WORLD METEOROLOGICAL ORGANIZATION

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

CONJOINT SESSION

SEVENTH WMO VAAC "BEST PRACTICE" WORKSHOP (VAAC BP/7)

AND

NINTH WMO/IUGG VOLCANIC ASH SCIENTIFIC ADVISORY GROUP MEETING (VASAG/9)

Washington DC, United States of America

21-22 November 2019

FINAL REPORT

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GROUP PHOTO

Pictured left to right: Dave Schneider, Philippe Héreil, Ian Lisk, Alice Crawford, Barbara Stunder, Paula Acethorp, Sigrún Karlsdóttir, Jeff Osiensky, Claire Witham, Yuichi Imamura, Klaus Sievers, Sam Engwell, Jarrad Denman, Larry Mastin, Anton Muscat, Marcel Roux, Matt Hort, Rory Clarkson, Dov Bensimon, Jamie Kibler, Mike Pavolonis, Tristan King, Nickolay Krotkov, Tammy Flowe, Arnau Folch, Ellen Ramirez, Soledad Osores, Greg Brock, Raul Romero and Pierrick Mialle
[Not pictured: Larry Burch and Tom Helms]

VAAC MANAGERS (November 2019)

Pictured left to right: Jamie Kibler (VAAC Washington), Jeff Osiensky (VAAC Anchorage), Yuichi Imamura (VAAC Tokyo), Jarrad Denman (VAAC Darwin), Anton Muscat (VAAC London), Marcel Roux (VAAC Wellington), Soledad Osores (VAAC Buenos Aires), Dov Bensimon (VAAC Montreal) and Philippe Héreil (VAAC Toulouse)

1. ORGANIZATION OF THE CONJOINT SESSION

1.1. Opening and introductions

1.1.1. The conjoint seventh WMO Volcanic Ash Advisory Centres 'Best Practice' workshop (VAAC BP/7) and ninth WMO/IUGG Volcanic Ash Scientific Advisory Group meeting (VASAG/9) was held at the offices of RTCA, Inc. in Washington DC, United States of America from 21 to 22 November 2019.

1.1.2. The conjoint session was opened at 0900 hours on 21 November 2019 by Mr Ian Lisk, president of the WMO Commission for Aeronautical Meteorology (CAeM). Mr Lisk welcomed all participants to Washington DC and thanked the government of the United States of America for their willingness and ability to host the conjoint session. In view of a number of areas of common interest, Mr Lisk acknowledged that this was the second time that a VAAC BP workshop and a VASAG meeting had been convened as a conjoint session[1].

1.1.3. Mr Lisk also acknowledged that the conjoint session was being held immediately following meetings of the ICAO Meteorology Panel (METP) Working Group on Meteorological Operations Groups (WG-MOG) and Working Group on Meteorological Information and Service Development (WG-MISD) at the same venue (18 to 20 November 2019) addressing issues of common concern regarding volcanic ash clouds and gases within the context of the international airways volcano watch (IAVW). In addition, he alluded to a Cross Working Group Progress meeting of the ICAO METP Management Group held in Daytona Beach, Florida in the week prior (12 to 15 November 2019) of which several outcomes were of relevance to WMO and this conjoint session of VAAC BP and VASAG (specific details provided under Agenda Item 3).

1.1.4. In respect of the objective of the conjoint session, Mr Lisk indicated that attention would be placed on responding, from scientific and technological perspectives, to the outcomes of the aforementioned ICAO meetings, and in particular in the context of the introduction over the coming several years of a quantitative volcanic ash information service and the trialling of a sulphur dioxide (SO_2) information service. He also noted that the conjoint session was an opportunity to place special consideration on the planning for the next International Workshop on Volcanic Ash to be held in October 2020.

1.1.5. The full list of participants is given at Annex 1 to this report.

1.2. Adoption of the agenda

1.2.1. The agenda given at Annex 2 to this report was adopted without modification.

1.3. Working arrangements

1.3.1. Participants adopted working arrangements appropriate for the conjoint session, including an order of business.

1.3.2. Mr Ian Lisk and Dr Larry Mastin moderated proceedings assisted by Mr Greg Brock, Acting Chief of the Aeronautical Meteorology Division of WMO who served as the Secretary of the conjoint session.

[1] The first conjoint session was held in Wellington, New Zealand in November 2018.

2. REVIEW OF OPEN OUTCOMES/ACTIONS OF PREVIOUS MEETINGS

2.1 Open VAAC BP outcomes

2.1.1 Participants undertook a review of outcomes that remained open from previous VAAC Best Practice workshops – specifically from the workshops held in 2016 (VAAC BP/4) and 2018 (VAAC BP/6).

2.1.2 In the context of VAAC BP/4 (2016), it was noted that Outcome VW4-O-03 concerning volcanic ash modelling and VAAC 'Ins and Outs' modelling tables was a recurrent task, with the tables to be reviewed, updated and shared every 2-years. Dr Hort made the latest update (2018) available to participants for ease of reference. Given an intention for the VAAC 'Ins and Outs' modelling tables to form part of a wider peer-reviewed paper in 2020, Dr Hort encouraged the VAACs to send suggestions for improvement to the document/tables by 17 January 2020. Suggestions could include, for example, areas to expand the scope of the document/tables and the specifications on the modelling capabilities and tools available to VAAC forecasters. **VAAC BP/7 Outcome VW7-O-01**

2.1.3 In the context of VAAC BP/6 (2018), it was noted that Outcomes VW6-O-01 (VAAC strength of evidence checklists), VW6-O-02 (Satellite inter-comparisons of discernible ash), VW6-O-04 (VAAC collaboration tool) and VW6-O-05 (IWXXM schema implementation), VW6-O-07 (VAAC Washington backup arrangements) and VW6-O-08 (Competency framework for VAAC Forecasters) would be addressed under Agenda Item 6 of this conjoint session; while the follow-up to Outcomes VW6-O-03 (VAAC key performance indicators) and VW6-O-06 (IWXXM Scheme Clarifications) could be considered complete.

2.1.4 Upon the conclusion of this conjoint session, the status of the aforementioned open outcomes of previous VAAC BP workshops was reviewed and updated, as given at Annex 3 to this report.

2.2 Open VASAG actions

2.2.1 Participants undertook a review of actions items that remained open from previous VASAG meetings – specifically from the meetings held in 2015 (VASAG/6), 2017 (VASAG/7) and 2018 (VASAG/8).

2.2.2 In the context of VASAG/6 (2015), it was agreed that Action 6/6 (Global volcano ESP database for restless volcanoes) could be closed in view of the current availability of a beta version of the database, a journal manuscript that is nearing completion, and an operational version expected in 2020. It was also agreed that VASAG/6 Action 6/10 (Use of radar data for volcanic ash application training) could be closed in view of an intent to include a paper, by the Icelandic Meteorological Office (IMO), on the validation of the VESPA method (Volcanic Eruptive Source Parameter Analyzer) used to calculate mass eruption rate from radar observations of ash-cloud height in a special edition of the journal *Atmosphere: Forecasting the Transport of Volcanic Ash in the Atmosphere*. In addition, IMO intended to provide a technical report where the code used in VESPA could be made available to interested parties upon request.

2.2.3 In the context of VASAG/7 (2017), it was noted that Action 7/4 (State volcano observatory responsibilities) would be replaced by a new action owing to a lack of progress **VASAG/9 Action 9/1** while Action 7/5 (Aircraft encounters database and severity index)

could be considered ongoing insofar as the update to the aircraft encounters database was concerned and complete insofar as the update of the severity index was concerned.

2.2.4 In the context of VASAG/8 (2018), it was noted that Actions 8/1 (Publications and outreach), 8/2 (IWVA concept note) and 8/3 (Review and update of WOVO guidance on the IAVW) would be addressed under Agenda Items 6, 5 and 4 respectively of this conjoint session.

2.2.5 Upon the conclusion of this conjoint session, the status of the aforementioned actions of previous VASAG meetings was reviewed and updated, as given at Annex 4 to this report.

3. SUMMARY OF RELEVANT OUTCOMES/ACTIONS FROM PRECEDING ICAO MEETINGS

3.1 METP MG CWGP/1

3.1.1 Participants were informed that the ICAO Meteorology Panel Management Group (METP MG) had convened an inaugural Cross-Working Group Progress (CWGP/1) from 12 to 15 November 2019 in Daytona Beach, Florida, United States of America. Mr Brock and Mr Romero outlined that the purpose of the CWGP/1 had been to undertake a holistic review of the work of the METP across its five working groups and multiple work streams – given increasing workloads and increasing complexity associated with the transformation of the aviation system, including aeronautical meteorology, set against a backdrop of diminishing resources – in order to identify opportunities for improved efficiency and effectiveness over the coming 3 to 5 years at least, including in the context of ICAO's working arrangements with WMO.

3.1.2 Mr Lisk highlighted that the 'volcanic ash' topic could be an excellent demonstrator (proof of concept) for a much more integrated, joined-up approach across WMO and ICAO to better serve the needs of the entire community – volcano observatories, VAACs and other aeronautical meteorological service providers, universities/academia and aviation users – and that WMO Governance Reform (see Section 8 below) was an excellent opportunity that WMO was seeking to exploit with ICAO to forge closer working ties, for example through a joint WMO-ICAO working group (or similar) on volcanic ash in the 2021 timeframe.

3.1.3 It was also highlighted that it was incumbent upon WMO, its Members and the meteorological community including academia to demonstrate the 'art of the possible' in response to the current and foreseen future needs of aviation users, and that over the next 5 to 10 years there would be a transformation in the way in which aeronautical meteorological services are provided. Also, that the associated roles and responsibilities of aeronautical meteorological forecasters, including VAAC forecasters, and the approach to the underpinning science would transform too.

3.2 METP WG-MOG/11 (IAVW)

3.2.1 Participants were informed that an eleventh meeting of the ICAO Meteorology Panel (METP) Working Group on Meteorological Operations Groups (WG-MOG) addressing the international airways volcano watch (IAVW) had convened on 18 and 19 November 2019 at the same location as this conjoint session. It was noted that all nine VAAC managers had attended the WG-MOG/11 (IAVW) meeting and that the report of the meeting would be publicly available here in due course.

3.2.2 Ms Acethorp, IAVW work stream lead within the WG-MOG, gave an overview of the main outcomes of WG-MOG/11 (IAVW) of relevance to the conjoint session. She highlighted

ongoing efforts to ensure effective communication of reports on volcanic activity (pre- and post-eruption), advances in the infrasound network of relevance to the IAVW, consideration of how to communicate information on re-suspended volcanic ash and volcanic ash deposition at aerodromes, the introduction of a consolidated VAAC Management Report and associated key performance indicators, and lessons learnt from recent volcanic ash exercises. She also highlighted the availability of an IAVW Concept of Operations and Roadmap (also referenced at 6.1.3 below).

3.2.3 In the context of volcanic ash deposition at aerodromes, it was noted by the conjoint session that while there had not been a specific request from ICAO for the VASAG to address, it may nonetheless be worthwhile for the VASAG Members to review the state of science with regard to volcanic ash deposition from a modelling perspective.

3.3 **METP WG-MISD/5 (VASD)**

3.3.1 Participants were informed that a fifth meeting ICAO Meteorology Panel (METP) Working Group on Meteorological and Information Service Development (WG-MISD) addressing volcanic ash and sulphur dioxide (VASD) had convened on 20 November 2019 at the same location as this conjoint session. It was noted that all nine VAAC managers had attended the WG-MISD/5 (VASD) meeting.

3.3.2 Ms Flowe, VASD work stream lead within the WG-MISD, assisted by Mr Burch, AvMet Applications, gave an overview of the outcomes of WG-MISD/5 (VASD) of relevance to the conjoint session. They highlighted that the WG-MISD/5 had agreed to the phased introduction of a quantitative volcanic ash information service between 2022 and 2026 as part of the ICAO Annex 3 provisions supporting the IAVW. In addition, VAAC London had been requested to commence a trial of a global sulphur dioxide (SO_2) forecast capability. In this latter regard, it was noted that the VASAG had been specifically requested by ICAO to determine the thresholds to be used in the trial. [This is considered further at 7.3 below.]

3.3.3 The conjoint session appreciated that both main outcomes of WG-MISD/5 – namely the phased introduction of a quantitative volcanic ash information service and the trial of a global SO_2 forecast capability – were significant in the context of taking the IAVW forward over the next decade, with linkage to ICAO's Global Air Navigation Plan. In view of the ambitious timelines, the importance of ensuring wide communication of these developments at national and international levels was considered paramount in order to secure appropriate and necessary supporting resources, including financial. The conjoint session also highlighted that there may be aspects common to both developments, such as accuracy and timeliness metrics and the application of probabilistic methodologies.

3.3.4 Since a majority of VASAG Members had not attended the WG-MISD/5 and to provide greater context to the outcomes of the meeting, Mr Romero agreed to make a courtesy copy of the WG-MISD/5 final report available to the VASAG Members in due course for reference purposes only. **VASAG/9 Action 9/2**

4. VOLCANO MONITORING

4.1 **ESP database for restless volcanoes**

4.1.1 In response to VASAG/6 Action 6/6, Dr Engwell gave a progress report on the update to a global volcano eruption source parameter (ESP) database for restless volcanoes, where systematic comparisons were made between default plume heights specified in the existing

database and plume heights noted in volcanic ash advisories issued by the VAACs. Observed heights were systematically lower. Dr Engwell also documented a significant increase in the number of VAAs issued per year over the past 10 years, and attributed much of the increase to better detection of volcanic ash by new satellites. The presentation highlighted how there were ongoing efforts to produce a community-driven, online database (hosted by the British Geological Survey, BGS) of independently estimated ESP, with a data compilation phase expected to be completed in early 2020 prior to operational availability in mid-2020. The presentation also gave examples of recent improvements and remaining limitations in the independently estimated ESP datasets. In view of the developments the conjoint session agreed that VASAG/6 Action 6/6 could be closed.

4.1.2 The conjoint session discussed that the upwards trend in the number of VAA issued per year was, in part, attributable to the fact that the VAACs were now able to discern volcanic ash plumes from smaller scale eruptions more readily than in the past due to the advances in satellite remote sensing capability. In addition, the analysis appeared to show that such smaller scale eruptions were often lower than what their default source terms derived from the ESP database might have predicted. It was highlighted also that while larger scale eruptions were, of course, of relevance to aviation users, smaller scale eruptions were of relevance too since, for example, many volcanoes are proximal to airports and small scale eruptions can sometimes possess high concentrations of volcanic ash and/or gases. From numerical weather prediction and atmospheric transport dispersion modelling perspectives, it was emphasized that volcanic ash clouds from small scale eruptions can, in some instances, be sub-grid scale, episodic and/or exist in low wind shear atmospheric regimes (such as in the tropics), presenting unique challenges from a forecasting perspective compared with larger scale eruptions.

4.2 **Remote sensing monitoring of volcanoes including infrasound**

4.2.1 The conjoint session gave consideration to remote sensing technologies, including infrasound, to monitor volcanoes.

4.2.2 A presentation given by Dr Schneider in collaboration with Dr Pavolonis illustrated that, for volcano monitoring, remotely-sensed data is gathered to forecast, detect and characterize an eruption. From satellites, common observable parameters used to forecast a volcanic eruption include heat signature (thermal anomalies), degassing of SO_2 and deformation of the vent. While infrasound could be used to characterize an eruption, it was indicated that the relationship between satellite, infrasound and other seismic detection data was still not fully understood, and that work was ongoing in this regard. Interactive tools and alerting systems such as VOLCAT (VOLcanic Cloud Analysis Tool), ARISE (Atmospheric dynamics Research Infra-Structure in Europe) and VIS (Volcanic Information System) showed promise insofar as the needs of VAACs and SVOs was concerned, but additional effort would be required before they were considered ready for deployment in the 24/7 operational environment of the IAVW.

4.2.3 In respect of infrasound, Mr Héreil gave a presentation on the use of infrasound data in support of the IAVW, based on an ongoing collaboration between VAAC Toulouse, the Preparatory Commission of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) and other partners. The presentation highlighted that VIS, referenced above, was a potential asset for communities across ARISE (research), CTBTO (operations) and ICAO/WMO (aviation). A VIS prototype had been developed and tested with the operational support of CTBTO and had shown promise, especially in the case of major eruptions. In respect of future work, it was indicated that there was a need to improve the reliability of the VIS notifications and reduce the false alarm rate, perhaps through evaluation by an increased number of VAACs. Other

cited improvements included calculation of the source amplitude from long-range infrasound measurement to estimate acoustic energy, integration of data from regional infrasound arrays to lower the response time and improve reliability, and an evolving of VIS from a data re-analysis tool to a near-real-time alerting system.

4.2.4 The conjoint session unanimously agreed that the integration of traditional remote sensing data such as satellite-derived data with non-traditional data such as infrasound was critical to enhancing the real-time or near-real-time detection of volcanic eruptions in support of the IAVW. Notwithstanding that many NMHS (of WMO Members) already have associations with CTBTO, it was noted that there was a need to enhance the exchange of infrasound detection data derived from CTBTO observing networks with IAVW stakeholders, in particular the VAACs as well as State volcano observatories (SVOs) located in the volcanically-active regions of the world. In this regard, it was agreed that WMO, ICAO and CTBTO should explore the possibility to enhance their cooperation in support of the IAVW, perhaps through an exchange of letters and/or an enhancement to existing working arrangements. **VASAG/9 Action 9/3**

4.3 WOVO guidance review and update

4.3.1 In response to VASAG/8 Action 8/3, Dr Schneider gave a progress report on the review and update of WOVO *Guidance for State Volcano Observatories: The International Airways Volcano Watch* (available here). The progress report revealed that a native Word version of the document had been obtained from WOVO and was undergoing review, with an expectation that outcomes of the ICAO METP WG-MOG/11 (IAVW) meeting and a WOVO Volcano Observatory Best Practices workshop (VOBP/4) both taking place in the same week as this conjoint session would feed the update process. The intention was to then present an updated version to WOVO and SVOs at the Eleventh Cities on Volcanoes (COV/11) event scheduled for May 2020 in Crete, Greece, prior to publication (by WOVO). Given these developments, the conjoint session agreed to keep VASAG/8 Action 8/3 open.

4.3.2 Dr Schneider also informed the conjoint session of intentions of SVOs and IUGG-IAVCEI to seek to restructure WOVO to make it more purposeful. In this regard, while progress had been slower than anticipated, discussions were continuing between WOVO executive committees and senior scientists from volcano observatories, including at VOBP/4 referenced above.

4.3.3 The conjoint session noted that in view of the intent of ICAO to elevate the status of the Volcano Observatory Notice for Aviation (VONA) from a Note to a Recommended Practice and (eventually) a Standard within the ICAO Annex 3 provisions over the coming years, States with responsibility to provide a volcano observatory (or observatories) within the context of the IAVW would be further mandated to ensure the observing of active or potentially active volcanoes in support international civil aviation. Moreover, from a capacity development perspective, there may be opportunities for organizations such as ICAO and WMO to assist States in their implementation of the international standards through, for example, socialization at the IWVA workshops (see Section 5 below) and any future integration of ICAO and WMO constituent bodies (see Section 8 below).

4.4 SVO-VAAC interactions including capacity development opportunities or other needs/expectations

4.4.1 Further to 4.3.3 above, the conjoint session gave consideration to interactions between State volcano observatories and VAACs, including capacity development opportunities and other needs/expectations.

4.4.2 A presentation given by Dr Witham and Dr Schneider summarized the objectives and key recommendations of a European SVO-VAAC workshop (EUROVOLC) convened in February 2019, gave examples of the continuously improving interactions between VAACs Darwin and Wellington and their associated SVOs, and informed of a possible USGS Volcano Disaster Assistance Programme (VDAP)-funded workshop in Argentina in 2021 intended to improve coordination between South American SVOs and VAAC Buenos Aires as well as improve SVO capabilities to fulfil their ICAO Annex 3 obligations. The presentation also drew attention to key topics being addressed by the WOVO VOBP/4 referenced at 4.3.1 above, and highlighted both issues being raised by SVOs in the context of the VONA *and* potential technological solutions (e.g. interactive online tools) to improve VONA production and dissemination.

4.4.3 In respect of interactive online tools, it was noted that some VAACs and SVOs had started to make active use of messaging applications such as WhatsApp to overcome gaps in communication caused by slow or non-existent local internet connections as well as to overcome local language barriers (noting that some SVO personnel may not speak or have sufficient command of the English language). VAAC Darwin, for example, was using WhatsApp with SVOs in Indonesia and Papua New Guinea to obtain supplemental information. The Indonesian SVO personnel would send plain-text 'instant messages' with images via WhatsApp in the local (non-English) language. The VAAC Darwin forecasters would then use an online translation tool to convert the messages into English. The reverse process could then be used for reply messages from VAAC Darwin to Indonesia. Similarly, VAAC Wellington gave examples of how they were communicating with SVOs in the SW Pacific via email, and were receiving photographic evidence of an erupting volcano (offering plume shape, colour and other characteristics) that can further strengthen the awareness of the VAAC forecaster to the real-time or near-real-time situation close to the volcano and provide further validation of content for the VAA.

4.4.4 It was remarked that, in some instances, the SVO contact information in ICAO Doc 9766, *Handbook on the International Airways Volcano Watch – Operational Procedures and Contact List,* was out-of-date. [This is addressed further at Section 10 below.]

4.4.5 In respect of workshops or other such events addressing the science of volcanic eruptions and volcanic ash clouds and gases in the atmosphere and service delivery, such as EUROVOLC mentioned above, it was suggested that partners such as civil aviation administrations and ICAO could be worthwhile invitees where feasible to facilitate broader community interactions.

4.5 Other relevant developments

4.5.1 No other relevant developments were presented.

5. PREPARATIONS FOR IWVA/8

5.1 Background and latest developments

5.1.1 Participants recalled that at VASAG/8 (2018) initial consideration had been given to the objective, timing, duration, location, intended audience, number of participants, format etc. of the next (eighth) International Workshop on Volcanic Ash (IWV/8) to help guide preparations, in particular a draft Concept Note.

5.1.2 In view of an official offer to host by the Icelandic Meteorological Office (IMO), IWVA/8 was being planned for late 2020 in Iceland – more specifically, the week commencing 19 October 2020 in Reykjavik. Participants noted that the timing of IWVA/8 was consistent with a 3 to 5 year cycle of convening such international workshops – the first workshop was in 1995 while the most recent workshop was in 2015. Moreover, 2020 marked the tenth anniversary of the Eyjafjallajökull eruption in Iceland and the centenary of IMO.

5.2 Draft concept note

5.2.1 Participants were pleased to note that in response to VASAG/8 Action 8/2 a draft Concept Note for IWVA/8 had been matured. Participants undertook a review of the latest draft Concept Note and agreed that it should be matured further taking into account suggestions offered by participants at the conjoint session.

5.2.2 Participants were informed that a final draft Concept Note for IWVA/8 would be submitted to WMO Executive Management in early 2020 for consideration, accompanied by a financial assessment. Subject to approval by WMO Executive Management, the Concept Note would be appended to the invitation letter announcing the workshop and calling for papers.

5.2.3 In respect of the estimated number of participants attending IWVA/8, the conjoint session considered that 100-150 may be an underestimate given the probable interest across a range of communities associated with the tenth anniversary of Eyjafjallajökull and centenary of IMO in 2020, and that it would be worthwhile to increase the estimate to 250-300 subject to logistical, financial or other considerations. Irrespective of the number of participants, it was suggested that there would be merit in exploring the possibility to provide a live stream/webcast of the event for any interested parties that may be unable to travel to the event in person.

5.2.4 In respect of supporting funding for the workshop, the meeting was informed that WMO funding was expected to be available to support the organization of the conference and to support the attendance of a limited number of delegates. In addition it was expected that a delegation registration fee would likely need to be charged to support the provision of lunches and other refreshments and that the organizers (IMO and WMO) should consider seeking sponsorship from third parties and/or partner international organizations e.g. IATA and IUGG where feasible, to help reduce this fee.

5.3 Formation of a scientific organizing committee

5.3.1 Notwithstanding that the convening of IWVA/8 was still subject to approval by WMO Executive Management in early 2020, participants agreed that there would be merit in the

formation of a Scientific Organizing Committee (SOC)[2]. It was proposed that the SOC should comprise core members (nominally 6 experts) and supporting members (nominally an additional 6 to 12 experts) whose duties could be summarized as follows:

Primary duties:

- Programme development – Provisional agenda, daily schedule, etc.,
- Identification of keynote and other speakers, and
- Reviewing, shortlisting and final selection of abstracts for oral and (if held) poster presentations.

Secondary duties:

Assisting WMO Secretariat and Local Organizing Committee (LOC) with:

- Invitations, communications/outreach, hospitality, funding, sponsorship and exhibiting, as appropriate, and
- Recommendations and report arising from the workshop.

5.3.2 In respect of the composition of the SOC, it was agreed that a preliminary composition – comprising core and supporting members – would be established following this conjoint session and that the final composition would be determined once the convening of IWVA/8 had been approved by WMO Executive Management.

5.4 Preliminary programme development, including potential topics/themes and contributors

5.4.1 Participants gave preliminary consideration to the development of a programme for IWVA/8, including potential topics/themes and contributors, taking in account the draft Concept Note discussed above.

5.4.2 The conjoint session agreed to progress the development of the programme in a timely manner through the efforts of the SOC mentioned above. Additional ideas with regard the format of the workshop included poster presentations, panel and breakout group discussions. With regard to a proposed (optional) half-day or one-day field trip, it was considered desirable to investigate the feasibility of convening a trip or trips on the Monday or Wednesday (subject to logistical, financial or other considerations) rather than the end of the week.

5.5 Next steps

5.5.1 Participants reviewed a provisional timeline of activities between December 2019 and December 2020 to cater for the planning, preparation, execution and post-event phases of IWVA/8, as given at Annex 5 to this report.

5.5.2 In view of the foregoing (5.1 to 5.5.1 inclusive), the conjoint session agreed that WMO, in coordination with VASAG Members and VAAC Managers, should progress the formation of the SOC, the finalization of the Concept Note, development of the programme and other activities associated with IWVA/8 consistent with the referred timeline. **VASAG/9 Action 9/4**

[2] The conjoint session proposed replacing 'Scientific Organizing Committee (SOC)' with 'Organizing Committee (OC)'. However, post-session, it was decided by Messrs Brock, Lisk and Mastin in coordination with Dr Tupper (VASAG co-chair) to retain Scientific Organizing Committee (SOC) to ensure clear differentiation from the Local Organizing Committee (LOC).

6. VOLCANIC SCIENCES INTO CURRENT VAAC OPERATIONAL APPLICATIONS

6.1 Advancements in remote sensing and in-situ monitoring of volcanic ash and other gases

6.1.1 The conjoint session gave consideration to advances in remote sensing and in-situ monitoring of volcanic ash and other gases in the atmosphere, including sulphur dioxide (SO_2).

6.1.2 A presentation given by Dr Pavolonis and Dr Hort provided an update on the satellite constellations, the development of satellite-based, remote-sensing workflows to support the current and foreseen future needs of the IAVW community (including the associated advances and challenges), and an update on in-situ observations and ground-based remote-sensing.

6.1.2.1 In respect of satellite constellations, it was noted that there was a continual growth in the number of meteorological and other environmental satellites with multispectral capabilities, and an associated significant expansion in the number of earth observations available on a daily basis that presented an information overload challenge for VAACs and others. While satellite data was the most common source of observation data utilized by the VAACs, the leveraging of additional data sources (see 6.1.2.3 below for examples) was important. Moreover, given the heterogeneous nature of satellite constellations and the enormous volumes of data, a complete reliance on manual analysis was already evidently impractical.

6.1.2.2 In respect of a satellite-based, remote-sensing workflow in support of the IAVW, it was noted that work was ongoing to:

- improve the automated detection of new volcanic clouds and gases through, for example, the application of artificial intelligence (AI);
- improve the initial and ongoing characterization of key parameters (height, loading, microphysics) across a broad range of conditions and uncertainty estimates;
- automate, through AI, the tracking of volcanic clouds and gases in a manner that is consistent with human expert analysis; and
- support forecasting applications by the systematic provision of key volcanic cloud properties and associated uncertainty for automated dispersion modelling applications.

It was also noted that additional research, development and testing would be required to support the foreseen changes within the IAVW (e.g. quantitative VA and SO_2 information services) and that such supporting initiatives would increasingly look to better integrate the application of non-satellite based observational capabilities such as infrasound, lightning, lidar, radar and so on.

6.1.2.3 In respect of in-situ observations and ground-based remote-sensing, an overview was given of the array of equipment available to detect volcanic clouds and gases, including meteorological research aircraft, unmanned aerial vehicles (UAV) and drones, aerosol-sonds, particle counters and air quality monitoring stations amongst others. Acknowledging that operational application always lags advances demonstrated in literature – since there are real-world practical issues to be overcome such as timeliness and performance – it was highlighted that there could be a better alignment between the interests of the research community and the needs of the IAVW community, and that the former should be responsive to the latter. It was suggested that a coordinated higher-level of outreach to the agencies that operate the VAACs was considered vital to avoid a situation where the

supporting research needs are under-prioritized, especially within those agencies that possess a large and competing mission scope.

6.1.3 In connection with the foregoing, the conjoint session agreed that there was a need for the wider socialising of the IAVW Concept of Operations and Roadmap developed by ICAO with a view to helping to inform, through the relevant channels such as the Coordination Group for Meteorological Satellites (CGMS), future priorities for remote-sensing and in-situ monitoring capabilities development and exploitation. **VASAG/9 Action 9/5 and Action 9/6**

6.2 Advancements in modelling of eruptive plumes, transport and dispersion

6.2.1 The conjoint session gave consideration to advances in the modelling of eruptive plumes, transport and dispersion.

6.2.2 A presentation given by Dr Witham and Dr Mastin provided an overview of current capabilities (including a comparison of the models used by VAACs London and Montreal during the Mount Raikoke eruption in June 2019), future capabilities (including data assimilation and use of observations in models, and the characterization of uncertainty in the model forecast through dispersion ensemble prediction systems), modelling of re-suspended volcanic ash, preparing for the next generation of high-performance computing in the next decade, and the promotion of science.

6.2.3 In respect of data fusion (including data assimilation and data insertion), it was emphasized that its effects are wide ranging and can make a significant difference. And, since it also represented a means to improve quantitative forecast output there was growing interest and activity across many centres and projects. This said however, it was also stressed that challenges remain since the application of data fusion was not straightforward and could still result in the persistence of relatively large uncertainties. [Addressing uncertainty is a consideration at 7.2.4 below.]

6.2.4 A presentation given by Mr Imamura (and Mr Kensuke Ishii *in absentia*) summarized the development of a volcanic ash forecast model by VAAC Tokyo and the Meteorological Research Institute (MRI) of the Japan Meteorological Agency (JMA). The presentation highlighted how volcanic ash cloud thickness estimation techniques and satellite analysis techniques were being used to improve the accuracy of the initial and forecast conditions to (eventually) enable the provision of quantitative volcanic ash information. In this latter respect, it was highlighted that a Himawari-8 volcanic ash product ("VAP") retrieval algorithm, catering for ash mass loading, was still in the development phase (2019-2022) and still had to be validated.

6.2.5 Given that there can often be few direct measurements of the geometric thickness of a volcanic ash cloud (due to obscuration or other constraints), the conjoint session discussed the relationship (empirical or statistical) between wind shear and cloud thickness. It was considered that there would likely be instances where the techniques used by JMA could work quite well (e.g. high wind shear situations) and less well (e.g. low wind shear situations), and in those situations where observations were limited or non-existent that there would be merit in estimating the uncertainties and to highlight when the technique was yielding potentially misleading output.

6.3 **Scientific publications and outreach**

6.3.1 In response to VASAG/8 Action 8/1, Dr Mastin indicated that there had been a general lack of progress, partly owing to uncertainty since the last conjoint session of how long the VASAG might exist. This said, however, it was highlighted that since the last VASAG meeting a special edition of the journal Atmosphere addressing *Forecasting the Transport of Volcanic Ash in the Atmosphere* had been put forward (with Dr Witham and Dr Chris Lucas (BoM) as guest editors) with paper submissions expected by early 2020. The conjoint session also considered it beneficial for VASAG Members to link prospective volcanic ash-related scientific articles and publications with the upcoming IWVA/8 in October 2020 (Section 8 refers), for example by way of a special volume of scientific papers. The conjoint session agreed to close VASAG/8 Action 8/1 and to create a new action accordingly. **VASAG/9 Action 9/7**

6.4 **VAAC strength of evidence checklists**

6.4.1 In connection with VAAC BP/6 Outcome VW6-O-01, Dr Denman and Mr King of VAAC Darwin presented a progress report on the volcanic ash strength of evidence checklist, including the outcome of feedback (pros and cons) identified during consultation with other VAACs and the VASAG, and a case study demonstrating how the checklist could be used during the response to an eruption. The presentation highlighted how multiple sources of information – such as satellite imagery, the issuance of VONA and special air reports, lightning data, seismic data, webcams and social media – could collectively be used by a VAAC to compile evidence with which to make informed decisions and ultimately determine the issuance, non-issuance or cancellation of volcanic ash advisory information. These additional sources will be included in the evidence checklist to provide a holistic view of all information received by the VAAC. The evidence checklist is a way for the VAACs to measure consistency between operational procedures to align with the requests for users.

6.4.2 The conjoint session agreed that evidence checklists for VAAC forecasters were highly relevant given providers of meteorological service for international air navigation are required to possess a quality management system (QMS). Several VAAC managers shared their thoughts on the application of the strength of evidence checklist within operational environment (i.e. amongst VAAC forecaster). While the checklists performed very well in many situations, there were also instances where other methodologies worked equally well or perhaps performed better. This said, the value of evidence checklists and other such aids was not to be understated. In respect of other aids, the attention of the conjoint session was drawn to 'decision trees' in use amongst some of the VAACs and SVOs.

6.4.3 The conjoint session agreed that VAAC BP/6 Outcome VW6-O-01 part a) could be closed while part b) would be kept open. It was also agreed that examples of 'decision trees' in use amongst SVOs would be shared with VAAC Darwin to assist, as necessary, in the further refinement of the VAAC forecaster toolset. **VAAC BP/7 Outcome VW7-O-02**

6.5 **Lessons learned/challenges identified during recent eruptions**

6.5.1 Mr Sievers gave perspectives of the International Federation of Airline Pilots' Associations (IFALPA) on the operational response to and operational impact of the eruption of Mount Raikoke (Kuril Islands, Russian Federation) in June 2019[3]. It was highlighted that the Mount Raikoke eruption had emitted both volcanic ash and sulphur dioxide (SO_2) yet there was

[3] The eruptions of Mount Sinabung (Indonesia) in April 2019 and Mount Ubinas (Peru) in July 2019 were also cited in the presentation of Mr Sievers but were not presented in view of their presentation during the preceding ICAO METP WG-MISD meeting.

currently no official information available through the IAVW on the location/extent, forecast movement and concentration of SO_2 in the atmosphere. [Discussed further at 7.3 below.]

6.5.2 Mr Muscat presented a timeline on the eruption of Mount Raikoke in June 2019 from the perspective of VAAC London. The presentation illustrated that Met Office teams co-located with VAAC London extensively monitored and modelled the eruptive plume of all volcanic material emitted, and estimated the time of arrival in the UK to be about 10 days after the eruption on 21 and 22 June 2019. By 1 and 2 July 2019 there was sufficient strength of evidence – for example from ground-based lidar observations – to conclude that the eruptive plume had crossed the Pacific, North America and Atlantic and had reached Europe. The concentrations of volcanic ash observed over Europe were considered to be well below (typically 1 to 2 orders of magnitude below) any 'discernible ash' threshold warranting the issuance of VAA and VAG. The plumes detected comprised a mixture of volcanic sulphates, trace amounts of volcanic ash and other particulate matter considered to have originated from the Raikoke eruption as well as wildfires in Canada.

6.5.3 Mr Osiensky (on behalf of Mr Nate Eckstein, Science and Operations Officer at VAAC Anchorage) presented a volcanic ash advisories retrospective intended to support verification processes and improve consistency in VAA output by VAAC forecasters. In essence, the retrospective takes account of the observed and forecast polygons of a volcanic ash cloud in issued VAAs and attempts to verify the output, post-event, through comparison with (where available) special air-reports, satellite imagery comparison, in-situ observations and other data sources. Mr Osiensky agreed to make the coding used to verify VAAC Anchorage VAA/VAG available to the VAACs and others concerned. **VAAC BP/7 Outcome VW7-O-03**

6.5.4 Taking the foregoing presentations into account, and noting that the advancement in remote sensing by satellite was often resulting in the detection of discernible volcanic ash at least one order of magnitude below the situation that prevailed in the early 2010s, say, and also noting that there appears to be no safety or economic impact on aviation associated with low or very low concentrations of volcanic ash (i.e. below 0.2 mg/m^3), the conjoint session suggested that it would be beneficial to ensure that such advances were conveyed during the IVAW/8 in Iceland in October 2020 (see Section 8 below) and at other events as necessary.

6.6 **VAAC collaboration tools**

6.6.1 In response to VAAC BP/6 Outcome VW6-O-04, Mr Imamura and Mr Roux gave a progress report on the continued development and testing of a VAAC collaboration tool – consistent with basic functional needs identified in 2017, the development of a prototype by VAAC Tokyo, and taking into account feedback provided at VAAC BP/6 in 2018 – leading, potentially, to rollout across all VAACs.

6.6.2 The progress report revealed that since the last meeting the VAAC Tokyo prototype collaboration tool had been made available to all VAACs for use on a trial basis, that functionality improvements had been introduced, and that some VAAC collaborations had been conducted using the tool. The tool had, for example, been used during backup tests between VAACs Tokyo and Darwin, regional volcanic ash exercises, and system tests between VAACs Tokyo and Wellington. Illustrations were also given of how the VAAC Tokyo tool was going to be used by VAACs Darwin and Wellington to further complement existing collaboration activities.

6.6.3 Notwithstanding the progress, some challenges had been identified in use of the collaboration tool to support VAAC operations, for example the importing of large volumes of

data could decline the usability of the tool. There was also a need to develop clear requirements for the operational use of the tool (considered necessary for an effective development plan and the acquiring of necessary financial resources) and whether it was desirable for the tool to be supported by multiple VAACs rather than a single VAAC.

6.6.4 The conjoint session agreed that VAAC collaboration tool as well as other similar tools (e.g. for SIGMET coordination amongst meteorological watch offices) were proving beneficial regionally and inter-regionally, especially in those instances where there was a need to coordinate the forecast output and conduct a handover of responsibility from one area of responsibility to the next. In this latter respect, it was noted that the VAAC collaboration tool was an opportunity to replace traditional methods of handover such as email and telephone.

6.6.5 Encouraging such collaborations to continue, especially amongst groups of neighbouring VAACs, through the use and further refinement of the VAAC collaboration tool (or tools), the conjoint session agreed that VAAC BP/6 Outcome VW6-O-04 could be closed.

6.7 **VAAC backup arrangements**

6.7.1 In response to VAAC BP/6 Outcome VW06-O-07, Mr Kibler gave a progress report on the establishment of a more viable backup arrangement for VAAC Washington as well as the prevailing suitability of VAAC Washington serving as the primary backup centre for three other VAACs (namely Anchorage, Buenos Aires and Montreal).

6.7.2 In respect of a more viable backup arrangement for VAAC Washington, it was noted that discussions had taken place between VAACs Washington, Anchorage, Darwin and Montreal resulting in an agreement that VAACs Darwin and Montreal would, in the first instance, become contingent backup for VAAC Washington, while VAAC Anchorage may at a future stage become involved in providing backup capability for VAAC Washington subject to the availability of sufficient manpower and other considerations. As a consequence, efforts were now underway between VAAC Washington and VAACs Darwin and Montreal to conduct data exchanges, implement software and/or hardware reconfigurations and testing, conduct staff training etc., all supported by Memoranda of Understanding (MoU) between the organizations concerned.

6.7.3 In respect of the prevailing suitability of VAAC Washington serving as the primary backup centre for VAACs Anchorage, Buenos Aires and Montreal, participants were informed that there had been a lack of progress, essentially owing to focus having been placed on establishing a more viable backup arrangement as outlined at 6.7.2 above.

6.7.4 In concluding, the conjoint session agreed that VAAC BP/6 Outcome VW06-O-07 could be closed on the basis that the more viable backup arrangement for VAAC Washington was progressing well and that the suitability of VAAC Washington serving as the primary backup centre for VAACs Anchorage, Buenos Aires and Montreal would likely be addressed in the context of the holistic review of the IAVW (see 7.1 below).

6.8 **VAAC forecaster competency framework**

6.8.1 In connection with VAAC BP/6 Outcome VW6-O-08, Mr Lisk gave a progress report on the proposed establishment of a VAAC forecaster competency framework. The presentation outlined existing qualification and top-level competency requirements for aeronautical meteorological forecasters (AMF), as required under WMO-No. 49, *Technical Regulations*,

Volume I, *General Meteorological Standards and Recommended Practice* (available here), and how these could be updated to accommodate the VAAC forecaster role.

6.8.2 Whilst recognizing that the State volcano observatory (SVO) observer role does not currently fit neatly within the remit of WMO, the presentation nonetheless also illustrated how, potentially, aeronautical meteorological observer (AMO) top-level competencies could be updated to accommodate the SVO observer role. [See also 6.8.3 below.]

6.8.3 The conjoint session was informed that guidance on competency was on a WMO Moodle platform (available here) was well as within WMO-No. 1205, *Guide to Competency* (available here) and WMO-No. 1209, *Compendium of Competency Frameworks* (available here). In addition, a CAeM Expert Team on Education, Training and Competency (ET-ETC) had been tasked to initiate and lead work on updating the top- and/or second-level competencies for aeronautical meteorological personnel to accommodate the role of VAAC forecasters. This leadership role of ET-ETC could be extended to consider SVO observers in view of the proposed elevation of the VONA from a Note to a Recommended Practice and (eventually) to a Standard within ICAO Annex 3, as alluded to at 4.3.3 above.

6.8.4 In order to progress, the conjoint session agreed to establish VAAC and SVO points of contact to assist ET-ETC as follows:

- For VAACs: Mr Dov Bensimon (VAAC Montreal) and Dr Jarrad Denman (VAAC Darwin)
- For SVOs: Dr Dave Schneider (AVO) and Dr Sigrún Karlsdóttir (IMO)

The conjoint session agreed that ET-ETC should be notified of the foregoing developments while the VAAC Managers and VASAG Members would be kept informed of progress. **VAAC BP/7 Outcome VW7-O-04**

6.9 IWXXM implementation status amongst VAACs

6.9.1 In response to VAAC BP/6 Outcome VW6-O-05, Mr Bensimon gave a progress report on the status of implementation across all nine VAACs of the ICAO meteorological information exchange model (IWXXM) for volcanic ash advisory (VAA) information.

6.9.2 It was recalled that a prevailing recommended practice pertaining to IWXXM for VAA information – as given at ICAO Annex 3/WMO-No. 49, Volume II, Chapter 3, §3.1.2 (20th Edition, July 2018) – would be elevated to a Standard on 5 November 2020. Therefore, it was necessary for all VAACs to be in a position to disseminate VAA information using IWXXM by this deadline. The progress report revealed that work was ongoing within all VAACs to implement IWXXM in accordance with the indicated timeline.

6.9.3 Participants noted that the IWXXM schema developed by WMO at the request of ICAO was available here and that the associated technical specifications for IWXXM were given in the WMO *Manual on Codes* (WMO-No. 306), Volume I.3, Part D — *Representation Derived from Data Models* (available here). In addition, guidance on the implementation of IWXXM was provided in the ICAO *Manual on the Digital Exchange of Aeronautical Meteorological Information* (Doc 10003) (available here, ICAO Portal account required).

6.9.4 The conjoint session agreed that VAAC BP/6 Outcome VW6-O-05 could be closed in view of the fact that the establishment and maintenance of the IWXXM within each VAAC was becoming business-as-usual.

7. VOLCANIC SCIENCES INTO FUTURE OPERATIONAL APPLICATIONS

7.1 Holistic review of the IAVW

7.1.1 Mr Romero reported on the status of a holistic review of the IAVW emanating from the fourth meeting of the ICAO Meteorology Panel (METP/4) in September 2018 through Recommendation 4/1. Thus far, there had been little progress however proposals formulated by METP Members tasked to respond to Recommendation 4/1 were expected in time for the METP/5 meeting in September 2020, taking into account the prevailing arrangement of nine VAACs as well as the current and foreseen trends in aeronautical meteorological service provision guided by ICAO's Global Air Navigation Plan.

7.1.2 In this latter respect, it was remarked by Mr Lisk that a recently introduced space weather information service for aviation had been implemented globally (by ICAO) using consortia of space weather providers/centres located around the world and that this could, potentially, be a model considered in an IAVW context by the existing nine VAACs. The benefits of such an approach would include increased harmonization and consistency of service provision and the improved and more joined-up exploitation of the long-standing expertise of the existing VAACs, thereby mitigating the risk of any review unwittingly resulting in an increase in the number of VAACs (since an increase would be against the expressed wishes of aviation users, especially IATA).

7.1.3 Given the foreseen emergence of requirements for an SO_2 forecast information service, in addition to the planned introduction of a quantitative volcanic ash information service, the conjoint session commented that, potentially, there may be merit to distribute roles and responsibilities for both information service types across the VAACs, possibly in a consortium/consortia arrangement, thereby allowing workloads to be shared/normalized whilst also responding to the needs of aviation users.

7.1.4 While considering the evolution of volcanic ash services to aviation, Dr Hort and Mr Lisk gave a presentation highlighting changes within the aviation industry, the implications of the changes on aeronautical meteorological service providers, including VAACs, in terms of the forecast production process and its outputs (products and services versus data and information), the role of science in the evolution of service delivery, the foreseen challenges and opportunities, and possible strategies to be employed by service providers to respond to change.

7.1.5 Attention was also drawn to a long-term plan for aeronautical meteorology (available here) recently developed by the WMO Commission for Aeronautical Meteorology. The long-term plan provides a framework upon which aeronautical meteorological service providers of WMO Members in particular, and the broader meteorology and aviation communities in general, can plan a progressive transformation from a conventional "product-centric" approach to a modern "information-centric" approach to service provision for aviation through to 2030 and beyond.

7.2 Quantitatively-based volcanic ash information services

7.2.1 The conjoint session gave consideration to the introduction of quantitatively-based volcanic ash information services, in particular in the context of evolving science and technology to enable future operational applications and taking into account the outcomes of the preceding ICAO METP WG-MISD/5 (VASD) meeting (see 3.3 above).

7.2.2 Mr Muscat and Mr Hereil gave a presentation summarising the history of the emergence in 2010 of volcanic ash concentration charts by the meteorological offices co-located with VAACs London and Toulouse (namely UK Met Office and Météo-France), the reasons for such developments, the current status of the charts and expected changes over the coming months. In respect of the latter, it was noted that the UK Met Office and Météo-France intended to produce a snapshot (or pseudo-snapshot) chart (which displays instantaneous rather than time-averaged concentrations) by mid-2020 and that the temporal frequency of issuance may increase subject to user requirements. It was highlighted, however, that an increased number of charts would reduce the ability of the meteorologists to intervene in the forecast production process. It was also highlighted that there was a need to increase focus on assuring a reliable source term (eruption source parameter) for the dispersion modelling and to improve the understanding of and communicating of uncertainty in the forecast.

7.2.3 The conjoint session held an extensive discussion on the operational introduction of quantitative volcanic ash forecast information in support of aviation in the 2022 to 2026 timeframe. It was accepted that there was an absolute need for the IAVW to move towards quantitative information, since this was consistent with global trends and the expressed needs of aviation users. This said, since volcanic eruptions vary in type, size and duration it was suggested that *one size may not fit all* and, rather, that different approaches may need to be adopted to ensure the supply of relevant, reliable and consistent information to aviation users.

7.2.4 The continued advancement of remote sensing and in-situ observing of volcanic eruptions and volcanic ash clouds and gases in the atmosphere combined with the continued advancement of numerical weather prediction models and atmospheric transport dispersion modelling, including deterministic and probabilistic output, were viewed by the conjoint session as necessary means to constrain uncertainty and increase confidence in both the observations and the forecasts of volcanic ash clouds and gases supplied to aviation users.

7.2.5 The conjoint session also remarked that there would be a need to evolve the competencies of VAAC forecasters to respond to the likely fundamental changes in job role and to also assist in the educating of aviation users in the appropriate and optimal use of the quantitative information.

7.3 **Volcanic Sulphur dioxide information services**

7.3.1 The conjoint session gave consideration to the introduction of volcanic sulphur dioxide (SO_2) information services, in particular in the context of evolving science and technology to enable future operational applications and taking into account the outcomes of the preceding ICAO METP WG-MISD/5 (VASD) meeting (see 3.3 above).

7.3.2 A presentation given by Dr Schneider offered historical background of the requirement for volcanic sulphur dioxide (SO_2) information services, in particular through the work of the ICAO METP supported by expert input from the WMO/IUGG VASAG, techniques for estimating volcanic SO_2 concentrations in the atmosphere (at mean sea level and at altitude) and associated scientific challenges.

7.3.3 The conjoint session was reminded that the aviation requirements were, as per an ICAO METP Job Card, presently *only* concerned with the health effects of volcanic SO_2 on aircraft occupants and *not* concerned with the effects of volcanic SO_2 on the aircraft and/or its avionics.

7.3.4 The conjoint session devoted extensive discussion from scientific and technological perspectives on the introduction of a volcanic SO_2 forecast information service in support of

aviation, commencing with the initiation of a trial to be conducted by VAAC London in the 2020 timeframe. It was recalled that the ICAO METP WG-MISD/5 (VASD) had specifically requested the VASAG to determine the thresholds to be used in the trial. In this regard, occupational health SO_2 exposure thresholds of the World Health Organization (WHO) discussed at the last conjoint session (Wellington, November 2018) were revisited supplemented by consideration of the discernibility of volcanic SO_2 from satellite remote sensing, quantitative forecast output and thresholds and units appropriate for the ICAO METP WG-MISD trial by VAAC London.

7.3.5 At the conclusion of the discussion, the VASAG Members present during the conjoint session agreed to recommend the following thresholds and units for evaluation by VAAC London during the referred trial:

WMO exposure for 10 minutes:

- 0.175 parts per million (ppm) (the WHO standard)
- 1.750 ppm (WHO x 10)
- 4.375 ppm (WHO x 25)

Thus, 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:

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

7.3.6 It was agreed that these thresholds and units should be conveyed to the ICAO METP WG-MISD accordingly. **VASAG/9 Action 9/8**

8. PROPOSED ESTABLISHMENT OF AN EXPERT NETWORK ON VOLCANIC SCIENCES AND APPLICATIONS (EN-VSA)

8.1 Background and latest developments

8.1.1 Participants recalled that VAAC BP workshops and VASAG meetings had been convened by WMO and partners over the past decade or so to better enable the community to share operational best practices across the nine VAACs and to increase the awareness and integration of leading scientific and technological advances into VAAC operations. While such endeavours were highly appreciated, some issues in respect of the governance and functioning of the two groups had been noted – for example, neither group is directly attributed to a WMO technical commission or other subsidiary body. Participants had therefore welcomed recent efforts by WMO in 2018 and 2019 to convene the VAAC BP workshops and VASAG meetings as conjoint sessions, in an attempt to bridge a gap between the science and technology advances (VASAG) and the operational capabilities (VAAC).

8.1.2 Taking into account a presentation given by Mr Brock and Mr Lisk, the conjoint session noted that an ongoing major reform of WMO's governance structures, impacting all constituent bodies and secretariat structures, presented an opportunity to establish a more robust volcanic ash clouds and gases research-to-operations, science-for-services focus within the WMO construct. To this end, participants were apprised of a proposal to establish, in the 2020 timeframe, an Expert Network on Volcanic Sciences and Applications (EN-VSA) [working title] under the auspices of a new Standing Committee on Services for Aviation (SC-AVI) of a new Services Commission.

8.2 **Draft objective, terms of reference and composition**

8.2.1 Participants were apprised of a draft objective, terms of reference and composition of the proposed EN-VSA. Overall, feedback from the conjoint session was positive, including in the context of efforts to improve regional and gender balance in the activities of the new expert network and an increased ability for SVO representatives to contribute to the work.

8.2.2 It was noted that the EN-VSA, once established, would interface with other expert teams or expert networks of SC-AVI as well as with other WMO constituent bodies, including the new Infrastructure Commission, Research Board or their subsidiary bodies.

8.3 **Next steps**

8.3.1 In the near-term (before end-2020) and in view of the ongoing governance reform of WMO referenced above, participants were informed that it was anticipated that the proposed objective, terms of reference and composition of EN-VSA would be finalized in Q1/Q2 2020 prior to formal establishment under SC-AVI in the Q3/Q4 2020 timeframe. It was noted that, for continuity, any open outcomes or actions arising from this conjoint session (and previous workshops/meeting/sessions) would be considered by EN-VSA as appropriate.

8.3.2 In the longer-term (2021 or after), and taking into account the outcomes of the ICAO METP MG CWGP/1 referenced at 3.1 above, it was noted that WMO was keen to pursue a more integrated arrangement with ICAO to address IAVW-related issues, perhaps in the form of a joint working group (or similar).

8.3.3 It was noted that the VAAC Managers and VASAG Members would be kept appropriately informed of these developments by Mr Lisk and Mr Brock.

9. REVIEW OF OUTCOMES/ACTIONS ARISING FROM THE CONJOINT SESSION

9.1 Participants undertook a review of the outcomes/actions arising from this conjoint session and agreed to their content as given at Annex 6 to this report.

10. ANY OTHER BUSINESS

10.1 Recalling earlier remarks (4.4.4 above refers) concerning the out-of-date nature of some SVO contact information in ICAO Doc 9766, Mr Romero advised that corrected information could and should be forwarded to the ICAO Secretariat by SVOs (or VAACs on their behalf) for incorporation into a future update to Doc 9766. Ms Acethorp, in her capacity as the ICAO METP WG-MOG (IAVW) work stream lead, offered to assist.

10.2 Several participants expressed their appreciation for the convening of this conjoint session, helping to bridge the gap between science, technology and VAAC operations. In addition, in light of the foreseeing reform of VASAG and VAAC BP (see Section 8 above), the participants expressed their appreciation to Messrs Lisk, Tupper and Mastin for their leadership over the past decade or so.

11. CLOSURE OF THE CONJOINT SESSION

11.1 Mr Lisk led the closure of the conjoint session. He expressed his deep appreciation to all participants for their active contribution and he highlighted the importance for the work to be sustained over the coming months and years despite the foreseen reform of WMO's constituent

bodies. He highlighted also that IWVA/8 in October 2020 would be a prime opportunity to demonstrate the progress over the past 10 years, to showcase future developments given the introduction of quantitative volcanic ash and volcanic SO_2 information services for aviation, and to address known issues such as the capacity and capability of SVOs. He appreciated that this two-day conjoint session had been very limited in terms of time given the breadth of subject matter addressed, but that it had nonetheless achieved the key outcomes that he had challenged the group to deliver at the start of the meeting.

11.2 Also alluding to WMO reform, in closing Mr Mastin indicated that the next meeting might look quite different in terms of composition but that he hoped that the professionalism of the experts involved would be maintained given the experience of the past decade or so.

11.3 After an exchange of courtesies, the conjoint session closed at 1700 hours on Friday 22 November 2019.

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AGENDA

1. **Organization of the conjoint session**
   - 1.1. Opening and introductions
   - 1.2. Adoption of the agenda
   - 1.3. Working arrangements
2. **Review of open outcomes/actions of previous meetings**
   - 2.1. Open VAAC BP outcomes
   - 2.2. Open VASAG actions
3. **Summary of relevant outcomes/actions arising from preceding ICAO meetings**
   - 3.1. METP MG CWGP/1
   - 3.2. METP WG-MOG/11 (IAVW)
   - 3.3. METP WG-MISD/5 (VASD)
4. **Volcano monitoring**
   - 4.1. ESP database for restless volcanoes
   - 4.2. Remote sensing monitoring of volcanoes including infrasound
   - 4.3. WOVO guidance review and update (status update only)
   - 4.4. SVO-VAAC interactions including capacity development opportunities or other needs/expectations
   - 4.5. Other relevant developments
5. **Preparations for IWVA/8**
   - 5.1. Background and latest developments
   - 5.2. Draft concept note
   - 5.3. Formation of a scientific organizing committee
   - 5.4. Preliminary programme development, including potential topics/themes and contributors
   - 5.5. Next steps
6. **Volcanic sciences into current VAAC operational applications**
   - 6.1. Advancements in remote sensing and in-situ monitoring of volcanic ash and other gases
   - 6.2. Advancements in modelling of eruptive plumes, transport and dispersion
   - 6.3. Scientific publications and outreach
   - 6.4. VAAC strength of evidence checklists (status update only)
   - 6.5. Lessons learned/challenges identified during recent eruptions
   - 6.6. VAAC collaboration tools (status update only)
   - 6.7. VAAC backup arrangements (status update only)
   - 6.8. VAAC forecaster competency framework (status update only)
   - 6.9. IWXXM implementation status amongst VAACs (status update only)

7. Volcanic sciences into future operational applications

7.1. Holistic review of the IAVW (status update only)

7.2. Quantitatively-based volcanic ash information services

7.3. Volcanic Sulphur dioxide information services

8. Proposed establishment of an Expert Network on Volcanic Sciences and Applications (EN-VSA)

8.1. Background and latest developments

8.2. Draft objective, terms of reference and composition

8.3. Next steps

9. Review of outcomes/actions arising from the conjoint session

10. Any other business

11. Closure of the meeting

STATUS UPDATE ON THE OUTCOMES OF THE FOURTH VOLCANIC ASH BEST PRACTICE WORKSHOP (VAAC BP/4) (2016)			
Outcome No.	**Description**	**Lead**	**Status at VAAC BP/7 (2019)**
VW4-O-03	**Modelling** - All VAACs in coordination with the relevant NWP provider(s), to further investigate and report on NWP errors/performance (taking into account region specific issues e.g. tropics) relevant to volcanic ash modeling and VAAC 'Ins and Outs' Modelling tables to be reviewed, updated and shared **every 2-years** (next update 2020).	VAAC London (Updated tables added to VAAC BP website by end of July 2016)	**Open** (Recurrent activity)
VW4-O-16	**Volcanic hazard monitoring and observing capabilities** Volcanic ash AIREPS, in-situ, remote sensing and volcano monitoring information availability and dissemination processes need to be enhanced and better coordinated with associated guidance including operational application best practice updated/developed. (IAVWOPSG ref 7/23, 8/3, 8/21, 8/22) – METP WG-MOG paper	WMO. Routine VASAG updates submitted to METP WG-MOG meetings.	**Open** (Recurrent activity)

All other VAAC BP/4 outcomes were closed prior to VAAC BP/7

STATUS UPDATE ON THE OUTCOMES OF THE SIXTH VOLCANIC ASH BEST PRACTICE WORKSHOP (VAAC BP/6) (2018)			
Outcome No.	**Description**	**Lead**	**Status at VAAC BP/7 (2019)**
VW6-O-01	**VAAC Strength of Evidence Checklists** a) All VAAC Managers encouraged to introduce, as soon as possible, operational use of the strength of evidence checklists within their respective forecast office (and non-operational use for training purposes where appropriate) and to provide feedback to VAACs Tokyo and Darwin (as focal points) on the utility of the checklists, including suggestions for improvement, by 30 June 2019; b) Taking into account the feedback received from a) above as well as that received from the VASAG in 2018, VAACs Darwin and Tokyo (Jarrad Denman and Kazuki Ito) to further improve the checklists methodologies and to present progress reports in this regard on a biennial basis (next report in 2020).	All VAACs with Tokyo and Darwin as focal points	a) **Closed** (Complete) b) **Ongoing** (Next report 2021, not 2020 as indicated)

STATUS UPDATE ON THE OUTCOMES OF THE SIXTH VOLCANIC ASH BEST PRACTICE WORKSHOP (VAAC BP/6) (2018)

Outcome No.	Description	Lead	Status at VAAC BP/7 (2019)
VW6-O-02	**Satellite inter-comparisons of discernible ash** Strongly encourage the VAACs to continue or to commence satellite inter-comparisons of the old and new generation of satellite imagery – as a minimum between a VAAC and its backup centre – and to consider the feasibility of establishing similar inter-comparison efforts for ATDM output for volcanic ash in the atmosphere. Progress report by all VAACs on a biennial basis (next report in 2020).	All VAACs	**Closed** (Overtaken by events)
VW6-O-04	**VAAC Collaboration Tool** VAAC Tokyo (Kazuki Ito), with the assistance of VAAC Wellington (Marcel Roux) and in coordination with the other VAACs, encouraged to lead the further development and operational introduction of a VAAC collaboration tool consistent with the basic functional needs identified in 2017 and taking into account the feedback at VAAC BP/6 in 2018. Progress report not later than 2020.	VAAC Tokyo	**Closed** (Complete and business-as-usual)
VW6-O-05	**IWXXM Schema Implementation** All VAACs are encouraged to continue to pursue the introduction of the IWXXM schema for the VAA/VAG in readiness for November 2020 applicability of associated ICAO Annex 3 provisions. Progress report not later than 2020.	All VAACs	**Closed** (Complete and business-as-usual)
VW6-O-07	**VAAC Washington Backup Arrangements** VAAC Washington (Jamie Kibler) to: a) work with other VAACs, particularly but not necessarily exclusively those in the Americas, to seek the establishment of a more viable VAAC backup arrangement for their operations; and b) consider whether serving as the primary backup centre for three other VAACs (Anchorage, Buenos Aires and Montreal) is entirely suitable given the operational risk this represents within the IAVW during periods when VAAC Washington itself is unserviceable. Alternative proposals to be investigated accordingly. Progress report not later than 2020.	VAAC Washington	a) **Closed** (More viable backup arrangement nearing conclusion) b) **Closed** (To form part of holistic review of IAVW)

STATUS UPDATE ON THE OUTCOMES OF THE SIXTH VOLCANIC ASH BEST PRACTICE WORKSHOP (VAAC BP/6) (2018)			
Outcome No.	**Description**	**Lead**	**Status at VAAC BP/7 (2019)**
VW6-O-08	**Competency Framework for VAAC Forecasters** Ian Lisk, in his capacity as president of CAeM, to task the CAeM Expert Team on Education, Training and Competency (ET-ETC) to initiate and lead work on amending the top- and/or second-level competencies for AMF such that they can be applied for VAAC forecasters. This work should be undertaken in consultation with VAAC managers/representatives and VASAG members as necessary. Progress report via correspondence by 30 June 2019.	Lisk	**Closed** (Replaced by new outcome at VAAC BP/7)

All other VAAC BP/6 outcomes were closed prior to VAAC BP/7

ANNEX 4

STATUS UPDATE ON THE ACTIONS ARISING FROM THE SIXTH VOLCANIC ASH SCIENTIFIC ADVISORY GROUP MEETING (VASAG/6) (2015)		
Action No.	**Description**	**Status at VASAG/9 (2019)**
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).	**Closed** (Business-as-usual)
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 training modules, in collaboration with other relevant countries and with CAeM ET-ETC.	**Closed** (Incorporated into outreach and publications plus establishment of VA-related personnel competencies)

All other VASAG/6 actions were closed prior to VASAG/9

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STATUS UPDATE ON THE ACTIONS ARISING FROM THE SEVENTH VOLCANIC ASH SCIENTIFIC ADVISORY GROUP MEETING (VASAG/7) (2017)			
Action No.	**Description**	**Lead**	**Status at VASAG/9 (2019)**
7/4	**State Volcano Observatory responsibilities** 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.	Romero	**Closed** (Replace by new action at VASAG/9)
7/5	**Aircraft encounters database and severity index** 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.	Schneider (for Guffanti)	Encounters database – **Open** (Ongoing)

STATUS UPDATE ON THE ACTIONS ARISING FROM THE SEVENTH VOLCANIC ASH SCIENTIFIC ADVISORY GROUP MEETING (VASAG/7) (2017)			
Action No.	**Description**	**Lead**	**Status at VASAG/9 (2019)**
	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.		Severity index – **Closed** (Doc 9691 updated in 2019)

All other VASAG/7 actions were closed prior to VASAG/9

STATUS UPDATE ON THE ACTIONS FROM THE EIGHTH VOLCANIC ASH SCIENTIFIC ADVISORY GROUP MEETING (VASAG/8) (2018)			
Action No.	**Description**	**Lead**	**Status at VASAG/9 (2019)**
8/1	**Publications and Outreach** Andrew Tupper and Larry Mastin requested, in coordination with VASAG members and Matt Hort (representing GAW APP SAG), to: a) lead further discussions and devise proposals on outreach in support of the IAVW; b) specifically consider becoming involved with an ACP publication (Andrew Tupper); and c) determine the feasibility of authoring a 2020 publication that provides a ten-year retrospective on the progress made since the eruption of Eyjafjallajökull in Iceland (Larry Mastin). Progress report via correspondence by 30 June 2019.	Tupper and Mastin	**Closed** (Replaced by new action at VASAG/9)
8/2	**IWVA Concept Note** David Schneider is requested, in coordination with VASAG members and Matt Hort (representing GAW APP SAG), to lead the development of an update to a draft Concept Note for a proposed IWVA/8 in the late-2020 timeframe. Progress report via correspondence by 30 June 2019.	Schneider	**Closed** (Complete)

STATUS UPDATE ON THE ACTIONS FROM THE EIGHTH VOLCANIC ASH SCIENTIFIC ADVISORY GROUP MEETING (VASAG/8) (2018)

Action No.	Description	Lead	Status at VASAG/9 (2019)
8/3	**Review and Update of WOVO guidance on the IAVW** David Schneider and Sara Barsotti to lead a review and, as necessary, update of the WOVO Guidance for State Volcano Observatories: The International Airways Volcano Watch (available at URL: http://www.wovo.org/assets/docs/gvo2009s.pdf). Progress report via correspondence by 30 June 2019.	Schneider and Barsotti	**Open** (Ongoing)

ANNEX 5

PROVISIONAL TIMELINE OF ACTIVITIES ASSOCIATED WITH IWVA/8

When	What	Who
December 2019	**Planning phase** Formation of SOC Finalisation of Concept Note	WMO WMO with SOC
January 2020	Securing of budget (WMO and host) Draft Letter of Agreement (WMO and host)	WMO and LOC WMO and LOC
February	**Preparation phase** Establishment of website Securing of sponsors/exhibitors (if any) Issuance of invitation (including Concept Note) and First Call for Papers	WMO WMO and LOC WMO with SOC
March	Second (Final) Call for Papers Identification of keynote speakers	WMO with SOC SOC
April	Review, shortlisting and selection of abstracts Notification to those selected (and not selected) Communication/outreach (first wave)	SOC SOC/WMO WMO/SOC/LOC
May	Programme development Review/publication of papers received Identification of recipients of financial support (if any)	SOC SOC/WMO WMO
June	Programme development (ongoing) Review/publication of papers received (ongoing)	SOC SOC/WMO
July	Programme development (ongoing) Review/publication of papers received (ongoing)	SOC SOC/WMO
August	Programme development (ongoing) Review/publication of papers received (ongoing) Preparation of draft (skeleton) report Communication/outreach (second wave)	SOC SOC/WMO WMO WMO/SOC/LOC
September	Finalisation of the programme Preparation of draft recommendations	SOC SOC
October	**Execution phase** Convening of IWVA/8 Satisfaction survey conducted with participants	WMO and LOC WMO
November	**Post-event phase** Preparation of final report including recommendations Review of satisfaction survey results	WMO with SOC WMO with SOC
December 2020	Publication of final report	WMO

ANNEX 6

OUTCOMES OF THE SEVENTH VOLCANIC ASH BEST PRACTICE WORKSHOP (VAAC BP/7) (2019)			
Outcome No.	**Description**	**Lead**	**Deadline**
VW7-O-01 (para. 2.1.2)	**VAAC 'Ins and Outs' Modelling Tables** VAACs to send Matt Hort suggestions for improvement to the document/tables (available here). *For example, areas to expand the scope of the document/tables and the specifications on the modelling capabilities and tools available to VAAC forecasters.*	All VAACs	17 January 2020
VW7-O-02 (para. 6.4.3)	**SVO Decision Tree examples** Dave Schneider to make examples of State volcano observatory 'decision trees' available to VAAC Darwin to facilitate the further enhancement of the VAAC Strength of Evidence Checklists.	Schneider	**Closed** (Completed 22 November 2019)
VW7-O-03 (para. 6.5.3)	**VAAC Anchorage verification of VAA/VAG** Jeff Osiensky to make the coding used to verify VAAC Anchorage VAA/VAG available to the VAACs and others concerned.	Osiensky	30 March 2020
VW7-O-04 (para. 6.8.4)	**Competency framework for VAAC forecasters and SVO observers** a) ET-ETC to be notified of the outcomes of the VAAC BP/7 workshop in respect of a competency framework for VAAC forecasters and SVO observers, including the following identified points of contact: • For VAACs: Mr Dov Bensimon (VAAC Montreal) and Mr Jarrad Denman (VAAC Darwin) • For SVOs: Dr Dave Schneider (AVO) and Dr Sigrún Karlsdóttir (IMO) b) VAAC Managers and VASAG Members to be kept informed of progress.	Lisk and Brock	a) **Closed** (Completed 2 December 2019) b) 30 June 2020

ACTIONS ARISING FROM THE NINTH VOLCANIC ASH SCIENTIFIC ADVISORY GROUP MEETING (VASAG/9) (2019)

Action No.	Description	Lead	Deadline
9/1 (para. 2.2.3)	**State Volcano Observatory responsibilities** 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. *[Replaces VASAG/7 Action 7/4]*	Romero	30 March 2020
9/2 (para. 3.3.4)	**Final report of ICAO METP WG-MISD/5 (VASD)** Raul Romero to make a courtesy copy of the WG-MISD/5 (VASD) final report available to the VASAG Members for reference purposes only.	Romero	As soon as available
9/3 (para. 4.2.4)	**Infrasound detection data in support of the IAVW** WMO, ICAO and CTBTO to explore the possibility to enhance their cooperation in support of the IAVW, perhaps through an exchange of letters and/or an enhancement to existing working arrangements.	Brock, Romero and Mialle	30 March 2020
9/4 (para. 5.5.2)	**Planning and preparation for IWVA/8** WMO should progress the formation of the SOC, the finalization of the Concept Note, development of the programme and other activities associated with IWVA/8 consistent with the timeline given at Annex 5 of this report.	Brock and Lisk in coord. with VASAG Members and VAAC Managers	As per timeline given at Annex 5 of this report
9/5 (para. 6.1.3)	**IAVW Roadmap and Concept of Operations (ICAO)** Raul Romero to make the latest IAVW Roadmap and Concept of Operations available to the VASAG as information only.	Romero	**Closed** (Completed 4 December 2019)

ACTIONS ARISING FROM THE NINTH VOLCANIC ASH SCIENTIFIC ADVISORY GROUP MEETING (VASAG/9) (2019)			
Action No.	**Description**	**Lead**	**Deadline**
9/6 (para. 6.1.3)	**Input to Coordination Group for Meteorological Satellites (CGMS)** WMO and/or ICAO to provide input to CGMS regarding the identified need of aviation users for quantitative volcanic ash cloud and gas information services within the next decade and the potential implications on supporting the exploitation of meteorological satellite capabilities	Brock and Romero in coord. with VASAG Members	30 March 2020
9/7 (para. 6.3.1)	**Scientific outreach and publications** VASAG Members to link prospective volcanic ash-related scientific articles and publications with the upcoming IWVA/8 in October 2020, for example by way of a special volume of scientific papers *[Replaces VASAG/8 Action 8/1]*	Witham in coord. with other VASAG Members	IWVA/8 (October 2020)
9/8 (para. 7.3.6)	**Volcanic SO_2 thresholds for VAAC London trial** WMO to inform ICAO of the volcanic SO_2 thresholds recommended by the VASAG for use in the VAAC London trial in response to ICAO METP WG-MISD Action 5/2 as follows: WMO exposure for 10 minutes: • 0.175 parts per million (ppm) (WHO) • 1.750 ppm (WHO x 10) • 4.375 ppm (WHO x 25) Thus, for a cloud that is 1,000 m thick (3,280 ft) at an altitude of 10 km (32,800 ft), this equals an SO2 total column loading of: • 3 Dobson Units (DU) (WHO) • 55 DU (WHO x 10) • 140 DU (WHO x 25)	Brock	**Closed** (Completed 23 November 2019)

— END —