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Identification of existing research airborne remote sensing platforms for fast response service

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Abstract

This report provides an overview of existing research and civil contingency aircraft for remote sensing measurements for crisis secenarios with volcanic ash, desert dust and biomass burning aerosol in the air space over Europe. This includes information on the aircraft and the remote sensing sensors. Measurement examples are also given. Finally, limitations are addressed in terms of aircraft availability and airborne remote sensing instrumentation.

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Executive Summary

Remote sensing observations from aircraft represent an important element of an integrated observation system in case of a volcanic eruption, sand storm and biomass burning event in Europe.

In this report an overview is provided of European research and civil contingency aircraft available with remote sensing instruments. Information is given on the aircraft operator, type of aircraft and engine, and type of remote sensing instrument.

In addition, the aircraft instrumentation for remote sensing observation of hazardous plumes is briefly described. Also, examples of Lidar and DOAS measurements are shown for the Eyjafjallajökull (2010) plume.

Finally, limitations of aircraft availability and airborne remote sensing instrumentation are addressed.

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1. Introduction

This document provides an overview of existing research and civil contingency aircraft for fast response remote sensing observations of volcanic clouds, desert dust and biomass buring aerosol clouds. It complements the deliverable report D17 and the milestone reports M10 and M31. Airborne remote sensing measurements from aircraft are of particular interest for EUNADICS-AV since this data can be obtained without the interception of hazardous particle clouds with the risk of a negative impact on the aircraft systems.

The need of observations from airborne platforms as an additional source of information emerged during the recent eruptions of the Eyjafjallajökull and Grimsvötn volcanoes in 2010 and 2011. Aircraft lidar remote sensing measurements during the Eyjafjallajökull eruption provided important information on the location and top height of the volcanic ash plumes (Schumann et al. 2011, Turnbull et al. 2012). The aircraft deployed during the Eyjafjallajökull crisis were commissioned by the national authorities (e.g. meteorological offices) and research organisations. Thus, there was limited coordination between the aircraft operations and limited exchange of data. After the Eyjafjallajökull crisis, the need for a European coordination scheme emerged and dedicated contingency aircraft were prepared for fast response measurements.

2. Available research aircraft for fast response remote sensing observations

European research aircraft with instrumentation for remote sensing measurements in volcanic ash and dust clouds are listed in Table 2.1 including information on the sensor type. These aircraft are in principle available for measurements during future events (volcanic eruptions, dust storms). However, there are issues which may make the fast deployment of the aircraft difficult including the availability of funding and commitments of the aircraft in other projects.

Table 2.1: List of research aircraft in Europe with remote sensing instruments for volcanic ash, dust, and forest fire cloud observations

Operator	Country	Aircraft	Engine type	Endurance, max (h)	Remote sensing sensor
DLR	DE	Falcon 20	Jet	4.5	Lidar
FAAM	UK	BAe146	Jet	6	Lidar
FH Düsseldorf	DE	Flight Design CT	propeller	10	DOAS
CARIBIC	DE	A340	Jet	12	DOAS
NLR	NL	Citation	Jet	5	Lidar
SAFIRE	FR	Falcon 20	Jet	5	Lidar
SAFIRE	FR	ATR42	propeller	5	Lidar

3. Civil contingency aircraft for fast response remote sensing observations

Two dedicated civil contingency aircraft were commissioned by European meteorological offices for fast response measurements in volcanic plumes. The UK Met Office commissioned a Cessna 421 as contingency aircraft, called MOCCA (Meteorological Office Civil Contingency Aircraft). The payload of the MOCCA aircraft includes a Lidar instrument which can be operated in upward and downward viewing modes (Figure 3.1) Details are given on the website: https://www.metoffice.gov.uk/services/public-sector/emergencies/civil-contingency-aircraft.

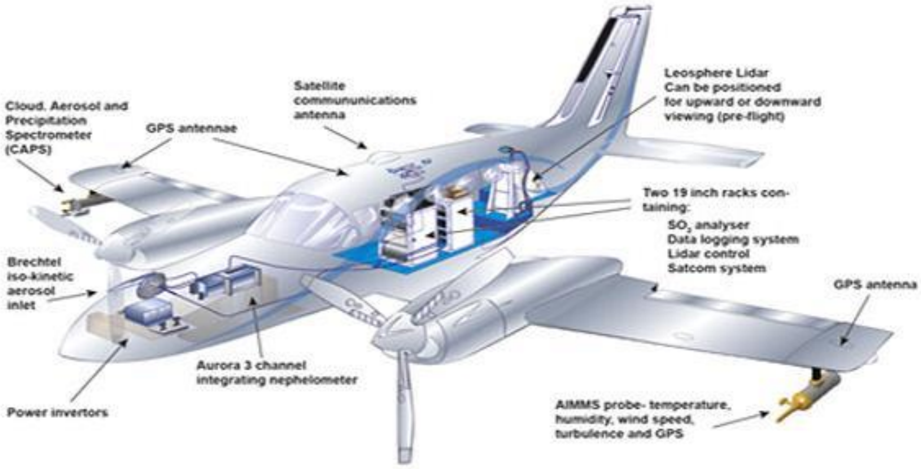

Figure 3.1: UK Met Office Civil Contingency Aircraft for fast response measurements of volcanic ash clouds including lidar remote sensing measurements (MOCCA)

The German Weather Service supports as contingency aircraft a piston-motor driven "Flight Design CT" of the University of Applied Sciences in Düsseldorf (Figure 3.2). Besides in-situ sensors, this aircraft is also equipped with an upward-looking DOAS system for remote sensing of SO_2 (Weber et al. 2012).

Figure 3.2: Flight Design CT deployed by the University of Applied Sciences of Düsseldorf for fast response volcanic cloud measurements

4. Information on the available remote sensing instruments

Table 4.1 includes the sensors recommened by ICAO for remote sensing measurements of volcanic ash clouds (ICAO WP: IVATF/4-WP/10, 2012). The Lidar and DOAS measurement techniques are described in detail in Wendisch and Brenguier (2013).

Table 4.1 Airborne remote sensing instrumentation for volcanic ash observations

Instrumentation	Measured quantity	Object
Lidar (down, up, or ahead viewing)	aerosol backscatter ratio, depolarization	horizontal, vertical structure of ash plumes
IR imaging cameras (ahead viewing)	IR radiance at different wave-lengths	location and properties of ash and SO_2 clouds
DOAS (down, up, sidewards viewing)	SO_2 slant column density	location of SO_2 clouds

Lidar (light detection and ranging) is a very powerful remote sensing technique to probe aerosol clouds because of its capability to provide data with very high spatial resolution. The basic lidar principle includes the transmission of a laser pulse into the atmosphere where it encounters gas molecules and particles. A small amount of this energy is backscattered in the direction of a receiver telescope, and transferred to a photodetector. The resulting electrical signal is proportional to the optical power received, which depends on the presence, range and concentration of atmospheric scatterers and absorbers in the light path volume.

Lidar techniques have already been used very successfully for monitoring the dispersion of volcanic clouds in the atmosphere providing geometrical properties (top, bottom and thickness) for volcanic layers as well as optical properties (extinction, backscatter and optical depth).

DOAS (Differential Optical Absorption Spectroscopy) is a well-established technique for measurements of atmospheric trace gases and aerosols. The DOAS instrument observe scattered sunlight at different viewing directions enabling the determination of the integrated concentration of trace gases along the light paths using as fingerprints the individual absorption cross sections of the corresponding trace gas in the UV/Vis spectral region.

Aircraft and ground-based observations during the Eyjafjallajökull eruption have demonstrated the potential of DOAS for the detection of volcanic ash and SO_2 plumes (Heue et al., 2011). However, as a passive technique, DOAS measurements can only be performed during daytime.

In addition to Lidar and DOAS techniques, infra-red imaging cameras are capable of fast-detecting volcanic plumes from aircraft and ground. IR cameras are operated in the wavelength region of 8–12 µm and can be used during day and night. They can provide information on gases and ash including fine-ash mass loading, effective particle radius (fine mode), and optical depth.

An aircraft-borne uncooled infrared camera device (AVOID) have been developped by Prata et al. (1991) and successfully tested at Etna and Stromboli volcanoes using a light aircraft and during an artificial ash cloud experiment from a long-range flight test aircraft (Prata et al. 2016).

5. Examples of airborne remote sensing measurements

As an example, Lidar measurements from the DLR Falcon of the Eyjafjallajökull plume are shown in Figure 5.1 (Schumann et al. 2011). In addition to volcanic ash, the Lidar detected also cirrus clouds above the ash cloud and aerosol pollution in the boundary layer.

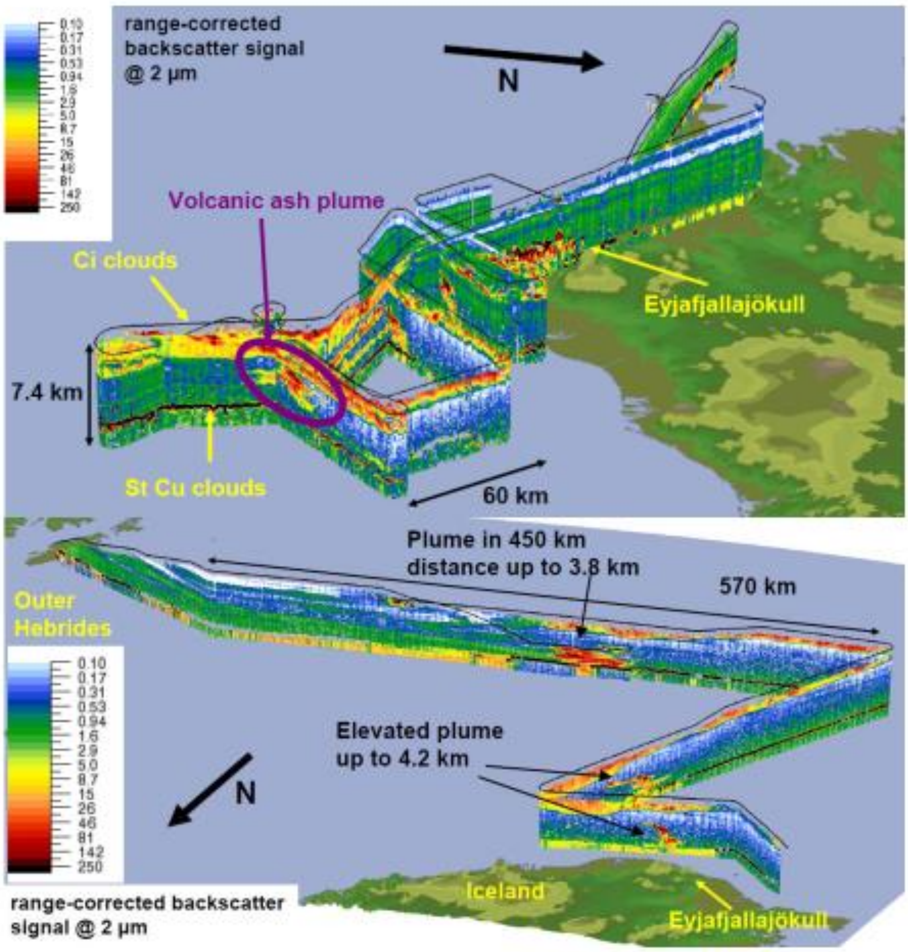

Figure 5.1: Lidar cross-sections of the Eyjafjallajökull ash plume (range corrected backscatter) of flights on 1 May and 2 May 2010 (from Schumann et al., 2011)

An example of DOAS measurements from the CARIBIC aircraft of the Eyjafjallajökull plume located north of Ireland is shown in Figure 5.2. The volcanic gases sulphur dioxide (SO_2) and bromine monoxide (BrO) were measured in the plume during a flight on 16 May 2010. The BrO and the SO_2 observations coincide very well indicating that BrO have been formed inside the volcanic plume. Average SO_2 and BrO mixing ratios of ≈40 ppb and ≈5 ppt, respectively, were retrieved inside the plume. The SO_2 and BrO observations with DOAS agreed well with simultaneous satellite (GOME-2) observations.

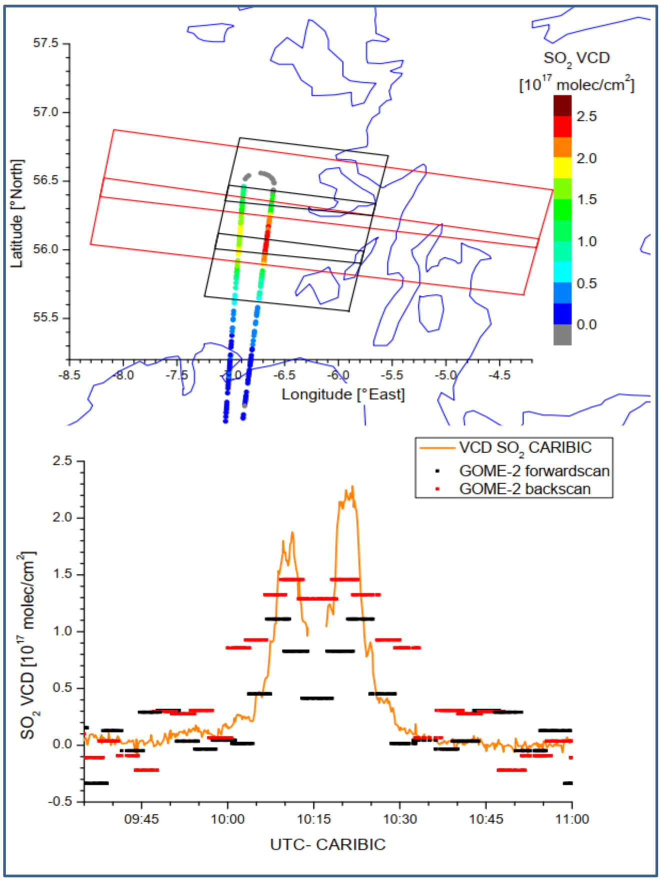

Figure 5.2: Top panel: SO_2 vertical column density from CARIBIC-DOAS and the observed plume position relative to the GOME-2 pixel (black: forward, red: back scan); Bottom panel: Comparison of the vertical SO_2 columns, measured by CARIBIC (nadir) and GOME-2. For each CARIBIC-DOAS measurement the pixels crossed by the aeroplane (forward and backward scans) are shown (from Heue et al. 2011)

6. Limitations of the availability of aircraft and sensors

6.1 Fast response aircraft:

It is very likely, that only a limited number of research aircraft will be available for remote sensing measurement on a short notice during a future volcanic crisis due to other ongoing deployments or maintenance of the aircraft. Thus, an effective coordination of the deployment of the available European research aircraft is needed during a future volcanic eruption in order to provide the most usefull observation to support VAAC forecasts and the decision making authorities.

Another important issue is the funding of the operation of research aircraft for a fast response service in case of a crisis. Concerning the coverage of costs, responsibilities need to be defined beforehand.

Presently, two contingency aircraft for fast resonse observations are available in the UK and Germany commissioned by the national Weather Services. It is not clear, however, if these aircraft will only perform measurements over the countries were the aircraft are based or also over other European regions.

6.2 Remote sensing instruments:

Lidar and DOAS observations can be obstracted by dense clouds. The DOAS technique has also the limitaion of only daytime measurements.

Data of the location and structure of the volcanic plume layers can be provided very quickly after the flight, however, the analysis of mass loadings and optical depths need more time.

The use of IR imaging camera technique for the detection of ash clouds is very promising, however, presently there exists only one aircraft instrument.

7. References

Heue, K.-P-, et al., SO2and BrO observation in the plume of the Eyjafjallajokull volcano 2010: CARIBIC and GOME-2 retrievals, Atmos. Chem. Phys., 11, 2973–2989, 2011 doi:10.5194/acp-11-2973-2011

ICAO Working Paper of the International Volcanic Ash Task Force, IVATF/4-WP/10, 2012

Prata, A. J., Barton, I. J., Johnson, R. W., Kamo, K. & Kingwell, J. *Hazard from volcanic ash*. *Nature* **354**(6348), 25 (1991).

Prata, A.J., et al., Artificial cloud test confirms volcanic ash detection using infrared spectral imaging, S*cientific Reports*, *V*volume 6, Article number: 25620 (2016), doi:10.1038/srep25620

Schumann, U., et al. (2011), Airborne observations of the Eyjafjalla volcano ash cloud over Europe during air space closure in April and May 2010, Atmos. Chem. Phys. 11, 2245–2279, doi:10.5194/acp-11-2245-2011

Turnbull, K., B. Johnson, F. Marenco, J. Haywood, A. Minikin, B. Weinzierl, H. Schlager, U. Schumann, S. Leadbetter, and A. Woolley (2012), A case study of observations of volcanic ash from the Eyjafjallajökull eruption: 1. In situ airborne observations, J. Geophys. Res., 117, D00U12, doi:10.1029/2011JD016688

Weber K., J. Eliasson, A. Vogel, C. Fischer, T. Pohl, G. van Haren, M. Meier, B. Grobéty, D. Dahmann (2012), Airborne in-situ investigations of the Eyjafjallajökull volcanic ash plume on Iceland and over north-western Germany with light aircraft and optical particle counters, Atm. Environment, 48, 9 –21, doi:10.1016/j.atmosenv.2011.10.030

Wendisch, M., and J.L. Brenguier, (Editors), Airborne Measurements for Environmental Research: Methods and Instruments, Wiley, ISBN-13: 978-3527409969, 2013.