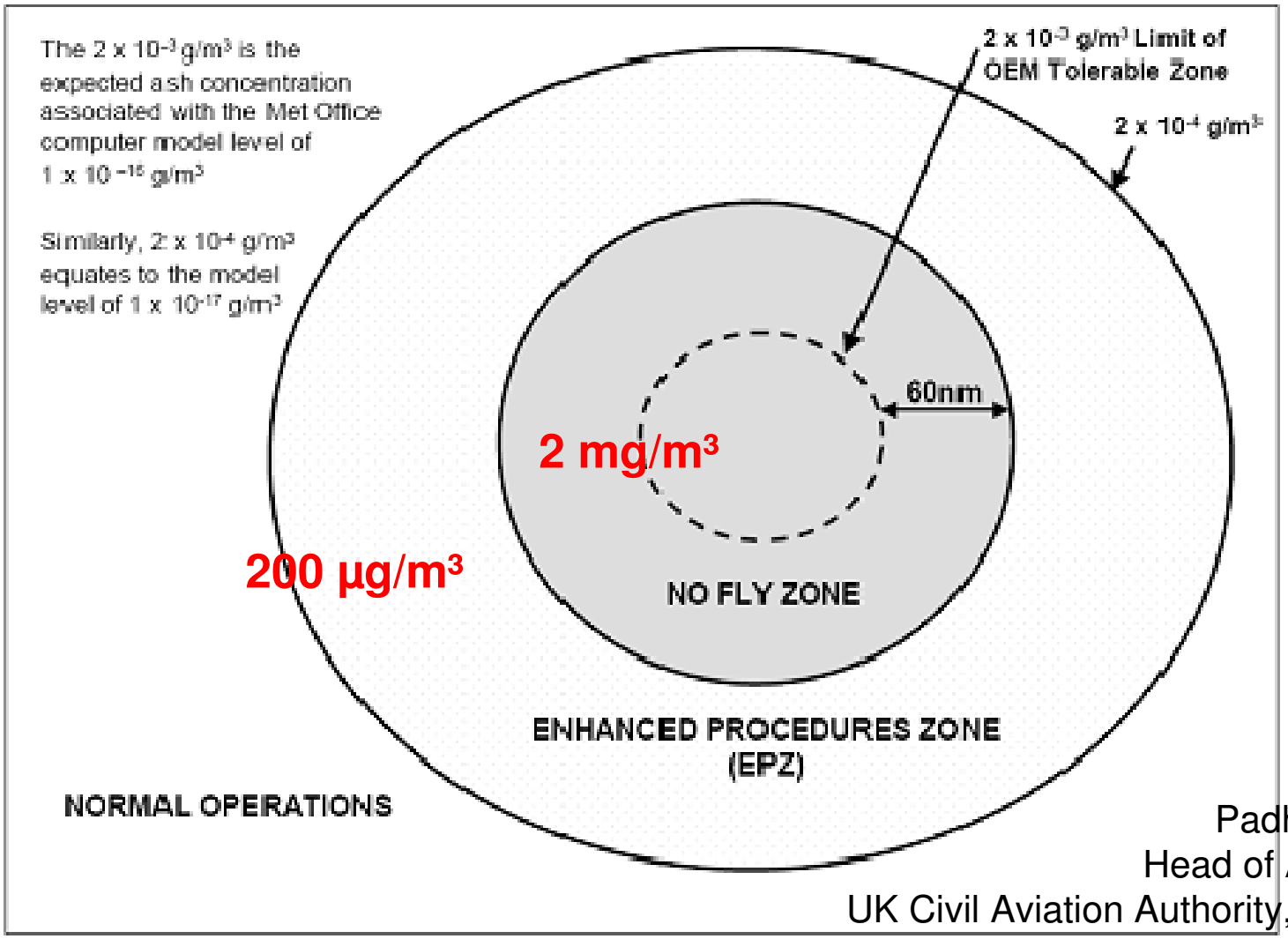
The situation in April 2010



TERRA MODIS measurements on April 17, 2010

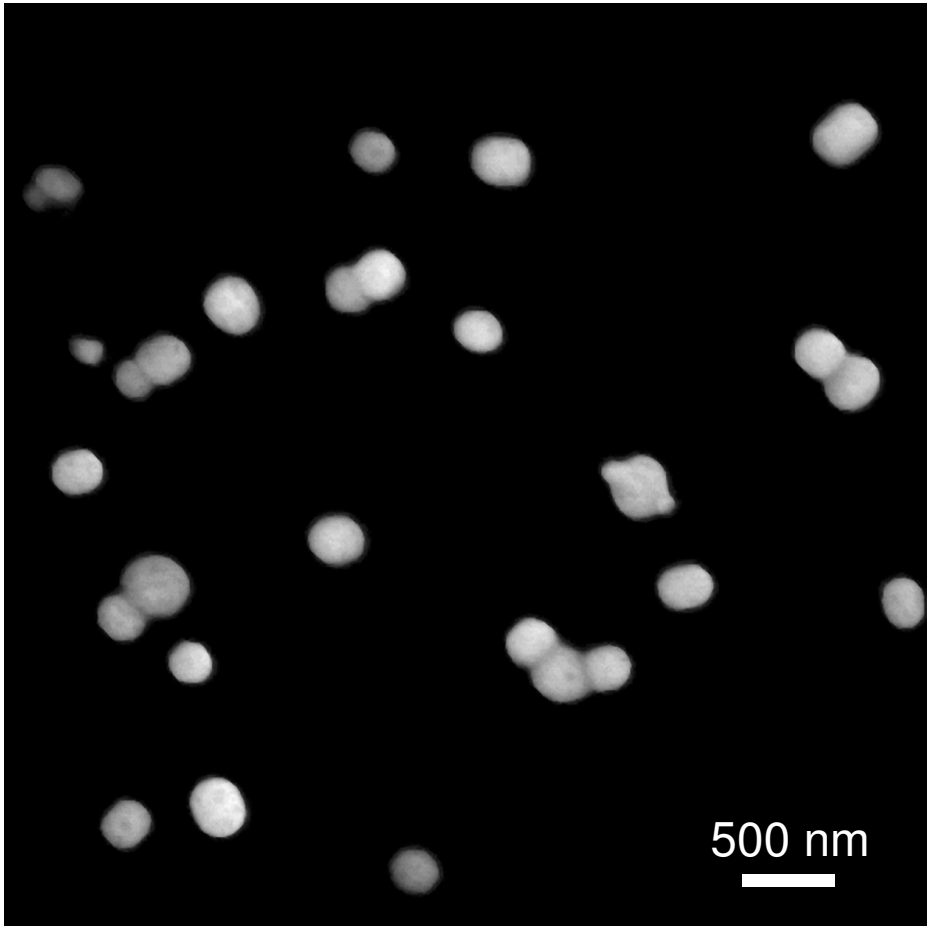
Source:
NASA Earth Observatory

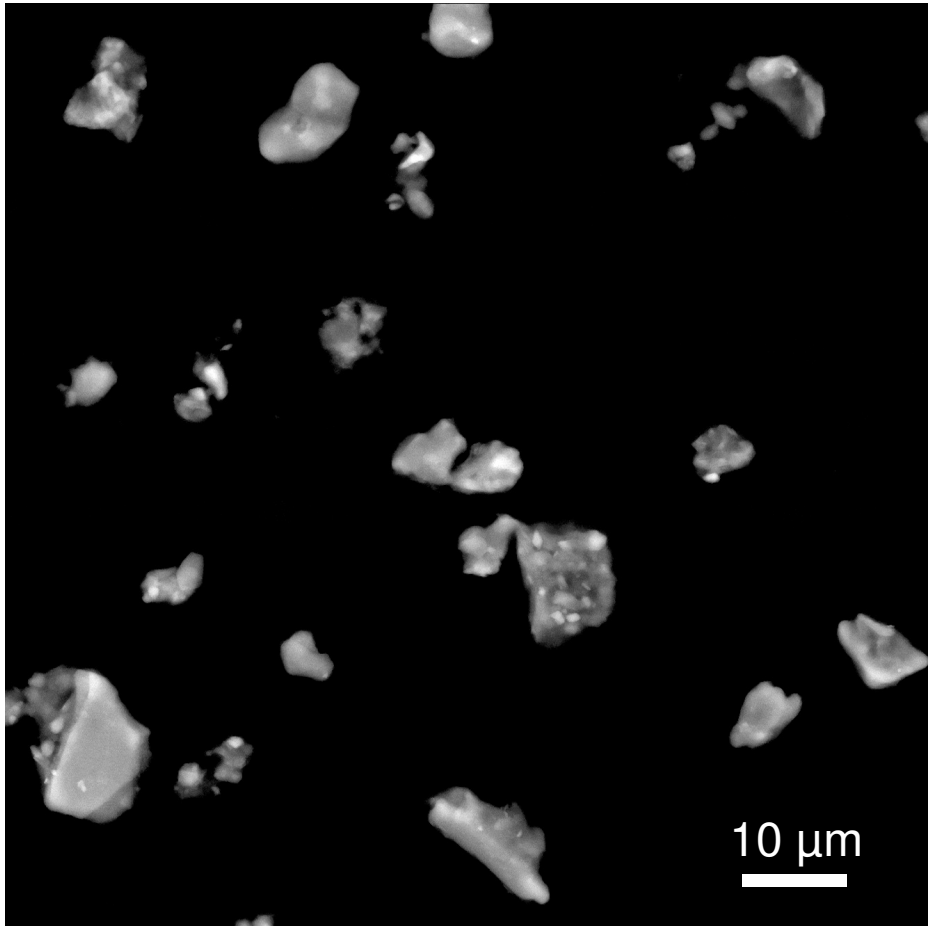
VOLCANIC ASH INTERNATIONAL TELECONFERENCES, 17-23 April 2010



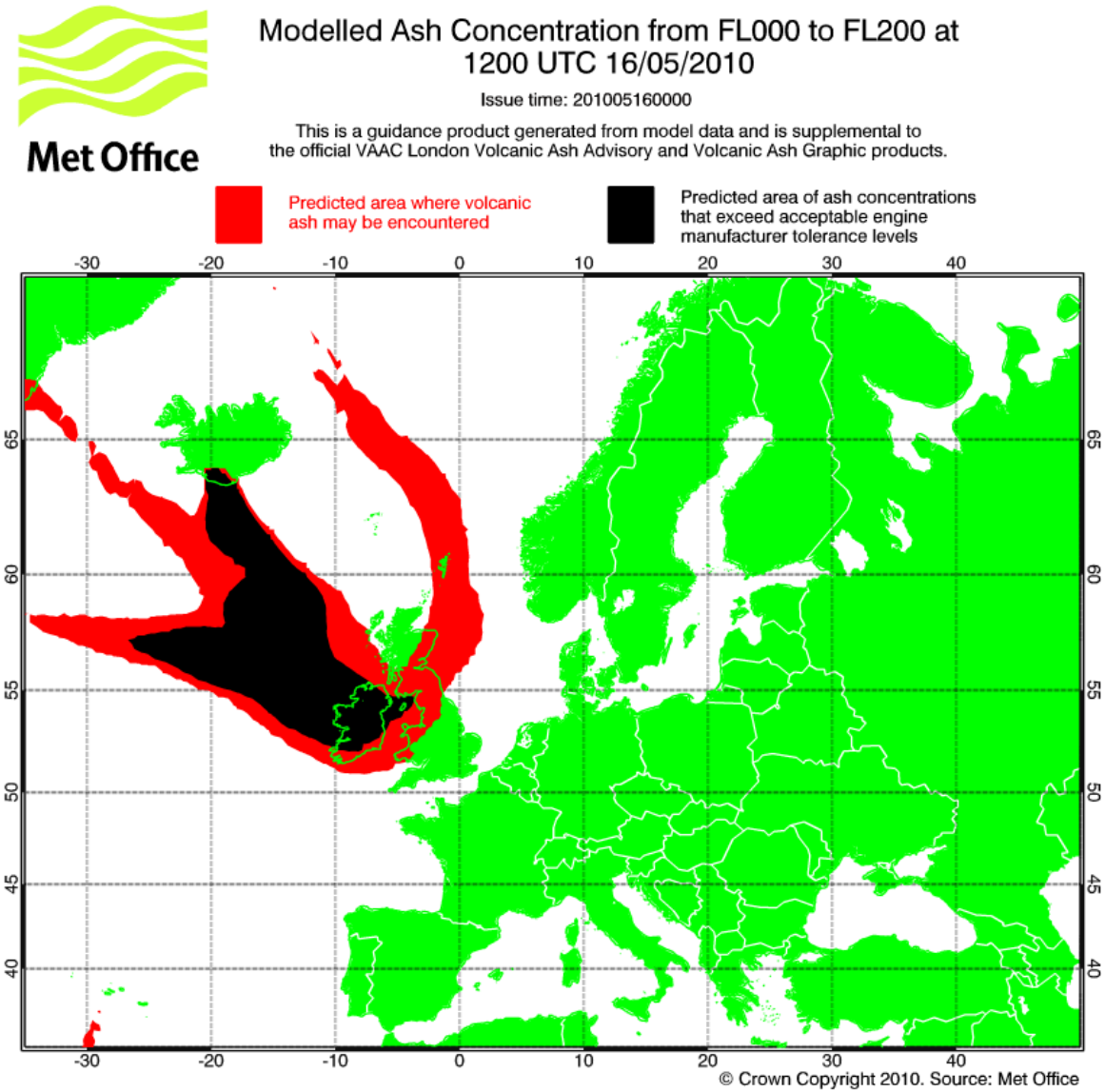
Padhraic Kelleher
Head of Airworthiness
UK Civil Aviation Authority, May 5, 2010

Saharan dust

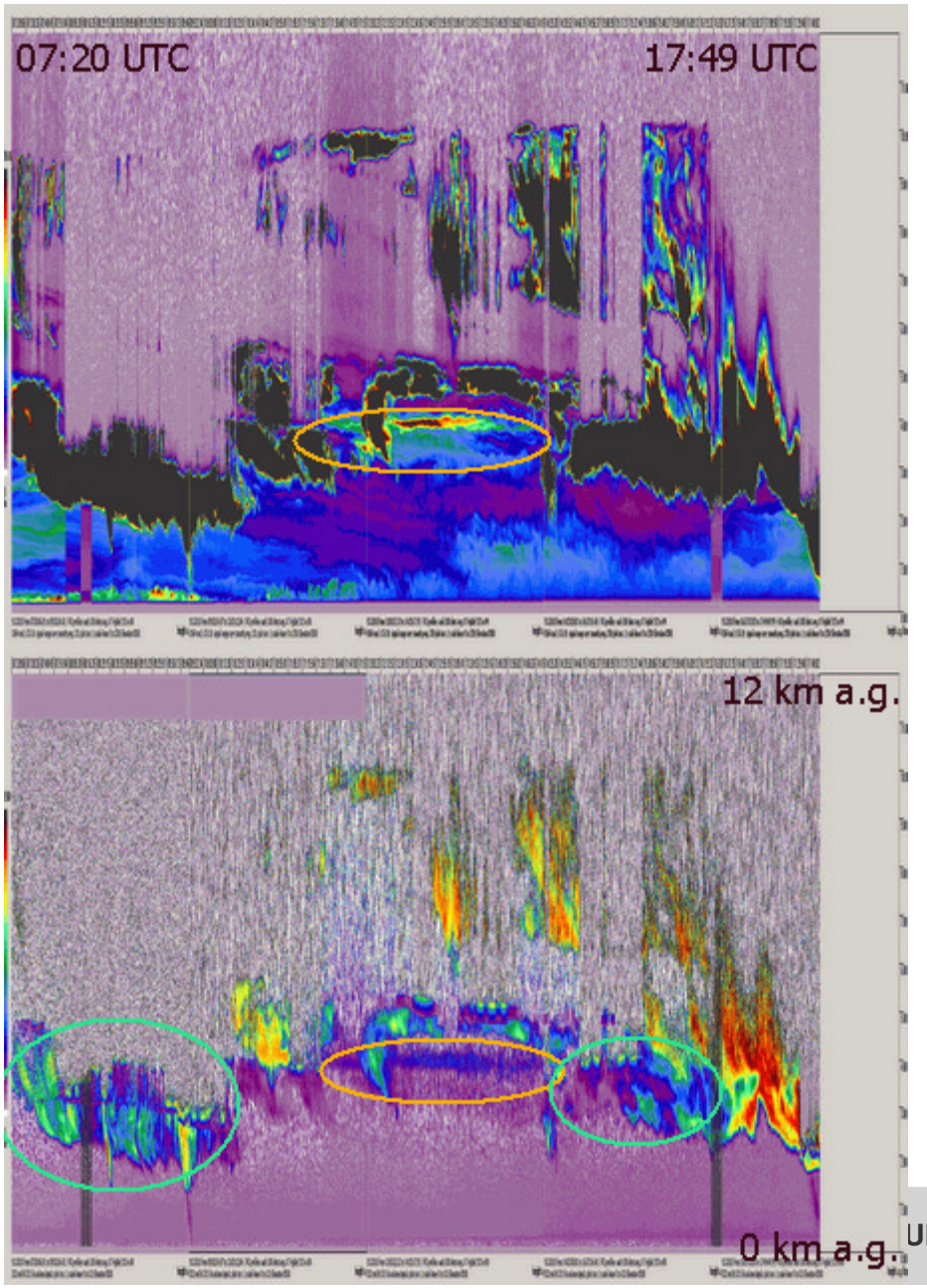




Weinzierl et al., 2009, TELLUS

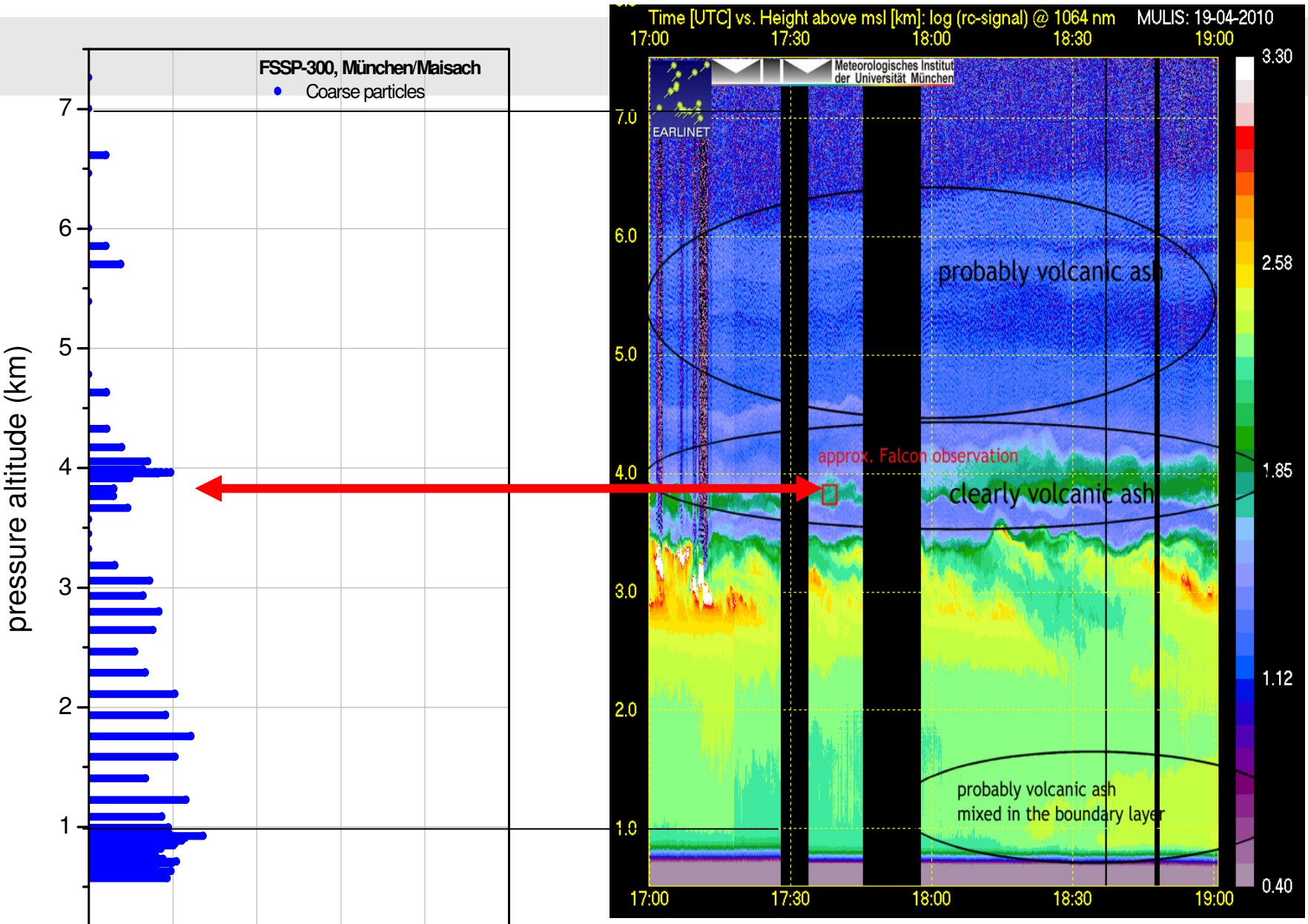

Met Office
Modelled Ash Concentration from FL000 to FL200 at
1200 UTC 16/05/2010
Issue time: 201005160000
This is a guidance product generated from model data and is supplemental to
the official VAAC London Volcanic Ash Advisory and Volcanic Ash Graphic products.
Predicted area where volcanic ash may be encountered
Predicted area of ash concentrations that exceed acceptable engine manufacturer tolerance levels
-30 -20 -10 0 10 20 30 40
65 60 55 50 45 40
© Crown Copyright 2010. Source: Met Office

DLR-Falcon flight over Southern Germany, May 9, 2010



mass loading below 10 µg/m3

<- Measurements performed by the Met. Institute of the LMU Munich



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Vergleich Lidar LMU München & Falcon Messungen

Volcanic ash mass concentrations from aircraft measurement?

- **mass concentration is what everyone wants, but it is not a direct measurement. Estimate is (highly) uncertain at present** for the following reasons:
- total volume (mass) is entirely dominated by supermicron particles
- this size range is only covered by the upper channels of the one instrument, the FSSP-300, in our case
- FSSP-300 gives clear indication of presence of supermicron particles in the volcanic ash plume
- different refractive index (e.g. with/without) absorption can change mass concentration by one order of magnitude!
- density of volcanic ash is not known; values discussed in the community vary between 1 and 3 g/cm^3
- any aircraft aerosol in situ payload not capable of measuring up to some tens of µm particle size will not cover the relevant size range of volcanic ash and is unable to determine mass concentrations in ash