Airborne in-situ measurements with light aircraft – examples of research flights during Eruptions of Eyjafjallajökull, Etna, Grímsvötn, Sakurajima and quality assurance

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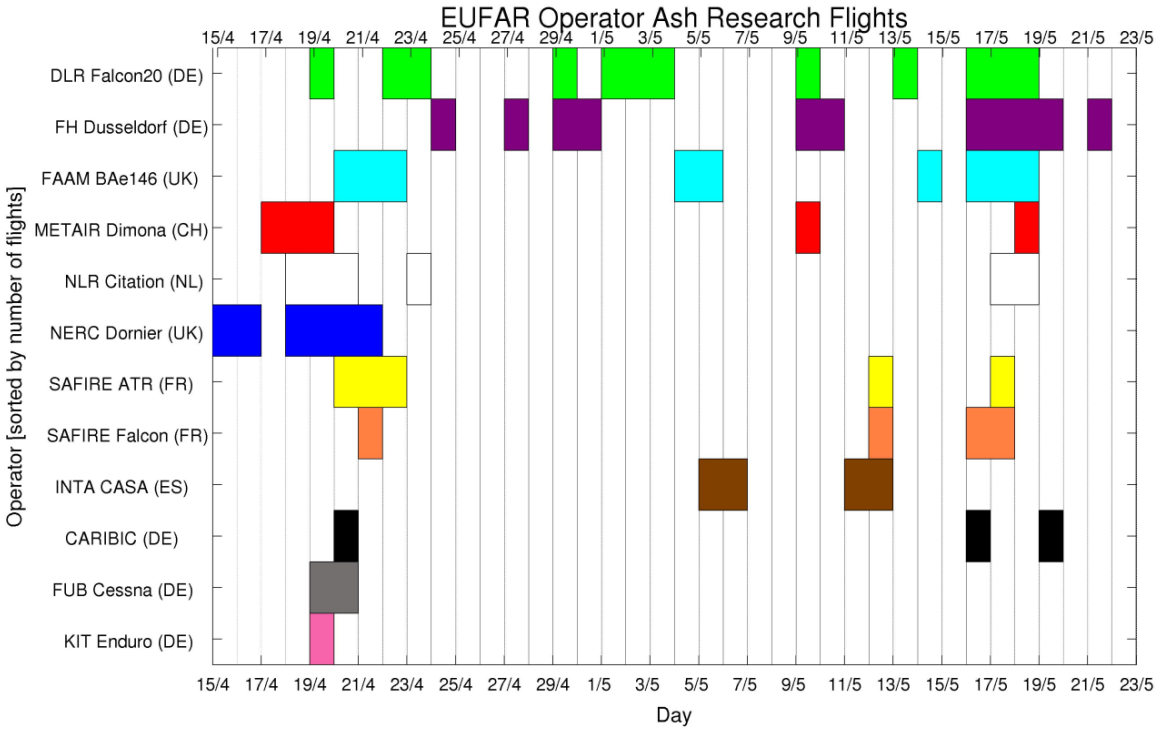
Piston motor driven aircraft for ash plume measurements

In this presentation

- example of research flights of the University of Applied Sciences Duesseldorf during the 2010 **Eyjafjallajökull eruption** in the ash plumes over Germany
- example of research flights during the **Grimsvötn** eruption 2011
- Example of research flights at volcano **Etna** 2011
- Recent flights at **Sakurajima** volcano in Japan
- Aspects of quality assurance
- Artificial ash plume

Overview about measurement flights in central Europe

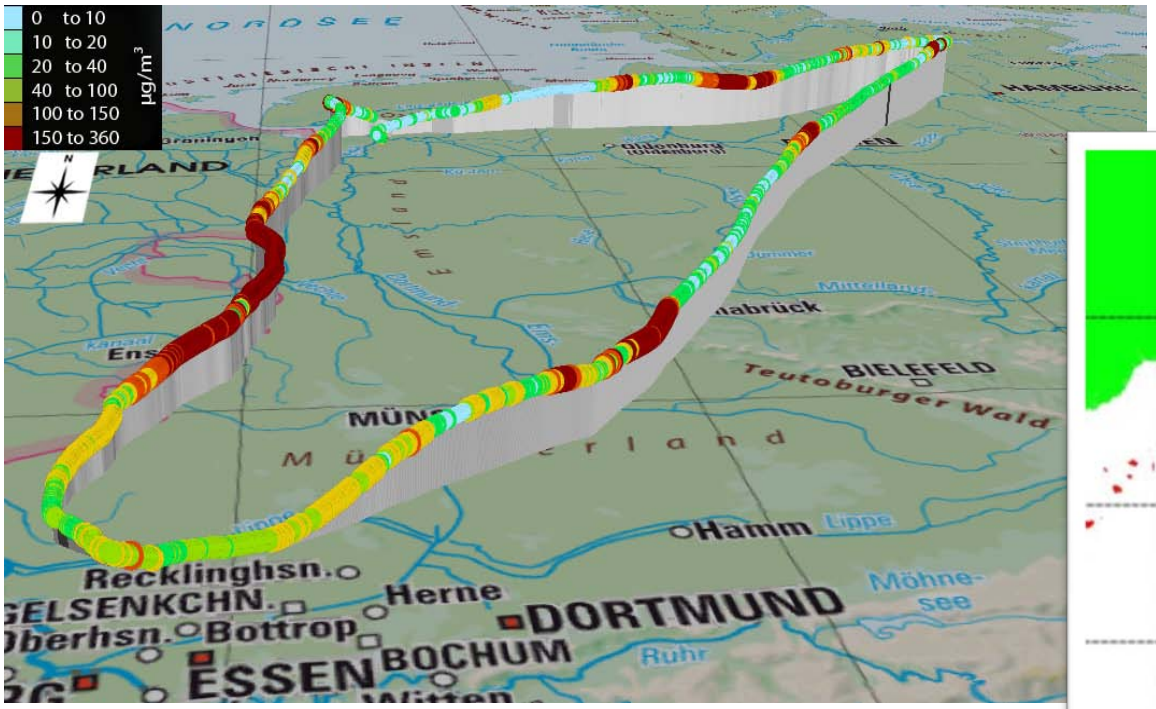


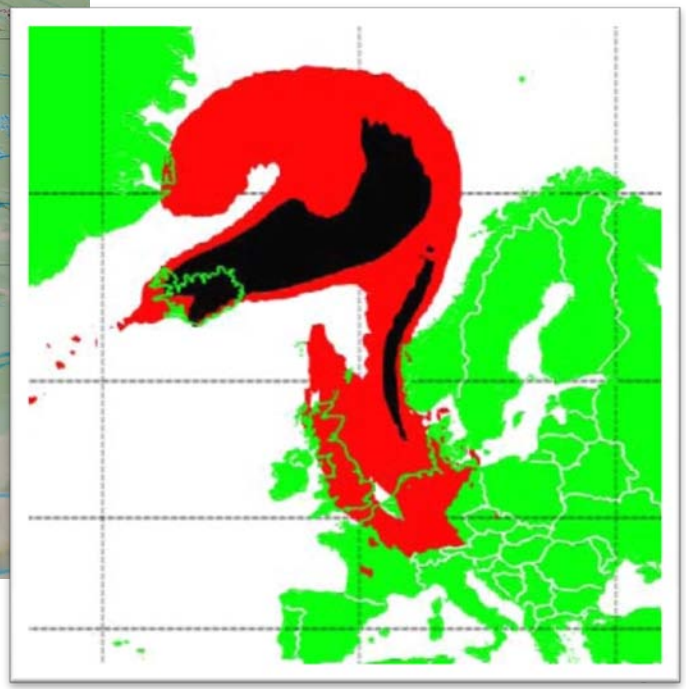
EUFAR, Additional flights were performed by the BAZL Switzerland and the University of Iceland

Different ash plume situations

One typical example of ash plume situations during the Eyjafjallajökull eruption 2010:

- „Red zone of ash plume“ predicted over Germany on May 18th 2010

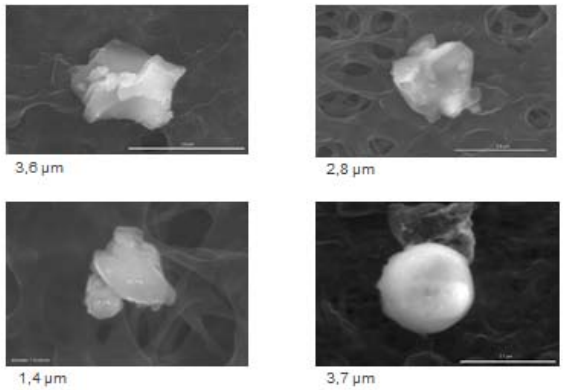




Different ash plume situations

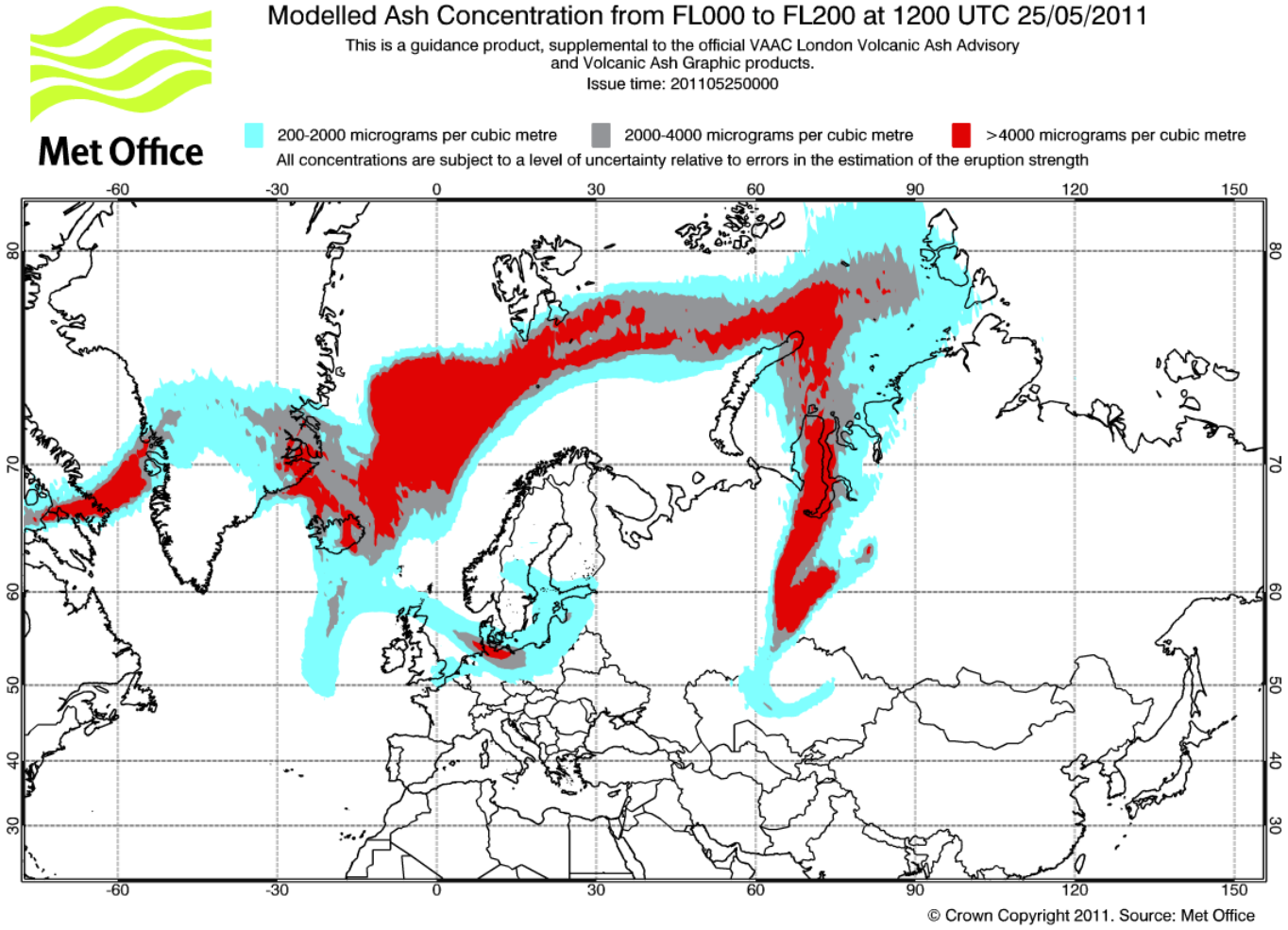
Results:

- Ash plume over Germany very inhomogenous in time and space (several 100 µg/m3)
- Full size distribution of ash particles could be measured
- Airborne ash could be sampled for electron microscope analysis
- Ash plume over Germany looked as a small brown level at the horizon



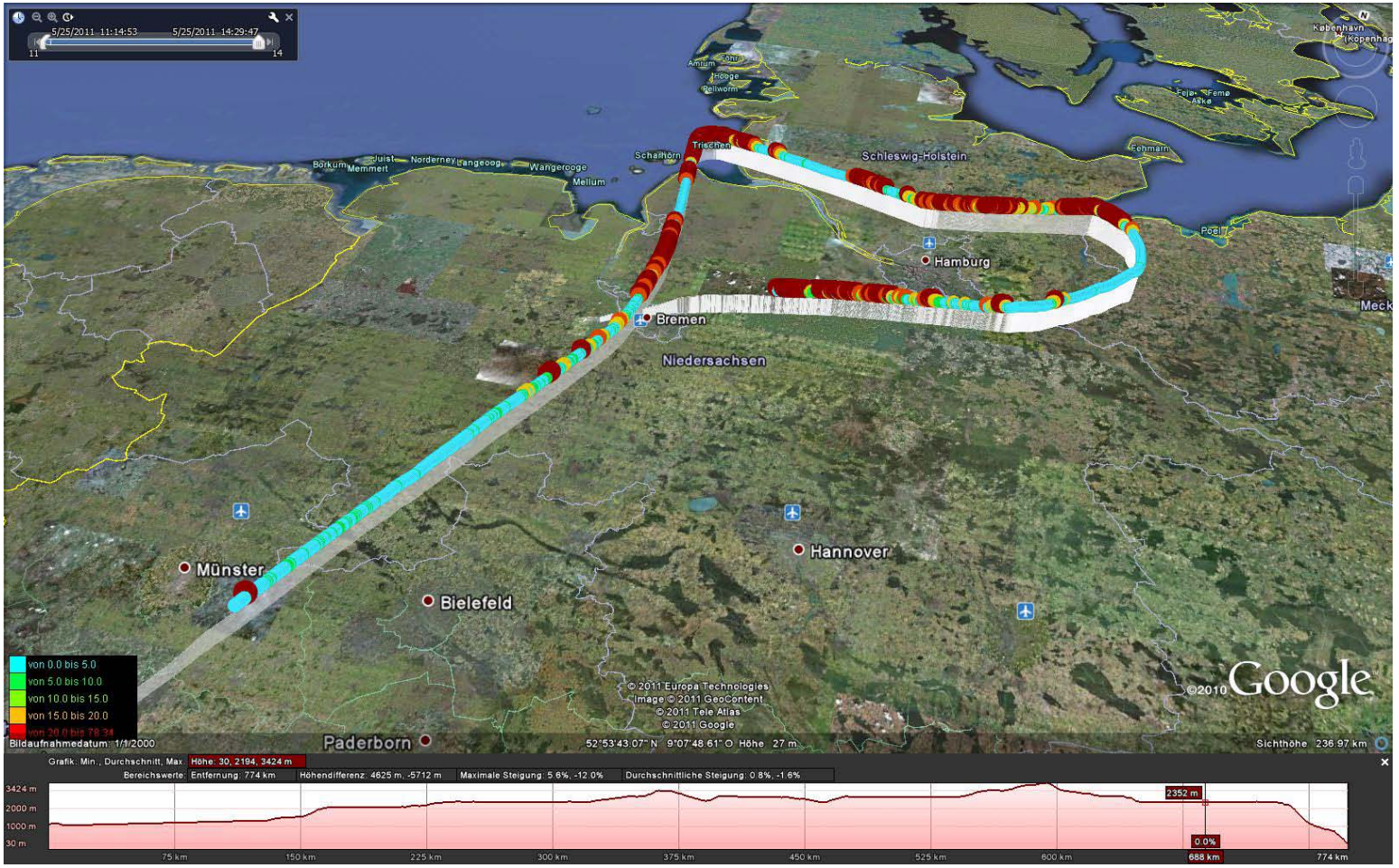
Grimsvötn Eruption May 2011

VAAC Model 25 May 2011

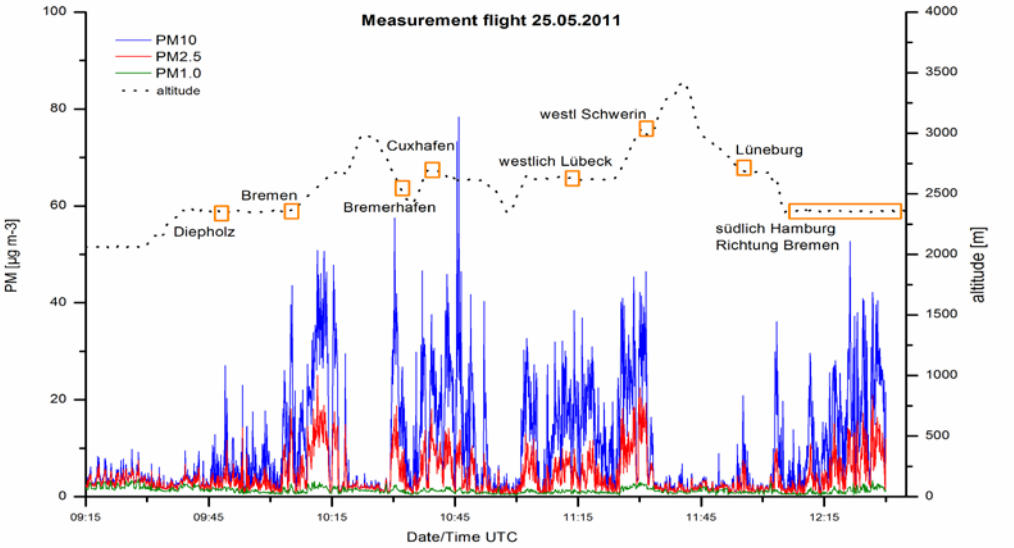


Grimsvötn Eruption May 2011

Research Flight 25 May 2011 North Germany on behalf of DWD



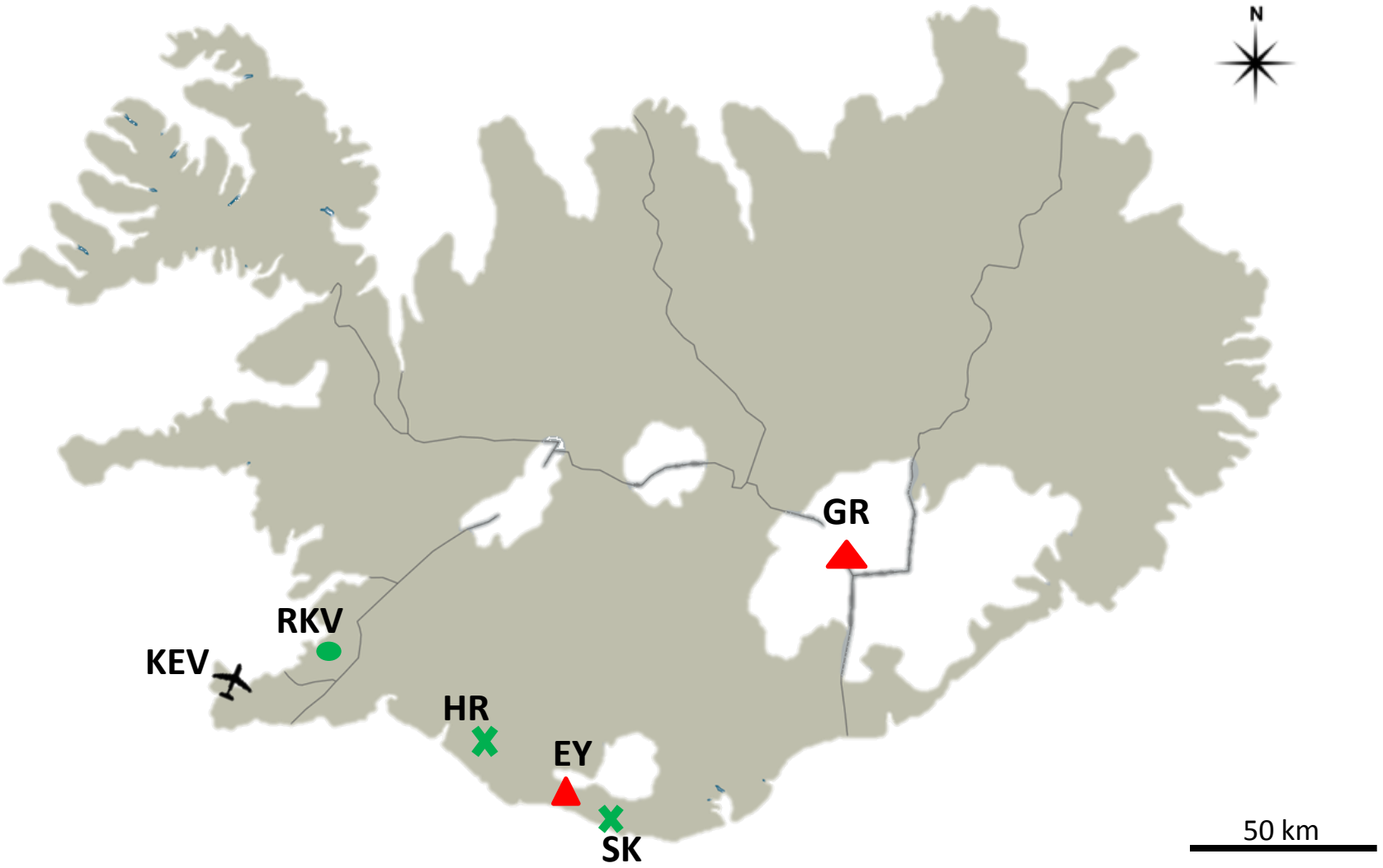
Grimsvötn Eruption May 2011



Moderate airborne measured concentration over north Germany

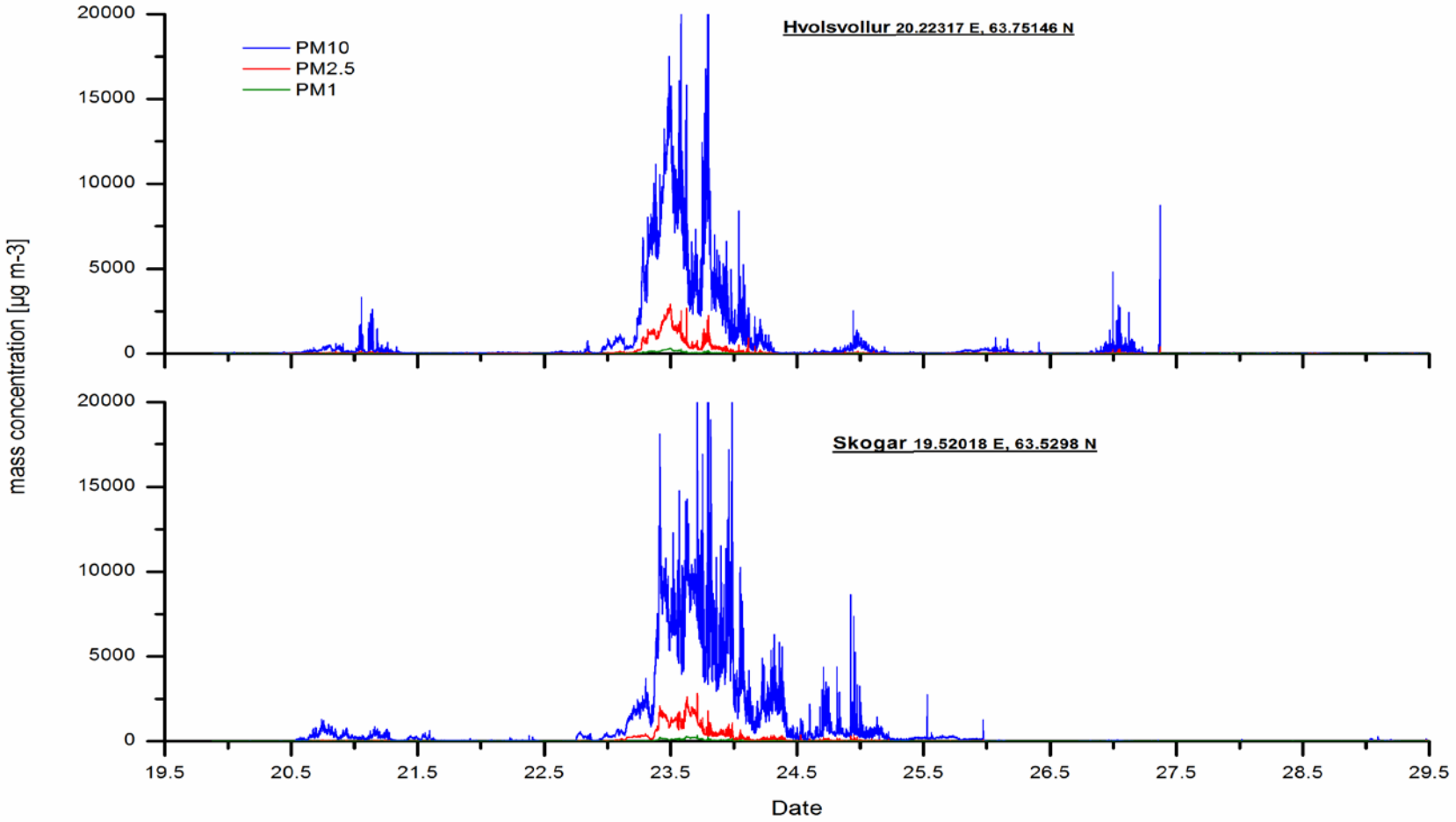
Ash plume layer as seen over part of northern Germany from the aircraft cockpit

Groundbased particle measurement stations HR and SK with Grimm OPCs on Iceland



Grimsvötn Eruption May 2011

Concentration results of groundbased measurements by FHD and IMO in the south of Iceland

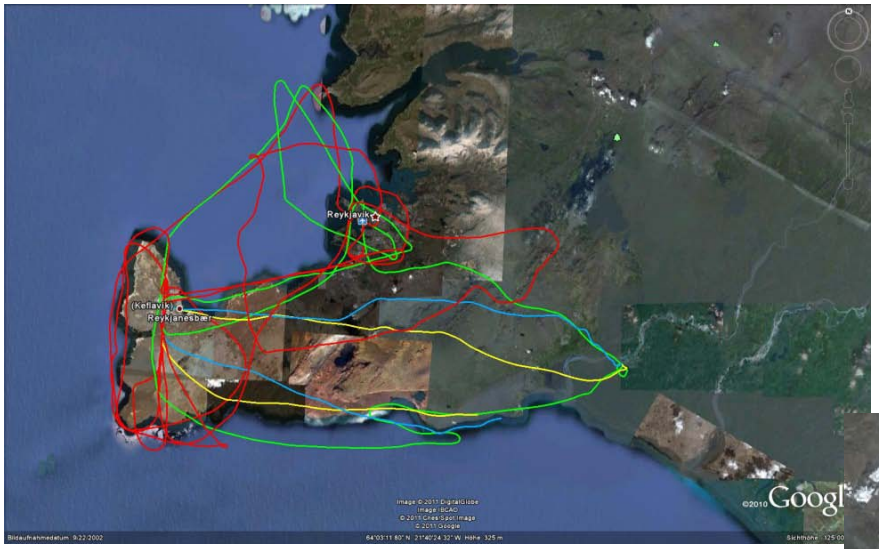


Grimsvötn Eruption May 2011

Mobile and stationary groundbased ash particle measurements of the Gromsvötn ash plume in the south of Iceland by FHD

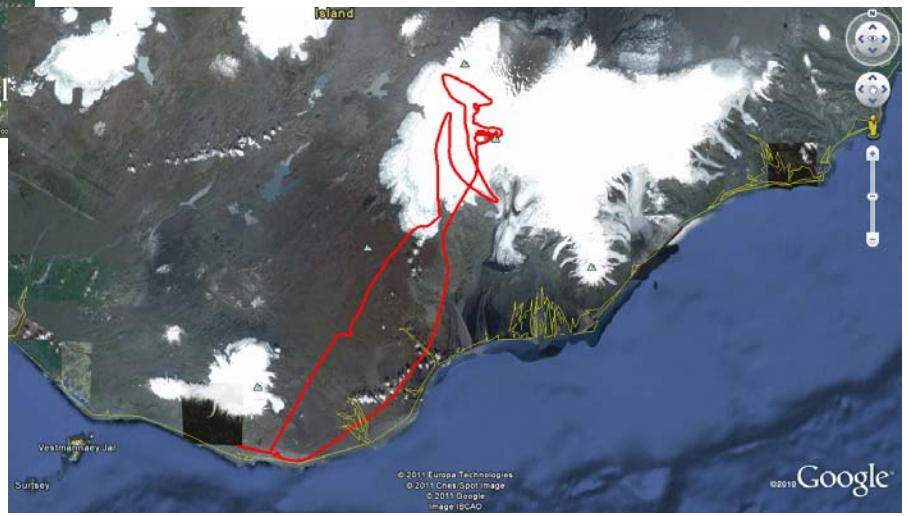
Grimsvötn Eruption May 2011

Flight tracks of the flights of the University of Iceland and the Duesseldorf University of Applied Sciences over Iceland during the Grimsvötn eruption



Flight tracks over west Iceland

Flight tracks near the Grimsvötn



Grimsvötn Eruption May 2011

11 measurement flights over Iceland

- Most time low ash concentrations over East Iceland, while over South island the concentraion was high

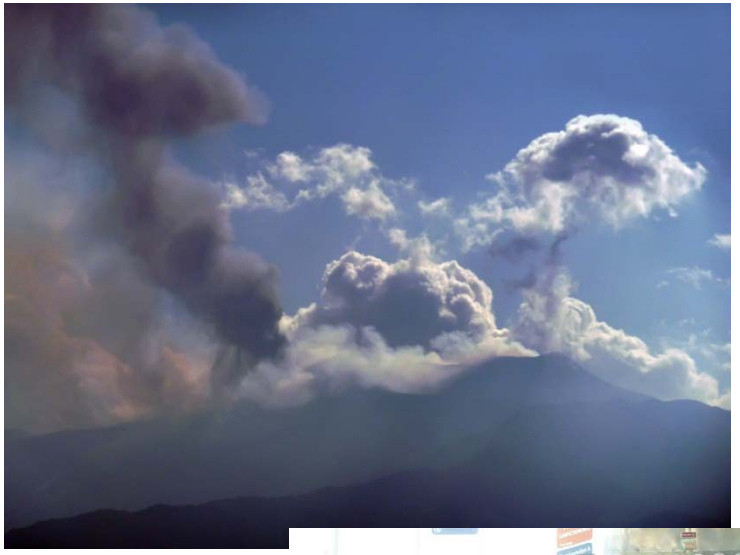
- Aircraft measurements helped that Keflavik Airport could be re-opened ealier by flight authority ISAVIA

On-going and future research

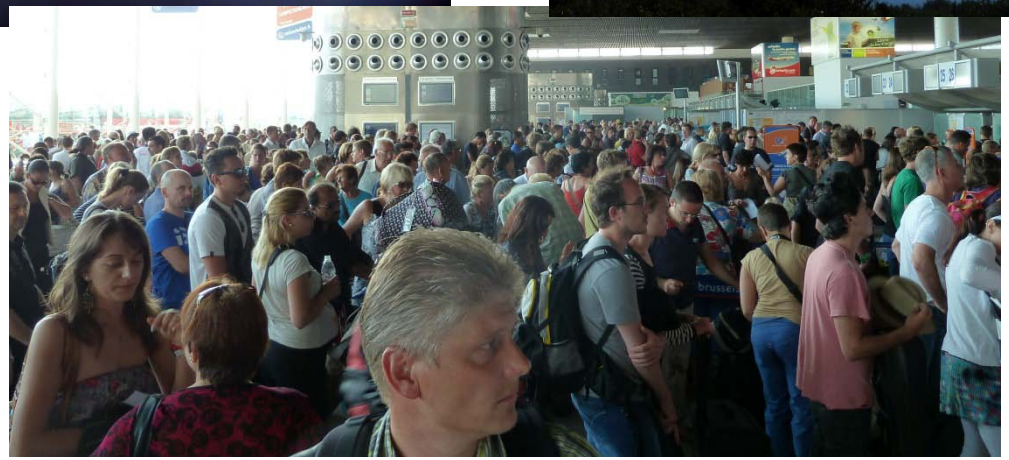
- Flights at Etna, Stromboli

Research flights at Etna Volcano

- Several Eruptions of volcano Etna in 2011, two measurement campaigns for investigation of the plume composition and for testing of new instrumentation



Here eruption on 9 July



On-going and future research

„Imaging DOAS“ system and
„in flight direction looking DOAS system“ for SO2-plume detection and tracking by University of Heidelberg (U. Platt et al.)

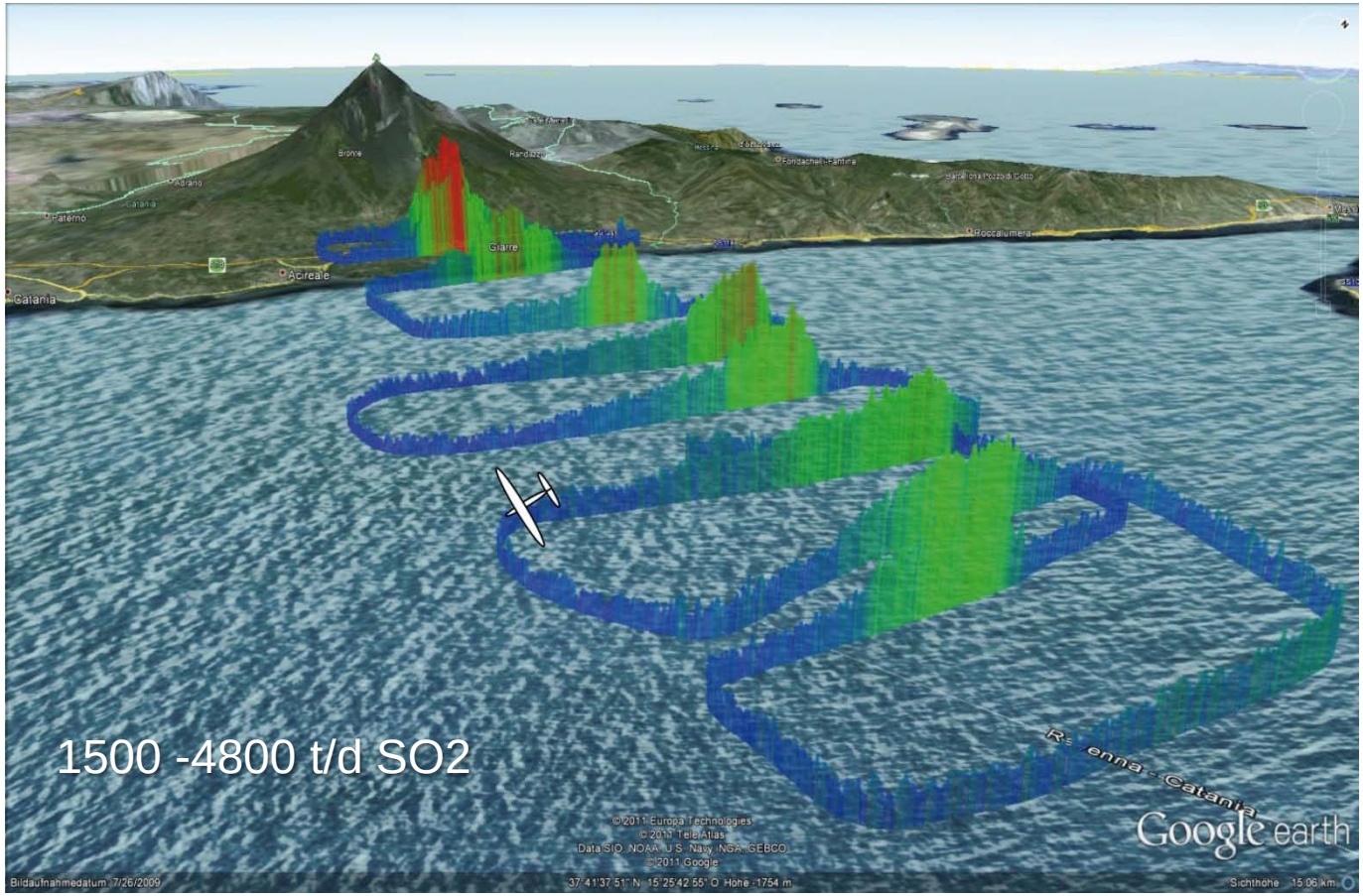
On-going and future research

Under-wing in-situ instrumentation

AVOID system under wing

On-going and future research

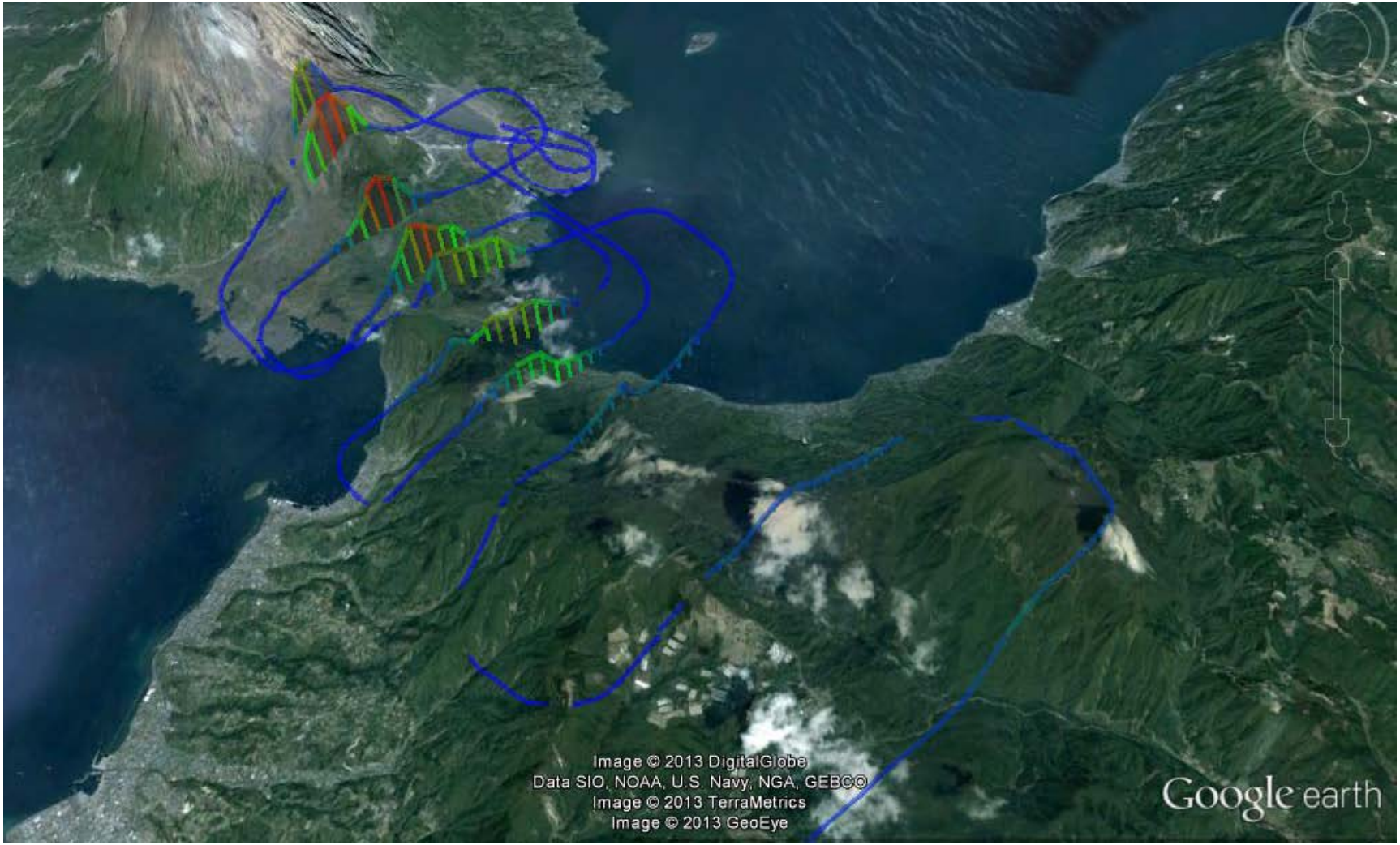
Example of flight track and measurement of SO2 column concentrations at volcano Etna



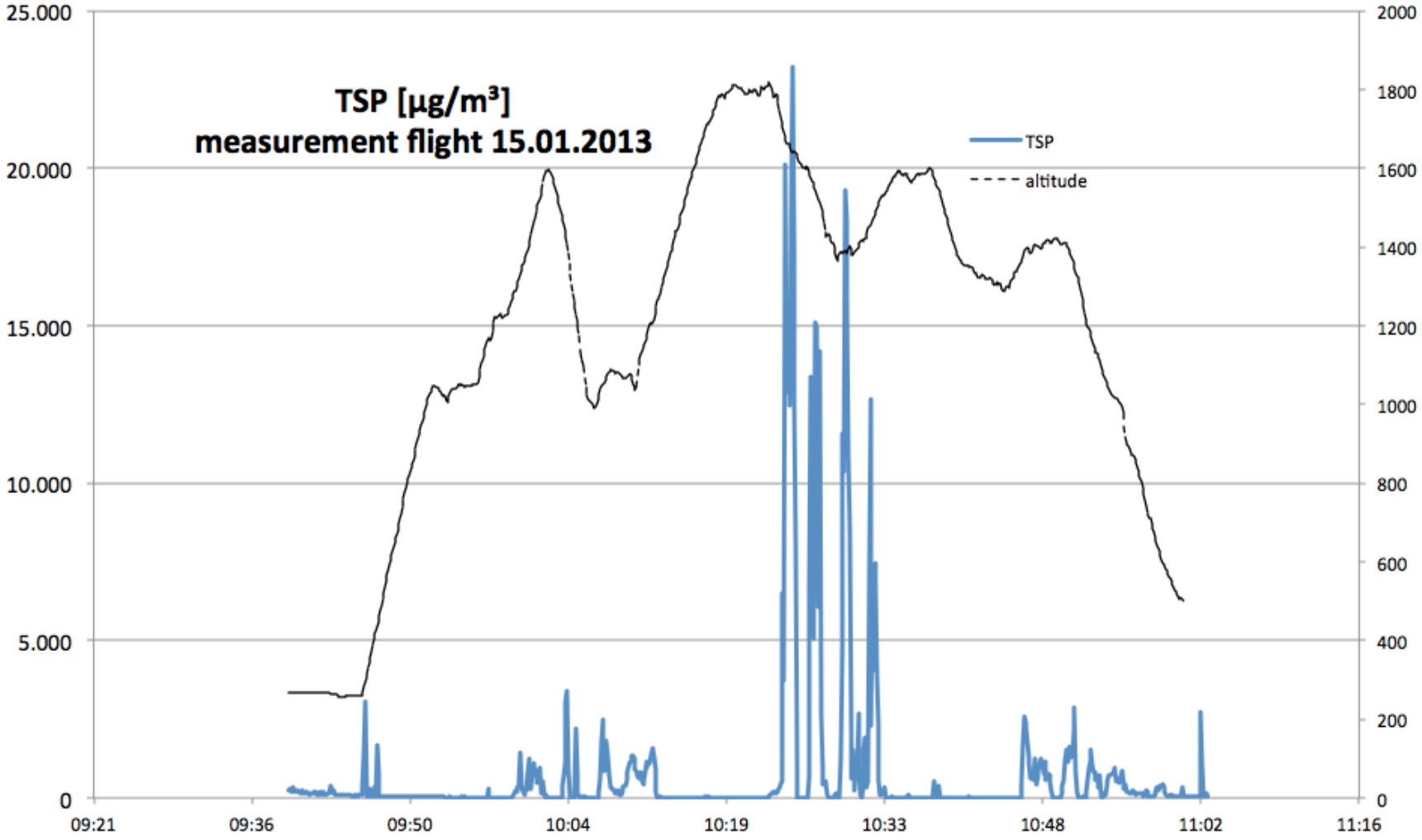
Sakurajima with Uni Kyoto and Uni Iceland

Sakurajima volcano January 2013

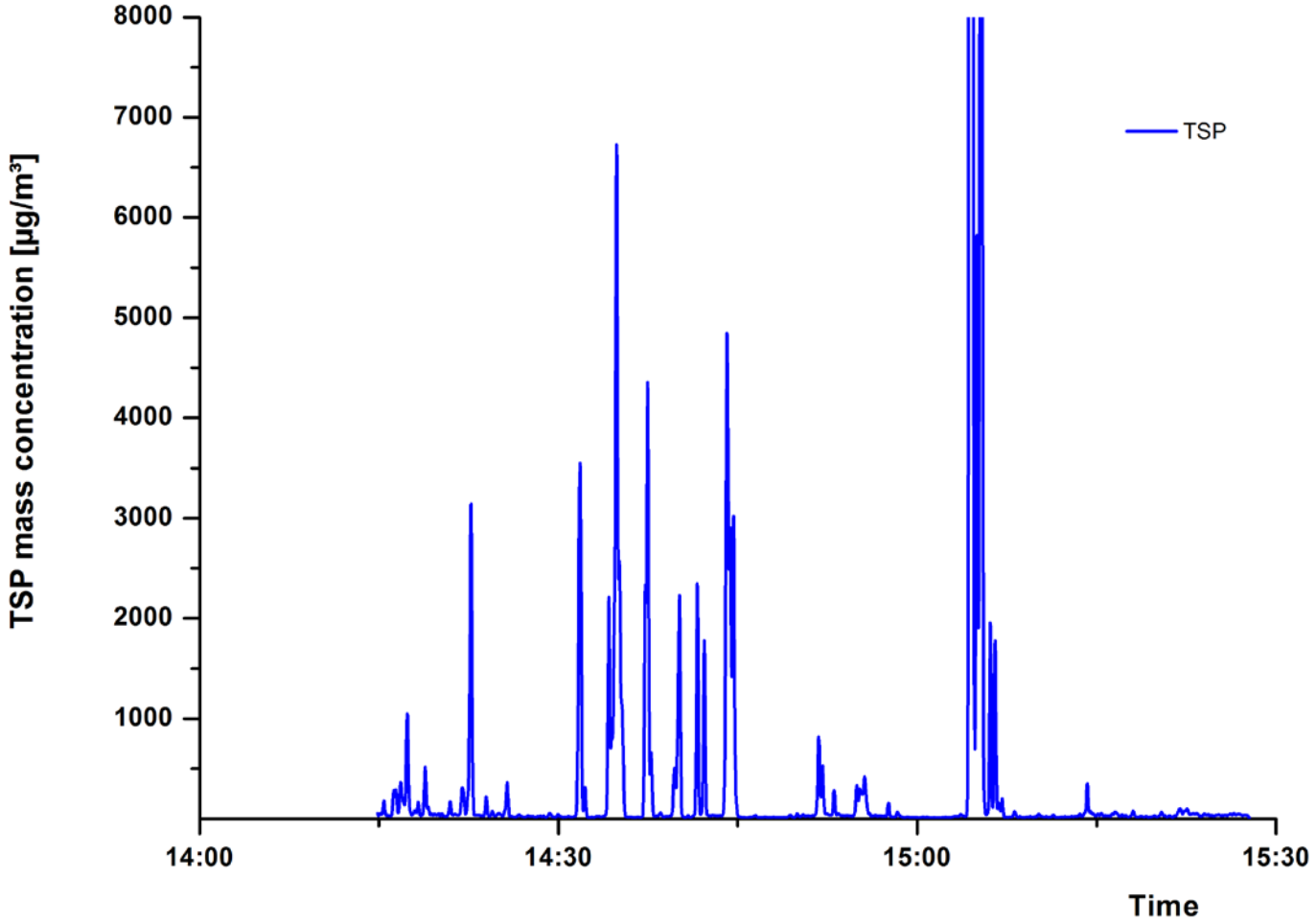
Sakurajima volcano Japan 16 Jan 2013



Sakurajima volcano Japan 15 Jan 2013

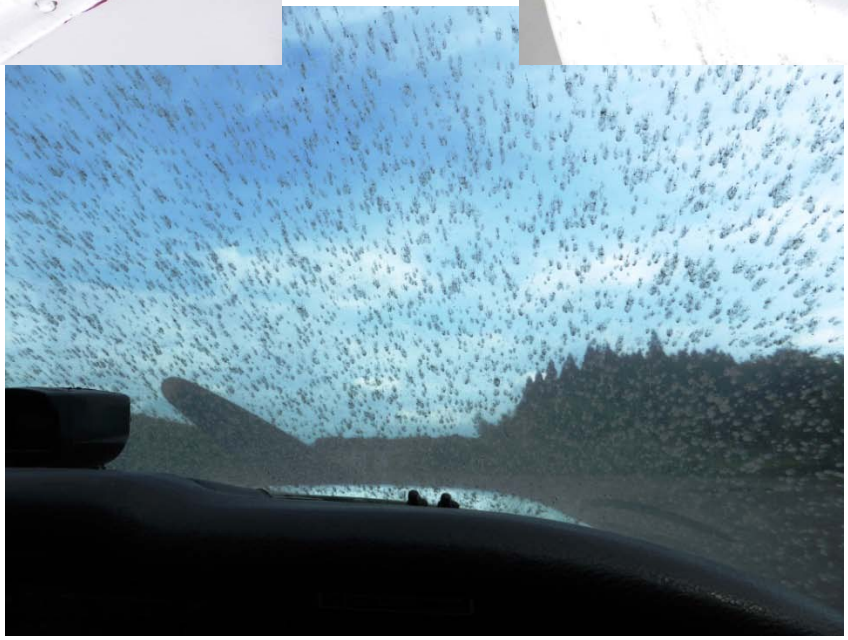


Sakurajima volcano Japan July 2013



Sakurajima visibility within the plume 15 Jan

Ash on the aircraft after the ash plume flight



Quality assurance, in certified ash loaded windtunnel

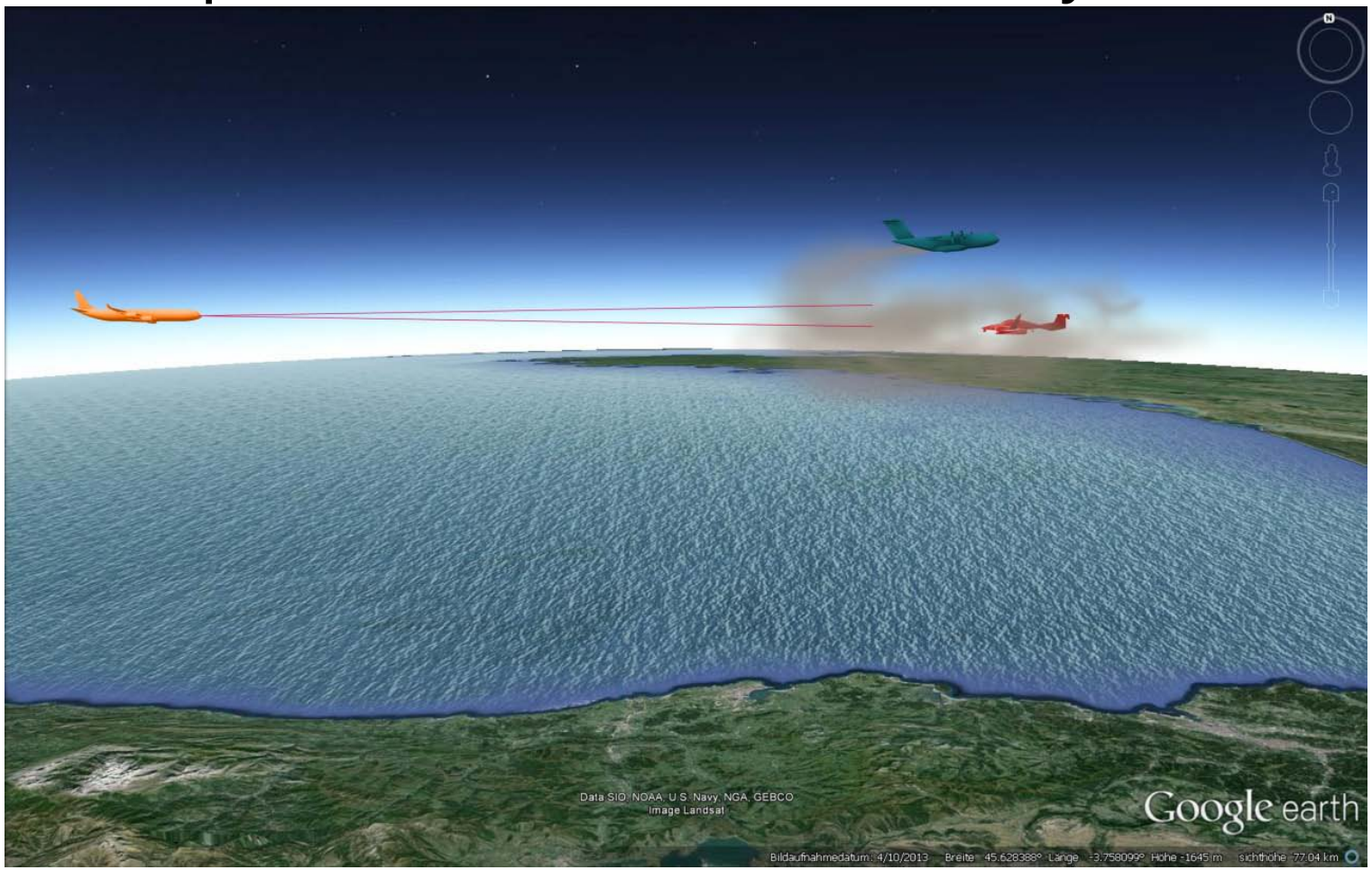
Artificial ash plume

Release of „laboratory scale“ ash plume by Duesseldorf University of Applied Sciences (FHD) for testing of ash measurement systems

Release of „significant large ash plume“ (1000 kg) from A400M for tests of AVOID system (Fred Prata), Project envolved AIRBUS, Easyjer, Nicarnica, Duesseldorf University

Atlantic Ash Release Experiment

Important task: Test of AVOID system



Experiment by AIRBUS, Easyjet, Nicarnica (Fred Prata), Duesseldorf Uni FHD

Aircraft within Atlantic Ash Release Experiment

A340 with AVOID system

In-situ measurement
DA42 aircraft
and A400M aircraft for
ash release

Atlantic Ash Release Experiment

A400 M with ash plume release

DA 42 MPP

Within A340 during experiment

On-line satellite broadcasting of measured ash concentration by DA42 to A340

Results

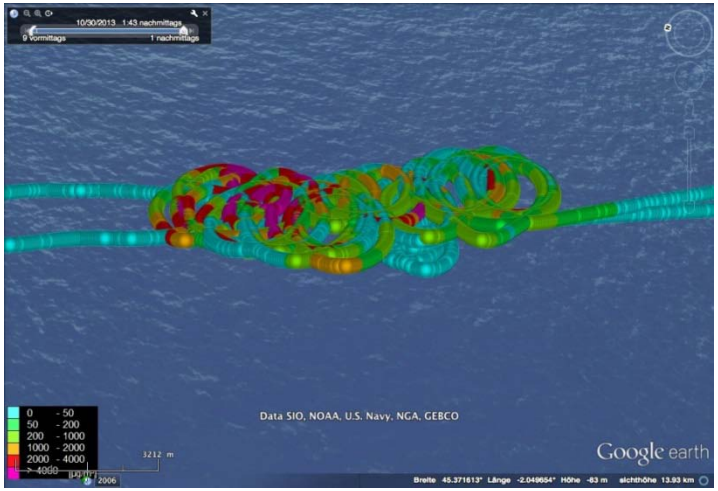
The AVOID system could detect the ash plume successfully from a distance (approximately 60 km)

The ash plume was generated by the A400M with concentrations as planned

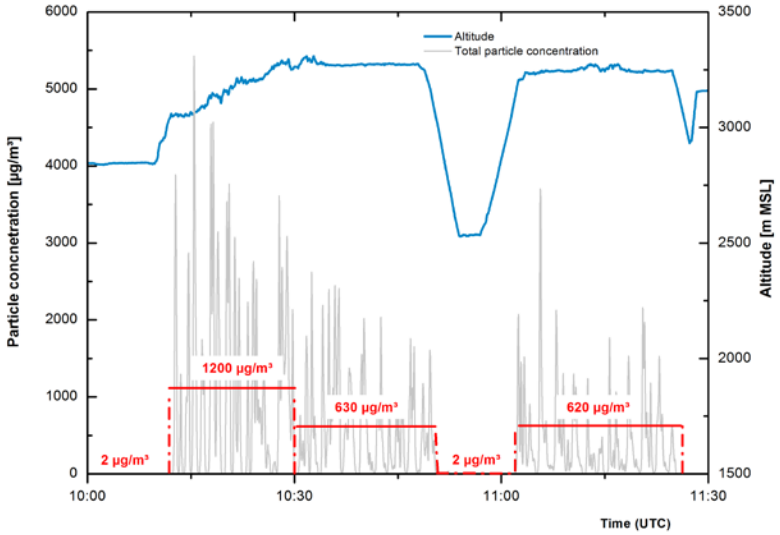
The DA42 aircraft could record the plume concentrations with high precision on-line

The in-situ data could be transmitted on-line to the A340 aircraft

The twin-engined DA42 aircraft had no problem with the ash encounters



Ash plume in-situ measurements



Closing remarks

- **Duesseldorf University of Applied Sciences is has signed last year a contract for a research aircraft standby for volcanic ash emergency response in Germany for the German Weather Service (DWD) and the German Ministry of Traffic**
- **We are operating aircraft which can fly even at elevated ash concentrations**
- **The twin engine DA 42 aircraft can even reach altitudes of about 9000m**
- **We are preparing research flights during the next eruption on Iceland and for other international operations**

On-Going Research

UAVs

On-going and future research

- **Measurement equipment for plume chemistry measurement campaigns at aircraft**
  - Optical particle counters for ash particles (GRIMM)
  - Nano-Particle counters (GRIMM)
  - CAS-DEPOL instrument
  - Different UV-DOAS systems
  - Mobile in-situ FTIR system for various gases
  - Web-Cams for visual recording of ash plume
  - GPS tracking system
  - Ultrafast measurement meteorological measurements
  - For flux measurements

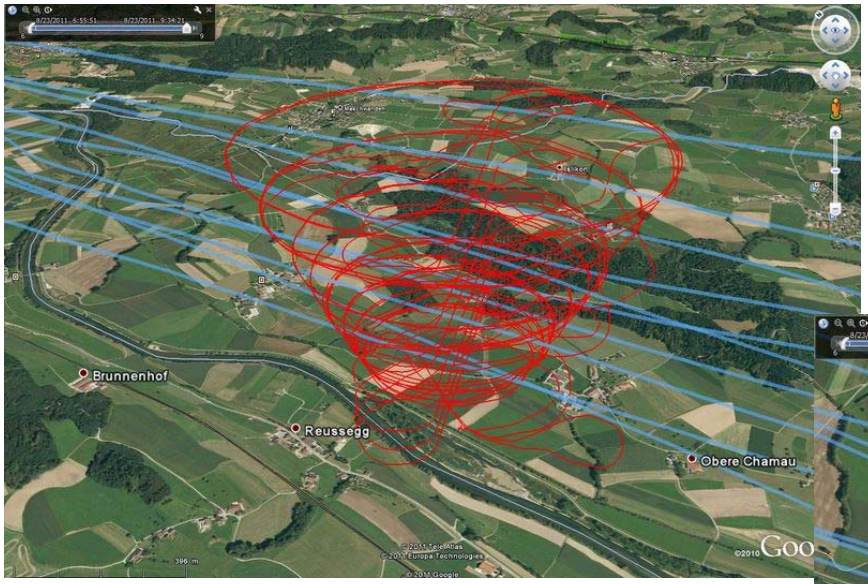
On-going and future research

Planned: Cooperation project of METAIR/ZHAW and FHD for additional unmanned aircraft measurements for near eruption source ash and SO2 investigations

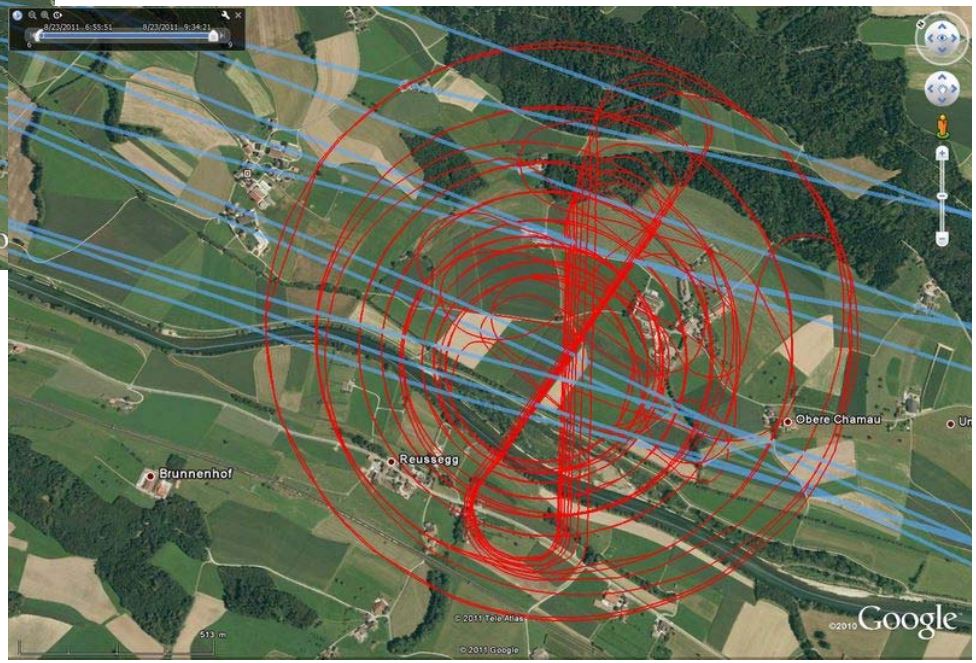
Unmanned aircraft developed by B.Neininger and H. Hesselbarth an co-workers in Switzerland (Metair and ZAHW)

On-going and future research

Example of flight test of unmanned aircraft in Switzerland by METAIR/ZHAW



Real flight pattern with autopilot in Switzerland



UAV can fly with autopilot and radiocontrolled
(GPS and integrated IMU and magnetic field sensor

Conclusion

Light piston motor driven aircraft have proved to be a valuable and very flexible tool for exploring volcanic ash plumes

They can be equipped by various types of measurement systems to explore the ash particles and the gaseous composition of the volcanic plumes

Because of low possible measurement speed they are able to give high spatial resolution results and

The measurements of these aircraft can be accomplished by measurements with unmanned aircrafts in high concentration ash regimes near the eruption vent

We are going to be prepared for the next eruption

Acknowledgement

The partial funding of the projects by DWD, AIRBUS and German Federal Ministry of Transport , Building and Urban Environment

is greatly acknowledged.

References:

- Weber, K.; Eliasson, J.; Vogel, A.; Fischer, C.; Pohl, T.; van Haren, G.; Meier, M.;.Grobéty, B.; Dahmann, D.: Airborne in-situ investigations of the Eyjafjallajökullvolcanic ash plume on Iceland and over North-Western Germany with light aircrafts and optical particle counters,

  Atmospheric Environment 48 (2012) 9-21, doi:10.1016/j.atmosenv.2011.10.030

- Eliasson, J., Palsson, A., Weber, K, Monitoring ash clouds for aviation. *NatureVol. 475(2011) Page 455,DOI:10.1038/475455b*

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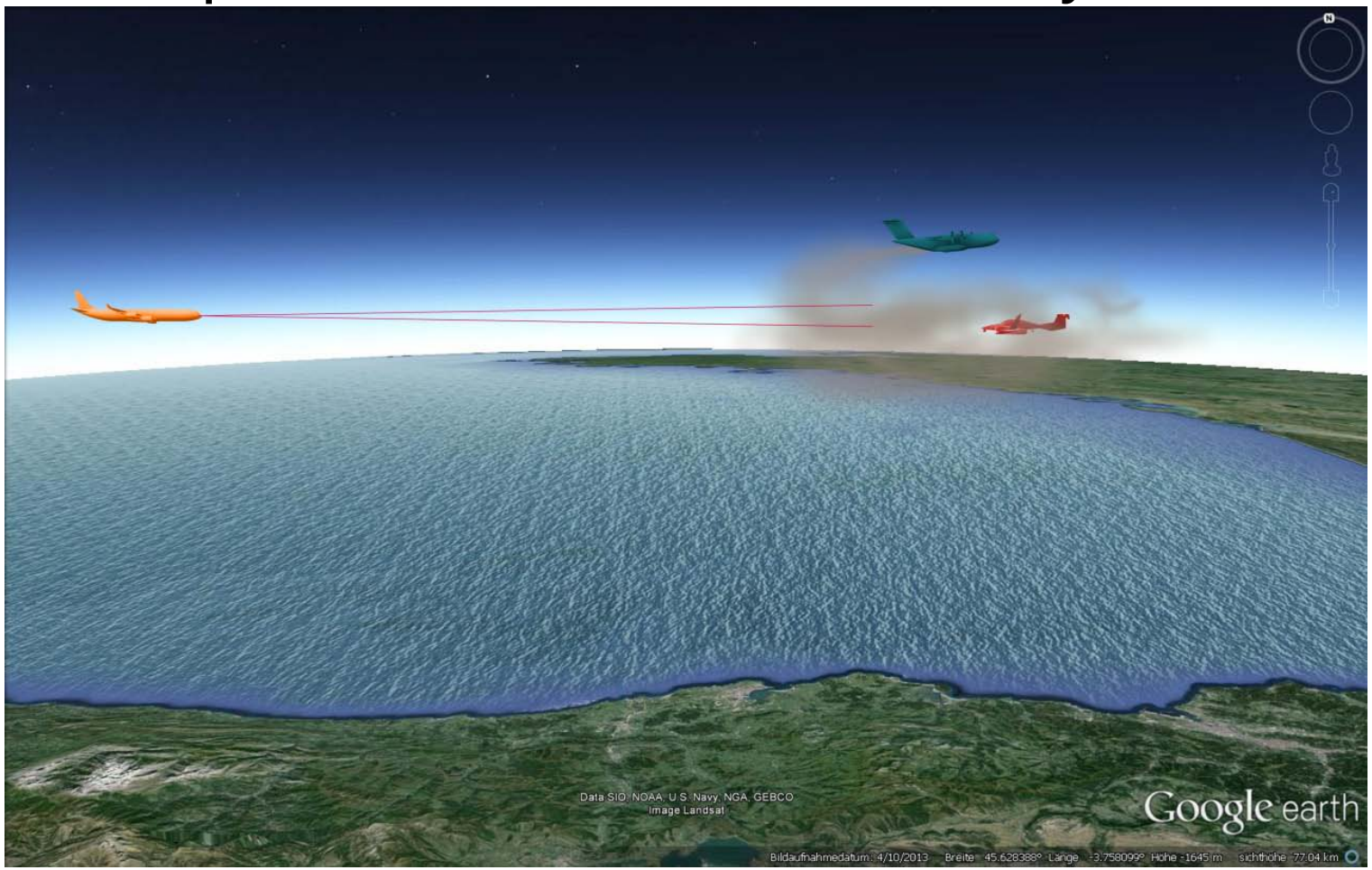

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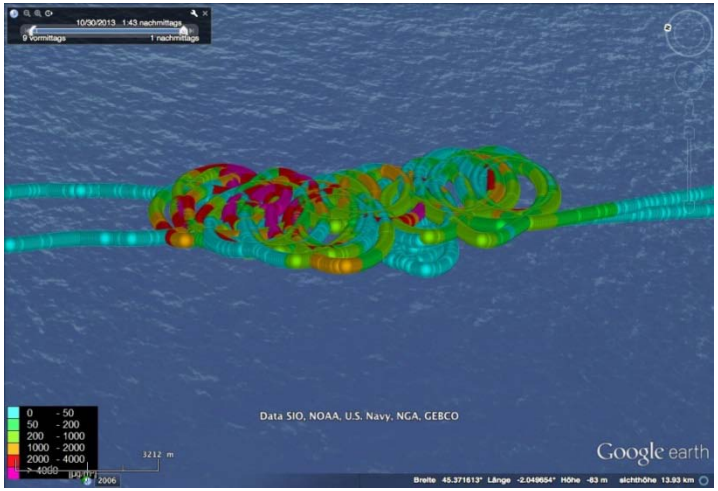
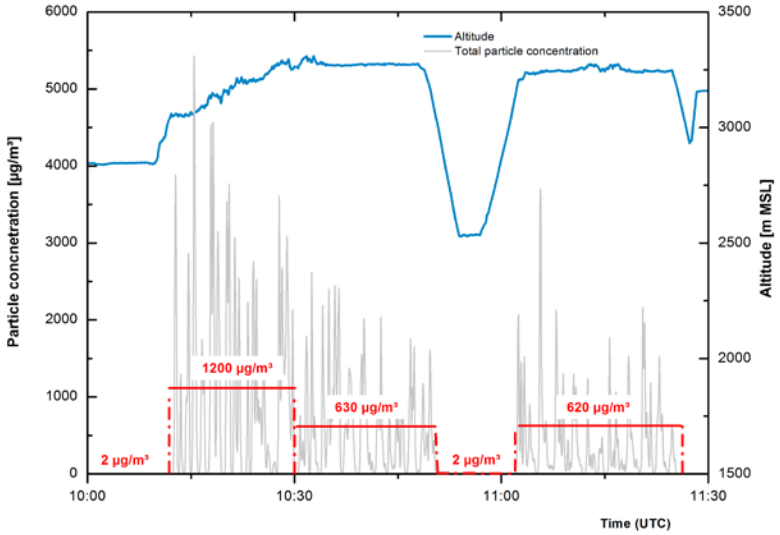
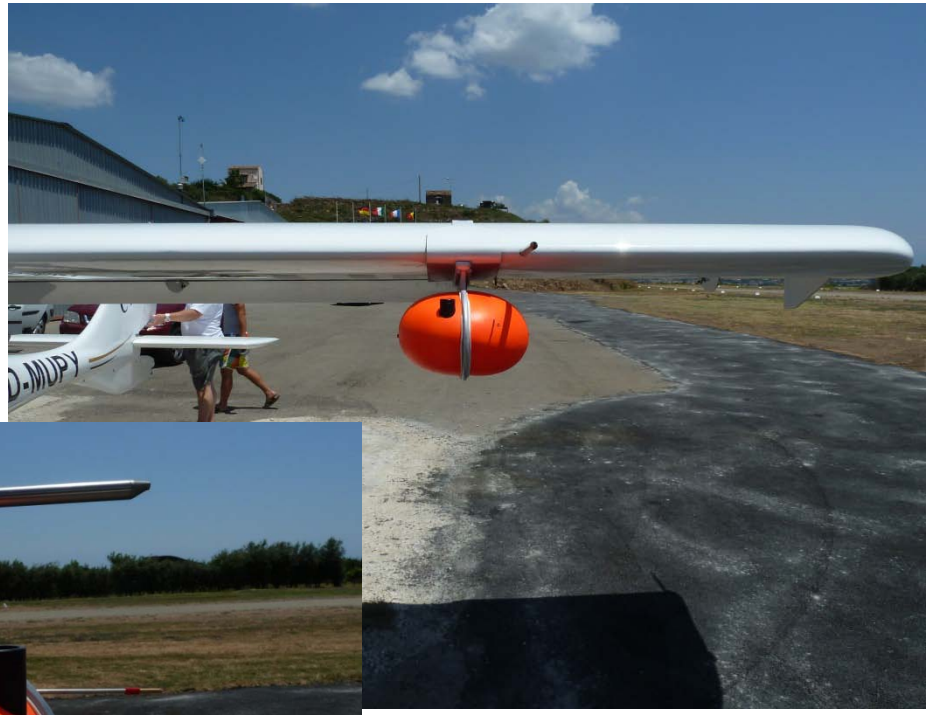


Ash plume in-situ measurements



Aircraft with measurement POD

- Aircraft with measurement POD (OPC, UV-DOAS)

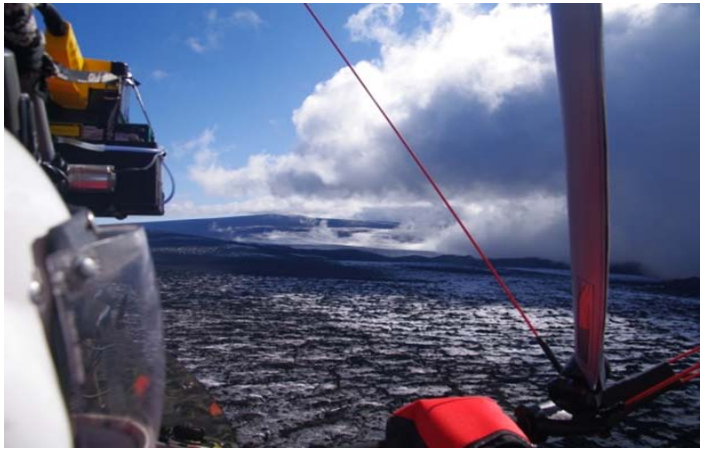


On-going and future research

- Cessna on Iceland eqipped with 3 optical particle counters for tests

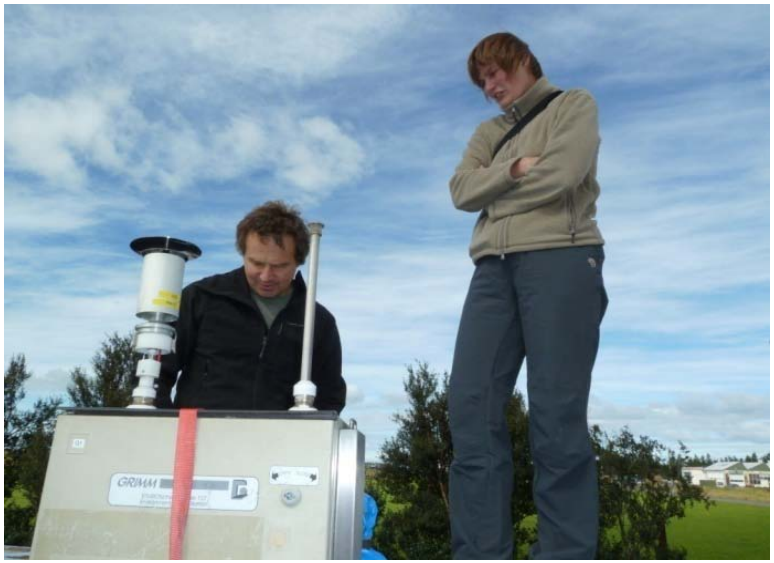
On-going and future research

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



On-going and future research

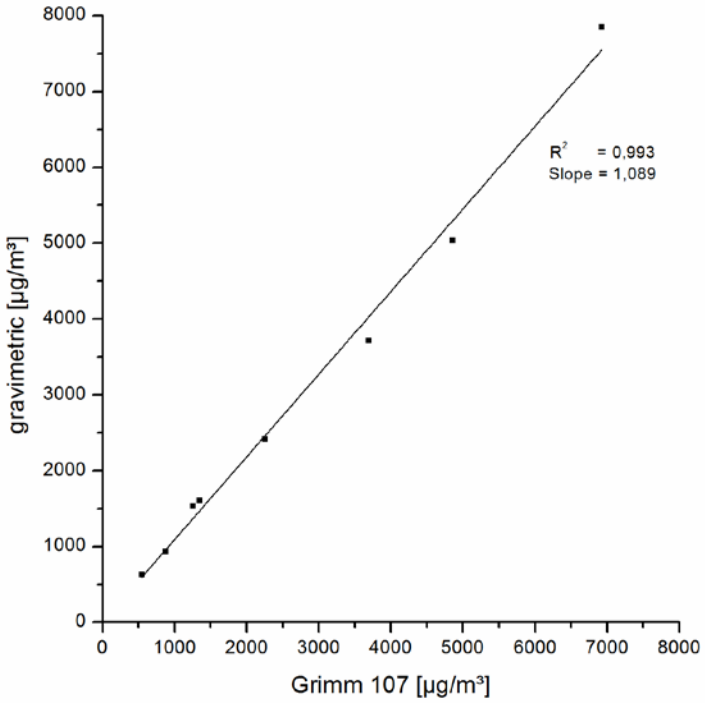
- Comparison of Optical Particle Counters with gravimetric particle reference samplers for PM-10, PM-2.5 and PM-1.0,
- In cooperation with the Icelandic Meteorological Office



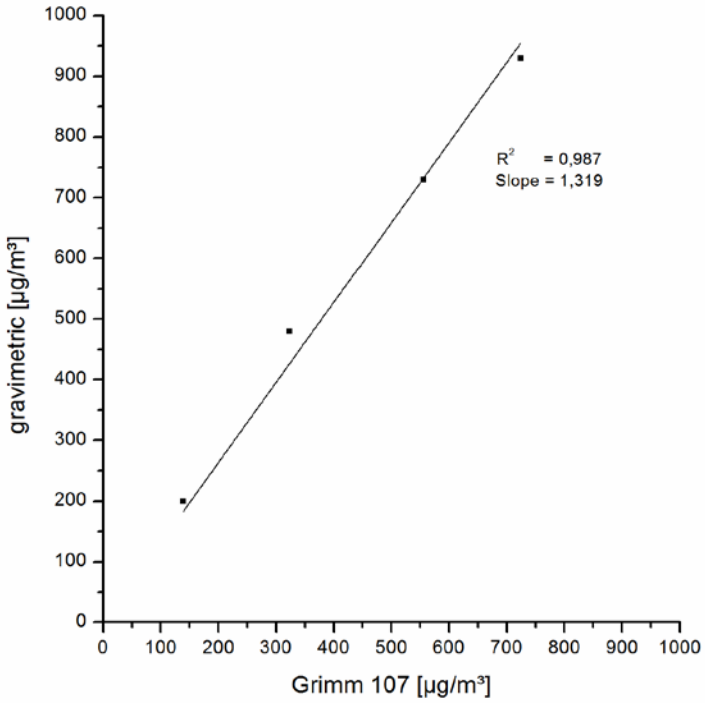
Quality assurance

- Gravimetric vs. Optic (Grimm 107)

PM10

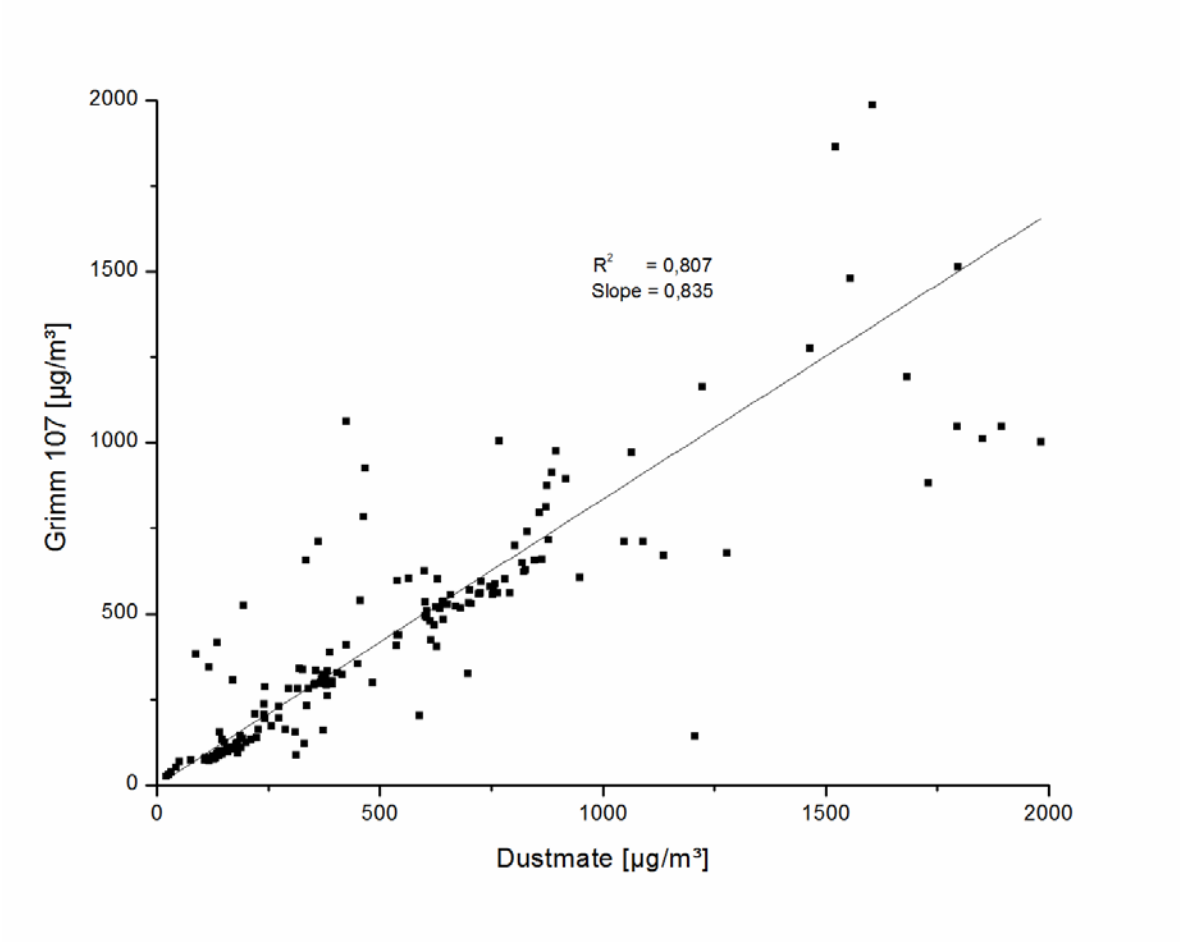


PM2.5

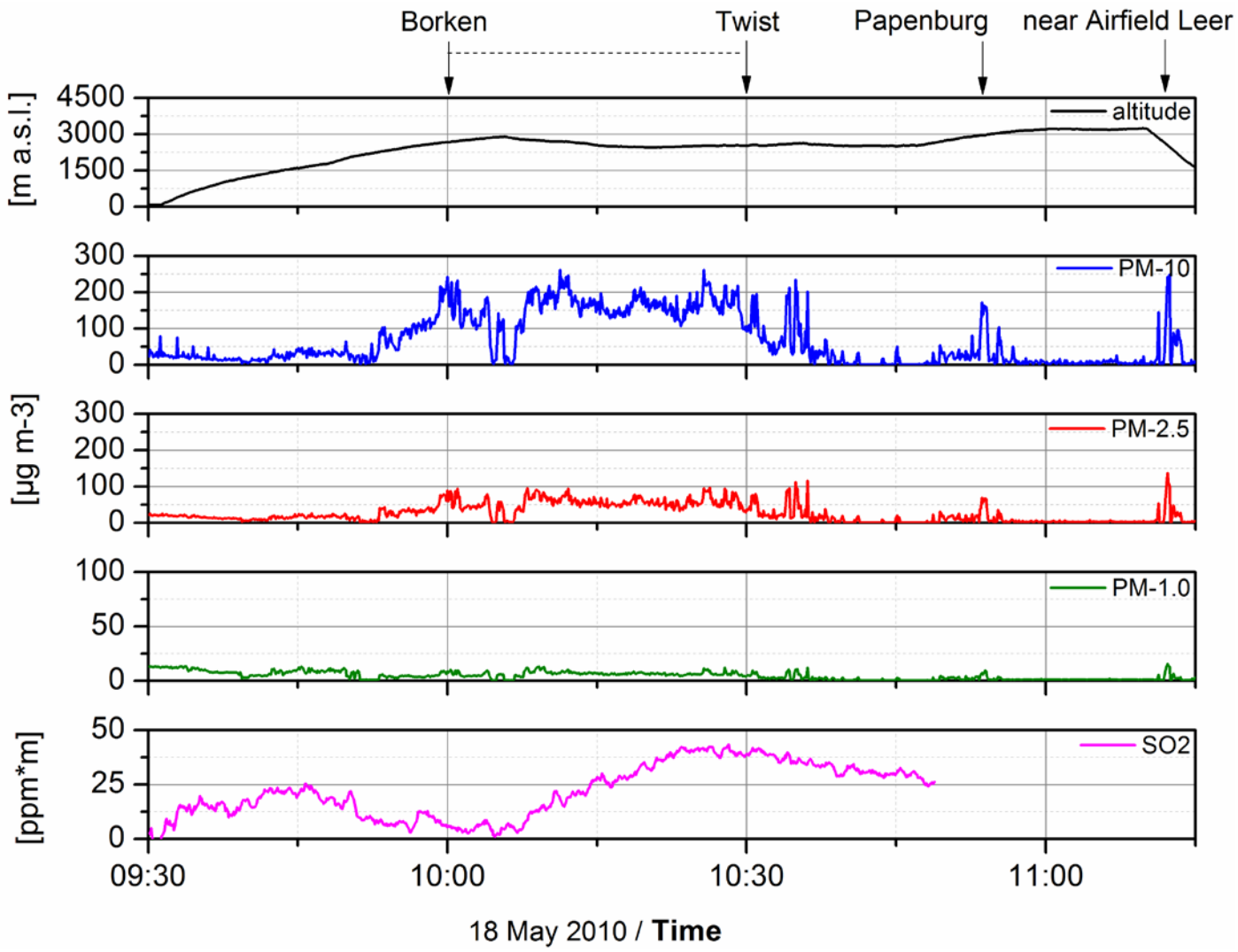


Quality assurance

- Dustmate vs. Optic (Grimm 107)



18 May 2010


Borken
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PM-1.0
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50
25
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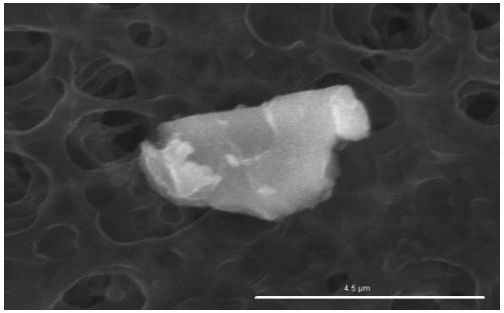
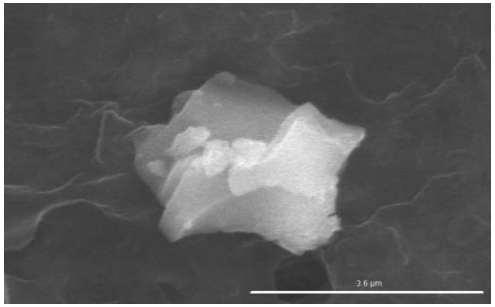
SO2
09:30
10:00
10:30
11:00
18 May 2010 / **Time**

Airbone particles in ash plume

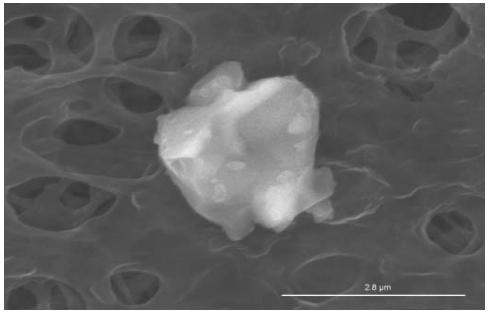
- Examples of particles found during the measurement flight on 18 May 2010



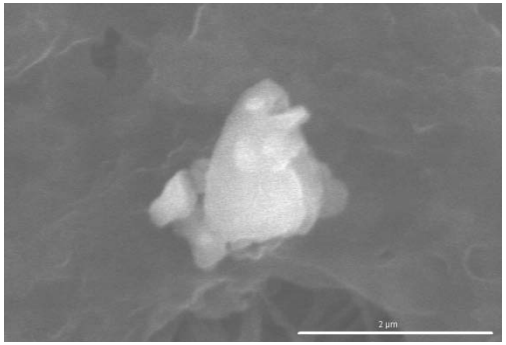
4,5 µm



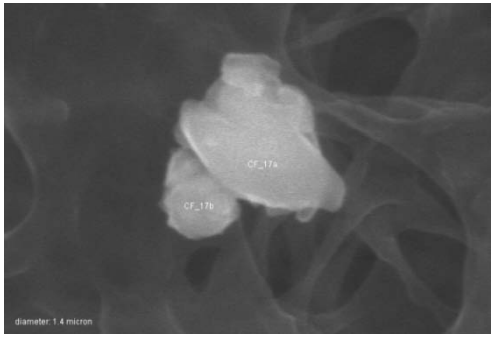
3,6 µm



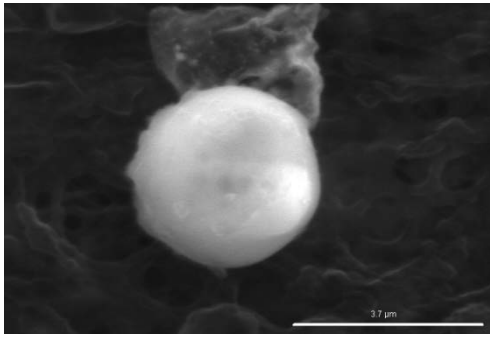
2,8 µm



2 µm

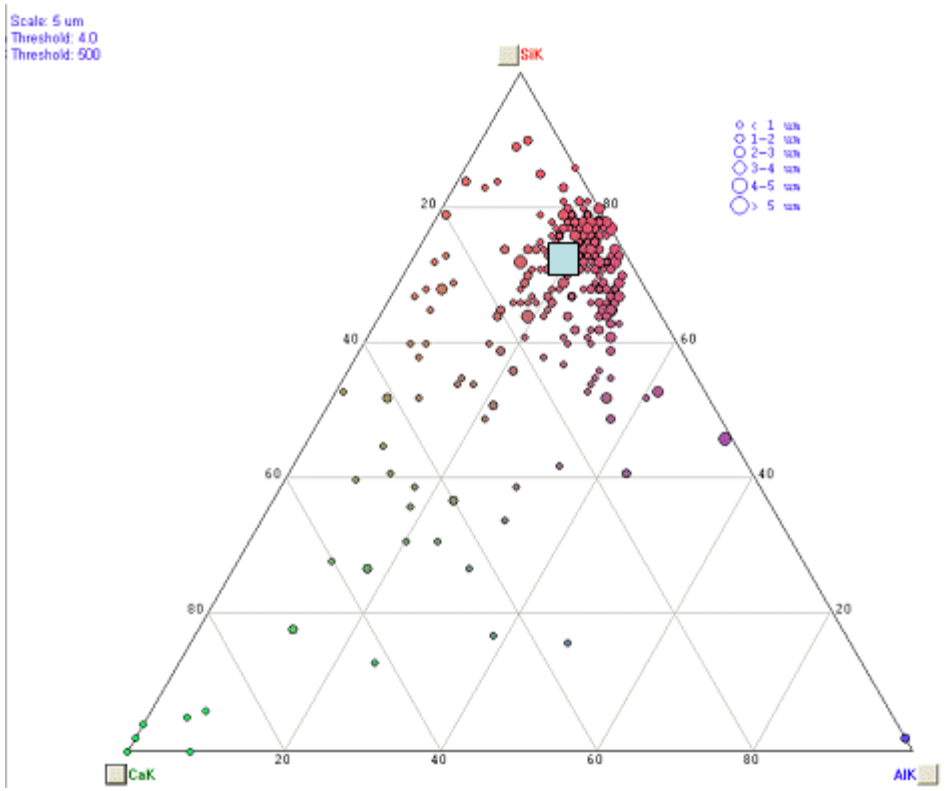


1,4 µm



3,7 µm

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

18 May 2010

- Layer of ash visible from the aircraft during flight in horizontal direction
- Sometimes double structure visible

On-going and future research

Result from research flights during the Eyjafjallajökull 2010 eruption

- The ash plume over Germany seemed to be very inhomogeneous in time and space
- Aircraft 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 as it could be proven in Iceland
- Because of the slow possible measurement speed of the light aircraft highly resolved measurements in time and space were possible
- Even bigger particles could be measured

Quality Assurance

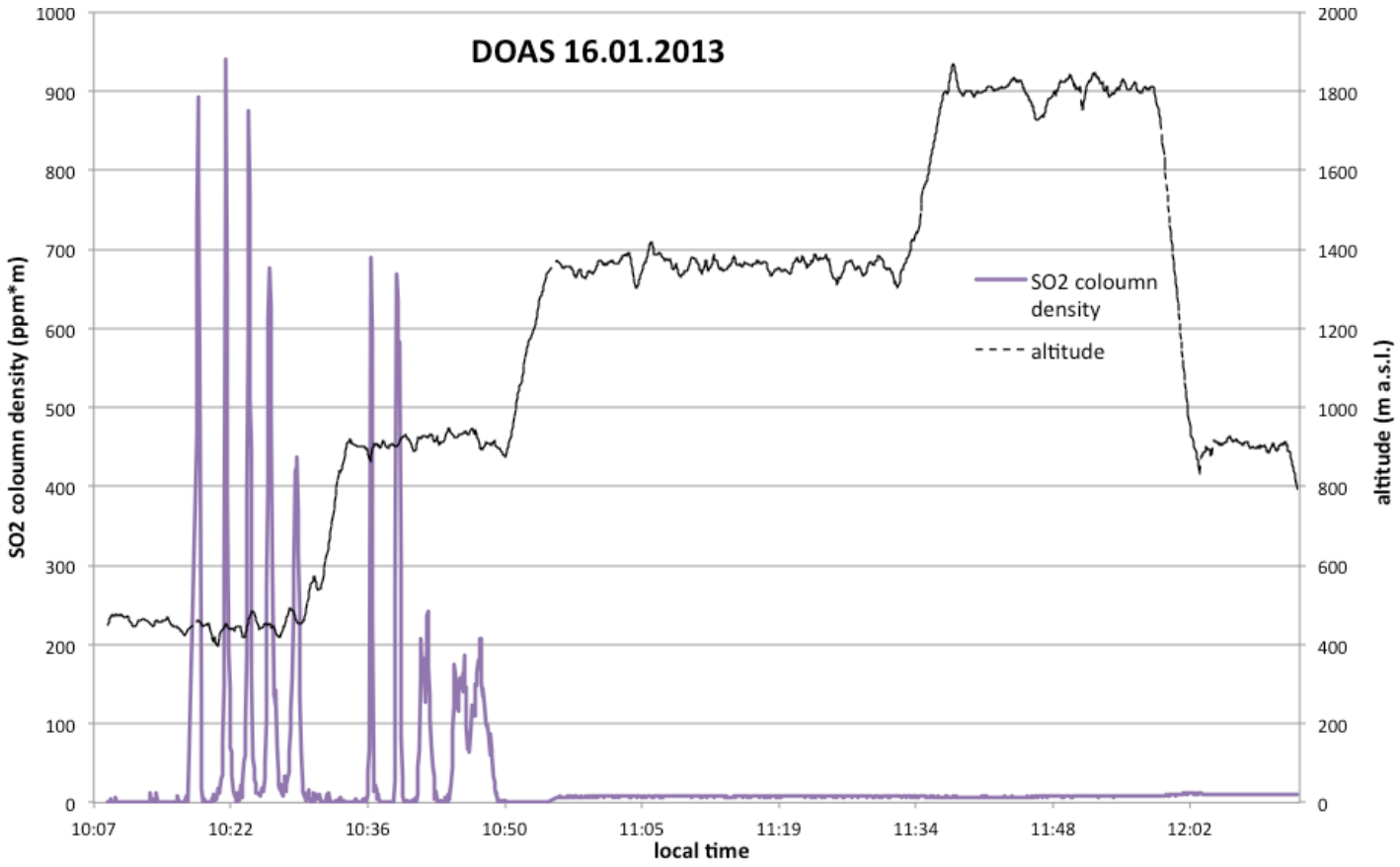
Optimization and quality assurance of measurement systems by

- **University of Applied Sciences Duesseldorf**
- **University of Iceland**

- Tests of systems and aircraft are tested within the resuspended ash plume on Iceland

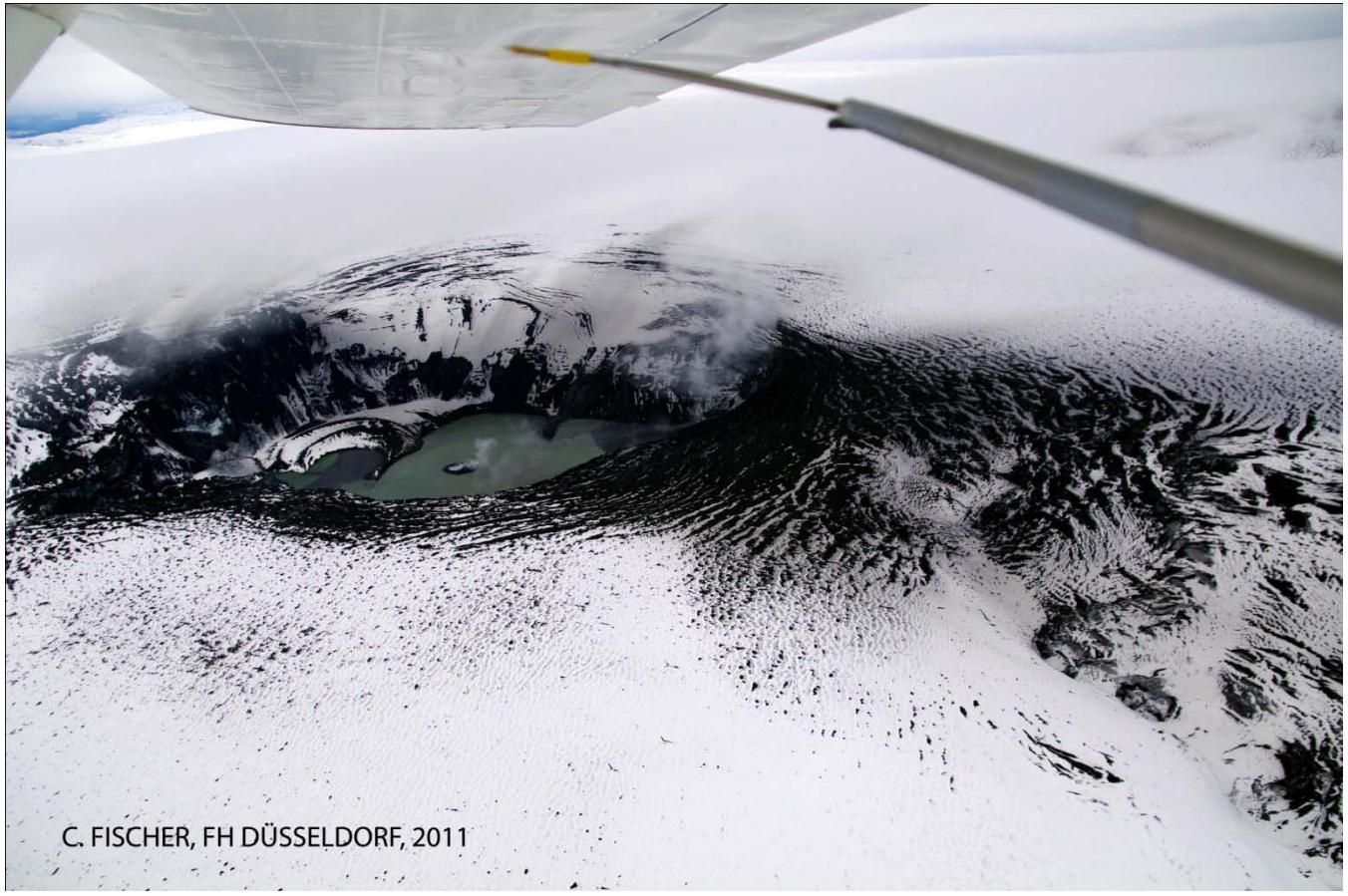
- Tests of systems within the laboratory
  (e.g. wind tunnel experiments and dust tunnel experiments, comparison with gravimetric absolute mass samplers)

Sakurajima volcano Japan 16 Jan 2013



Grimsvötn Eruption May 2011

Research flight of FHD on 28 May 2011 proved:
eruption stopped, nearly no ash emission, some amount of SO2 emissions



Quality assurance, in resuspended ash plume

Test flights and test drives in the resuspended ash plume on Iceland

Grimsvötn Eruption May 2011

Example of flight track and measured concentration on 24 May 2011