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

17 March 2026

Version 5.0

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
4.2	28 October 2024	Minor revisions
5.0	17 March 2026	Major edits.

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.* The timeline for the ConOps is reflected in section 1.1, aligning with the Aviation System Block Upgrades (ASBU).

This ConOps is a living document that is intended to evolve as operational requirements evolve and will be updated between each Meteorological Panel (METP) Working Group Meteorological Operations Group (WG-MOG) IAVW Work Stream meeting.

1.1 Information Identification

This ConOps presents the future use of volcanic hazard information for international air navigation in support of the International Civil Aviation Organization (ICAO) Global Air Navigation Plan (GANP)[1] and associated 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 previous Blocks 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

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

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.

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 information supplied for aviation purposes by a provider may form part of a broader civil contingency at the national or local level.

The potential initial impact on users of the volcanic hazard will depend on the phases of a volcanic eruption that present particular hazards to aviation, which include:

- Volcano is exhibiting heightened unrest and is expected to erupt or is posing a high risk for sudden eruptions.
- Volcano is erupting, with the likelihood of intense convection within the eruptive column yielding highly turbulent conditions and/or frequent lightning.

Moreover, there may be:

- Volcanic ash from an erupting volcano or that has been re-suspended from a previous/ancient eruption deposit:
  - in the atmosphere, that is visible from an aircraft,
  - in the atmosphere greater than a specified threshold, or
  - on the runway/taxiway, greater than a specified thickness.
- Sulphur dioxide (SO_2) and other hazardous gases greater than a specified threshold.

Note: Specified thresholds can vary depending on the user's needs. For example, for volcanic ash and SO_2 it can be as simple as discernible from satellite, or it could be a defined amount, 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 the portion of the hazard expected to affect the flight route, including any revised routes due to, for example, critical engine failure or depressurization.

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[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).

Information overload can occur for the user if information is excessive, duplicative, not relevant to, or will not affect their operation. To avoid information overload, users must be able to obtain the appropriate information promptly and in the desired format 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.
- *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 applicable from November 2025).
- *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 users to have access to harmonized and consistent information on volcanic hazards. This information must be accurate, timely, 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 principal users of volcanic hazard information.

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

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 dispatchers promptly (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 fulfil 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), 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 (ATC).

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.

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

2.1.2.2 Air Traffic Control

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

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, guidance, approval, and oversight 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 (including reducing to a zero-flow rate) to specific or all types of flight operations.

New and improved information on volcanic hazards will be used by CAAs to proactively engage with users to manage these risks.

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 already impacting or is forecast to impact aerodromes (e.g., the volcano entering a state of heightened unrest or a continuous ash emission is expected to affect the aerodrome). This information allows aerodrome operators to plan logistics around asset relocation, runway cleaning, etc. to mitigate and minimize disruption due to ashfall.

2.2 Need for Information on Volcanic Activity and Volcanic Ash Clouds

Users need to know the current and future state of a volcanic hazard, including the location and extent (vertical and horizontal) of ash clouds and the evolution through time. To improve efficiencies in air transportation during periods of significant pre-eruptive activity, eruptive volcanic events, and volcanic ash cloud dispersion and transport 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 specific concentration and dose of volcanic ash.

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

- Determine and notify pre-eruption volcanic activity, including heightened unrest, that signifies that an eruption might occur, to enable aviation users to prepare accordingly.
- Determine and notify the onset of a volcanic eruptive event and/or a volcanic ash re-suspension event.
- Using real- or near-real-time observations as well as historical eruptive behaviour characteristics and eruption source parameters (ESP) where available, provide aviation users with a qualitative assessment of the event.
- Determine if an eruption and any associated volcanic cloud is a hazard to international civil aviation based on any standard or user defined quantitative threshold values, or the historical eruptive behaviour of the volcano.
- Determine and notify which aerodromes and airspace are impacted by the eruption and/or a volcanic ash cloud, including a re-suspended volcanic ash cloud event, and on what timescales.
- Determine and notify where the volcanic ash cloud is forecast to move in space and time.
- Determine and notify when the volcanic activity has ceased and/or when the volcanic ash cloud, including a re-suspended volcanic ash cloud, has dispersed below standard or user-defined quantitative threshold values, to enable aviation users to return to business-as-usual at the earliest opportunity.
- Ensure the information provided is globally consistent and conforms to the users' requirements, including the requirements for flight documentation.

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 CO_2, SO_2, and hydrogen fluoride amongst many others. Such toxic gases can be emitted without the emission of significant amounts of volcanic ash, for example during unrest or effusive eruptions. Each toxic gas has different atmospheric dispersion properties. Volcanic 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.

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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 $4 mg/m^3$ for an hour (equivalent to $2 mg/m^3$ for 2 hours) – qualified as a dose of $14.4 g s/m^3$ – should not lead to a significant erosion of engine related flight safety margins.

Even though previously documented experiences to date of in-flight encounters with sulphurous gases suggests that SO_2 may not pose an immediate and significant safety hazard to an aircraft and/or represent a serious health hazard to its occupants, the 2019 eruption of Mount Raikoke (Sea of Okhotsk in the northwest Pacific Ocean) emitted large amounts of SO_2 that were transported and dispersed over much of the northern hemisphere. 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. At present, impact information on occupants' health and/or on aircraft components has not been collected systematically, e.g., via the volcanic activity report (VAR) and any future reporting tools, and is a matter that would need to be addressed if the potential severity of such impacts is to be better understood and quantified.

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 observed (or forecast) that would pose a health risk to its occupants by passing through the ventilation system. However, this work has been paused until such time that the SO_2 concentration thresholds appropriate in view of managing the risk to health of aircraft occupants is identified or a revised user requirement is presented to the Work Stream.

3.0 Legacy Capability Assessment

The legacy capability equates to the service level for the ASBU Block 0 and Block 1 timeframe (before 2025).

The information contains the legacy products and services. Each of these products is unique in format and content, but a majority of them provide detailed information regarding the location of the volcanic ash cloud but with varying degrees of details, accuracy and precision. These products may be the same or slightly different from the current capability assessment outlined in section 4.

3.1 Volcanic Activity and Volcanic Ash Clouds

The 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 the volcanic ash graphic (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 (Part 2 of the Handbook of the IAVW (ICAO Doc

[4] SIGMET: Information issued by a meteorological watch office concerning the occurrence or expected occurrence of specified en-route weather and other phenomena in the atmosphere that may affect the safety of aircraft operations

[5] VAAC details can be found in the Handbook on the International airways Volcano Watch – Operational Procedures and Contact list, ICAO Doc 9766 (IAVW Documents - All Documents (icao.int))

9766)). 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 (T+0-hour) and a T+6-, T+12- and T+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, and may be based on the guidance provided by a VAAC. They are valid for up to six hours and describe the current location (T+0-hour) and expected location (T+6-hour) of the ash cloud within the area of responsibility of the MWO, which is normally just one FIR.

VAA/VAG and SIGMETs (which may be based on VAA/VAG) 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 ICAO Annex 3- *Meteorological Service for International Air Navigation*, the aerial coverage of a SIGMET is limited to only one FIR. Thus, an ash cloud impacting multiple FIRs will have multiple SIGMETs, each one only describing the ash cloud within the FIR. The VAA/VAG is not restricted to FIR boundaries and thus may cover multiple FIRs. In those instances where a volcanic ash cloud reaches a VAAC boundary, the neighbouring VAACs will coordinate and discuss a possible handover as well as issuance of a rebroadcast VAA. Similarly, in those instances where a volcanic ash cloud reaches an FIR boundary, the neighbouring MWOs should coordinate and discuss a possible handover.

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). Aerodrome meteorological offices may report falling ash at an aerodrome using the METAR/SPECI[8] reports.

NOTAMs and ASHTAMs are issued by a 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.* State volcano observatories (SVO) provide information on the state of the volcano to its associated VAAC, MWO and ACC/FIC, some with limited distribution to local users. Some State volcano observatories distribute information on volcanoes through the issuance of a Volcano Observatory Notice for Aviation (VONA). The VONA contains a multi-level aviation colour code which reflects the activity level assessed by volcanologists at or near the volcano and does not pertain to any hazard downwind of the volcano, e.g., the ash cloud. The

[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.

aviation colour code provides a quick reference to indicate the general level of eruptive activity at a given volcano. The VONA allows the volcanologists to provide a succinct message on the state of the volcano as well as the height of the eruptive column (if measurable) to the MWO, VAAC, and NOF, which as noted above assists in the issuance of SIGMET, VAA/VAG, and NOTAM respectively.

Each of these products is unique in format and content, but 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 also refer to section 2.3.

Compared to information on volcanic ash clouds, beyond Special AIREP, there is little information currently provided to aviation users on the observed presence of SO_2 in the atmosphere.

Pilots have the responsibility to report encounters with SO_2 from volcanic activity as soon as possible via a special AIREP and, post-flight, via the Volcanic Activity Report[9] (VAR), which is Part II of the Special Air Report (AIREP).

SO_2 can be detected via remote sensing techniques from satellites as well as ground-based instruments. Information on the observed extent of SO_2 clouds is available from various Meteorological Service Providers.

4.0 Current Capability Assessment

The current capability equates to the service level for the ASBU Block 2 timeframes (from 2025).

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.

4.1 Volcanic Activity and Volcanic Ash Clouds

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

The two primary volcanic ash cloud forecast products are the volcanic ash advisory (VAA) the volcanic ash graphic (VAG), and the SIGMET information message. These products are described in section 3.1 and are now additionally issued in IWXXM format.

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

The Quantitative volcanic ash concentration information (QVA) service provides ash concentration forecasts, enabling operators to move away from the traditional discernible/visible ash criteria and instead use OEM declared susceptibility. For an initial operating capability (IOC), QVA will be comprised of the following:

- horizontal grid point resolution of 0.25° of latitude and longitude;
- vertical resolution of 5,000 feet;
- 3-hourly temporal resolution through forecast 24-hours;
- updated as necessary but at least every 6 hours;
- probabilities for ash concentration thresholds of 10, 5, 2 and 0.2 mg/m^3;
- ash concentration ranges of:
  - equal to or above 10 mg/m^3;
  - equal to or above 5 and below 10 mg/m^3;
  - equal to or above 2 and below 5 mg/m^3;
  - equal to or above 0.2 and below 2 mg/m^3; and
  - below 0.2 mg/m^3.

Initially, these forecasts will be issued for significant[10] volcanic ash clouds and coexist with current VAA/VAG and volcanic ash cloud SIGMETs.

4.1.3 Other Products

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

NOTAMs and ASHTAMs are issued by a 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.*

As of November 2025, the issuance of a VONA is a recommended practice in Annex 3 – *Meteorological Service for International Air Navigation* with Amendment 82, with distribution to extend to international OPMET databanks[11], by regional agreement. The technical specifications around the VONA and the VONA template in IWXXM format will be contained in the *Procedures for Air Navigation Services – Meteorology,* ICAO Doc 10157 (available from 2025). Once the VONA is elevated to a recommended practice (through the aforementioned amendment to Annex 3) and becomes more widely available to their associated VAACs, MWOs, NOTAM office, Area Control Centres and international OPMET, if in a position to do so, it will also allow airline

[10] Significant volcanic ash 'clouds' in this content means an ash 'cloud' that poses a widespread impact to aircraft operations and air navigation. Guidance on the criteria is provided in *Handbook on the International Airways Volcano Watch* (IAVW) – Operational Procedures and Contact List (Doc 9766).

[11] OPMET databanks are databanks established to store and share international operational meteorological (OPMET) information for aeronautical use.

operators to use the information as part of their risk management practices during periods of significant pre-eruptive activity.

4.2 Sulphur Dioxide (SO_2)

Of the products discussed in section 3.1 only the Special AIREP is currently used for reporting the presence of SO_2. Investigations are ongoing with a view to determining the need and feasibility to expand the volcanic hazard information services to include other hazardous toxic gases typically associated with volcanic eruptions also refer to section 2.3.

There are currently no provisions for SO_2 forecast information in ICAO Annex 3. Notwithstanding, as part of the aforementioned amendment to Annex 3, it will be possible for State volcano observatories to report SO_2 as part of the VONA.

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 a special AIREP and, post-flight, via the Volcanic Activity Report[12] (VAR), which is Part II of the Special Air Report (AIREP).
- SO_2 can be detected via remote sensing techniques from satellites as well as ground-based instruments
    - Information on the observed extent of SO_2 clouds is available from various Meteorological Service Providers.

5.0 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 ATC 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 aerodromes.

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

- Improved quantification of eruption data (known as eruption source parameters (ESP)), observations of ash clouds, and subsequent data integration and modelling to enable forecasts of the location and concentration of volcanic clouds as well as potential impacts from a volcanic event to international air navigation. Enabling access to up-to-date

[12] AMD 84 to Annex 3 as endorsed by METP/6 proposes to transfer the VAR to the PANS-MET and rename the updated form the Aircraft Volcanic Encounter Report or "AVER" with applicability date of Nov 2030.

regional and global catalogues of volcano characteristics, including ESP, will be important for success.

- The content and utility of current SVO information such as VONA and aviation colour code should be routinely reviewed to ensure it is fit for purpose as other services within the IAVW are improved. Development of impact-based forecasts of SO_2 clouds associated with volcanic eruptions.
- Improved forecasts, making use of ensembles and data fusion techniques, 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 spatio-temporal information.
- Increased availability and frequency of in-situ, lidar, infrasound, and ceilometer observations and forecasts to assist in the determination of when volcanic eruptions and volcanic ash clouds will impact aerodromes and airspace.
- Information that is consistent across FIR boundaries.
- From the operators' perspective, a user will reach a risk-assessed operational outcome based on the likelihood of all possible outcomes described using both the deterministic and probabilistic forecast information and other known operational information via the System-Wide Information Management (SWIM) environment.

6.0 Concept Definition

6.1 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 consequential downstream effects that could impact aircraft routing operations. 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.

6.2 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 – and from a qualitative or semi-quantitative service paradigm to a fully quantitative, probabilistic service paradigm – will better 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 congested airspace the most, where decision makers can benefit from more than just a deterministic forecast. Also, decision support systems can use probabilistic information to provide route and altitude selections based on user's acceptance thresholds.

Improved capability of State volcano observatories to detect and quantify ESP (such as plume height and grain size distribution) will greatly enhance the quality of forecasts of volcanic ash clouds.

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. In addition, these developments will support users to apply their own safety risk management thresholds to their decision making.

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

6.3.1 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 QVA, has commenced.

The initial operating capability (IOC) for QVA provides ash concentration forecasts, enabling operators to move away from traditional discernible/visible ash criteria and instead use certified or OEM declared susceptibility for flight route planning. For those operators who do not have OEM certifications, it will provide a higher level of resolution to avoid the ash. QVA issued by the VAACs will be generated for varying concentration thresholds, vertical and horizontal extents, and 3 hourly time intervals up to 24 hours. The IOC for QVA became a recommended practice in Annex 3 – *Meteorological Service for International Air Navigation* as part of Amendment 82 and supplemented by *Procedures for Air Navigation Services – Meteorology (PANS-MET)* with applicability in November 2025. Throughout ASBU Block 2, VAACs will take full advantage of the evolving science and technology and make available QVA with enhanced spatial and/or temporal resolution as agreed between the VAAC and users concerned.

Initially, these forecasts will be issued for significant volcanic ash clouds that have met certain criteria. During this time, they will coexist with current VAA/VAG and volcanic ash SIGMETs. By the ASBU Block 3 timeframe (2031-2036), it is foreseen that the incremental improvements will be made to QVA, which will include finer four-dimensional resolution data and possibly data available for all volcanic ash clouds. It is anticipated that the VAA/VAG and SIGMET will then begin to be phased out. In addition, QVA will evolve during this phase based on lessons learned during the IOC.

6.3.2 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 type of 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 i.e., 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 meteorological/hazard parameter's risk of exceeding a defined magnitude/threshold. Probabilistic forecasts help decision makers use the same information, applying their own operational constraints to determine risk to their operation.

6.3.3 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.

These developments will likely result in changes to the roles and responsibilities of IAVW users.

6.3.4 Role of the forecasters

The roles and responsibilities of the forecaster will evolve with the implementation of high-resolution probabilistic volcanic hazard forecasts, including ash concentration, combined with the integration of these into decision support systems. In the early stages, the forecaster will provide a quality control function supporting the new QVA service. As quality control of the service is implemented, the forecaster will also analyse the data and meteorological conditions to support operators and provide guidance on the current situation shown in the data.

Automation, including the use of artificial intelligence, machine-learning, and computer-modelling output, will replace many of the manual processes currently required. This 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. In this connection, it will be important for users' requirements for satellite ash detection capabilities, to be identified and clearly articulated to satellite researchers and developers, so that capabilities can be investigated and, where feasible, developed to fulfil the users' needs.

6.4 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.

6.4.1 Avoidance of the Volcanic Ash Cloud

In the avoidance scenario, high-resolution four-dimensional forecasts of the volcanic ash cloud can provide users with a detailed representation of the spatial and temporal structure of the ash cloud, as well as the perimeter of the highest acceptable[13] threshold of ash concentration, in a common exchange format. This provides integration into decision making tools, as well as offering 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. In addition, satellites and other observations will provide information that is critical for avoidance, especially during the early, rapidly evolving stages of an eruption.

6.4.2 Flight into acceptable thresholds of volcanic ash concentration

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 concentrations and within acceptable thresholds. This will minimise airspace disruptions, especially but not exclusively in high-density 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. During pre-flight, the flight planning decision support system will also record the likely ash dosage for each route option.

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. In the absence of such instrumentation on board aircraft, new and improved Aircraft Volcanic Encounter Reports (AVER) (applicable 2030), which will replace the VAR, can help VAACs verify the QVA forecasts as well as provide other useful information related to the VA encounter.

6.4.3 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 (when and if available), 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.

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

Information on the development of SO_2 information is detailed in the latest version of the Roadmap for the IAVW. As discussed in Section 2.3, this work has been put on pause until the SO_2 concentration threshold that poses a risk to the health of aircraft occupants is identified, or a revised user requirement is presented to the MOG-IAVW Work Stream.

6.4.4 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.

Flight crew are likely to require the most detailed information under the aforementioned scenarios, benefitting from high-resolution satellite imagery as long as proper training in its use is provided.

In addition, information from aviation decision-makers (dispatchers, flight crew, etc.) on the nature and timing of strategic and operational decisions should be shared with the meteorological and volcanological service providers so that there is a common awareness and understanding that can help improve the co-design and co-development of new and improved service offerings.

6.5 Assumptions and Constraints

6.5.1 Assumptions

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

- Worldwide, improved remote sensing techniques and *in-situ* measurements of the airborne volcanic ash (from ground-based, space-based, or airborne-based observing platforms), and detailed and regularly updated volcano ESP that is accessible regionally and globally, will be needed to provide short-term forecasts and forecasts that have levels of accuracy and confidence acceptable to the users.
- VAACs working with their associated national meteorological and hydrological service, should continue to engage with the relevant meteorological agencies and SVOs in their area of responsibility regarding observation and information sharing to ensure that SVOs have access to information necessary to support effective volcanic hazards monitoring and continuity of outputs related to the IAVW, including today's VONA or future forms of such hazard information.
- That the provision of volcanic hazard information services should be reviewed by ICAO and its partners and stakeholders 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.
- Frequent and timely reporting of aircraft ash encounters with volcanic ash clouds and gases, through improved methods, will assist in model validation and provide more accurate forecasts. Service providers (e.g., VAACs) will require access to such aircraft reports, ideally in near-real-time, so that they can be used efficiently and effectively in addition to other datasets to help validate or adjust (improve) the forecast.
- The Meteorological Service Providers are capable of providing the information at the required resolution, in the required format and update frequency, and with an acceptable latency.

- Meteorological Service Providers have sufficient information to produce useful probabilistic forecasts.
- High-resolution four-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 fully digital, data-centric environment – and from a qualitative or semi-quantitative service paradigm to a fully quantitative, probabilistic service paradigm.
- High-resolution four-dimensional representation forecasts of the volcanic ash cloud and longer-term probabilistic forecasts will replace the need for today's VAAs, VAGs, and volcanic ash SIGMETs, especially for large scale events.
- Probabilistic forecasts are useful when there is more uncertainty in the eruption and /or meteorology, which could result in larger areas being impacted. This typically is the case in the tropics. Probabilistic forecasts are understood by and can be utilized by aviation decision makers.
- With the introduction of QVA, the volcanological and meteorological communities should provide clear communication to aviation stakeholders on the strengths and limitations of the supporting science and information that is being provided.
- Dispatchers, flight crew, and other aviation decision makers will receive training and education on the appropriate application and use of probabilistic forecasts and QVA to support the transition from legacy to contemporary products and services.
- 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.
- 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.
- Operator decision makers will use these probabilities within their decision support systems to better determine the temporal impact of the ash cloud – both in the immediate term of a flight operation and in the longer term with regards to equipment maintenance. Moreover, to make the best use of QVA information, operators will likely possess information on the susceptibility/tolerance of their engines to volcanic ash ingestion.
- Continuing user demand for seamless, globally consistent, harmonized phenomena-based information.
- There are acceptable thresholds of volcanic ash that do not pose an overall safety hazard to flight operations, but that may require additional maintenance inspections.
- Acceptable thresholds of volcanic ash may vary based on the type of aircraft, system, and engine requiring the development of index levels.
- The aviation community conducts volcanic ash exercises using the current capabilities and information. However, as new improvements such as VONA elevation and QVA become operational, the scope of volcanic ash exercises should be expanded or adjusted to accommodate the new developments, and the outcomes should be reported as appropriate, including aviation user feedback sent to service providers (e.g., VAACs and SVOs).
- The SO_2 concentration threshold that poses a risk to the health of aircraft occupants, including at cruise altitudes, will be understood.

6.5.2 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 additional challenges from an observation and forecast perspective.
- Monitoring three-dimensional ash concentration distribution remains challenging. While a two-dimensional mass loading distribution obtained via satellite retrieval can be a prospective alternative, it has a limitation in ash detection accuracy.
- The critical quantity (contamination and mass loading) will need to be determined by the Meteorological Service Provider to support the generation of high-quality forecasts and data
- The critical quantity (exposure and dosage) will need to be determined by the operators and OEMs to support the operations and maintenance of aircraft.
- Funding for these developments and improvements, which is State-specific, may not occur or may be delayed. Sustainable funding mechanisms should therefore be identified and secured to support SVOs, in particular, in the monitoring of active and potentially active volcanoes.
- An interpolation between two stated positions is the best estimate of the location of the volcanic ash cloud at an intermediate timestep. However, this may result in an overestimation of ash when the concentration is forecast to change.
- As more frequent observations become available, the service providers may not be capable, for example, due to resources (including staffing), to deliver frequent updates.
- With the increasing volume of observations from multiple sources, the service provider will need to identify ways not only to appropriately manage and use voluminous datasets but also to resolve potentially conflicting information before incorporating it into the forecasts or data.
- The development, production, and delivery of probabilistic forecasts for volcanic ash may not be possible or delayed for some or all service providers.

6.6 Operational Policies

Moving from a product-centric environment to a data-centric environment with integration into decision support systems requires 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, litigation, and research). 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, 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 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
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATS	Air Traffic Service
AVER	Aircraft Volcanic Encounter Report
CAA	Civil Aviation Authority
ConOps	Concept of Operations
ESP	Eruption Source Parameter
FIR	Flight Information Region
FOC	Full Operating Capability
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	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.
OEM	Original Equipment Manufacturer
QVA	Quantitative volcanic ash concentration information
SIGMET	Significant Meteorological Information
SMS	Safety Management System
SO_2	Sulphur Dioxide
SPECI	Aerodrome special meteorological report
SVO	State volcano observatory
SWIM	System-Wide Information Management
VAA	Volcanic Ash Advisory
VAAC	Volcanic Ash Advisory Centre
VAG	Graphical version of the VAA
VAR	Volcanic Activity Report
VONA	Volcano Observatory Notice for Aviation

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