METEOROLOGY PANEL

Concept of Operations

for

Volcanic Hazard Information

for

International Air Navigation

in

Support of the Global Air Navigation Plan

and the

Aviation System Block Upgrades

07 February 2023

Version 4.1

Revision	Date	Description
0.1	15 April 2011	Internal draft. New Document.
0.2	06 May 2011	Initial draft. Presented to IAVW coordination group of IVATF.
0.3	13 July 2011	Initial draft. Presented to IVATF/2 (Working Paper 04).
0.4	08 February 2012	Revised draft. Complete rewrite based on comments received on initial draft.
0.4.1	10 February 2012	Minor revision. Minor edits. Presented to IAVW coordination group at IVATF/3.
1.0	14 December 2012	Draft version for IAVWOPSG/7. Format and structure changed to harmonize with other ConOps being developed. Considered and/or incorporated comments received in response to IAVWOPSG Memorandum 56.
1.1	12 November 2015	Based in part on the *Roadmap for International Airways Volcano Watch (IAVW) in Support of International Air Navigation*, 21 November 2013, version 1.0, ICAO Doc 10045 *Meteorology (MET) Divisional Meeting (2014)*, Appendix C. New format and structure changed.
1.2	11 December 2015	Minor revision based on comments received at MISD/VA/1.
2.0	29 April 2016	Complete revision.
2.1	8 August 2016	Minor revision per METP MISD Rapporteur. Included the phrase “Need for information” to the titles of sections 2.4 and 2.5. Added the word “thresholds” twice in section 5.3 for the short-term forecasts.
3.0	12 November 2018	Revisions to align with the 5th Edition of the GANP. Other revisions in response to the review and input of the METP WG-MOG IAVW Work Stream.
3.1	18 November 2019	Minor revision in response to the review and input of the METP WG-MOG/IAVW meeting 8 (Wellington, NZ, 12-14 Nov 2018). State provided ash concentration forecasts added to the current capabilities section.
4.0	01 November 2021	Significant revision to incorporate outcomes of METP/5 (virtual, June 2021) and METP WG-MISD/VASD meeting (Wash DC, USA, 20 Nov 2019).
4.1	07 February 2023	Minor revisions

Table of Contents

1.0 Introduction.

This Concept of Operations (ConOps) document describes the **need for** and **use of** volcanic hazards information for operational decisions, in qualitative and quantitative terms, from the perspective of the end user and relevant to an operator's Safety Management System (SMS). This document is primarily intended for executive management of the service providers and service users.

This ConOps is **not** intended to describe **how** future volcanic hazard information is to be provided or by **whom** the future information is to be provided, which is one of the roles of the ConOps' companion document. That companion document is the *Roadmap for International Airways Volcano Watch (IAVW) in Support of International Air Navigation.*

This ConOps is a living document that is intended to evolve as operational requirements evolve.

1.1 Information Identification

This ConOps presents the future use of volcanic hazard information for international air navigation in support of International Civil Aviation Organization (ICAO) Global Air Navigation Plan (GANP) [1] and associated Aviation System Block Upgrades (ASBU). Specifically addressed are ASBU Blocks 0, 1, 2 and 3 in their respective timeframes: 2013-2018, 2019-2024, 2025-2030 and 2031-2036. Information on Block 0 is retained for a baseline perspective.

The GANP calls for meteorological and environmental hazard services to enhance operational decisions through integrated meteorological information, with meteorological information supporting automated decision processes or aids involving: meteorological information, meteorological translation, air traffic management (ATM) impact conversion and ATM decision-making support.

This ConOps describes how improved information on the status of the volcano and associated hazards will help meet the need called for in the GANP.

1.2 Information Overview

An aviation user must know if a hazard will affect their operation, and if so, what actions to take in order to mitigate the risk in accordance with SMS practices or procedures agreed to in any contingency plan.

[1] *The Global Air Navigation Plan,* ICAO Doc 9750 (https://www4.icao.int/ganpportal/)

A provider of aviation hazard information needs to determine if a hazard exists, or is expected to exist, in their area of responsibility[2]. The provider compiles information about the hazard into format(s) that can be accessed by the aviation user to mitigate the risk.

The potential impact of the volcanic hazard may vary depending on the user. Volcanic hazards to aviation include:

- Volcano expected to erupt or posing a high risk for sudden eruptions
- Erupting volcano
- Volcanic ash (either from an erupting volcano or re-suspended from a previous/ancient eruption):
  - in the atmosphere, that is visible from an aircraft including discernible from remote sensing or *in-situ* observations
  - in the atmosphere greater than a specified threshold
  - on the runway/taxiway greater than a specified depth
- Sulphur dioxide (SO_2) and other hazardous gases greater than a specified threshold

Note: Specified thresholds can vary depending on the user. For example, for volcanic ash and SO_2 it can be as simple as discernible from satellite, or it could be a defined metric, such as 2 milligrams per cubic meter, or some other value (per a user's SMS).

Note: Hereafter, references to ash and gases are assumed to be from a volcanic source.

Depending on the user, quantitative and qualitative information requirements on the hazard will vary. A user may not need to know every detail regarding the hazard, only the information pertaining to their operation. For example, a flight crew's need for detail and accuracy will be high for that period and portion of the hazard expected to affect the flight route including any revised routes due to, for example, critical engine failure or depressurization.

Information overload can occur for the user if too much or duplicate hazard information is provided that is not relevant to or will not affect their operation. To avoid information overload, users must be able to obtain the appropriate information in a timely manner in order to successfully complete their evidence-based risk assessment and operate safely and efficiently. The aim is to have consistent, i.e. not contradictory, information received from multiple official sources.

1.3 References

The following documents are referenced in this ConOps

- ICAO Annex 3 - *Meteorological Service for International Air Navigation*
- ICAO Annex 15 – *Aeronautical Information Services*
- *Global Air Navigation Plan,* ICAO Doc 9750, including the Aviation System Block Upgrades
- *Handbook on the International Airways Volcano Watch– Operational Procedures and Contact List*, ICAO Doc 9766

[2] Service providers' area of responsibility could range from the local scale (e.g. the aerodrome and its vicinity) up to the regional or global scale (e.g. large continental and oceanic airspaces).

- *Flight Safety and Volcanic Ash,* ICAO Doc 9974
- *Procedures for Air Navigation Services - Air Traffic Management,* ICAO Doc 4444
- *Procedures for Air Navigation Services – Meteorology,* ICAO Doc 10157 (expected to be available from 2024)
- *Roadmap for International Airways Volcano Watch (IAVW) in Support of International Air Navigation*
- *Volcanic Ash Contingency Plan – European and North Atlantic Regions* (EUR/NAT VACP), EUR Doc 019, NAT Doc 006, Part II.
- Rolls-Royce World-Wide Communication, WWC 11365-1, Rolls-Royce plc, 24 May 2017.

2.0 User Need Identification

Large volcanic events can impact multiple users over a wide geographic area. In addition, the collaborative nature of some aviation-decisions, in which multiple users in multiple Flight Information Regions (FIR) have input into decision-making, requires all of the users to have access to harmonized and consistent information on volcanic hazards. This information must be of defined accuracy, highly reliable and in a format that is usable by multiple aviation decision-makers and in decision support systems, the latter of which may be fully or highly automated with little or no human intervention.

2.1 Users

2.1.1 Operators

Operators are entities engaged in the conduct of domestic and international commercial flights. Operators are responsible for the safe and efficient conduct of flight operations and are therefore a principal user of volcanic hazard information.

Typically, operators have two distinct functions: flight planning and flight operation. In larger operators, these are usually separate roles performed by different individuals. Smaller operators may combine these roles and require flight crew members to fulfill flight planning and flight operation functions.

2.1.1.1 Flight operations centres, dispatchers, and flight planners

Flight operations centres, dispatchers, and flight planners are generally responsible for flight planning (e.g., route selection, calculation of required fuel). In some instances, these roles may also be responsible for en-route deviations and identifying in-flight route improvement.

Flight operations centres, dispatchers, and flight planners use information on volcanic hazards in combination with meteorological information to plan routes that allow flights to avoid or fly through airspace in which the risk of encountering a volcanic ash cloud is within the limits of the operator's SMS. As an example of an operational limitation, flying over a volcanic ash cloud may not be possible in some cases since flight planners need to consider the loss of cabin pressure (depressurization) or engine failure, which would require the flight crew to descend through the ash cloud to lower altitudes.

To achieve maximum utility, volcanic hazard information should be available to flight operations centres, flight planners, and dispatcher in a timely manner (i.e. on-time, in-full) and in an agreed format that can be ingested by decision support systems that can then output the required user driven visualization options.

2.1.1.2 Flight crew members

Flight crew members, typically pilots, are responsible for safely conducting flight operations. For smaller operators, flight crew members may also fulfill the flight planning responsibilities.

Flight crew members use volcanic hazard information to make decisions regarding the acceptability of a planned route as well as en route deviations or diversions. These decisions are based upon information compiled by dispatchers, like the visualized output of the decision support systems (if available), as well as information from service providers. The decisions are thus based on a comprehensive set of information, encompassing observations (e.g., near real-time satellite images/depictions annotated with the ash cloud) and reports of an eruption of ash in the atmosphere, and forecasts of airspace likely to be affected by a volcanic eruption and/or volcanic ash cloud.

2.1.2 Air Traffic Service

Air Traffic Service (ATS) is a generic term referring to flight information service, alerting service, air traffic advisory service, and air traffic control service (area control service, approach control service, or aerodrome control service). The two components of ATS that most require volcanic hazard information are Air Traffic Management (ATM) and Air Traffic Control Service (ATCS).

2.1.2.1 Air Traffic Management

ATM, including Air Traffic Flow Management (ATFM), is a service established with the objective of contributing to a safe, orderly, and expeditious flow of air traffic by ensuring that air traffic control capacity is utilized to the maximum extent possible, and that the traffic volume is compatible with the capacities declared by the appropriate ATS authority.

ATM plans the flow of air traffic through airspace based on filed flight plans and known or forecast constraints, particularly those caused by weather. ATM also identifies the flight tracks that will be used for trans-oceanic flights.

Future new and improved forecasts of volcanic hazards on airspace will enable ATM to maximize the flow of aircraft through the airspace reducing flow impacts to a minimum. In particular, ATM will use new and improved forecast information to begin planning aircraft flows through previously affected airspace in a more timely manner. Similar to the flight operations centres, flight planners and dispatchers, ATM requires the new and improved forecast information in a format that can be ingested by decision support systems.

2.1.2.2 Air Traffic Control Service

ATCS is a service provided for the purpose of preventing collisions between aircraft and, on the maneuvering area, between aircraft and obstructions. ATCS also expedites and maintains the orderly flow of air traffic.

ATCS requires new and improved forecasts of volcanic hazards to plan for and manage the potential airspace disruptions to air navigation. The new and improved forecast information will be used by ATCS to assist, predict and facilitate requests for route deviations and altitude changes from aircraft that may be or will likely be impacted.

2.1.3 Civil Aviation Authorities

Civil Aviation Authorities (CAAs) are responsible for maintaining the safe operation of airspace through the promulgation of appropriate national regulations, policies, and guidance and approval of the airlines´ Safety Risk Assessments for flight operations in the presence of volcanic ash / clouds.. In order to ensure the safety of operations and the traveling public, as well as national security, CAA's have the authority to temporarily restrict airspace usage (including reducing to a zero flow rate) to specific or to all types of flight operations.

New and improved forecasts of the airspace likely to be impacted by volcanic hazards will be used by CAAs to proactively manage the airspace.

2.1.4 Aerodrome Operators

Aerodrome operators are responsible for the day-to-day operations and safety at an aerodrome (e.g. maintenance, security, ground staff and equipment, emergency response, runways).

Aerodrome operators use volcanic hazard information to determine when ashfall is affecting/forecast to impact aerodromes (e.g volcano entering state of heightened unrest or continuous ash emission expected to affect aerodrome). This information allows aerodrome operators to plan logistics around asset relocation, runway cleaning etc to mitigate disruption due to ashfall.

2.2 Need for Information on Volcanic Activity and Volcanic Ash Cloud

Users need to know the current and future state of a volcanic hazard, including location and extent (vertical and horizontal) of an ash cloud and its evolution through time. To improve efficiencies in air transportation during periods of significant pre-eruptive activity and eruptive volcanic events, high-quality, timely and consistent volcanic hazard information is essential to mitigate the safety risk of aircraft encountering a volcanic hazard.

In 2017, after several years of research, a major original equipment manufacturer[3] (OEM) announced that certain models of their engines could safely operate for a specified time in a specified concentration and dose of volcanic ash.

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[3] Rolls-Royce PLC (R-R) issued a world-wide communication WWC 11365-1 to operators, applicable to all RB211 and Trent family of engines. WWC 11365-1 states that acceptable operation in dispersed ash of up to a maximum of 4mg/m3 for an hour (equivalent to 2mg/m3 for 2 hours) – qualified as a dose of 14.4 g s/m3 – should not lead to a significant erosion of engine related flight safety margins.

The following is a set of high-level operational needs of aviation users:

- Determine the onset of a volcanic event (i.e., pre-eruption activity warning) and, using historical eruptive behaviour characteristics where available, provide the expected qualitative impact following initial eruption
- Determine if an eruption and any associated volcanic ash cloud is a hazard to international civil aviation based on any standard or user defined quantitative threshold values, or the historical eruptive behavior of the volcano
- Determine which aerodromes and airspace are impacted by the eruption and associated volcanic ash cloud
- Determine when the volcanic activity has ended
- Determine when the volcanic ash cloud has dispersed below standard or user defined quantitative threshold values, which may be probabilistic - based
- Ensure the information provided is globally consistent
- Determine the extent of re-suspended volcanic ash

2.3 Need for Information on Volcanic Gases

During volcanic eruptions, gases that are toxic to human health may be emitted in addition to volcanic ash; these include SO_2, hydrogen fluoride and hydrogen sulphide amongst many others. Each toxic gas has different atmospheric dispersion properties. Gas clouds may be found coincident or separate from ash clouds. Of these gases, SO_2 is of particular importance as it may be emitted from a volcanic eruption in significant quantities and potentially has significant health effects and could, through prolonged exposure, impact the service life of certain aircraft components.

Previously documented experience to date of in-flight encounters with sulphurous gases suggests that SO_2 has never been an immediate and significant safety hazard to an aircraft or health hazard to its occupants. The 2019 eruption of Mount Raikoke (Sea of Okhotsk in the northwest Pacific Ocean) emitted the highest ever SO_2 levels observed by satellite sensors. The observed levels of SO_2 were mostly co-located with the volcanic ash, but once the volcanic ash cloud dissipated the remaining SO_2 cloud lingered for weeks. This event has highlighted that further research is needed in this area.

ICAO's Meteorology Panel has been tasked through the job card (METP.012.01) to determine a clear meteorological/atmospheric chemistry requirement for a critical level of SO_2 in the atmosphere that would be observed (or forecast) that would pose a health risk to its occupants by passing through the ventilation system.

3.0 Current Capability Assessment

The current capability equates to the service level for the ASBU Block 0 and Block 1 timeframes (from 2013 and 2019 respectively).

A detailed description of current service providers and their functions with respect to volcanic ash cloud information can be found in ICAO's *Handbook on the International Airways Volcano Watch*, Doc 9766.

3.1 Volcanic Eruption and Volcanic Ash Cloud

Current volcanic ash cloud forecasts are basic textual and graphical products derived and produced using the output from dispersion and transport models validated and calibrated against available volcanic ash cloud observations.

The two primary volcanic ash cloud forecast products are the volcanic ash advisory (VAA) (and its corresponding graphical version [VAG]), and the SIGMET information message[4].

VAAs (and VAGs) are produced and issued by the nine Volcanic Ash Advisory Centres (VAAC)[5], each with a defined geographical area of responsibility. VAACs are operated by an ICAO Contracting State and designated through ICAO regional air navigation agreement. The VAA/VAG provides an analysis of the volcanic ash cloud and a 6-, 12- and 18-hour forecast for the location of the volcanic ash cloud and associated flight levels that may be affected.

SIGMETs for a volcanic ash cloud are produced and issued by Meteorological Watch Offices (MWO), operated by ICAO Contracting States, based on the guidance provided by a VAAC. They are valid for up to six hours and describe the location and expected location of the ash cloud within the area of responsibility of the MWO, which is normally just one FIR.

Per ICAO Annex 3 - *Meteorological Service for International Air Navigation*, SIGMETs are valid for only one FIR, whereas a VAA/VAG is not restricted to FIR boundaries and thus may cover multiple FIRs.

VAA/VAG and SIGMET provide a simple outline of the volcanic ash cloud (observed and forecast), which often is an over simplification due to format requirements (limited number of vertices/points). Also, base and top of the volcanic ash cloud are simplified due to the format requirements and uncertainties in both observations and the model output. Temporal resolution of information in the VAA/VAG and SIGMET is six-hours, which is very coarse and may limit users' ability to determine the location of the hazard in various time frames (e.g., at two hours after issuance of a VAA/VAG and SIGMET). Per Annex 3 the aerial coverage of a SIGMET is limited to the FIR. Thus, an ash cloud impacting multiple FIRs will have multiple SIGMETs, each one only describing the ash cloud within the FIR.

[4] SIGMET: Information concerning en-route weather phenomena which may affect the safety of aircraft operations.

[5] VAACs details can be found in the Handbook on the International airways Volcano Watch – Operational Procedures and Contact list, ICAO Doc 9766 (https://www.icao.int/airnavigation/METP/MOG/IAVW%20Documents/Doc.9766.alltext.pdf)

3.1.3 Other Products

In addition to the SIGMET and VAA/VAG, other products may be issued for a volcanic eruption and/or ash cloud including NOTAM[6], ASHTAM[7], and Special Air Report (AIREP), and ash concentration forecasts. Aerodrome meteorological offices may report falling ash at an aerodrome using the METAR/SPECI[8] reports.

NOTAMs and ASHTAMs are issued by State's International NOTAM Offices (NOF) and are described in ICAO Annex 15 – *Aeronautical Information Services*. Special AIREPs, also sometimes referred to as pilot reports, are described in ICAO – Annex 3 - *Meteorological Service for International Air Navigation.* Volcanic Ash concentration forecasts are a graphical product provided by select States' national meteorological service provider in response to requirements in select regional ICAO volcanic ash contingency plans[9].

Since 2010, the United Kingdom (Met Office) and France (Météo France) have been providing annotated satellite imagery of volcanic ash clouds to users. In addition, Volcanic Ash contamination forecasts are available, referred to as Volcanic Ash Concentration Charts. Full detail can be found in regional ICAO volcanic ash contingency plans [8]., which include:

- three vertical layers: FL000 to FL200, FL200 to FL350, and FL350 to FL550.
- 6-hourly temporal resolution (T+0, T+6, T+12 and T+18).
- three levels of ash concentration ranges:
    - low contamination: below or equal to 2 milligrams per cubic meter (mg/m^3);
    - medium contamination: above 2 mg/m^3 and below 4 mg/m^3; and

high contamination: equal to or above 4 mg/m^3.

These are intended to supplement the VAAs and VAGs issued by VAAC London and Toulouse.

State volcano observatories provide information on the state of the volcano with limited distribution. Some State volcano observatories issue information the for of a Volcano Observatory Notice for Aviation (VONA). The issuance of a VONA is expected to become a recommended practice in Annex 3 – *Meteorological Service for International Air Navigation* with Amendment 81 (applicability in November 2024), with distribution to extend to international OPMET databanks, by regional agreement. The technical specifications around the VONA and the VONA template will be contained in the *Procedures for Air Navigation Services – Meteorology,* ICAO Doc 10157 (expected to be available from 2024). The VONA contains a four-level color code for quick reference to indicate the general level of threat of an eruption for a given volcano. The VONA allows the volcanologists to provide a succinct message on the state of the volcano to the

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[6] NOTAM. A notice distributed by means of telecommunication containing information concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations

[7] An ASHTAM is a special case NOTAM for the status of a volcano as well as volcanic ash cloud in the atmosphere.

[8] METAR: Aerodrome routine meteorological report. SPECI: Aerodrome special meteorological report.

[9] *Volcanic Ash Contingency Plan – European and North Atlantic Regions* (EUR/NAT VACP), EUR Doc 019, NAT Doc 006, Part II, Edition 2.0.1, June 2021. (https://www.icao.int/eurnat/eur%20and%20nat%20documents/forms/allitems.aspx)

MWO, VAAC, and NOF, which as noted above assists in the issuance of SIGMET, VAA and NOTAM respectively. Once the VONA is elevated to a recommended practice and becomes more widely available, it will also allow airline operators to use the information as part of their risk management practices during periods of significant pre-eruptive activity.

Each of these products is unique in format and content, but all (except for the VONA which describes the state of the volcano, and the METAR/SPECI that reports volcanic ash as an obscuration) provide detailed information regarding the location of the volcanic ash cloud but with varying degrees of quality and accuracy. The challenge is the need for consistency in their overall message.

3.2 Sulphur Dioxide (SO_2)

Of the products discussed in section 3.1 only the Special AIREP may currently be used for reporting the presence of SO_2. Investigations are ongoing with a view to determining a need and feasibility to expand the volcanic hazard information services to include other hazardous toxic gases typically associated with volcanic eruptions.

During volcanic eruptions, gases that are toxic to human health may be emitted in addition to volcanic ash; these include SO_2, hydrogen fluoride and hydrogen sulphide among many others. Each of these gases will originate in varying amounts, and possibly different heights, in the eruption column and will undergo varying chemical transformations (e.g., sulphur dioxide to sulphate) and have different atmospheric dispersion properties. As previously stated, gas clouds may or may not be found coincident with volcanic ash clouds. Of these gases, SO_2 is of particular importance, since it has potentially significant health effects, operational efficiency impacts on the airframe and avionics, and may be emitted in large quantities.

Compared to information on volcanic ash clouds beyond special AIREP, little information is currently provided to aviation on the observed presence of SO_2 in the atmosphere and there are currently no provisions for SO_2 forecast information in ICAO Annex 3.

The following is a list of current responsibilities and information:

- Guidance to pilots on the detection of sulphurous gases is provided in ICAO's *Handbook on the International Airways Volcano Watch,* Doc 9766
- Pilots have the responsibility to report encounters with SO_2 from volcanic activity as soon as possible via an special airep, and after flight, via the Volcanic Activity Report[10] (VAR), which is part of a Special Air Report (AIREP)
- SO_2 can be detected via remote sensing techniques from satellites
    - Information on the extent of SO_2 clouds is available from various national service providers[11]

[10] Detailed information on the VAR is contained in ICAO's *Procedures for Air Navigation Services - Air Traffic Management,* Doc 4444, Appendix 1.

[11] Such as the Support to Aviation Control Service SO_2 and Ash Notification System by the Belgian Institute for Space Aeronomy, http://sacs.aeronomie.be

4.0 Anticipated Change Identification (Shortfall Analysis)

In the coming years, new forecasts with further improved spatial and temporal resolutions and increased accuracy will provide users with local, regional, and globally consistent information on the likely impacts to aviation operations from volcanic events. This information will be used by flight operations centres, flight planners, flight crews, dispatchers, and ATM to plan the most efficient flight routes and tracks while avoiding the likely impacts from volcanic events. Flight crews and ATCS will use this information when reviewing and deciding upon the flight plan, as well as to anticipate any likely route and altitude changes, and perhaps the potential impact on arrival and departure operations at airports.

To achieve this future operational environment, the following enhancements to volcanic event information are necessary:

- Improved eruption source parameters (ESP) and subsequent forecasts of the volcanic clouds as well as potential impacts from a volcanic event to international air navigation.
- Development of impact-based forecasts on SO_2 clouds associated with volcanic eruptions.
- Improved forecasts of when specific areas of airspace will have restricted usage (including flow rates reduced to zero) due to volcanic events.
- The use of probability information with decision support systems to assist in improving traffic flow and provide improved temporal information.
- Increased availability and frequency of in-situ, lidar, infrasound and ceilometer observations and forecasts when significant airports are impacted.
- Information that is consistent across FIR boundaries.
- From the user perspective, a user would like to reach a “single answer” or decision based on the likelihood of all possible outcomes described using probabilistic forecast information via the System-Wide Information Management (SWIM) environment.

5.0 Concept Definition

5.1 Objectives and Scope

The objective of this concept is to describe the information to be provided which will overall, improve the safety and efficiency of international air navigation during volcanic events.

Volcanic events can be on a local, regional, and multi-regional scale, can impact both short and long-haul flight operations, and on rare occasions have a global impact on aviation users due to knock-on network effects. Information on volcanic hazard information services must be consistent across all these scales. Thus, the scope of the information required to satisfy the needs described in this concept ranges across all spectrums from local to global.

5.2 Potential Benefits of New or Modified Information

The proposals for new and improved volcanic hazard information and services to be developed and implemented will provide users with volcanic hazard information that has greater confidence and utility – for example, probability, short-period, and user defined concentration threshold-based forecasts. Moving from a product-centric environment to a data-centric environment will meet the future operational needs of aviation decision-makers. The integration of volcanic ash cloud short-term 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.

The application of probabilistic forecasts will benefit high-density (congested) traffic areas the most, 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.

Finally, the routine provision of global verification statistics will provide the necessary confidence for operators and pilots to fly in and around active or potentially active volcanic areas.

5.3 Description of Change in Operational Decision Environment that Produces the Benefits

5.3.1 Improved representation of the volcanic hazard

Beginning in the late ASBU Block 1 (2019-2024) timeframe and continuing into Block 2 (2025-2030), the development and implementation of new ash concentration forecasts, referred to as Quantitative Volcanic Ash (QVA) information, are anticipated.

The initial operating capability (IOC) for QVA information will provide ash concentration forecasts to offer operators the opportunity to move away from traditional discernible/visible ash criteria and instead use certified or OEM declared susceptibility for flight route planning. QVA information will be issued by the VAACs and will be generated for varying concentration thresholds, vertical and horizontal extents, and 3 hourly time intervals up to 24 hours. The IOC for QVA is expected to become a recommended practice in Annex 3 – *Meteorological Service for International Air Navigation* as part of Amendment 81 with intended applicability in November 2024.

Initially, these forecasts will be issued for significant[12] volcanic ash clouds which have met certain criteria. During this time, they will coexist with current VAA/VAG and volcanic ash cloud SIGMETs. Eventually (most probably in the Block 2 timeframe) the VAA/VAG and SIGMET will be phased out. By the ASBU Block 3 timeframe (2031-2036), it is foreseen that the Full Operating Capability

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[12] Significant volcanic ash clouds in this content means an assessment of widespread impact to aircraft operations and air navigation is based on considerations[1] by the responsible VAAC of known or expected volcanic ash 'cloud'[2] spatial extent and persistence in the proximity of aerodromes and international airways. The criteria is planned to be documented in the *Handbook on the International Airways Volcano Watch* (Doc 9766).

[1] *Informed by discussions and pre-agreement with relevant aviation users and, to ensure a consistency of approach, the other VAACs and SVOs.*
[2] *Based on satellite-derived mass-loading detection threshold of 0.2 gm^{-2} which, although not directly comparable to ash concentration, provides a recognized quantitative constraint (lower threshold) for satellite-based remotely sensed discernible ash.*

(FOC) of QVA forecasts will be implemented, which will include finer four-dimensional resolution data and data available for all volcanic ash clouds.

5.3.2 Use of probability in the provision of volcanic hazard (ash and gas) 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.

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 four-dimensional shape (three-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 exceeding a defined magnitude/threshold. Probabilistic forecasts help multiple decision makers use the same weather information, applying their own operational constraints to determine risk to their operation.

5.3.3 Integration of volcanic hazard forecasts into decision support systems

One of the key elements in meteorological modules of the ASBUs is the integration of meteorological/hazard information into decision support systems. Future ATM decision support systems will need to directly incorporate volcanic hazard 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 hazard forecasts, combined with the use of probabilistic forecasts to address uncertainty, reduces the likelihood of misinterpretation by the user and thus reduces the effects of volcanic hazards on air traffic operations.

5.3.4 Role of the forecasters

The roles and responsibilities of the forecaster will change with the implementation of high-resolution probabilistic volcanic hazard forecasts, including ash concentration, combined with the integration of these into decision support systems. Automation and computer-modeling output will replace many of the manual processes currently required, which will create more time for forecasters to provide other services such as consultative decision support to the user and data interpretation/analysis in collaboration with the user.

New satellite ash detection and depiction methods will provide enhanced capability to forecasters to assess the accuracy and truthfulness of the computer modelling output in near real time.

5.4 Operational Scenarios

Three kinds of operational scenarios are presented: 1) avoidance of the volcanic ash cloud, 2) planned flight into a volcanic ash cloud that has concentration thresholds below that which is acceptable to an operator's designated aircraft/engine type and meets the operator's SMS, and 3) flight in areas of SO_2 from a volcanic eruption. Other scenarios exist but are not included in this document. The information for these scenarios is in the form of forecasts that are integrated into decision support systems.

5.4.1 Avoidance of the Volcanic Ash Cloud

In the avoidance scenario, high-resolution three-dimensional representation forecasts of the volcanic ash cloud provide users with a depiction of the perimeter of the highest acceptable[13] threshold of ash concentration, in a common exchange format that provides integration into decision making tools, as well as offers a graphical depiction of the information. As the volcanic ash moves or changes, the forecast is updated at a temporal frequency that meets user's needs and service provider's capabilities.

5.4.2 Flight into acceptable thresholds of volcanic ash concentration

For planned flight into acceptable thresholds of ash concentration, four-dimensional representations of volcanic ash cloud, including depictions of the acceptable thresholds of concentration in both deterministic and probabilistic terms, in a common exchange format that provides integration into decision support tools.

High resolution four-dimensional volcanic ash data is tailored to the user's needs and derived from the best available science. With the volcanic ash data set being ingested into decision support tools, operators can extract and, if necessary, visualize the hazard information needed to make the highest-quality safety risk assessment and operate in the most efficient way through acceptable concentration thresholds. This will minimise airspace disruptions, especially but not exclusively high-density (congested) airspace, and will maximise the cost benefit of operations while maintaining safety.

For maintenance constraint purposes, it is desirable that aircraft have appropriate instrumentation to indicate to the flight crew and record the concentration of volcanic ash encountered by the aircraft. The in-situ quantitative measurements of volcanic ash can also be extremely useful within the VAACs to support validation and verification of the QVA forecasts. During pre-flight, the flight planning decision support system should also record the likely ash dosage for each route option.

5.4.3 Flight in areas of SO_2 from a volcanic eruption

For planned flights in areas of SO_2, operators will apply observations and forecasts of SO_2, in accordance with their SMS, to either avoid the SO_2 cloud or transition the cloud.

It is desirable that aircraft have appropriate instrumentation to indicate to the flight crew, report to ground stations and record the concentration of SO_2 encountered by the aircraft, including those levels entering the aircraft's cabin after transition through aircraft ventilation systems.

Information on the development of SO_2 information is detailed in the latest version of the Roadmap for the IAVW.

5.4.4 Information for decision-makers

For the above scenarios, it is important that all decision-makers have consistent and common information at the resolution necessary to make their decisions. This includes spatial and temporal resolution as well as updated frequency of the information.

[13] Acceptable is defined by individual operators safety risk assessment

Flight crew are likely to require the most detailed information under the aforementioned scenarios. Flight crew may benefit from high-resolution satellite imagery as long as proper training in their use is provided, e.g. the use of annotated satellite imagery as in 3.1.3.

5.5 Assumptions and Constraints

5.5.1 Assumptions

The proposed concept contained herein is based on the following assumptions:

- High-resolution three-dimensional representation forecasts of the volcanic ash cloud and longer-term probabilistic forecasts will replace the need for today's SIGMETs (for volcanic ash cloud) and VAAs.
- For those operators who choose not to invest in systems to utilize the new information, there may be a need to continue to provide a legacy product to make safe but less efficient flight decisions, i.e., typically to avoid an affected area entirely.
- High-resolution three-dimensional representation of the volcanic hazard will not be a traditional plain language (text-based) product. This concept moves away from a product-centric environment to a data-centric environment.
- Probabilistic forecasts are understood by and can be utilized by aviation decision makers.
- Probabilistic forecasts are best suited for users in high-density (congested) airspace but can also be beneficial for users in low-density (uncongested) airspace.
- Operator decision makers will use these probabilities within their decision support systems to better determine the temporal impact of the ash – both in the immediate term of a flight operation and in the longer-term with regards to equipment maintenance.
- Dispatchers, flight crew and other decision makers will receive training on the application and use of probabilistic forecasts, as appropriate.
- Continuing user demand for seamless, globally consistent, harmonized phenomena-based information.
- Worldwide, improved remote sensing techniques and *in-situ* measurements of the airborne volcanic ash (from ground-based, space-based or airborne-based observing platforms), volcano ESP, will be needed to provide short-term forecasts and forecasts that have levels of accuracy and confidence acceptable to the users.
- There are acceptable thresholds of volcanic ash that may be a maintenance concern for an aircraft but do not pose a safety hazard.
- Acceptable thresholds of volcanic ash and SO_2 may vary based on the type of aircraft, system and engine requiring the development of index levels.
- The forecast providers are capable of providing the information at the required resolution and update frequency, and with an acceptable latency.
- The systems used by the decision-makers, including dispatchers and flight crew, will be able to receive and process the information, including the display if required, at the required resolution and update frequency, and with an acceptable latency.
- That the provision of volcanic hazard information services should be reviewed by ICAO to ensure that the information is globally consistent as well as efficiently provided, which may result in an adjustment of the number of VAAC providers required to provide this service.
- Forecasts for re-suspension of volcanic ash will be implemented in the future but not within IOC for QVA.

5.5.2 Constraints

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

- Determining the height of bases and tops of the volcanic ash cloud, as well as bases and tops of multiple layers often presents challenges from an observation and forecast perspective.
- The critical quantity (contamination, mass loading, exposure) will need to be determined.
- Funding for these developments and improvements, which is State-specific, may not occur or may be delayed.
- Regarding improved forecast information, unless new satellite imagery or another observation of the area of volcanic ash becomes available, an interpolation between two previously stated positions is the best estimate of the location of the volcanic ash cloud.
- Assuming more frequent observations become available, the service providers may not be capable, for example due to resources (including staffing), to deliver frequent updates.
- The development, production, and delivery of probabilistic forecasts for volcanic ash may not be possible or delayed for some or all service providers.

5.6 Operational Policies

Moving from a product-centric environment to a data-centric environment with integration into decision support systems require changes in policies for flight documentation as well as retention of information by the provider. Currently, products are artifacts that can easily be provided for flight documentation and then archived for future reference (e.g., accident investigation). Archived data should be accessible to operators and flight crew.

With the implementation of probabilistic forecasts along with integration into decision support systems, the concept of flight documentation changes. A database of information will replace a folder with charts and text reports and messages. Policies relating to system storage capacity for data retention (archival) will need to be revisited. This need could vary depending on a State's legal requirements.

It is essential that these issues will be addressed with the implementation of the SWIM concept, which is part of the GANP and associated ASBUs.

Appendix A. Glossary and Acronyms

A.1 Acronyms

Acronym	Term
AIREP	Air Report
ASBU	Aviation System Block Upgrades
ASHTAM	A special class of NOTAM
ATCS	Air Traffic Control Service
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATS	Air Traffic Service
CAA	Civil Aviation Authority
ConOps	Concept of Operations
ESP	Eruption Source Parameter
FIR	Flight Information Region
FOC	Full Operating Capabiltiy
GANP	Global Air Navigation Plan
IAVW	International Airways Volcano Watch
ICAO	International Civil Aviation Organization
IOC	Initial Operating Capability
METAR	Aerodrome routine meteorological report
MWO	Meteorological Watch Office
NOF	International NOTAM Office
NOTAM	NOTAM[14]
OEM	Original Equipment Manufacturer
QVA	Quantitative Volcanic Ash
SIGMET	SIGMET information[15]
SMS	Safety Management System
SO_2	Sulphur Dioxide
SPECI	Aerodrome special meteorological report
SWIM	System Wide Information Management
VAA	Volcanic Ash Advisory
VAAC	Volcanic Ash Advisory Center
VAG	Graphical version of the VAA
VAR	Volcanic Activity Report
VONA	Volcano Observatory Notice for Aviation

- END OF DOCUMENT -

[14] NOTAM: A notice distributed by means of telecommunication containing information concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations.

[15] SIGMET: Information concerning en-route weather phenomena which may affect the safety of aircraft operations.