METEOROLOGY PANEL

Roadmap

for

International Airways Volcano Watch (IAVW)

in

Support of International Air Navigation

17 March 2026

Version 6.0

Revision	Date	Description
0.1	29 July 2013	Initial draft. Based on draft ConOps for the IAVW in response to IAVWOPSG Conclusion 7/17. Aligns with Meteorological Information Supporting Enhanced Operational Efficiency and Safety from ICAO's Aviation System Block Upgrades (ASBU).
0.2	27 September 2013	Revised draft based on comments from IAVWOPSG ad hoc group.
0.3	24 October 2013	Revised draft based on comments on version 0.2 from the IAVWOPSG ad hoc group.
0.4	10 November 2013	Revised draft based on comments on version 0.3 from the IAVWOPSG ad hoc group
1.0	19 November 2013	Submitted to IAVWOPSG Secretariat
1.0 rev	21 November 2013	Revised to include additional comments from WMO
1.1	11 December 2015	Key changes were the move of sulphur dioxide and other gases from block 3 timeframe (2028[1] and beyond) to block 1 timeframe (2018-2023). Removed functional goals, which will be placed in a requirements document. Minor updates to other sections as needed.
1.2	19 January 2016	Internal revision based on comments from MISD VA Work Stream.
2.0	29 April 2016	Complete revision. Document focuses on the on time-line of the roadmap as well as brief descriptions of the anticipated changes.
2.1	10 May 2016	Minor revision to reflect comments received at METP/WG-MISD/VA/2 meeting (29 April 2016, Buenos Aires, AR).
3.0	11 December 2017	Major revision, which includes input from METP WG-MOG/IAVW Work Stream and others. Changes include the consolidation of several concepts in the document.
4.0	18 November 2019	Major revision, which incorporates comments received at METP WG-MOG/8-IAVW meeting (12-14 Nov 2018, Wellington, NZ) as well as changes in accordance with the 6th Edition of the GANP (2019).
5.0	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).
5.1	07 February 2023	Minor revisions.
5.2	29 October 2024	Minor revisions.
6.0	17 March 2026	Major reformatting, change to AMET Block 2 and revisions.

[1] ASBU block timeframes for Blocks 1, 2 and 3 in the Fourth Edition of the GANP were slightly different from those in the Fifth and Sixth Editions of the GANP

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1.0 Introduction

This document provides a plan for the development and implementation of volcanic ash and gas-related information in support of the International Civil Aviation Organization's (ICAO) Global Air Navigation Plan (GANP), 2013-2037 (Doc 9750)[2], and associated Aviation System Block Upgrades (ASBU) for aviation meteorological information (AMET) modules for:

- AMET Block 0 = 2013 - 2018
- AMET Block 1 = 2019 - 2024
- AMET Block 2 = 2025 - 2030
- AMET Block 3 = 2031 - 2036
- AMET Block 4 = from 2037.

This document is intended to provide aviation users and providers of meteorological and volcanological information within the International Airways Volcano Watch (IAVW) with a roadmap (i.e., the "what" and "when") that defines improved services, including the integration of volcanic ash-related information into decision support systems for performance-based navigation. The roadmap is not intended to provide detailed descriptions of all the areas presented in the document, rather, it presents a high-level overview for the user.

The roadmap for the IAVW is a living document to support ICAO's Meteorology Panel (METP) and applicable working groups and work streams. The roadmap's companion document is 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.

1.1 Overview of the ASBU Blocks for AMET

The following are brief descriptions of the five AMET blocks. While the following descriptions refer to 'meteorological information', it is to be understood that this encapsulates a range of meteorological and non-meteorological phenomena that includes volcanic ash and gas clouds.

AMET Block 0 (2013-2018): Global, regional, and local meteorological information to support flexible airspace management, improved situational awareness, collaborative decision-making, and dynamically optimized flight trajectory planning.

AMET Block 1 (2019-2024): Meteorological information supporting automated decision process or aids, involving meteorological information, meteorological information translation, air traffic management (ATM) impact conversion, and ATM decision support.

AMET Block 2 (2025-2030): Integrated meteorological information in support of enhanced operational ground and air decision-making processes, particularly in the planning phase and near-term.

[2] Sixth Edition, 2019

AMET Block 3 (2031-2036): Integrated meteorological information in support of enhanced operational ground and air decision-making processes, for all flight phases and corresponding air traffic management operations.

AMET Block 4 (from 2037): Integrated meteorological information supporting both air and ground decision making for all phases of flight and ATM operations, especially for implementing immediate weather mitigation strategies.

2.0 Roadmap

Roadmap for the International Airways Volcano Watch (IAVW) in support of the Aviation System Block Upgrades (ASBU)		**AMET Block 0** (2013-2018)	**AMET Block 1** (2019-2024)	**AMET Block 2** (2025-2030)	**AMET Block 3** (2031-2036)	**AMET Block 4** (from 2037)
Collaborative decision-making processes		I	M	M	M	M
Provide guidance to State volcano observatories to provide improved pre-eruption information and eruptive source term information for their volcanoes of responsibility		P	I	M	M	M
Improve ground-based, in-situ airborne and space-based observing networks		I	M	M	M	M
Scientific research in support of reducing risks from volcanic ash clouds and gas hazards including the development of improved dispersion modelling and forecasting of their spread		I	P, I	M	M	M
Scientific research in support of reducing risks from volcanic ash and gas hazards to including understanding of the impact on aircraft and occupants		I	P,I	M	M	M
Review of the IAVW for the provision of improved, consistent, and efficient volcanic hazard information		P	P	I	I	-
Transition to all digital format for all volcanic ash information		P	I	I	M	M
Development of volcanic ash cloud information and forecasts that includes quantitative and probabilistic information	Initial operating capability (IOC)	P	P, I	I	-	M
	Next generation of volcanic ash service	-	-	P	I	
Development of other volcanic derived gas forecasts, specifically sulphur dioxide (SO_2), that also includes probabilistic information		P	P	P,I	I	M
Integration of volcano and volcanic hazard information into the System-Wide Information Management (SWIM) environment		P	P	I	M	M

Legend: P = planning phase. I = implementation phase. M = maintenance and improvement phase. The year listed by each block (0-4) means that the listed activities will be either in the planning, implementation, or maintenance/improvement phase from the year listed at the beginning of the block until the start of the next block period. For example, the collaborative decision-making activity was implemented between 2013-2018.

3.0 Description of Roadmap

Future IAVW-related services focus on several changes that are intended to match the time frames of the Blocks of the ASBUs. The IAVW strives to represent a uniform capability to provide the high-quality, consistent, globalized information required by all aviation users.

Each activity is represented by the main activity heading and subsequently broken down into each AMET Block. Note: the legacy AMET Blocks have been retained so that aviation users and providers of meteorological and volcanological information within the IAVW can track the work done for each activity throughout the years.

3.1 Collaborative decision-making processes

3.1.1 AMET Block 0 (2013 – 2018) – Implementation phase (Legacy)

The term Collaborative Decision-Making (CDM) is a process used in Air Traffic Management (ATM) that allows all members of the ATM community, including airspace users and providers of aviation-relevant information, to participate in the ATM decisions affecting all members. CDM means arriving at an acceptable solution that considers the needs of those involved. CDM is described in ICAO Document 9971 – Manual on Collaborative Decision-Making, Document 9854 - Global Air Traffic Management Operational Concept, and Document 9982 – Manual on Air Traffic Management System Requirements.

A similar process has been implemented for volcanic ash and is called Collaborative Decision Analysis and Forecasting (CDAF). From a high-level perspective and as an example, collaboration on the location and extent of a discernible[3] volcanic ash cloud can be done, at a minimum, for events that affect high-density traffic areas, or several Flight Information Regions (FIR) and extend beyond the area of responsibility of one or more of the Volcanic Ash Advisory Centres (VAAC). This collaboration is currently in place for the VAACs and is detailed in ICAO Doc 9766 Handbook on the International Airways Volcano Watch (IAVW), Part 4.

The outcome of the CDAF can take many forms. One example is the agreed upon graphical depiction of a volcanic ash cloud, which could include the two-dimensional analysis, using high resolution satellite imagery, provided by a VAAC's host agency (i.e., National Meteorological Service).

It is desired that the VAAC's collaboration process be expanded to include other participants, e.g., Meteorological Watch Offices (MWO) and other meteorological offices serving aviation, State volcano observatories (SVO), aviation regulatory authorities (or equivalent), aerodromes, operators, and ATM. To be effective with all these groups involved there needs to be a transparent CDM structure developed so that, for example, when an eruption occurs participants will know who is talking to whom and how subsequent information is communicated. This

[3] Volcanic ash detected by defined impacts on/in aircraft or by agreed in-situ and/or remote sensing techniques.

structure should contain procedures and guidance showing how the total process delivers more informed decision-support information for the users, especially ATM and operators.

ATM and users have begun using CDM practices to derive acceptable and more informed solutions for performance-based operations.

3.1.2 AMET Block 1 (2019 – 2024) – Maintenance and Improvement phase (Legacy)

Performance-based operations (where the operator is responsible for where it operates) will necessitate operators to seek, integrate and use high-quality, meteorological and volcanological information. For these future operations, the use of CDM practices will become increasingly integrated into aviation decision-making. Continued development and improvements to the CDM process will continue in Block 1.

3.1.3 AMET Block 2 (2025 – 2030) – Maintenance and Improvement phase (Current)

Improvements in the CDM process for sharing volcano and volcanic hazard information, including satellite-based, ground-based, and airborne data, will continue in Block 2 with increased collaboration amongst the SVOs, MWOs, and VAACs. This will continue to strengthen the cooperation mechanisms and thereby helping each agency to better fulfil the respective current and future ICAO mandates for products and data.

Collaboration tools may include, but are not limited to, email, phone calls, and collaboration networks and software (e.g., Microsoft Teams™, Google Workspace™, Dropbox™, and Slack™). Operational CDM including aviation stakeholders, will share information around the uncertainties in the volcanic hazard information provision (pre-eruptive to through airborne volcanic ash).

3.1.4 AMET Block 3 (2031 – 2036) – Maintenance and Improvement phase (Future)

Aspects of the work implemented in Block 2 will be continued in Block 3.

3.1.5 AMET Block 4 (from 2037) – Maintenance and Improvement phase (Future)

From the timeframe of 2037, it is envisioned that all the planned developments and improvements outlined for this task will be successfully and fully implemented. Necessary improvements are expected to continue in the maintenance and improvement phase.

3.2 Provide guidance to State volcano observatories to provide improved pre-eruption information and eruptive source term information for their volcanoes of responsibility

3.2.1 AMET Block 0 (2013 – 2018) – Planning phase (Legacy)

Per ICAO Annex 3 – Meteorological Service for International Air Navigation, SVOs may use the Volcano Observatory Notices to Aviation (VONA) and its aviation colour code alert system for the

provision of volcano information in support of aviation. Despite being intended to provide a concise statement describing the activity at the volcano, as well as the specific time of the onset and duration of the eruptive activity, not all SVOs currently have the capacity or capability to issue VONA messages.

The VONA is the only volcano-related product that provides pre-eruption activity information to aviation users, which is considered as safety critical information by aircraft operators. In support of this, VONAs allow for the inclusion of a colour code in the message. The colour codes reflect 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 World Organization of Volcano Observatories (WOVO)[4] has recommended an ICAO aviation colour code scale, although some States have developed their own activity alerting code to address the unique needs of the State.

3.2.2 AMET Block 1 (2019 – 2024) – Implementation phase (Legacy)

Enhancements to the information provided by the SVOs, including the VONA, are expected to be implemented during Block 1. For instance, some SVOs have added mobile radar and webcams to their monitoring capabilities.

To increase information available on volcanic pre-eruption and source term information, the fifth meeting of ICAO's Meteorology Panel (June 2021) endorsed the provisions for the VONA to be a Recommended Practice in Amendment 82 to Annex 3 (with intended applicability in November 2023 but then adjusted by ICAO to November 2025), as well as the proposed Procedures for Air Navigation Services – Meteorology (PANS-MET).

3.2.3 AMET Block 2 (2025 – 2030) – Maintenance and Improvement phase (Current)

Due to the delay in Annex 3 updates, the elevation of the VONA to a Recommended Practice in Annex 3 through Amendment 82 became applicable in November 2025. The updated VONA will have a new template and will be issued in abbreviated plain language text as well as in ICAO Meteorological Information Exchange Model (IWXXM) schema form. With the elevation of VONA to a Recommended Practice, SVOs will be encouraged to disseminate volcanic activity information to their associated VAACs, MWOs, NOTAM office, Area Control Centres, and international OPMET, if in a position to do so.

SVOs will need guidance and support in progressing through these changes. In coordination with WOVO, education and guidance material on the creation, dissemination, and use of VONA for SVOs and users respectively, will be developed. With the introduction of Quantitative volcanic ash concentration information (QVA) service by the VAACs, it will be important to engage with SVOs to inform their understanding of how their information and data provided will support the new service. New efforts are underway in the IAVW to review the VONA template and ensure

[4] WOVO is a volunteer science organization and a commission of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI).

user requirements are met, and to also provide guidance on how the SVOs can better support the provision of QVA.

Additional enhancements to the information and dissemination provided by the SVOs, including the VONA or its successor, are expected to occur during this timeframe. Increased collaboration amongst the users of SVO information should help review and improve the existing products (i.e., VONA and use of aviation colour code) as a matter of routine by ICAO and partner agencies as well as consider future SVO products and dissemination, including additional guidance documentation.

Development and integration of cameras, unmanned aerial systems, and other technology, including the incorporation of artificial intelligence will continue to improve source term information as well as pre-eruptive monitoring to support aviation safety risk management.

3.2.4 AMET Block 3 (2031 – 2036) – Maintenance and Improvement phase (Future)

Aspects of the work implemented in Block 2 will be continued in Block 3.

3.2.5 AMET Block 4 (from 2037) – Maintenance and Improvement phase (Future)

From the timeframe of 2037, it is envisioned that all the planned developments and improvements outlined for this task have been successfully and fully implemented. Necessary improvements are expected to continue in the maintenance and improvement phase.

3.3 Improve ground-based, in-situ airborne and space-based observing networks – Implementation phase

3.3.1 AMET Block 0 (2013 – 2018) – Implementation phase (Legacy)

Observational information on volcanic ash requires continued improvement of observational capabilities globally, including volcano-monitoring networks, ground-based aerosol networks, satellite platforms and sensors, and in-situ airborne sampling. Improvements in observational capabilities will also improve forecasts through near-real-time data fusion techniques and forecaster expert use, aide in verification and validation of volcanic ash cloud forecasts, and support the production of quantitative volcanic ash forecasts. It is important, therefore, that observational information is shared, for example, with each responsible VAAC.

During this timeframe, improvements in volcanic ash cloud detection were realized with new satellites from Japan (Himawari-8) and the United States (GOES-16). These satellites and improvements in the science required to interpret and process their observations contributed greatly to the improvement of volcanic ash analysis techniques and methods, enabling VAACs to

provide aviation users with more reliable information on the presence of discernible volcanic ash clouds and gases in the atmosphere, their extent, and movement.

This improving capability offers users the ability to request more flexible and increasingly detailed requirements, as needed, for operations in airspace impacted by volcanic ash clouds. Meeting these requirements with improved information, when supplied timely and consistently, will enhance both the safety and efficiency of flying operations.

Notwithstanding the advances that continue to be made, it is worthwhile to note, however that the different observing and forecasting techniques have strengths and weaknesses in their application. Remote sensing has not replaced the need for ground-based seismic, geodetic, and geochemical monitoring of volcanoes operated by SVOs, particularly for advance warning of eruptions at dormant volcanoes. Given the often-unique circumstances and uncertainties that can prevail at the time of a volcanic eruption, making optimal use of a suite of available methodologies rather than applying any single methodology in isolation often offers the optimum approach to the detection and parameterization of volcanic eruptions and the observation and forecasting of volcanic ash clouds and gases.

3.3.2 AMET Block 1 (2019 – 2024) – Maintenance and Improvement phase (Legacy)

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

New spectral channels, improved resolution, faster scanning, and improved processing of the data from the new generation geostationary satellites will continue to improve the detection of volcanic ash clouds. Continued improvement of sensors on board satellites and the processing of this data, as well as increased numbers of satellite-based observations with the advent of small satellites, also known as "cubesats" or "smallsats", will continue improving the state of science by increasing the number and quality of real-time observations.

3.3.3 AMET Block 2 (2025 – 2030) – Maintenance and Improvement phase (Current)

Improvements to volcano-monitoring networks, alert systems, ground-based aerosol and particulate networks, satellite platforms and sensors, and in-situ airborne sampling will continue in Block 2.

Given improving technology, there is the potential to develop on-board ash detection equipment incorporated into the commercial aircraft (manned and unmanned) avionics suite (e.g., radar or new technology), providing the aircrew with real-time information. The addition of a crosslink capability or data-sharing arrangements could inform other aircraft in the vicinity about the ash cloud. The provision of information to support this new capability will require additional consideration for both preflight and in-flight information.

To support informed and consistent cross-sector, data-driven intelligence, the aviation industry, volcanological, and meteorological communities should ensure the timely sharing of relevant data, ideally in near-real-time, such as aircraft encounters with volcanic ash and gases and reports of operational impacts at airports due to volcanic ash deposition.

In addition, to allow operators to take full advantage of tactical on-board volcanic ash detection equipment, ATM processes and procedures will need to be developed and incorporated into ATM Contingency Plans. It is important that the data retrieved from future on-board ash detection capabilities be rapidly shared with VAACs. The VAACs can incorporate the data into their subsequent forecasts as inputs to their dispersion models and used for verification of forecasts.

Next-generation satellites will contribute to improved observations of volcanic ash clouds and SO_2. In addition, the use of machine-learning will continue to assist in the identification and determination of quantitative ash cloud properties and in turn, improve quantitative volcanic ash cloud modelling capabilities. Other breakthroughs in satellite products will likely be associated with quantitative applications such as ash cloud property mapping, eruption alerting, and operational dispersion models.

3.3.4 AMET Block 3 (2031 – 2036) – Maintenance and Improvement phase (Future)

Aspects of the work implemented in Block 2 will be continued in Block 3.

3.3.5 AMET Block 4 (from 2037) – Maintenance and Improvement phase (Future)

From the timeframe of 2037, it is envisioned that all the planned developments and improvements outlined in this roadmap have been successfully and fully implemented. Necessary improvements are expected to continue in the maintenance and improvement phase.

3.4 Scientific research in support of reducing risks from volcanic ash and gas hazards including the development of improved dispersion modelling and forecasting of their spread

3.4.1 AMET Block 0 (2013 – 2018) – Implementation phase (Legacy)

Scientific research in support of reducing risks from volcanic ash clouds and gas hazards continues to aim for tangible improvements in the detection and quantitative measurement of volcanic plumes, ash, and gas clouds during eruptions and in the accuracy of model forecasts of ash and gas transport and dispersion. In addition, the ability to detect and track the movement of a resuspended volcanic ash cloud (that may or may not be associated with an ongoing eruption) is garnering attention. Research topics (both new and on-going) pertinent to these goals include the following:

- *Detecting and characterizing volcanic plumes at/near the source*
- *Characterization (including quantitative-based assessments) of volcanic ash and gas clouds in time and space, and conveyance of the uncertainty associated with the observations and forecasts*
- *Development of data fusion techniques to combine observations and modelling to produce improved forecasts*
- *Developing sets of quantitative volcanic ash-cloud data that can be used to improve and validate models and track improvements in forecast accuracy*
- *Use of observations and new research to verify and improve volcanic ash models*

In addition,

- *Scientific research to support service delivery for volcanic ash and gas hazard risk reduction information*

3.4.2 AMET Block 1 (2019 – 2024) – Maintenance and Improvement phase (Legacy)

Scientific research in support of reducing risks from volcanic ash and gas hazards will continue in Block 1. In addition, some of the research defined in the bullet points has progressed. There is a new eruption source parameter database being developed that will help the VAACs define parameters to use in dispersion modelling systems. These databases will need ongoing support from research sections, volcano observatories, and volcanologists to provide the most accurate information.

There has also been new scientific research areas which have been explored during Block 1:

- *Development of data fusion techniques to combine observations and modelling to produce improved forecasts*
- *The use of machine learning techniques is currently growing in different disciplines of science, showing reductions in computational cost with similar performance, and in some cases, improvements over physical models. Exploration of these techniques in the framework of volcano monitoring, eruption detection, characterization of eruptive plumes and ash clouds using ground and remote sensing data, and ash dispersion forecasts will be necessary to identify possible improvements in the IAVW process. This will require large and high-quality data sets to be shared globally, as well as computational resources to train and validate these statistical models.*

3.4.3 AMET Block 2 (2025 – 2030) – Maintenance and Improvement phase (Current)

Scientific research in support of reducing risks from volcanic ash cloud and gas hazards will continue in Block 2.

There will be continuing work by research sections, volcano observatories, and volcanologists to update the eruption source parameter database to ensure each volcano has the most accurate information. As part of the updates, the research team is expected to engage with the VAACs to ensure the eruption source parameter database contains the necessary information required for the QVA service.

There is ongoing research into artificial intelligence and data fusion techniques to combine with observation data and modelling to improve forecasts. In addition to this, the use of ensemble datasets should be considered to improve the representation of atmospheric uncertainties, which will improve the confidence in the dispersion output.

With the introduction of QVA service in Block 2, the data will provide aviation users with the ability to adjust their risk-based assessment to incorporate specific tolerance to volcanic ash. There will be a renewed push to ensure each OEM provides research outcomes on engine and airframe susceptibility to volcanic ash. Other lessons learned from the aviation users related to the QVA service and their specific requirements may lead to changes in the frequency (i.e., it could be issued for all VA eruptions), interval, and decommission of legacy products.

3.4.4 AMET Block 3 (2031 – 2036) – Maintenance and Improvement phase (Future)

Aspects of the work implemented in Block 2 will be continued in Block 3.

3.4.5 AMET Block 4 (from 2037) – Maintenance and Improvement phase (Future)

From the timeframe of 2037, it is envisioned that all the planned developments and improvements outlined for this task have been successfully and fully implemented. Necessary improvements are expected to continue in the maintenance and improvement phase.

3.5 Scientific research in support of reducing risks from volcanic ash and gas hazards to including understanding the impact on aircraft and occupants

3.5.1 AMET Block 0 (2013 – 2018) – Implementation phase (Legacy)

Scientific research in support of reducing risks from volcanic ash clouds and gas hazards continues to aim for tangible understanding of the impact of ash and gas on aircraft structure, systems, engines, and occupants to provide enhanced guidance to operators. Research topics (both new and on-going) pertinent to these goals include the following:

- *Scientific research continues to aim for a tangible understanding of the impact of ash and gas on aircraft structure, systems, engines, and occupants to provide enhanced guidance to operators*
- *Initial OEM research into the engine and airframe susceptibility from volcanic ash*

- *Assess the relationship between gases emitted from volcanic eruptions, specifically sulphur dioxide (SO_2), in the atmosphere and their health risks to aircraft occupants and their effect on the lifetime of aircraft components.*

3.5.2 AMET Block 1 (2019 – 2024) – Maintenance and Improvement phase (Legacy)

Scientific research in support of reducing risks from volcanic ash and gas hazards will continue in Block 1. In addition, some of the research defined in the bullet points has progressed. Initial research from OEM has provided the basis for volcanic ash impacts on engine and airframe susceptibility to support the QVA service. There still needs to be continued research in this area as well as expanding into the health aspects of SO_2*.*

There has also been new scientific research areas which have been explored during Block 1:

- *Operators will need to develop their safety risk assessments to use the Quantitative volcanic ash concentration information (QVA). To support this, continued research on engine and airframe susceptibility to volcanic ash from each OEM is required to support QVA.*
- *Studies from the World Health Organisation (WHO) on* SO_2 *and its impact to human health based on exposure length and altitude will be required to support a* SO_2 *service.*

3.5.3 AMET Block 2 (2025 – 2030) – Maintenance and Improvement phase (Current)

Scientific research in support of reducing risks from volcanic ash cloud and gas hazards will continue in Block 2.

Additionally, to allow for optimum use of the new QVA service, all OEMs will need to provide output on engine and airframe susceptibility to volcanic ash.

Research into the impacts of volcanic gases on engines and airframe susceptibility will support work towards an SO_2 service. Continued work towards understanding the studies from WHO and appropriate thresholds.

With the introduction of QVA service in Block 2, the data will provide aviation users with the ability to adjust their risk-based assessment to incorporate specific tolerance to volcanic ash. There will be a renewed push to ensure each OEM provides research outcomes on engine and airframe susceptibility to volcanic ash.

3.5.4 AMET Block 3 (2031 – 2036) – Maintenance and Improvement phase (Future)

Aspects of the work implemented in Block 2 will be continued in Block 3.

3.5.5 AMET Block 4 (from 2037) – Maintenance and Improvement phase (Future)

From the timeframe of 2037, it is envisioned that all the planned developments and improvements outlined for this task have been successfully and fully implemented. Necessary improvements are expected to continue in the maintenance and improvement phase.

3.6 Review of the IAVW for the provision of improved, consistent, and efficient volcanic hazard information

3.6.1 AMET Block 0 (2013 – 2018) – Planning phase (Legacy)

The IAVW was formed in the late 1980s due to multiple major eruptions. As a result, the nine VAACs became operational with their own defined geographic area of responsibility, in the early 1990s.. In December 2016, global coverage of the IAVW was realized. Notwithstanding this progress, the International Air Transport Association (IATA) had strongly suggested that the current structure of the nine VAAC system is not optimal in terms of delivering a consistent, high-quality, and cost-efficient service in an increasingly global and interoperable environment.

IATA has requested that ICAO, through the Meteorology Panel, conduct a holistic review of the IAVW to establish the optimal number of service providers required to deliver future volcanic ash services. The process should begin with the development of the framework and terms of reference for conducting a review. The review should also consider how State MWOs support and collaborate in the future system. IATA believes it would be beneficial to undertake this review as part of the development of the system to address phenomenon-based information for select en-route hazardous meteorological conditions.

3.6.2 AMET Block 1 (2019 – 2024) – Planning phase (Legacy)

The holistic IAVW review described in Block 0 was delayed to Block 1, with completion expected in Block 2.

3.6.3 AMET Block 2 (2025 – 2030) – Implementation phase (Current)

As alluded to with 3.5.2 above, the holistic review of the IAVW described in Block 0 was further delayed until Block 2.

The aviation industry, volcanological and meteorological communities should further their proactive engagement in the operation and development of IAVW, strengthening engagements where necessary and appropriate, and steered by the articulation of aviation users' needs and regulatory requirements, and the harnessing of advances in volcanological and meteorological science, technology and operational capabilities.

IATA with support from the METP, are looking to revise the original request and scope of the holistic review of the IAVW.

It is noted that the Hazardous Weather Information Service (HWIS) is being planned under the METP. Incorporation of volcanic ash cloud information could be part of this service in the future, but not likely until the Block 3 timeframe.

3.6.4 AMET Block 3 (2031 – 2036) – Implementation phase (Future)

It is anticipated that the results from the holistic review of the IAVW will be implemented in late Block 2 or in Block 3. This could incorporate the inclusion of volcanic ash cloud information in the HWIS mentioned in section 3.6.3.

3.6.5 AMET Block 4 (from 2037) – Planning phase (Future)

From the timeframe of 2037, it is envisioned that all the planned developments and improvements outlined in this task have been successfully and fully implemented. Necessary improvements are expected to continue in the maintenance and improvement phase.

3.7 Transition to an all digital format for all volcanic ash information

3.7.1 AMET Block 0 (2013 – 2018) – Planning phase (Legacy)

There is a need to provide users with a four-dimensional (4-D) view of the observed and forecast position of volcanic ash clouds. Today's products are primarily text-based (e.g., VAA and SIGMET for VA), with some supplementation of graphic-based products (i.e., VAG and SVA[5]). Future volcanic ash cloud-related information must be provided in a globally consistent digital format that can be fully integrated into flight planning and other operational systems to better serve aviation users and decision makers. The visualization of volcanic information must be capable of being displayed on moving maps, cockpit displays, radar screens, etc.

It is expected that Aeronautical Information Services (AIS) pertaining to volcano eruption and volcanic ash clouds, i.e., ASHTAMs and NOTAMs, will also transition to digital form.

3.7.2 AMET Block 1 (2019 – 2024) – Implementation phase (Legacy)

The transition from text and graphic-based products to all-digital formats is progressing as the supporting data representations and infrastructures are developed. There will continue to be a need for legacy products to be available for several years during the transition to ensure that there will not be a gap in data service for those who are not able to receive the new format.

As of 5 November 2020, with Amendment 79 to Annex 3, SIGMETs for volcanic ash cloud and the VAA/VAG shall be issued in digital form based on the ICAO IWXXM schema in addition to abbreviated plain language text, which is a first step in the envisaged transition.

[5] VA advisory information in graphical format and SIGMET for VA in graphical format respectively.

Work is underway to develop an IWXXM Schema for the global Quantitative Volcanic Ash Concentration information service as discussed below.

3.7.3 AMET Block 2 (2025 – 2030) – Implementation phase (Current)

Perhaps the last phase of implementation of an all-digital format will be the withdrawal of legacy abbreviated plain language (text-based) products and portable network graphics (PNG) format products. During Block 2, the planning for SIGMET for VA, and VAA in abbreviated plain language format, and the VAG and SVA in PNG format, withdrawal, in view of the availability of digital/digitized information, is expected to occur.

With the elevation of VONA to a Recommended Practice in 2025, SVOs have started to issue the new VONA template in abbreviated plain language and IWXXM. However, given the vast capability difference of SVOs around the world, the VAACs and MWOs are looking to support the generation and dissemination of the VONA, especially in IWXXM, which will help with the transition to all-digital formats.

3.7.4 AMET Block 3 (2031 – 2036) – Maintenance and Improvement phase (Future)

Following the consolidation and acceptance of volcanic information, the SIGMET for VA, and VAA in abbreviated plain language format, and the VAG and SVA in PNG format, are anticipated to be withdrawn in view of the availability of digital/digitized information.

3.7.5 AMET Block 4 (from 2037) – Maintenance and Improvement phase (Future)

From the timeframe of 2037, it is envisioned that all the planned developments and improvements outlined for this task have been successfully and fully implemented. Necessary improvements are expected to continue in the maintenance and improvement phase.

3.8 Development of volcanic ash cloud information and forecasts that includes quantitative and probabilistic information

3.8.1 AMET Block 0 (2013 – 2018) – Planning phase (Legacy)

Supplementary quantitative volcanic ash concentration forecasts were initially developed during the Eyjafjallajökull eruption in Iceland in 2010. The forecasts, issued by the national meteorological service providers of some States in Europe according to their local directives or agreements, are used to support the delivery of the ICAO European North Atlantic Volcanic Ash

Contingency Plan (EUR/NAT VACP). The EUR/NAT VACP details a safety risk assessment-based approach to operations in airspace where volcanic ash is present or forecast.

In 2017, Rolls-Royce issued a world-wide communication WWC11365-1 to operators, applicable to all RB211 and Trent family of engines. WWC11365-1 states that acceptable operation in dispersed ash of up to a maximum of 4 milligrams per cubic metre (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. Rolls-Royce is working with other Original Equipment Manufacturers (OEM) to explore if similar thresholds could be applicable to other engine types.

The Rolls-Royce work, together with other recent developments such as the advancement of satellite-based detection of volcanic ash clouds and gases, improvements to forecast models and the use of data fusion techniques to combine these observations and forecast models paves the way for the development and global adoption of data services that provide quantitative volcanic ash forecast information, detailing relevant forecast concentration thresholds through both time and space, to enable users to make appropriate decisions regarding aircraft exposure to, or anticipated dosage of, volcanic ash.

3.8.2 AMET Block 1 (2019 – 2024) – Planning and Implementation phase (Legacy)

The fifth meeting of ICAO's Meteorology Panel (June 2021) endorsed the provisions for QVA to be included in Amendment 82 to Annex 3[6], as well as the proposed Procedures for Air Navigation Services – Meteorology (PANS-MET). 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.*

[6] Note that due to a significant number of comments through the State Consultation process, there was a delay in the Air Navigation Commission review. As a result, the changes endorsed at the METP/5 regarding volcanic ash information in Annex 3 and PANS-MET was adopted and now be included in Amendment 82 to Annex 3 and PANS-MET (Doc 10157). The applicability date for QVA was 27 November 2025.

Initially, these forecasts will be issued for significant[7] volcanic ash clouds and coexist with current VAA/VAG and volcanic ash cloud SIGMETs.

Implementation of QVA will be done in phases with the first phase being a Recommended Practice for those VAACs in a position to issue QVA in November 2025. In November 2026 the Recommended Practice will apply to all VAACs.

It is important that the implementation of any new forecasts is supported by a verification system to ensure they meet the needs and expectations of users in terms of accuracy and provide user confidence to operate in areas of ash. The development of detailed education, best practices, and guidance material for users is another important consideration with the introduction of this service. The development of any new forecasts and services will mature over time as will the verification and guidance material.

3.8.3 AMET Block 2 (2025 – 2030) – Planning and Implementation phase (Current)

3.8.3.1 IOC – Implementation phase (continued)

QVA service is expected to be elevated to a Standard Practice in November 2027 (with delayed applicability until 2030) with the applicability of Amendment 83 to Annex 3.

QVA service will continue to be limited to significant volcanic ash clouds; however, more work to tailor the definition of "significant" to the individual VAACs will be done. Further improvements in automation, leading to a decrease in workload at the VAACs could be made to support the next generation of QVA. The VAA/VAG and volcanic ash cloud SIGMETs will continue to be issued for all volcanic ash clouds, but efforts to decommission the legacy VAA/VAG and SIGMET products will likely occur in Block 3.

Education, best practice, and guidance material will continue to be developed for users and SVOs and will continue to be updated as needed. As science and technology improves, VAACs need to ensure that aviation users have clear information and education on the strengths and limitations of the supporting science.

3.8.3.2 Next generation of volcanic ash services – Planning phase

Following the completion of the IOC for QVA, development of the next steps for QVA will commence. This was originally known as the Full Operating Capability (FOC), however, during the ICAO MOG-IAVW meeting (October 2024), IATA raised that waiting for a FOC to be implemented

[7] 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).

would delay progress with QVA. A proposal was put forward and adopted to allow small incremental changes to QVA with each release of ICAO Annex 3 and the Handbook of the IAVW.

In Block 3, it is expected that the VAACs, taking full advantage of evolving science and technology, can make available forecasts of QVA with enhanced spatial and/or temporal resolution.

It is expected that QVA for all ash clouds, including re-suspended ash will be considered as incremental changes to the service. Further refinement of the identified performance requirements will be developed based on user needs and ICAO mandates.

One challenge is the accelerating pace of scientific and technological advancements and the comparative lag of international standards set by ICAO and WMO, and their application by regulators. This needs to be adapted into language in these standards to allow for incremental changes to services in line with advancements in the field. The other challenge is the availability of expertise within the VAACs, SVO and MWOs to fulfil the respective mandates within the framework of the IAVW.

3.8.4 AMET Block 3 (2031 – 2036) – Implementation phase (Future)

3.8.4.1 Next generation of volcanic ash services – Implementation phase

QVA could be provided for all volcanic ash clouds in Block 3. Finer four-dimensional resolution information and forecasts will also continue to be made available to the service. With the implementation of these improvements, the traditional VAA/VAG and volcanic ash cloud SIGMETs will likely be phased out.

3.8.5 AMET Block 4 (from 2037) – Maintenance and Improvement phase (Future)

From the timeframe of 2037, it is envisioned that all the planned developments and improvements outlined for this task have been successfully and fully implemented. Necessary improvements are expected to continue in the maintenance and improvement phase.

3.9 Develop other volcanic-derived contaminant forecasts, specifically sulphur dioxide, that also include probabilistic information

3.9.1 AMET Block 0 (2013 – 2018) – Planning phase (Legacy)

During volcanic eruptions, several hazardous gases may be emitted in addition to volcanic ash; these gases include SO_2, hydrogen fluoride (HF), and hydrogen sulphide (H_2S) amongst many others, impacting aircraft in-flight. These hazardous gases are problematic because aircraft occupants breathe air that originates from outside the aircraft. Outside air is drawn in through the engines, compressed (i.e., pressurized), and then passed through the aircraft's ventilation system. Each gas will likely have different eruption source parameters and atmospheric dispersion

properties; therefore, during an eruption, gas clouds may be found coincident with or wholly separated from volcanic ash clouds.

The importance of these gases for aviation varies. So far, gaseous volcanic HF has not been found at high concentrations in locations where it would have an adverse effect on people's health[8] , and so is not discussed further here. H_2S has caused fatalities but is generally localized, and it is likely that this can be well managed from a ground-based, civil defence perspective. Volcanic SO_2 has also caused only local fatalities, but is generally of more importance to aviation as it may be emitted in large quantities to cruising altitudes during large eruptions and is frequently detected by remote sensing techniques.

Depending on the levels of concentration, SO_2 can also have an adverse effect on the performance of aircraft engines and systems, as well as on aerodrome infrastructure. This effect is not immediate, but rather it affects the service life of the aircraft components. Thus, it is an economic impact rather than a safety of flight impact.

Following the scientific determination of a critical level or levels of SO_2 (in the atmosphere) that could pose a health threat to aircraft occupants, or any determination of concentrations above which OEMs do not recommend flight within an SO_2 cloud, provisions for the detection and forecasts of gas clouds, including concentration of SO_2 and probabilistic information, can be developed.

3.9.2 AMET Block 1 (2019 – 2024) – Planning phase (Legacy)

At the ninth meeting of the World Meteorological Organization (WMO) and the International Union of Geodesy and Geophysics' (IUGG) Volcanic Ash Scientific Advisory Group[9], the group recommended three threshold levels of SO_2 for evaluation during a trial conducted by VAAC London. These thresholds are based on World Health Organization (WHO) guidelines for exposure for 10 minutes:

- *0.175 ppm: WHO*
- *1.750ppm: WHO x 10*
- *4.375 ppm: WHO x 25*

Hence, for a cloud that is 1,000 m thick (3,280 ft) at an altitude of 10 km (32,800 ft), this equals an SO_2 total column loading of:

- *WHO: 3 Dobson Units (DU)*
- *WHO x 10: 55 DU*
- *WHO x 25: 140 DU*

The results from the trial are expected to form the basis for requirements of global SO_2 information to be implemented in Block 2; however, the WHO thresholds may not be appropriate

[8] International Volcanic Health Hazard Network, IVHHN, http://www.ivhhn.org/index.php?option=com_content&view=article&id=86

[9] Washington DC, USA, 21 and 22 November 2019

to use for a global SO_2 information service for aircraft at altitude. The development of Annex 3 SARPs has been put on hold until the SO_2 concentration threshold(s) that pose a risk to the health of aircraft occupants are identified or a revised user requirement is presented to the MOG-IAVW Work Stream.

3.9.3 AMET Block 2 (2025 – 2030) – Planning and Implementation phase (Current)

Following the anticipated provision of revised user requirements or threshold(s) of SO_2 which pose a health impact on aircraft occupants at altitude, provisions for a global information and forecast service are expected to be formulated for inclusion in an appropriate Annex 3 update.

When developing provisions for an SO_2 service, the capability and capacity of IAVW-related service providers requires careful consideration by ICAO and partner agencies to ensure that volcanic SO_2 observation and forecast capabilities are aligned with aviation users' potential responses to volcanic SO_2 in the atmosphere.

3.9.4 AMET Block 3 (2031 – 2036) – Planning and Implementation phase (Future)

Once SO_2 information and forecasts have been implemented, attention can be given to the consideration of other volcanic gases during the remainder of Block 3.

3.9.5 AMET Block 4 (from 2037) – Maintenance and Improvement phase (Future)

From the timeframe of 2037, it is envisioned that all the planned developments and improvements outlined for this task have been successfully and fully implemented. Necessary improvements are expected to continue in the maintenance and improvement phase.

3.10 Integration of volcano and volcanic hazard information into the SWIM environment

3.10.1 AMET Block 0 (2013 – 2018) – Planning Phase (Legacy)

The ICAO Global Air Navigation Plan (GANP) defines the strategy to achieve a globally interoperable air navigation system that offers safe, secure and efficient air transport for people and goods worldwide, while reducing the impact of aviation on the environment. The current system showed that some products within ICAO Annex 3 were not being distributed correctly to the right users. As a way to improve this dissemination the global Air Traffic Management (ATM) industry initiative to harmonise the exchange of aeronautical, meteorological and flight information for all airspace users and stakeholders via modern communication methodologies.

The concept of the provision of aeronautical services, including meteorological services, via System-Wide Information Management (SWIM) was incorporated into the GANP and, with it, the

notion of transitioning from a traditional product-centric service delivery model to an information and data-centric operating model.

The first step towards SWIM in the aeronautical meteorology domain was the generation of operational meteorological (OPMET) information, including VAAs and SIGMETs in the new IWXXM form in parallel to the TAC version. This would start in Block 1 for VAA and SIGMET, which is linked to 3.6.2.

3.10.2 AMET Block 1 (2019 – 2024) – Planning phase (Legacy)

Integrated meteorological information service in the SWIM environment is a key tenet of the GANP and associated ASBUs. Volcano and volcanic hazard information, in support of enhanced operational ground and air decision-making processes, is planned for implementation into the SWIM during Blocks 2 and 3.

3.10.3 AMET Block 2 (2025 – 2030) – Implementation phase (Current)

One of the key elements of the ASBUs is the integration of meteorological information into decision support systems. Future ATM decision support systems need to directly incorporate volcanic ash cloud and gas observations and forecasts, allowing decision makers to determine the best response to the potential operational effects and minimize the level of traffic restrictions. This integration of information, combined with the use of probabilities to address uncertainty, can reduce the effects of the volcanic ash clouds and gases on flight operations.

Beginning with Block 2, partial implementation of volcano and volcanic hazard information into the SWIM is expected.

3.10.4 AMET Block 3 (2031 – 2036) – Implementation phase (Future)

Within Block 3, it is expected that the implementation of volcano and volcanic hazard information into SWIM will be finalized.

3.10.5 AMET Block 4 (from 2037) – Planning phase (Future)

From the timeframe of 2037, it is envisioned that all the planned developments and improvements outlined for this task have been successfully and fully implemented. Necessary improvements are expected to continue in the maintenance and improvement phase.

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