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AIRCRAFT ENCOUNTERS FROM THE 18 AUGUST 2000 ERUPTION AT MIYAKEJIMA, JAPAN

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Abstract

Four large commercial aircraft are known to have encountered clouds produced by the 16-17 km high phreato-magmatic eruption of 18 August 2000 at Miyakejima, Japan, which lies close to Japan's two busiest airports at Haneda and Narita. Many other aircraft flew close by the eruption clouds. A near-new Boeing 737-800 and a Boeing 747 both suffered extensive damage and required engine replacement. Another 747 encountered ash and sulphur dioxide, was inspected for three days without any damage found, and a third 747 encountered the cloud approximately 800 km (430 nautical miles) to the southeast, smelt sulphur dioxide but suffered no damage. Costs to the aviation industry are known to exceed US $12,000,000, but this figure is probably a gross under-estimate. The eruption was very well observed from the air and from the ground, and initial warnings were issued quickly, however SIGMETs did not give sufficient detail of the ash cloud dispersion, air-traffic management decisions appear to have been made on the basis of superseded VAAC forecasts for the prior, low-level eruption, and the known encounters all happened to foreign airlines, while Japanese airlines had access to more information about the activity at Miyakejima and made appropriate flight plans. The Miyakejima incidents teach us about the importance of pre-eruption information and planning, of having worldwide rather than country-specific ash-avoidance procedures, of universal and consistent information distribution, and of rigorous post-event investigations. On the positive side, the rapid eruption observation and reporting and the pre-flight planning of local airlines probably contributed to the lack of fatalities from this extremely dangerous eruption.

Introduction

The phreato-magmatic eruption of Mount Oyama, Mikayejima, Japan, on 18 August 2000 was one of the most dangerous volcanic eruptions from the viewpoint of aviation safety in recent years. The eruption began on 8 July 2000 with a crater collapse. Several larger eruptions then occurred, on 10, 18[t] and 29 August (Kinoshita *et al.*, 2002). An evacuation order for Miyakejima residents was announced on 1 September 2000, and high SO_2 fluxes continue to affect the region.

The eruption of 18 August was sudden, but not completely unexpected in the context of the preceding activity. Researchers from the Earthquake Research Institute of Tokyo University had already set up a camera to record the eruptions (Kinoshita *et al.*, 2002), and since the volcano lies only 160 km south of Tokyo, public awareness was already very high. The event was well reported by pilots and ground observers, and seen remotely with hourly satellite imagery and radar (Iino *et al.*, 2001: Tupper *et al.*, 2004). Despite this, two aircraft suffered severe damage from the eruption cloud 90 minutes after the beginning of the eruption, and two other aircraft are known to have flown through the cloud.

Remote sensing issues associated with the eruption, and a brief chronology of events, are given in Tupper et al. (2004). The purpose of this paper is to focus on factors pertinent to the aircraft encounters. We are not seeking to apportion blame to individuals or agencies, but to examine issues associated with what is a complex and still developing warning International Airways Volcano Watch.

Location of Encounters

The 18 August 2000 eruption occurred at 0802 UTC (17:02 JST) Fig. 1 shows the location of Miyakejima, and of the four verified encounters, the first two of which occurred at about sunset:

i) A Boeing 747 had requested a diversion that was only partially allowed because of military airspace ("Octagon" on Fig. 1). The aircraft encountered ash cloud at 34,000 ft (10.3 km) at about 0930 UTC, and exited the cloud at 30,000 ft (9.1 km) 2 minutes later. The aircraft made an emergency landing at Narita. Three engines, the flight deck windshield, and some forward passenger windows were replaced. The fourth engine was to be replaced after 100 hours flying time. The airline made an initial cost estimate of at least US $5 million.

ii) A near-new Boeing 737-800 also encountered the cloud at about 0930 UTC, at 36,000 feet (10.9 km), having received no verbal warnings from Air Traffic Control or nearby aircraft. Just before penetration into the ash cloud, Air Traffic Control had given the flight a radar vector directing the aircraft 40NM (74 km) northeast of Airway B586, an action that was ineffective for avoidance. The flight management computer and electronic engine controls failed, but the engines still functioned. The cockpit filled with 'haze and dust'. The aircraft made an emergency landing. Both engines were damaged and had to be replaced, forward visibility was lost on the windscreen except for a small area under the windshield wiper. The leading edges and tail were abraded, and the radome, air data probes damaged. The cost was at least US $ 5 million.

iii) At 1235 UTC, a Boeing 747 encountered strong sulphuric smells and 'sparking' on the windshield, strongly indicative of an ash encounter. The aircraft had diverted from Airway B586 to Airway 337 in an attempt to avoid the ash, and was partially successful since satellite imagery suggests less ash in that area. The aircraft was removed from service and inspected for three days, but no ash or damage was found. Nevertheless, the cost to this airline of diversions and inspections exceeded US $2 million.

iv) At 2010 UTC, another 747 reported sulphuric smells. There was no evidence of ash in this encounter, although the aircraft was apparently not removed from service for a detailed inspection. This aircraft had diverted a considerable distance eastward from Airway 337, after receiving the report of the 1235 UTC encounter.

Other aircraft movements

The movement of other aircraft around the eruption cloud are incompletely known. A DC-10 transited the same airspace at almost the same time as the first two confirmed encounters, but made no report. Given the extent of the eruption clouds and their proximity to Narita and Haneda airports, it seems likely that other aircraft encountered ash.

Four Japan Airlines flights observed the eruption during the evening (from 0830 UTC to 0924 UTC), and successfully avoided the ash clouds, as did later night flights. It appears that the action taken was generally to fly to the northwest of the eruption, the only area unpolluted at cruising levels. This avoidance action appears quite contrary to the Air Traffic Control advice to the aircraft in encounter ii), and reflects the fact that the Japan Airlines flights were operating with superior information and were not reliant on the official warnings.

Performance of International Airways Volcano Watch

Fig. 2 summarises the time and stated cloud height of advisories and warnings. The eruption was exceptionally well observed by the Japan Meteorological Agency and by pilots, reports were made extremely quickly, and the speed of issue of warnings was probably the fastest of any major event in the history of the International Airways Volcano Watch. The time from eruption, to the issue of a volcanic ash advisory, then to the domestic 'Area Meteorological Advisory' (ARMAD) and then the international SIGMET, the official meteorological warning for the eruption, was still twenty-three minutes in total, reflecting a long chain of communication. However, the first SIGMET was still issued over an hour before the two most serious aircraft encounters.

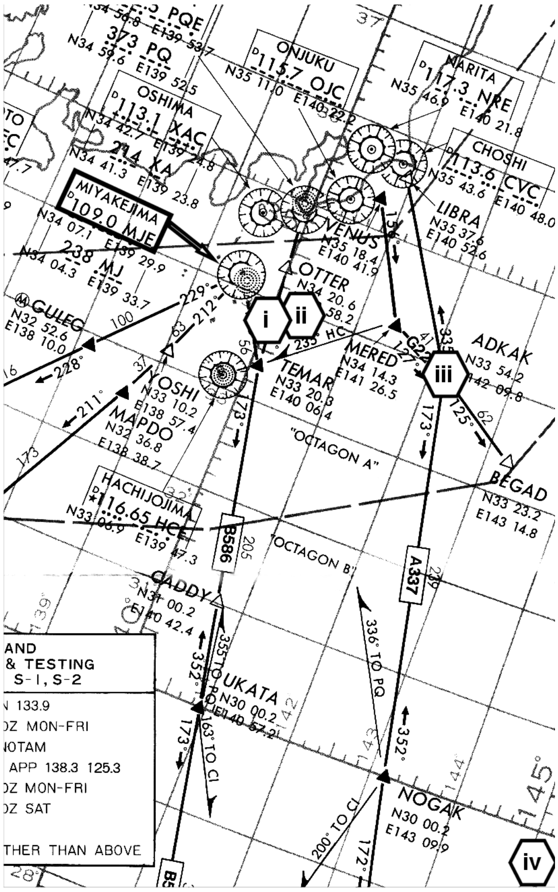

Figure 1 - Detail of air routes around Miyakejima. Hexagons labelled i-iv denote positions of reported aircraft encounters. The areas of restricted airspace are labelled 'Octagon A' and 'Octagon B'

A number of major problems can be identified. Firstly, the observation received by Tokyo VAAC at 0812 UTC of an eruption with tops ***greater than*** FL190 (5.8 km) was translated into tops ***to*** FL190 in the official NOTAM and SIGMETs (Fig 2, 'a'). The entire avoidance procedure during the critical first phase of the eruption was based on the incorrect assumption of a low-level eruption.

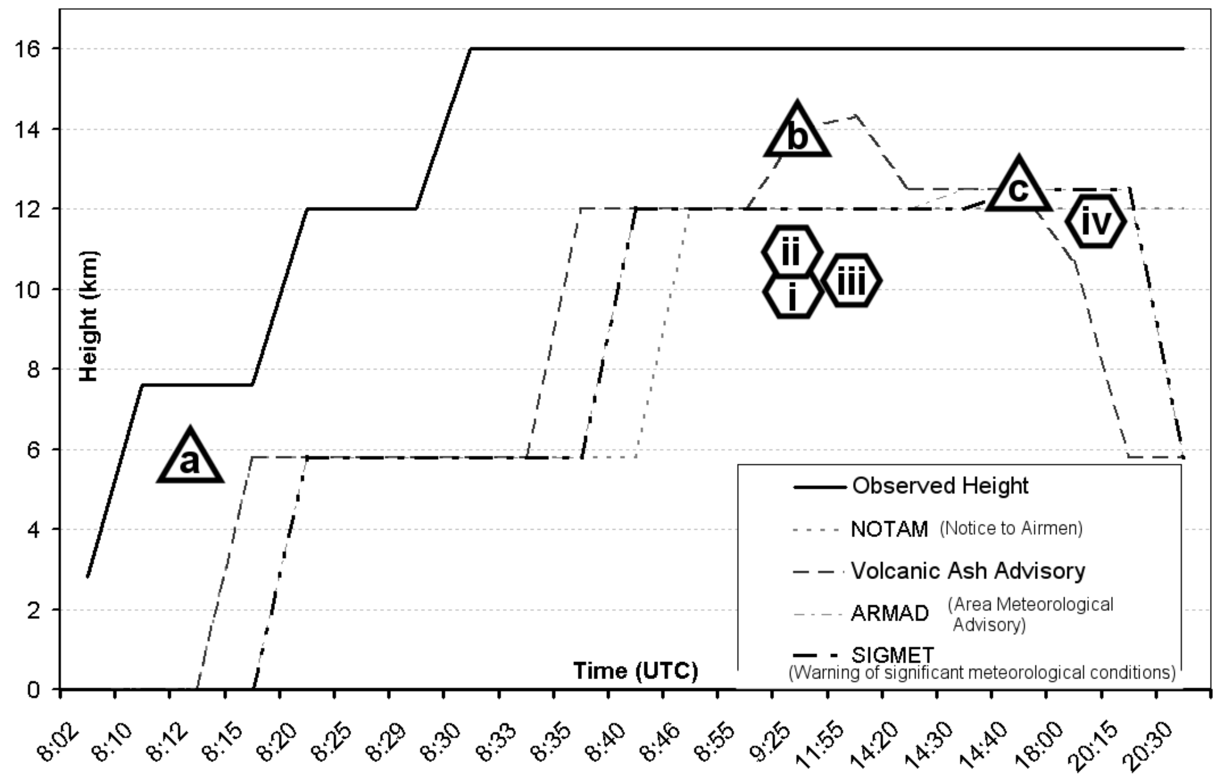

Figure 2 - Height of eruption reflected in observations, advisory and warning products. Lettered triangles show the time of key events described in the text, and hexagons show the time and height of confirmed aircraft encounters.

Even though these warnings were superseded around 0835 UTC, the misinformation continued to propagate through the warning system, as the initial information was passed on. This kind of height confusion is actually quite common: a useful guideline may be to assume that eruption clouds above 5 km extend to the tropopause until evidence is given to the contrary (Tupper and Kinoshita, 2003).

Secondly, the cloud dispersion at cruising levels was not well understood. The Tokyo VAAC was unable to prepare and issue a full dispersion forecast for the eruption until 0925 UTC ('b' in Fig.2), i.e. about the time of the encounters. The SIGMETs, the official warning product, never included a dispersion forecast and stated only that the ash was going to the southeast or east-southeast. The wind field in the area and likely dispersion of the plume was well known, with an upper air observation station just to the south, and an observation of eruption height over 45,000 ft (13.7 km) and spot wind observation of northwest winds at 50 knots (92 km/h) reported to Air Traffic Control by JAL at 0830 UTC. Despite this controllers apparently failed to grasp the extent of the cloud and were directing aircraft into the ash an hour after the JAL report and high-level SIGMET.

During the event, staff at Tokyo VAAC became concerned these issues, and took the initiative of distributing extra graphics showing a 'close-up' view of the eruption cloud.

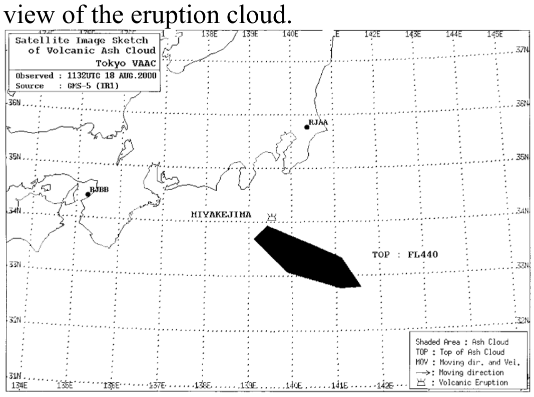

Figure 3 - Supplementary nephanalysis issued during the event by Tokyo VAAC.

Thirdly, as in many other volcanic ash events, the procedures for warning cessation at the stage where ash becomes difficult to detect were not defined. Encounter iv) occurred after the high level ash had become impossible to detect on satellite imagery and as Tokyo VAAC staff were beginning to concentrate on the lower level eruption clouds (Fig. 2, 'c').

Fourthly, it appears that, where local operators such as Japan Airlines were in direct receipt of graphical warnings, followed their own contingency plans, and were well aware of the situation at Miyakejima, foreign operators were not as well informed. All operators should receive the official warnings, and an arrangement exists where Japan Airlines redistributes graphical advices to other airlines. However it is evident from the written reports of airlines that suffered damage that justifiably or otherwise, they felt badly informed. As a consequence, the Tokyo VAAC was pressured with phone calls from several airlines, as well as the media, frustrating the VAAC's efforts to get information into the official warning system, and also frustrating the foreign operators who struggled with language issues.

Finally, despite the seriousness of the encounters and some direct complaints by airline operators, we have been unable to find any evidence of an investigation by the government agencies concerned. We assume that, because no post-analysis is explicitly mandated in the arrangements of the International Airways Volcano Watch, and no agreement was in existence between the responsible agencies in Japan that required an investigation in a situation where aircraft have been damaged but no fatalities have occurred, no process existed to trigger such an investigation.

<u>Discussion</u>

None of the issues identified above are uniquely Japanese. For example, in the Australian region, Qantas functions as a conduit for volcanic information to other international airlines in the same way that Japan Airlines does in Japan, and it is likely that any sudden eruption in Australian airspace would show that some airlines are far better informed than others.

Formally, Volcanic Ash Advisory Centres exist to advise Meteorological Watch Offices about the dispersion of volcanic ash cloud. However, airline dispatchers, who make critical decisions about their aircraft, are often desperate for information during crises and will use whatever resources are available to make their decisions. Personal relationships are also highly emphasised in meteorological / aviation relationships the world over; information flows much more freely where offices perceive a good working relationship.

A major challenge for the International Airways Volcano Watch is to ensure that enough information is distributed over *official* warning channels to allow all operators to avoid the ash cloud. Current initiatives, such as globally consistent volcanic ash graphics, universal SIGMET and NOTAM implementation, and better training, could substantially improve the information distribution. In turn, this will reduce the pressure on VAACs to provide telephone service to aviation operators.

There are substantial issues of workload. For example, the SIGMET 2 for this event was:

RJTG SIGMET 2 VALID 180845/181445 RJAA – TOLYO FIR VA MIYAKEJIMA (34.1N 139.5E) OBS at 0829 OVER MIYAKEJIMA VA TOPS MORE THAN FL400 DRIFTING TO E-SE BY B747 INTSF

This SIGMET, while informative, contains no explicit dispersion forecast. In today's coding, an appropriate SIGMET for that time may have been:

RJTG SIGMET 2 VALID 180845/181445 RJAA-TOKYO FIR VA ERUPTION MIYAKEJIMA LOC N31 E139 VA CLD OBS AT 0830Z SE OF MIYAKEJIMA SFC/FL460 N3415 E13925 - N3410 E13950 - N3345 E13955 - N3350 E13930 - N3415 E13925 MOV SE 40KT INTSF FCST 1445Z VA CLD APRX N3430 E13915 - N3420 E14105 - N3035 E14330 - N3155 E13850 - N3430 E13915 OTLK 012045Z VA CLD APRX N3435 E13905 - N3035 E13830 - N2855 E14505 - N3415 E14220 - N3435 E13905 020130Z VA CLD APRX N3440 E13905 - N2955 E13830 - N2730 E14700 - N3410 E14305 - N3440 E13905

Even this SIGMET is a simplification, as it treats all the ash as one layer in a situation where the wind changed markedly with height. Text SIGMETs will be necessary for some time yet, until graphical products are universal. When composing and then decoding SIGMETs such as those above, which are derived from even more complex Volcanic Ash Advisories, some delay is inevitable unless the whole process can be simplified and/or automated.

The deamnds of the media are unlikely to be reduced by informative warnings. It is difficult to keep operational contact numbers confidential, and every centre should have a firm policy for handling media enquiries during an event. Since there is virtually no public benefit in feeding extra information to the media during an event, responding these calls should be given a low priority at most.

Large volcanic eruptions in any particular area are relatively infrequent. The mistakes made in the VAAC, Meteorological Watch Office, airline offices and Air Traffic Control centres are likely to recur for future eruptions in other regions unless regular training is performed. Similarly, the sensitivities associated with any damage from a volcanic event are such that, unless a clear protocol is already in place for post-analysis, it is possible that no effective investigation would be performed.

A final point of interest is that no damage was found to the aircraft involved with encounter (iii), despite three days of inspections. When compared to the Hekla 2000 incident (Grindle and Burcham, 2003), this suggests that further research is necessary to determine the danger threshold of ash clouds.

Following the Miyakejima eruptions, the Tokyo VAAC has had substantial experience with other eruptions. Volcanic SIGMETs, previously restricted to heights around 5 km, are now issued for all altitudes. Numerous case studies have been conducted for training purposes, a VAAC web site has been created, and the Japan Meteorological Agency provides a representative to the ICAO International Airways Volcano Watch Operations Group, which is shaping the future warning system.

Conclusions

The eruption of Miyakejima provides us with a remarkable example of a major eruption of a monitored volcano, in airspace serviced by highly sophisticated aviation and meteorological services. The eruption therefore gives us an insight into the issues that are likely to be prominent over the rest of the world once the basic technological challenges of monitoring are sorted out.

In this case, despite rapid observation of the eruption and a relatively rapid issue of warnings, two aircraft were seriously damaged, and at least two others encountered the cloud. To address these challenges, we suggest:

1) Further development of the International Airways Volcano Watch to ensure that information before and during an eruption is adequate for international aviation operators.
2) Regular training and drills to ensure operational readiness.
3) The development of internationally agreed post-analysis procedures for improvement of the International Airways Volcano Watch.

Acknowledgements

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References

Grindle, T. J. and F. W. Burcham, 2003, Engine damage to a NASA DC-8-72 airplane from a high-altitude encounter with a diffuse volcanic ash cloud. Technical Memorandum NASA/TM-2003-212030, 22 pp.

Iino, N., K. Kinoshita, M. Koyamada, S. Saitoh, K. Maeno, and C. Kanagaki, 2001, Satellite imagery of ash clouds of the 2000 eruption of Miyake-jima volcano. *CEReS International Symp. on Remote Sensing of the Atmosphere and Validation of Satellite Data*, Chiba, Japan, 13-8.

Kinoshita, K., C.Kanagaki, N.Iino, M.Koyamada, A.Terada, and A.Tupper, 2002, Volcanic plumes at Miyakejima observed from satellites and from the ground. *Optical Remote Sensing of the Atmosphere and Clouds III*, H.-L. Huang, D. Lu, and Y. Sasano, Eds., SPIE, 227-36.

Tupper, A. and K. Kinoshita, 2003. Satellite, air and ground observations of volcanic clouds over islands of the Southwest Pacific. South Pacific Study, *23*, 21-46.

Tupper, A., S. Carn, J. Davey, Y. Kamada, R. Potts, F. Prata, and M. Tokuno, 2004. An evaluation of volcanic cloud detection techniques during recent significant eruptions in the western 'Ring of Fire'. Remote Sens. Environ., *91*, 27-46, doi:10.1016/j.rse.2004.02.004.