



## **INTERNATIONAL AIRWAYS VOLCANO WATCH OPERATIONS GROUP (IAVWOPSG)**

### **EIGHTH MEETING**

**Melbourne, Australia, 17 to 20 February 2014**

#### **Agenda Item 5: Operation of the IAVW (Deliverables 01, 03, 04 and 05)**

##### **5.1: Implementation of the IAVW, including the IAVW management reports (Deliverable 01)**

#### **ROADMAP FOR THE IAVW IN SUPPORT OF INTERNATIONAL AIR NAVIGATION**

(Presented by an ad-hoc group consisting of Australia, Canada, China, France,  
Japan, New Zealand, United Kingdom, United States (Rapporteur), IATA,  
ICCAIA and WMO)

#### **SUMMARY**

This paper summarizes the outcome of the ad hoc group that has prepared the roadmap for the IAVW which is presented for endorsement by the IAVWOPSG/8 Meeting and subsequent submission to the Met Divisional Meeting.

### **1. INTRODUCTION**

1.1 The group will recall the discussion on the updated draft of the concept of operations (ConOps) for the international airways volcano watch (IAVW) at the seventh meeting of the International Airways Volcano Watch Operations Group (IAVWOPSG), as noted on pages 26 and 27 of the final report. The group recognized the inherent value of the ConOps document and agreed to use the material included in the ConOps for the development of an IAVW roadmap to be consistent with the outcomes of ICAO's 12th Air Navigation Conference (Montréal, Canada, November 2012). The group then formulated the following conclusion:

#### **Conclusion 7/17 — Development of an IAVW roadmap**

That an ad-hoc group consisting of Canada, China, France, Germany, New Zealand, United Kingdom, United States (Rapporteur), IATA, ICCAIA, and WMO to be tasked to:

- a) develop an IAVW roadmap for the provision of information services in support of the aviation system block upgrade (ASBU) methodology to be included in ICAO's Global Air Navigation Plan, taking into consideration the draft concept of operations for the IAVW as presented in Appendix J to this report; and
- b) provide a draft of the roadmap called for by a) above by 29 November 2013 for onward consideration at the IAVWOPSG/8 meeting and the proposed ICAO MET Divisional Meeting in July 2014.

1.2 This working paper discusses that review process with the draft versions of the roadmap.

1.3 Appendix A to this paper contains the final version of the roadmap, titled *Roadmap for International Airways Volcano Watch (IAVW) in Support of International Air Navigation*.

## 2. DISCUSSION

2.1 Version 0.1 was drafted by the rapporteur and sent to the ad hoc group on 30 July 2013. Many comments were received from the ad hoc group. All comments were reviewed and a comment adjudication document was prepared. The primary concern raised with version 0.1 was from Germany, and others, with the proposed enhancements to the SIGMET information, i.e., replacing the SIGMET with the first 6-hour portion of the VAA.

2.2 Version 0.2 was sent to the ad hoc group for review on 26 September 2013. Version 0.2 included the changes as noted in the adjudication document and presented a revised proposal for SIGMET enhancements, which was accepted by the ad hoc group.

2.3 Version 0.3 was sent to the ad hoc group for review on 24 October. Version 0.3 included the changes as noted in the adjudication document which accompanied version 0.3. Thirty-three comments were received on version 0.3. The primary concern with version 0.3 was that it lacked a placeholder for the current development work. Thus new sections were added and some content moved from the earlier Block 1 timeframe to Block 0 timeframe.

2.4 Version 0.4 was sent to the ad hoc group on 10 November along with the comment response document. No further comments were received and version 0.4 became version 1.0 which is Appendix A to this paper for endorsement by the IAVWOPSG/8 and subsequent submission to the MET Divisional Meeting.

2.5 As a result of the above, the ad hoc group has completed its assigned task.

## 3. CONCLUSION

3.1 With regard to the information provided in this working paper and the associated appendix, the group is invited to note that in accordance to Conclusion 7/17 b), the Secretariat has

included the IAVW roadmap in WP/6 for consideration by the MET Divisional Meeting under agenda item 2.2, therefore, the group may wish to formulate the following decision:

**Decision 8/xx — Roadmap for IAVW in support of international air navigation**

That the version 1.0 of the Roadmap for IAVW in Support of International Air Navigation included in the appendix be endorsed.

4. **ACTION BY THE IAVWOPSG**

4.1 The IAVWOPSG is invited to:

- a) note the information in this working paper; and
- b) decide on the draft decision for the group's consideration.

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**APPENDIX**

**Roadmap**

**for**

**International Airways Volcano Watch (IAVW)**

**in**

**Support of International Air Navigation**

**21 November 2013**

**Version 1.0**

**Appendix**

| Revision | Date              | Description   |
|----------|-------------------|---|
| 0.1      | 29 July 2013      | Initial draft. Based on draft ConOps for the IAVW in response to IAVWOPSG Conclusion 7/17. Aligns with <i>Meteorological Information Supporting Enhanced Operational Efficiency and Safety</i> from ICAO's Aviation System Block Upgrades (ASBU). |
| 0.2      | 27 September 2013 | Revised draft based on comments from IAVWOPSG ad hoc group.   |
| 0.3      | 24 October 2013   | Revised draft based on comments on version 0.2 from the IAVWOPSG ad hoc group.  |
| 0.4      | 10 November 2013  | Revised draft based on comments on version 0.3 from the IAVWOPSG ad hoc group   |
| 1.0      | 19 November 2013  | Submitted to IAVWOPSG Secretariat   |
| 1.0 rev  | 21 November 2013  | Revised to include additional comments from WMO   |

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## Preface

At the first meeting of the International Volcanic Ash Task Force (IVATF/1), held at ICAO Headquarters in Montréal from 27 to 30 July 2010, it was recognized that there was a need to further promote and improve the services provided by Volcanic Ash Advisory Centres (VAAC) and Meteorological Watch Offices (MWO). It was agreed that a global Concept of Operations (ConOps) for volcanic ash should be developed that would cut across all service fields from a perspective of the providers of information to the users/operators of that information in support of both tactical and strategic decision making. This resulted in IVATF Task TF-VAA10, *Development of a Concept of Operations for the International Airways Volcano Watch (IAVW)*.

A draft version, and follow-on revisions, of the ConOps for volcanic ash were presented to the IVATF at their subsequent meetings. At the IVATF's fourth meeting the IAVW Operations Group (IAVWOPSG) was tasked with developing a version 1.0 of the ConOps, and this was subsequently presented to the seventh meeting of the IAVWOPSG (Bangkok, Thailand, 18-22 March 2013). At that meeting the group recognized the inherent value of the ConOps document and agreed to use the material included in the ConOps for the development of an IAVW roadmap to be consistent with the outcomes of ICAO's 12<sup>th</sup> Air Navigation Conference (Montreal, Canada, November 2012) and formulated Conclusion 7/17 which states:

### **Conclusion 7/17— Development of an IAVW roadmap**

That an ad-hoc group consisting of Canada, China, France, Germany, New Zealand, United Kingdom, United States (Rapporteur), IATA, ICAIA, and WMO to be tasked to:

- a) develop an IAVW roadmap for the provision of information services in support of the aviation system block upgrade (ASBU) methodology to be included in ICAO's Global Air Navigation Plan, taking into consideration the draft concept of operations for the IAVW as presented in Appendix J to this report; and
- b) provide a draft of the roadmap called for by a) above by 29 November 2013 for onward consideration at the IAVWOPSG/8 meeting and the proposed ICAO MET Divisional Meeting in July 2014.

This roadmap replaces the ConOps as originally proposed and is a living document that will evolve as the science and technology improves, and as operational requirements evolves.

## 1.0 Introduction/Scope

The roadmap for the International Airways Volcano Watch (IAVW) is based on the draft Concept of Operations (ConOps) for the IAVW which was presented at the seventh meeting of the IAVW Operations Group (IAVWOPSG/7). This roadmap replaces the ConOps.

The roadmap is not intended to provide detailed descriptions on all the areas presented in the document, rather it presents a high-level overview for the user.

### 1.1 Purpose

This document is intended to provide international air navigation users and providers of information under the IAVW with a roadmap that defines improved services including the integration of volcanic meteorological information into decision support systems for trajectory based operations (TBO).

This document provides a plan for the development and implementation of volcanic meteorological information for modules *B1-AMET* and *B3-AMET*, time frames 2018 and 2028 respectively<sup>1</sup>.

Module *B0-AMET*<sup>2</sup> of ICAO's Aviation System Block Upgrades (ASBU), titled *Meteorological Information Supporting Enhanced Operational Efficiency and Safety*, describes the baseline of meteorological information provided in Block 0 of the ASBU which is defined as beginning in 2013. The IAVW element is included in module *B0-AMET* and describes the information services provided by State Volcano Observatories (VO), Meteorological Watch Offices (MWO) and Volcanic Ash Advisory Centers (VAAC).

### 1.2 Background

The Eyjafjallajökull volcanic eruption of April and May 2010 highlighted issues relating to all aspects of volcanic ash service provision including underpinning science and observational capabilities. Eyjafjallajökull brought direct attention to the need for a better understanding of volcanic ash information and the use of that information in Air Traffic Management (ATM) and flight operations. In addition it was recognized that there were no measureable certificated tolerances for volcanic ash for safe and permissible aircraft operations.

While the provision of contemporary volcanic ash information has served the international community well for many years, especially in areas where the airspace is not congested and operators have greater flexibility in avoiding airspace identified with ash, the application of this operational procedure did not work well in congested airspace. This was evident from the Eyjafjallajökull volcanic ash episode in April and May of 2010. During this time period, volcanic ash of mostly unknown concentrations, were detected visually and/or by satellite imagery at times over parts of Western Europe and parts of the North Atlantic. This was due to the prevailing meteorological conditions and the prolonged period of eruption. The busy and

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<sup>1</sup> Module *B1-AMET* encompasses the timeframes of Block 1 (2018) and Block 2 (2023).

<sup>2</sup> Advanced Meteorological Information (AMET).

congested air routes over Europe were significantly impacted and issues also arose with the many Air Navigation Service Providers (ANSP) and MWOs serving a multitude of Flight Information Regions (FIRs). At one time during the Eyjafjallajökull eruption, more than 40 volcanic ash SIGMET messages were in effect.

The limited ability to identify observed areas of volcanic ash as well as forecast areas of volcanic ash concentrations hazardous to aircraft was another significant factor in the resultant closing of airspace, especially during the first few days after the initial eruption.

Aviation users (i.e. ANSP, operators and pilots) need to know the location, size and vertical extent of a given volcanic cloud, and where it will be located in the future. Ideally, the precise location and future location of the volcanic ash cloud would be known with great accuracy and confidence and over time scales ranging from minutes to days. However, the current science for observing and forecasting volcanic ash cannot provide that precision or accuracy.

Currently there are no requirements to observe and forecast volcanic gases, such as sulphur dioxide (SO<sub>2</sub>), thus these observation and forecasts do not exist. However, Grímsvötn (2011) highlighted shortfalls in our understanding of and service provision for possible SO<sub>2</sub> impacts.

Aviation users need to know how much volcanic ash is in the atmosphere and if those amounts pose a threat to the aircraft's engine(s) and system(s). However, there are no agreed values of ash which constitute a hazard to an aircraft.

In addition, many volcanoes are not monitored despite continued efforts from the International Union of Geodesy and Geophysics (IUGG), ICAO and WMO. The lack of this monitoring contributes to uncertainty in the model output in that the source data from the eruption is based on an estimate.

### ***1.3 Problem Statement***

Explosive volcanic eruptions eject pulverized rock (volcanic ash) and corrosive/hazardous gases high into the atmosphere. Depending on the energy and duration of an eruption, there is potential for an ash cloud to cover a wide area for timescales ranging from hours to days.

Volcanic eruptions represent a direct threat to the safety of aircraft in flight and present major operational difficulties at aerodromes and in airspaces located proximal to volcanoes. Currently there are no agreed values of ash loading metrics (amount and rate of ash ingestion) that represent quantified hazard to aircraft or gas turbine engines. The exposure time of aircraft or engines to the ash, type of ash and the thrust settings at the time of the encounter, both have a direct bearing on the threshold value of ash loading that may constitute a hazard. Hence, the current globally recommended procedure is to avoid any volcanic ash, regardless of the level of ash contamination. Many years of service have demonstrated this to ensure safe operation.

In order to improve efficiencies in air transportation during volcanic events, quality, timely and consistent volcanic ash information (observations and forecasts) are essential to mitigate the

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safety risk of aircraft encountering volcanic ash. Education of all users (operators and ATM) is also needed to ensure proper use of volcanic ash information within the operator's risk assessment process.

If demonstrated to be beneficial and without compromising safety, it may be desirable to agree to standards on where and for how long aircraft can operate in specified concentrations. Until those standards are established, if indeed they can be, considerable effort is required to establish rigorous and well understood practices and products provided by the VAACs.

### ***1.4 Identification***

This roadmap is expected to provide the guidance on services tasked by the IVATF and the ICAO challenge team and identified in the ICAO's ASBUs. This document will be updated as required as procedures changes or as technology warrants a change to take advantage of new state of the art capabilities to detect, monitor, and forecast ash.

This document is intended to complement the ICAO *ATM Volcanic Ash Contingency Plan*, ICAO Doc 9974 *Flight Safety and Volcanic Ash*, ICAO Doc 9691 *Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds*, and ICAO Doc 9766 *Handbook on the International Airways Volcano Watch*.

## **2.0 Current Operations and Capabilities**

During a volcanic event the coordination and flow of information regarding the location and forecast position of the volcanic cloud is the primary concern. It involves cooperation among all information providers in support of operational decision makers. Providers of information primarily include MWO, VAACs, and VOs. Users of information are ANSPs that include Aeronautical Information Services (AIS), Air Traffic Control (ATC) and Air Traffic Flow Management (AFTM) units, flight crews, and airline operations centers (AOC). The cooperation between operators and civil aviation authorities (CAA) using the information provided by the providers is essential for the purpose of supporting the pre-flight process, and the in-flight and post-flight decision-making process, as part of the risk mitigation in accordance with ICAO Doc 9974 *Flight Safety and Volcanic Ash*.

### ***2.1 Description of Current Operations***

Services in support of the provision of meteorological information for volcanic events can be categorized in four areas: (1) monitoring the threat, onset, cessation, dimensions and characteristics of an eruption, (2) monitoring the volcanic ash in the atmosphere, (3) forecasting the expected trajectory and location of the ash cloud, and (4) communicating the information to the users.

#### **2.1.1 Monitoring the threat, onset, cessation, dimensions and characteristics of an eruption**

The ability to provide an advanced warning of an imminent eruption and the onset of the eruption rests with the VOs which are loosely organized under the banner of the World Organization of Volcano Observatories (WOVO) of the International Union of Geodesy and

Geophysics (IUGG). These VOs provide guidance on the magnitude of the eruption, including dimensions and characteristics, which are then used in support of numerical dispersion and transport models.

Pre-eruptive activity may come from several sources, including, but not necessarily limited to: seismic monitors, physical observations of deformation, hydrologic activity, gaseous activity, steam explosions, or debris flow. The international aviation community has established a four-level color code chart for quick reference to indicate the general level of threat of an eruption for a given volcano. The color codes identify the state of the volcano (i.e. pre-eruptive vs. eruptive stage)<sup>3</sup> and not to ash in the atmosphere. While the international community has developed the color code chart, it should be noted that these codes are not assigned to all volcanoes for various reasons.

In 2008, the IAVWOPSG agreed to implement a message format to assist volcanologists in the provision of information on the state of a volcano in support of the issuance of volcanic ash advisories (VAA) by VAACs, and the issue of SIGMET information by MWOs, and the issuance of a Notice to Airmen (NOTAM) for volcanic ash by Air Traffic Services (ATS). The message, referred to as Volcano Observatory Notice for Aviation (VONA), was introduced into the ICAO *Handbook on the International Airways Volcano Watch*, Doc 9766. The VONA should be issued by an observatory when the aviation color code changes (up or down) or within a color code level when an ash producing event or other significant change in volcanic behavior occurs. The VONA allows the volcanologists to provide a succinct message on the state of volcano to MWO, VAAC, and ACC which as noted above assists in the issuance of SIGMET, VAA and NOTAM respectively.

For safety purposes, operators have stated the importance of having available pre-eruption activity for situational awareness. Some VOs and a VAAC<sup>4</sup> currently provide information the volcanic activity within their area of responsibility. This is expected to be extended so that all volcanic areas have improved activity reporting for aviation and is a task being looked at by the IAVWOPSG<sup>5</sup>.

### 2.1.2 Volcanic ash-cloud monitoring

Depending on many variables, an ash cloud can be detected from the ground, air, or from satellite. A large number of different ground and air-based instruments are available to monitor volcanic ash clouds, including lidar, ceilometers, sun photometers, radar, imaging cameras and aerosol sondes. However, none of these are yet designed, networked or quality controlled for operational use and many are operated in ad-hoc research mode only<sup>6</sup>. Satellite-based sensors are used to locate ash cloud and aid in discerning the perimeter of ash clouds. Ash clouds can

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<sup>3</sup> In the aviation volcano color code; Green denotes a non-eruptive state; Yellow denotes a state of elevated unrest; Orange denotes a state of heightened unrest with the likelihood of eruption, or minor eruption underway; and Red denotes a forecast of imminent major eruption, or that major ash-producing eruption is underway.

<sup>4</sup> The Darwin VAAC provides a daily volcanic activity summary on the volcanoes in their area of responsibility.

<sup>5</sup> IAVWOPSG Conclusion 7/13 refers.

<sup>6</sup> In 2012 WMO had established the GALION activity as a network (see also [www.dwd.de/ceilomap](http://www.dwd.de/ceilomap)) with a focus also on operational volcanic ash monitoring. This European network already now consists of several thousand systems, for which algorithms have been developed to get quantified volcanic ash information in a quality much better than (passive) satellite observation, although the location of systems is certainly restricted to continental (land-surface) stations.

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be detected on visible satellite imagery, but only during the day. Single and multi-spectral infrared imagery and applied techniques can be used both day and night, and can provide a means of estimating the top of the ash cloud and in the case of the multi-spectral Meteosat SEVERI sensor ash cloud composition characteristics including mean particle size and ash mass loading estimates. Both visible and infrared imagery have limitations when meteorological clouds (e.g., cirrus, etc.) are present depending on the thickness and height of the meteorological cloud cover. Infrared measurements can only detect volcanic ash if the ash is the highest cloud layer, regardless of the level of ash contamination.

Until recently, what was detected by satellite was assumed or interpreted by many to be the “visible ash cloud.” This term was also used to refer to ash clouds seen by pilots in the air and people on the ground. To avoid further confusion and misuse of terms, the IAVWOPSG formulated Conclusion 7/16 which defined “visible ash” and “discernible ash”. According to Conclusion 7/16:

- visible ash be defined as “volcanic ash observed by the human eye” and not be defined quantitatively by the observer
- discernible ash be defined as “volcanic ash detected by defined impacts on/in aircraft or by agreed in-situ and/or remote-sensing techniques”

It is noted that there is no single quantitative threshold value for ‘visible ash’. Discernible ash agreed in-situ and/or remote-sensing techniques are based on the findings and recommendations of the IUGG/WMO Volcanic Ash Scientific Advisory Group.

### **2.1.3 Volcanic ash forecasts**

Today’s volcanic ash forecasts are basic textual and graphical products derived and produced using the output from dispersion and transport models validated and amended against available volcanic ash observations. Most of the numerical models utilized by VAACs depend on meteorological input (e.g. wind speed and direction) as well as input regarding the eruptive parameters at the volcanic source (Eruption Source Parameters - ESP). ESPs include (1) plume height, (2) eruption duration or start/stop time, (3) mass eruption rate, (4) fraction of fine ash particles, and (5) the vertical distribution of mass with height above the vent. Uncertainty or inaccuracy in any of the various sources can result in large errors in the resultant volcanic ash forecasts.

Forecasters provide value added input to the model output as required before issuing a VAA and VAG. This work is dependent on real-time verification of the ash cloud model output against a range of observational resources, principally, remote sensing by satellite.

Today’s two primary volcanic ash forecast products are the VAA and the SIGMET. The VAA is produced and issued by the VAAC, and the SIGMET is produced and issued by the MWO. The VAAC provides the VAA in a text and/or graphic-based format (the graphic version of the VAA is referred to as a VAG), that provides an analysis of the ash cloud and a 6, 12 and 18-hour forecast on the trajectory of the ash cloud and the associated flight levels that may be affected. The VAAs are produced and issued by nine VAACs across the world, each with a defined geographical area of responsibility, as shown in Figure 1. MWOs issue volcanic ash cloud SIGMETs based on the guidance provided by the associated VAAC. These SIGMETs are valid for

up to six hours and describe the location and expected location of the ash cloud within the FIR or area of responsibility of the MWO.

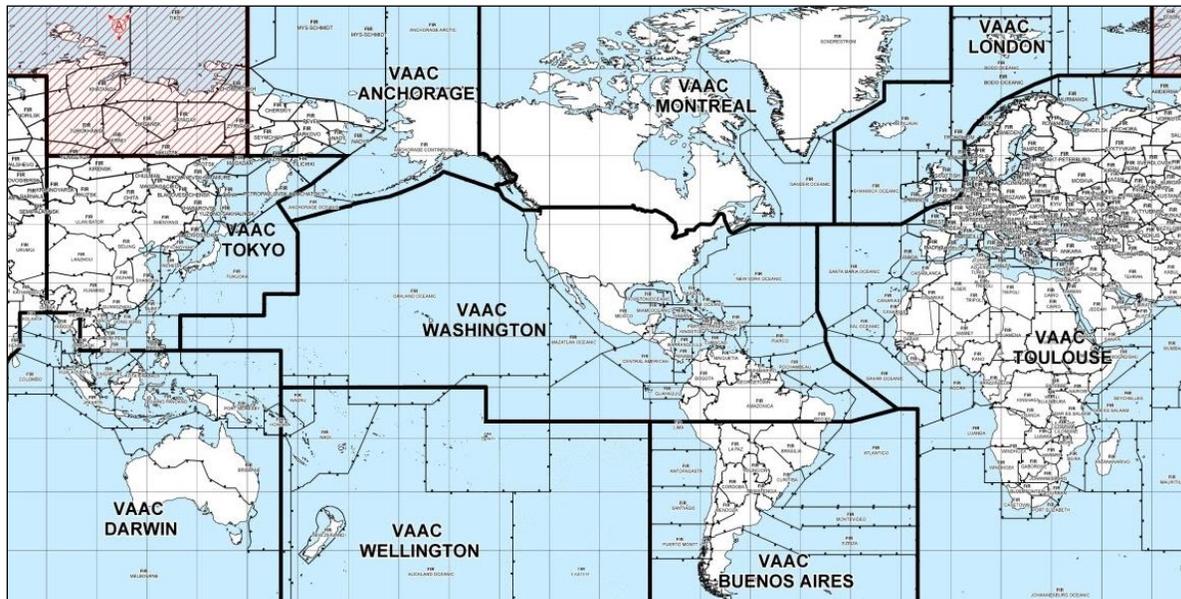


Figure 1. Areas of responsibility for the nine VAACs.

As a supplementary service, meteorological (MET) offices collocated with the EUR/NAT VAACs are required by regional documentation to issue forecast ash concentration charts. Such charts, depicting forecast ash concentration were first provided to users in April 2010 in response to the Eyjafjallajökull volcanic event. It is important to note that there are no globally agreed standards and procedures for the production and provision of such information. Despite lack of global requirement and large uncertainties the ICAO EUR/NAT Volcanic Ash Contingency Plan still includes the provision and use of such charts to underpin the current airlines volcanic ash safety risk assessments.

#### 2.1.4 Communicate volcanic ash information to users

In the simplest terms, MET services are required to provide volcanic ash information to airline operators and ANSPs who then pass the information to aircraft and pilots. Figure 2 depicts an example of information flow following a volcanic eruption. The Figure identifies participants in the provision of contemporary volcanic ash cloud information. The lines between the providers in the diagram do not imply one-way communication, or communication relationships. The lines represent the distribution of information over aeronautical fixed services, with the exception of the VONA<sup>7</sup>. The box colors do not represent significance; rather they help distinguish the information products (e.g., observations and forecasts) (red) from the providers/users (shades of blue, purple and green).

The initial report of volcanic ash can result in many products being delivered to the end user. In most cases, information about a volcanic ash cloud will be provided to the pilot, either in-flight,

<sup>7</sup> VOs disseminate the VONA via facsimile or e-mail.

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or during pre-flight planning, in the form of a SIGMET, NOTAM or ASHTAM<sup>8</sup>, Special AIREP, or VAA. Each of these products is unique in format and content, but all provide information regarding the location of the volcanic ash. It is critically evident that all of these products must be consistent in their overall message.

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<sup>8</sup> ASHTAM is a special series NOTAM for a volcanic eruption and/or volcanic ash cloud.

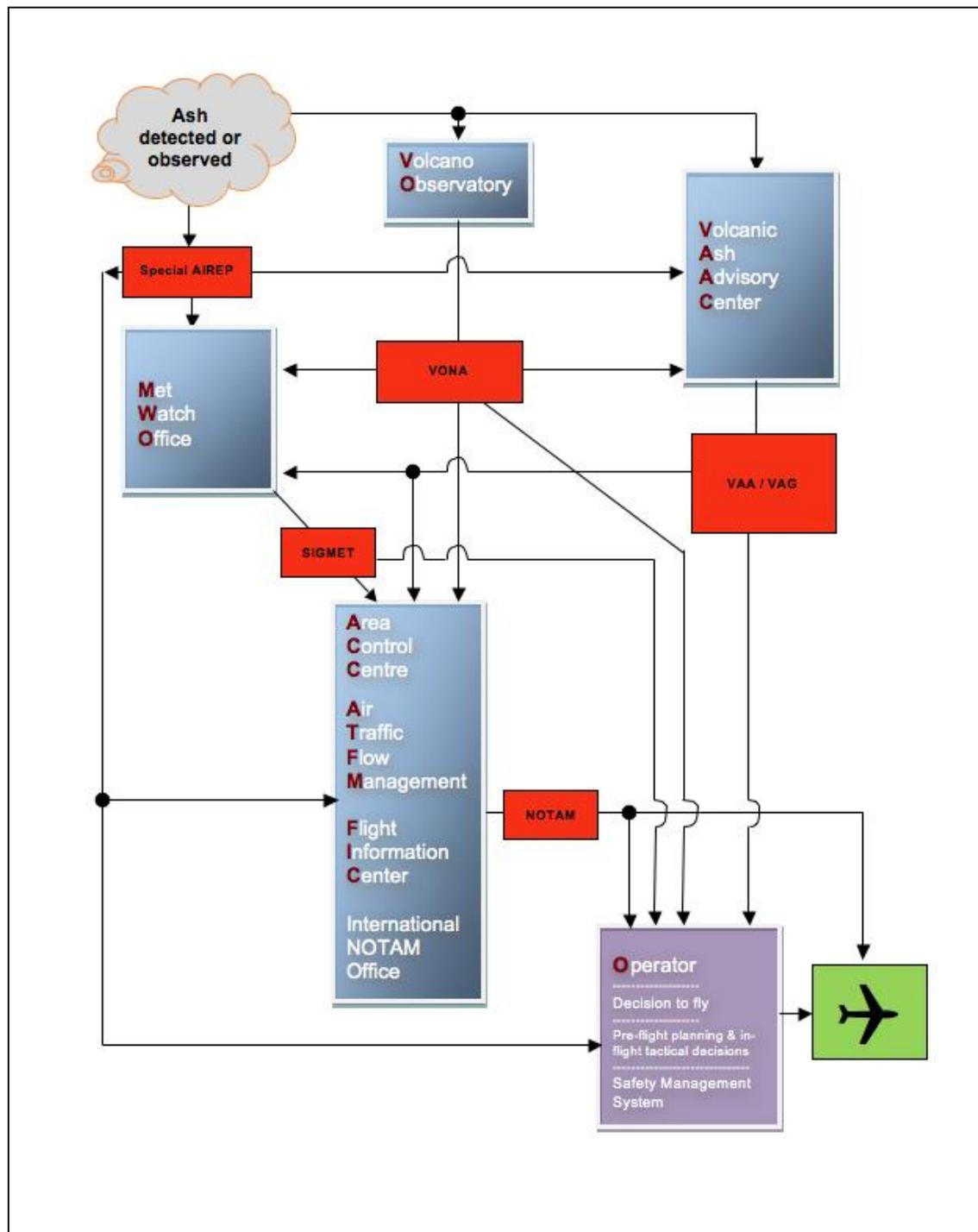


Figure 2. High-level information flow diagram between the users and providers of contemporary volcanic ash cloud information. The lines represent the distribution of information over aeronautical fixed services, with the exception of the VONA. The box colors do not represent significance; rather they help distinguish the information products (e.g., observations and forecasts) (red) from the providers/users (shades of blue, purple and green). It should be noted that there are other distribution networks and information sources that may be unique to different States which are not depicted in the diagram.

## 2.2 Current Supporting Infrastructure

Table 1 outlines service providers and their functions with respect to volcanic cloud information. The exact role of each provider depends on various circumstances that are not exhaustively described in the table.

| Current Services and Providers |  | Functions for:  |  |  | Information  |                                   |
|--------------------------------|--|---|--|--|--|-----------------------------------|
| Service Provider               | Pre-Eruption   | Eruption <sup>9</sup>   | Volcanic Ash <sup>10</sup>   | Information Received and Used  | Information Provided (shared)  |                                   |
| Volcano Observatory (VO)       |  | Monitor volcano, report changes in status.<br><br>Pre-eruption activity for situational awareness | Monitor eruption, report changes in status.  | Monitor and report   | Data from ground-based, air-based and satellite-based observing networks.  | VONA                              |
| MET Service Provider           | Met Watch Office (MWO)   |   | Provide location and notice of eruption  | Provide location and dimension of volcanic ash   | AIREP, VONA (report from VO), VAA/VAG, METAR/SPECI, NOTAM.<br><br>Data from ground-based, air-based, satellite-based observing networks. Input from VAACs and other research institutes. | SIGMET                            |
|                                | Aerodrome Met Office and Stations  | Report pre-eruption activity  | Report   | Report   |  | METAR/SPECI.<br>Aerodrome Warning |
|                                | Volcanic Ash Advisory Center (VAAC)  | Pre-eruption activity for situational awareness.  | Initial analysis including dispersion model initialization), forecast and coordination.  | Determine and predict location and dimensions of airspace impacted by volcanic ash   | VONA (report from VO).<br>Data from ground-based, air-based, satellite-based observing networks. Input from other VAACs and other research institutes.                                   | VAA and VAG                       |
|                                | Other State, Research, University, Commercial Services (including research modeling centers) | Coordinate with VO and VAACs  | Initialize dispersion model.<br>Operate aircraft and sondes for airborne sampling of ash. LIDAR etc for ground based sampling. | Produce model derived predictions of volcanic ash.<br>Operate aircraft and sondes for airborne sampling of ash. LIDAR etc for ground based sampling. | Data from ground-based, air-based, satellite-based observing networks. ESP.  | Deliver model derived predictions |

<sup>9</sup> Known as the “Start of Eruption” cycle in Doc 9974 - ICAO Doc 9974 *Flight Safety and Volcanic Ash*.

<sup>10</sup> Same as the “Ongoing Eruption” cycle in Doc 9974 ICAO Doc 9974 *Flight Safety and Volcanic Ash*.

| Current Services and Providers         |   | Functions for:  |  |  | Information  |   |
|--|---|---|--|--|--|---|
| Service Provider                       |   | Pre-Eruption  | Eruption <sup>9</sup>  | Volcanic Ash <sup>10</sup>   | Information Received and Used  | Information Provided (shared)   |
| Air Navigation Service Provider (ANSP) | Air Traffic Control Units (Area, Approach, Aerodrome) | Identify appropriate areas <sup>11</sup> within airspace to outline hazard  | Identify appropriate areas within airspace to outline hazard. Reroute traffic as necessary | Identify appropriate areas within airspace to outline hazard. Reroute traffic as necessary         | SIGMET, NOTAM/ASHTAM, VAA/VAG, VONA or report from VO, VAR (Special AIREP)   | IFR clearances. FIR's sector capacity. Affected aerodrome arrival and departure acceptance rate |
|  | Air Traffic Management (ATM)                          | Maintain communications links and ATS monitoring systems  | Implement contingency plans  | Lead CDM process for adjusting traffic capacity and routes   | SIGMET, NOTAM/ASHTAM, VAA/VAG, VONA (report from VO), VAR (Special AIREP, other <sup>12</sup> )                    | FIR traffic capacity  |
|  | Flight Information Center (FIC)                       | Maintain communications links and ATS monitoring systems  | Provide preflight and in-flight information about eruption                                 | Provide preflight and in-flight information about volcanic cloud                                   | SIGMET, NOTAM/ASHTAM, VAA/VAG, VONA (report from VO), Special AIREP  | SIGMET, NOTAM/ASHTAM VAA/VAG, VONA (report from VO), Special AIREP                              |
|  | International NOTAM Office (NOF)                      | Maintain communications links and ATS monitoring systems. Provide notice of pending hazard.                                 | Provide notice of hazard   | Provide notice of hazard   | SIGMET, VONA (report from VO), Special AIREP   | NOTAM/ASHTAM  |
| Aerodrome                              |   | Maintain communications links and monitoring systems  | Address ash contamination on runways, taxiways, ground equipment, planes                   | Address ash contamination on runways, taxiways, ground equipment, planes                           | Aerodrome Warning  | Information for the NOTAM/ASHTAM  |
| Operator                               | Airline Operations Center (AOC)                       | Maintain communications links and monitoring systems. Reroute aircraft around volcanoes identified in a pre-eruption state. | Reroute aircraft away from eruption.   | Apply agreed SMS processes to adjust routes. Provide information to flight crew. Plan for reroute. | SIGMET, NOTAM/ASHTAM, VAA/VAG, VONA (report from VO), ash or SO2 report from flight crew, or ANSP (ATS, FIS, AIS). | Route/altitude selection, fuel, go/no-go decision, in-flight route/destination change.          |
|  | General Aviation Operators                            | Maintain communications links and monitoring systems  | Appropriate decisions per SMS for operators of Large and Turbojet Aeroplanes.              | Appropriate decisions per SMS for operators of Large and Turbojet Aeroplanes.                      | SIGMET, NOTAM/ASHTAM, VAR (Special AIREP), ash or SO2 report from ANSP (ATS, FIS, AIS)                             | Special AIREP, VAR  |
|  | Pilot / Flight crew (Commercial and General Aviation) | Maintain communications links and monitoring systems  | Report eruption  | Report volcanic ash, sulphur   | SIGMET, NOTAM/ASHTAM, VAR (Special AIREP), ash or SO2 report from AOC or ANSP (ATS, FIS, AIS)                      | Special AIREP, VAR  |

<sup>11</sup> In accordance with the *ATM Volcanic Ash Contingency Plan*

<sup>12</sup> Ash concentration forecast (if provided)

## Appendix

| Current Services and Providers  | Functions for:                        |                                     |                                     | Information                                       |   |
|---|---------------------------------------|-------------------------------------|-------------------------------------|---|---|
| Service Provider  | Pre-Eruption                          | Eruption <sup>9</sup>               | Volcanic Ash <sup>10</sup>          | Information Received and Used                     | Information Provided (shared)   |
| Original Equipment Manufacturers (OEM) or Type Certificate Holder (TCH) | Guidance and information to operators | Advice and information to operators | Advice and information to operators | Engineering and operations reports from operator. | Technical information about aircraft operation in volcanic ash, future/ongoing maintenance information requirements, details of inspection requirements |

**Table 1. Current service providers and their functions with respect to volcanic cloud information.**

### 3.0 Description of Changes

Future services center on a number of changes that are intended to match the time frames of the Blocks of the ASBUs.

Module *BO-AMET* of the ASBUs is the baseline services for Block 0. The following is taken from ASBU module *BO-AMET*:

*VAACs within the framework of the International Airways Volcano Watch (IAVW) respond to a notification that a volcano has erupted, or is expected to erupt or volcanic ash is reported in its area of responsibility. The VAACs monitor relevant satellite data to detect the existence and extent of volcanic ash in the atmosphere in the area concerned, and activate their volcanic ash numerical trajectory/dispersion model in order to forecast the movement of any ash cloud that has been detected or reported. In support, the VAACs also use surface-based observations and pilot reports to assist in the detection of volcanic ash. The VAACs issue advisory information (in plain language textual form and graphical form) concerning the extent and forecast movement of the volcanic ash cloud<sup>13</sup>, with fixed time validity T+0 to T+18 at 6-hour time-steps. The VAACs issue these forecasts at least every six hours until such time as the volcanic ash cloud is no longer identifiable from satellite data, no further reports of volcanic ash are received from the area, and no further eruptions of the volcano are reported. The VAACs maintain a 24-hour watch. Argentina, Australia, Canada, France, Japan, New Zealand, the United Kingdom and the United States are designated (by regional air navigation agreement) as the VAAC provider States. Accordingly, VAACs Buenos Aires, Darwin, Montreal, Toulouse, Tokyo, Wellington, London, Anchorage and Washington make available the aforementioned advisories on the ICAO AFS.*

This baseline describes the services as they are for the beginning of Block 0 with the timeframe of 2013. During Block 0, several improvements are proposed and they are described in subsequent sections of this roadmap.

<sup>13</sup> There is no requirement in Annex 3 – *Meteorological Service for International Air Navigation* to monitor, observe and forecast volcanic gases.

Module B1-AMET - *Enhanced Operational Decisions through Integrated Meteorological Information* enables the identification of solutions when forecast or observed meteorological conditions impact aerodromes or airspace. Full ATM-MET integration is needed to ensure that MET information is included in decision making process and the impact of the MET conditions (e.g., volcanic ash) are automatically taken into account. Module B1-AMET improves upon current operations where ATM decision makers manually determine the change in capacity associated with an observed or forecast MET condition (e.g., volcanic ash), manually compare the resultant capacity with the actual or projected demand for the airspace or aerodrome, and then manually devise ATM solutions when the demand exceeds the MET-constrained capacity value. Module B1-AMET *also* improves in-flight avoidance of hazardous MET conditions by providing more precise information on the location, extent, duration and severity of the hazard(s) affecting specific flights.

The aim of Module B3-AMET - *Enhanced Operational Decisions through Integrated Meteorological Information* is to enhance global ATM decision making in the face of hazardous MET conditions in the context of decisions that should have an immediate effect. Key points are a) tactical avoidance of hazardous MET conditions especially in the 0-20 minute timeframe; b) greater use of aircraft based capabilities to detect MET parameters (e.g. volcanic ash); and c) display of MET information to enhance situational awareness.

### ***3.1 Changes intended through 2018:***

Changes intended within the timeframe of 2013-2018 (i.e., Block 0 timeframe) to support Module B0-AMET (*Meteorological Information Supporting Enhanced Operational Efficiency and Safety*) are:

- Incorporate collaborative decisions and information sharing into volcanic ash cloud analyses and forecasts
- Increase the use of the aviation color-code alert system and provision of VONA by State VOs
- Develop confidence levels to aid decision makers as part of their safety risk assessment
- Improve ground-based, air-based and space-based observing networks to determine ESP and existing ash loading in the atmosphere
- Scientific research in support of reducing risks from volcanic ash hazards including understanding the impact of ash on aircraft and engines and the provision of enhanced guidance to operators

#### **3.1.1 Collaborative decision analysis, forecasting and information sharing**

The term Collaborative Decision Making (CDM) is a process used in ATM that allows all members of the ATM community, especially airspace users, to participate in the ATM decisions affecting all members. CDM means arriving at an acceptable solution that takes into account the needs of those involved. CDM for ATM is described in ICAO Document 9854 -*Global Air Traffic Management Operational Concept*, and Document 9982 – *Manual on Air Traffic Management System Requirements*.

A similar process has been proposed<sup>14</sup> for volcanic ash and is called Collaborative Decision Analysis and Forecasting (CDAF). From a high level perspective and for an example, collaboration on the perimeter of the volcanic ash could be done, at a minimum, for events that affect high density traffic areas, or several FIRs and extend beyond the area of responsibility of one or more VAACs. This collaboration could be undertaken between predetermined partners, based on the event and extent. Table 2 lists some of the volcanic ash information needed by airspace users. As part of this process, information sharing between the partners is essential, so that all possible outcomes can be considered. Table 3 lists the partners for collaboration and information sharing as well as the expected role of the partners. The final decision (i.e., the location of horizontal/vertical airspace volcanic ash contamination boundaries) will depend on agreed upon guidelines that may vary depending on the size and scope of the volcanic event, but efforts should be made to ensure that the authority for the final decision concerning volcanic ash information resides with the designated Primary VAAC, otherwise the final output (e.g., forecast) may lead to inconsistency and hamper effective decision making by ATM and airlines. Once the decision is finalized it can be integrated into ATM decision tools for a CDM process by ATM decision makers and airspace users.

One of the challenges for the IAVWOPSG is to establish agreed procedures to support CDAF which have not been defined.

| Need to know   | Information Sharing  | Output from a Collaborative Decision   |
|--|--|--|
| Location of volcanic ash contamination boundaries.                                 | Share data from ground, air, and space observing platforms | Current horizontal and vertical extent (perimeter) of volcanic ash contamination to be used in decision support systems and forecast products. |
| How the volcanic ash boundaries are changing and where will they be in the future. | Share various outputs of dispersion models                 | Forecast horizontal and vertical extent of the volcanic ash contamination and produce seamless products  |
| If provided and available, multiple contours of ash contamination                  | Share various outputs of dispersion models                 | Forecast horizontal and vertical extent of multiple contours of ash contamination  |

**Table 2. Collaborative decisions for volcanic ash cloud information**

<sup>14</sup> IVATF Recommendation 4/18, IAVWOPSG Conclusion 7/21 refers.

| Partners   | Role   |
|--|--|
| Primary VAAC   | Produces preliminary forecast and shares with rest of partners. Considers input and suggested changes from participating partners. Has the final decision on the forecast after considering information and input from partners. |
| Other VAAC(s)  | Shares new information with participating partners. Reviews preliminary forecast and provides suggested changes.   |
| VO(s)  |  |
| MWO(s)   |  |
| State's NMHS   |  |
| University or Research Centers (dispersion modeling) |  |
| Others (TBD), e.g., operators                        | Share information.   |

**Table 3. Partners for the collaboration and information sharing and expected roles**

### **3.1.2 Increase the use of the aviation color-code alert system and provision of VONA by State VOs**

Not all State VOs issue a VONA, which provides a concise statement describing the activity at the volcano, as well as the specific time of the onset and duration of the eruptive activity. VONAs also contain a color code (see 2.1.1). As a form of “best practice”, this roadmap recommends that all State VOs use the VONA and its aviation color-code alert system for the provision of volcano information.

### **3.1.3 Develop confidence levels to aid decision makers as part of their safety risk assessment**

In February 2012, the IATA met with the VAACs and discussed their need for levels of confidence in the volcanic analyses and forecasts (i.e., VAA/VAG). These confidence levels would be used or translated into the risk assessment conducted by operators to best determine the aircraft flight route or track.

The VAAC practices for presentation of ‘confidence’ must be consistent and be a well understood process to ensure a harmonized regional interoperability within the operator’s risk assessment process. Development of guidance material should be conducted in parallel with the development of the presentation of confidence.

Development of confidence levels are considered to be a key factor in improving the quality of information provided which will aid in the decision making process as part of an operators safety risk management plan.

### **3.1.4 Improve ground-based, air-based and space-based observing networks to determine ESP**

Observation and forecasts information on volcanic ash will require continued improvement of observational capabilities globally, including volcano-monitoring networks, ground-based aerosol networks, satellite platforms and sensors, and airborne sampling.

### **3.1.5 Scientific research in support of reducing risks from volcanic ash hazards including understanding the impact of ash on aircraft and engines and the provision of enhanced guidance to operators**

Scientific research in support of reducing risks from volcanic ash hazards should aim for tangible improvements in the detection and measurement of volcanic plumes and ash clouds during eruptions and in the accuracy of model forecasts of ash transport and dispersion. Research topics (both new and on-going) pertinent to these goals include the following:

- Characterizing volcanic plumes at/near the source
- Understand the evolution of volcanic ash and gas clouds in time and space
- Verification of the model forecasts

In addition,

- Develop an understanding of the impact of ash on aircraft and engines and provide enhanced guidance to operators
- Scientific research to support service delivery for volcanic ash hazard risk reduction

Since 2010 manufacturers have continued work on developing their understanding of the impact of volcanic ash. This will continue through a number of initiatives including involvement of the major manufacturers in the National Aeronautics and Space Administration (NASA) and United States Air Force (USAF) Vehicle Integrated Propulsion Research (VIPRIII) test programme and coordination between manufacturers through the International Coordinating Council of Aerospace Industries Associations (ICCAIA) Volcanic Ash working group. As this knowledge and understanding increases enhanced guidance to operators will be provided where possible.

Further description and discussion regarding research is detailed in Working Paper 14 from the fourth meeting of the IVATF.

### ***3.2 Changes intended within 2018-2023:***

Changes intended within the timeframe of 2018-2023 (i.e., Block 1 timeframe) to support Module B1-AMET (*Enhanced Operational Decisions through Integrated Meteorological Information*) are:

- Enhance the provision of SIGMETs in support of operational decisions
- Transition to all digital format for all volcanic ash information
- Further develop ATM for operations in or close to areas of volcanic ash
- Increase the VAA/VAG issuance frequency and time steps

- Provide additional information which reflects the forecast of volcanic ash beyond 18 hours
- Continued improvement in ground-based, air-based and space-based observing networks to determine ESP
- Continued scientific research in support of reducing risks from volcanic ash hazards

### **3.2.1 Enhance the provision of SIGMETs in support of operational decisions**

A large volcanic ash cloud over congested, multi-States areas such as Europe could result in multiple SIGMET information messages, all being in effect at the same time. Each of these SIGMETs becomes a part of a jigsaw puzzle for the user to assimilate, in order to obtain a good understanding of the entire area of the volcanic cloud. As a result the International Air Transport Association (IATA) has stated that they have strong preference for the VAA vs. the SIGMET, i.e., that is one message covering a large region.

Since SIGMETs are, in most cases, based on the first portion of a VAA, that portion of the VAA/VAG could technically be elevated in status to serve as a SIGMET. Making the VAA/VAG's first six-hour portion (i.e., T+0 and T+6 hour) equivalent to the SIGMET would reduce the information overload experienced by users (pilots, operators, etc) who must currently track dozens of SIGMETs for their particular flight in congested areas.

Under today's operations each MWO is responsible for the provision of a SIGMET for their FIR in support of defining the location and forecast position of the ash cloud. However, many MWOs do not have the skill to provide this service and are dependent on the VAAC for this information via the VAA. Some MWOs have more advanced skill levels to provide value input. In those cases the MWO should coordinate with the VAAC and advise the VAAC that the information provided in the VAA is not necessarily reflective of conditions in their FIR. With the proposal to support CDAF this divergence of information should be minimized where the information provided in the VAA is consistent with the SIGMET or vice versa. If achievable this then begs the issue on whether there is a need to retain both products but rather provide a single high quality product to the operator and ANSP in support of integration of MET information into air traffic flow management (ATFM) systems for the routing of aircraft away from a hazard.

Proposed SIGMET enhancements are:

- The first six-hour portion of the VAA (i.e., T+0 and T+6 hour) is equivalent to the SIGMET for a volcanic ash cloud (with validity for one or more FIRs)
- MWOs should participate in the CDAF process and share information with the VAAC to ensure the VAA reflects the conditions in their FIR
- SIGMET *Information* messages should only be issued by a MWO for those cases where the VAA is not yet available or the VAA does not reflect the conditions in the FIR even after the CDAF process.

It is noted that IATA has formulated a set of requirements which were presented to the VAAC Best Practices Seminar of 12-13 June 2012 and expanded upon at IAVWOPSG/7. Those

**Appendix**

requirements will be considered in this enhancement process taking into account the issues of sovereignty, cost recovery and collaborating procedures among related States.

**3.2.2 Transition to all-digital format for all volcanic ash information**

Today's volcanic cloud products are primarily text-based (e.g., SIGMET information message), with some supplementation of graphic-based products (e.g., VAG). Future volcanic cloud information must be provided in a digital format in order to better serve aviation users and decision makers. The visualization of volcanic information must be capable of being displayed on moving maps, cockpit displays, radar screens, etc.

The IAVWOPSG, recognizing the need for digital information, formulated Decision 7/25 which calls for the development of a digital format of the VAA/VAG in an XML/GML format for implementation with Amendment 77 to Annex 3 – *Meteorological Service for International Air Navigation*.

The transition from text and graphic-based products to all-digital formats will take time, as there will continue to be a need for legacy text-based products for several years, especially in certain regions of the world.

**3.2.3 Further develop ATM for operations in or close to areas of volcanic ash**

In an effort to increase information exchange between ATM and operators, make available to affected ANSP's the outcomes of the operators risk assessment for their consideration, especially where applicable to ATFM.

**3.2.4 Increase VAA/VAG issuance frequency and time steps**

Operators need frequent updates of volcanic ash information especially in congested airspace and around constrained airports. The current VAA/VAG with its 6-hourly issuance and 6-hour time steps does not meet those needs.

The VAA/VAG presenting levels of certainty should be developed to include three hourly time-step information. There is a need to have the capability to increase the frequency of VAA/VAG for pre-defined operational conditions. This would be when ash is present in congested airspace and around capacity constrained airports.

**3.2.5 Provide additional information which reflects the forecast of volcanic ash beyond 18 hours**

Operators at IAVWOPSG/7 expressed an interest in having volcanic ash information beyond the current practice of T+18 hours for long-haul flight planning and management of airline operations. While it is understood that today's numerical models provide information for various meteorological elements out to several days, providing volcanic ash information beyond T+18 hours introduces a number of uncertainties into the forecast as a result of unknown or uncertain source terms and meteorology as well as inaccuracies in the physics of the dispersion/transport models. With this understanding, the goal is to provide additional information which can realistically reflect the forecast of volcanic ash beyond 18 hours.

### **3.2.6 Continued improvements in ground-based, air-based and space-based observing networks to determine ESP**

Improvements to volcano-monitoring networks, ground-based aerosol networks, satellite platforms and sensors, and airborne sampling will continue in Block 1, building on the accomplishments from Block 0.

### **3.2.7 Continued scientific research in support of reducing risks from volcanic ash hazards**

Scientific research in support of reducing risks from volcanic ash hazards will need to continue in Block 1 and build upon the area and topics listed in section 3.1.5.

## ***3.3 Changes intended within the time frame of 2023-2028***

Changes intended within the time frame of 2023-2028 (i.e., Block 2 timeframe), which is an extension of ASBU Block 1, to support Module B1-AMET (*Enhanced Operational Decisions through Integrated Meteorological Information*) are:

- Develop volcanic ash nowcasts
- Develop volcanic ash forecasts that include the use of probability

### **3.3.1 Develop volcanic ash nowcasts**

Users need to know the current location of the volcanic ash. The VAA/VAG and SIGMET provide information about the ash at T+0, but these products are issued every six hours, thus at two hours after T+0, users must do some kind of interpolation between T+0 and T+6 to obtain an estimate of where the ash contamination boundary lies. Providing VAA/VAG at three hour time-steps will help this issue, but more can be done with the transition to a digital information data base for meteorological information, as part of the ASBUs, including volcanic ash.

In the Block 2 timeframe, it is foreseen that a three-dimensional representation of the current or near-current volcanic ash contamination boundaries, known in this document as a “nowcast”, could be made available and extracted by the user. Nowcasts would be updated at a high frequency and provide a more realistic assessment of the location and extent of the ash cloud.

### **3.3.2 Develop probabilistic volcanic ash forecasts**

Current volcanic ash forecasts, such as the VAA/VAG, are deterministic forecasts. They are a yes/no forecast, with respect to the depiction of the airspace impacted by volcanic ash contamination. These forecasts are based on the definition of “discernible ash” as a fundamental criterion.

Volcanic ash transport and dispersion models can produce an array of solutions (e.g., forecasts) by varying the model input. Changes in meteorological parameters and ESP will result in different forecast outputs that affect the 4-dimensional shape (3-dimensional shape and change of shape with time) of the cloud. The purpose of a probabilistic forecast is to provide decision makers with an assessment of all the likelihoods of a weather parameter’s risk of

occurrence exceeding a defined magnitude. Probabilistic forecasts help multiple decision makers use the same weather information, applying their own operational constraints to determine risk to their operation. Section 5.2 identifies those functions that could be provided in deterministic and probabilistic terms.

From a high-level perspective, probability forecasts may be based on an ensemble approach. An ensemble is one way to account for some degree of uncertainty. For instance, the model can be run many times, each time with a realistic variant of one of the uncertain parameters (e.g. ash amount, ash column height, eruption start time and duration, input meteorology dataset, with and without wet deposition, etc.). Taken as a whole, the variability of the ensemble members' output gives an indication of the uncertainty associated with that particular ash forecast.

The application of probabilistic forecasts will best benefit high-density (congested) traffic areas, where decision makers can benefit from more than just a deterministic forecast. Also, decision support systems can use the probabilistic information to provide route and altitude selections based on user's acceptance thresholds.

For operators to effectively use 'probabilities' for specific time and space within the initial and ongoing risk assessments, a thorough understanding of the output from the VAAC is needed by operators and flight crew.

### ***3.4 Changes intended by 2028 and beyond***

Changes intended by 2028 (i.e., Block 3 timeframe) in support of Module B3-AMET (*Enhanced Operational Decisions through Integrated Meteorological Information*) are:

- Develop other volcanic derived contaminant forecasts, specifically SO<sub>2</sub>
- Integrate volcanic ash forecasts into decision support systems for trajectory based operations
- Develop understanding of the impact of ash on aircraft and engines and provide enhanced guidance to operators
- Incorporate processes and procedures for the use of airborne detection equipment

#### **3.4.1 Develop other volcanic derived contaminant forecasts, specifically sulphur dioxide**

While the document has focused on volcanic ash there is strong evidence that there is a need to expand the services to other toxic elements that are typically associated with volcanic eruptions.

During volcanic eruptions, a number of toxic gases may be emitted in addition to ash; these include SO<sub>2</sub>, hydrogen fluoride, and hydrogen sulphide amongst many others. Each of these gases has different atmospheric dispersion properties, and so gas clouds may be found coincident or separate from ash clouds. Of these gases, SO<sub>2</sub> is of particular importance as it may be emitted in large quantities and potentially has significant health effects. The documented

experience to date of in-flight encounters with sulphurous gases suggests that SO<sub>2</sub> has never been a significant immediate safety hazard to an aircraft or health hazard to its occupants.

Through the work of the IVATF and IAVWOPSG<sup>15</sup>, it was determined that ICAO, through an appropriate expert group or groups, should determine a clear meteorological/atmospheric chemistry requirement (such as a critical level of SO<sub>2</sub> in the atmosphere that would be observed or forecast) that, after passing through the aircraft's ventilation system, could pose a health risk to the aircraft's occupants.

### **3.4.2 Integrate volcanic ash forecasts into decision support systems for trajectory based operations**

One of the key elements in Module B3-AMET of the ASBUs is the integration of meteorological information into decision support systems. Future ATM decision support systems need to directly incorporate volcanic ash nowcasts and forecasts, allowing decision makers to determine the best response to the potential operational effects and minimize the level of traffic restrictions. This integration of volcanic ash nowcasts and forecasts, combined with the use of probabilistic forecasts to address uncertainty, reduces the effects of volcanic ash on air traffic operations.

### **3.4.3 Development of index levels for ash tolerances**

Different aircraft and engine designs may be affected differently by volcanic ash. For example, modern turbofan engines ingest large volumes of air and their turbines run hotter than the melting point for volcanic ash constituents. They typically utilize exotic turbine component coatings that can be affected by volcanic aerosols such as sulfates and chlorides. They also use turbine nozzle cooling and blade cooling with passages that are vulnerable to ash blockage. Older turboprop or turbofan engines typically do not have these same features and have different vulnerabilities. These design and operational differences can significantly affect the engine's susceptibility to volcanic ash.

In the longer term the development of a volcanic ash index for ash tolerances of various types of engine/aircraft combinations may allow operators and ATM to take advantage of quantitative volcanic ash forecasts. It should be recognized that this may not be feasible due to the extensive testing and evaluation required to adequately cover the range of aircraft and engines in service.

### **3.4.4 Develop processes associated with airborne detection equipment**

To allow operators to take advantage of tactical on-board volcanic ash detection equipment, ATM processes and procedures will need to be developed and incorporated into ATM Contingency Plans.

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<sup>15</sup> IAVWOPSG Conclusion 7/34 and Decision 7/35 refers.

## 4.0 Proposed Roadmap

The proposed way forward will involve all the changes described in Section 3 above. Specifically:

Through 2018:

- Incorporate collaborative decisions and information sharing into volcanic ash cloud analyses and forecasts
- Increase the use of the aviation color-code alert system and provision of VONA by State VOs
- Develop confidence levels to aid decision makers as part of their safety risk assessment
- Improve ground-based, air-based and space-based observing networks to determine ESP
- Scientific research in support of reducing risks from volcanic ash hazards including understanding the impact of ash on aircraft and engines and the provision of enhanced guidance to operators

2018-2023:

- Enhance the provision of SIGMETs in support of operational decisions
- Transition to all digital format for all volcanic ash information
- Further development of ATM for operations in or close to areas of volcanic ash
- Increase the VAA/VAG issuance frequency and time steps
- Provide additional information which reflects the forecast of volcanic ash beyond 18 hours
- Continued improvements in ground-based, air-based and space-based observing networks to determine ESP
- Continued scientific research in support of reducing risks from volcanic ash hazards

2023-2028:

- Develop volcanic ash forecasts that include the use of probability
- Develop volcanic ash nowcasts

2028 and beyond:

- Develop other volcanic derived contaminant forecasts, specifically SO<sub>2</sub>
- Integrate volcanic ash forecasts into decision support systems for trajectory based operations
- Development of index levels for ash tolerances
- Incorporate processes and procedures for the use of airborne detection equipment

### ***4.1 Assumptions and Constraints***

The proposed concept is based on the following assumptions:

- IAVW retains global legal mandate for volcanic ash service delivery

- The first six-hour forecast from the VAA (i.e., T+0 and T+6 hour) can be used equivalent to a SIGMET
- Probabilistic forecasts can be utilized by aviation decision makers
- Probabilistic forecasts are best suited for users in congested airspace, but can also be beneficial for users in uncongested airspace
- Before a probability can be derived from an ensemble, there is a need to “calibrate” the ensemble, as the number of elements in a “cluster” is not necessarily a reliable measure of probability if the variations of the initial states and ESP’s are not driven by a scientifically sound selection principle
- Index levels for volcanic ash tolerances can be developed
- Continuing user demand for phenomena based information rather than FIR based information

The following constraints may impede the implementation of the proposed concept:

- The development of certifiable volcanic ash tolerances may take many years, or may not be feasible or beneficial to operators (if by 2028 the development is not possible then further work will be done to improve the avoidance of ash)
- Some States may not accept the VAA as equivalent to the SIGMET due to legal and political issues

## ***4.2 Operational Environment***

By 2028, volcanic cloud information will reside on a common information sharing platform and be part of the System Wide Information Management (SWIM) concept in support of global ATM.

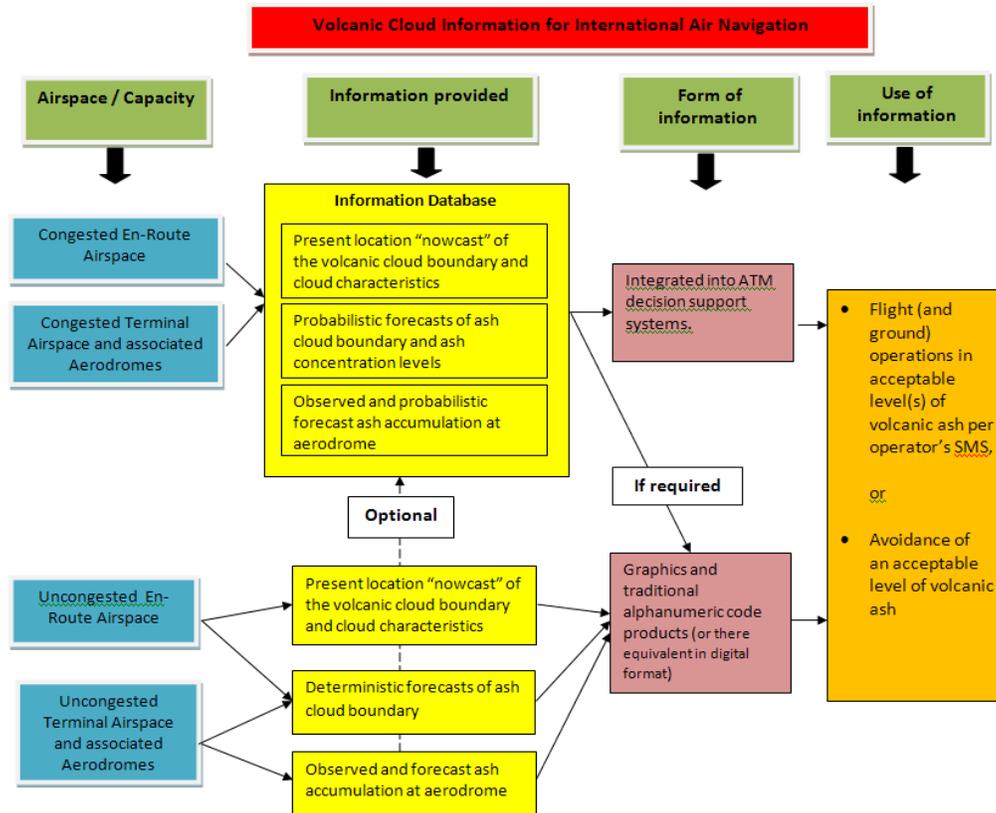
## ***4.3 Operations***

Operations during a volcanic event depend on the information available as well as a function of classification of airspace that being high density (congested) airspace versus low density (uncongested) airspace.

Nowcasts and deterministic forecasts may adequately serve the users of airspace that is not congested, and offers ample options for volcanic ash avoidance without great fuel penalties for the operator. But for congested airspace, the provision and use of probabilistic forecasts of the volcanic ash could be beneficial in order to achieve maximum efficiency of the air traffic system.

Figure 3 provides a high level schematic of meteorological service per airspace capacity. It should be noted that the provision and use of probabilistic forecasts is not restricted or limited to congested airspace, rather the “optional” block in Figure 3 denotes that operators in uncongested airspace, e.g., oceanic User Preferred Routes (UPR), can take full advantage of these forecasts.

**Figure 3. Operations concept using volcanic cloud information per airspace capacity. Note that the “optional” box indicates that the Information Database and its probabilistic forecasts are available for users of uncongested**



airspace.

#### 4.4 Supporting Infrastructure

In Blocks 0 through 2, the information on volcanic ash will continue to be product centric and be produced by humans in traditional alphanumeric text along with a graphical image. Production of these products will inevitably migrate from the MWOs to the VAACs.

In the Block 3, all relevant information on the volcanic clouds will reside on a common information sharing platform.

#### 4.5 Benefits to be realized

The proposals for volcanic cloud information to be developed and implemented as noted in sections 3.1, 3.2, and 3.3 will provide users with volcanic ash information that has greater confidence and usability. Moving from a product centric environment to an information centric environment will meet the future operational needs of aviation decision-makers. Also, decision support systems can use the probabilistic information to provide route and altitude selections based on user's acceptance thresholds. The integration of volcanic cloud forecasts, combined with the use of probabilistic forecasts to address uncertainty, will lead to more effective and informed decision making and planning for air traffic operations. Finally, if feasible, the

development of a volcanic ash index for ash tolerances for various types of engine/aircraft combinations may allow operators and ATM to take advantage of volcanic ash concentration forecasts.

## 5.0 Needs and Goals

### 5.1 Operational Needs

The following is a set of high-level operational needs<sup>16</sup> of aviation users for trajectory based operations in support of international air navigation:

- Determine the onset of a volcanic event (i.e., eruption)
- Determine if an eruption and any associated volcanic ash are a hazard to international air navigation based on any agreed threshold values of mass concentration
- Determine what aerodromes and airspace are affected by the eruption and associated cloud
- Determine when the eruption has ended
- Determine when the volcanic ash has dispersed below agreed threshold values
- Determine when the aerodrome/airspace affected by the eruption and/or cloud is safe to operate in or through
- Determine the cost of the event and stakeholder satisfaction

### 5.2 Functional Goals

Table 4 lists a set of functional goals for volcano eruption and volcanic cloud information based on different types of airspace and aerodrome densities (i.e., capacity or congestion). An “X” in the table’s cell indicates that this function is needed for this airspace and aerodrome. A “P” or “D” indicates whether the forecast function is Probabilistic or Deterministic. A “D, P” indicates that both are provided.

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<sup>16</sup> As determined by the author based on information from users at ICAO’s IVATF.

## Appendix

| Future Functional Goals for Volcano Eruption and Volcanic Cloud Information   |                                    |                            |  |                            |              |             |
|---|------------------------------------|----------------------------|--|----------------------------|--------------|-------------|
|   | Route operations                   |                            | Terminal control area (TMA) operations |                            | Aerodrome    |             |
|   | Congested (high density)           | Un-congested (low density) | Congested (high density)               | Un-congested (low density) | High density | Low density |
| <b>Volcano Eruption</b>   |                                    |                            |  |                            |              |             |
| Detect an Eruption in all kinds of meteorological and day/night conditions (i.e., including tropical regions where convective activity is common) | X                                  | X                          | X                                      | X                          | X            | X           |
| Determine the height of the eruption plume  | X                                  | X                          | X                                      | X                          | X            | X           |
| Determine the duration of the eruption  | X                                  | X                          | X                                      | X                          | X            | X           |
| Detect, determine and report the heightened volcanic activity (pre-eruption)  | X                                  | X                          | X                                      | X                          |              |             |
| <b>Volcanic Cloud</b>   |                                    |                            |  |                            |              |             |
| Determine the perimeter, top and base of the volcanic cloud in all kinds of meteorological and day/night conditions                               | X                                  | X                          | X                                      | X                          |              |             |
| Determine when the "volcanic cloud" is a hazard due to:   | Ash                                | X                          | X                                      | X                          | X            | X           |
|   | SO <sub>2</sub>                    | X                          | X                                      | X                          | X            | X           |
|   | Electro-magnetic risks to avionics | X                          | X                                      | X                          | X            | X           |
|   | Other (TBD)                        |                            |  |                            |              |             |
| Determine the perimeter of the lowest acceptable ash contamination level (ash cloud)  | X                                  | X                          | X                                      | X                          | X            | X           |
| Determine the perimeter of the gaseous cloud  | X                                  | X                          | X                                      | X                          | X            | X           |
| Determine the eruption source parameters  | X                                  | X                          | X                                      | X                          | X            | X           |
| Forecast the perimeter of the lowest acceptable ash contamination level (ash cloud)   | D, P                               | D, P                       | D, P                                   | D                          | P            | D           |
| Forecast the top and base height of the lowest acceptable ash contamination level (ash cloud)   | D, P                               | D, P                       | D, P                                   | D                          | P            | D           |
| Forecast the movement of the lowest acceptable ash contamination level  | D                                  | D                          | D                                      | D                          |              |             |
| Forecast the growth and   | D, P                               | D, P                       | D, P                                   | D                          |              |             |

| Future Functional Goals for Volcano Eruption and Volcanic Cloud Information  |                          |                            |  |                            |              |             |
|--|--------------------------|----------------------------|--|----------------------------|--------------|-------------|
|  | Route operations         |                            | Terminal control area (TMA) operations |                            | Aerodrome    |             |
|  | Congested (high density) | Un-congested (low density) | Congested (high density)               | Un-congested (low density) | High density | Low density |
| decay of the lowest acceptable ash contamination level (ash cloud)   |                          |                            |  |                            |              |             |
| Forecast the location of the gaseous cloud   | D, P                     | D, P                       | D, P                                   | D                          | P            | D           |
| Forecast the top and base height of the gaseous cloud  | D, P                     | D, P                       | D, P                                   | D                          | P            | D           |
| Forecast the movement of the gaseous cloud   | D, P                     | D, P                       | D, P                                   | D                          |              |             |
| Forecast the growth and decay of the gaseous cloud   | P                        | D, P                       | P                                      | D                          |              |             |
| Determine when the volcanic cloud is no longer a hazard  | X                        | X                          | X                                      | X                          |              |             |
| Determine when the volcanic cloud is hidden or mixed with clouds, especially cumulonimbus clouds and cirrus clouds | X                        | X                          | X                                      | X                          |              |             |
| Forecast when the volcanic cloud is hidden or mixed with meteorological clouds                                     | P                        | D, P                       | P                                      | D                          |              |             |
| <b>Volcanic Ash Accumulation</b>   |                          |                            |  |                            |              |             |
| Determine the ash accumulation at the aerodrome  |                          |                            |  |                            | X            | X           |
| Forecast the ash accumulation at the aerodrome   |                          |                            |  |                            | D, P         | D           |

Table 4. Future functional goals for volcano eruption and volcanic cloud information

## 6.0 Operational Scenarios

Two kinds of operational scenarios are envisioned, avoidance of the volcanic cloud, and planned flight into a cloud. The information for both scenarios is in the form of nowcasts and forecasts that are integrated into decision support systems.

### Nowcasts

The three-dimensional representation of the current or near-current volcanic ash cloud, including depiction of the perimeter of the lowest acceptable level of ash contamination, in a common exchange format that provides integration into decision making tools as well as offers a graphical depiction of the information. In the avoidance scenario, the nowcast provides users with the location of discernible volcanic ash. As the volcanic ash moves or changes, the nowcast is updated at a temporal frequency that meets user needs and service provider capabilities. For

**Appendix**

flight into acceptable levels of ash, volcano ESP, *in situ* measurements of the airborne volcanic ash (from ground-based, space-based, or airborne-based observing platforms) are required to provide a nowcast that has a high level of confidence of the ash concentration levels inside the cloud.

**Forecasts**

The four-dimensional representation of volcanic ash, including depiction of the perimeter of the lowest acceptable level of ash contamination, ash concentration levels and indices, in both deterministic and probabilistic terms, in a common exchange format that provides integration into decision making tools as well as offers a graphical depiction of the information. For both scenarios, the forecasts would be valid “X” hours and up to “Y” days, but would contain finer temporal resolution in the near time frame. Forecasts would also be provided in terms of uncertainty (use of probability). For flight into acceptable levels of ash contamination, volcano ESP, quantitative measurements of the airborne volcanic ash (from ground-based, space-based or airborne-based observing platforms), would be needed to enable accurate validation of ash contamination to support airline decision making.

**The Collaboration Process**

Aligned with the above forecast process is the collaborative decision and information sharing process. In this scenario, collaboration on the nowcasts and forecasts will occur on a regular basis such that all users are afforded the opportunity to contribute information. Information will be shared and could be made available on an information database or web portal that is jointly run by the VAACs.

Civil aviation operators will then apply these new nowcasts and forecasts to their operations specifications per their Safety Management System (SMS) and any specific Safety Risk Assessments (SRA) for any operations other in areas of a volcanic ash cloud.

— END —