The Application of Light Research Aircraft for the Investigation of Volcano Eruption Plumes, Industrial Emissions and Urban Plumes

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Abstract: - Airborne measurements have proved to be an important tool for the investigation of volcanic emission plumes, industrial pollution plumes, fugitive emissions and urban pollution plumes. In this paper several examples are demonstrated, how these investigations can be performed by light and microlight propeller aircraft. Throughout the last years innovative aircraft were developed.in the light and microlight class showing an excellent flight performance. This enables airborne measurements, which were performed in former years normally by big jet engine driven research aircraft. Moreover, these light and microlight aircraft are equipped with piston motors, which are sturdy enough to operate even in adverse and harsh flight conditions, e.g. in volcanic plumes with high ash concentration. Additionally, turbo charged versions of these airborne piston motors are available, which allow flight altitudes of 7000m – 9000m enabling a large variety of research missions. Another advantage of light and microlight research aircraft is that they are quite cost effective and have a comparatively short certification process for the installation of new measurement equipment. This made it possible to respond fast to the eruption of the Icelandic volcano Eyjafjallajökull 2010 and Grimsvötn 2011 with research flights in volcanic ash plumes over Germany and Iceland. In this way it was possible to deliver real airborne measurements additional to the ash plume model calculations of the London Volcanic Ash Advisory Center (VAAC). In this paper examples of airborne measurements in the volcanic plumes of the recent eruptions of Icelandic volcanoes are given. Moreover examples are presented, which highlight the outstanding capabilities of these aircraft for pinpointing industrial emissions and for characterizing urban pollution plumes.

Key-Words: - Airborne measurements, research aircraft, OPC, UV-DOAS, volcano, urban plume, fugitive emissions, industrial emissions

1 Introduction

During the eruption of the Icelandic volcano Eyjafjallajökull 2010 the airspace over Europe was closed for several days, causing high economic losses. When the Grimsvötn volcano erupted on Iceland 2011 again the airspace over parts of Europe was closed temporarily. These airspace closures were caused by the predictions of high ash concentrations over Europe by the dispersion model of the London Volcanic Ash Advisory Center (VAAC). During these airspace closures it became clear, that real ash plume measurements are necessary additional to the predictions of the dispersion model of the London VAAC, as the predictions often were overestimating the ash concentrations and the model could not map the ash plume in all details. In this situation aircraft measurements became important to deliver more detailed in-situ information about the ash plume. Meanwhile, the responsible organizations, in Germany the German Weather Service and in Iceland the ISAVIA, accept aircraft measurements as so called second information sources additional to the VAAC model for their decision, if the airspace should be closed or not in case of the threat by a volcanic ash plume.

Moreover, the success of aircraft measurements with light aircraft in volcanic plumes lead to the approach in Germany, to use these aircraft for environmental measurements at industrial and urban sites as well. In this way a fast overview about the ambient air concentrations over large areas as well as information of emissions of sources like power plants or industrial sites can be gained. This paper gives several examples about airborne measurements of volcanic plumes as well as airborne measurements at industrial and urban sites.

2 Measurement Equipment

2.1 Aircraft

The measurements were performed in Germany with an aircraft “Flight Design CT” and a “Diamond DA42”, in Iceland and Japan with a “Cessna 206” or a “Cessna 172”. All these aircraft were equipped with optical particle counters (OPCs, laser based instruments) for the measurement of ash particles. These are able to measure ash concentrations und fine dust in classes PM10, M2.5, PM1 and TSP. More details of these measurement systems can be found e.g. in [1,2,3]. Additionally, the light research aircraft were equipped with sensors for gaseous pollutants.

Figure 1: Research aircraft “Flight Design CT” with underwing measurement PODs

2.2 Optical Particle Counter OPC

The optical particle counters Grimm EDM.107, Grimm Sky OPC and sometimes Turnkey Dustmate were used for the determination of PM10, PM2.5, PM1, TSP mass concentrations and for measurements of particle numbers, size distribution of particles. On-line measurements and in-situ measurements are possible with these instruments. The measurement principle is based on the measurement of orthogonal scattering of a laser beam by the particles. The Grimm OPCs measure the particle number concentrations in the size range between 250 nm and 32 µm. They use a laser diode emitting radiation of about 660 nm, which is illuminating every single particle. More information about this measurement technique can be found e.g. in [4,5,6,7]

2.3 Passive UV-DOAS Measurement System for SO2

For the measurement of SO2 column content throughout our studies a UV-DOAS system was used. It is based on a UV Spectrometer with a spectral range from 280-400 nm. The optical resolution is 0.05 nm because of a holographic UV grating with 2400 lines. The spectrometer uses a CCD type detector. The UV-DOAS system was mounted outside the fuselage of the aircraft with the telescope directed vertically into the sky. The UV-DOAS system measures the SO2 column density above the telescope by determining the integral SO2 absorption with the scattered sky light as a light source. More information about this measurement technique can be found e.g. in [8,9].

3 Results

3.1 Typical Example of an Ash Plume Flight in the Eyjafjallajökull Ash Plume over Germany on 18 May 2010

The Duesseldorf University of Applied Sciences performed 14 research flights within the Eyjafjallajökull eruption period of April/May 2010 over North Germany in situations with and without ash plumes. A typical ash plume situation was on 18 May 2010, when the London VAAC predicted an ash concentration zone (red) over Germany, that means a zone where ash could be encountered by aircraft (see Fig. 2).

Therefore the German Weather service stipulated research flights for that day by the Duesseldorf

University of Applied Sciences. One example of these flights is shown in Figure 3.

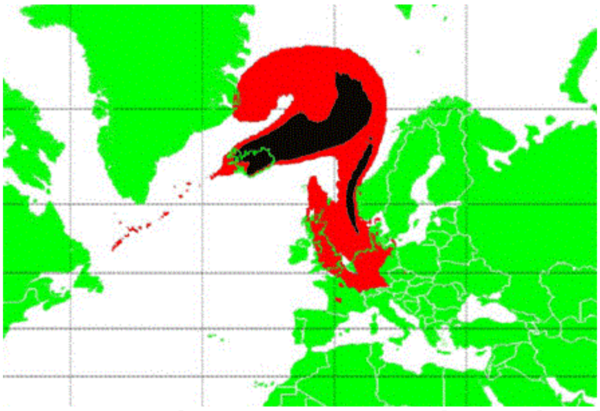


Figure 2: Ash concentration prediction by the London VAAC for 18 May 2010, caused by the Eyjafjallajökull eruption

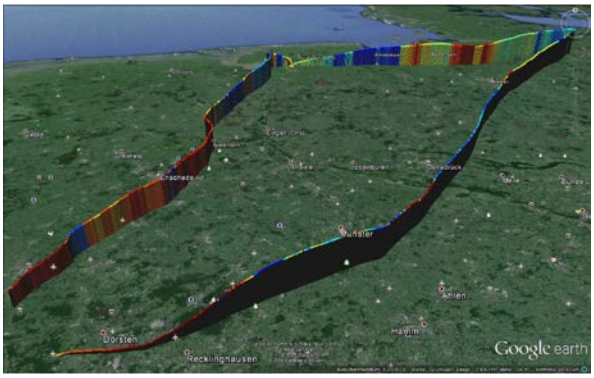


Figure 3: Flight track and measured ash concentrations in the Eyjafjallajökull ash plume over Germany on 18 May 2010

The aircraft started in the Rhein-Ruhr area, travelled along the Dutch border to the North Sea, from there it moved in direction of Hamburg and further on via Recklinghausen back to the Rhein-Ruhr area (see Fig. 3). In this Figure high measured ash concentrations are visualized in red (above 100 µg/m3), low measured ash concentrations are visualized in blue and green.

In this way it could clearly be demonstrated that higher ash concentrations could be observed at the Dutch border and at some spots near the North Sea. Moreover it can be seen clearly in figure 3, that the ash plume was not homogeneously distributed over Germany, as it was suggested by the dispersion model in Figure 2.

3.2 Example of a research flight on 22 May 2011 on Iceland because of the Grimsvötn eruption

The Icelandic volcano Grimsvötn erupted in spring 2011. The eruption started on 21 May and stopped on 25 May 2011. During the period of the eruption the South of Iceland was severely affected by the ash plume. The London VAAC provided to the air traffic authorities ash dispersion charts with the predictions of the spread of the ash plume. Because the London VAAC model predicted significant high ash concentrations for the whole Island, the international airport Keflavik was closed several times during the eruption period and this caused the cancellation of several flights.

Therefore the University of Iceland in cooperation with the Duesseldorf University of Applied Sciences started research flights on Iceland for ash plume observations on 22 May – 26 May 2011. A Cessna 206 served as a platform for the optical particle counters, which were used for the ash particle measurements. The research flights on 22 May and 23 May were on behalf of both Universities, the flights on 24 May to 26 May were performed for the Icelandic air navigation service provider Isavia. Most of the flights were performed in the region of the airports Reykjavik and Keflavik in order to investigate, if the airspace there showed high or low ash concentrations. Figure 4 shows the tracks of the flights over western Iceland.

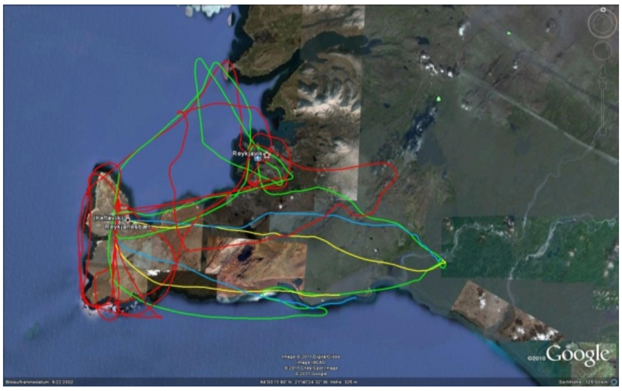


Figure 4: Flight tracks of research aircraft over Iceland during the Grimsvötn eruption 2011

Figure 5: Example of flight track on 24 May 2011, The height of the belt of the track in the figure is corresponding to the altitude of flight

The research flights revealed generally significant lower concentrations of ash over west Iceland (region Keflavik and Reykjavik) than predicted by the London VACC. The results of the measurements were reported immediately after the flights to the air navigation service provider Isavia. The reports of low ash concentrations in the regions of Keflavik and Reykjavik contributed to the decision of Isavia, to re-open the airport of Keflavik, despite higher predicted ash concentrations by the London VAAC [3].
Figure 5 shows as one example of the 11 research flights on Iceland the visualization of the flight track, measured ash concentration (in color) and the flight altitude on 24 May 2011. In this example of ash research flight on 24 May 2011 it could be clearly demonstrated, that the concentrations were low in the region of Keflavik and Reykjavik in Western Iceland, despite of sometimes high ash concentrations in the middle South of Iceland. .

3.2 Example of aircraft measurements at the volcano Sakurajima in Japan

The Sakurajima volcano in Japan is active since years with sometimes several eruptions per day. The Sakurajima is located in close vicinity to the big city Kagoshima, which is often affected by the ash emitted by the volcano. The Kyoto University, the University of Iceland and the Duesseldorf University of Applied Sciences performed several research flight campaigns at the volcano Sakurajima throughout the last years. The aims of these flight campaigns were:

- Investigation of the emitted ash particle distribution, particle formation and particle size change within the plume,
- Investigation of the concentration range of the emitted ash particles of the volcano,
- Investigation of the SO2 gas concentrations in the emission plume
- Determination of SO2 gas flux from the volcano.

In this paper an example is given of the SO2-measurements of the plume of the volcano Sakurajima. Figure 6 shows the measured SO2 column content as it was determined by the passive UV-DOAS system, mounted on the aircraft with upward view operation. The volcano Sakurajima is shown schematically in a Google Earth map together with the flight track of the research aircraft (meander shaped flight track in blue color). The column density of SO2-concentrations is sketched in different colors on the flight track (red: high concentrations, green: middle concentrations, blue: low concentrations). Picture 6 shows as an example the results of the research flight on 15 Februar 2015. From this flight an SO2 emission rate of about 5000 t/d could be calculated.

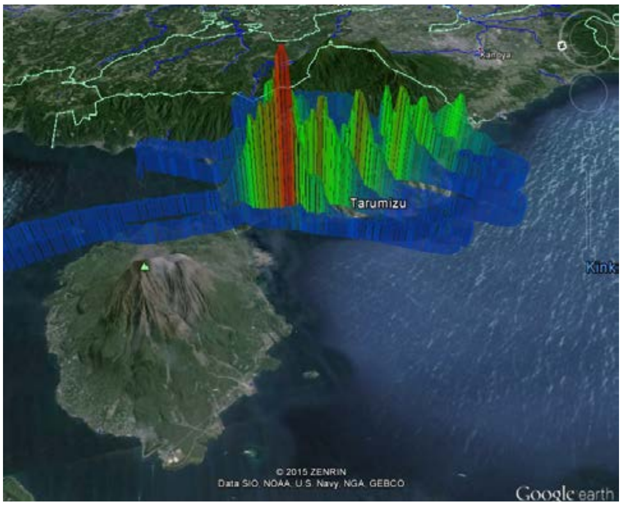


Figure 6: SO2-plume measured by the aircraft at Sakurajima volcano, Japan, 15 Februar 2015

3.3 Example of aircraft measurements of fine dust PM10 at an industrial site

Throughout the last years the Dusseldorf University of Applied Sciences could demonstrate successfully within several measurement campaigns that light research aircraft, equipped with appropriate instrumentation, are very useful to investigate fugitive emissions from area sources like industrial plants, refineries, open coal mines, agriculture, and urban areas. Here it turns out to be of advantage that the light research propeller aircraft can fly at lower altitudes and at lower speed than big research aircraft, which are jet engine driven. Therefore the light research propeller aircraft can achieve high spatial resolution of the measurements and can easier pinpoint local sources.

In this paper an example is given of the investigation of fugitive PM10 fine dust emissions out of the area of a large industrial complex in Germany with a light propeller research aircraft. For these investigations a light twin engine propeller aircraft was used.

The task of this special measurement campaign was to identify sources of fugitive PM10 fine dust emissions within the large area of the industrial complex in a situation, when a pronounced atmospheric inversion layer was present over Germany and Central Europe. Because of this inversion layer the fine dust had been concentrated over the complete Middle Europe, resulting in general high concentrations of PM10. Similar situations have been observed already before [10]. Figure 7 shows the simulation of PM10 fine dust concentrations over Middle Europe, which were calculated for the 14 May 2014 by the RIU institute of the University of Cologne with a simulation model. Figure 7 shows daily maximum PM10 concentrations for Germany of 120-200 µg/m3, which were calculated for 14 March 2014 based on the simulation model.

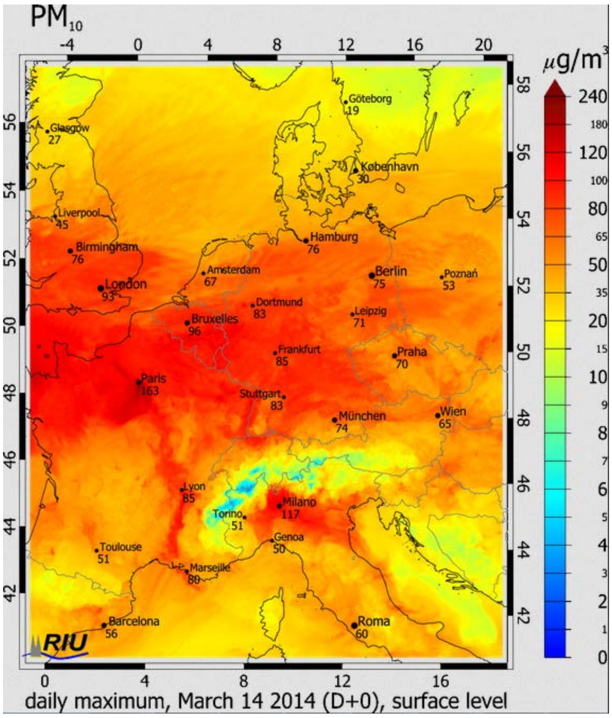


Fig. 7: Calculated daily maximum PM10 fine dust concentrations for Middle Europe by a simulation model by RIU institute of the University of cologne (http://hermes.eurad.uni-koeln.de/PLOTS// 201403/14/an01w-p15-PM10-l01-dmax.gif)

Figure 8 shows the results of a research flight over the area of the steel company at 24 March 2014. The colored dots show the meander-like flight path. The flight was performed in 150m above ground. The color of the dots represents the measured PM10 concentration. Green dots represent PM10 concentrations of 50-75 µg/m3, red dots represent PM10 concentrations of 200-250 µg/m3, violet dots represent PM10 concentrations of above 500 µg/m3.

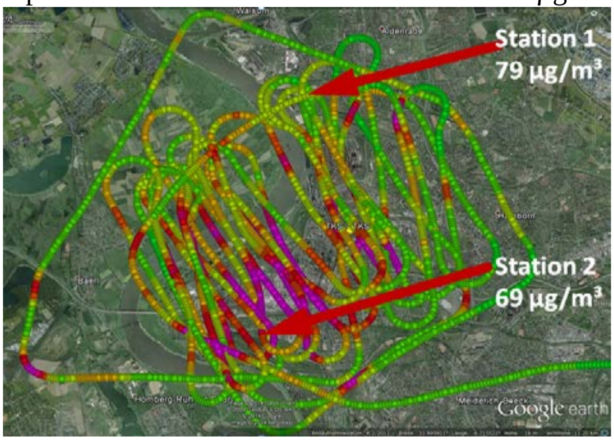
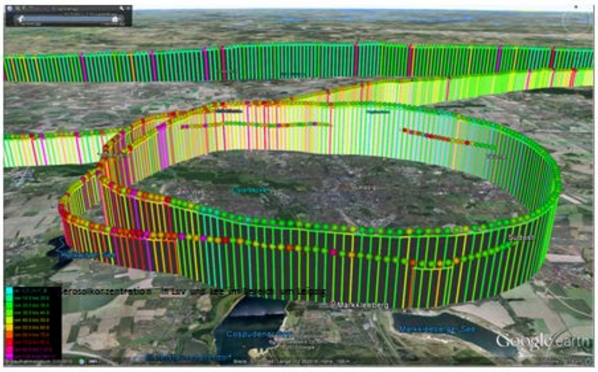


Fig. 8: Aircraft investigations of PM10 emission hot spots within the area of a steel company

As it can be seen in Figure 8 the aircraft measurements could clearly identify hot spots of higher emissions of PM10 within the area of the steel company with peaks of more than 500 µg/m3 PM10 concentration. The arrows in Figure 7 demonstrate the location of ground based measurement stations for PM10. These stations measured PM10 concentrations of 69 µg/m3 and 79µg/m3, respectively. Therefore it turns out that the aircraft measurements not only could identify hot spots of fugitive emissions, but could demonstrate that the fugitive emissions out of the industrial processes arise partly at elevated altitudes. Therefore the research aircraft measurements could deliver information, which would not be available in a conventional way.

3.4 Example of aircraft measurements of an urban plume

The air quality within cities in Germany is frequently monitored by fixed measurement stations. These measurement stations give information of the air quality at representative points of the city. However, normally the role of the city as a total source of fugitive emissions is not known in a quantitative way. Here can research aircraft measurements give valuable information. An example is given in Figure 9, which shows the result of a research flight around the city of Leipzig in Germany at 23.03.2012. The wind was blowing from East (right hand side in Figure 9). Figure 9 demonstrates clearly that the city of Leipzig is a significant source of fugitive emissions of fine dust PM10, PM2.5, PM1, as the downwind concentrations (red in the Figure 9) are much higher than the upwind concentrations.



Leipzig	PM10 µg/m³	PM2,5 µg/m³	PM1 µg/m³
upwind	25,4	25,0	21,3
downwind	68,4	56,0	45,9

Figure 9: Investigation of fugitive emissions of a city as an area source of fine dust.

4 Conclusion

It could be shown that light research propeller aircraft are a very versatile tool for measurements in volcanic ash plumes, at industrial sites and in urban plumes. They have the advantage that they are durable and sturdy enough to fly even at elevated ash concentrations, where jet-engine driven aircraft cannot fly because of possible damage of the jet engines. These light aircraft allow slow measurement speed so that they can deliver concentration and plume data with high accuracy. For this study the aircraft were equipped mostly with optical particle counters, an UV-DOAS system and electrochemical sensors. Therefore particles and gases like SO2 could be measured.

More measurement campaigns at industrial sites, for ambient air research and at volcanoes overseas are planned in the near future.

5 Acknowledgement

This work was partly funded by the German Ministry of Transport, Building and Urban Development, the German Weather Service, AIRBUS and the Saxon State Office for Environment, Agriculture and Geology and the
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