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Identification of existing research and operational aircraft for fast response service

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Abstract

This report provides an overview of existing research and civil contingency aircraft for measurements in volcanic clouds in the air space over Europe. This includes information on the aircraft operator, type of aircraft and engines, maximum endurance, and cruise altitudes. Further, recommended aircraft instrumentation is listed for the observation of volcanic plumes including remote sensing and in-situ sensors. Two measurement examples are also given. Finally, gaps and limitations are addressed in terms of aircraft availability and operation, airborne instrumentation, and data usage.

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Summary

Aircraft measurements represent an important element of an integrated observation system in the event of a volcanic eruption in Europe, besides satellite- and ground-based remote sensing measurements. The need of observations to support the forecasts of the dispersion of volcanic ash in the European air space emerged during the Eyjafjallajökull crisis.

Presently, in-situ aircraft measurements of the size distribution of ash particles in a volcanic cloud are the only direct observation-related information to derive ash mass concentrations and thereby validate corresponding model simulations.

In this report an overview is provided of European research and civil contingency aircraft available for observations during a volcanic eruption. Information given includes aircraft operator, type of aircraft and engine, maximum endurance, and cruise altitudes.

In addition, aircraft instrumentation that is recommended for the observation of volcanic plumes (based on the experiences from the Eyjafjallajökull crises) is described. This includes remote sensing and in-situ sensors. Two measurement examples are also shown of lidar and in-situ observations in the aged Eyjafjallajökull eruption plume.

Finally, gaps are identified concerning aircraft availability and operation, airborne instrumentation, and exchange of data.

Content

1. Introduction

This document provides an overview of existing research and civil contingency aircraft for fast response observations of volcanic clouds. Besides satellite- and ground-based remote sensing, measurements from aircraft represent an important element of an integrated observation system in the event of a volcanic eruption in Europe addressed in the project EUNADICS-AV.

The eruptions of the Eyjafjallajökull and Grimsvötn volcanoes in 2010 and 2011 severely affected the air traffic transport system in Europe and the North Atlantic including the disruption of more than 100,000 flights. Ash mass concentrations predicted by the Volcanic Ash Advisor Center (VAAC) exceeded levels considered save for flight operations for many days in many regions in Europe. The need of observations as an additional source of information emerged during these events with volcanic ash in the European air space. Aircraft measurements performed during the Eyjafjallajökull eruption proved to provide important information on the mass concentration and nature of the ash in the volcanic plumes (Schumann et al. 2011, Turnbull et al. 2012, Weber et al. 2012).

A number of research aircraft performed measurements during the Eyjafjallajökull crisis using different sets of instrumentation. The starting time of the flight operations and the type of sensors deployed were given by the availability of the research aircraft and readiness of the instruments. The aircraft were commissioned by the national authorities (e.g. meteorological offices) and research organisations. There was an exchange of information on the deployment times and regions of the different aircraft through the European Facility for Airborne Research (EUFAR) but otherwise very limited coordination. Thus, after the Eyjafjallajökull event the need emerged for a European coordination scheme and for a dedicated contingency aircraft for fast response measurements during a volcanic crisis.

2. Available research aircraft for volcanic cloud observations

European research aircraft with suitable certified instrumentation for measurements in volcanic clouds are listed in Table 2.1 including information on engine type, maximum endurance, and cruise altitude. These aircraft performed measurements during the Eyjafjallajökull crisis (Fig. 2.1) and are in principle available for measurements in volcanic clouds during future eruptions. However, there are several issues which hamper the deployment of the research aircraft during a crisis including funding, risk of damage of engines and other aircraft parts, and conflicting commitments to other projects. Also, the installation of suitable instrumentation into the aircraft takes at least several days making fast response measurements difficult.

Table 2.1: List of research aircraft in Europe available for volcanic ash observations

Operator	**Country**	**Aircraft**	**Engine type**	**Endurance, max (h)**	**Max. cruise altitude (kft)**
DLR	DE	Falcon 20	jet	4.5	41
ENVISCOPE	DE	Learjet	jet	5	45
FAAM	UK	BAe146	jet	6	35
FH Düsseldorf	DE	Flight Design CT	propeller	10	4.5
FU Berlin	DE	Cessna	propeller	4	19.5
INTA	ES	Casa	propeller	4	25
METAIR	CH	Dimona	propeller	5	16.5
NLR	NL	Citation	jet	5	43
KIT	DE	Enduro	motor glider	7	14
SAFIRE	FR	Falcon 20	jet	5	39
SAFIRE	FR	ATR42	propeller	5	25

For the operation of research aircraft in ash contaminated air space closed for commercial air traffic, a special permission is needed (status of Government aircraft). After such a flight, the aircraft need to be inspected including boroskope inspection of the engines.

Fig. 2.1 European research aircraft deployed during the Eyjafjallajökull eruption for measurements in the volcanic plume (number of flights are included)

3. Available civil contingency aircraft for volcanic cloud observations

The number of research aircraft equipped with a suitable set of instrumentation for measurements in volcanic clouds is limited. Thus, research aircraft will not always be available on a short notice in case of a volcanic eruption. Therefore, dedicated civil contingency aircraft were commissioned by European meteorological offices for fast response volcanic plume measurements.

The UK Met Office commissioned a Cessna 421 as contingency aircraft (MOCCA: Meteorological Office Civil Contingency Aircraft). The Cessna 421 is a twin piston engine pressurized aircraft. Since piston engines operate at cooler temperatures, MOCCA is able to sample ash clouds with higher ash mass concentrations compared to jet aircraft. The MOCCA instrumentation is depicted in Fig. 3.1. The payload consists of an aerosol lidar (upward and downward looking) for remote sensing of ash clouds and a package of in-situ instruments including a Cloud Aerosol and Precipitation Spectrometer (CAPS) probe (wing-mounted), an integrating nephelometer, an SO_2 detector, and inlets for gas sampling using Tedlar bags. Meteorological parameters (temperature, humidity, and pressure) are measured by a wing-mounted air data probe (https://www.metoffice.gov.uk/services/public-sector/emergencies/civil-contingency-aircraft).

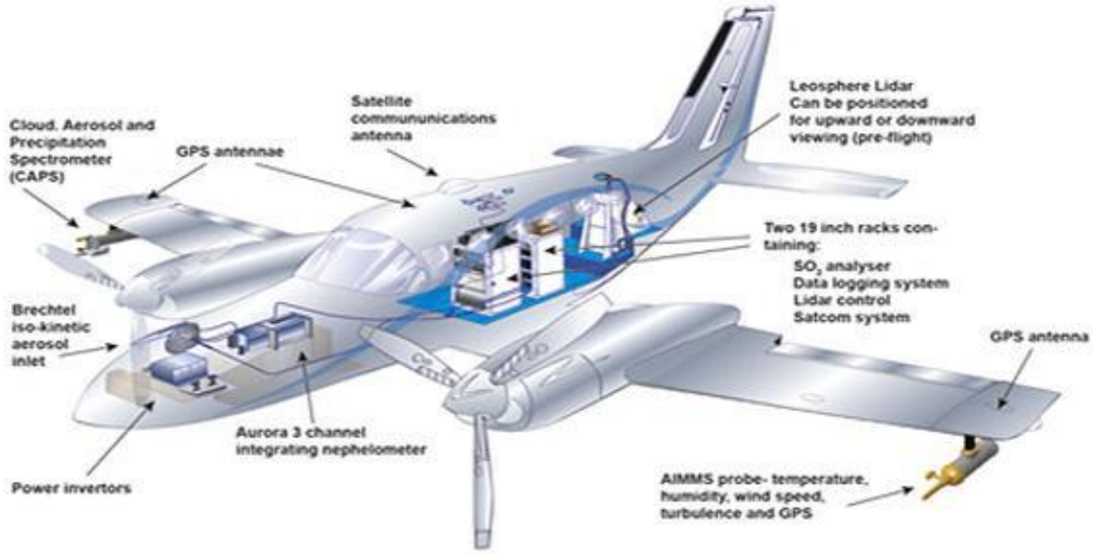

Fig. 3.1 UK Met Office Civil Contingency Aircraft (MOCCA) for fast response measurements of volcanic ash clouds in the air space

The MOCCA observations can be transmitted directly via satellite in real-time to the response teams at the UK Met Office Hazard Centre.

The German Weather Service supports as contingency aircraft a piston-motor driven “Flight Design CT” of the University of Applied Sciences in Düsseldorf (Fig. 3.2). The aircraft is equipped with an optical particle counter (OPC) for in-situ ash concentration measurements, a particle collector attached to the OPC outlet line, an upward-looking DOAS system for remote sensing of SO_2, and a non-dispersive infrared CO_2 detector (Weber et al. 2012).

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

4. Instrumentation recommended for volcanic cloud measurements

Amongst the observations of European research aircraft in the ash plumes from the Eyjafjallajökull eruption in April and May 2010, the most comprehensive data sets were sampled by the DLR Falcon and the BAe-146 of FAAM. Both aircraft were equipped with a lidar and in-situ instruments for the detection of ash particles and gas-phase plume tracers (SO_2, CO, CO_2). Based on the experiences from these airborne measurements, a recommendation on a set of aircraft sensors best suited for volcanic cloud observations was provided to the International Civil Aviation Organization (ICAO). Table 4.1 includes a list of recommended sensors for remote sensing and in-situ measurements (ICAO WP: IVATF/4-WP/10, 2012).

The instrumental techniques listed in Table 4.1 are described in detail in Wendisch and Brenguier (2013). A comprehensive set of the in-situ gas and particle measurement systems given in Table 4.1 as well as lidar instruments are available for the large European research aircraft, FAAM BAe146, SAFIRE ATR, and DLR Falcon.

Table 4.1 Recommended aircraft instrumentation for volcanic ash observations

Instrumentation	Type of sensor	Measured quantity	Object
Lidar (down, up, or ahead viewing)	remote sensing, (in aircraft cabin)	aerosol backscatter ratio, depolarization	horizontal, vertical structure of ash plumes
IR sensor (ahead viewing)	remote sensing, (in under-wing canister)	IR radiance at different wave-lengths	location of ash cloud
DOAS	remote sensing	SO_2 slant column density	location of SO_2 cloud
Condensation particle counter (with/without thermodenuder)	in-situ (in aircraft cabin)	integral number of ultrafine particles and non-volatile fraction (0.005µm<D_p<2.5µm	size distribution of ash particles, derived ash mass concentration
Optical particle counter	in-situ (in aircraft cabin)	fine particles (0.25µm<D_p< 2.5µm)	
UHSAS-A	in-situ (wing-mounted aerosol spectrometer)	fine particles, dry state (0.15 µm<D_p< 3.0 µm)	
CAS	in-situ (wing-mounted aerosol spectrometer)	size distribution coarse mode, ambient state (1 µm <D_p< 50 µm)	
2D-C probe	in-situ (wing-mounted aerosol spectrometer)	shape and size distribution of very large particles, water droplets and ice-crystals (25µm<D_p< 800µm)	
Impactor sampler	in-situ (in aircraft cabin).	sampling of fine particles (< 2.5µm)	composition of fine ash particles
Particle collector	in-situ (wing-mounted)	sampling of coarse particles	composition of coarse ash particles
CIMS	in-situ (in aircraft cabin)	SO_2, HCl, HF, HNO_3	volcanic cloud gas composition
Fluorescence detector	in-situ (in aircraft cabin)	CO	
CRDS	in-situ (in aircraft cabin)	CO_2	
Chemiluninsecence	in-situ (in aircraft cabin)	NO, NO_y	
Met. probes	in-situ	temperature, pressure, humidity, wind	

(DOAS: Differential optical absorption spectroscopy; UHSAS: Ultra-High Sensitivity Aerosol Spectrometer, CAS: Cloud Aerosol Spectrometer, 2D-C probe: Two-Dimensional Optical Array Cloud Probe, CIMS: Chemical Ionization Mass Spectrometry, CRDS: Cavity Ring Down Spectrometry)

5. Aircraft measurement examples

As an example of remote sensing observations, lidar measurements from the DLR Falcon are depicted in Fig. 5.1 of a survey flight across Germany during the Eyjafjallajökull crisis (Schumann et al. 2011). A large-scale volcanic ash layer was detected in the mid-troposphere (4-6 km altitude) with a vertical thickness of 0.5-2 km. In addition, the lidar detected cirrus clouds above the ash cloud and aerosol pollution in the boundary layer.

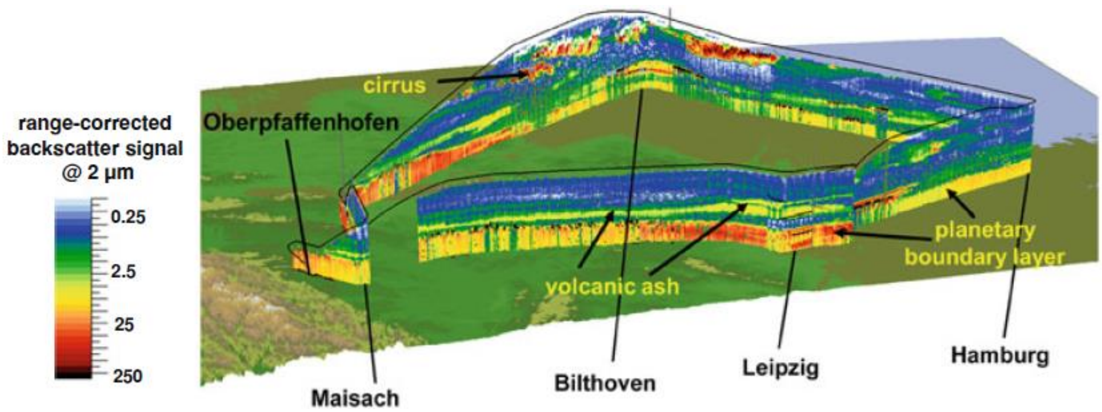

Fig. 5.1 Lidar measurements over Germany from the DLR Falcon during the Eyjafjallajökull eruption on 19 April 2010 (Schumann et al. 2011)

An example of aircraft in-situ measurements is shown in Fig. 5.2.

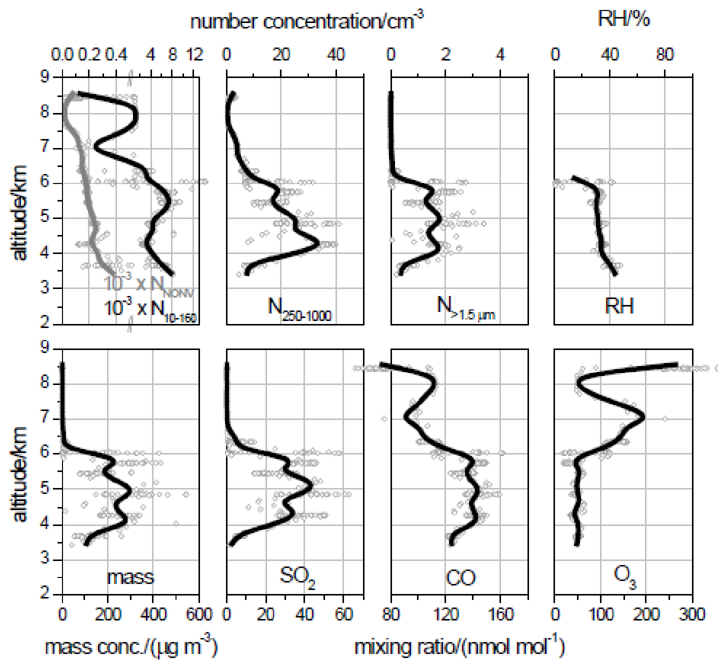

Fig. 5.2 In-situ measurements through an ash cloud over the North Sea on 17 May 2010 from the DLR Falcon (adapted from Schumann et al. 2011)

Given are number concentrations of Aitken mode, accumulation mode, and coarse mode particles, ash mass concentrations derived from the size distributions, SO_2, CO, and O_3 volume mixing ratios, and relative humidity during a vertical profiling of the volcanic ash layer.

6. Gap analysis and limitations

Here gaps and limitation are addressed, which are identified for the use of research and contingency aircraft for volcanic cloud observations.

Research aircraft:

- There is a need of a European coordination of the deployment of research aircraft during a future volcanic eruption. It is very likely, that only a very limited number of research aircraft will be available for measurement flights on a short notice during a future volcanic crisis due to other commitments or maintenance. Through coordination the available aircraft could be deployed in the most effective way in Europe to support VAAC forecasts and the decision making authorities.

- The funding of the operation of research aircraft needs to be clarified beforehand of a future volcanic ash crisis in order not to lose time for a fast deployment.

- Responsibilities need to be defined beforehand concerning the cost coverage of potential damage of aircraft parts during the volcanic ash flights.

Civil contingency aircraft:

- The two contingency aircraft presently commissioned by European Weather Services are propeller-driven in order to be less susceptible to volcanic ash. Thereby the aircraft cannot reach the major cruising levels of commercial air traffic (9-12 km). However, during a major volcanic eruption, ash might be injected into these altitudes.

Instrumentation and airborne data:

- Airborne in-situ measurements in ash clouds should cover the entire size distribution of ash particles in order to infer sound values for the ash mass concentration. The few largest ash particles of a size distribution dominate the total ash mass in a sample. Only under-wing mounted laser particle spectrometer are able to cover also the largest ash particles present in a volcanic plume.

- It would be highly desirable to perform in-flight intercomparisons of aircraft instruments used for volcanic ash measurements. Thereby, data of different aircraft could be better merged to construct a data composite of all airborne observations performed during a volcanic eruption period.

- Presently there is no aircraft instrument available for direct measurements of the mass of ash particles.

- An agreement is missing on a quick exchange of data obtained by European aircraft during a volcanic crisis.

7. References

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