Volcanic Ash Cloud Observations with the DLR-Falcon over Europe during Air Space Closure

Ulrich Schumann, Bernadett Weinzierl, Oliver Reitebuch, Andreas Minikin, Hans Schlager, Stephan Rahm, Monika Scheibe, Michael Lichtenstern, Caroline Forster, Robert Baumann, Martin Wirth, Thomas Sailer, Kaspar Graf, Hermann Mannstein, DLR, IPA

+ many partners (IPA, FB, CNRS-LaMP, TU Darmstadt, IfT Leipzig, LMU München, NILU, Uni. Iceland, DWD, VAAC, DFS, LBA, KNMI, etc.)
April 14 - April 17, 2010: EUMETSAT-DWD-DLR_IPA

processing and animation by K. Graf, DLR-IPA
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, until May 3

- Closure of airspace justified or exaggerated?
- Quality of forecasts?
- Comparable to Saharan dust?
  - What do the lidar instruments see?
  - How to convert particle number concentrations to mass concentration?

- Aviation conditions near Iceland
  - Volcanic source (mass, particle sizes, chemistry)
  - Chemical composition
  - Volcanic dynamics
Falcon 20E D-CMET, DLR Oberpfaffenhofen, since 1976

- **aerosol & trace gas inlet**
  - total & non-vol. aerosol, 3-λ B_{ap}, particle comp. & shape (4 nm - 2.5 µm)
  - CO (UV fluoresc.), O\textsubscript{3} (UV photom.), SO\textsubscript{2} (fluoresc.), H\textsubscript{2}O (τ-point, Ly-α)

- **meteorological measurements**

- **DLR Falcon 20-E5**
  - max. altitude: 42,000 ft
  - max. endurance: 4 h

- **FSSP-300 & 2-DC** (0.3 - 800 µm)
  - DLR & CNRS

- **2-µm-Wind-Lidar** (heterodyne)

- **PCASP-100X** (dry accumulation mode concentration)

- **GP\textalpha C** (particle collector)
  - TU Darmstadt
Nine DLR Falcon flights, April 19 - May 2: OP - Iceland

OP – Keflavik: 2700 km

range-corrected backscatter signal @ 2 µm
Vulcanic ash layer over Leipzig, April 19, 2010, 15:00 UTC
19 April 2010: Vertical profile measurements over Leipzig

Leipzig lidar

DLR-Falcon, 14:50 - 15:30 UTC

(If Leipzig: A. Ansmann, M. Tesche, P. Seifert et al.)
Lagrangian: Iceland - North Atlantic - Ireland - Scotland

(29/04/2010: 50 km distance, arriving in Iceland)
01/05/2010: (8-)200 km distance, 62.5 N, 16.5 W, 11:44 UTC, 1-5 km altitude
  (age < 3.7 h)
02/05/2010: 450 km distance, 15 W, 60 N, 15:00 UTC, May 2, 2010, age 7 h
04/05/2010: Mace Head, W, N, ? UTC, May 4, 2010, age about 60 h
05/05/2010: ARSF and FAAM (U Manchester), Scotland airborne, age about 80 h
Eyjafjallajökull volcano plume, 29 April, late afternoon time
Eyjafjallajökull volcano plume, May 1, noon time
Eyjafjallajökull volcano plume, May 1, noon time
Plume and Keflavik (Iceland) soundings, May 1

plume sounded 1st time

range-corrected backscatter signal @ 2 µm

Volcanic ash plume

Ci clouds

St Cu clouds

Eyjafjallajökull

7.4 km

60 km

N
Simulated (HYSPLIT) cross-section of the plume

HYSPLIT model, GDAS 1x1°, 7 particle size classes, line-source from 1.7 km to 4.5 km height a.s.l., mass flux 5000 t/h in 0-50 µm size-range
From Keflavik to Stornoway, May 2

Plume sounded and sampled, 2nd time

range-corrected backscatter signal @ 2 µm

570 km

N

Outer Hebrides

Iceland

Eyjafjallajökull
North Atlantic (60° N): 15 minutes before flying into the plume
Mass concentrations in the plume over the North Atlantic

May 2, 2010 - 60°N

PCASP-100X
- FSSP-300, m = 1.54 + 0.0i
- FSSP-300, m = 1.50 + 0.0008 i

no signal in the 2-DC probe (D_p > 30 µm)!

\[ dN / d\log D_p \text{ (cm}^{-3}\text{)} \]

\[ \text{particle diameter (µm)} \]

\[ \text{distance settled within 7 h (km)} \]

\[ \text{Deff 26 µm} \]

\[ \text{Deff 7 µm} \]

\[ \text{m = 1.54 + 0i} \]

PM2.5 10 µg/m³
FSSP-300 "total" 400 µg/m³

\[ \text{m = 1.50 + 0.008i} \]

PM2.5 10 µg/m³
FSSP-300 "total" 3400 µg/m³

...assuming a particle density of 1 g/cm³

(273 K, 1013 hPa, no turbulence)
In-situ chemistry in the plume over the North Atlantic

450 km dist., 15 W, 60 N, 15:00 UTC, 02/05/2010, age 7 h

3 min in volcanic ash plume, 3400 – 3700 m altitude (FL 110 und 120):

$O_3$ mixing ratio decrease
CO increase
CO correlates with $O_3$
$SO_2 > 150$ nmol/mol (outside 0.1 nmol/mol)
$H_2O$-RH: reduced to 45 % (outside: 70 %) – adiabatic warming?

Ozone-CO correlation
inside Plume (54660–54900 UTC sec)
Vulcano Ash F8 Keflavik - Stornoway f100502a

preliminary data, to be used for quicklook purposes only

$VMR(O_3) = -3 \times VMR(O_3) + 290$ nmol/mol
$r = 0.89$
Conclusions (science & operations)

- Falcon measurements between April 19 and May 3, 2010: 2- µm-Lidar, in-situ aerosols, CO, O₃, SO₂, H₂O
- Particles sizes 10 nm - 30 µm age dependent (mainly silicate, ammonia sulfate, more Na, K than in Saharan dust),
- Mass loading (60 µg/m³, Leipzig, 5 days) comparable to Saharan dust (< 0.2 mg/m³)
- 200 km distance, 3-4 h age: 40 km wide, 2 km thick, 15 m/s, sharply edged, strong wet convective turbulence, well mixed?
- 450 km distance (same plume), 7 h age: at upper plume edge: 400- 3400 µg/m³, no 2-DC probe particles, mass flux > 3000 kg/s, strong chemistry
- Lidar signal and FSSP-300 signal strongly dependent on refractive index, ash density, particle size spectrum 1- 50 µm

- Mid-European airspace closure justified until Sat. April 17; then ageing of ash load
- Keflavik/Iceland free of ash as predicted on April 19 - May 2
- Quality of forecasts reliable enough for aviation
- Future: Combination of models + lidar + satellite + in-situ
- Improved linking between operations and academia
- Continue operations of the DLR Falcon as Emergency Aircraft
Further Falcon Flights

May 9: Southern Germany: < 10 μg/m3; questionable air space closure

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

May 18: Thin ash cloud over Germany (Lidar Stuttgart)
Institut für Physik der Atmosphäre

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

17:53 UTC: profile measurements at Munich airport and over Maisach lidar

mass loading below 10 \( \mu g/m^3 \)

<- Measurements performed by the Met. Institute of the LMU Munich
Guided by MSG ash product: Falcon observes heavy VA plume
Satellite image with Falcon track, volcano ash plume reaching Amsterdam at about 19:00 UTC

colours to compare approximately with VAAC predictions
Particle size distribution; 0.1 to 25 μm diameter: derived mass concentration assuming refractive index 1.54+0i and density 3 g/cm³: 450 μg/m³ ± 50 %
UV LIDAR CABAUW: Falcon-traced ash plume arrived at Cabauw, NL, 16:30 UTC

cesar_uvlidar_backscatter_la1_t30s_v1.0_20100517.nc

Time [Hrs] UTC

cesar_uvlidar_backscatter_la1_t30s_v1.0_20100517.nc

Time [Hrs] UTC
Further Conclusions, after 5 weeks with 51.5 Falcon flight hours

- Falcon measurements between April 19 and May 18, 2010: 2-μm-Lidar, in-situ aerosols, CO, O₃, SO₂, H₂O
- Falcon confirms MSG ash product at least qualitatively
- Further in-situ data for comparison to Lidar observations

- The set of flight paths data (waypoints versus time) are available on the internet with permit of BMVBS/DWD
- DLR offers comparison of Falcon in-situ (CO, O₃, SO₂, H₂O, particles, mass concentration) and 2-um-Lidar data with any other available data. Contact via Ulrich Schuman

- Southern German airspace closure Sun. May 9, 6 days aged VA: questionable
- Closure over UK, May 16, 1-2 days aged plume: fully justified
- Fresh and heavy VA is well predictable - >3 days aged VA: far more difficult
- 1 hour of flight in VA ash of 450 um/m³: no Falcon engine problem detected
- Next: HSRL on HALO