METEOROLOGY PANEL

Roadmap

for

International Airways Volcano Watch (IAVW)

in

Support of International Air Navigation

07 February 2023

Version 5.1

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.

[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 International Civil Aviation Organization's (ICAO) Global Air Navigation Plan, 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 on 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 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 clouds and gases.

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

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3.0 Description of Roadmap

Future IAVW-related services focus on a number of 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.

3.1 AMET Block 0 (2013 – 2018)

The following briefly describes changes within the Block 0 timeframe (i.e., from 2013-2018) to support operational efficiency and safety.

Note: While Version 5.0 of the Roadmap is dated 2021 (i.e., in the Block 1 timeframe), the content for Block 0 is retained in the Roadmap for background information and continuity.

3.1.1 Collaborative decision-making processes – *Implementation phase*

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 takes into account 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 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, section 4.10.

The outcome of the CDAF can take many forms. One example is the agreed upon graphical depiction of 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), airports, 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 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 Enhance the capacity and capability of State Volcano Observatories to provide improved pre-eruption information and eruptive source term information for their volcanoes of responsibility – *Planning phase*

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. Although the World Organization of Volcano Observatories (WOVO)[3] has established a recommended colour code scale, some States have developed their own activity alerting code to address unique needs of the State.

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

Observation and forecast 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 aide in verification and validation of volcanic ash cloud forecasts and may be used to produce quantitative volcanic ash forecasts.

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 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

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

application. In particular, remote sensing has not replaced the need for ground-based seismic monitoring of volcanoes, 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.

3.1.4 Scientific research in support of reducing risks from volcanic ash and gas hazards including understanding the impact on aircraft structure, systems, engines and occupants, and the provision of enhanced guidance to operators – *Implementation phase*

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 re-suspended 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:

- Characterizing volcanic plumes at/near the source
- Characterization (including quantitative-based assessments) of volcanic ash and gas clouds in time and space and expressions of the uncertainty associated with the observations and forecasts
- Developing sets of quantitative volcanic ash-cloud data that can be used to validate models and track improvements in forecast accuracy
- Verification of the model forecasts
- 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 effect to the lifetime of aircraft components.

In addition,

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

3.1.5 Review of the IAVW for the provision of improved, consistent, and efficient volcanic hazard information – *Planning phase*

The IAVW was formed in the late 1980s, with the nine VAACs, each with a defined geographic area of responsibility, being implemented in the early 1990s. In December 2016 global coverage of the IAVW was realized. Notwithstanding this progress, the International Air Transport Association (IATA) has 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 MWO's 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.

3.1.6 Transition to all-digital format for all volcanic ash information – *Planning phase*

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[4]). 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 in order to better serve aviation users and decision makers. The visualization of volcanic information must be capable of being displayed on moving maps, cockpit displays, radar screens, etc.

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.

3.1.7 Development of volcanic ash cloud information and forecasts that includes quantitative and probabilistic information – *Planning phase*

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 paves the way for the development

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

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.

3.1.8 Develop other volcanic derived contaminant forecasts, specifically sulphur dioxide, that also includes probabilistic information – *Planning phase*

During volcanic eruptions, a number of 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. These hazardous gases are problematic because aircraft occupants breathe air that originates from outside the aircraft. Outside air is drawn in through the engines, is compressed (i.e., pressurized), then passes through the aircraft's ventilation system. Each gas will likely have different eruption source parameters and atmospheric dispersion properties; therefore, gas clouds may be found coincident with, or wholly separate 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[5] , 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. This effect is not immediate; rather it is long-term and 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.

3.2 AMET Block 1 (2019 - 2024)

The following briefly describes intended changes from 2019 through 2024 in support of operational efficiency and safety.

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

3.2.1 Collaborative decision-making processes – *Maintenance and improvement phase*

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.

3.2.2 Enhance the capacity and capability of State Volcano Observatories to provide improved pre-eruption information and eruptive source term information for their volcanoes of responsibility – *Implementation phase*

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.

In order 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 81 to Annex 3 (with intended applicability in November 2023 but then adjusted by ICAO to November 2024), as well as the proposed Procedures for Air Navigation Services – Meteorology (PANS-MET). The 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 required to disseminate volcanic activity information to their associated VAACs, MWOs, NOTAM office, area control centres and international OPMET.

3.2.3 Improvements in ground-based, in-situ airborne and space-based observing networks – *Maintenance and improvement phase*

Improvements to volcano-monitoring networks, ground-based aerosol 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, and faster scanning from the GOES-16 and GOES-17 Advanced Baseline Imager (ABI) as well as the Himawari-8 satellite will continue to improve the detection of volcanic ash clouds. Continued improvement of sensors on board satellites 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 of real-time observations.

Volcanic ash and gas detectors on aircraft are expected to be introduced in Block 1, with downlink capability to better inform the stakeholders on the ground about actual conditions and thus improve the overall awareness of the volcanic ash cloud.

Given improving technology, there is the potential to have on-board ash detection equipment incorporated into the aircraft avionics suite, 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.

It is important that the objective data retrieved from on-board ash detection be rapidly shared with VAACs so that they can incorporate the data into their subsequent forecasts as inputs to their dispersion models, and used for verification of forecasts.

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.

3.2.4 Scientific research in support of reducing risks from volcanic ash and gas hazards – *Maintenance and improvement phase*

Scientific research in support of reducing risks from volcanic ash and gas hazards will continue in Block 1.

3.2.5 Review of the IAVW for the provision of improved, consistent, and efficient volcanic hazard information – *Planning phase (continued)*

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

3.2.6 Transition to all-digital format for all volcanic ash information – *Implementation phase*

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.

3.2.7 Development of volcanic ash cloud information and forecasts that includes quantitative and probabilistic information – *Planning phase (continued) followed by the implementation phase*

The fifth meeting of ICAO’s Meteorology Panel (June 2021) endorsed the provisions for QVA information to be included in Amendment 81 to Annex 3, as well as the proposed Procedures for Air Navigation Services – Meteorology (PANS-MET). For an initial operating capability (IOC), QVA information 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 24-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[6] volcanic ash clouds and coexist with current VAA/VAG and volcanic ash cloud SIGMETs.

Implementation of QVA information will be done in phases with the first phase being a Recommended Practice for those VAACs in a position to issue QVA information in November 2023. In November 2025 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 and guidance material for users is another important consideration with the introduction of this service.

3.2.8 Development of other volcanic derived contaminant forecasts, specifically sulphur dioxide, that also includes probabilistic information – *Planning phase (continued)*

At the ninth meeting of the World Meteorological Organization (WMO) and International Union of Geodesy and Geophysics' (IUGG) Volcanic Ash Scientific Advisory Group[7], the group recommended three threshold levels of SO_2 for evaluation during a trial to be 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

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

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

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

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.

3.2.9 Integration of volcano and volcanic hazard information into the System Wide Information Management (SWIM) environment – *Planning phase*

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.

3.3 AMET Block 2 (2025 - 2030)

The following briefly describes intended changes from 2025 through 2030 in support of operational efficiency and safety.

3.3.1 Collaborative decision-making processes – *Maintenance and improvement phase*

Improvements in the CDM process for sharing volcano and volcanic hazard information will continue in Block 2 with increased collaboration amongst the SVOs, MWOs, and modelers.

3.3.2 Enhance the capacity and capability of State Volcano Observatories to provide improved pre-eruption information and eruptive source term information for their volcanoes of responsibility – *Maintenance and improvement phase*

Additional enhancements to the information and dissemination provided by the SVOs, including the VONA or its successor, may occur during this timeframe, depending on the successful implementation in Block 1. Increased collaboration amongst the users of SVO information may improve the existing products (i.e., VONA) as well as future SVO products and dissemination. Development and integration of cameras, and other technology will continue to improve source term-information.

3.3.3 Improvements in ground-based, in-situ airborne and space-based observing networks – *Maintenance and improvement phase*

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

Volcanic ash and gas detectors on aircraft are expected to be introduced in Block 2, with downlink capability to better inform the stakeholders on the ground about actual conditions and thus improve the overall awareness of the volcanic ash cloud.

Improvements to airborne radar may allow aircrew to avoid ash clouds at night or that is obscured by meteorological clouds, as well as avoid higher ash concentrations within an ash cloud.

Given improving technology, there is the potential to have on-board ash detection equipment incorporated into the aircraft avionics suite, 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.

It is important that the data retrieved from on-board ash detection be rapidly shared with VAACs so that they can incorporate the data into their subsequent forecasts as inputs to their dispersion models, and used for verification of forecasts.

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.

Next generation satellites will lend to improved observations of volcanic ash clouds and SO_2. In addition, use of artificial intelligence will assist quantitative ash cloud properties and in turn improve quantitative volcanic ash cloud modeling 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 Scientific research in support of reducing risks from volcanic ash and gas hazards – *Maintenance and improvement phase*

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

3.3.5 Review of the IAVW for the provision of improved, consistent, and efficient volcanic hazard information – *Implementation phase*

As alluded at 3.2.5 above, the holistic review of the IAVW described in Block 0 will be completed in Block 2.

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

3.3.6 Transition to all-digital format for all volcanic ash information – *Implementation phase (continued)*

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

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

3.3.7.1 IOC – *Implementation phase (continued)*

QVA information is expected to be elevated to a Standard in November 2026 with the applicability of Amendment 82 to Annex 3. Once QVA is a Standard, the VAA/VAG and volcanic ash cloud SIGMETs for significant volcanic ash clouds will be phased out.

QVA information will still be limited to significant volcanic ash clouds until improvements are made such that QVA can be applied to all ash clouds. Therefore, the VAA/VAG and volcanic ash cloud SIGMETs will continue to be issued for non-significant volcanic ash clouds.

Education and guidance material for users will be updated as needed.

3.3.7.2 FOC – *Planning phase*

Following the completion of the IOC for QVA information, development of the FOC for QVA will commence. The FOC is expected to consider QVA for all ash clouds including re-suspended ash. Further refinement of the identified performance requirements will be developed based on user-needs and ICAO mandates.

3.3.8 Development of other volcanic derived contaminant forecasts, specifically sulphur dioxide, that also includes probabilistic information – *Implementation phase*

Following the anticipated successful trial of SO_2 information and forecasts in Block 1, provisions for a global information and forecast service is expected to be formulated for inclusion in Amendment 82 to Annex 3 with expected applicability in November 2026. Once implemented, attention can be given to the consideration of other volcanic gases during the remainder of Block 2. No specifics are available at this time.

3.3.9 Integration of volcano and volcanic hazard information into the SWIM environment – *Implementation phase*

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.

3.4 AMET Block 3 (2031 - 2036)

3.4.1 Review of the IAVW for the provision of improved, consistent and efficient volcanic hazard information – *Implementation phase (continued)*

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 include inclusion of volcanic ash cloud information in the HWIS mentioned in section 3.3.5.

3.4.2 Development of volcanic ash cloud information and forecasts that includes quantitative and probabilistic information – *Implementation phase*

3.4.2.1 FOC – Implementation phase

QVA information is expected to be provided for all volcanic ash clouds in the FOC. Finer four-dimensional resolution information and forecasts are also expected under the FOC. With the implementation of the FOC, the VAA/VAG and volcanic ash cloud SIGMETs previously issued for non-significant volcanic ash clouds, will be phased out.

3.5 AMET Block 4 (from 2037)

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.

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