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International Civil Aviation Organization

WORKING PAPER

INTERNATIONAL AIRWAYS VOLCANO WATCH OPERATIONS GROUP (IAVWOPSG)

EIGHTH MEETING

Melbourne, Australia, 17 to 20 February 2014

Agenda Item 4: Review of ICAO provisions related to the IAVW (Deliverable 02)
4.3: Review of IAVW-related guidance material

DEVELOPMENT OF GUIDANCE TO SUPPORT THE APPLICATION OF THE "DISCERNIBLE ASH" DEFINITION FOR OPERATIONAL USE

(Presented by the United Kingdom as Rapporteur of the ad-hoc working group on Conclusion 7/6)

SUMMARY

This paper provides an update on the above conclusion concerning the development of guidance material to support VAAC monitoring of relevant ground-based and airborne data to detect the existence and extent of volcanic ash in the atmosphere.
Action by the meeting is in paragraph 5.

1. INTRODUCTION

1.1 The seventh meeting of the International Airways Volcano Watch Operations Group (IAVWOPSG/7) approved the following definitions for inclusion in the *Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds* (Doc 9691).

a) *Visible ash — volcanic ash that can be observed by the human eye; and*

b) *Discernible ash — volcanic ash detected by: defined impacts on/in aircraft; or by agreed in-situ and/or remote-sensing techniques.*

Defined impacts on/in aircraft are outlined in the ICAO manual on *Flight Safety and Volcanic Ash* (Doc 9974).

1.2 The term "visible ash" should **only** be used to describe the human-eye observation of volcanic ash and thereby be acknowledged as a purely qualitative definition. The term "discernible ash" applies to both qualitative aircraft-related impacts and to quantitatively-based in-situ and remote sensing detection methods. If ash has been observed by the human eye or detected by impacts on/in the aircraft, then it is universally recognized that some form of reactive mitigating action should be taken. Whenever possible, volcanic ash advisory centres (VAACs) will primarily use "*agreed in-situ and/or remote sensing techniques"* to underpin their analysis and forecast advisories upon which strategic planning decisions are then taken.

1.3 IAVWOPSG/7 also developed the following proposed amendment to Annex 3 – *Meteorological Service for International Air Navigation*, Chapter 3, 3.5.1:

> 3.5.1 A Contracting State, […] shall arrange for that centre to respond to a notification that a volcano has erupted, or is expected to erupt or volcanic ash is reported in its area of responsibility, by arranging for that centre to:
>
> a) monitor relevant geostationary and polar-orbiting satellite data and, where available, relevant ground-based and airborne data and observations, to detect the existence and extent of volcanic ash in the atmosphere in the area concerned;
>
> *Note.— Relevant ground-based and airborne data and observations include data derived from Doppler weather radar, ceilometers, Lidar, in-situ measurements and passive infrared sensors.*
>
> […]

1.4 Remote-sensing techniques for volcanic ash detection utilizing backscatter ceilometer and Lidar data are being developed with a view to these subsequently being integrated into the development of multi-capability volcanic ash observing networks. In-situ measurements (i.e. taken directly at the point of interest and in contact with the subject of interest) from suitably instrumented aircraft can also provide additional detailed information on the dimensions and characteristics (e.g. ash concentration) of volcanic cloud layers.

1.5 Given the above information, this paper is developed in support of:

Conclusion 7/6 — Guidance material to support VAAC monitoring of relevant ground-based and airborne data to detect the existence and extent of volcanic ash in the atmosphere

That an ad-hoc working group consisting of Australia, France, Germany, United Kingdom (Rapporteur), United States and WMO be tasked to:

a) develop adequate guidance material for inclusion in the *Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds* (Doc 9691), to support VAAC monitoring of relevant ground-based and airborne data to detect the existence and extent of volcanic ash in the atmosphere; and

b) report to the IAVWOPSG/8 meeting.

1.6 Therefore, this paper's purpose is to report on the progress since the IAVWOPSG/7 meeting and what may be required for future development work.

2. DISCUSSION

2.1 The following is a status of the science on detecting discernible ash.

2.2 Near real-time satellite-based remote-sensing imagery is utilized by the VAAC as the primary agreed means of volcanic ash detection. This information has traditionally been complemented, where available, by AIREPs of volcanic ash and in METAR/SPECI in situations where the observation site is in relatively close proximity to the eruption source. In the most favorable conditions, the satellite-derived mass column loading detection threshold of 0.2 g/m^2 ($\pm$0.150 g/m^2) is recognized (IVATF/4-WP/11) as the quantitative constraint (lower threshold to be used by the VAACs) for satellite-based remotely sensed discernible ash. Assuming an ash cloud of 1000 metres mean thickness this would equate to an approximate equivalent ash mass concentration threshold of 0.2 mg/m^3.

2.3 Research (e.g. Ansmann *et. al*,. 2011; Flentje *et. al*., 2010; Winker *et. al*., 2012) based largely on European sourced data from the Eyjafjallajökull event of April/May 2010 has demonstrated that detection thresholds of ground, airborne and space-based (CALIOP) Lidar and ceilometer aerosol techniques are equivalent to $\leq$0.03 mg/m^3 i.e. around an order of magnitude below the ash detection threshold of infrared satellite sensors. Both Lidars and ceilometers are based on optical remote-sensing technology, with the primary differences between the two being the power of the laser used and the complexity of the instrument itself, although the capabilities of both are significantly impacted by the presence of meteorological clouds. The more powerful Lidars are able to detect fine aerosol particles e.g. volcanic ash, throughout the depth of the atmosphere whereas ceilometers have a reliable volcanic ash detection range of typically between 4000 and 6000 metres. Ceilometers have been used operationally for many years to measure the height of cloud bases, whilst Lidar have until now primarily been operated by research establishments. It should also be noted that in the absence of other sources of observational information, it is difficult for ceilometers to discriminate volcanic ash from other aerosol types such as water droplets and sulphates unless additional techniques, for example dual polarization Lidar capability, are available. Even with a dual-polarization Lidar capability it can still be difficult to discriminate between similarly angular shaped ash, desert dust and ice particles.

2.4 Lidar co-located with sun-photometers can, under ideal conditions (daytime and largely cloud-free skies), be used to derive estimates of ash mass concentration by using sun-photometer measurements of aerosol optical depth. Other assumptions such as those relating to the non-spherical shape of the ash particles need also be made but initial research has evidenced encouraging results, error bars of a factor of 2 or 3. The challenge now is to develop improved algorithms that can be used in near-real-time. It should also be recognized that the use of powerful multi-wavelength Lidar can pose significant "eye safety" issues that can limit the range of wavelengths available for use.

2.5 Aircraft mounted probes and sensors offer in-situ measurements of volcanic ash concentration although there are only a limited number of suitably equipped research and "civil contingency" aircraft and the majority of these operate only in European airspace. It is also recognized that regulatory considerations related to safety risk assessment need to be taken into consideration.

2.6 Other aircraft mounted detectors including passive infra-red sensors such as the airborne volcanic object identifier and detector (AVOID) system are currently the subject of ongoing research and development and, as such, no definitive detection thresholds or operational applications are currently available.

2.7 Doppler radar can be utilized to determine near-source eruptive plume height, plume dynamics, and particle size. For example, the Iceland Meteorological Office now maintains two fixed C-band Doppler weather radar and two mobile dual-polarization X-band “volcanic ash detection” radar to monitor ash from Icelandic volcanic eruptions in near-real-time.

2.8 Research (e.g. Marzano *et. al.*, 2012) has demonstrated that Doppler radar (X band) cannot reliably detect fine ash once it is transported more than 15 kilometers from the eruptive source . Applications of radar for detecting ash in the distal plume are therefore very limited.

2.9 Aerosol sondes, capable of the in-situ measurement of volcanic ash have been the subject of preliminary research over the last few years with the result that a few prototypes have been tested in the United Kingdom. These particle counter based systems have not yet proved accurate enough to progress from the research arena although further research to develop fully operational and commercially viable units is ongoing.

2.10 Traditional air-reports (AIREPs) continue to offer a very subjective assessment of the presence of volcanic ash and the reliability of such reports inevitably diminishes with distance from the eruptive source. Nevertheless, AIREPs, cross-checked against other observational data as available, will continue to be given a high weighting in the assessment of volcanic ash and particularly so when other observational data are not available.

3. **FINDINGS**

3.1 The development of new capabilities and techniques for the detection and monitoring of discernible volcanic ash continues to be an active area of research.

3.2 Multi-spectral satellite imagery is already being used in operational applications, although it should be noted that geostationary satellite capabilities vary significantly around the world depending on geographic location.

3.3 Ceilometers and Lidar are increasingly being transitioned into operations, particularly in Europe where the EARLINET (European Aerosol Research Lidar Network) and EUMETNET (network of 29 European National Meteorological Services) E-PROFILE programs are working closely with the World Meteorological Organization (WMO) Global Atmosphere Program (GAW) to develop an operational Lidar and ceilometer network for Europe.

3.4 In-situ measurements of volcanic ash concentrations are available from only a small number of suitably equipped aircraft located in, or readily accessible to, areas with volcanic ash so spatial coverage is very limited in comparison to satellite networks. Similarly Lidar/ceilometer networks cover a small area in comparison to satellite networks. Commercial aircraft mounted remote sensing and in-situ probes and sensors are the subject of further research but the operational deployment and application of such capabilities is still to be realized.

3.5 Doppler radar can be used to monitor the height of the eruptive plume, but the fine nature of distal volcanic ash limits radar derived applications to no more than 15 kilometers from the volcanic eruption.

3.6 Aerosol sondes remain an ongoing field of research with potential for significant geographical coverage in remote parts of the world or in areas where traditional observations are not available.

3.7 As discussed above, no one capability can be used as sole source to provide guidance on the location of the ash cloud. Rather, an integrated observing network that incorporates the full range of existing capabilities and techniques is recommended.

3.8 It should be recognized that with the exception of the very limited number of suitably equipped strategically located aircraft, extensive, **accurate near-real-time measurements** of ash mass concentration are simply not available, notwithstanding that **estimates** of mass concentration based on "educated" assumptions, algorithms, and observations utilizing satellite derived ash mass column loading retrievals, Lidar, ceilometer and sun-photometer data are being rapidly developed.

4. CONCLUSIONS

4.1 Considering that the minimum detection threshold of Lidar and ceilometer systems is around **0.03 mg/m^3**, which is almost an order of magnitude below an approximation associated with the minimum satellite detection threshold, it is proposed that the "agreed technique" for these capabilities should be limited to clear skies evidence of "no discernible ash" i.e. Lidar and ceilometers systems should not to be used as evidence of 'discernible ash' unless supported by other forms of observational evidence such as qualitative satellite imagery or ash concentration measurements of at least **0.2 mg/m^3** derived from in-situ airborne or Lidar/sun-photometer measurements. Without traditional infrared satellite observations to the contrary, VAACs should treat areas having Lidar/sun-photometer measurements less than 0.2 mg/m^3 as an area without discernible ash.

4.2 With regard to the information provided in this paper, the group is invited to formulate the following conclusion:

Conclusion 8/xx — Agreed in-situ and/or remote sensing techniques for discernible ash

That an ad-hoc group consisting of members from all the VAAC Provider States, with the United Kingdom as Rapporteur, IATA, IUGG and WMO, be tasked to:

a) further review the conclusions and state of the science related to the development and use of "agreed techniques" for remotely sensed and in-situ volcanic ash observations; and

b) develop associated proposed guidance material for a "Best Practices" document rather than the *Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds* (Doc 9691) for consideration by the

IAVWOPSG/9 meeting.

5. ACTION BY THE IAVWOPSG

5.1 The IAVWOPSG is invited to:

a) note the information contained in this working paper; and

b) decide on the draft conclusion proposed for the group's consideration.

References:

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