



**WORLD METEOROLOGICAL ORGANIZATION
INTERNATIONAL UNION OF GEODESY AND
GEOPHYSICS**



**7th meeting of the
Volcanic Ash Scientific Advisory Group
(VASAG)**

**Vancouver, WA, USA
21-23 August 2017**

FINAL REPORT



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1. OPENING OF THE MEETING

1.1 The seventh meeting of the World Meteorological Organization (WMO) and International Union of Geodesy and Geophysics (IUGG) Volcanic Ash Scientific Advisory Group (VASAG/7) took place at the David A. Johnston Cascades Volcano Observatory of the United States Geological Survey (USGS) in Vancouver, WA, USA from Monday 21 to Wednesday 23 August 2017.

1.2 Dr Larry Mastin (USGS) opened the meeting and extended a warm welcome to all participants. The meeting was also addressed during its opening by Dr Andrew Tupper (Bureau of Meteorology). Dr Mastin and Dr Tupper co-chaired proceedings assisted by Mr Greg Brock, Aeronautical Meteorology Division, WMO. Prof. Alexander Baklanov, World Weather Research Division, WMO also attended the meeting.

1.3 During the opening of the meeting, it was highlighted that the objectives of the VASAG were of direct relevance to supporting the operation and further development of the International Airways Volcano Watch (IAVW), and that there were a number of interfaces of the work of the VASAG with other WMO activities including VAAC Best Practices as well as working groups of the Meteorology Panel (METP) of the International Civil Aviation Organization (ICAO).

1.4 It was noted that VASAG/7 was being held immediately following the 2017 Scientific Assembly of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) (14 to 18 August 2017, Portland, OR, USA) and, as a consequence, that the meeting was benefitting from the attendance of a number of VASAG members and observers who had attended IAVCEI-2017.

1.5 The full list of participants of the VASAG/7 meeting is provided in **Annex 1** to this report.

1.6 The meeting adopted an agenda in the form of an order of business. The agenda included a review of the outcomes of recent meetings/events of direct relevance to the VASAG, a scientific review of advances in source term characterization, remote sensing, quantitative volcanic ash contamination information and other relevant matters such as volcanic ash sulphur dioxide (SO₂) and preparations for upcoming meetings/events. The agenda is provided in **Annex 2** to this report.

2. OUTCOMES OF RECENT MEETINGS AND VASAG/6 ACTIONS STATUS

2.1 *IAVCEI-2017 outcomes*

2.1.1 The VASAG members who had attended the preceding IAVCEI-2017 scientific assembly (see 1.4 above) gave an insight into their impressions of the event and its outcomes. The assembly had covered a wide range of themes relevant to the VASAG, including volcanic plume dynamics, mass eruption rates, and aggregation processes (necessary for source term discussions), eruption forecasting using ground-based and remote sensing techniques, volcanic cloud transport and forecasting, aviation, climate and other impacts of volcanic clouds, crisis management, communication techniques including social media, and other 'traditional' volcanological subjects such as petrology. For many of these topics, progress was regarded as incremental, but there were also some significant new trends.

2.1.2 It was noted that the assembly had considered a very substantial increase in presentations on the use of lightning detection equipment at a range of frequencies to give insights into volcanic cloud processes and as a volcano eruption monitoring tool. Progress on particle aggregation and fall-out processes, on the other hand, appeared to still be hindered by some practical issues. One invited presentation at the assembly had noted that aggregation can dramatically deplete distal fine ash concentration, and that the processes involved are complex. In order to progress this difficult problem, field work and data analysis, laboratory

studies, remote sensing and modelling studies can all assist. Other presentations of interest to VASAG included a system for automatic height estimation using meteorological radar (Icelandic Meteorological Office), a number of presentations on the difficult Alaskan Bogoslof eruption (a submarine eruption resulting in many moist plumes that pose remote sensing issues), inter-comparisons and refinements of volcanic plume models, including 2D and 3D models, and approaches for estimating ash dosages during flight. The use of drones for volcanic monitoring, the growing sophistication of communications techniques within the volcanological community, and the automated processing of near real-time geophysical data were just some of the noteworthy highlights of the assembly.

2.1.3 Overall, the VASAG members who had attended IAVCEI-2017 considered that there was considerable evidence of the 'mainstreaming' of volcanic ash cloud management within the volcanological community, which includes a range of disciplines. It was noted that next IAVCEI scientific assembly would take place in 2021 in Rotorua, New Zealand.

2.2 WMO-IUGG VASAG/6 (2015) actions status

2.2.1 The meeting recalled that the WMO-IUGG VASAG/6 meeting had been held in Anchorage, AK, USA from 23 to 24 October 2015 (Final Report [available here](#)) and that there had been fifteen actions arising (6/1 to 6/15 inclusive).

2.2.2 The meeting undertook a customary review of the follow-up to the actions of the last meeting and was pleased to note that a good deal of progress had been made such that a majority of the VASAG/6 actions could be considered complete. For the small number of VASAG/6 actions that were considered to be ongoing, the meeting was pleased to note that progress was continuing to be made in most areas. For two actions arising from VASAG/6 the meeting agreed that they be cancelled in view of a) a practical inability to progress at the present time (6/9) and b) there no longer being a requirement (6/13).

2.2.3 The meeting formulated an update to the status of the VASAG/6 actions as shown in **Annex 3** to this report.

2.3 WMO VAAC BP/5 (2017) outcomes

2.3.1 The meeting was informed that the fifth WMO Volcanic Ash Advisory Centre "Best Practices" Workshop (VAAC BP/5) had been held in Tokyo, Japan from 7 to 9 June 2017 (Final Report [available here](#)) and that there had been fifteen outcomes. The meeting was given an overview of these outcomes where it was noted that a number were either of interest to the VASAG or required specific support from/action by the VASAG.

2.3.2 The meeting acknowledged that issues concerning aviation colour codes, discernible ash strength of evidence checklists, satellite inter-comparison, quantitative VA contamination information and SO₂, as discussed at the VAAC BP/5 as well as the immediately following ICAO METP working group meetings (see 2.4 below), would be addressed from a scientific perspective during the proceedings of this VASAG/7 meeting.

2.4 ICAO METP WG-MOG/5 (IAVW) and WG-MISD/3 (VASD) outcomes

2.4.1 The meeting was informed that a fifth meeting of the ICAO Meteorology Panel (METP) Working Group on Meteorological Operations Groups (WG-MOG/5) addressing an IAVW work stream and a third meeting of the ICAO METP Working Group on Meteorological Information and Service Development (WG-MISD/3) addressing a volcanic ash sulphur dioxide (VASD) work stream had been held from 12 to 14 June 2017 in Tokyo, Japan, immediately following the VAAC BP/5 workshop (see 2.3 above).

2.4.2 The meeting was given an overview of the outcomes of these working group meetings where it was noted, in particular, that WG-MOG/5 Actions Agreed 5/7 (Aircraft encounter information), 5/10 (aviation colour codes) and 5/12 (quantitative VA contamination information) as well as WG-MISD/3 Action Agreed 3/1 (SO₂ state of science review) had each

requested follow-up action by or support from the VASAG.

2.4.3 As with the foregoing remarks (see 2.3.2 above), it was acknowledged that these specific outcomes of WG-MOG/5 and WG-MISD/3 would be addressed during the proceedings of this VASAG/7 meeting.

3. SOURCE TERM CHARACTERIZATION

3.1 The latest developments in respect of source term characterization were presented and discussed – specifically 1) updates to an eruption source parameter (ESP) database hosted by the British Geological Survey (BGS) and 2) an update on dispersion model initialization within the USA’s NOAA and Cooperative Institute for Climate and Satellites at the University of Maryland (CICS-MD).

3.1.1 In the context of updates to an ESP database hosted by the BGS [[link to presentation](#)], the meeting noted that an existing ESP database had been converted into an SQL database (with query functionality) and that efforts were underway to update the information in the database based on scientific advice from the Global Volcano Model (GVM) ESP working group as well as operational requirements from the VAACs. It was further noted that a statistical evaluation by BGS of volcanic ash advisories (VAA) issued by the VAACs had commenced in order to validate the information in the database, better understand trends in eruptive activity and investigate the relation between parameters defined by analysis of deposits, historical information and requirements of the VAACs. It was indicated that since the database had been updated, the online platform based around the current [LaMEVE database](#)¹ would take about 2 weeks to build. The VASAG greatly appreciated the leadership of BGS in the maintenance and further development of the ESP database, and also noted the additional best-practice insights to be gained through analysis of the VAAs. It was recognized that since the last VASAG meeting held in 2015 there was now much greater awareness and use of the ESP database by the VAACs, both in an operational sense (i.e. response to actual eruptions) and in a non-operational sense (e.g. for running simulations). The meeting welcomed news that the ESP database would continue to be enhanced by BGS consistent with Action 6/6 of the last meeting (see **Annex 3** to this report) with inputs from the VASAG and the VAACs.

3.1.2 In the context of an update on dispersion model initialization within NOAA and CICS-MD [[link to presentation](#)], the meeting was apprised of the current NOAA operational initialization and potential future initialization methodologies intended to reduce the initialization/source term uncertainty as well as a summary of ongoing research on model initialization from the perspectives of data insertion and inverse modelling. The VASAG remarked that the NOAA and CICS-MD progress was a good illustration of how to turn science into operations and a demonstration of how such developments can serve to improve the level of and opportunities for collaboration across the scientific and operational communities. In addition, it was considered that, 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 appeared to offer the optimum approach to the detection and parameterization of volcanic eruptions and the observation and forecasting of volcanic ash clouds. The role of the VAAC forecaster in the determination of which methodologies to use and when was identified as a key consideration and one that could be best supported through local personnel training or other awareness activities (e.g. workshops) to ensure an appropriate level of understanding of the trade-offs or limitations that can often exist between the various methodologies.

¹ Large Magnitude Explosive Volcanic Eruptions database of the [Volcano Global Risk Identification and Analysis \(VOGPIPA\) Project](#) endorsed by IAVCEI.

4. REMOTE SENSING

4.1 The latest developments in respect of remote sensing were presented and discussed. It was noted that VAAC BP/5 (see 2.3 above) had considered two related matters concerning discernible ash strength of evidence checklists and satellite inter-comparison activities.

4.1.1 In respect of the latest remote sensing developments, an overview was provided [[link to presentation](#)] of the new and upcoming operational capabilities of satellites (including GOES-16 and Himawari-8), space-borne lidar research missions, new satellite missions relevant to SO₂, preliminary impacts and challenges of the next generation of satellites on operations, and other relevant recent research highlights. While welcoming the paradigm shift in the spatial and temporal resolution capabilities of the latest generation of satellite systems (GOES-16 and Himawari-8), the VASAG expressed a keen desire to see the temporal resolution of GOES-16 come into alignment with Meteosat 3rd Generation and Himawari-8 of 10-minute interval full disk imagery for volcanic ash clouds and gases detection. In a related matter, it was acknowledged that this paradigm shift in satellite capability – at the full-disk and regional scales – had corresponded to significant increases in data volumes. The meeting recognized that the ‘Big Data’ challenge posed by such advances would require some form of automated data fusion research effort to ensure sufficient and appropriate handling of the data – not just in a volcanological sense but also a broader meteorological sense.

4.1.2 In respect of discernible ash strength of evidence checklists, an overview of ‘tick-box style’ and ‘pyramid style’ checklists currently under development and trial within the VAACs was given [as per the [presentation](#) given at VAAC BP/5]. Consistent with discussions at the VAAC BP/5, the VASAG expressed a view that the checklists could serve as a valuable tool for VAAC forecasters when there is a lack of (or ambiguity in) volcanic ash evidence/reports and that, as a quality management system (QMS) best practice, the checklists would add credibility to the VAACs’ decisions and output. Notwithstanding, the VASAG noted already that a refinement of certain aspects of the checklists could be merited – such as the weight given to anomalous cloud development over volcanoes, and volcanic cloud-like multi-spectral signatures (for example, in moist eruptive clouds). The meeting agreed that these refinements, and others, should be fed back to the VAACs in line with a request arising from VAAC BP/5. To this end, the meeting agreed that Dr Pavolonis would collate feedback from the VASAG on the scientific perspectives of the discernible ash strength of evidence checklists and to provide feedback to VAACs Darwin and Tokyo (as the VAAC BP activity leads). **VASAG/7**

Action Agreed 7/1

4.1.3 In respect of satellite inter-comparison and as alluded to above (4.1.1), it was noted the newer generation of satellite such as GOES-16 and Himawari-8 were leading to a step-change/paradigm shift in detection capability (and hence VAAC capability) over their predecessors – for example, improved detection of small eruptions and small areas of volcanic ash, better identification of volcanic ash under poor observing conditions, and improved detection of distal areas of volcanic ash as well as being able to track volcanic ash in the atmosphere for longer. Primary conclusions from satellite inter-comparison activities appeared to reflect that the accuracy of satellite-based volcanic ash products was a strong function of the retrieval methodology, satellite sensor and scene complexity; and, moreover, that additional analyses would be required to better understand differences and to provide a consensus outlook on the end-to-end capabilities for operational applications. The meeting noted with appreciation that a WMO SCOPE-Nowcasting initiative² was progressing these issues and considered that more VAACs should be informed of and involved in the initiative where feasible.

² Sustained, Coordinated Processing of Environmental Satellite Data for Nowcasting ([website](#)).

5. QUANTITATIVE VOLCANIC ASH CONTAMINATION INFORMATION AND LONG-RANGE FORECASTS

5.1 The latest developments in respect of quantitative volcanic ash (VA) contamination information and long range forecasts were discussed. It was noted that VAAC BP/5 and WG-MOG/5 had both considered these issues where it had been determined, essentially, that in view of a) the recent scientific and technological advancement in volcanic ash observation and forecasting through the increased availability of multi-spectral techniques and improved algorithms, b) the recent (May 2017) public announcement by Rolls-Royce of their engine-type tolerability to volcanic ash dosage, and c) the 'richer' data requirements associated with the future global air traffic management system, the future IAVW service provision arrangements would increasingly require quantitative volcanic ash contamination information (including ash concentration forecasts and forecast confidence level assessments/expressions of uncertainty) covering an extended, longer-range forecast period (i.e. beyond the current T+18 hours forecast).

5.2 The meeting noted that the WG-MOG/5 (IAVW) had formulated Action Agreed 5/12 which had, *inter alia*, invited the VASAG and ICCAIA³ to further review the state of the science related to the global development and use of quantitative volcanic ash contamination information and forecasts in advance of the next WG-MOG (IAVW) meeting (2018).

5.3 The VASAG expressed its strong willingness to assist the WG-MOG (IAVW) to progress this issue from a scientific perspective. The VASAG noted that one of the major challenges to this issue concerned how to address uncertainty. Given that uncertainties exist when an eruption is occurring and when volcanic ash is in the atmosphere, finding an appropriate means to represent the uncertainty with integrity (for example through improvements to eruption source parameterization) and in a manner that is meaningful to users was considered to be a key issue. It was highlighted that uncertainty would prevail to varying degrees throughout the IAVW service delivery chain, starting at the level of the State volcano observatories and their ability to adequately convey the confidence or uncertainty associated with an erupting volcano (for example, in eruptive cloud composition, which is critical to estimation of fine ash content and post-eruptive cloud processes). This said, it was accepted that the continued advancement of volcanic monitoring and its underlying science, remote sensing techniques, numerical weather prediction and atmospheric transport dispersion modelling, amongst others, should lead to a narrowing of the uncertainty range and an increase in confidence.

5.4 In addition to the foregoing, the meeting was reminded of related discussions that had taken place during an Inputs and Outputs (Ins and Outs) VAAC Modelling Workshop in November 2012 and the progression of this work subsequently through the VAAC BP workshops, including most recently at VAAC BP/4 (2016) where investigations on numerical weather prediction errors/performance relevant to volcanic ash modelling and VAAC 'Ins and Outs' Modelling tables were being progressed ([VAAC BP/4 final report](#), outcome VW4-O-03 refers). In the context of supplementary volcanic ash products (concentration charts) that were available in the ICAO EUR/NAT Region during and subsequent to the eruption of Eyjafjallajökull in Iceland in 2010, the meeting was also reminded of the position of ICAO's International Volcanic Ash Task Force (IVATF)⁴ which, at its third meeting in February 2012, had recommended that work on developing modelled volcanic ash concentrations information for users be *discontinued* in view of (at the time) a lack of a global user requirement, the spread of uncertainties in volcanic ash observing and forecasting, and noting the scientific and operational progress in enhancing volcanic ash advisory centre (VAAC) best practices ([IVATF/3 Recommendation 3/11](#) refers).

³ International Coordinating Council of Aerospace Industries Associations ([website](#)).

⁴ The IVATF ([website](#)) was established by ICAO in response to disruption to air traffic caused by the volcanic eruptions in Iceland in 2010 and to support the efforts of the (then) ICAO International Airways Volcano Watch Operations Group (IAVWOPSG). The IVATF held four meetings between 2010 and 2012.

5.5 Taking the foregoing into account and noting the expressed request of the WG-MOG/5 (IAVW) for the VASAG and ICCAIA to undertake a further review of the state of the science related to the global development and use of quantitative volcanic ash contamination information and long-range forecasts, the meeting agreed that Dr Mastin, assisted by other members and observers, would lead the VASAG follow-up of METP WG-MOG/5 (IAVW) Action Agreed 5/12. **VASAG/7 Action Agreed 7/2** It was noted that this follow-up would likely result in a study note (or similar) for the next WG-MOG (IAVW) meeting.

5.6 To supplement the foregoing discussion, the meeting was provided with information on a volcanic ash dosage calculator [[link](#) to presentation] under development by the University of Reading in the UK. The VASAG was informed that, as a project funded under the UK's NERC Environmental Risks to Infrastructure Innovation programme and partnered by the UK Civil Aviation Authority and British Airways, the goal of the project was to deliver a proof-of-concept interactive, educational web-tool for calculating volcanic ash dosage on air routes and enabling a discussion on uncertainty with operators and regulators. It was noted that the tool has been designed to understand how operators and regulators make decisions when presented with uncertainty information and was not designed to be an operational tool. Recognizing the synergy with the foregoing discussion and potential future developments under the project, the VASAG warmly welcomed the information provided.

6. AVIATION COLOUR CODES AND THE VONA

6.1 The latest developments in respect of volcano level of alert colour codes for aviation ("aviation colour codes") and the Volcano Observatory Notice for Aviation (VONA) were discussed. It was noted that VAAC BP/5 and WG-MOG/5 (IAVW) had both considered this issue and had determined, essentially, that there was support to recommend the removal of the aviation colour code entry from the volcanic ash advisory template (to prevent possible confusion amongst operators arising from combining into a single message the conditions at a volcano as described by the colour code with the hazards associated with the dispersing cloud as described by the VAA) and that the VONA should be proposed to be elevated to the status of a recommended practice and (eventually) a standard within ICAO Annex 3 provisions.

6.2 In this connection, the meeting noted that WG-MOG/5 (IAVW) had formulated Action Agreed 5/10 tasking an ad hoc group (including the VASAG) to develop a corresponding proposed amendment to ICAO Annex 3 – *Meteorological Service for International Air Navigation* to remove the aviation colour code from the VAA and to elevate the status of the VONA plus the supporting guidance material for, say, the *Handbook on the IAVW – Operational Procedures and Contact List* (ICAO Doc 9766). The meeting agreed that Dr Schneider (for Ms Guffanti), assisted by Dr Engwell (for Dr Witham) and Dr Barsotti, would provide the VASAG support to the follow-up of METP WG-MOG/5 (IAVW) Action Agreed 5/10. **VASAG/7 Action Agreed 7/3**

6.3 While expressing general support for the approach being taken by the WG-MOG (IAVW) to address issues with the aviation colour codes within the VAA and the elevating of the status of the VONA, as described at 6.1 and 6.2 above, the meeting considered some of the many challenges that exist in the harmonized delivery of the aviation colour code and VONA by volcano observatories in some parts of the world. The VASAG acknowledged, for example, prevailing challenges within volunteer science organizations such as the World Organization for Volcano Observatories (WOVO), a Commission of IAVCEI, to build capacity amongst volcano observatories. In this regard, the meeting expressed some frustration at the inability to progress related themes through the GEO Secretariat hosted at WMO (as discussed earlier as follow-up to VASAG/6 Action Agreed 6/9) as well as the shortcomings that exist at a national level in some countries between national civil aviation administrations and the volcanological community. The meeting noted that a recent assessment through the [Global Volcano Model](#) project supported the view that there remains a wide variation in volcano observatories capabilities and governance, with resulting impacts on the ability of States to meet the relevant ICAO provisions, including Annex 3, 3.6.

6.4 In view of the foregoing, the meeting agreed that ICAO should be requested (through Mr Romero as the ICAO ex-officio VASAG member) to undertake efforts to remind ICAO Contracting States with active or potentially active volcanoes of their State volcano observatory responsibilities under ICAO Annex 3, 3.6 and the supporting operational procedures contained within ICAO Doc 9766, particularly in the context of the arrangements for the monitoring of such volcanoes and the preparation, dissemination and communication of the VONA. **VASAG/7 Action Agreed 7/4** The VASAG acknowledged that any follow-up by ICAO in this regard, such as by way of a State letter, may, in the first instance, require coordination with the IAVW work stream of the METP WG-MOG (IAVW). The VASAG also expressed that, in order to maximize the potential for in-country cooperation in response to such future ICAO correspondence, both IUGG and WMO could assist in the communication/coordination outreach.

7. AIRCRAFT ENCOUNTERS DATABASE

7.1 The meeting was apprised of a discussion that had taken place during WG-MOG/5 (IAVW) concerning the improvement of information on aircraft encounters with volcanic ash. Specifically, it had been highlighted that an existing database of encounters only contained information up to August 2008 while work undertaken by researchers at DLR (German Aerospace Centre) and the USGS continued to investigate aircraft encounters with volcanic ash up to 2016, with an approximate doubling in the number of encounters recorded in the database (to some 253 incidents, with many incidents occurring during 2010, in particular in the ICAO EUR/NAT Region). In addition, it was highlighted that the DLR and USGS research had led to proposed modifications to the encounter severity index which took into account the effects of the exposure to volcanic ash of aircraft occupants as well as some additional criteria concerning the effects on the aircraft and its systems.

7.2 In this connection, it was noted that WG-MOG/5 (IAVW) had formulated Action Agreed 5/7 tasking the VASAG undertake a review a) of the DLR and USGS findings with a view to developing a collaborative update of Appendix F to the *Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds* (ICAO Doc 9691) and b) the proposed modifications to the severity index in view of its potential inclusion in Appendix F to Doc 9691.

7.3 The meeting undertook an initial review of the proposed modifications to the severity index. While some proposed modifications appeared suitably sound from a scientific perspective, the meeting considered that other modifications, particularly those relating to health impacts on aircraft occupants caused volcanic ash/gases exposure, required greater consideration and that such consideration may lie beyond the expertise (and remit) of the VASAG.

7.4 In respect of the database of aircraft encounters with volcanic ash and with the potential improvements to the severity index, the meeting identified a link with the advancement of remote sensing capabilities. As the remote sensing of volcanic ash clouds and gases continues to improve, such as through advances in satellite detection, the meeting considered that it should be possible to more readily identify those situations where SO₂, say, has been present. With this improved capability and with knowledge of which aircraft were operating in or near to the area of interest, the meeting believed that it should be possible to further increase the number of records in the aircraft encounters database.

7.5 In view of the foregoing, the meeting agreed that Dr Schneider (for Ms Guffanti), assisted by other members, would lead the VASAG effort regarding changes to Appendix F of ICAO Doc. 9691 with new data on aircraft encounters and any agreed-upon modifications of the encounter severity index, as follow-up to METP WG-MOG/5 (IAVW) Action Agreed 5/7. **VASAG/7 Action Agreed 7/5**

8. SO₂ AND OTHER TOXIC GASES

8.1 The meeting was apprised of discussions that had taken place during VAAC BP/5 and WG-MISD/3 (VASD) concerning sulphur dioxide (SO₂), where it had been noted that most but not all VAACs presently have SO₂ detection, monitoring and/or predication capabilities but that where any capability does exist it is mainly in the research/non-operational area. Moreover, the WG-MISD/3 (VASD) meeting had also briefly discussed volcanic eruptions over the past 25 years or so that were known to have ejected considerable amounts of SO₂ into the troposphere and lower stratosphere⁵ as well as aviation encounters with SO₂ and its impact on the performance of the aircraft and the health of the aircraft occupants. While there appeared to be some existing SO₂ health exposure guidelines available – e.g. World Health Organization (WHO), USA FAA Civil Aerospace Medical Institute (CAMI) – these appeared to be mainly associated with the occupational health hazard of SO₂ exposure at ground level. There appeared to be no known guidance on the impacts of encountering SO₂ at altitude on an aircraft and its occupants.

8.2 In this connection it was noted that WG-MISD/3 (VASD) had formulated Action Agreed 3/1 tasking an ad hoc group in coordination with VASAG to further review the state of science related to volcanic ash SO₂ that poses a threat to aircraft occupants as well as investigate the possible impacts to the aircraft.

8.3 The VASAG considered that there was, to some extent, a lack of clarity in the request emanating from the WG-MISD/3 (VASD), i.e. what was it *exactly* that the VASAG was now being asked to support given, in particular, that a significant amount of scientific advice on the SO₂ issue had already been given to predecessor ICAO groups including the International Volcanic Ash Task Force (IAVTF) in 2010-2012 and more recently the METP WG-MISD in 2016⁶. Notwithstanding, the meeting did acknowledge that some research was now emerging (e.g. Cranfield University in the UK and DLR in Germany) that may yield complementary scientific advice to support the operational concerns surrounding SO₂. Hence, the VASAG agreed that, to the extent practicable, it would assist ICAO in undertaking the SO₂ 'state of science' review called for by METP WG-MISD/3 (VASD) Action Agreed 3/1. **VASAG/7 Action Agreed 7/6**

8.4 In concluding its consideration of SO₂ impacts and aviation's related needs, the meeting drew potential analogies with national practices for the management of toxic chemicals at ground level through civil contingency warning/notification systems.

9. OTHER IAVW-RELEVANT SCIENTIFIC DEVELOPMENTS, INCLUDING THE WMO GLOBAL ATMOSPHERE WATCH (GAW)

9.1 To supplement the foregoing, the meeting considered other IAVW-relevant scientific developments which included the WMO Global Atmosphere Watch (GAW).

9.2 An overview [[link](#) to presentation] of the GAW mission, stations network and governance structure was given as well as specific components including the GAW SIS⁷, GALION⁸ and GAW near real-time data access. Information on one of the eight GAW Scientific Advisory Groups (SAG) was given, namely the GAW SAG on Modelling Applications (SAG-APPs) which had been established by the WMO Congress in 2016 to enhance exchanges between the GAW observational community, the modelling communities and other end-users of atmospheric composition data. An outline of several volcanic ash-related data assimilation activities was given including a NOAA-supported activity to utilize GOES-16 data to improve volcanic ash forecasts.

⁵ Pinatubo (1991), Hekla (2000), Grimsvötn (2011) and Nabro (2011).

⁶ ICAO METP WG-MISD/2, 29 April 2016, Buenos Aires, Argentina, Study Notes 4, 10 and 11 refer.

⁷ Global Atmosphere Watch Station Information System (GAW SIS). Information available at: <http://gaw.empa.ch/gawsis/>.

⁸ GAW Aerosol Lidar Observation Network

9.3 Based on the foregoing the meeting acknowledged potential opportunities for relevant GAW SAGs and the VASAG to work more collaboratively going forwards in areas of mutual interest.

10. FUTURE EVENTS

10.1 AeroMetSci-2017

10.1.1 The meeting was apprised that WMO was convening an Aeronautical Meteorology Scientific Conference (AeroMetSci-2017) from 6 to 10 November 2017 at Météo-France in Toulouse, France. The meeting was informed that the objective of the conference was to inform WMO Members, constituent bodies and others of the strategic direction for scientific research in support of aviation over the coming 10-15 years or more.

10.1.2 The meeting noted that an announcement and call for papers had been issued by WMO in July 2017 ([available here](#)), that a conference website had been set up ([available here](#)) and that a scientific committee was in the process of receiving abstracts and selecting papers and posters for presentation based on the following three thematic areas of the conference:

- 1) *Science underpinning meteorological observations, forecasts, advisories and warnings;*
- 2) *Integration, use cases, fitness for purpose and service delivery;*
- 3) *Impacts of climate change and variability on aviation operations and associated science requirements.*

10.1.3 The meeting was informed of the topics likely to be addressed during the conference (available via the conference website). It was noted that the topic list was quite broad but with little or no apparent attention on volcanic ash/gases. The meeting was informed that this was, to some extent, intentional given the prominence and role of the International Workshops on Volcanic Ash in such matters (see 10.2 below). This said, it was possible that some volcanic ash-related issues may be presented at the conference based on the abstracts received.

10.1.4 The VASAG was encouraged to visit the website, to review the announcement and concept note, and to consider participation through respective administrations.

10.2 IWVA/8 planning

10.2.1 The meeting recalled that International Workshops on Volcanic Ash (IWVA) had been convened by WMO in collaboration with ICAO typically on a 3 or 4 year cycle to foster scientific and technological advancement in volcanic ash-related issues of importance to aviation. It was noted that the previous workshop (IWVA/7) had been held in Anchorage, AK, USA in October 2015 (Final report [available here](#)) immediately prior to VASAG/6. It was further noted that the IWVA workshops were self-funded by participants (i.e. no WMO financial support) and that local arrangements were to be provided by the host country.

10.2.2 Given the breadth of the continuing work being undertaken by the meteorological and volcanological communities in support of the IAVW, as highlighted during this meeting, and acknowledging the strategic direction and evolving needs of aviation in support of ICAO's vision for a globally interoperable, harmonized air traffic management system of the future, the VASAG considered that there was a sufficiently strong justification for convening an Eighth International Workshop on Volcanic Ash (IWVA/8) in the near future.

10.2.3 Appreciating the upcoming AeroMetSci-2017 in November 2017 (see 10.1 above) and the Sixteenth Session of the Commission for Aeronautical Meteorology (CAeM-16) and Technical Conference in July 2018, as well as other relevant considerations on the WMO and

ICAO sides, the meeting suggested that the earliest realistic opportunity to convene IWVA/8 would be in 2019. It was noted that to maximize interest and secure appropriate participation it may be desirable to convene IWVA/8 back-to-back with another relevant event. In this connection, it was noted that the IUGG General Assembly was expected to be held in Montreal, Canada from 8 to 19 July 2019 which could generate significant interest amongst not only the volcanological community but also the aviation community given the host city.

10.2.4 The meeting agreed that Dr Mastin and Dr Tupper, in coordination with the Secretariat, would develop a concept note⁹ for IWVA/8 (2019) for consultation with the wider VASAG membership. **VASAG/7 Action Agreed 7/7**

11. VASAG TERMS OF REFERENCE

11.1 The VASAG members in attendance (closed session) undertook a review of the VASAG terms of reference and succession planning needs. It was determined that, while there were no immediate changes required to the terms of reference of the group, there was a need to update the composition of the VASAG in view of the recent retirement of Ms Marianne Guffanti from the USGS (see 15.1 below). In this regard, an official communication from the Permanent Representative of the United States of America with WMO would be required.

11.2 The VASAG members in attendance were apprised that, given the proximity of the 16th Session of the WMO Commission for Aeronautical Meteorology (CAeM-16) in July 2018, a review of the CAeM expert teams and other related groups including VASAG was probable over the coming 6 to 12 months to ensure that the expert group arrangements suitably reflect and support the required work heading into the next four-year period of the CAeM.

11.3 The VASAG members in attendance noted that regardless of the future decisions that may or may not be taken on the working arrangements of the VASAG, ensuring continuity in expertise and continuation of the volcanic ash work in support of aviation from a WMO and IUGG perspective was important. Ensuring appropriate geographic representation and gender balance were also noted.

11.4 The VASAG members in attendance considered a proposal to add a GAW SAG-APP representative on the VASAG in an *ex-officio* capacity. While welcoming the interest, the VASAG members in attendance recommended that a decision on such matters be deferred until such time as there is clarity on the future working arrangements under the CAeM, as described above (11.2).

12. REVIEW OF ACTIONS ARISING FROM VASAG/7

The meeting undertook a review of the actions arising from the VASAG/7 meeting and agreed to their content, as given in **Annex 4** to this report.

13. ANY OTHER BUSINESS

Nil.

14. DATE AND PLACE OF NEXT MEETING

14.1 Notwithstanding the remarks at 11.2 above and recognizing the benefits to be derived from convening VASAG meetings usually on an annual basis, the VASAG gave due consideration of where and when to convene its next meeting, namely VASAG/8.

⁹ The concept note may address the workshop's theme and expected outcome, intended audience and expected level of participation, format, timing, duration and location plus co-sponsorship opportunities.

14.2 In this connection, the VASAG was informed that during the VAAC BP/5 workshop in June 2017 the VAACs had considered that, if practicable, it could be mutually beneficial to convene their next workshop or other future workshop in concert with a VASAG meeting (e.g. back-to-back, overlapping or in parallel)¹⁰. The VASAG was informed that the next VAAC BP workshop was (subject to confirmation) likely to be convened in New Zealand in Q4 2018.

14.3 Given the recent and upcoming scientific and technological advances and their direct relevance to the operations of all nine VAACs and the fact that no joint meeting/workshop had taken place previously, the VASAG agreed that there would be merit in convening a future meeting conjointly with a VAAC BP workshop. Moreover, it was expressed that convening in the Q4 2018 timeframe could be suitable given the intention to convene IWVA/8 in the 2019 timeframe (see 10.2 above).

14.4 The VASAG expressed that an early decision (preferably before year-end) on where and when VASAG/8 would be held was desirable for planning purposes together with an indication of the extent of WMO funding that may be available to support members' attendance. The VASAG agreed that the Secretariat should undertake the associated follow-up. **VASAG/7 Action Agreed 7/8**

15. CLOSURE OF THE MEETING

15.1 The meeting expressed its sincere appreciation to Ms Marianne Guffanti who, after many years of dedicated work in this field and tremendous support to the activities both of WMO and ICAO, had recently retired from the USGS and was therefore relinquishing her role as a member of the VASAG. The meeting also expressed its sincere appreciation to Dr Gelsomina Pappalardo and Dr Fred Prata for their prior contributions to the work of the VASAG.

15.2 After the customary exchange of courtesies, the meeting closed at 1300 hours on 23 August 2017.

¹⁰ WMO VAAC BP/5 (2017) Final Report ([available here](#)), 10.3.2 refers.

LIST OF PARTICIPANTS

1. VASAG MEMBERS

COUNTRY	NAME	E-MAIL
AUSTRALIA	TUPPER, Andrew (co-chair)	Andrew.Tupper@bom.gov.au
USA	MASTIN, Larry (co-chair)	lgmastin@usgs.gov
GERMANY	SCHLAGER, Hans	hans.schlager@dlr.de
UK	LISK, Ian	ian.lisk@metoffice.gov.uk
UK	WITHAM, Claire	claire.witham@metoffice.gov.uk
USA	PAVOLONIS, Mike	Mike.Pavolonis@noaa.gov
USA	GUFFANTI, Marianne	guffanti@usgs.gov

Note. — The following VASAG members joined the meeting via teleconference for the items on eruption source parameters and quantitative volcanic ash forecasts and long-range forecasts: BARSOTTI, Sara (Iceland); FOLCH, Arnau (Spain); and NERI, Augusto (Italy).

2. OTHERS PARTICIPANTS / OBSERVERS

COUNTRY / ORGANIZATION	NAME	E-MAIL
British Geological Survey	ENGWELL, Samantha L.	sameng@bgs.ac.uk
Japan Meteorological Agency (JMA)	IGARASHI, Yohko	y_igarashi@met.kishou.go.jp
NOAA Air Resources Laboratory	STUNDER, Barbara	barbara.stunder@noaa.gov
University of Bristol	THOMAS, Helen	Helen.Thomas@bristol.ac.uk
University of Reading	PRATA, Andrew	a.t.prata@reading.ac.uk
USGS	SCHNEIDER, David	djschneider@usgs.gov

3. WMO SECRETARIAT

TITLE	NAME	E-MAIL
SO/AEM	BROCK, Greg	gbrock@wmo.int
SO/WWR	BAKLANOV, Alexander	abaklanov@wmo.int

AGENDA (ORDER OF BUSINESS)

Note. — The actual running order of the meeting varied slightly to that shown below to allow flexibility. All agenda items were nonetheless addressed by the close of the meeting.

MONDAY 21 AUGUST		TUESDAY 22 AUGUST		WEDNESDAY 23 AUGUST	
		0830	Remote sensing (VAAC BP/5 request) ➤ Latest developments introduction ➤ Discernible ash and strength of evidence checklists ➤ Satellite inter-comparison	0830	Future events ➤ AeroMetSci-2017 ➤ IWVA/8 planning VASAG terms of reference review and succession planning needs ¹¹
		1000	<i>Break</i>	1000	<i>Break</i>
		1015	Quantitative VA contamination information and long-range forecasts (WG-MOG/5 IAVW request) ➤ Drivers for change and future requirements (including confidence) ➤ Supporting science review (including WMO VAAC BP modelling Ins and Outs table) ➤ Discussion of IVATF recommendation to discontinue work on concentration charts.	1015	Review of actions arising from VASAG/7 Next VASAG meeting Any other business
		1145	Summary	1245	Closing remarks
1330	<i>Registration</i>	1200	<i>Lunch</i>	1300	<i>Close of Day 3</i>
1400	Welcome, opening remarks Objectives, working arrangements Group introductions General discussion of IAVCEI-2017 outcomes.	1330	Aviation colour codes (WG-MOG/5 IAVW request) ➤ Latest developments introduction ➤ VONA as an ICAO recommended practice Aircraft encounters database (WG-MOG/5 IAVW request) ➤ Review of encounter severity index and any updates to ICAO Doc 9691		
1445	Review status of follow-up to VASAG/6 (2015) actions Review relevant outcomes of WMO VAAC BP/5, ICAO METP WG-MOG/5 (IAVW) and WG-MISD/3 (VASD)				
1530	<i>Break</i>	1500	<i>Break</i>		
1545	Source term characterization latest developments	1515	SO ₂ and other toxic gases (WG-MISD/3 VASD request in part) ➤ Drivers and future requirements ➤ Supporting science review ➤ Convergence with management of toxic gases on ground Other IAVW-relevant scientific developments, including the WMO Global Atmosphere Watch (GAW)		
1715	Summary	1645	Summary		
1730	<i>Close of Day 1</i>	1700	<i>Close of Day 2</i>		

¹¹ Closed session (VASAG members only)

**STATUS OF FOLLOW-UP TO
ACTIONS ARISING FROM WMO-IUGG VASAG/6 (2015)**

Action No.	Description	Status (as at VASAG/7)
6/1	WMO SCOPE-NOWCASTING update VASAG's continued strong support for this project as an essential component in the science to services system should be expressed to the SCOPE-NOWCASTING panel (through Dr Pavlonis)	Complete <i>Note: To be included as a standing agenda item of future VASAG given SCOPE-Nowcasting group has been established by WMO.</i>
6/2	Relevant publications VASAG (through Ms Guffanti) to contribute as required to the updated IAVCEI guidelines here and promote conformance to these guidelines.	Ongoing <i>Note: Modified to Dr Tupper lead.</i>
6/3	ICAO mechanisms and role of VASAG VASAG reaffirms its commitment to providing and supporting the METP with expert advice on volcanic ash issues. Co-chairs to convey this to the METP chair (completed).	Complete
6/4	Aircraft encounters with ash from Kelud The ICAO METP to be asked to promote the importance of sharing the outcomes of VA-related investigations with the science community to facilitate more focussed research (Action: Dr Tupper / Ms Guffanti).	Complete
6/5	Aircraft encounters with ash from Kelud (continued) Coordinate, through Dr Tupper, Dr Pavlonis, Dr Mastin, the further investigation of the Kelud encounter, and report back to the ICAO METP.	Complete
6/6	Global volcano ESP database for restless volcanoes Encourage BGS to continue to work on making the web-based version of the ESP database available for VASAG review as soon as possible (Dr Mastin).	Ongoing <i>Note: Refer to paragraph 3.1.1 of the VASAG/7 report.</i>
6/7	Outreach Further development of graphically-based information brochures and the website to underpin and complement the priorities and themes of the 3-yearly science workshops (Secretariat, with inputs from VASAG members).	Ongoing <i>Note: Possible linkage with GAW SAG-Aerosol annual bulletin articles.</i>
6/8	Next generation geostationary satellite applications Mr Lisk to liaise with the VAACs at the next VAAC Best Practice meeting to discuss how VAAC provider States can best be supported in undertaking their training opportunities.	Complete
6/9	'Volcano Desk' at WMO WMO Secretariat, with Mr Lisk, to make contact with the GEO Secretariat to explore options for future engagement.	Cancelled <i>Note: Unable to progress at this time.</i>
6/10	Use of radar data for volcanic ash applications training Icelandic Meteorological Office, through Dr Barsotti and Dr Karlsdóttir, to consider potential approaches to radar	Ongoing <i>Note: Possible linkage with workshop at Cities on Volcanoes (COV/10)</i>

Action No.	Description	Status (as at VASAG/7)
	training modules, in collaboration with other relevant countries and with CAeM ET-ETC.	<i>in 2018.</i>
6/11	<p>Appropriate methods for assessing aviation hazards and risk</p> <p>The VASAG agreed to, under the leadership of the co-chairs, develop an information paper to present at the next meeting of the METP WG-MOG in 2016, based largely on the information provided to VASAG and relevant outcomes (including 'Ins and Outs' modelling tables update, other relevant comparison exercise outcomes, and so on) arising from the seventh International Volcanic Ash Science Workshop in Alaska in October 2015.</p>	Complete
6/12	<p>SO2 monitoring</p> <p>The VASAG (Dr Witham leading, subject to confirmation) agreed to coordinate the gathering of hazardous gases health impact data and science to (potential) service capability assessments to support the delivery of a paper to the 2016 meeting of the ICAO METP WG-MISD (date to be advised later).</p>	Complete
6/13	<p>Future Space-based payloads</p> <p>VASAG (Dr Pavolonis leading) to coordinate the development of a paper to be submitted to the US National Academies' decadal review.</p>	Cancelled <i>Note: Overtaken by events. No longer required.</i>
6/14	<p>IAVW Roadmap</p> <p>Co-chairs to ensure that sufficient discussion time is allocated at VASAG/7 to review the ICAO METP IAVW and SO2 job cards and the ICAO IAVW Roadmap and to consider the opportunities to map these plans to the on-going and future science and research activities in preparation for a more detailed discussion at the next VASAG meeting. Co-chairs to raise any other related business for discussion between meetings as required.</p>	Complete <i>Note: Directly or indirectly forms part of the discussions of VASAG/7.</i>
6/15	<p>Date and place of next meeting</p> <p>a) Co-chairs to discuss proposed meeting arrangements with WMO Secretariat;</p> <p>b) VASAG (Ms Guffanti) to contact other Scientific Organizing Committees to discuss possible relevant sessions;</p> <p>c) Consideration be given to updating the explanatory material on the IAVW previously prepared for SVOs (Dr Tupper).</p>	Complete

ACTIONS ARISING FROM WMO-IUGG VASAG/7 (2017)

No.	Description	Lead	Deadline
7/1	<p>Strength of Evidence Checklists [Refer to 4.1.2] Agreement that Dr Pavolonis would collate feedback from the VASAG on the scientific perspectives of the discernible ash strength of evidence checklists and to provide feedback to VAACs Darwin and Tokyo (as the VAAC BP activity leads).</p>	Pavolonis	31 Dec. 2017
7/2	<p>Quantitative VA contamination information and long-range forecasts [Refer to 5.5] Agreement that Dr Mastin, assisted by other members and observers, would lead the VASAG follow-up of METP WG-MOG/5 (IAVW) Action Agreed 5/12.</p> <p><i>Note. — This follow-up will entail leading a state of science review (by VASAG and ICCAIA) on the global development and use of quantitative volcanic ash contamination information and forecasts with a study note (or similar) to be prepared for the next WG-MOG (IAVW) in 2018.</i></p>	Mastin	30 June 2018
7/3	<p>Aviation colour codes and VONA [Refer to 6.2] Agreement that Dr Schneider (for Ms Guffanti), assisted by Dr Engwell (for Dr Witham) and Dr Barsotti, would provide the VASAG support to the follow-up of METP WG-MOG/5 (IAVW) Action Agreed 5/10.</p> <p><i>Note. — This follow-up will entail assisting WG-MOG (IAVW) in the development of a proposed updates to ICAO Annex 3 regarding VAA/VAG on VONA and supporting guidance material for ICAO Doc 9766.</i></p>	Schneider (for Guffanti), Engwell (for Witham) and Barsotti	30 June 2018
7/4	<p>State Volcano Observatory responsibilities [Refer to 6.4] Agreement that ICAO should be requested (through Mr Romero as the ICAO ex-officio VASAG member) to undertake efforts to remind ICAO Contracting States with active or potentially active volcanoes of their State volcano observatory responsibilities under ICAO Annex 3, 3.6 and the supporting operational procedures contained within ICAO Doc 9766, particularly in the context of the arrangements for the monitoring of such volcanoes and the preparation, dissemination and communication of the VONA.</p>	Romero	31 Dec. 2017
7/5	<p>Aircraft encounters database and severity index [Refer to 7.5] Agreement that Dr Schneider (for Ms Guffanti), assisted by other members, would lead the VASAG follow-up of METP WG-MOG/5 (IAVW) Action Agreed 5/7.</p> <p><i>Note. — This follow-up will entail assisting WG-MOG (IAVW) in the drafting of changes to Appendix F of ICAO Doc 9691 with new data on aircraft encounters and any agreed-upon modifications to an encounter severity index.</i></p>	Schneider (for Guffanti)	30 June 2018

No.	Description	Lead	Deadline
7/6	SO₂ State of Science review [Refer to 8.3] Agreement that, to the extent practicable, VASAG would assist ICAO in undertaking the SO ₂ 'state of science' review called for by METP WG-MISD/3 (VASD) Action Agreed 3/1.	VASAG members	To be confirmed by WG-MISD (VASD) activity lead
7/7	IWVA/8 Concept Note [Refer to 10.2.4] Agreement that Dr Mastin and Dr Tupper, in coordination with Secretariat, would develop a concept note ¹² for IWVA/8 (2019) for consultation with the wider VASAG membership.	Mastin and Tupper	31 Dec. 2017
7/8	Next Meeting [Refer to 14.4] Agreement that the Secretariat should identify where and when VASAG/8 will be held together with an indication of the extent of WMO funding that may be available to support members' attendance. <i>Note. — The VASAG agreed that there would be merit in convening a future meeting conjointly with a VAAC Best Practice workshop.</i>	Secretariat	31 Dec. 2017

¹² The concept note may address the workshop's theme and expected outcome, intended audience and expected level of participation, format, timing, duration and location plus co-sponsorship opportunities.