In-situ measurements of the Eyjafjallojökull ash plume with small aircrafts and optical particle spectrometers over north-western Germany and Iceland - comparison between the aircraft measurements and the VAAC-model

WEBER,K., VOGEL, A., FISCHER, C., VAN HAREN, G.; POHL, T.;
University of Applied Sciences, Duesseldorf, Germany

ELIASSON, J.
University of Island, Reyjkjavik, Island

GROBETY,B., MEIER,M.,
University of Fribourg, Switzerland

Geneva, 19 October 2010

Fachhochschule Düsseldorf
University of Applied Science

Pictures

Fachhochschule Düsseldorf
University of Applied Science

In this presentation

- examples of measurement flights of the University of Applied Sciences Duesseldorf with and without ash plume over Germany
- examples of measurement flights of the University of Iceland within the boundary and outside the ash plume on Iceland
- aspects of now on-going measurement flights on Iceland in the resuspended ash plume

Context to dispersion models:

- airborne in-situ-measurement data
  - could be used for improving and “calibration” of the dispersion models
  - could be used in the emergency case to deliver input data for dispersion models and direct on-line information for air-traffic and decision makers

Fachhochschule Düsseldorf
University of Applied Science

Measurements of the University of Applied Science Duesseldorf over North-Western Germany

- In the time from 23th of April until 21th of May
- 14 flights with a light sport aircraft, additional 4 flights for visual observations, referencing and transfer
- Detection of the volcanic ash plume over north-western Germany and comparison of the values with the predictions by the VAAC
- Measured in altitudes up to 4500 m
- Flights covering parts of northern and western Germany (From Bitburg/Aachen to Hamburg)

Fachhochschule Düsseldorf
University of Applied Science

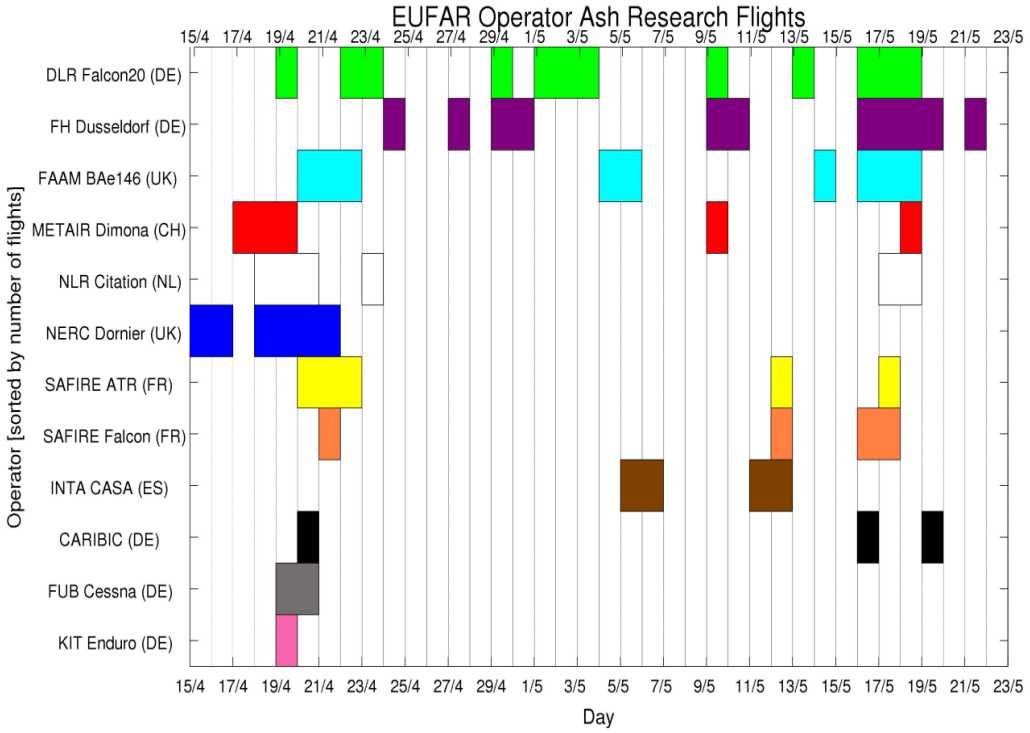
Measurement Setup

- In-situ OPC (optical particle counter) Grimm 1.107
  - Measures particles in 31 channels
  - In a range between 250 nm and 32 µm
  - On-line results are available
- Isokinetic sampling device
  - Suitable for a measurement velocity from 90 km/h up to 120 km/h
- GPS, meteorological parameters and flight parameter

- Measurement setup upgraded in one flight with other systems, e.g. passive DOAS (SO2), CO2-measurement system

Fachhochschule Düsseldorf
University of Applied Science

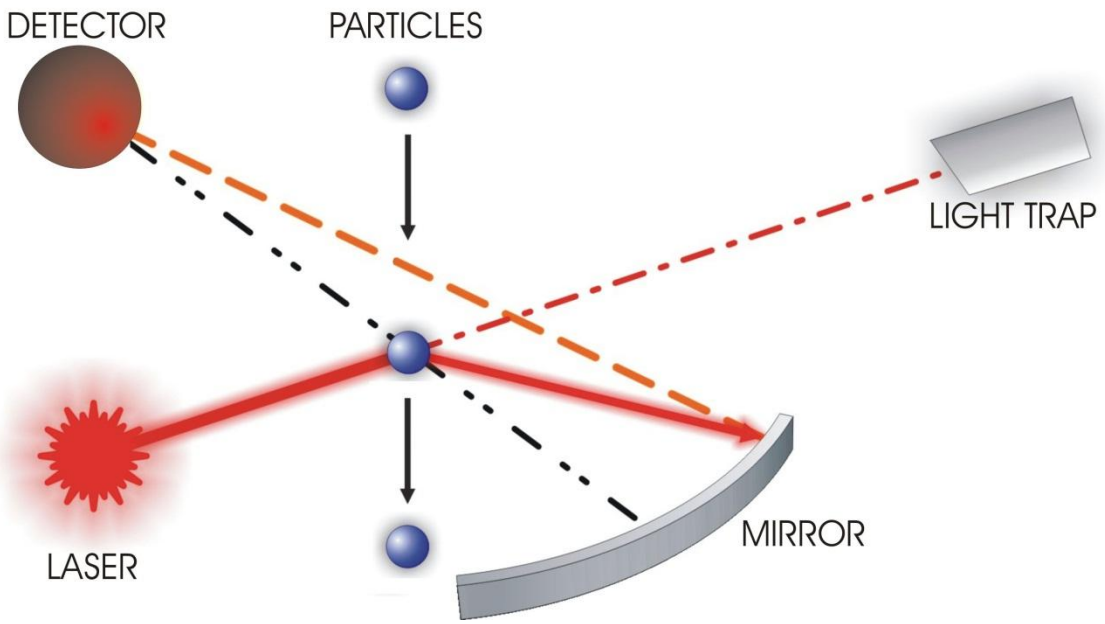
Overview about measurement flights in central Europe



Additional flights were performed by the BAZL Switzerland and the University of Iceland

Optical particle counter (OPC)

Measurement principle, orthogonal laser scattering



Light sport aircraft

Light sport aircraft: Flight Design CTSW Shortwing

- Velocity between 90 and 260 km/h
- Travelling distance typical 1500 km
- Maximum cruising altitude: 4500 m

Fachhochschule Düsseldorf
University of Applied Science

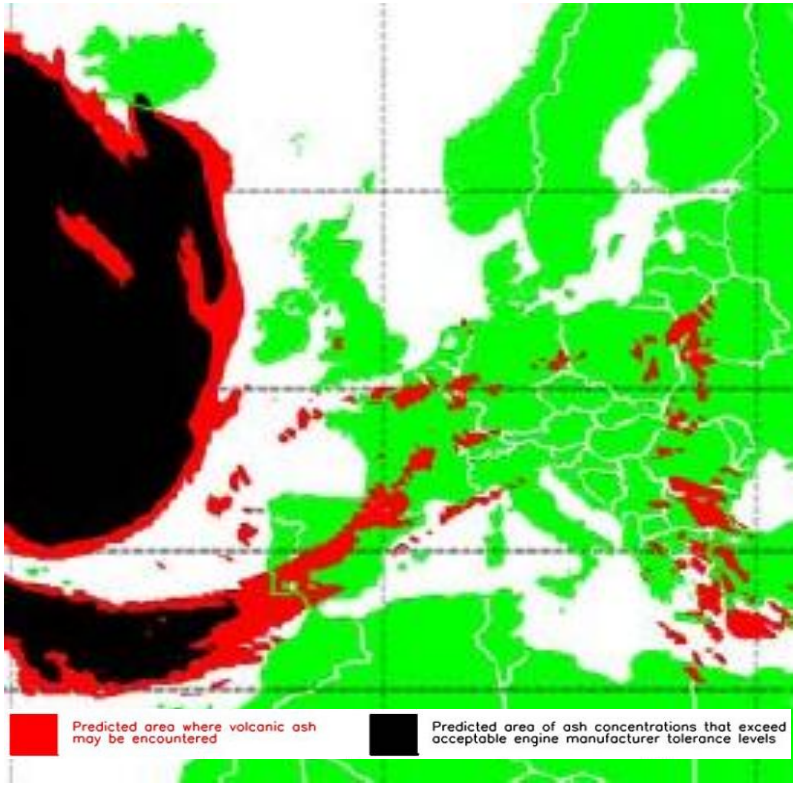
Different ash plume situations

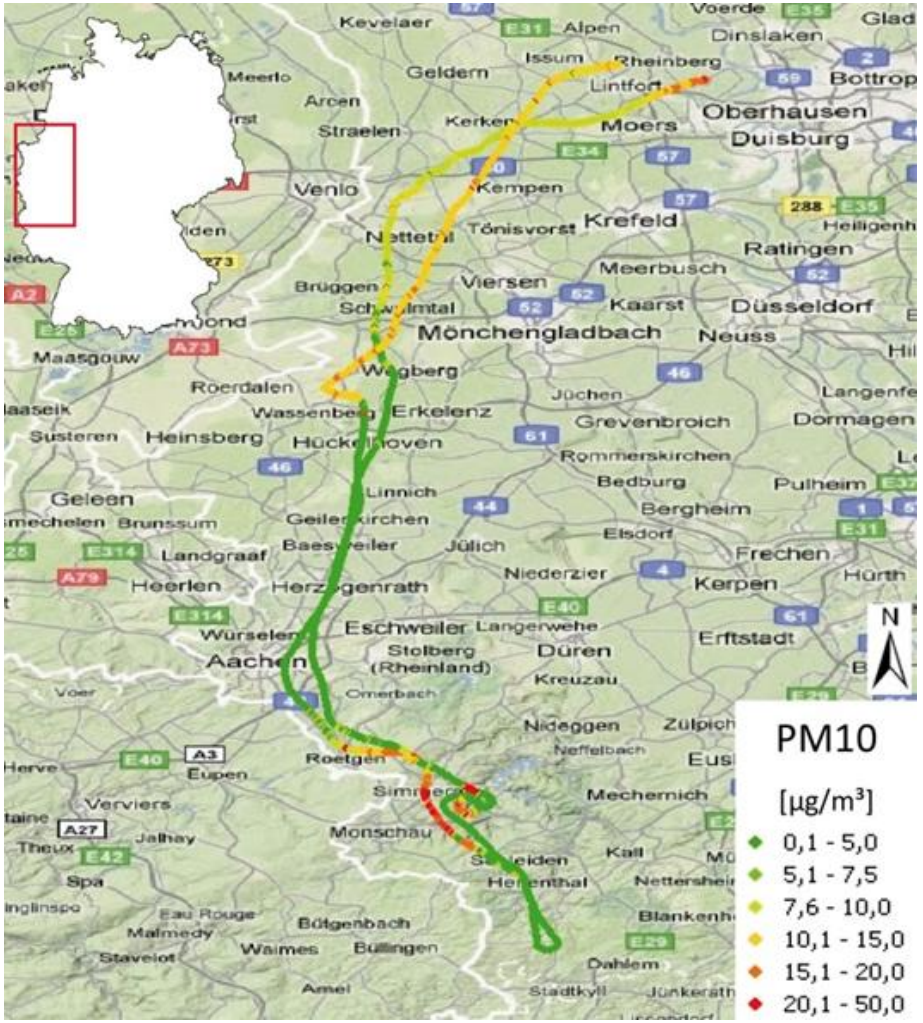
Three typical examples of ash plume situations:

- Ash plume locally predicted over Germany
- „Red zone of ash plume“ predicted over Germany
- No ash plume predicted over Germany

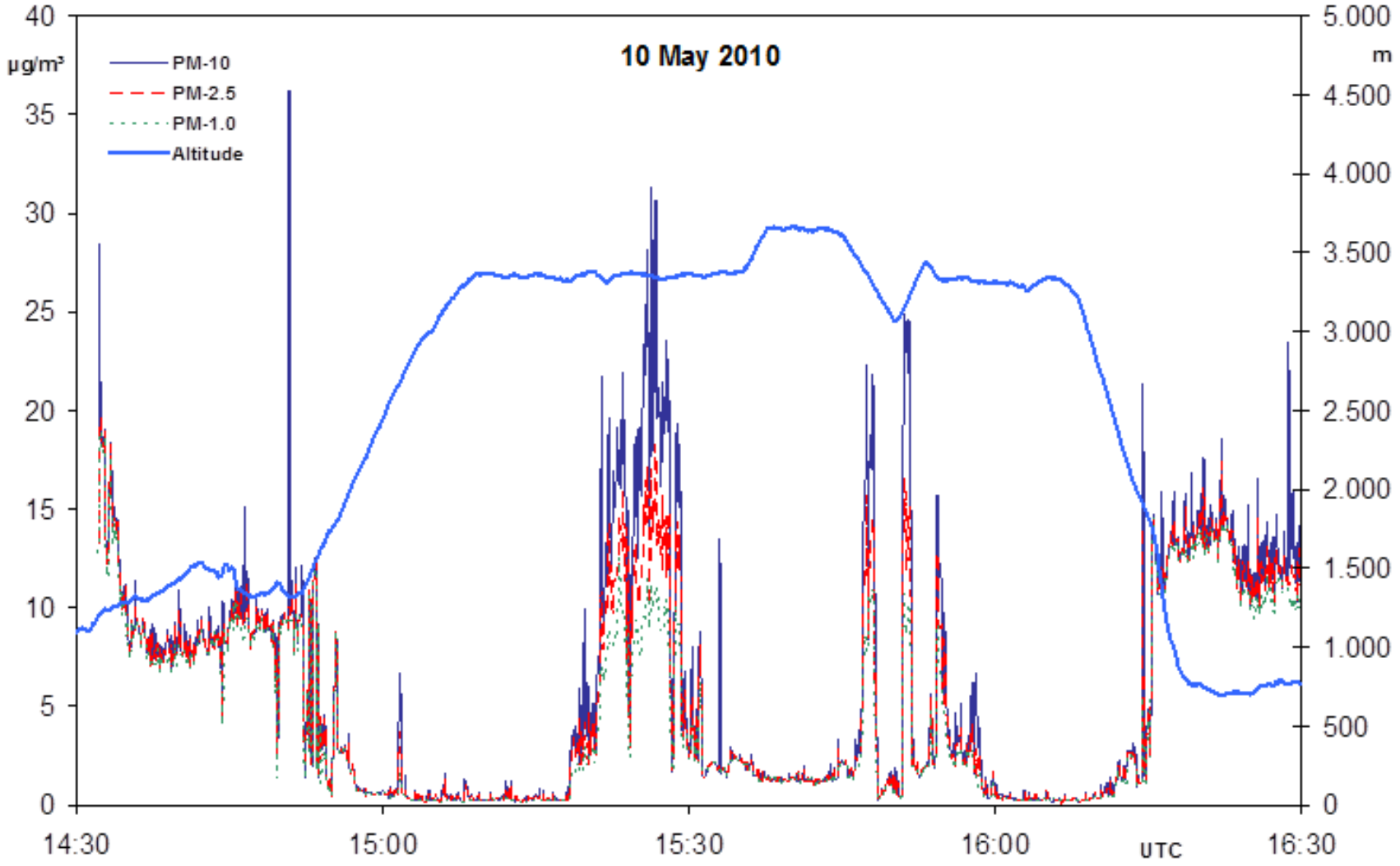
10 May 2010

- **Ash plume locally predicted over Germany**



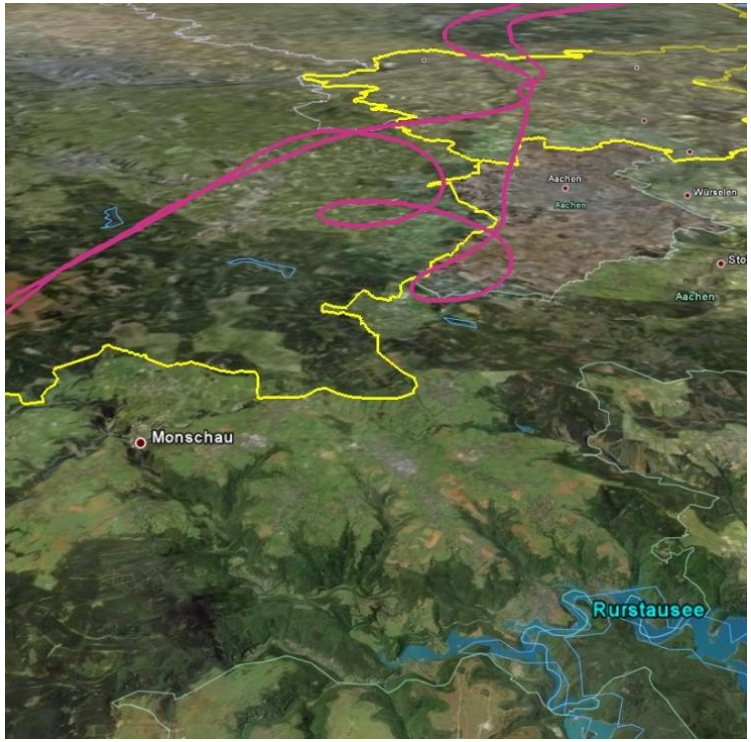


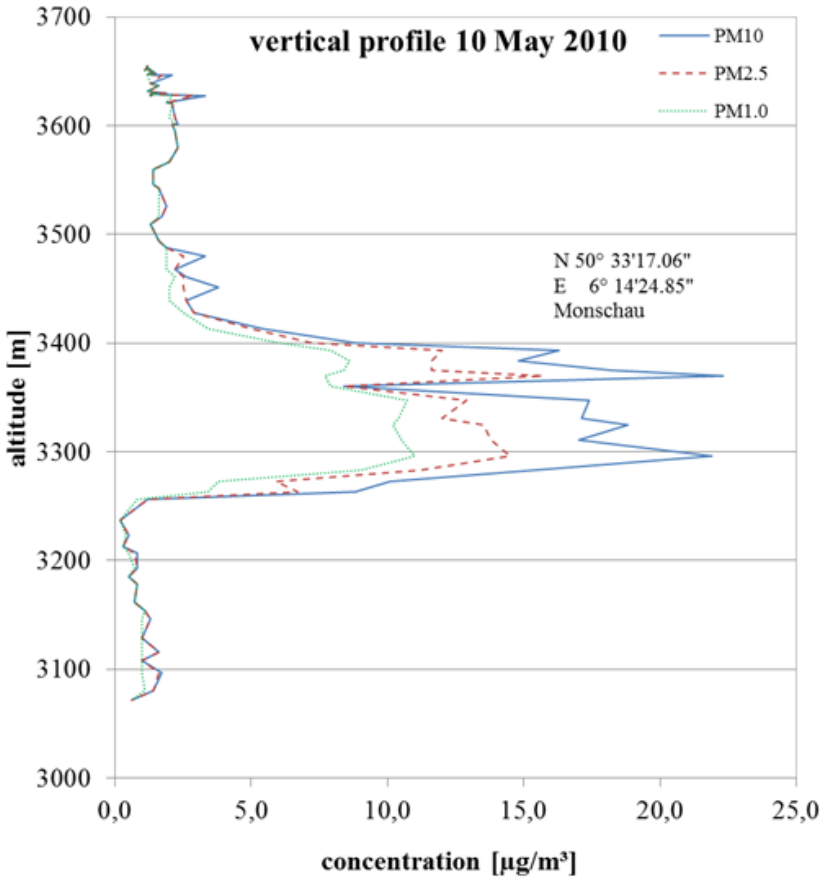
10 May 2010


10 May 2010
µg/m³
m
PM-10
PM-2.5
PM-1.0
Altitude
40
35
30
25
20
15
10
5
0
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
500
0
14:30
15:00
15:30
16:00
UTC
16:30

10 May 2010

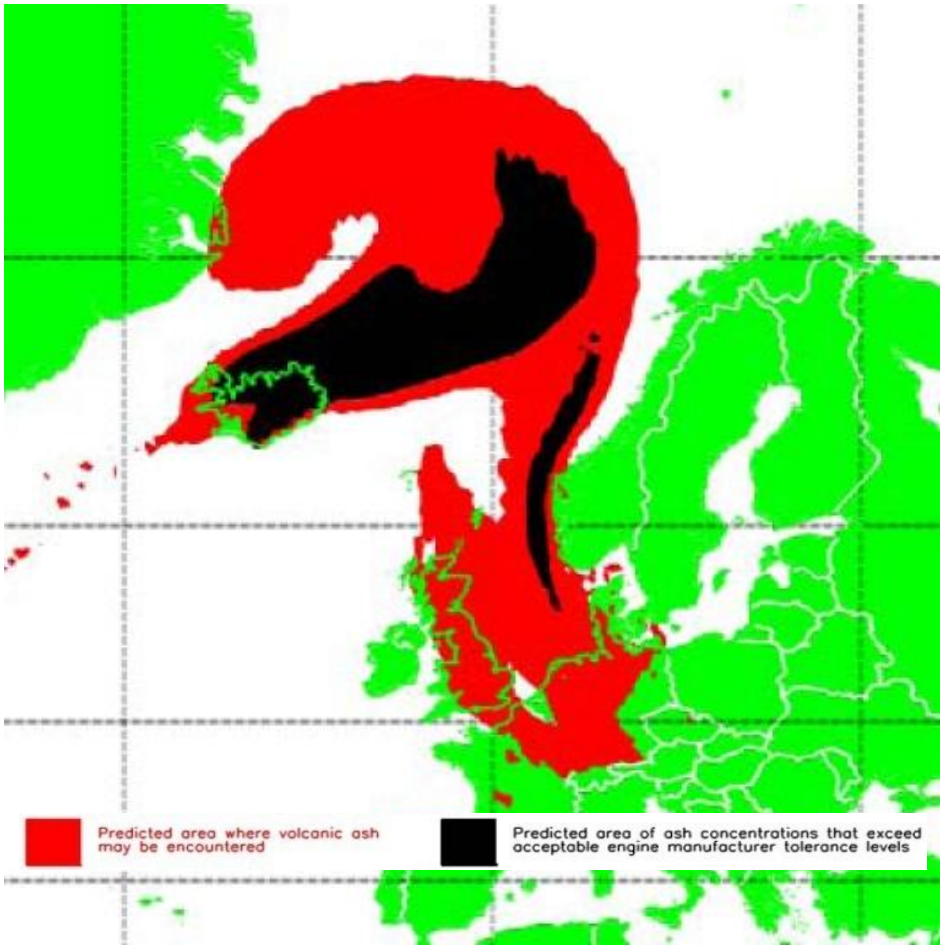
- **Verticale Profile**





18 May 2010

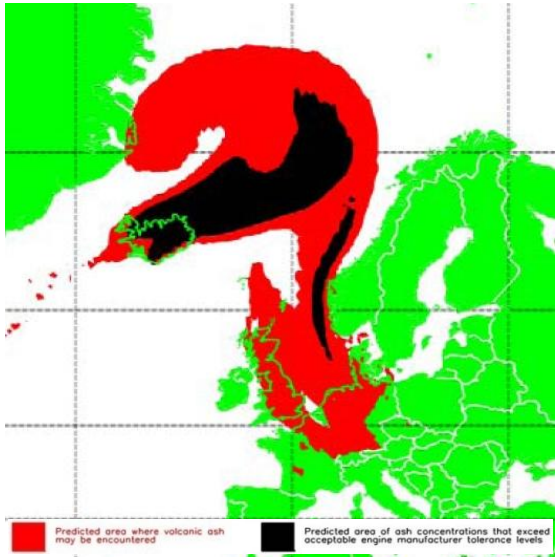
- **Red warning zone of ash plume predicted over Germany**



Fachhochschule Düsseldorf
University of Applied Science

18 May 2010

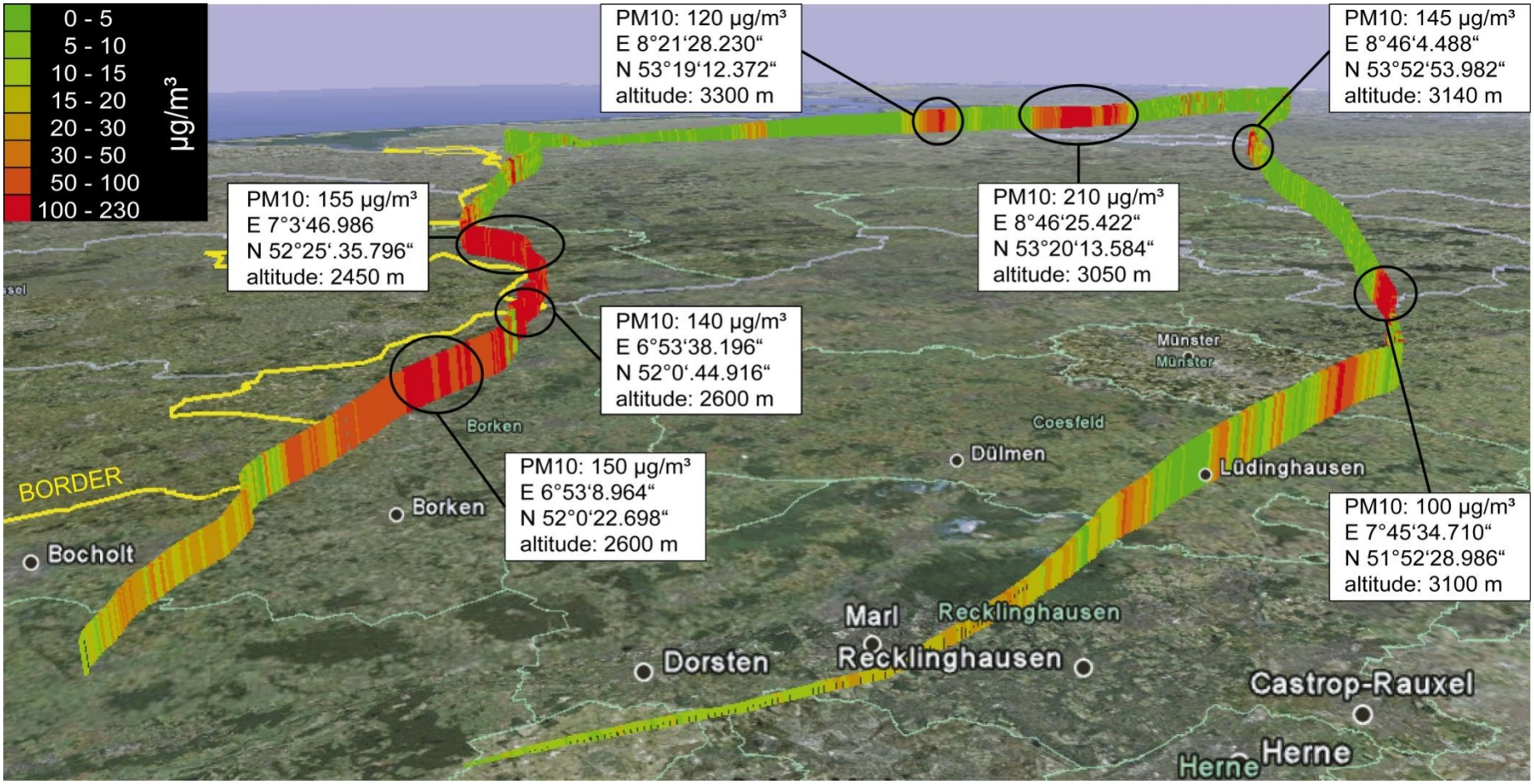
- **Red warning zone of ash plume predicted over Germany**



Fachhochschule Düsseldorf
University of Applied Science

18 May 2010

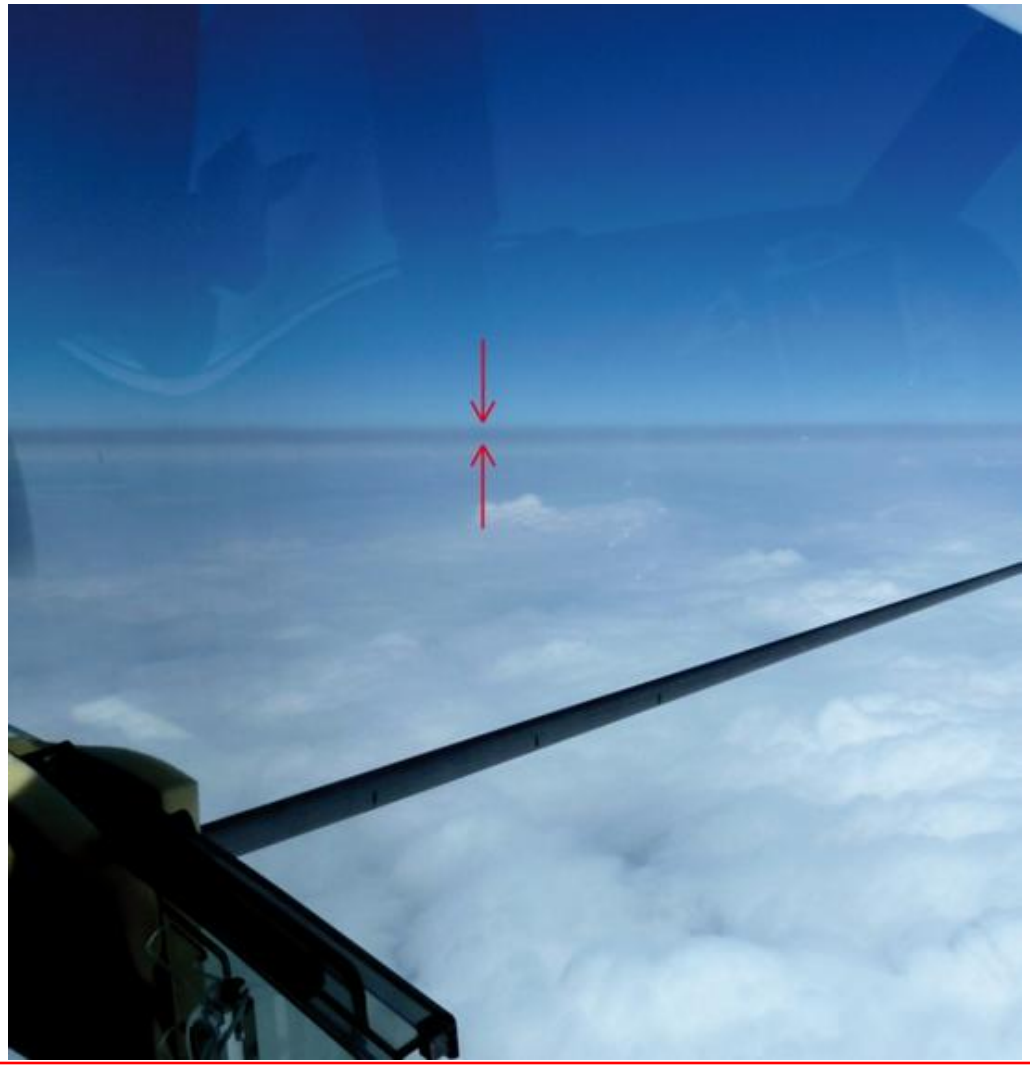
- **Flight track, red warning zone of ash plume predicted over Germany**



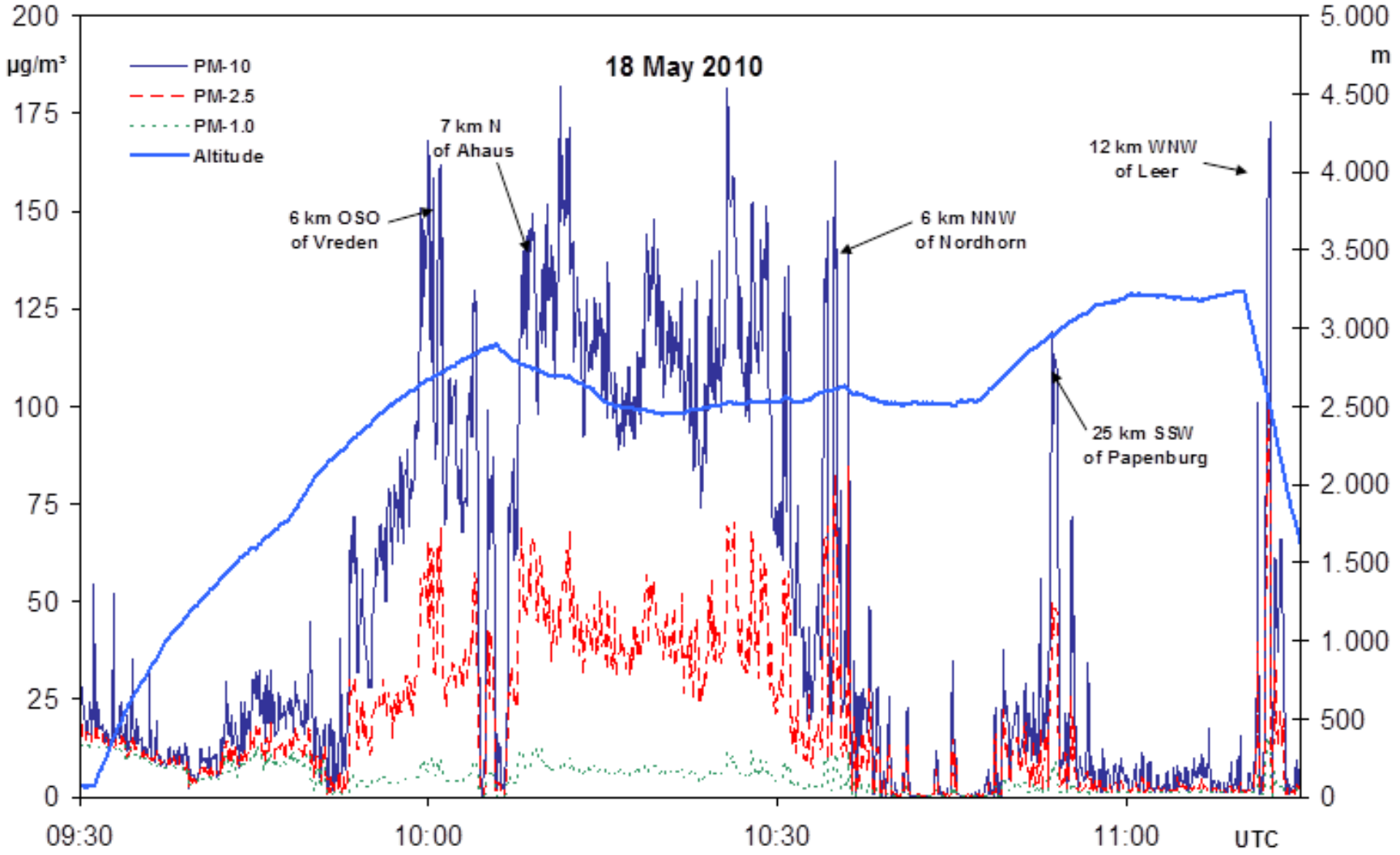
18 May 2010

Layer of ash visible from the aircraft during flight in horizontal direction

Sometimes double structure visible

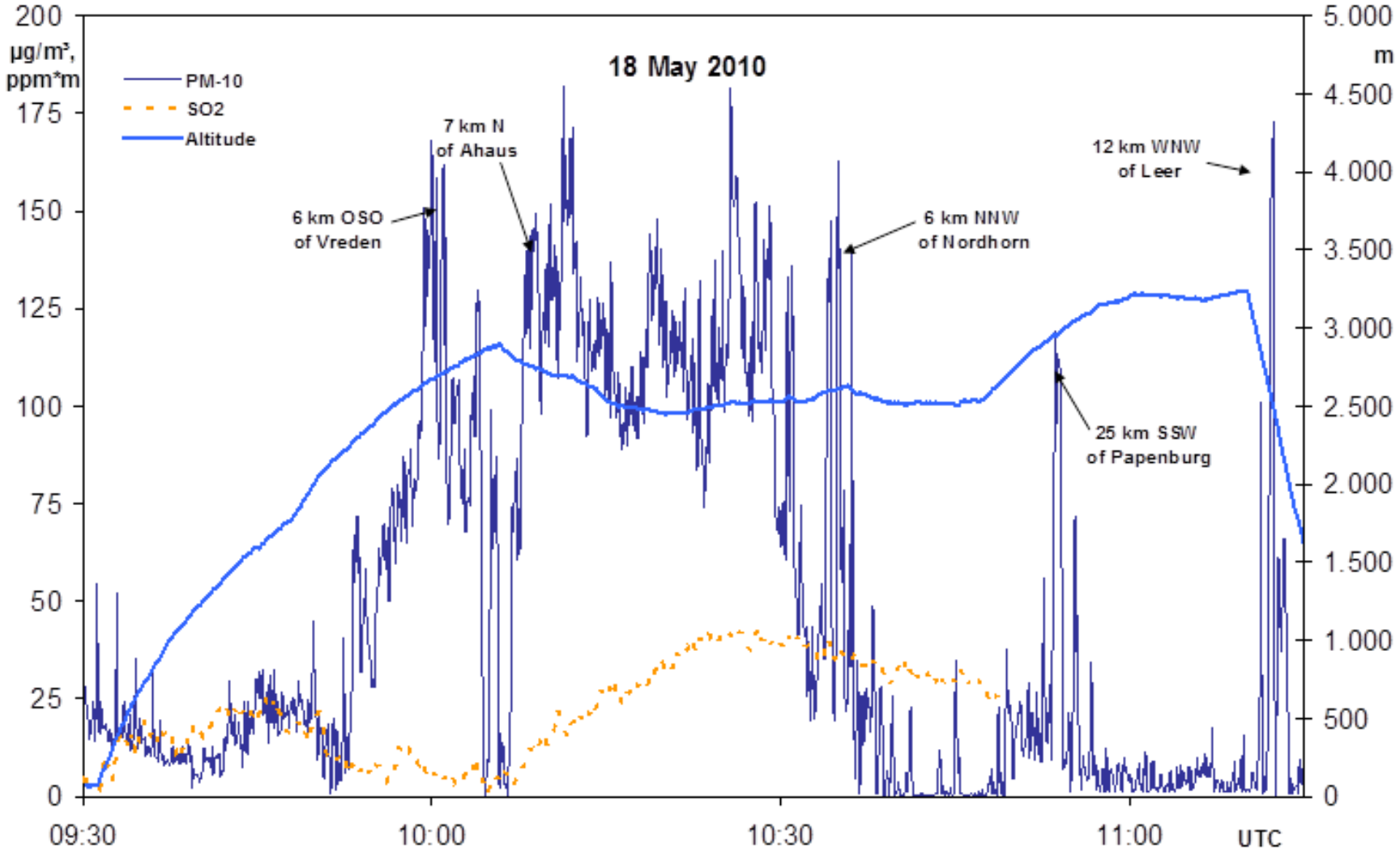


18 May 2010

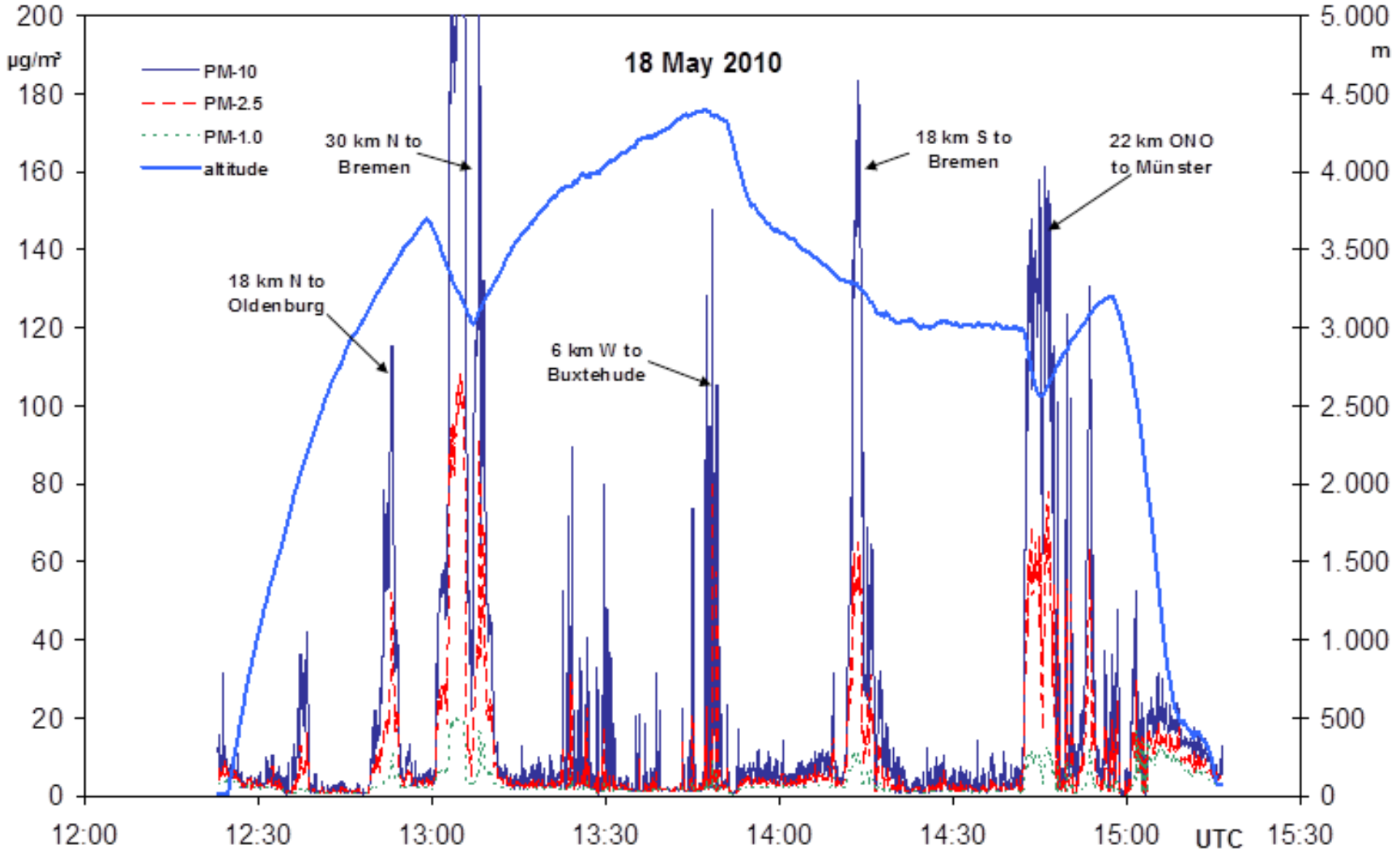

18 May 2010
µg/m³
m
PM-10
PM-2.5
PM-1.0
Altitude
7 km N of Ahaus
6 km OSO of Vreden
6 km NNW of Nordhorn
12 km WNW of Leer
25 km SSW of Papenburg
200
175
150
125
100
75
50
25
0
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
500
0
09:30
10:00
10:30
11:00
UTC

Fachhochschule Düsseldorf
University of Applied Science

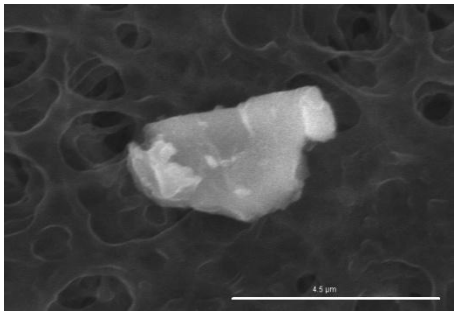
18 May 2010



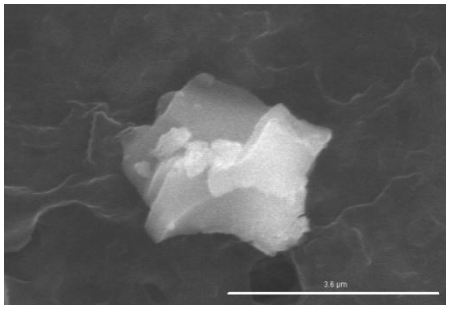
18 May 2010


18 May 2010
µg/m³
m
PM-10
PM-2.5
PM-1.0
altitude
30 km N to Bremen
18 km S to Bremen
22 km ONO to Münster
18 km N to Oldenburg
6 km W to Buxtehude
200
180
160
140
120
100
80
60
40
20
0
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
500
0
12:00
12:30
13:00
13:30
14:00
14:30
15:00
UTC
15:30

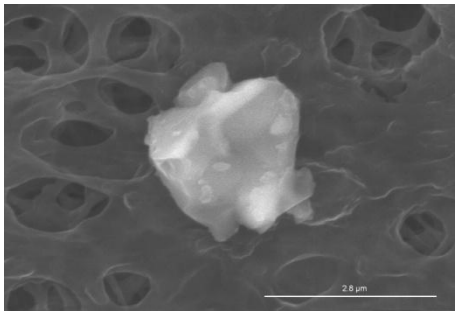
Airborne particles in ash plume



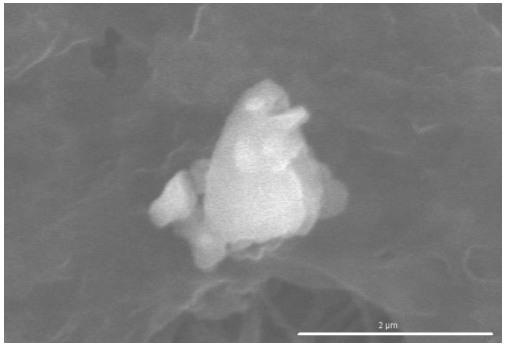
4,5 µm



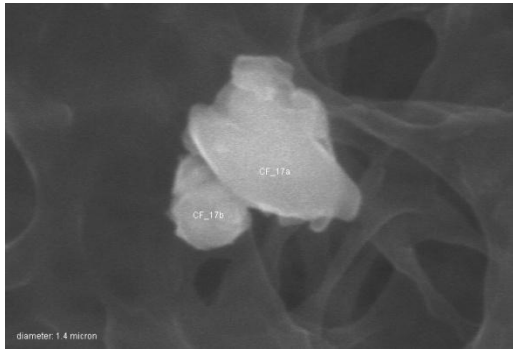
3,6 µm



2,8 µm



2 µm

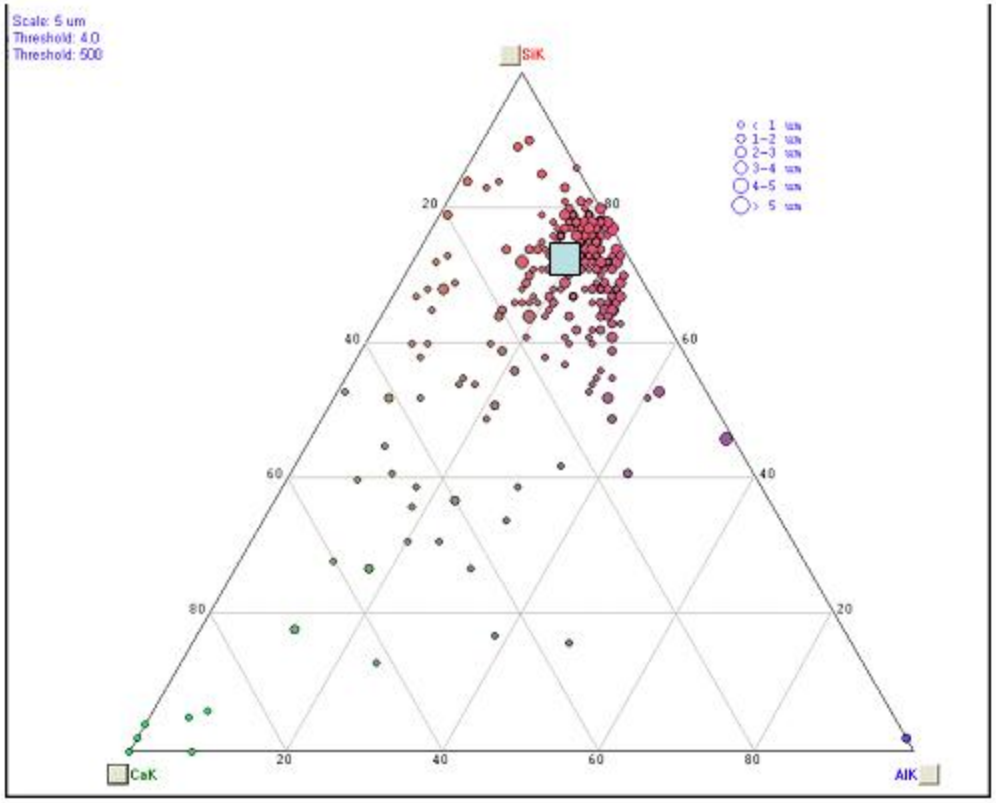


1,4 µm

Examples of particles found during the measurement flight on 18 May 2010

Fachhochschule Düsseldorf
University of Applied Science

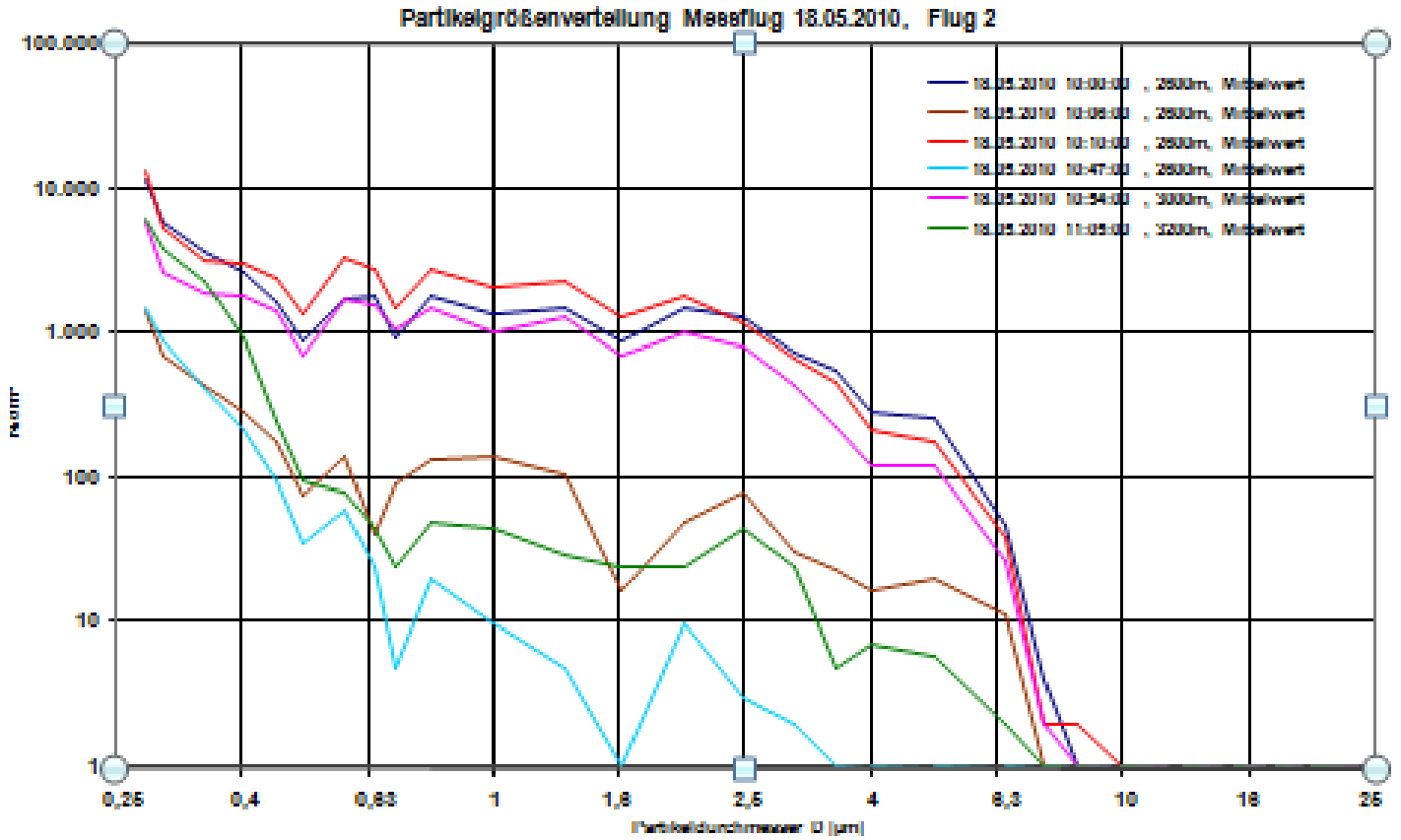
Airborne particles in ash plume



- Ternary (Si-Ca-Al) diagram of particles from the airborne sample on 18 May 2010. The blue box corresponds to the average composition of Eyafjallajökull volcanic ash sampled on Iceland

Fachhochschule Düsseldorf
University of Applied Science

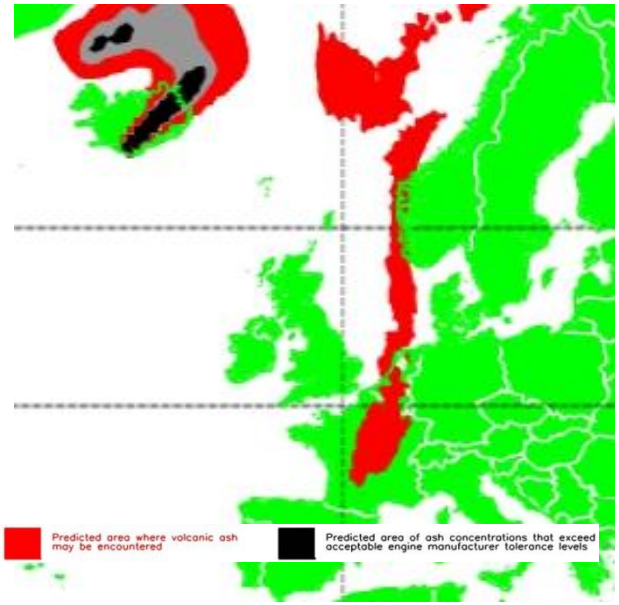
Airborne particles in ash plume



Example of particle size distribution during on 18 May 2010

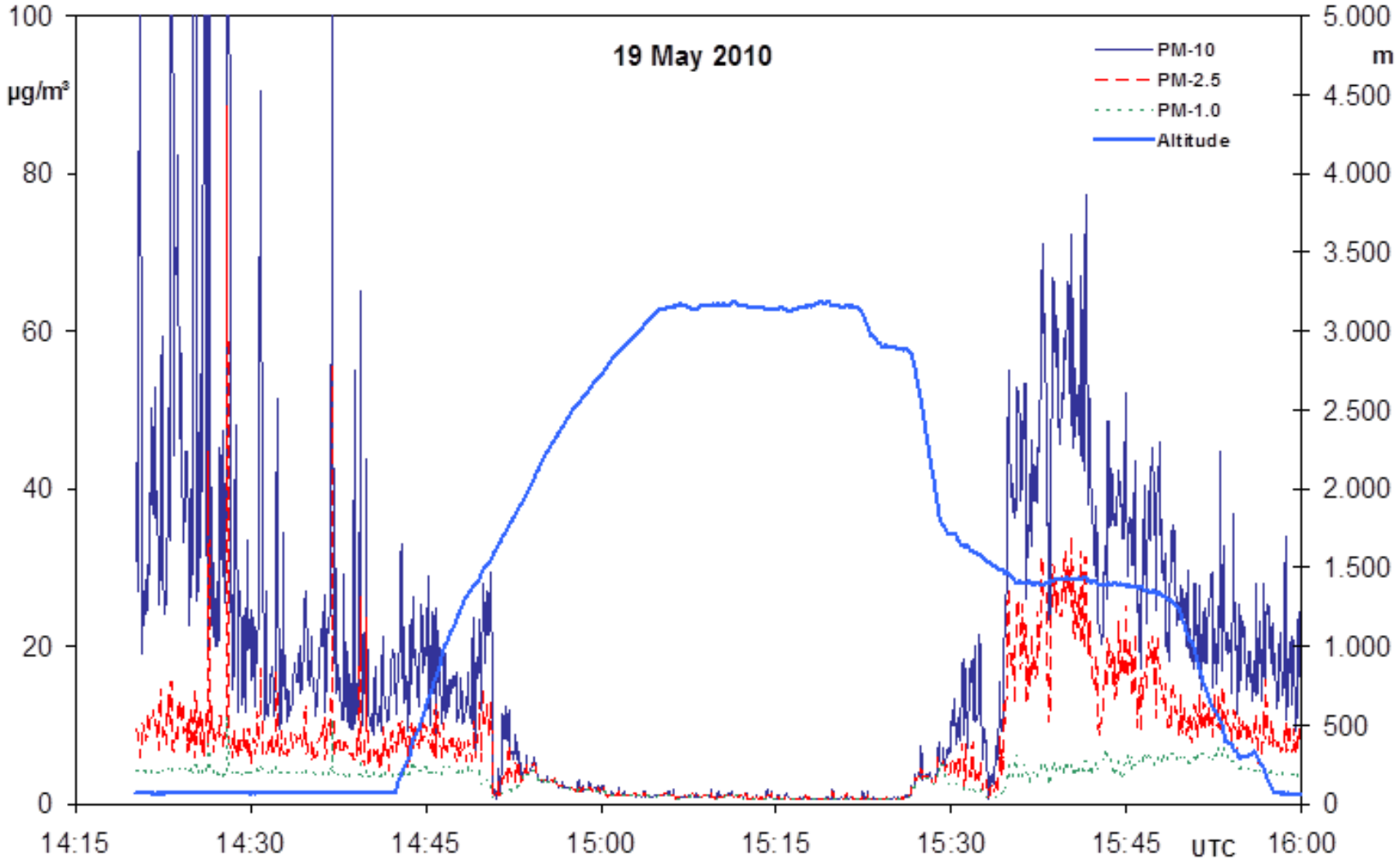
19 May 2010

- **no ash plume predicted over Germany**



Fachhochschule Düsseldorf
University of Applied Science

19 May 2010



Fachhochschule Düsseldorf
University of Applied Science

Conclusions

- The „ash plume“, found by the aircraft measurement of the Duesseldorf University of Applied Sciences over north western Germany in the “red zone” predicted by the VAAC turned out to be inhomogeneous during the measurement flights
- Clusters of ash plume sometimes had only a height extension of several hundred meters or less
- Ash substructures with a horizontal extension of ten kilometres up to several tenth of kilometres could be found
- Vertical double structures of ash plume could be measured by spiral flights and could be observed visually in horizontal direction
- Ash plume could be observed visually as small brown layer in horizontal direction
- Particles collected during flight could be identified as ash particles by electron microscope analysis and chemical analysis

Fachhochschule Düsseldorf
University of Applied Science

Conclusions

- Clusters of ash plume with peak concentrations of more than 150 µg/m3 up to 230 µg/m3 could be detected within the „red zone“ of VAAC prediction in a height between 2500 – 4500 m
- Our measurements support the predictions of the VAAC model

- Optical Particle Counters based on a piston motor driven aircraft proved to be a versatile tool for measurements of the ash plume
- Advantages of a piston motor driven aircraft: very cost effective, robust, slow possible measurement speed, so highly spatial resolved particle measurements are possible

Measurement flights performed by the University of Iceland

Measurement flights performed by the University of Iceland between 9 May and 11 May 2010

In this presentation:

- Measurement situations outside the ash plume in Iceland
- Measurement situations within the boundary of ash plume in Iceland

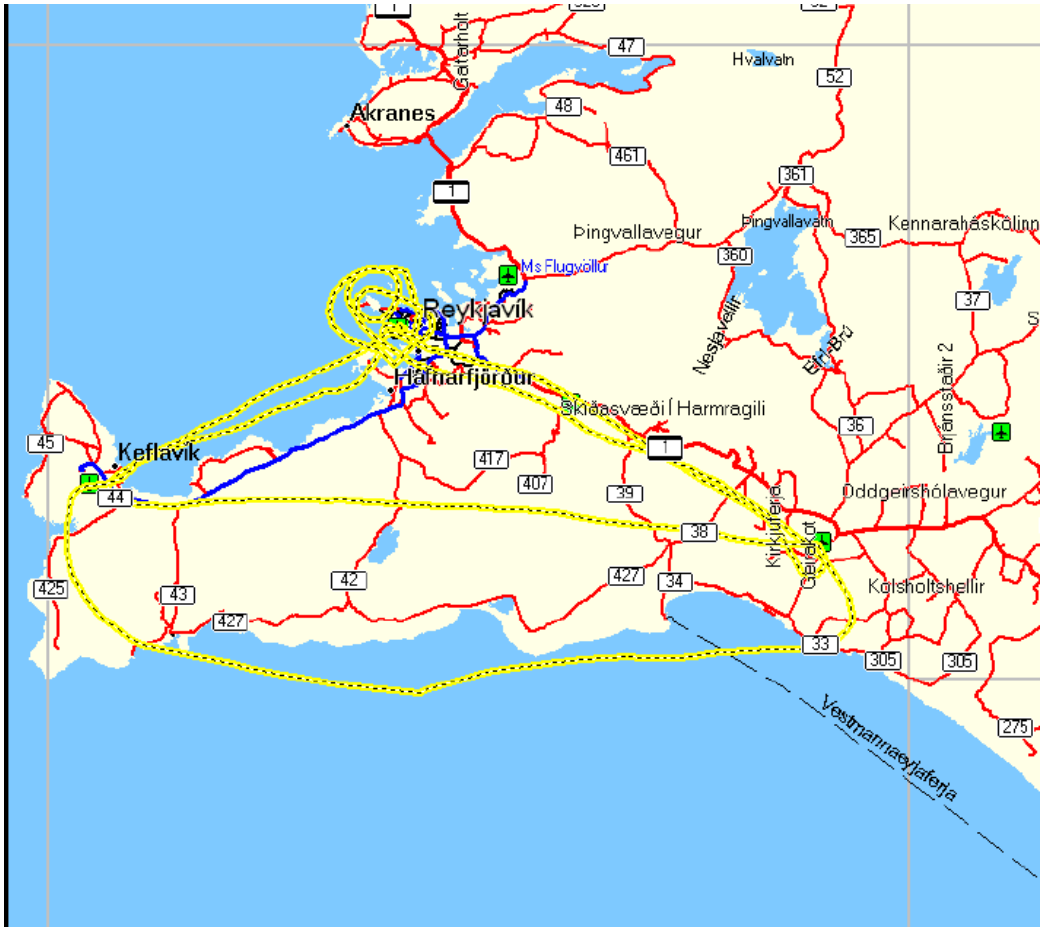
Cessna 206

aircraft: Cessna 206

- Typical Cruising Speed between 240 km/h and 250 km/h
- Typical measurement speed 135 km/h – 200 km/h
- Maximum travelling distance about 1600 km

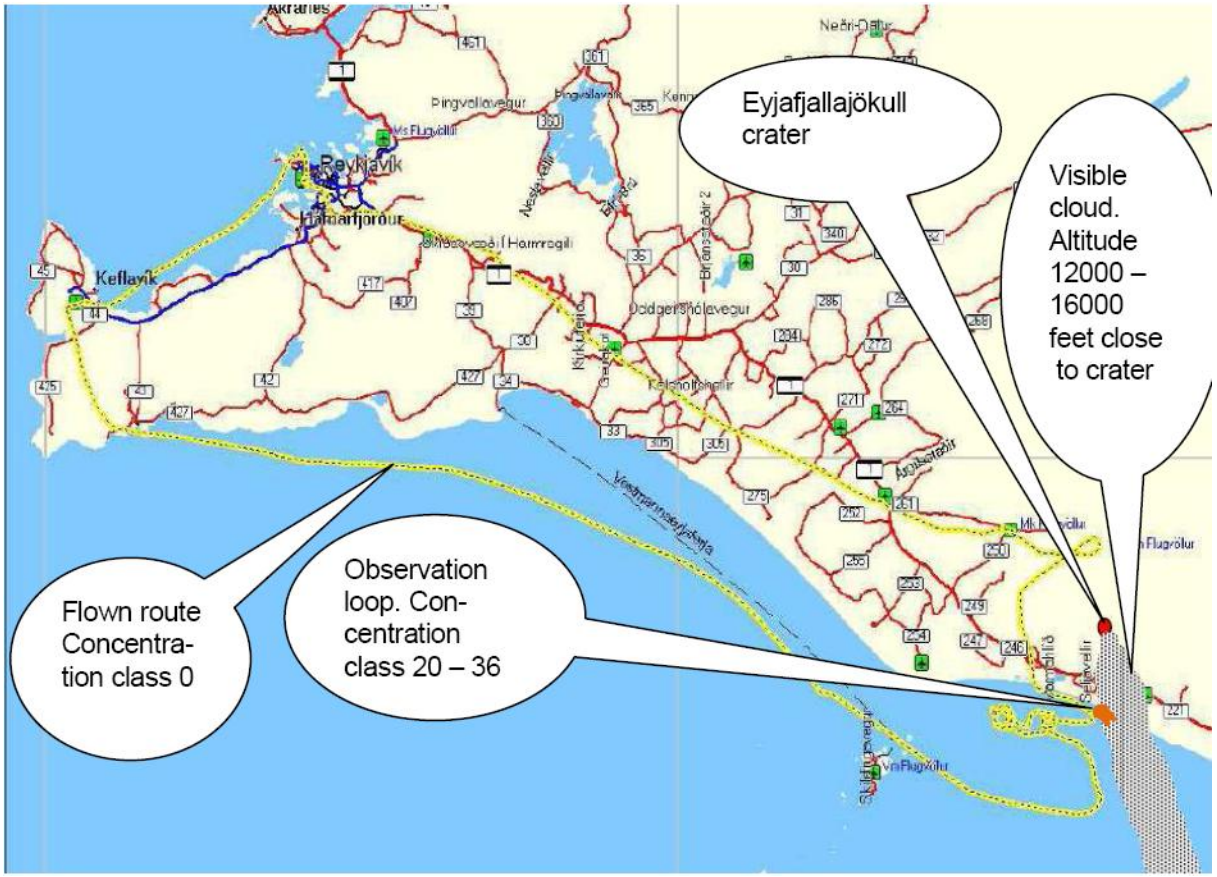
Observation flight 9 May 2010

- Plume height 12000 – 16000 feet variable
- Wind from NNW 30 – 40 knots in 10000 feet
- Insignificant pollution (Class 0) observed
- Clear sky with occasional drifting clouds, no rain
- Overall impression: No problem for aircraft
- Conversion to µg/m³: (Class no + 1)x50



Fachhochschule Düsseldorf
University of Applied Science

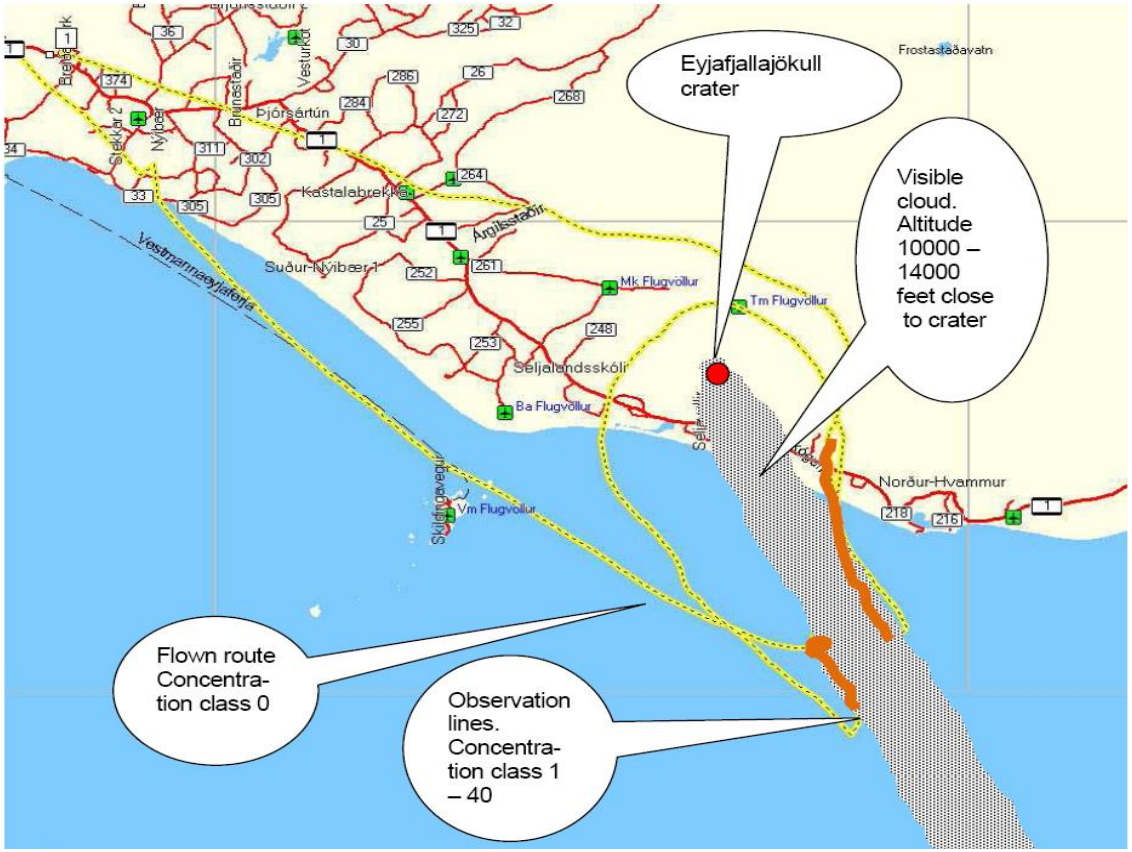
Observation flight 10 May 2010



Plume height 12000 – 16000 feet variable. Wind from NNW 30 – 40 knots in 10000 feet. Insignificant pollution (Class 0) observed outside visible ash cloud. Overall impression: No problem for aircraft keeping safe distance from visible cloud. Weather: Clear sky with occasional drifting clouds, no rain.

Fachhochschule Düsseldorf
University of Applied Science

Observation flight 11 May 2010



Plume height 10000 – 14000 feet variable. Wind from NNW 30 – 40 knots in 10000 feet. Insignificant pollution (Class 0) observed outside visible ash cloud. Pollution measured on the visible cloud boundary, flying through drifting cloud puffs. Results varied 10 – 40 inside the puffs, 1 – 10 outside. Color of cloud: Dark grey close to the crater, white on top over the sea, darker below. Air turbulence in cloud low. Overall impression: No problem for aircraft keeping safe distance from visible cloud.

Weather: Clear sky with occasional drifting clouds, no rain.

Fachhochschule Düsseldorf
University of Applied Science

Conclusions of the observations on Island

- Concentrations above 2000 – 3000 $\mu g/m^3$

  make VISIBLE CLOUD. This seems to be the same as the JET ENGINE LIMIT so for commercial airliners DANGEROUS ASH CLOUDS ARE VISIBLE
- Concentrations outside cloud : VERY SMALL
- Crosswind measurements inside the cloud are possible from light aircrafts (manned or unmanned) with commercial instrumentation

Fachhochschule Düsseldorf
University of Applied Science

On-going and future research

- The University of Iceland and the University of Applied Sciences Duesseldorf started a joint work for optimisation of the instrumentation for particle measurements on small piston motor driven aircrafts

- Systems and aircrafts are going to be tested and compared within the resuspended ash plume on Iceland

- Systems are going to be tested and compared within the laboratory (e.g. wind tunnel experiments and dust tunnel experiments, comparison with gravimetric absolute mass samplers)

Fachhochschule Düsseldorf
University of Applied Science

On-going and future research

Eyjafjallajökull in August 2010

Resuspended ash plume in August 2010

On-going and future research

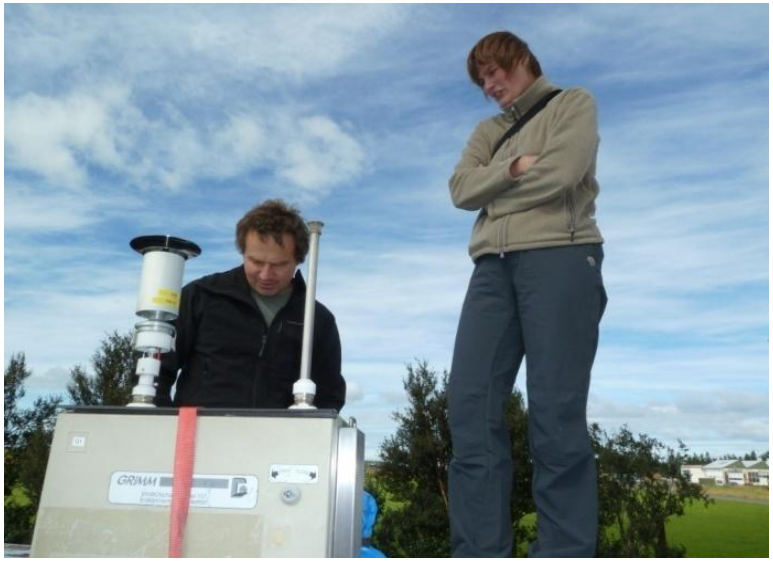
Cessna on Iceland eqipped with 3 optical particle counters for tests

Fachhochschule Düsseldorf
University of Applied Science

On-going and future research

Experimental aircraft for easy testing of 3 optical particle counters in parallel in the open atmosphere

On-going and future research



Comparison of Optical Particle Counters with gravimetric particle reference samplers for PM10, PM2.5 and PM1,
In cooperation with the Icelandic Meteorological Office

On-going and future research

Conclusion and Outlook

- The results of measurement flights in April/May over North-Western Germany support the predictions of the VAAC model in the areas and time periods, which were investigated during the measurement flights, so far known
- aircrafts with a piston engine, equipped with optical particle counters (OPC), proved to be able to fly in concentration areas with concentrations higher than 2000 µg/m3
- aircrafts with a piston engine are cost effective and robust. They can be equipped with OPCs, SO2-measurement devices (DOAS and in-situ), CO2-measurement devices to deliver on-line data
- OPC s can deliver number concentrations, particle size distributions and estimates of mass distributions during flight and are able to deliver measurements downwind to the eruption of the volcano

Fachhochschule Düsseldorf
University of Applied Science

On-going and future research

Outlook idea for the case of an eruption:

- downwind measurements to the eruption of the volcano with piston motor driven aircrafts at distance and concentrations possible for the equipment
- use piston driven aircrafts equipped
  - with OPCs for particle size distributions and particle number and mass concentrations, SO2-measurement devices (DOAS and in-situ),
  - CO2-measurement devices to deliver on-line data
  - real particle samplers for later chemical analysis und analysis with electron microscope
- Scanning the plume by crosswind measurements
- Together with the wind speed of the plume: flux estimation may be possible with these measurements

On-going and future research

Acknowledgement

We thank all institutes contributing to this work. e.g.

- University of Iceland
- University of Fribourg
- Technical University of Berlin
- The German Weather Service