Doc 9691
AN/954

Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds

Approved by the Secretary General
and published under his authority

Third Edition — 2015

International Civil Aviation Organization

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AMENDMENTS

Amendments are announced in the supplements to the *Publications Catalogue;* the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS		
No.	Date	Entered by

CORRIGENDA		
No.	Date	Entered by

FOREWORD

On 24 June 1982, the aviation community and much of the world learned of the drama involving a British Airways B747 aircraft which lost power on all four engines while flying at 11 300 m (37 000 ft) from Kuala Lumpur, Malaysia to Perth, Australia. During the ensuing sixteen minutes, the aircraft descended without power from 11 300 m to 3 650 m (37 000 ft to 12 000 ft), at which point the pilot was able to restart three of the engines and make a successful emergency landing at Jakarta, Indonesia.

Over the next few days the civil aviation authorities, engine manufacturers and the airline company involved mounted an urgent investigation into the cause of the four-engine flame-out. On-site inspection of the airframe and engines revealed a general "sand-blasted" appearance to the leading edges of the wing and engine inlet surfaces, the radome and the cockpit windows. Borescope inspection of the engines revealed no apparent mechanical damage and no fuel problem, but heavy deposits of an unknown material were found on the concave surfaces of the high-pressure turbine and nozzle guide vanes.

The report of the incident by the pilot indicated that an acrid electrical smell had been noticed in the cockpit at the time and what appeared to be very fine dust or smoke entered the cockpit. St. Elmo's fire was observed on the leading edge of the engine nacelles and around the cockpit windows, and a "search light" effect was visible shining out of the engines through the fan blades. Moreover, when the aircraft was making its emergency landing at Jakarta, it was immediately apparent that the cockpit windows were almost completely opaque and the landing had to be completed by the pilot looking through a small side- section of the cockpit window that had remained relatively clear.

Piecing together the available evidence and knowing that a large Indonesian volcano, Mt. Galunggung, had been erupting at the time of the incident, suspicion quickly focused on a volcanic ash cloud as being the likely culprit. This suspicion gained further support some three weeks later when another aircraft, a B747 of Singapore Airways bound for Melbourne, Australia, reported a similar incident. This time power was lost on two engines and the aircraft also diverted successfully to Jakarta.

Subsequent strip-down inspection of the engines from the British Airways aircraft revealed general evidence of "sand-blasting", erosion of compressor rotor paths and rotor blade tips, erosion of the leading edges of high-pressure rotor blades and fused volcanic debris on the high-pressure nozzle guide vanes and turbine blades. It was clear that the engines on the aircraft had all stalled due to ingestion of volcanic ash and that a restart had only been achieved because the aircraft, in descending without power, happened to fly out of the high-level volcanic ash cloud into clear air.

The seriousness of these two incidents was not lost on the aviation community. While it was known that aircraft had encountered difficulties in the past when inadvertently flying through volcanic ash cloud, these incidents had generally been restricted to the sand-blasting effect of the ash on cockpit windows and to blocked pitot-static tubes. It was now perfectly clear to all that such ash clouds had the potential to cause a major aircraft accident.

To meet this newly recognized threat, the ICAO Air Navigation Commission moved swiftly to develop a set of interim guidelines to assist States in the dissemination of information on volcanic ash to pilots and the development of contingency arrangements for the diversion of aircraft around affected areas, pending the development of the necessary formal amendments to the relevant Annexes to the Chicago Convention and Procedures for Air Navigation Services (PANS). These formal amendments were subsequently developed, with the assistance of the ICAO Volcanic Ash Warnings Study Group (VAWSG), and were adopted by the ICAO Council in March 1987.

The initial amendments to the ICAO Annexes and PANS comprised international Standards, Recommended Practices and Procedures covering the observation and reporting of volcanic activity, eruptions and ash cloud, the issuance to aircraft of warnings and, as necessary, information regarding the closure of air routes and the activation of alternative contingency routes, and the reporting by pilots to air traffic service units of any observed volcanic activity or encounter with volcanic ash cloud. These initial provisions essentially formed the framework for the ICAO International Airways Volcano Watch (IAVW), the establishment of which was made possible by the cooperation of States and a number of international organizations.

In addition, the need to develop guidance material on volcanic ash in the form of an ICAO circular was identified by the Air Navigation Commission. During the next few years, however, events moved faster than anticipated with a number of explosive eruptions occurring including Mt. Redoubt and Mt. Spurr in Alaska in 1989 and 1992, respectively, Mt. Pinatubo in the Philippines and Mt. Hudson in Chile in 1991, all of which affected aviation. The experience gained in conducting aircraft operations during these and other eruptions permitted the development of detailed regional procedures to cope with the situations. In view of this, the Air Navigation Commission agreed that the guidance material on volcanic ash should be issued as an ICAO manual and not as a circular.

Further amendments to the ICAO Annexes and PANS were made to provide for the issuance by meteorological watch offices (MWOs) of information concerning en-route weather phenomena which may affect the safety of aircraft operations (SIGMETs) encountering a volcanic ash cloud, to assist operators at the flight planning stage in the dispatch of aircraft on long-haul routes and to include provisions relating to Volcanic Ash Advisory Centres (VAACs). In this regard, international arrangements were made, in cooperation with the World Meteorological Organization (WMO), to designate nine regional volcanic ash advisory centres having the capability to detect, track and forecast the movement of volcanic ash clouds and provide advice to meteorological watch offices in their areas of responsibility. The role and responsibilities of the VAACs were introduced into Annex 3 by Amendment 71 which became applicable on 5 November 1998.

Since the eruptions of Mt. Galunggung in Indonesia in 1982 there have been numerous explosive volcanic eruptions around the world, many of which have affected aircraft operations. With the occurrence of each new eruption, the opportunity has been taken to focus on and review the local and international arrangements for the issuance of information to pilots and, where necessary, fine-tune these arrangements based on actual operational experience gained in dealing with the impact of the eruptions on aircraft operations. In this way, the IAVW is being steadily expanded and strengthened.

There have been many difficulties faced in the establishment of the IAVW, most of which have been of a technical or procedural nature which, with the cooperation of States and international organizations, have since been resolved. There is, however, a more general difficulty that is unlikely to ever be eliminated completely and which, therefore, requires constant attention. This concerns the fact that the IAVW depends entirely on cooperation between a number of different disciplines such as air traffic services, communications, meteorology and vulcanology and numerous and varied national observing sources such as forestry stations, customs/immigration border posts, etc., within sight of active volcanoes. Constant attention is required by States to maintain effective communications channels from the various observing sources to the relevant area control centres (ACCs) and MWOs. Moreover, because explosive volcanic eruptions in any one State are, thankfully, comparatively rare events, maintaining the currency of the local procedures during numerous staff changes and over long periods when the procedures may never have had to be activated under the circumstances of a real volcanic eruption in a particular State, is extremely difficult.

In addition to its potential to cause a major aircraft accident, the economic cost of volcanic ash to international civil aviation is staggering. This involves numerous complete engine changes, engine overhauls, airframe refurbishing, window re-polishing and/or replacement and pitot-static system repair, etc., and the inevitable loss of revenue due to aircraft down-time while the foregoing is accomplished. Delays to aircraft and their rerouting around volcanic ash has caused considerable expense to airlines operating in regions prone to volcanic eruptions. Also to be included is the cost of volcanic ash clearance from airports and the damage caused to equipment and buildings on the ground. Various estimates have been made, most citing costs to aviation well in excess of $250 million since 1982.

The Meteorology (MET) Divisional Meeting (2002), held conjointly with the Twelfth Session of the Commission for Aeronautical Meteorology (CAeM) of WMO, recommended the establishment of the International Airways Volcano Watch Operations Group (IAVWOPSG) to coordinate and develop the international airways volcano watch (IAVW) with a global perspective. Since then, the IAVWOPSG has held several meetings in various ICAO regions making considerable progress on the refinement of existing, and the development of new, Standards and Recommended Practices, procedures and associated guidance material, thereby placing the IAVW as a mature system to support international air navigation in ensuring the availability of up-to-date and relevant information on volcanic ash in the atmosphere.

In April 2010, the explosive phase of the Eyjafjallajökull eruption in Iceland provoked an unprecedented disruption of air operations, which paralyzed aircraft operations in the western and northern parts of the European (EUR) and eastern parts of the North Atlantic (NAT) regions for many days. This event prompted the establishment by ICAO of an International Volcanic Ash Task Force (IVATF) tasked to urgently address, in close coordination with the IAVWOPSG, issues relevant to the Eyjafjallajökull eruption. The IVATF was tasked to, inter alia, review the guidance material, establish volcanic ash contingency plans, improve ash detection systems and develop ash concentration thresholds. Without reaching agreement on ash concentration thresholds, the IVATF was disbanded in 2012 after completion of most of the assigned tasks and prompting several legacy tasks to the IAVWOPSG. Today, ICAO, with the assistance of the IAVWOPSG, continues the development of the IAVW in order to ensure that it continues to meet evolving operational requirements.

Given the safety and economic implications of volcanic ash to aircraft operations, it is necessary to maintain the ICAO International Airways Volcano Watch much in the same way that the aerodrome fire services are maintained: in constant readiness but with the fervent hope that it rarely has to be used.

Generally speaking, volcanic ash in the atmosphere is of little direct safety concern to anyone except aviation. It falls upon the aviation community, therefore, to take the lead in establishing and maintaining the essential channels of communication between volcano-observing sources and the relevant ACCs and MWOs and maintaining the currency of the local staff instructions and procedures. The main purpose of this manual, therefore, is to assist States and international organizations in this effort by gathering together in one document information on the problem of volcanic ash and provide guidance regarding what each of the parties in the IAVW is expected to do and why.

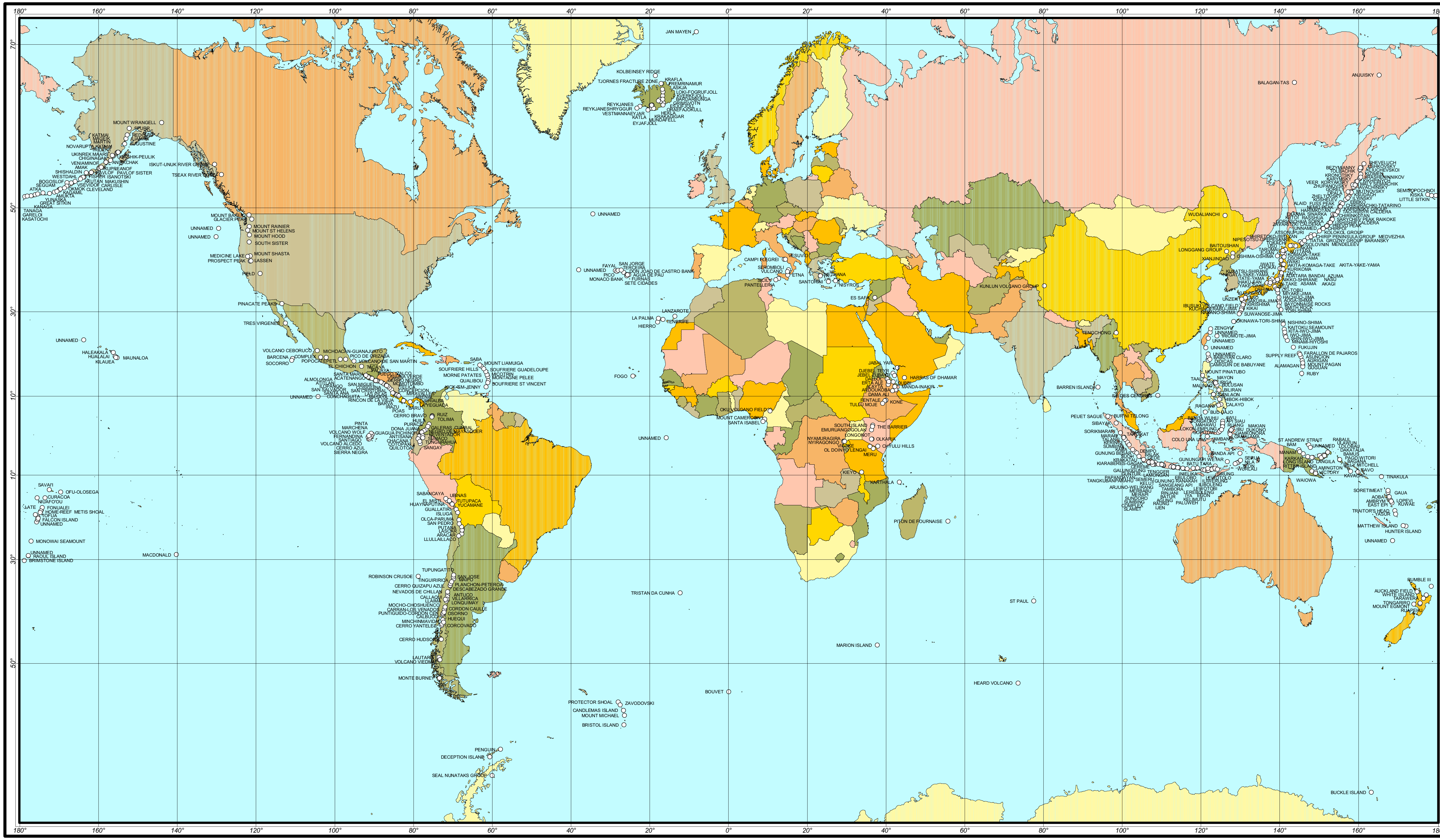
Since the aircraft incidents involving volcanic ash described above, which prompted the development of the IAVW, aviation has been faced with two other newly recognized hazards. These concerned radioactive materials and toxic chemicals discharged into the atmosphere following industrial accidents. The accident at the Chernobyl nuclear power plant in 1986, in which a cloud of radioactive debris spread across international borders, caused difficulties for aircraft operations in neighbouring States and drew attention to the potential risk for aircraft en-route to destinations which lay in the path of such a cloud. Similar accidents have occurred at industrial chemical plants and during the transport of toxic chemicals which so far have caused only local operational problems, but which also have the potential to affect international aircraft operations.

The Air Navigation Commission considered that, given the operational similarities in the provision of warnings to aircraft for radioactive materials and toxic chemicals on the one hand and for volcanic ash on the other, it would be expedient for the VAWSG to advise the Secretariat on the development of the necessary international arrangements and procedures for warning aircraft in flight of radioactive materials and toxic chemicals accidentally discharged into the atmosphere.

Accidents at nuclear or chemical facilities, in which hazardous materials are discharged into the atmosphere, present a danger to the general public, including those travelling by air, and are already the subject of detailed emergency procedures in States concerned, and regular international tests of the procedures are made. It is not the purpose of ICAO, therefore, to develop separate procedures for aviation, but to ensure that due account is taken of the special needs of international civil aviation, especially aircraft in flight, in the relevant Annexes to the Convention and in international arrangements developed to deal with such emergencies.

In addition to addressing the problem of volcanic ash, a secondary purpose of this manual, therefore, is to provide information concerning the requirements for the provision of warnings to aircraft of radioactive materials and toxic chemical clouds and guidance regarding how these requirements may be satisfied.

There is little point in having such guidance material unless it is used in the relevant training courses for staff whose duties are involved in any way with the provision of operational information to aircrew, and in the training courses for the aircrew themselves. States are, therefore, requested not only to make this manual available to staff concerned, but also to ensure that relevant training courses adequately cover the subject matter contained therein.



VOLCANOES OF THE WORLD

3000 0 3000 Km

Mercator Projection

Volcanoes with Eruptions During the Last 10,000 Years
Prepared in 1995 by Roland Pool, Smithsonian Institution,
Global Volcanism Program, NHB MRC 119, Washington, DC 20560

A 101x147 cm map, This Dynamic Planet, showing these volcanoes, earthquake epicenters, impact craters, plus tectonic and physiographic data is available from: US Geological Survey, Map Distribution Center, Box 25256, Federal Center, Denver, CO 800225 (800) USA-MAPS

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GLOSSARY

ACC	area control centre
AFTN	aeronautical fixed telecommunication network
AIA	Aerospace Industries Association
AIREP	air-report
AIRMET	information concerning en-route weather phenomena which may affect the safety of low-level aircraft operations
AIRS	Alliance Icing Research Study
AIS	aeronautical information service
ALPA	Air Line Pilots Association
AMIC	area manager-in-charge
AMSU-A	advanced microwave sounding unit-A
AMSU-B	advanced microwave sounding unit-B
ANC	Air Navigation Commission
APU	auxiliary power-unit
ATOVS	advanced TIROS observational vertical sounder
ATS	air traffic service
AVHRR	advanced very high resolution radiometer
AVO	Alaska Volcano Observatory
CCI	Convention Information Structure
CNES	Centre National d'Études Spatiales (the French space agency)
EGT	exhaust gas temperature
EOS	Earth observing system
EPR	engine pressure ratio
FIC	flight information centre
FIR	flight information region
GMS	geostationary meteorological satellite
GOES	geostationary operational environmental satellite
GTS	global telecommunication system
HF	high frequency
HIRS	high resolution infrared sounder
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
IAVCEI	International Association of Volcanology and Chemistry of the Earth's Interior
IAVW	International airways volcano watch
IFALPA	International Federation of Air Line Pilots'Associations
IUGG	International Union of Geodesy and Geophysics
JMA	Japanese Meteorology Association
LIDAR	light detection and ranging
MODIS	moderate resolution imaging spectroradiometer
MSU	microwave sounding unit
MTSAT	multifunctional transport satellites
MWO	meteorological watch office
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data and Information Service
NOAA	National Oceanic and Atmospheric Administration
NOF	international NOTAM office

NOTAM	notice to airmen
PANS	Procedures for Air Navigation Services
RSMC	Regional specialized meteorological centre
SADIS	satellite distribution system for information relating to air navigation
SAR	synthetic aperture radar
SBUV	solar back scattered ultra violet
SEVIRI	spinning enhanced visible and infrared imager
SIGMET	information concerning en-route weather phenomena which may affect the safety of aircraft operations
SIGWX	significant weather
SITA	International Society for Aeronautical Telecommunications
SSU	stratospheric sounder unit
TAF	aerodrome forecast
TOMS	total ozone mapping spectrometer
UNDRO	United Nations Disaster Relief Organization
USGS	United States Geological Survey
UUA	urgent pilot request
UV	ultraviolet
VAAC	Volcanic Ash Advisory Centre
VAFTAD	volcanic ash forecast transport and dispersion
VAR	volcanic activity reporting
VAWSG	Volcanic Ash Warnings Study Group
VEI	volcanic explosivity index
VFR	visual flight rules
VHF	very high frequency
WAFC	world area forecast centre
WAFS	world area forecast systemWIFS WAFS Internet file service
WMO	World Meteorological Organization
WOVO	World Organization of Volcano Observatories

PART I

Volcanoes and Volcanic Ash

INTRODUCTION TO PART I

Humanity has a primeval fear of volcanic eruptions as a manifestation of the awesome and capricious power of nature, totally beyond our control and more often than not the deliverer of death and destruction. Although there are hundreds of active volcanoes around the world, they are not evenly distributed, but generally located together in well-known geologically active regions.

The highest concentration of active volcanoes lies around the rim of the Pacific Ocean, the so-called “ring of fire”, which stretches northwards, more or less continuously, along the western edge of South and North America, across the Aleutian and Kurile Island chains, down through Kamchatka, Japan and the Philippines and across Indonesia, Papua New Guinea and New Zealand to the islands of the South Pacific. Other active regions are to be found in Iceland, along the Great Rift Valley in Central and East Africa, and in countries around the Mediterranean. This distribution is shown on the map provided as the frontispiece.

The behaviour of erupting volcanoes ranges from the quiet, steady effusion of lava at one extreme to highly explosive eruptions at the other which blast several cubic kilometres of glass particles and pulverized rock (volcanic ash) and corrosive gases high into the atmosphere and over a wide area for several days. Most people are familiar with the quiet activity typical of the volcanoes in Hawaii, where one can even touch the edge of the slowly moving lava flow; this is not the type of volcano that is of concern to aviation.

Aviation is only concerned with the explosive type of eruption, which presents a direct threat to aircraft in flight and major operational difficulties to aerodromes located downwind of the resulting ash cloud. The provision of warnings to aircraft in flight and aerodromes downwind of volcanic eruptions and volcanic ash clouds necessitates close operational coordination between the international aviation community, aviation meteorologists and vulcanologists. Coordination between the aviation community and meteorologists is of long standing, going back to the beginning of aviation, and is based upon well-established international arrangements and procedures; but coordination with the various vulcanological/seismological agencies has been a completely new concept requiring development of the necessary channels of communication, international arrangements and procedures virtually from scratch.

Vulcanological observatories are the first line of defence. They are usually sited in strategic locations from which one or more active volcanoes may be monitored. The wealth of continuous data from the various sensors sited on and around the volcanoes has to be analysed and interpreted by vulcanologists. If an explosive eruption is observed or if the analysis of the monitoring data indicates that such an eruption is imminent, this information has to be sent quickly through pre-arranged channels of communication to an agreed list of recipients, including the civil aviation and meteorological authorities, and then to pilots of aircraft which could be affected.

This is the basis of the ICAO International Airways Volcano Watch (IAVW). Unfortunately, and for obvious reasons, not all active volcanoes around the world are monitored. Moreover, explosive eruptions have a tendency to occur with little or no warning from volcanoes which have not erupted for hundreds of years. It was clear from the beginning that a dedicated volcano observing network could not be established specifically for aviation; the cost alone would have been prohibitive. In order to expand the volcano observing sources, therefore, recourse was made to other organized international networks of observatories such as meteorological, climatological and hydrological stations and to national organizations which maintain disciplined personnel in remote mountain areas in which volcanoes may be located, such as forestry, police, military, customs/immigration posts, and also disaster relief agencies. In all cases, unstinted cooperation was offered to ICAO by States and international organizations in the establishment of the IAVW, and in this way coverage was extended by making maximum use of existing resources.

Pilots themselves are also an important source of information on volcanic activity and volcanic ash cloud, and in this regard ICAO has developed a format for a special air-report of volcanic activity which pilots are encouraged to use when reporting volcanic activity to air traffic services units.

Finally, considerable progress has been made in the detection of volcanic ash from meteorological satellite data, especially data in certain of the infrared wavelengths, and the forecasting of volcanic ash cloud trajectories using computer models. The techniques and equipment needed to accomplish this work are not available in all meteorological watch offices (MWOs). ICAO, therefore, has designated, based upon advice from the World Meteorological Organization (WMO), certain specialized meteorological centres having the necessary capability to serve as volcanic ash advisory centres (VAACs). These centres provide advice to MWOs and area control centres (ACCs) in their area of responsibility of the forecast trajectory of the volcanic ash and the flight levels likely to be affected. The MWO and ACC then issue the required SIGMET and notice to airmen (NOTAM) messages, respectively, to pilots, based on the advice received.

The view is prevalent in the aviation community, rightly or wrongly, that there must have been an increase in explosive volcanic eruptions during the past twenty years or so. Otherwise, how to explain the apparent sudden appearance of volcanic ash on the scene as a serious hazard to aircraft operations? This view gives rise to some amusement among vulcanologists, who are more accustomed to consider volcanic eruptions over periods of thousands of years.

Any attempt to discern trends in volcanic eruptions from the historic record is fraught with difficulties. That there has been an overall increase in volcanic eruptions reported over the past two hundred years is evident, but this trend has closely paralleled the increase in the global population and its spread to all corners of the world over the same period. That this upward trend in volcanic eruptions is almost certainly due to more effective communications and increased reporting is illustrated by the sudden and temporary decrease in reports of volcanic eruptions during the two World War periods and during the Depression of the 1930s, when global communications were dislocated. Similarly, temporary increases in reports of volcanic eruptions around the world follow closely on the heels of a major volcanic eruption, no doubt due to the wide publicity accorded the event.

It would not, therefore, be surprising if the apparent “recent” increase in volcanic eruptions, cited by some observers as the likely cause of volcanic ash emerging as a hazard to aviation, were to become self-fulfilling due to the increased vigilance and reporting introduced by the IAVW.

Another factor to be considered is the steady increase in aircraft operations during the past twenty years, especially around the Pacific rim, most of which have involved aircraft powered by jet turbine engines, and especially the high by-pass ratio engines, which are inherently more susceptible to volcanic ash than piston-engined aircraft.

Wherever the truth of the matter lies, the last twenty years have certainly seen the emergence of volcanic ash as a serious hazard and financial cost to aircraft and aerodrome operations. With the cooperation of States through their civil aviation, meteorological, pilot and vulcanological communities and with the assistance of international organizations concerned, the IAVW has been developed to respond to this threat.

SCIENTIFIC BACKGROUND

Chapter 1

VOLCANIC ERUPTIONS

1.1 CLASSIFICATION

1.1.1 Volcanic eruptions can be classified in a number of different ways, but the most relevant for aviation purposes is a classification in terms of “explosivity”. Explosivity provides some idea of the magnitude of the eruption and more important whether, and how much, volcanic ash is ejected into the atmosphere and the likely height of the column. Vulcanologists have developed a “volcanic explosivity index”[1] (VEI) which ranges from 0 to 8 (Table I-1-1 and Table F-1 of Appendix F) based on a rough estimate of the volume of “ejecta”, height of the volcanic ash column and duration of continuous eruption blast. As may be seen from the table, the criteria overlap considerably because it is quite impossible to classify volcanic eruptions into rigid compartments.

1.1.2 Although volcanic eruptions range more or less continuously from one end of the scale to the other, certain “types” of eruption can be distinguished, and most of these have been named after typical volcanoes i.e. “Hawaiian”, “Strombolian”, “Vulcanian” (some sources use Peleean) and “Plinian” (or Vesuvian), the latter being the eponymous Pliny the younger who wrote perhaps the first detailed account of an explosive-type eruption (Vesuvius) in 79AD in a letter to Tacitus. The account, as translated from the Latin by Dr. E.R. Oxburgh[2] was as follows:

> “A cloud rose up (to distant onlookers it was not clear from which mountain it came, but it was subsequently established to have been Vesuvius). In general appearance and shape it resembled nothing so much as a pine tree: for it poured forth and was carried upwards into the sky like a very tall trunk with side branches here and there, rising I suppose under the first force of the blast; then when that was spent, or even because its own weight became too much for it, it spread out sideways, sometimes dazzling white, sometimes patchy grey, depending upon its content of earth or ash.”

1.1.3 This description admirably fits most of the major explosive volcanic eruptions which have caused problems for aviation over the past twenty years or so. From this preamble, therefore, it may be seen that aviation is especially interested in Plinian-type eruptions because they eject vast quantities of ash up to, and above, the cruising levels of international jet transport aircraft. Having said this, however, it must also be emphasized that volcanic eruptions of lower VEI than Plinian cannot be totally ignored because the ash column could reach jet cruising levels and, if the volcano is situated near approach/departure paths, even weaker columns could affect aircraft descending to or climbing from aerodromes. A good example of the latter is Kagoshima airport in Japan which is situated near the Sakurajima volcano (see also 2.3.2). Moreover, as many volcanoes are “mountains”, the cone from which a “moderate” ash column pours forth is already likely to be a few thousand metres above sea level, thus bringing even moderate columns within range of typical jet aircraft cruising levels (e.g. Popocatepetl in Mexico, altitude 5 465 m (18 000 ft)).

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1. Developed originally by C.G. Newhall and S. Self.
2. E.R. Oxburgh, “The Plain Man’s Guide to Plate Tectonics” in *Proceedings of the Geological Association*, London, Vol. 8, 1974, pp. 299-357.

1.1.4 Finally, to provide some perspective, the Mt. Galunggung eruption in 1982 which first focused the attention of the aviation community on the volcanic ash problem was VEI = 4; the Mt. St. Helens eruption in 1980 was classified as VEI = 5, as was the eruption of Mt. Vesuvius in 79AD. The eruption of Krakatau in Java in 1883 and Mt. Pinatubo in the Philippines in 1991 were both VEI = 6, and that of Tambora in the Lesser Sunda Islands (Indonesia) in 1815 was VEI = 7. This latter eruption poured such a vast quantity of ash and gases into the stratosphere that, in the northern hemisphere, the following year (1816) was called “the year without summer”, during which many thousands perished due to widespread crop failures.

1.2 MECHANISM OF VOLCANIC ERUPTIONS

1.2.1 Volcanoes are formed by the deposition and accumulation of lava and ash expelled from craters and vents during explosive and non-explosive eruptions (Figure I-1-1). The growth of a volcano into a cone-like mountain depends on the balance between the deposition of lava and ash during eruptions and their subsequent erosion by the forces of nature such as wind, rain and frost, etc., acting over geologically long periods of time. The lava originates as molten rock or “magma” deep in the earth’s mantle and is comprised of many chemical elements but primarily oxygen and silicon with smaller amounts of aluminium, iron, calcium, magnesium, potassium, sodium and titanium. The magma also contains volatile constituents which are in solution under the conditions of immense pressure deep in the earth. As the magma forces its way upwards towards the surface through fissures and cracks and eventually out through vents, a point is reached where the vapour pressure of the dissolved volatile constituents in the magma exceeds the ambient pressure and the volatile constituents boil off as gases. This phase-change essentially provides the energy for a volcanic eruption and the amount of dissolved gases and viscosity of the ascending magma largely determine how explosive the eruption will be.

1.2.2 In a Plinian eruption, massive quantities of dissolved gases are released over a very short period of time with the result that the rock is pulverized by shock waves and blasted vertically upwards (occasionally lateral blasts occur) as a vast column of ash-laden gases, which in major eruptions may reach the stratosphere within tens of minutes. If conditions are such that the magma encounters ground water when the dissolved gases are released, the combined explosive effect of superheated gases and steam can cause especially impressive eruptions[3]. The quantity of glass particles, shards and pulverized rock (ash) which is expelled during an explosive volcanic eruption can exceed tens of cubic kilometres and in many cases the top of the volcano mountain, or a good part thereof, may be completely eliminated explosively or by landslides. The detailed sequence of events in an explosive volcanic eruption is shown diagrammatically in Figure I-1-2.

1.3 DURATION AND FREQUENCY OF VOLCANIC ERUPTIONS

1.3.1 Volcanic eruptions may begin with small blasts of steam through surface vents, caused by the boiling of ground water by the rising molten rock. This activity can last for a few weeks or even months until the molten rock reaches the surface. The most energetic explosive eruptions frequently, but not always, occur early in the eruption sequence, tapering off during the ensuing weeks or months. Quiet periods may be followed by further large blasts, which quickly decrease in intensity.

3. G.A. Valentine, “Role of magma-water interaction in very large explosive eruptions”, Los Alamos National Laboratory Technical Publication, 1993.

Table I-1-1. Criteria used in assignment of Volcanic Explosivity Index (VEI) (from Simkin and Siebert).

	0	1	2	3	4	5	6	7	8
General description	Non-explosive	Small	Moderate	Moderate-Large	Large	Very Large			
Volume of tephra (m^3)	1 x 10^4	1 x 10^6	1 x 10^7	1 x 10^8	1 x 10^9	1 x 10^{10}	1 x 10^{11}	1 x 10^{12}	
Cloud column height (km) Above crater	<0.1	0.1-1	1-5						
Above sea level				3-15	10-25	>25 →			
Qualitative description	"Gentle,"	"Effusive"	← "Explosive" →		← "Cataclysmic,"		"Paroxysmal"		"Colossal" →
				← "Severe",		"Violent",	"Terrific" →		
Eruption type		← Strombolian →		← Plinian →					
	← Hawaiian →		← Vulcanian →			← Ultra-plinian →			
Duration (continuous blast)	← 1 hour →				← 12 hrs →				
			← 1 - 6 hrs →						
				← 6-12 hrs →					
CAVW max explosivity (most explosive activity listed in CAVW)	Lava flow	← Explosion or Nuée ardente →							
		← Phreatic → - - - →							
	Dome or mudflow								
Tropospheric injection	Negligible	Minor	Moderate	Substantial →					
Stratospheric injection	None	None	None	Possible	Definite	Significant →			
Eruptions (total in file)	699	845	3477	869	278	84	39	4	0

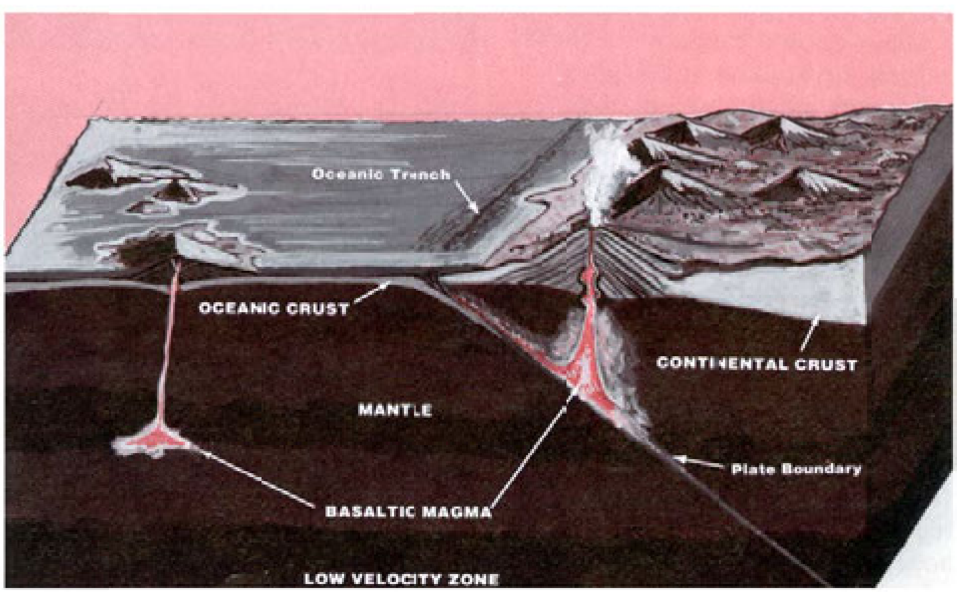

Figure I-1-1. An idealized diagram of a volcano in an oceanic environment (left) and in a continental environment (right). (from Tilling)

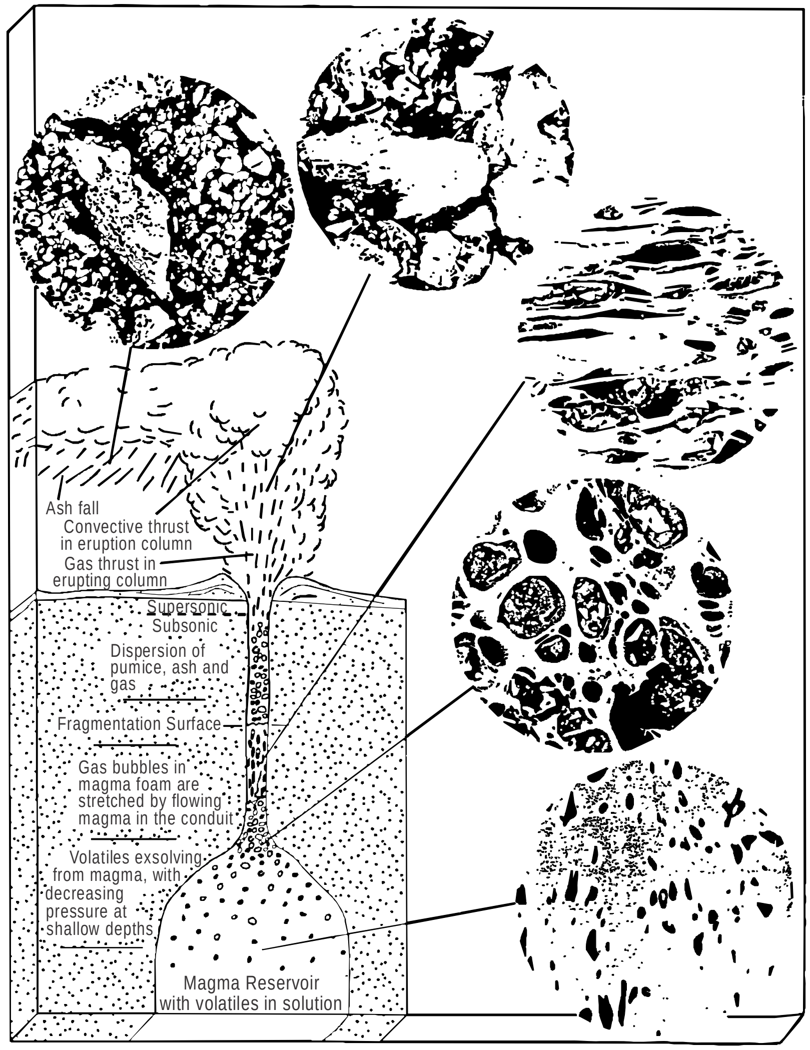

Figure I-1-2. Schematic diagram of processes leading to the formation of volcanic ash within explosive volcanic eruptions. This diagram is based nearly entirely on inference and some experimental studies of the processes of gas exsolution and explosive decompression of a rising magma with a composition similar to that found in the eruptions of Augustine Volcano. Scanning electron photomicrographs shown in the circles are about 300 µm (300 × 10^{-6} metres) in diameter. As magma rises to a depth where the pressure of gas in solution exceeds that of the overlying rock, some of that gas comes out of solution as small bubbles. As the pressure is lowered, those bubbles continue to grow. After the eruption begins, movement of the magma foam in the conduit may stretch the bubbles into elongate, tapered tubes. A fragmentation surface between the pressurized magma foam and the ambient atmosphere tears the brittle foam apart and accelerates the pieces out of the conduit in the eruption column. The particles are carried into eruption clouds and eventually fall to the ground, their final position depending on the height of the eruption column, the strength of winds, and particle size and density. (The samples used here to demonstrate the appearance of volcanic ashes, within the eruption column are from coarse ash fallout deposits — *in situ* samples from eruption columns have never been collected.) (from Heiken)

1.3.2 There are a few dozen well-known volcanoes around the world which erupt modest ash clouds daily or weekly, and have continued to do so for tens or even hundreds of years, such as the previously mentioned Sakurajima volcano in Japan. Some volcanoes have erupted more or less continuously for millennia, such as Stromboli in Italy (often referred to as the "lighthouse of the Mediterranean"), but these are normally mild eruptions. Of the more than 2 000 eruptions listed in the Smithsonian Institution's *Volcanoes of the World*, 9 per cent ended within two days, 19 per cent within a week, 25 per cent within two weeks, 40 per cent within a month, and 52 per cent within two months. It is an unfortunate fact that the most explosive volcanic eruptions (especially those of VEI of 4 or higher) are commonly preceded by long (hundreds or even thousands of years) quiet periods, as shown in Figure I-1-3. Vesuvius, for example, which erupted in 79AD (see 1.1.2) had long been considered as extinct. This means that while Plinian eruptions are less frequent than eruptions of lower VEI they often occur from volcanoes with no previously known historic record of volcanic activity (i.e. circa last 10 000 years). As a rough rule of thumb, vulcanologists expect around fifty to sixty volcanic eruptions per year globally, of which ten or more might be expected to produce a volcanic ash column which reaches jet aircraft cruise levels (up to FL450)[4]. The relative frequency of explosive volcanic eruptions of different magnitude and the relation to aircraft operations is shown in Figure I-1-4.

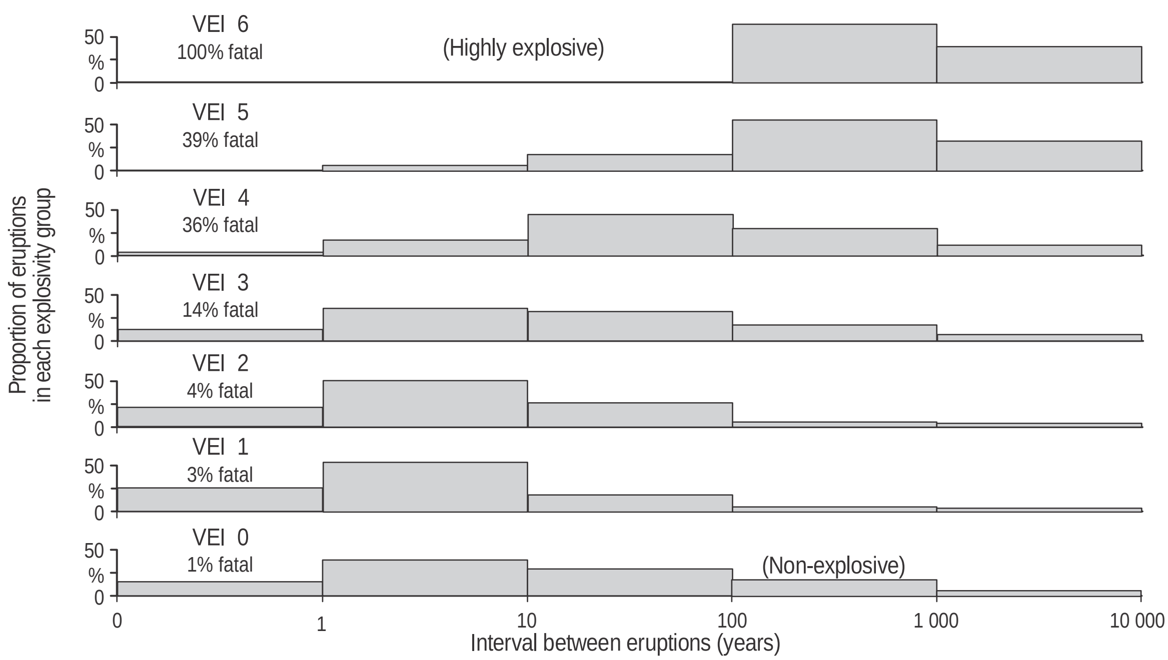

Figure I-1-3. Explosivity and time intervals between eruptions. For each VEI unit, eruptions are grouped by time interval from start of previous eruption. The number of eruptions in VEI groups 0 to 6 are, respectively: 446, 677, 2 991, 692, 230, 48 and 16. For each group, the percentage of historical eruptions that have been fatal is also shown to emphasize the danger of large explosive eruptions from volcanoes that have appeared to be quiet for hundreds to thousands of years. (from Simkin and Siebert)

4. S. Self and G.P.L. Walker, "Ash Clouds: Characteristics of Eruption Columns", *Proceedings of First International Symposium on Volcanic Ash and Aviation Safety*, 1991,U.S. Geological Survey Bulletin 2047 (1994), p. 70.

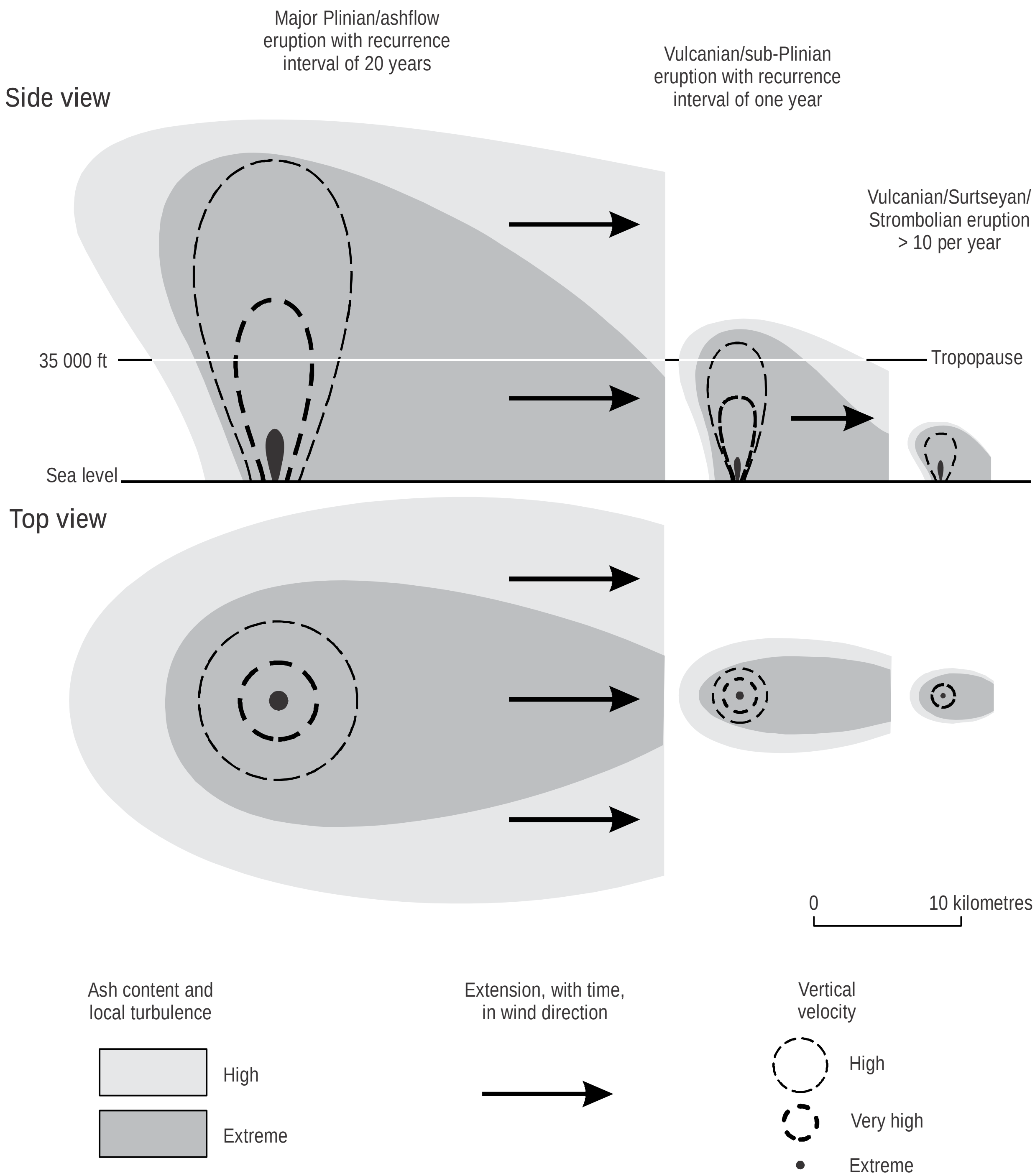

Figure I-1-4. Schematic diagram showing the distribution of hazards to aircraft around explosive eruption columns of three selected frequencies. Upper diagram is sectional view; lower diagram is plan view. Vertical and horizontal scales are equal. (from Self and Walker)

1.4 DISTRIBUTION OF ACTIVE VOLCANOES

1.4.1 The distribution of active volcanoes around the world was mentioned briefly in the introduction and is shown in the frontispiece. There are more than five hundred active volcanoes (i.e. those which have erupted at least once within recorded history). Most explosive vulcanism occurs where the moving “plates” of the earth’s crust collide. The theory of “plate-tectonics”[5] postulates that the earth’s crust is broken into a number of discrete and continually shifting “plates” of average 80 km thickness, moving relative to one another above the deeper mantle. Some plates are colliding, some being wrenched apart and others sliding past one another. The arrangement of the main “plates” on the earth is shown in Figure I-1-5.

1.4.2 Most active volcanoes are to be found along or near the boundaries between the plates and are, therefore, usually called plate-boundary volcanoes. There are active volcanoes which are not associated with plate boundaries and many of these form roughly linear chains in the interior of some oceanic plates (e.g. volcanoes in the Hawaiian islands). Generally speaking, volcanoes of high volcanic explosivity index are plate-boundary volcanoes or located on the continents.

1.4.3 The distribution of volcanoes by latitude is shown in Figure I-1-6. Two thirds of the volcanoes are located in the northern hemisphere and about 85 per cent are north of latitude 10°S. While this in itself is not surprising, given the similar distribution of land mass between the northern and southern hemispheres, it does mean that most volcanic eruptions which produce an ash column stand a good chance of affecting an international air route to some degree. There is a high concentration of volcanoes notorious for Plinian eruptions between 20°N and 10°S which means that vast quantities of gases and volcanic ash are ejected from time to time into the stratosphere near the equator with important consequences for the global climate.

1.5 MONITORING VOLCANOES AND FORECASTING VOLCANIC ERUPTIONS

1.5.1 Monitoring volcanoes involves measuring, recording and analysing a variety of phenomena including seismic events such as earth tremors, ground deformation, gas emission and ground water chemistry and temperature and variations in local electrical, magnetic and gravitational fields, all of which are associated with magma movement deep in the earth.

1.5.2 Seismic events often provide the earliest warning of increased volcanic activity. A typical series of earthquake recordings which preceded the Mt. St. Helens volcanic eruption in May 1980 is shown in Figure I-1-7. The sudden appearance of earthquakes in this record and the marked change in the number and magnitude of the earthquakes and the increased depth in the earth of their epicentres, graphically illustrates the movement in the earth’s crust as it adjusts to the movement of magma deep in the earth.

1.5.3 In addition to the occurrence of earthquakes, the actual shape of the volcano surface itself also changes during the build-up to an eruption. Such deformation of the surface can be observed and measured accurately using tiltmeters and various geodetic networks based on electronic and/or manual distance/elevation measurements or in the future from space-based measurements (see 1.5.5). The sequence of events leading up to an eruption and the associated ground deformation is shown diagrammatically in Figure I-1-8. The measurements of slope and distance between “fixed” reference points on the volcano is extremely precise (the order of a few parts per million is typical), and they are able to provide indications of the movement and expansion/contraction of magma deep in the earth.

5. Oxburgh, p. 208. (See note 2, p. I-1-1.)

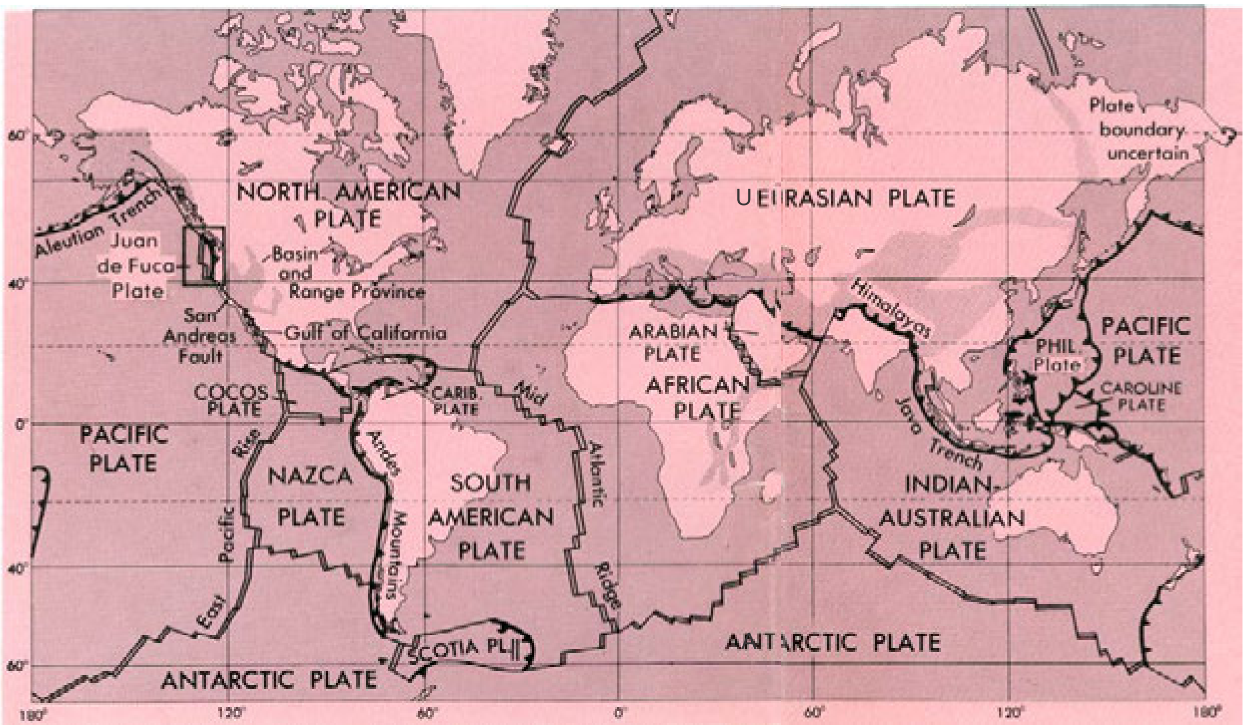

Figure I-1-5. Lithosphere plates of the Earth. (from Tilling)

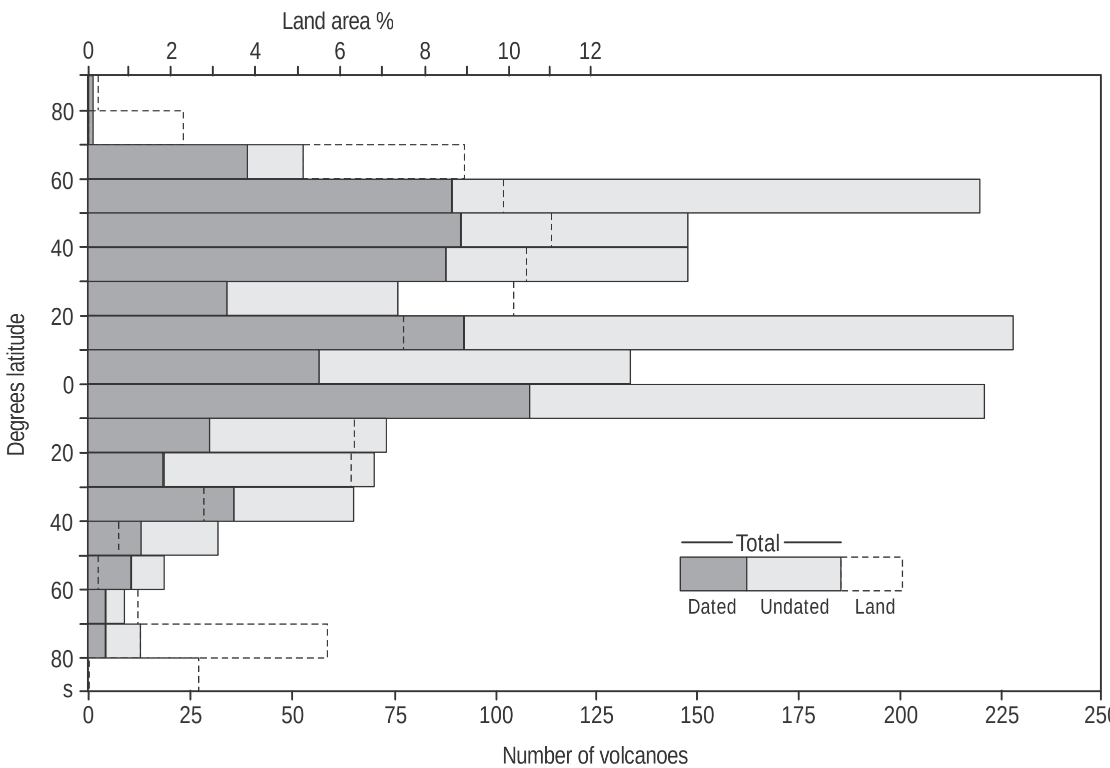

Figure I-1-6. Distribution of known volcanoes per 10 degrees of latitude. Thin dashed line shows the percentage of land area per 10 degrees. (from Simkin and Siebert)

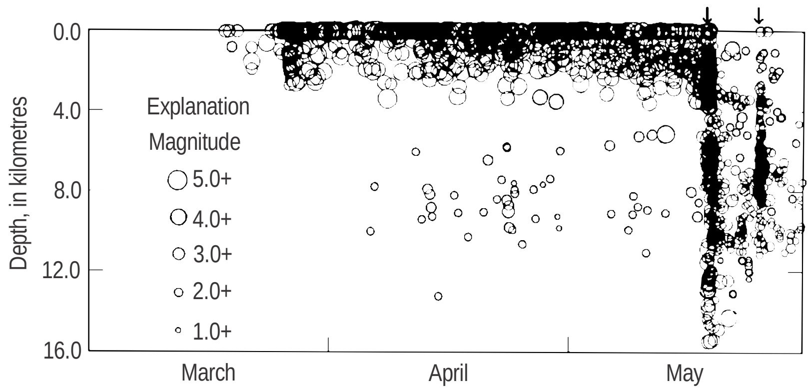

Figure I-1-7. Earthquakes (denoted by circles) beneath Mt. St. Helens, March 1 to May 31, 1980. Note the abrupt onset of earthquakes around March 17, building quickly to continuous, shallow seismicity from March 26 (beginning of explosions) to the climactic eruption on May 18. There was no additional increase in seismicity immediately preceding the May 18 event. Coincident with eruptions on May 18 and May 25 (denoted by arrows) earthquake hypocentres trace the movement of magma from depths above and below 5 kilometres, where there may have been a shallow magma storage area. Modified from Malone (1990). Used with permission (from Wright and Pierson).

1.5.4 The build-up to a volcanic eruption may also cause changes in the local geophysical properties such as electrical conductivity, magnetic field strength and/or gravity which appear to reflect temperature changes and/or changes in the composition of magnetic minerals in the magma. Changes in the composition of the vented gases at the surface due to the admixture of gases from the rising magma can be monitored and the gas composition compared to that of the volcano in its quiescent state. The foregoing data must be analysed by vulcanologists against a background knowledge of the geology and the geophysical history of the volcano and its surroundings. This requires a detailed and systematic mapping of the type, volume and distribution of lava/ash and landslides, etc., from historic and prehistoric eruptions in the area.

1.5.5 For the future, the use of the global positioning system of navigation satellites to monitor volcano deformation remotely, continuously and accurately has been suggested and proof of concept experiments have been carried out in California[6]. This system is already used extensively and very successfully for geodetic and geological surveys. It has been suggested that it would be possible in near real time to detect volcano surface deformations to a precision the order of a few centimetres per hour (Figure I-1-9). It remains to be seen if reliable volcanic eruption precursor patterns or trends could be identified to permit warnings to be issued based on this data. Similar success with the remote sensing of volcano deformation from satellites has been reported using the ERS 1 data produced from the on-board synthetic aperture radar (SAR) interferometry[7]. Using phase change information from two or more SAR images received from successive passes on the same orbit, shifts in the earth's crust in the order of centimetres may be detected. The ERS-2 satellite will also carry an ozone detection instrument and an "along-track scanning radiometer" sensing six infrared channels.

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6. F.H. Webb and M.I. Bursik, "The potential for using GPS for volcano monitoring", *Proceedings of First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 429.
7. ERS tandem mission, pp. 47 ff, INTERAVIA May 1995.

1.5.6 The establishment of volcano observatories to routinely monitor individual active volcanoes or groups of volcanoes is a comparatively recent development. A volcano observatory was established on Mt. Vesuvius in 1847 for more or less continuous monitoring of the volcano, but this was an isolated case. Generally, the monitoring of volcanoes at this time was restricted to short- or long-term expeditions to an active volcano rather than establishing a permanent presence on or near the volcano. In 1912, the Massachusetts Institute of Technology established the Hawaiian Volcano Observatory on the rim of the caldera formed by the Kilauea Volcano[8]. The express purpose of this observatory was the continuous monitoring of the volcano and the conducting of general scientific research into the geophysical and geochemical nature of volcanoes. In this way, the Hawaiian Volcano Observatory pioneered many of the volcano-monitoring techniques in use throughout the world today.

1.5.7 Nowadays most of the States that have volcanoes in their territories have organized the monitoring of at least some of their active volcanoes. Of course, bearing in mind that there are over five hundred known active volcanoes around the world, it is impractical to expect that each and every one could be monitored continuously. In fact only a small percentage of the known active volcanoes are monitored, and not all of these continuously. An effective method of dealing with this problem has been devised in Japan. There are eighty-three volcanoes in Japan which have a history of volcanic activity, nineteen of which are monitored routinely. The remaining sixty-four are considered dormant, but an emergency observation team is equipped for transport at short notice to any volcano which shows increased volcanic activity, to permit detailed 24-hour monitoring during this active period[9].

1.5.8 At the international level, the global network of volcano observatories is coordinated by the World Organization of Volcano Observatories (WOVO), operating under the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) which, in turn, is one of the semi-autonomous associations of the International Union of Geodesy and Geophysics (IUGG). WOVO publishes a directory of volcano observatories listed State by State in order of the volcano numbering system used by Simkin and Siebert in *Volcanoes of the World*[10]. The WOVO directory lists information provided by States on the location of the observatories and details of the volcano monitoring programme together with the names/addresses/ telephone numbers, etc., of the supervising vulcanologists and seismologists involved. Most volcano observatories employ some or all of the monitoring techniques referred to in 1.5.1 to 1.5.4 above, involving on-site measurements and remote-sensing equipment which permits the recording and analysis of data at offices distant from the volcano.

1.5.9 Forecasting volcanic eruptions in the long term is clearly not possible and is not expected of vulcanologists. What can be done, however, and is increasingly proving successful, is short-term forecasting based on the monitoring of the volcano. One example in this respect is the development of an empirical relationship between volcano tremor amplitude from seismographs and eruption explosivity. It has been postulated[11] that the following empirical relationship is significant at the 95 per cent level:

$$\log (\text{volcano normalized displacement}) = 0.46\ (\text{VEI}) + 0.08$$

It is claimed that when tested on past eruptions, when the seismic displacement reaches a critical amplitude, there is a 60 to 80 per cent chance of an explosive eruption taking place. Such short-term forecasting is of prime importance in the civil defence and/or national disaster plans of States having active volcanoes within their territorial borders. Indications of increased or unusual volcanic activity from the interpretation of regularly monitored data from the volcano may prompt increased monitoring on site in order to assess the likelihood of an eruption, its magnitude and timing. This information is vital to the civil defence authorities to enable evacuation arrangements, etc., to be organized and initiated where population centres are threatened by the volcano. It is also important that the operational units of the civil aviation

8. R.I. Tilling, *Volcanoes*, US Geological Survey Publications, 1996, p. 40.
9. Smithsonian Institution, 1994.
10. *Directory of Volcano Observatories*, World Organization of Volcano Observatories (WOVO), 1997, p.74.
11. S.R. McNutt, "Volcanic tremor amplitude with volcano explosivity index (VEI) and its potential use in determining ash hazards to aviation", *Proceedings of First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 377.

authority and meteorological authority (area control centre and meteorological watch office) are on the list in the civil defence/national disaster plans of those requiring immediate notification of volcanic activity, volcano status and any short-term forecasts provided by vulcanologists. These arrangements are discussed in more detail in Chapter 6. A good example of the provision of an effective warning of a volcanic eruption concerned Mt. Pinatubo in the Philippines in June 1991, which enabled the United States Air Force to evacuate people, vehicles and aircraft from Clark Air Force Base, which was located close to the volcano, before it was smothered by volcanic ash and mud caused by the subsequent heavy rain from tropical cyclone "Junior", thereby minimizing casualties and loss of aircraft and equipment.

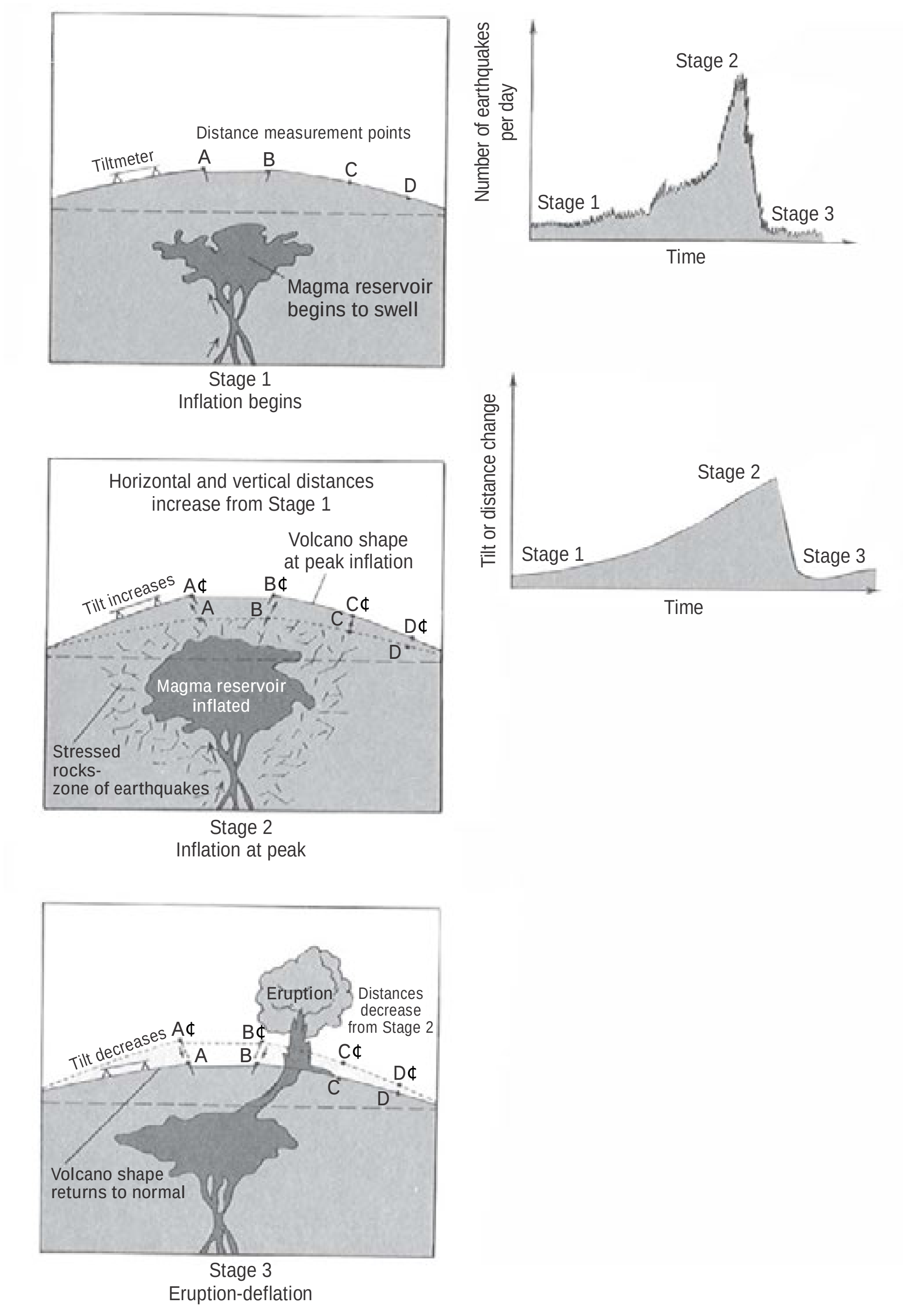

Figure I-1-8. Schematic diagrams show three commonly observed stages in the course of a typical Hawaiian eruption. The lower part of the figure shows idealized graphs of earthquake frequency and tilt or distance changes as a function of time during the three stages (modified from illustration by John D. Unger in Earthquake Information Bulletin, 1974, Vol. 6, p. 7). (from Tilling)

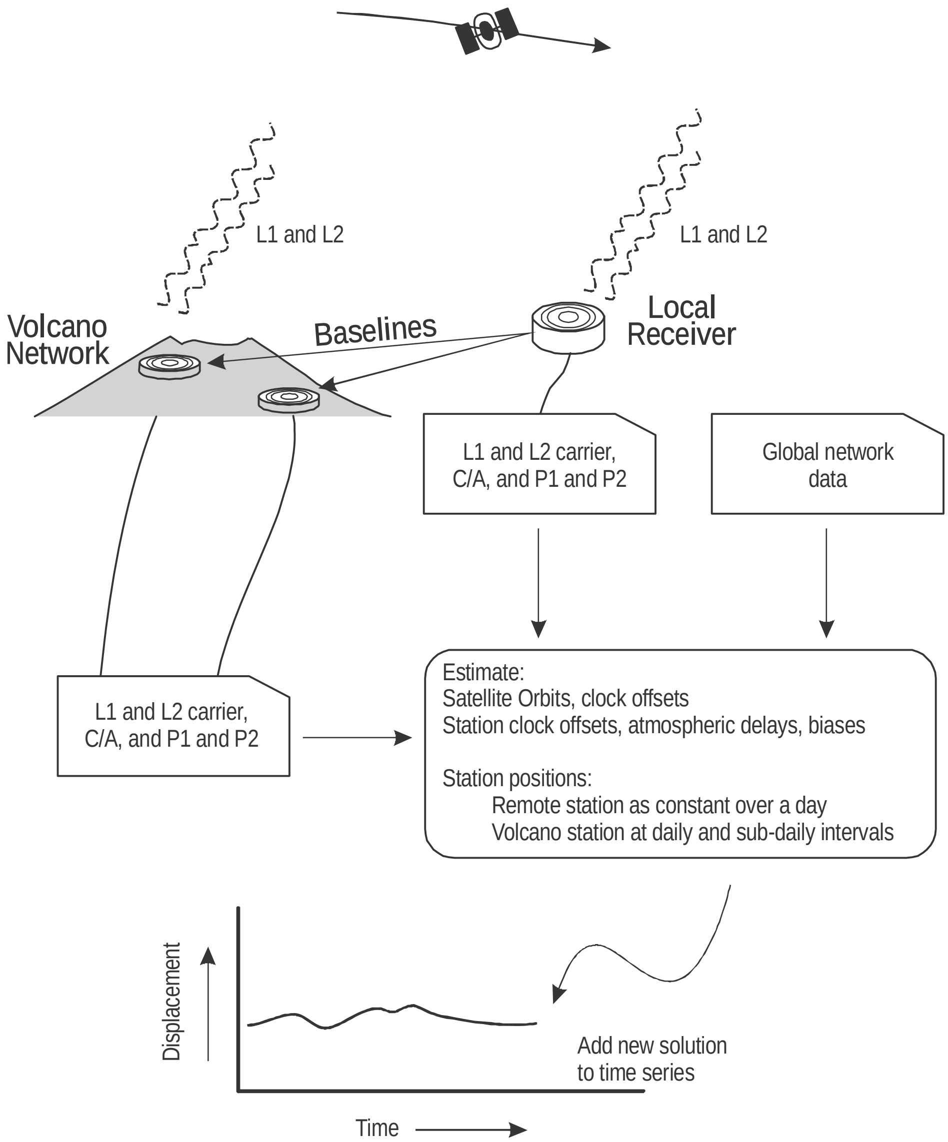

Figure I-1-9. One possible design for a real-time, continuous, GPS volcano-monitoring system. Data collected at a volcano receiver are transmitted via modem to a central processing facility; this facility also collects data from other global and/or local receivers. Data from all receivers are "added" to the estimation of the baselines between the volcano monitoring stations and the local and/or global receivers. The processing facility monitors the GPS baseline results for strain accelerations. This information is used to adjust the frequency with which data are obtained from the volcano station for estimating relative motion. (from Webb and Bursik)

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Chapter 2

VOLCANIC ASH CLOUD

2.1 COMPOSITION OF VOLCANIC ASH AND ASSOCIATED GASES

2.1.1 The composition of volcanic ash was mentioned briefly in general terms in Chapter 1, however, given the serious effect it has on jet transport aircraft engines, airframes and equipment, it warrants a separate section. Volcanic ash is, essentially, extremely fine particles of pulverized rock, the composition of which reflects the composition of the magma inside the volcano. The composition of volcanic ash clouds, therefore, varies from one volcano to another. Generally speaking, however, it is comprised predominantly of silica (> 50 per cent), together with smaller amounts of the oxides of aluminium, iron, calcium and sodium (Table I-2-1). The silica is in the form of glassy silicates and under the scanning electron microscope resembles sharp-edged glass shards (Figure I-2-1). The glassy silicate material is very hard, typically of hardness level 5 or 6 on the Mohs scale[1] (similar to typical pen-knife blade) (Table I-2-2), with a proportion of material of hardness equivalent to quartz (level 7), all of which in pulverized form is extremely abrasive. In fact, volcanic ash is used commercially as an abrasive powder. The abrasive nature of volcanic ash is very important due to its damaging effect on aircraft structures, cockpit windows and engine parts, the effects of which are discussed in detail in Chapter 4.

2.1.2 In addition to the abrasive nature of volcanic ash, another important property is its melting point. Being made up predominantly of glassy silicates, whose melting temperature (~1 100°C) is below the temperature of jet engines operating at normal thrust (1 400°C), volcanic ash can melt and be deposited in the hot section of the jet engine core[2], such as the nozzle guide vanes. The effects of this are also examined in more detail in Chapter 4, but even at this stage, it is possible to see the potential for serious engine damage. Moreover, this is the reason for the recommendation for pilots inadvertently entering a volcanic ash cloud to reduce engine power settings, where possible, to idle thrust, where the engine operating temperature (~600°C) is below the melting temperature of volcanic ash.

2.1.3 The solid ejecta from an explosive volcanic eruption are extremely varied, ranging from extremely fine particles (< 5µm) to large rock boulders. The term used by geologists to describe the whole range of particles is “tephra” from the Greek word for ash. The mean particle size in a volcanic ash cloud decreases with time as the larger, heavier particles settle out from the cloud (Figure I-2-2). The ash concentration with distance depends on the height reached by the original ash column (Figure I-2-3) and the meteorological conditions, such as wind speed and shear with height (especially stratospheric winds), and temperature lapse rate. Volcanic ash in general describes the smaller particles of tephra (< 2 mm diameter), and the clouds of volcanic ash most likely to be encountered by aircraft at some distance from the eruption are mainly comprised of the smallest particles (< 0.1 mm diameter). All of the foregoing considerations are of importance in determining the forecast trajectory of the volcanic ash cloud and its expected concentration. The fallout times for spherical particles from various heights under gravity alone are shown in Table I-2-3. It may be seen that, under such idealized conditions, there is a marked change in the residence time of volcanic ash particles in the atmosphere from days to hours, between particles size ~5 µm and those ~10 µm.

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1. The Mohs scale is named after the German mineralogist Friedrich Mohs and is based on a scale of hardness from talcum — level 1 to diamond — level 10.
2. S.E. Swanson and J.E. Boget, “Melting Properties of Volcanic Ash”, *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 87.

2.1.4 In addition to volcanic ash, volcanic eruption columns also contain many gases including water vapour, sulphur dioxide, chlorine, hydrogen sulphide and oxides of nitrogen. While the proportion of each of these gases in particular volcanic eruptions varies widely, the predominant constituent gases are water vapour, sulphur dioxide and chlorine. In their gaseous form these constituents of the volcanic ash cloud are not thought to cause significant harmful effects to aircraft. Following the eruption, however, oxidation and hydration of the SO_2 forms H_2SO_4 (sulphuric acid) droplets which are quite a different matter. The resulting ash/acid mix is highly corrosive and can cause damage to jet engines and pitting of windscreens, and may well present a long-term maintenance expense for aircraft operating regularly in airspace contaminated with even relatively low concentration of such ash/acid particles. An example of the high acidity of volcanic ash column induced acid rain from the Sakurajima volcano shows[3] that droplets falling as light rain from a column of altitude 300 m (1 000 ft) tested as pH < 1. One positive aspect of the gases and the residual ash/acid particles associated with volcanic ash clouds is that they can be detected by suitably equipped satellites, an aspect discussed in more detail in Chapter 5. Another interesting result of the acid droplets produced in volcanic ash cloud, that is discussed in 2.3.1, is their role in the production of certain electrical phenomena exhibited by volcanic ash clouds.

2.2 VOLCANIC ASH COLUMN CHARACTERISTICS

2.2.1 Formation and height of columns

2.2.1.1 The mechanism of explosive volcanic eruptions was described in 1.2.1 and 1.2.2. The volcanic eruption column which results is usually divided into three dynamic regimes: “gas thrust”, “convective thrust” and “umbrella region” (or “mushroom”) as shown in Figure I-2-4. As described earlier, the gas thrust region is produced by the sudden decompression of superheated volatile constituents dissolved in the ascending magma. This produces a jet of fluids and pulverized rock material of extremely high kinetic energy at the mouth of the volcano vent, the speed of which in extreme cases could exceed 500 kt[4]. Such exit vent speeds may reach supersonic speed depending on the ambient conditions at the time. The extremely high kinetic energy at the exit vent means that such explosive eruption columns can reach jet aircraft cruise levels of 10 to 14 km (30 000 to 45 000 ft) in five to six minutes. A typical time-to-height diagram for a theoretical model and an actual eruption is shown in Figure I-2-5. Due to the turbulent mixing with the atmosphere and associated high drag forces, the gas thrust region rarely extends upwards beyond ~3 km (10 000 ft). Deceleration of the jet of fluidized volcanic materials is rapid, and the ascent speed generally reduces at the top of the gas thrust region to less than one tenth the maximum speed at the vent. Unless an aircraft were unfortunate enough to actually fly low over a volcano at the time of eruption, the gas thrust region is not normally of direct concern to aviation.

2.2.1.2 Although initially the column is much denser than the surrounding atmosphere, if, as is usually the case, the turbulent mixing has entrained sufficient air into the jet of fluidized volcanic material, thereby heating the entrained air rapidly, the eruption column overshoots the level of neutral buoyancy with the surrounding atmosphere, thus forming the convective thrust region, where the continuing upward driving force is mainly due to thermal energy, i.e. the heat content of the column and its lower density than the surrounding air. If insufficient air is entrained in the gas thrust region, the column remains denser than the surrounding atmosphere and, as the initial kinetic energy dissipates, the column collapses due to gravitation without forming a convective thrust region. The convective thrust region largely controls the ultimate height of the column and hence is critical to the eruption’s potential concern to aviation. It is clear from the foregoing that the hotter the original jet of fluidized material at its release from the vent, the higher the thermal energy which can be carried through to the convective thrust region and the higher the column top[5].

3. J.S. Gilbert and S.J. Lane, “Electrical phenomena in volcanic plumes”, *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 31.
4. S. Self and G.P.L. Walker, p. 70. (See note 4, p. I-1-2).
5. *Volcanoes of the World*, Smithsonian Institution, 1994, p. 66.

Table I-2-1. Composition of the ash particles found in ash clouds from eruptions of four recent volcanoes (from Prata)

	Fuego,1974	*Mt. St. Helens,1980*	*El Chichón,1982*	*Galunggung,1982*
Constituent	*Per cent by weight*			
SiO_2	52.30	71.40	68.00	61.30
Al_2O_3	18.70	14.60	15.90	7.10
Fe_2O_3, FeO	9.10	2.40	1.60	7.10
CaO	9.40	2.60	2.12	5.70
Na_2O	3.90	4.30	4.56	4.00
MgO	3.40	0.53	0.25	1.70
K_2O	0.80	2.00	5.05	1.50
TiO_2	1.20	0.37	0.29	1.30
P_2O_5	—	0.99	0.00	0.33

Table I-2-2. Mohs scale of hardness

Talc	1
Asphalt	1-2
Glass (windscreen)	5
Pumice	6
Quartz and silicone	7
Carbon steel	7-8
Emery	7-9
Carborundum	9-10
Diamond	10

Table I-2-3. Fallout times for spherical particles dropping from various heights under gravity only (from Prata)

Height $m \times 10^3$ ($ft \times 10^3$)	r = 1.0 µm weeks	r = 2.0 µm days	r = 5.0 µm days	r = 10 µm hours	r = 50 µm hours	r = 100 µm minutes
2 (7)	8	15	2	14	0.6	9
5 (16)	21	37	6	36	1.4	21
8 (26)	34	59	10	57	2.3	34
10 (33)	42	74	12	71	2.9	43
12 (39)	51	89	14	86	3.4	51
15 (49)	64	111	18	107	4.3	64
20 (66)	85	149	24	143	5.7	86

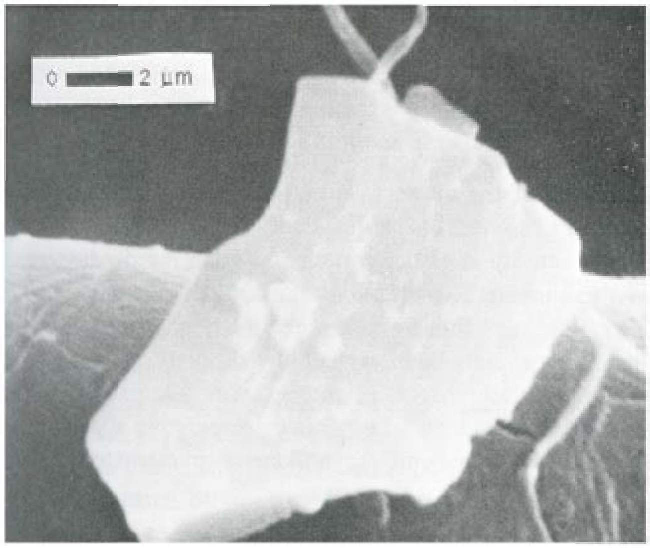

Figure I-2-1. Ash from the 18 May 1980 eruption of Mt. St. Helens, Washington. The 7-µm-long glass shard shown here is from a sample collected by high-altitude aircraft at an altitude of 18.3 km (60 000 ft) over south-central Wyoming on 21 May 1980. This shard is from a sample with a median particle size of 1.5 µm. (from Heiken).

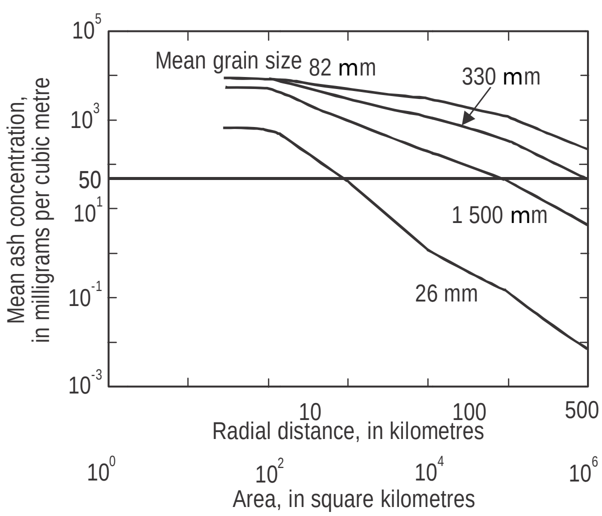

Figure I-2-2. Concentration variation for different total grain-size distributions with means shown next to curves. The standard deviation, in Þ units, for each curve was assumed to be 2.5. Distributions are for phreato-Plinian/coignimbrite (mean = 82 µm), Vulcanian (330 µm) and Strombolian (26 mm) eruptions. (from Woods and Bursik).

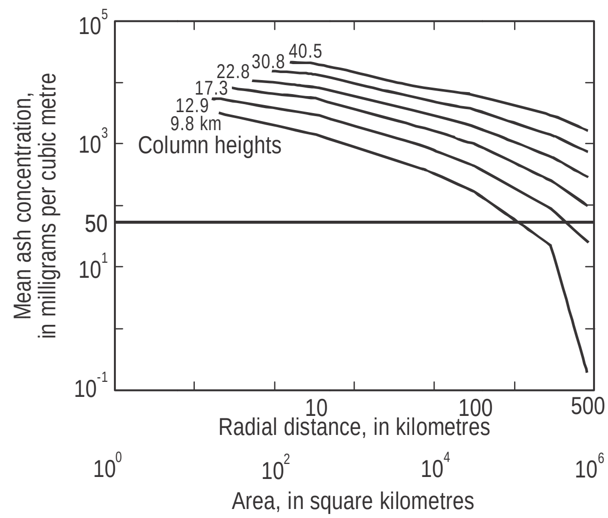

Figure I-2-3. Ash concentration as a function of the area encompassed by an isochronous surface within the umbrella cloud for column heights from 10 to 40 km (30 000 to 45 000 ft). (Isochronous meaning measured at the same time.) (from Woods and Bursik).

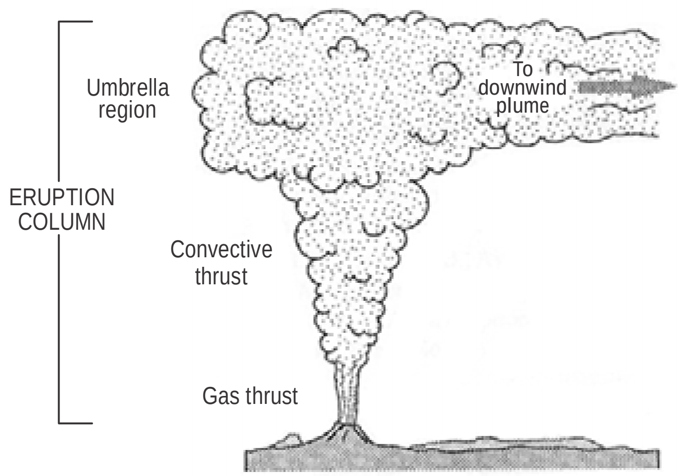

Figure I-2-4. Three parts or regions of an eruption column: gas thrust, convective thrust and umbrella. (from Self and Walker)

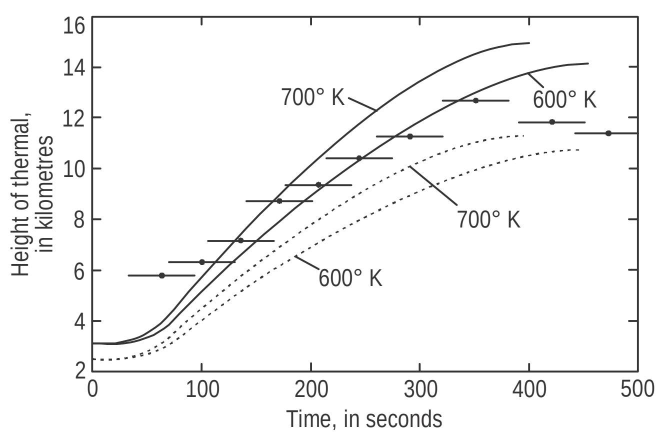

Figure I-2-5. Comparison of observed ascent of the 15 April 1990 Redoubt eruption cloud with the model predictions of the total cloud height (solid lines) and the height of the centre of the cloud (dashed lines). Calculations are shown for two initial model cloud temperatures (600°K and 700°K), which represent bounds on the initial temperature of the cloud (from Woods and Kienle). The data were collected by analysis of video recordings of the cloud ascent. Horizontal lines through data points represent error bars.

2.2.1.3 Not all convecting volcanic ash columns of concern to aviation originate from vents and gas thrust regions as described above. Some, referred to as "co-ignimbrite ash clouds", can be formed subsequent to a column collapse due to initial lack of sufficient entrained air described above, or from lateral blasts. The collapsed ash column forms a gravity current of hot tephra and gases called a "pyroclastic flow" which, as it plunges away from the volcano, finally entrains sufficient surrounding air to achieve buoyancy creating a co-ignimbrite cloud which bursts upwards in much the same way as the convective thrust regions of the volcanic ash column mechanism described in 2.2.1.2. Such co-ignimbrite ash clouds can comprise vast quantities of ash which generally reach the stratosphere over a very wide area.

2.2.1.4 The third dynamic regime of the volcanic ash column is the "umbrella region", the top of the mushroom-like ash cloud as its ascent begins to slow in response to gravity and the temperature inversions at the tropopause, with the top spreading radially to begin with and then predominantly in one or more particular directions in response to the upper winds at different levels of the atmosphere. This is the region of most concern to aviation because vast volumes of airspace at normal jet aircraft cruising levels of 10 to 14 km (30 000 to 45 000 ft) become contaminated with high concentrations of volcanic ash.

2.2.2 Volumes and concentrations of volcanic ash in columns

2.2.2.1 The immense volumes of tephra blasted into the atmosphere by Plinian volcanic eruptions can be difficult to fully appreciate. It has been estimated, for example, that the volume of tephra from the most explosive historical eruption, Tambora, Indonesia in 1815, exceeded 100 km^3 [6]. Even this massive eruption is dwarfed by a number of prehistoric eruptions, where magma deposits, in excess of 1 000 km^3 have been measured by present day geologists. The volume of ejecta from volcanic eruptions was referred to in 1.1.1 in connection with the "volcano explosivity index", and the approximate range of values is shown in Table I-1-1. It is important to appreciate that volcanic eruptions of VEI = 3 or 4 occur several times each year and can produce from 0.01 to 0.1 km^3 of tephra while those of VEI > 4 (Mt. St. Helens, Mt. Pinatubo) produce around 1 km^3 of tephra and statistically are likely to occur at least once every decade.

2.2.2.2 The concentration of volcanic ash in the atmosphere following an eruption is commonly referred to by vulcanologists as the "mass loading". The mass loading in the umbrella region of the column typically varies approximately linearly with the height of the volcanic ash column, from around 2 500 mg/m^3 for a column reaching 7 km to over 20 000 mg/m^3 for one reaching 40 km[7]. It has been estimated that the volcanic ash concentration encountered by the KLM B747 during the Mt. Redoubt eruption in December 1989 was of the order of 2 000 mg/m^3. The response of a jet engine when exposed to volcanic ash depends on a number of variables, including the concentration of the ash, engine type, engine thrust setting, time of exposure and ash composition, all of which are dealt with in some detail in Chapter 4. The density of typical dry volcanic ash is given as 1.4 g/cm^3, and wet volcanic ash as 2 g/cm^3.

2.2.2.3 Models of explosive volcanic eruptions have been developed based on theoretical and experimental particle sedimentation studies which provide estimates of the average concentration of volcanic ash particles greater than a given size in the atmosphere at radial distances from the volcano. The results of such an analysis for an eruption of Fogo Volcano in Cape Verde is shown in Figure I-2-6. Theoretical estimates of volcanic ash concentrations under different conditions of wind speed, particle aggregation, column height and mean grain size are shown in Figure I-2-7. The results obtained from the foregoing modelling studies agree reasonably well with the analysis of actual volcanic ash fall deposits on the ground. Moreover, they strongly support the conclusion that volcanic ash concentrations exceeding (by several orders of magnitude) concentrations known to cause severe jet engine damage can persist in the atmosphere at typical jet transport cruise levels several hundreds of kilometres from the site of the eruption.

6. A.J. Prata, "Volcanic Ash Detection and Air Safety", Final Report of the CSIRO, COSSA Publication 024, Australia, 1990, p. 39.
7. R.S.J. Sparks, M.I. Bursik, S.N. Carey, A.W. Woods and J.S. Gilbert, "The Controls of Eruption-Column Dynamics on the Injection and Mass Loading of Ash into the Atmosphere", *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 81.

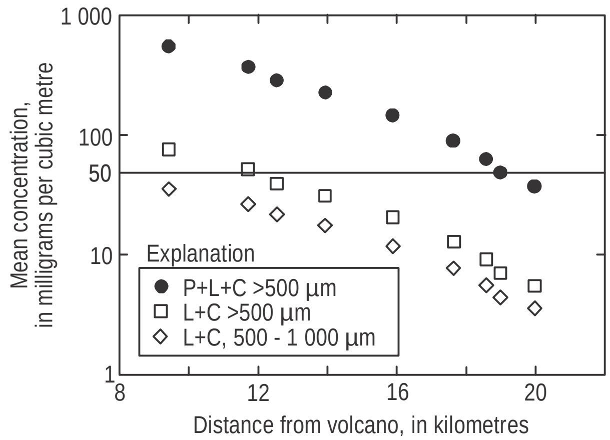

Figure I-2-6. Inferred concentration of pyroclasts in the Fogo umbrella cloud as a function of distance from the vent along the dispersal axis. Concentrations in other directions would be somewhat lower. P, pumice; L, lithic (rock) fragments; C, crystals. (from Bursik, Sparks, Carey and Gilbert).

2.2.2.4 Volcanic ash concentration is of critical importance in the detection and monitoring of the ash columns and ash clouds from satellite imagery and routing aircraft around the cloud. In this latter regard, there has been considerable discussion concerning so-called "old" volcanic ash clouds, or ash clouds persisting for more than 48 hours after an eruption. While such clouds are likely to be of low ash concentration, they may still be sufficiently noticeable to pilots due to various associated optical effects to cause a considerable problem to air traffic services, due to a large number of pilots requesting rerouting or change of flight levels. The question at issue is — when does the concentration of ash in the contaminated airspace decrease to a level considered safe for aircraft? Moreover, flying through even very low ash concentrations considered safe from the standpoint of immediate engine damage may, as indicated in 2.1.4, still cause *long-term* engine damage, with significant economic consequences. These questions are discussed in more detail in Chapter 4.

2.3 ELECTRICAL PHENOMENA IN VOLCANIC ASH CLOUDS

2.3.1 The occurrence of lightning in volcanic ash columns has been reported since antiquity. Frequently such lightning displays can be quite spectacular and clearly indicate that volcanic ash columns are highly charged electrically. Moreover, one of the prime means of recognizing that an aircraft has encountered volcanic ash is the static electricity discharge exhibited by St. Elmo's fire at points on the airframe and the glow inside the jet engines. The static electric charge on the aircraft also creates a "cocoon" effect which may cause a temporary deterioration, or even complete loss, of VHF or HF communications with ground stations. There is some uncertainty regarding how such a high degree of electric charge is generated. One body of opinion favours the build up of charge due to ash particle collisions in the column[8], whereas another postulates that the charge is generated mainly by fracto-emission processes during magma fragmentation within the volcano vent rather than by collision effects in the column[9]. Whatever the cause, it has been demonstrated that the potential gradient of the electric field in a volcanic ash column/cloud frequently reaches ±3 kv/m[1] and can reach up to 10 kv/m[1]. In general, the fallout of ash particles is accompanied by negative deviations of electric potential from the background potential, while during fallout of acid rain droplets positive deviations are observed.

8. Prata, p. 39. (See note 6, p. I-2-6).
9. Gilbert and Lane, page 31. (See note 3, p. I-2-3).

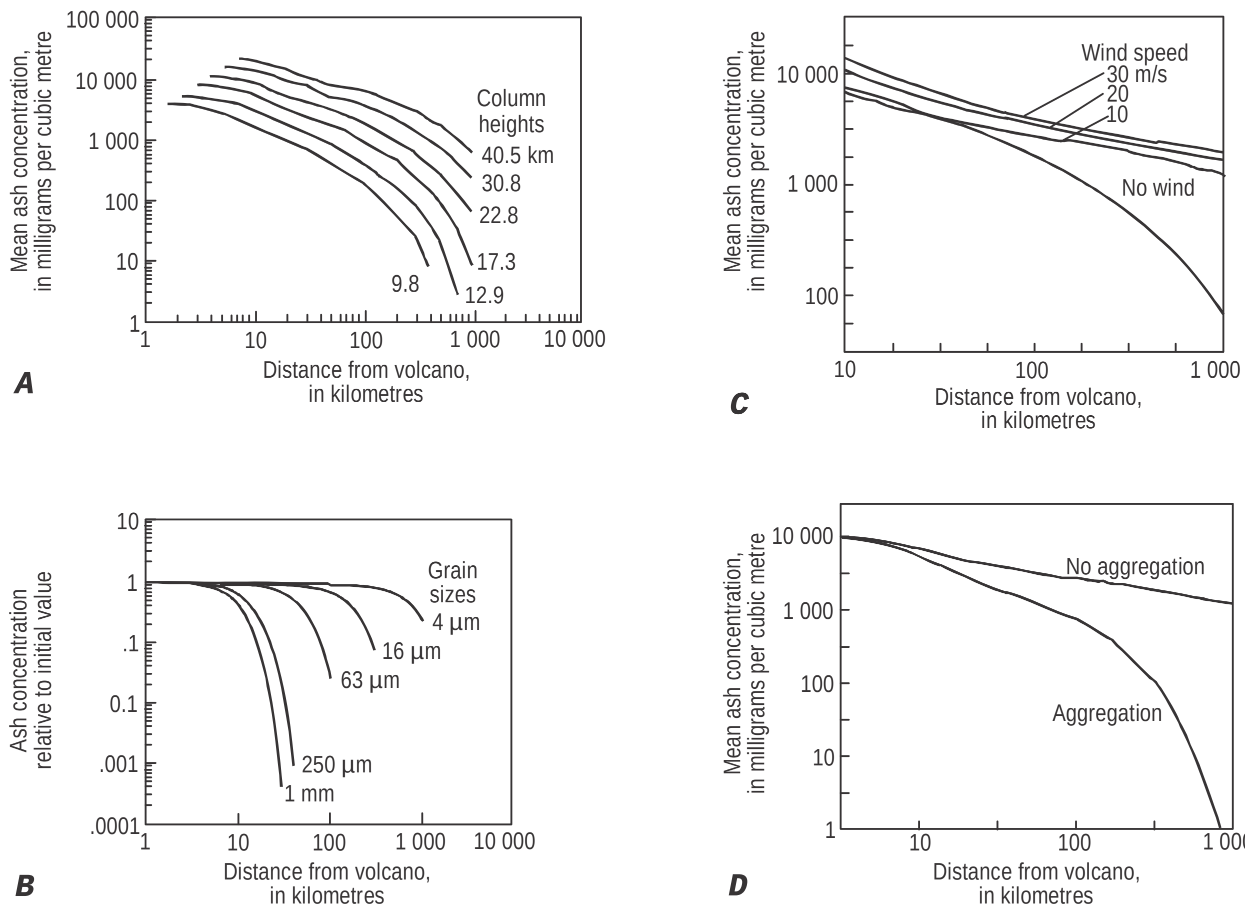

Figure I-2-7 ***A*. Ash concentration in an umbrella cloud (in mg/m^3) is plotted against distance for six different column heights and for dispersal in the absence of wind.**

***B*. Relative concentration of ash is plotted against distance for each grain size class for a 22.8 km (75 000 ft)-high column in the absence of wind.**

***C*. Concentration of ash (in mg/m^3) is plotted against distance for a 22.8 km (75 000 ft)-high column erupted in no wind and for downwind transport of a layer 5 km thick with its base at 15.9 km (52 000 ft) altitude for wind velocities of 20, 40 and 60 kt, and for the case of no wind.**

***D*. Comparison of the downwind change in ash concentration between the case of individual fallout of all sizes and the case where particles less than 63 µm aggregate. Calculations are for a wind speed of 20 kt and a 5 km (16 000 ft)-thick layer with base at 15.9 km (52 000 ft). (from Bursik, Sparks, Carey and Gilbert)**

2.3.2 The high electric charge of volcanic ash columns is of more than academic interest. To an extent, and especially early in the eruption, the associated lightning can be of use in monitoring the location and extent of the column. It has also been suggested[10] that the gradient of electric field strength could be monitored by equipment which could be installed on aircraft, thus providing an independent warning to aircraft of anomalous high electric charges in the atmosphere which could be associated with volcanic ash or thunderstorms, both of which are to be avoided. The electric field in volcanic ash columns has been investigated in some detail using the so-called "volcano working laboratory" of Mt. Sakurajima in Japan[11]. This particular volcano has undergone vulcanian-type eruptions on an almost daily basis since the 1950s. While the eruptions are often of an explosive type, accompanied by explosion earthquakes and atmospheric shock waves, they usually only last a few hours with columns reaching a maximum height of 3 km. These attributes have made the volcano an ideal test site for volcanic ash research. Given the high electric charge exhibited by volcanic ash particles and the fact that the ash is of sufficiently small diameter to penetrate aircraft filter systems, there is concern that the charged particles could enter aircraft electronics cooling systems and adversely affect semiconductor devices. No such reports have so far been received but the situation would bear close monitoring.

2.4 MOVEMENT OF VOLCANIC ASH CLOUDS

2.4.1 The "umbrella" region of a volcanic ash column described in 2.2.1.4 represents the beginnings of the formation of a volcanic ash cloud. The extent of the cloud and its subsequent movement away from the volcano site depend on a combination of its natural dispersion in the atmosphere and its transport as an entity due to the upper tropospheric and stratospheric winds. How rapidly the ash cloud disperses and the concentration/mean particle size of the ash cloud at any particular time in the future depend on the mass loading of the column and its initial height (see 2.2.2.2), the tropospheric and stratospheric winds (transport of each layer and wind shear), the stability of the atmosphere (including turbulence) and the deposition of ash particles due to gravity and scavenging by rainfall. Depending on the upper wind profile, the ash cloud may shear and move in markedly different directions at different levels of the atmosphere. The strongest winds are usually in the higher levels of the troposphere, below the tropopause and, depending on latitude, may include jet streams. It so happens that this layer of the atmosphere, from 10 to 14 km (~30 000 to 45 000 ft), which experiences the strongest winds, is also the region in which lie most jet transport aircraft cruise levels. This increases the probability of jet aircraft encountering volcanic ash cloud of significant concentration hundreds of kilometres from the volcano source. As an example, aircraft reports of encounters with volcanic ash from Mt. Pinatubo (1991) were received from aircraft flying over the Indian Ocean.

2.4.2 The meteorological conditions in the stratosphere are very different from those in the troposphere. In particular, winds are mainly zonal, moderate and steady for considerable periods, there is no scavenging of ash particles by rainfall, and there is little instability and turbulence. Under these circumstances, if the volcanic ash column penetrates into the stratosphere, the associated ash cloud may be transported for very long distances. Numerous examples are available of volcanic ash from such eruptions circling the earth in the tropics in around 14 days, and ultimately doing this more than once. These ash clouds are very diffuse by this stage and, generally, can only be detected from satellite data by the presence of anomalous high levels of SO_2 gas (see Chapter 3). It should be noted that the level of the tropopause, which is the "boundary" between the troposphere and the stratosphere, is highest near the equator and lowest at the poles. In winter in high latitudes the tropopause is frequently at altitudes below 10 km, so the probability of volcanic ash columns reaching the stratosphere from explosive eruptions in Kamchatka, the Kuriles, Aleutians and Alaska is rather high. The regular operation of aircraft in the stratosphere at high latitudes exposes them to the effects of very fine ash/sulphuric acid particles. The long-term maintenance consequences of such exposures are under investigation. It has already been noticed, however, that the cockpit/passenger windows seem to deteriorate more quickly on aircraft operating regularly over the Pacific, thus requiring more frequent re-polishing or replacement at considerable expense to the airlines.

10. Prata, p. 39. (See note 6, p. I-2-6).
11. Gilbert and Lane, page 31. (See note 3, p. I-2-3).

2.4.3 The movement of a volcanic ash cloud from the volcano site and gradual deposition of the larger ash particles during the first few hours has important consequences for airports located within less than one hundred kilometres downwind of a volcano. As will be discussed in detail in Chapter 5, such ash deposition can completely paralyse an airport located within sight of the volcano, and aircraft operations at airports at distances even further downwind may well be seriously affected.

Chapter 3

OBSERVATION/DETECTION AND FORECASTING MOVEMENT OF VOLCANIC ASH IN THE ATMOSPHERE

3.1 GROUND-BASED OBSERVATION

3.1.1 Direct visual observation of volcanic ash cloud from the ground is very much dependent on the observer having prior knowledge that a volcanic eruption has occurred in the vicinity. During an actual volcanic eruption, observation is straightforward and the ash column and mushroom associated with the umbrella region described in Chapter 2 are easily identified. Once the umbrella region has spread at high levels some distance from the volcano, however, it becomes increasingly difficult to discriminate from ordinary high (ice crystal) cloud. Generally, the high level veil of ash tends to dilute the yellowish colour of the sun, so that it appears very pale with brownish- or greyish-tinged edges. In some cases, especially following major eruptions, a type of corona is visible around the sun, with an inner radius of angular width of 10 degrees and outer radius of 20 degrees. The angular radius depends on the particle size distribution and the time of day (height of the sun); the foregoing values being typical of midday, with the radius increasing slightly the nearer the sun is to the horizon. This type of corona is known as a "Bishop's ring", which has an ecclesiastical connotation but not perhaps the obvious one, because in fact the phenomenon was named after Sereno E. Bishop of Honolulu who first described it, but it so happens that he was indeed the Reverend Sereno E. Bishop. Major Plinian eruptions pump vast quantities of volcanic ash high into the stratosphere, as described in Chapter 2. When such eruptions occur within tropical latitudes, the ash can be transported by stratospheric winds many times around the globe, the extreme case being the eruption of Tambora in 1815, which all but eliminated the summer of 1816 in the northern hemisphere. Such high level veils of ash are easily visible from the ground for what they are and can cause many subsequent months of spectacular and unusual sunsets. As regards the height of the volcanic ash column, it is probably true to say that these are generally underestimated by ground observers.

3.1.2 Ground-based radars are optimized to detect precipitation (weather radars) or moving targets (ATC and military). These radars normally operate in the X, C or S bands and occasionally the L band, with wavelengths ranging from 3 cm for X band up to 77 cm for L band. From theoretical considerations[1], the optimal wavelength for a radar to detect volcanic ash should be between 3 mm to 3 cm, e.g. in the K band. The foregoing explains why volcanic ash has often been detected on ground-based X band weather radars, especially when the radar is close (within 100 km) to the eruption, which is also the time when the ash column is at its most dense and still loaded with the larger size ash particles. In fact, radar is the only really effective way to gauge the actual height of the initial volcanic ash column.

3.1.3 The results of studies on the subject indicate that it would be possible to optimize ground-based radar to detect volcanic ash. In particular, as mentioned above, a wavelength in the K band would be suitable, and Doppler and polarization of the signal could provide important information on particle size, shape and velocity. Installing such a radar specifically optimized for volcanic ash detection to monitor a volcano or even a group of volcanoes, however, would be an expensive undertaking, especially as none of the volcanoes monitored may erupt for decades or even longer. If the radar could be made mobile, then at least it could be moved to within range of any volcano which exhibited significantly increased volcanic activity.

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1. W.I. Rose and A.B. Kostinski, "Radar Remote Sensing of Volcanic Clouds", *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 391.

3.2 AIRBORNE OBSERVATION

3.2.1 Although improvements are constantly made, only a minority of all active volcanoes in the world is subject to scientific monitoring. Due to their commanding view from the cockpit and regular travel over remote areas, pilots are often the first to observe a volcanic eruption or volcanic ash cloud. In view of the danger volcanic ash presents to aircraft, it is therefore of utmost importance that, workload permitting, States require aircraft pilots to report observed volcanic activity in a timely manner in accordance with Annex 3 — *Meteorological Service for International Air Navigation*, 5.5 g) and h), and to record a special air-report in accordance with Annex 3, 5.9. However, striking a balance between the continual reporting of a volcano which produces smoke/steam virtually every day on the one hand and ignoring all but a full-fledged eruption on the other hand, is rather difficult. The explanation for "pre-eruption volcanic activity", in this context, is given in Annex 3 as: "unusual and/or increasing volcanic activity which could presage a volcanic eruption". It is accepted that pilots should only report what they see, which may be largely subjective. Nevertheless, special air-reports of volcanic activity should still be made by pilots in these circumstances, and the relevant area control centre will decide if it is necessary to issue a NOTAM. Pilots should make and transmit a special aircraft observation in accordance with Annex 3, 5.5 g) and h) in the event that pre-eruption volcanic activity or a volcanic eruption is observed, or a cloud of volcanic ash is encountered or observed which may affect the safety of other aircraft operations, and to record a special air-report in accordance with Annex 3, 5.9. In order to make pilots aware of the importance of reporting volcanic activity and to familiarize them with the means to do so, it is recommended States require that airlines cover this in operations manuals and train flight crews to observe and report volcanic activity, and provide guidance material through, for example, manuals for recurrent training. Indications of inadvertent flight into volcanic ash are listed in 3.2.2. For procedures on dealing with volcanic ash encounters, flight crews may be referred to the original equipment manufacturer's instructions and procedures. General information on this subject is found in Chapter 4, 4.5.

3.2.2 Indicators that an aircraft is encountering volcanic ash are related principally to the following:

Odour. When encountering volcanic ash, flight crews usually notice a smoky or acrid odour that can smell like electrical smoke, burnt dust or sulphur.

Haze. Flight crews, as well as cabin crew or passengers, may see a haze develop within the aircraft cockpit and/or cabin. Dust can settle on surfaces.

Changing engine conditions. Surging, torching from the tailpipe and flameouts can occur. Engine temperatures can change unexpectedly, and a white glow can appear at the engine inlet.

Airspeed. If volcanic ash fouls the pitot tube, the indicated airspeed can decrease or fluctuate erratically.

Pressurization. Cabin pressure can change, including possible loss of cabin pressurization.

Static discharges. A phenomenon similar to St. Elmo's fire or glow can occur. In these instances, blue-coloured sparks can appear to flow up the outside of the windshield, or a white glow can appear at the leading edges of the wings or at the front of the engine inlets.

Additional engine and/or system anomalies may be noticeable. These are dealt with in Chapter 4, as is the action to be taken by the pilot in these circumstances. It is worth emphasizing again that volcanic ash cloud does not produce "returns" or "echoes" on the airborne weather radar.

3.3 SPACE-BASED OBSERVATION

3.3.1 General

3.3.1.1 A number of satellite systems are currently in operation which can assist in detecting volcanic ash columns/clouds. As was indicated earlier, one of the main problems in detecting volcanic eruptions is the fact that most active volcanoes are not monitored on the ground. The use of satellites, therefore, is seen as the ultimate solution to the remote monitoring of volcanoes. While in principle this is so, in practice there are a number of difficulties which limit the effectiveness of satellite monitoring of volcanic eruptions and ash cloud. Firstly, the satellite systems available are not optimized to detect volcanic ash. Secondly, generally speaking, it is still easier to detect and monitor a volcanic ash cloud if it is already known that a volcanic eruption has occurred. Detecting the eruption itself from current satellite data is extremely difficult and will likely remain so for some considerable time. Solutions to these and other difficulties have been proposed and are discussed in the final section of this chapter. The ensuing sections deal with existing satellite systems and their suitability for monitoring volcanic eruptions and ash cloud.

3.3.1.2 There are two basic kinds of satellite in operation: polar-orbiting and geostationary. Polar-orbiting satellites orbit the earth at an altitude between 700 and 1 200 km and are sun synchronous, which means they pass over the same points on the earth at approximately the same time each day and night, completing global coverage every 24 hours. Geostationary satellites orbit at the same speed as the earth's rotation and remain stationary to an observer on earth. They are located above the equator at an altitude of 36 000 km. Each kind of satellite has advantages and disadvantages. The polar-orbiting satellites give global coverage, albeit only twice daily and provide the highest resolution, given similar sensors. Geostationary satellites provide almost continuous coverage of that part of the earth each one views, but the resolution becomes progressively worse towards the poles. Polar-orbiting satellites are used for weather sensing, environmental, navigation, search and rescue and ground mapping purposes, while geostationary satellites are used primarily for telecommunications and weather sensing.

3.3.1.3 As far as the detection of volcanic eruptions and volcanic ash cloud are concerned, both kinds of satellites are of interest. As previously indicated, however, maximum use has to be made of existing sensors which were not optimized to observe or detect volcanic activity. At present the polar-orbiting satellite systems offer the best possibilities and the use of these systems will be described first.

3.3.2 Polar-orbiting satellites

3.3.2.1 Polar-orbiting weather satellites carry advanced very high resolution radiometers (AVHRR) which provide five spectral channels, two in the visible and three in the infrared wavelengths as shown in Table I-3-1.

3.3.2.2 The information is available as direct read-out at full resolution to suitably equipped ground stations around the world. The use of AVHRR data to detect volcanic ash cloud was suggested and research began in the early 1980s in Australia and gathered pace in the United States following the Mt. Redoubt eruptions in Alaska in 1989/90. Essentially, the technique is based on the different emission characteristics of volcanic ash (largely silicates) and water/ice clouds, especially in the 10 to 12 µm window — silicates having a lower emissivity at 11 µm than 12 µm, while the emissivity of water/ice is vice versa. Subtraction of the Channel 5 IR data from Channel 4 IR data and the display of the images in composite false colours highlights these differences and in many cases permits a positive discrimination of the ash cloud from the water/ice cloud. The technique works best during the time period when the ash has dispersed from the cone and become semi-transparent, but not yet of such a low density that it has become undetectable. The response characteristics of volcanic ash and ice cloud respectively are shown in Figure I-3-1. It is evident from the figure that, over most of the temperature range in question, there is a marked difference in the T_4-T_5 response between volcanic ash and ice, which explains the success of this split-window detection technique.

Table I-3-1. Characteristics of AVHRR channels

Channel	*Wavelength (µm)*	*Spectral region*	*Primary use*
1	0.58 – 0.68	Visible	Daytime cloud
2	0.725 – 1.10	Visible/near infrared	Surface water vegetation
3	3.55 – 3.93	Thermal infrared	Night-time cloud Forest fires
4	10.30 – 11.30	Thermal infrared	Sea surface temperatures Day/night cloud
5	11.50 – 12.50	Thermal infrared	Sea surface temperatures Day/night cloud

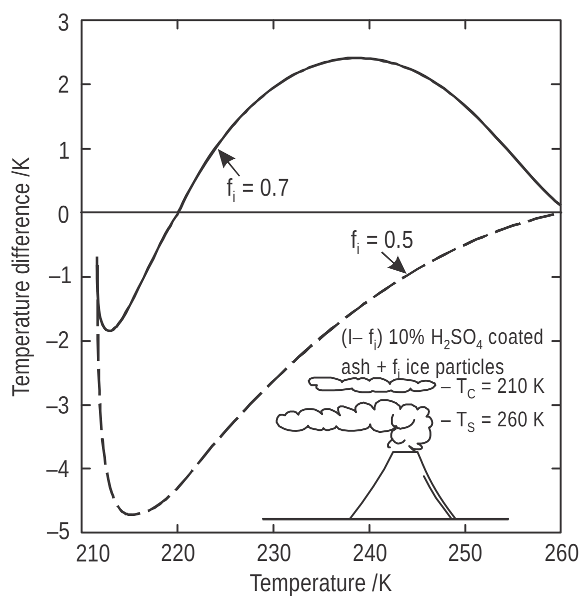

Figure I-3-1. Temperature difference (T_4-T_5) as a function of T_4 temperature for a mixture of ash and ice particles. (from Prata)

3.3.2.3 It has been suggested, on theoretical grounds, that this difference should be most noticeable for ash particles of less than 3 µm and might be expected to be enhanced for particles containing, or coated with, sulphuric acid, a condition quite common in explosive volcanic eruptions[2]. While Channels 4 and 5 are the most useful for these purposes, information from Channels 1 and 2 is also used to assist in the discrimination of ash cloud from water/ice cloud. A typical example of such an analysis is shown in Figures I-3-2 a) and b). It must also be stated that, while the analysis of T_4-T_5 data is the best means of identifying volcanic ash cloud currently available, there are occasions when particular ash clouds have been very difficult to distinguish from water/ice cloud. It has been suggested[3] that this may be due to abnormally high contamination of the ash cloud by water. This is not unusual in "young" ash clouds within a few hours of the volcanic eruption and in deep moist tropical conditions. A refinement of the split-window technique has been developed[4] using Channel 2 (3.9 µm) in the form (T_2-T_4) in addition to the (T_4-T_5) data. Some of the specific problems in discrimination (ash-water/ice) are caused by overshooting cloud tops (i.e. those penetrating into the stratosphere), the radiometer viewing geometry (nadir to off-nadir), pixel alignment between channels, refraction of sunlight depending on time of day and electronic noise.

3.3.2.4 Reference to Table I-3-1 shows that Channel 3 (3.55-3.93 µm) is used to detect forest fires[5]. Proposals have been made that similar use could be made of this channel to detect volcanic eruptions[6] and perhaps even use such "hot spots" to forecast volcanic eruptions (see Figure I-3-3). Again, successful use of this satellite data for this purpose would depend very much on knowing where to look. Moreover, the resolution of the satellite sensors may be too coarse to permit detection of a hot spot due to a volcano cone which is less than 1 km^2, which is probably typical of most volcanoes. Future improved sensors (see geostationary satellites in 3.3.3) may, however, permit automatic monitoring of "hot spots".

3.3.2.5 The polar-orbiting satellites carry other sensors which provide assistance in detecting volcanic ash and discriminating it from water/ice cloud. These include multi-spectral vertical sounding radiometers such as the Advanced TIROS observational vertical sounder (ATOVS) on the United States NOAA-series satellites which comprises a 20-channel high resolution infrared sounder (HRIS) and a 20-channel microwave sounding unit comprised of two instruments (Advanced Microwave Sounding Unit-A (AMSU-A) and Advanced Microwave Sounding Unit-B (AMSU-B)). The data from these instruments can often assist in detecting volcanic ash, and in addition, they provide information on the likely altitude of the ash cloud and the temperature and humidity of the surrounding atmosphere.

3.3.2.6 Special polar-orbiting satellites have been developed specifically to observe the earth's surface in order to monitor earth resources on a global scale. Such systems are operated by France (SPOT), the Russian Federation (RESURS) and the United States (LANDSAT). The instruments on these satellites are primarily concerned with the visible channels, although LANDSAT and RESURS do carry one infrared channel (10.4-12.5 µm). The main advantage of these satellites is the extremely high resolution they offer (~120 m in the infrared channel), which renders it possible to examine a volcanic ash cloud, or indeed an erupting volcano itself, in great detail once the location of the eruption is known. Moreover, given this extremely high resolution and with even higher resolution data becoming available in the future, it may be possible to monitor actual tectonic changes in active volcanoes and thereby assess the likelihood of an eruption[7].

2. Prata. (See note 6, p. I-2-4).
3. D.J. Schneider and W.I. Rose, "Observations of the 1989-90 Redoubt Volcano Eruption Clouds Using AVHRR Satellite Imagery", *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 405.
4. G.P. Ellrod and B. Connell, "Improvements in Volcanic Ash Detection using GOES Multi-spectral Image Data", 8th Conference on Aviation, Range and Aerospace Meteorology, January 1999, Dallas, USA.
5. T.F. Lee and P.M. Tag, "Improved Detection of Hot Spots using the AVHRR 3.7 µM Channel", *Bulletin of the American Meteorological Society*, Vol. 71, No. 12, December 1990.
6. Prata. (See note 6, p. I-2-4).
7. P.W. Francis and D.A. Rothery, Using LANDSAT Thematic Mapper to Detect and Monitor Active Volcanoes Geology, Vol. 15, 1987, pp. 614-616.

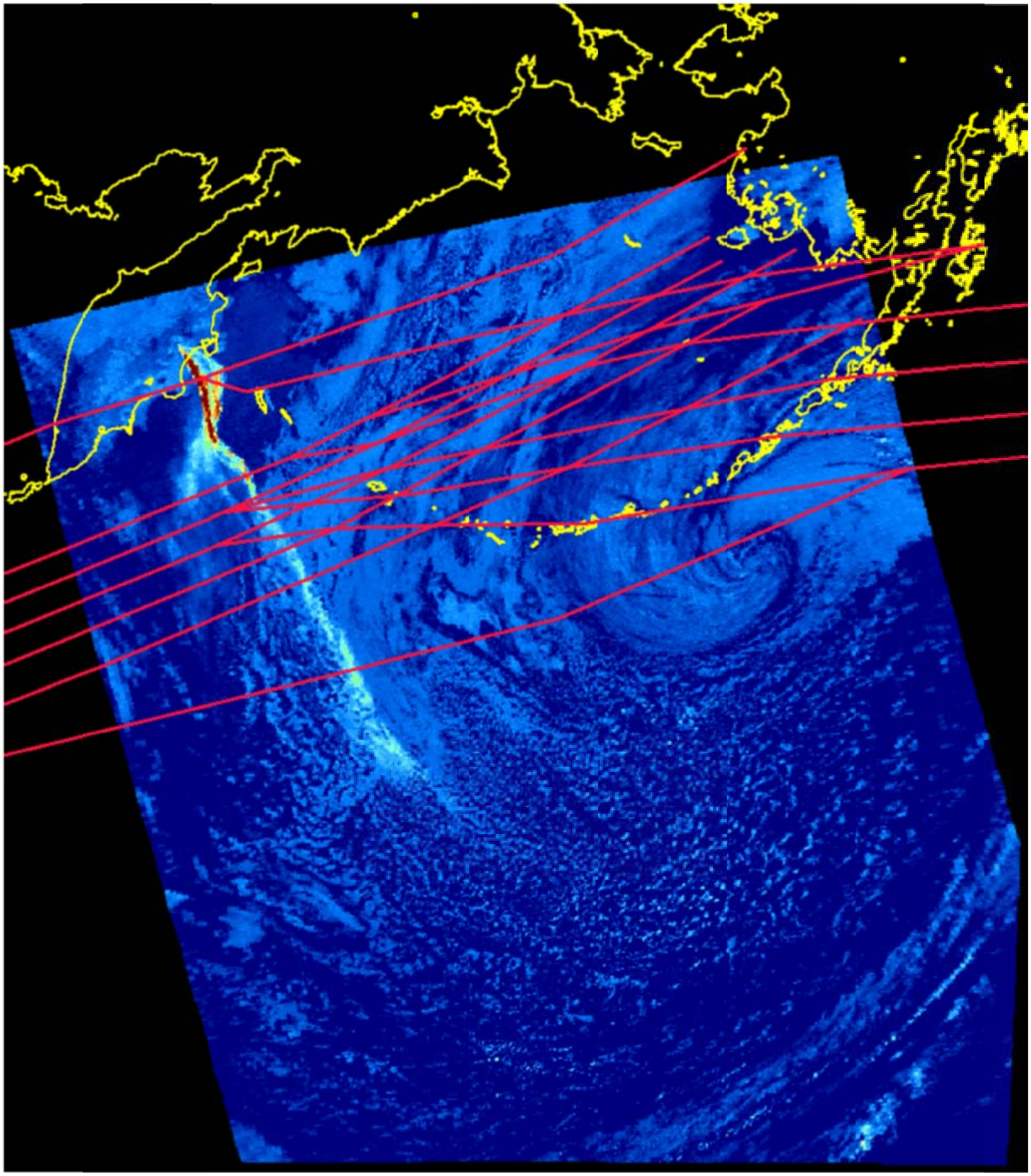

Figure I-3-2 a). AVHRR split-window image of the volcanic ash cloud from Klyuchevskoi Volcano, collected on 1 October 1994 at 0640Z. Both the proximal and distal regions of the ash cloud are highlighted using this method. (courtesy of D. Schneider, U.S. Geological Survey, Alaska Volcano Observatory.)

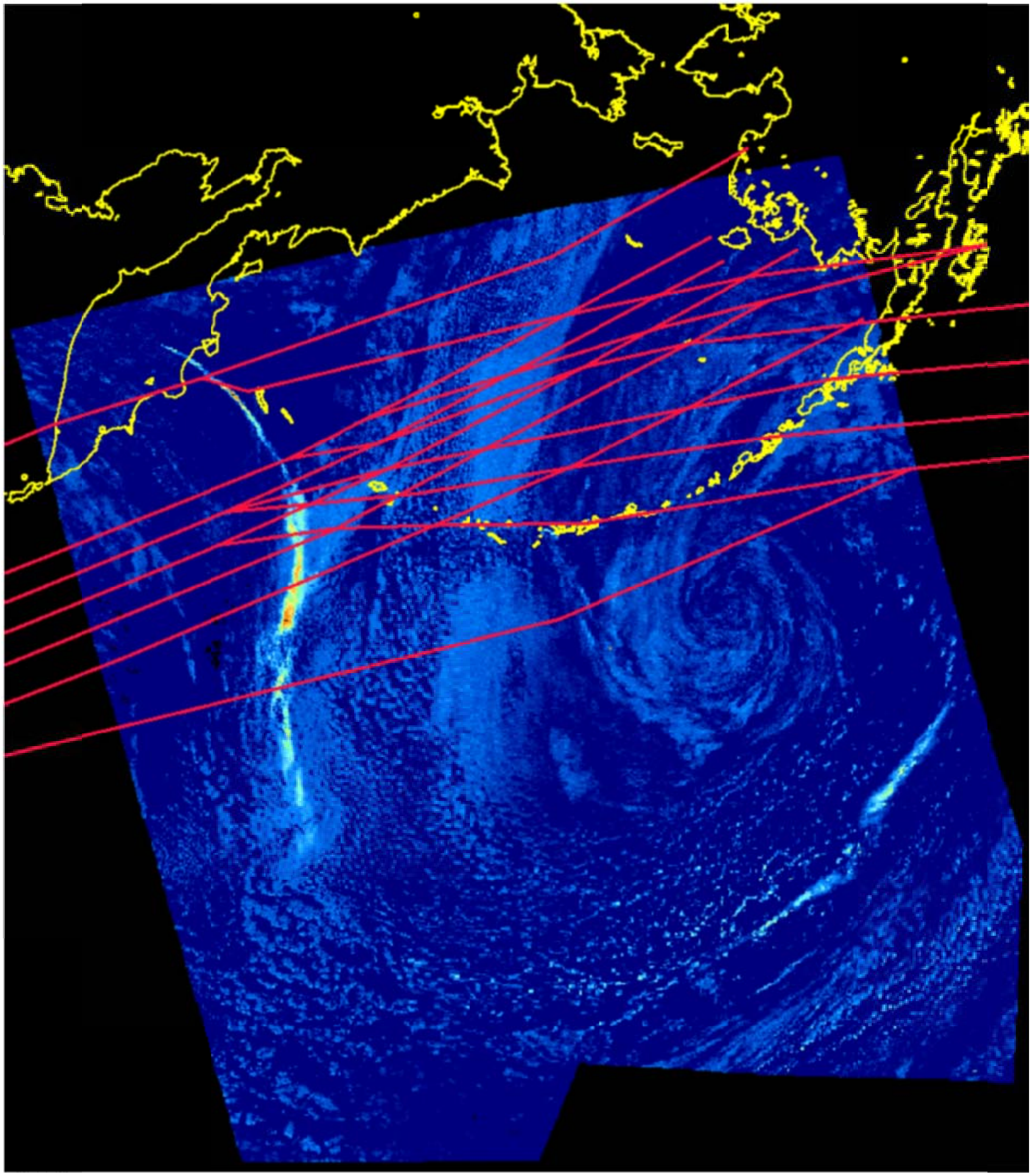

Figure I-3-2 b). A composite AVHRR split-window image of the volcanic ash cloud from Klyuchevskoi Volcano, collected on 1 October 1994 at 1990Z and 2030Z. The distal ash cloud is observed crossing many of the North Pacific air routes in this image. The extent of this cloud was difficult to discern without using this method. (courtesy of D. Schneider, U.S. Geological Survey, Alaska Volcano Observatory.)

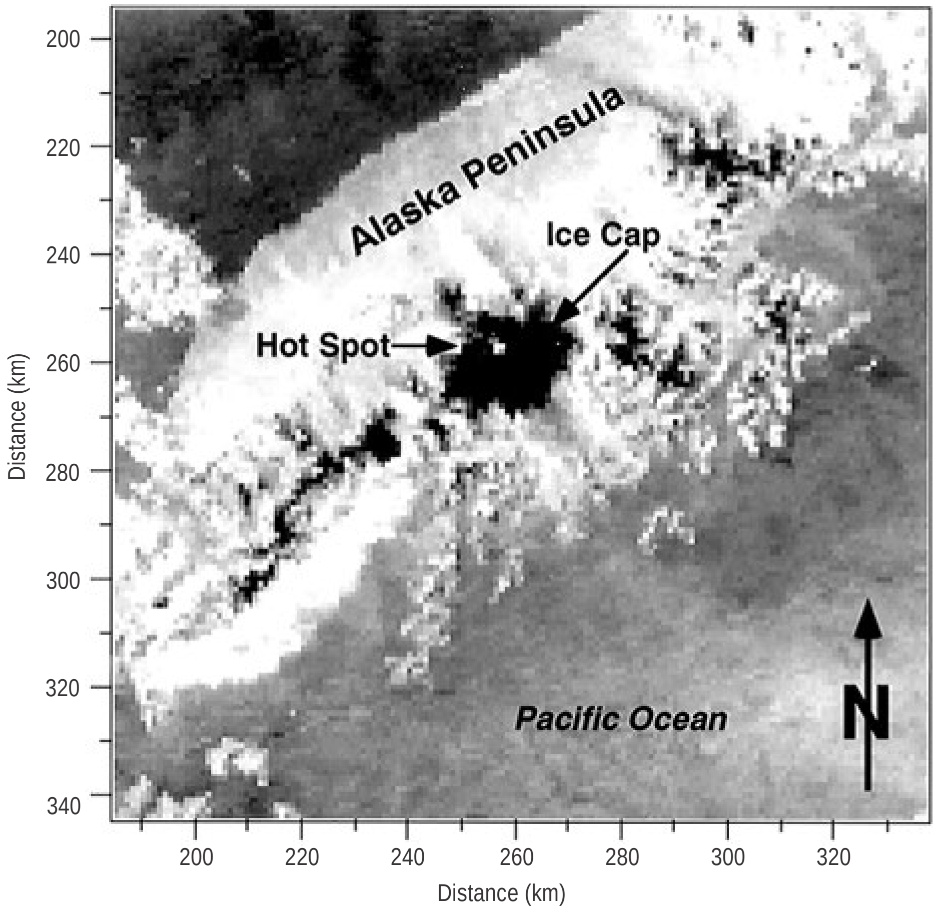

Figure I-3-3. An AVHRR, 30 June 1994, shows a hot spot at Veniaminof Volcano, Alaska. The hot spot (white) is caused by an eruption at a cone on the summit of the volcano that protrudes through the cold ice cap (black). The eruption has melted the ice, forming a pit east of the cone. The thermal infrared image was recorded by the NOAA 12 polar-orbiting weather satellite at wavelengths of 3.55-3.93 micrometres (Band 3) at 0513 UTC. (courtesy of Ken Dean, Geophysical Institute, University of Alaska Fairbanks and the Alaska Volcano Observatory.)

3.3.2.7 There are various other radiometers that provide useful data for studying volcanic clouds. These are on research satellites and, as such, there is a delay in the data availability, and therefore, limited use can be made of the data in an operational environment. However, as these data are becoming more widely used, satellite operators are endeavouring to make the data available with shorter delay. In addition, the repeat cycle of observations can be long. Data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra and Aqua NASA Earth Observing System (EOS) satellites and Alliance Icing Research Study (AIRS) on Aqua are particularly useful. MODIS is a 36-channel visible and infrared radiometer. Its data can be used to track volcanic ash clouds using the technique described in 3.3.2.2. MODIS data can also be used to detect co-erupted material[8] , i.e. sulphur dioxide and sulphuric

8. I.M. Watson *et al*, “Thermal infrared remote sensing of volcanic emissions using the moderate resolution imaging spectroradiometer, *Journal of Volcanology and Geothermal Research*, 135 (2004).

acid aerosol, using data from channels centred at 7.3, 8.6, 11.0 and 12.0 µm. Hot-spots caused by surface magma can also be detected by making use of data in the 3-4 µm region. MODIS data are available at a spatial resolution of 250 m, thereby providing a much more detailed image than from AVHRR data. The AIRS instrument is a 2 378-channel radiometer that senses radiation in the infrared (3.7 to 15.4 µm). AIRS data can also be used to study volcanic emissions of volcanic ash, sulphur dioxide and sulphuric acid.

3.3.2.8 The detection of sulphur dioxide can assist in identifying and tracking volcanic clouds. The Total Ozone Mapping Spectrometer (TOMS) is a sensor designed to map global ozone (O3); its data can also be used to retrieve sulphur dioxide and aerosol concentration. The Earth Probe satellite operated by NASA carries the current operational TOMS instrument. The TOMS sensor measures reflected sunlight from the atmosphere at six wavelengths near the strong ozone absorption band in the ultraviolet (UV) part of the spectrum and scans up to 51 degrees on either side of the satellite. Much of the research done on the so-called “ozone hole” over the Antarctic is based on data provided by the TOMS sensor. This sensor has since proved to have unexpected capabilities and uses, including the ability to detect sulphur dioxide (SO_2) in the atmosphere, a gas which almost invariably accompanies Plinian volcanic eruptions. TOMS data have been used to detect and monitor volcanic ash from over fifty volcanic eruptions since this capability was first applied in 1978[9], although an “aerosol index” derived from TOMS UV data cannot distinguish between ash and other aerosols such as smoke and dust. It should be emphasized that SO_2 detection cannot be used to define the extent of the volcanic ash because each has a different dispersal mechanism, but its presence in high concentration does confirm that a cloud is of volcanic origin.

3.3.2.9 The detection of SO_2 in the atmosphere is possible because it happens to have a UV absorption band in the same wavelengths as O_3. When SO_2 is present in high concentrations, such as in most Plinian volcanic ash clouds, it is possible to distinguish the SO_2 radiances from those attributable to O_3. Moreover, the TOMS instrument, naturally, is optimized to detect and measure O_3, and it would be possible to develop an instrument which was optimized to detect large concentrations of SO_2. The TOMS instrument being located on a polar-orbiting satellite means that points on the earth are only monitored by each satellite twice daily. In fact, the situation is worse than this as O_3/SO_2 data for any point are only monitored once per day because the TOMS instrument detects reflected sunlight and hence is only operative on the daylight side of the earth.

3.3.2.10 In the case of the Mt. Pinatubo eruptions in 1991, over 20 million tons of SO_2 were blasted into the atmosphere and the SO_2 cloud as it spread around the earth was monitored for months. The edge of the detected SO_2 cloud does not necessarily coincide with the edge of the volcanic ash cloud. Nevertheless, it does serve to confirm a detection of volcanic ash by other means and, in the future, could form part of an automated volcanic eruption detection system. The effectiveness of the TOMS SO_2 detection capabilities is illustrated by the sequence of events following the Mt. Hudson eruption in Chile on 15 August 1991. The infrared image of the eruption in Figure I-3-4 shows a typical ash cloud streaming downwind from the volcano, across Argentina and into the south Atlantic. On 20 August 1991, a flight from Melbourne to Sydney, Australia, reported an encounter with a “strange hazy cloud 260 km NE of Melbourne”[10]. A smell of sulphur was also reported by the crew and passengers. A NOTAM was issued as a precaution in case the cloud was volcanic ash. In fact the cloud was the remnants of the Mt. Hudson eruption cloud which had travelled as a coherent cloud in the band of strong westerly winds around the southern latitudes. This was proved conclusively by the analysis of TOMS data for the period shown in Figure I-3-5.

9. A.J. Krueger, *et al*, “Volcanic Hazard Detection with the Total Ozone Mapping Spectrometer (TOMS)”, *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, US Geological Survey Bulletin 2047 (1994), p. 367.
10. A.J. Prata, Smithsonian Institution Bulletin of the Global Volcanism Network, July 1991.

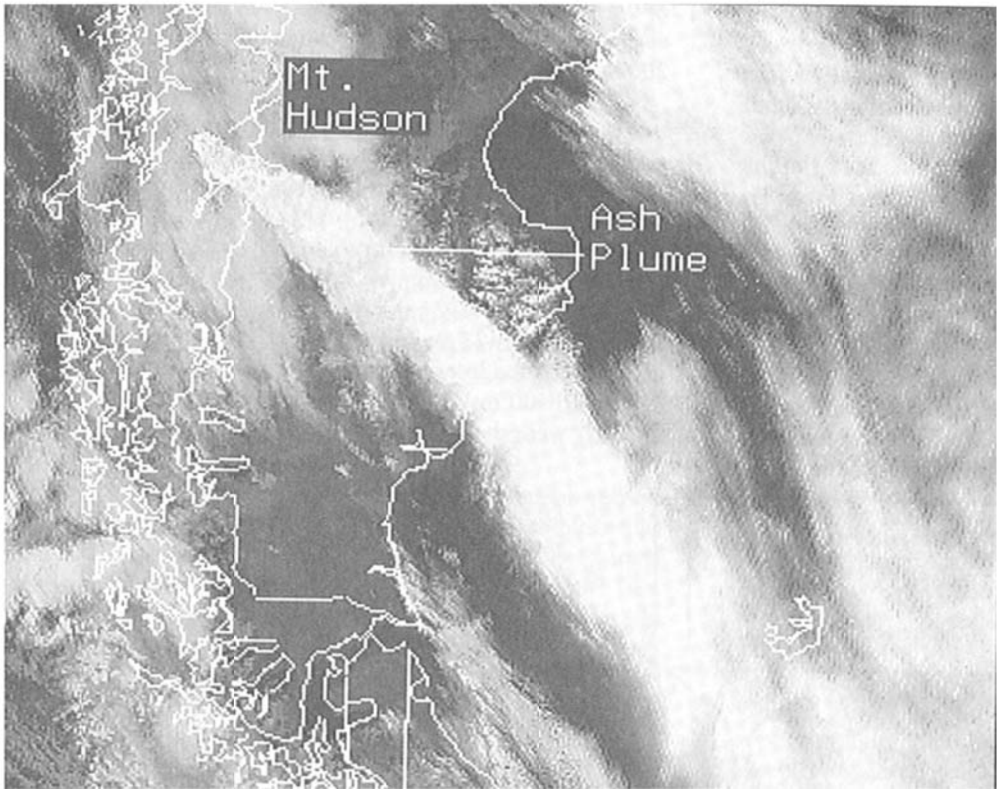

Figure I-3-4. Infrared image from the NOAA 10 polar-orbiting weather satellite on 15 August 1991 at about 0800, showing ash column extending SE from Hudson. Temperature estimates suggest that the column is at about 17-18 km altitude. (courtesy of Synoptic Analysis Branch, NOAA/NESDIS, from Global Volcanism Network)

3.3.2.11 Another application of the NOAA series of polar-orbiting satellites is the remote monitoring of ground-based data platforms. This system, called ARGOS, is a cooperative programme of the United States National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA), and the French space agency, le Centre National d'Études Spatiales (CNES). The ARGOS equipment on board the satellite automatically receives transmissions (telemetered data) from all ARGOS ground-based platforms which are within sight of the satellites, and the data are recorded and downloaded to three ground stations. Virtually any environmental data which can be measured by sensors associated with the ground station can be collected by the ARGOS system. In fact the system has been used to collect vulcanological and seismological data. In one example, the volcanic islands of Vanuatu in the Pacific were monitored and provided data on fifteen parameters nine times per day. In another case the crater lake temperature of the Kelut volcano in Java was monitored right up to the 1990 eruption and provided invaluable information[11].

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11. J.P. Cauzac, C. Ortega and L. Meuhlhausen, "Satellite Monitoring of Volcanoes Using ARGOS", *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 319.

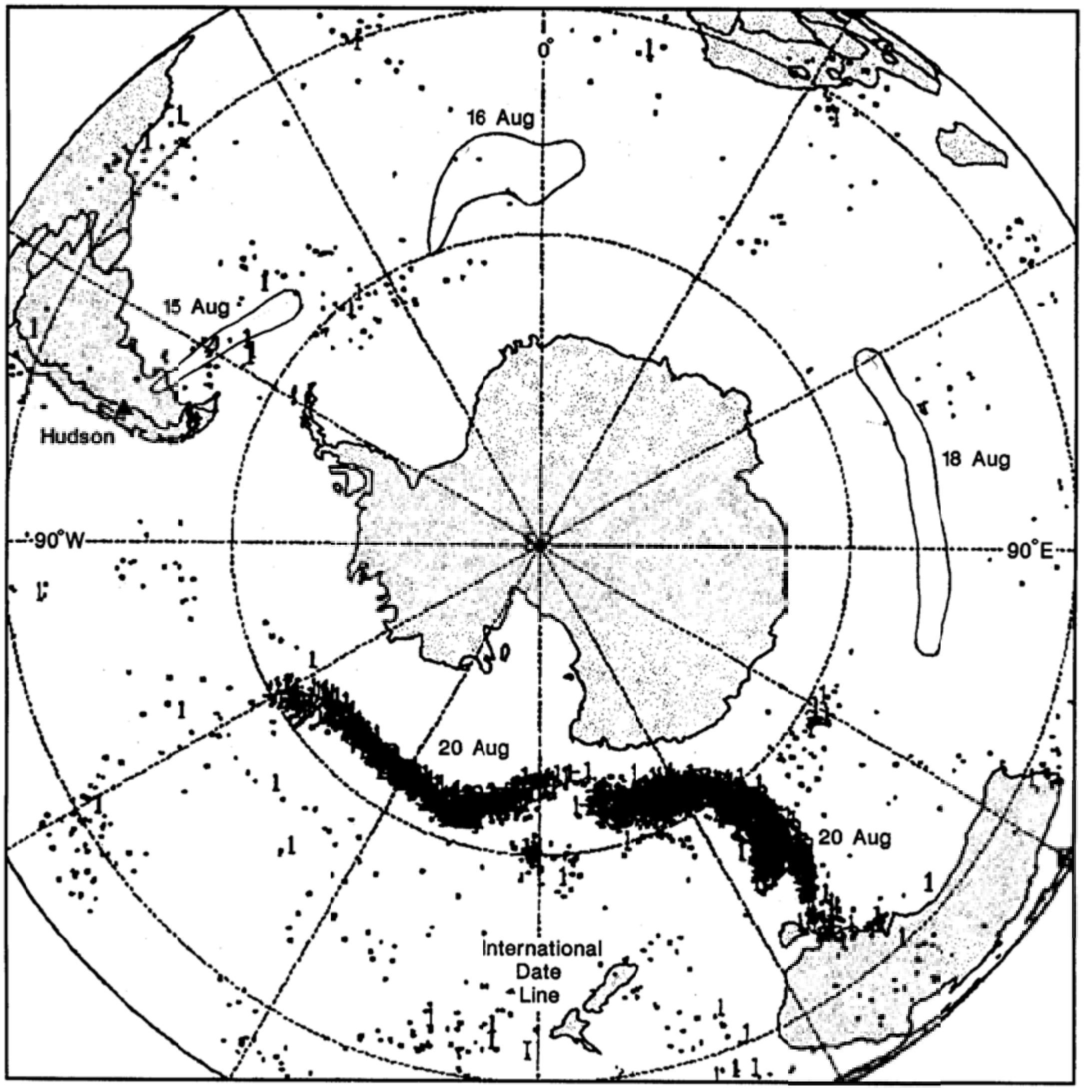

Figure I-3-5. Polar view of SO_2 column from Hudson: preliminary data from the total ozone mapping spectrometer (TOMS) on the Nimbus-7 satellite showing an eruption cloud from Hudson on 20 August 1991 at about 1100 (local time). Each dot represents SO_2 values about 10 milliatmosphere-cm (100 ppm-m), within an area 50 km across. The prominent concentration of SO_2 to the left represents the cloud's position 24 hours after that to the right, but both are 20 August because they straddle the International Date Line. Envelopes surrounding the cloud's position at approximately 1100 (local time) on 15, 16 and 18 August have been added to illustrate its passage around the globe. (courtesy of Scott Doiron from Global Volcanism Network)

3.3.3 Geostationary satellites

3.3.3.1 Geostationary meteorological satellites are operated by Europe, China, India, Japan, the Russian Federation and the United States. The principal sensor carried by these satellites is a multi-spectral radiometer. In general, the sensors have three main channels: visible (0.5 to 0.9 µm), thermal infrared water vapor (5.7 to 7.1 µm) and thermal infrared window (10.5 to 12.5 µm). This small set of channels limits the usefulness of data from these sensors for volcanic ash detection. However, some of the satellites carry sensors with additional channels that make the data far more useful for detecting and tracking volcanic ash clouds. In particular, Meteosat-8 and its successors (positioned at 0º E) carry the Spinning Enhanced Visible and Infrared Imager (SEVIRI) sensor which has 12 channels, many of which can be used for detecting volcanic emissions. Sensors on the Geostationary Operational Environmental Satellites (GOES) and geostationary meteorological satellites (GMS) also have additional channels that are useful for volcanic ash detection. A summary of the channels on the sensors currently on board geostationary satellites is shown in Table I-3-2. Data from geostationary satellites is of lower resolution than similar data from polar-orbiting satellites ranging from 3-11 km from geostationary imaging sensors compared with 1 km at sub-satellite point for AVHRR on NOAA's polar-orbiting satellites. In addition, the spatial coverage is not as high: the field of view of a geostationary imagery has a range of approximately 70º S – 70º N with spatial resolution decreasing away from the sub-satellite point. However, the major advantage of using data from geostationary satellites over polar-orbiting satellites is that they image the same area of earth at least every hour (Meteosat-8 images every 15 minutes).

3.3.3.2 Several of the imaging sensors on geostationary satellites have similar channels as the AVHRR instrument on the NOAA series of polar-orbiting satellites (Table I-3-2). Thus, geostationary data from GOES-10, GMS-5 and Meteosat-8 can be used to detect volcanic ash clouds using the same method employed with AVHRR data (3.3.2.2). However, the poorer spatial resolution and wider channel bands result in a lower detection rate. The high imaging cycle of geostationary sensors means that detection is possible soon after the start of an eruption, and the eruption cloud can be almost continuously tracked.

Table I-3-2. Central wavelengths of the principal imaging instruments on geostationary satellites in mid-2004.

Channels on AVHRR, the imager on NOAA polar orbiting satellites, are listed for comparison.

Note that since Spring 2003 GOES-9 (with the same sensor as GOES-10) has replaced GMS-5 which now acts as back-up.

Satellite	*Location*	*Central wavelengths of channels (µm)*											
		Visible			*Near IR*	*Infrared*							
Meteosat-5	E63º	0.7					6.4				11.5		
Meteosat-8	E0º	HRV*	0.6	0.8	1.6	3.9	6.2	7.3	8.7	9.7	10.8	12.0	13.4
GMS-5	E140º	0.7					6.7				11.0	12.0	
GOES-10	W135º	0.6				3.9	6.7				10.7	12.0	
GOES-12	W75º	0.6				3.9	6.7				10.7		13.3
NOAA	Polar orbiter	0.6	0.8			3.9					10.8	12.0	

**Note.— HRV is High Resolution Visible a broadband channel (0.4 – 1.1 µm).*

3.3.3.3 The imager on the new generation of GOES satellites (GOES-12 onwards) does not have a 12.0 µm channel. This presents problems for volcanic ash detection since the standard technique (3.3.2.2) cannot be used. Alternative methods[12] have been developed which involve the application of data from the 3.9 µm channel during the day (ash is high reflective at this wavelength). However, detection is problematic at night and therefore there is the need for a higher reliance on AVHRR data from polar-orbiting satellites.

3.3.3.4 The imaging sensor SEVIRI on Meteosat-8 has higher functionality than the other geostationary imagers. Hot-spots and sulphur dioxide can be detected in addition to volcanic ash. The detection and tracking of these volcanic emissions makes use of data from many of SEVIRI's channels, e.g. 3.9, 7.3, 8.7, 10.8 and 12.0 µm.

3.3.4 Future ground-based, airborne and satellite sensors and systems

3.3.4.1 In the realm of ground-based sensors, improved Doppler radars which are extremely sensitive, have good attenuation characteristics, and have powerful signal processing capabilities, are already being installed at aerodromes and along air routes in the United States Weather Surveillance Radar (WSR 88D). Moreover, Doppler weather radar is becoming the radar of choice all over the world when a meteorological authority has to replace its existing weather radars. Although such radars will not generally be located conveniently to monitor volcanic eruptions, in certain areas, e.g. Alaska and Japan, it is likely that future eruptions increasingly will be monitored by ground-based Doppler radar. Aside from its obvious operational use in providing ash column altitude and extent during an eruption, Doppler radar should also greatly enhance our knowledge of the detailed characteristics of volcanic ash columns/clouds such as the vertical velocity of the ascending column and the ash particle fall speed[13]. Such information could be correlated with ground ash sampling to compare with theoretical models currently in use. Research is proceeding rapidly on light detection and ranging (LIDAR) sensors which can detect and measure the particle size/density spectrum of virtually any aerosol including volcanic ash clouds, and it is expected that these sensors will be used for research into the particle size/concentration in volcanic ash clouds.

3.3.4.2 There have been a number of proposals for airborne sensors which could detect volcanic ash ahead of the aircraft, including LIDAR and passive infrared. Airborne LIDAR sensors would essentially be miniaturized versions of the ground-based sensor described in 3.3.4.1. A proposal was made to the Australian civil aviation authorities in 1982 for an airborne passive infrared sensor which was based on the two-channel thermal infrared AVHRR satellite data discrimination techniques already described in 3.3.2.1[14]. Since then the proposal has been considerably refined and a prototype built and tested as a ground-based and airborne sensor during a volcanic eruption[15]. The sensor is a multi-spectral radiometer operating in the infrared channels indicated in Table I-3-3.

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12. G.P. Ellrod, "Impact on volcanic ash detection caused by the loss of the 12.0 µm 'Split Window' band on GOES Imagers", *Journal of Volcanology and Geothermal Research*, 135 (2004) p. 91.
13. M.L. Stone, "Application of Contemporary Ground-Based and Airborne Radar for the Observation of Volcanic Ash", *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 419.
14. F.R. Honey, "Passive, Two-Channel, Thermal-Infrared Imaging Systems for Discrimination of Volcanic Ash Clouds", *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 347.
15. I.J. Barton and A.J. Prata, "Detection and Discrimination of Volcanic Ash Clouds by Infrared Radiometry —II: Experimental", *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 313.

Table I-3-3. Characteristics of channel filters used in airborne radiometer (from Prata and Barton)

Central wavelength (μm)	*Bandwidth (μm)*	*Function*
6.4	0.3	Water-vapour emission for clear air turbulence
8.6	0.5	SO_2 emission
10.1	0.5	Water/ash cloud discrimination
10.8	0.6	Water/ash cloud discrimination
10.91	1.0	Water/ash cloud discrimination
11.8	1.4	Water/ash cloud discrimination
12.0	0.6	Water/ash cloud discrimination

3.3.4.3 This radiometer was successfully calibrated against clear sky and various water/ice clouds and then tested from the ground with volcanic ash columns from the quasi-regular eruptions of Mt. Sakurajima in Japan. For the ash cloud, the SO_2 filter (8.6 μm), the narrow band filters (10.1 and 12.0 μm) and the wide-band filters (10.91 and 11.8) were used and the results are shown in Figure I-3-6. The results indicate that it would be feasible to detect volcanic ash in clear air and to discriminate between volcanic ash and water/ice clouds using a forward-looking, multi-spectral infrared radiometer mounted on an aircraft. In view of the fact that research is also being undertaken in a number of States into the use of passive infrared radiometers to detect wind shear (microbursts and gust fronts) and clear air turbulence, it is likely that a combined instrument could include volcanic ash detection as one of its modes of operation.

3.3.4.4 It is possible in the future that TOMS-like sensors could be installed on geostationary satellites, perhaps optimized to detect anomalous amounts of SO_2 in the atmosphere as well as O_3. A detailed proposal for a geostationary TOMS sensor (GEO-TOMS) has been developed in the United States[16]. A proposal for a mission (named VOLCAM) has been developed by NASA using a UV full earth disk filter wheel camera[17]. The UV camera detects the SO_2 in the initial explosive eruption and SO_2 associated with ash clouds. This camera package is planned to "piggy-back" as a secondary payload on suitable geostationary satellites. In 3.3.2.1 mention was made of the limitation of the GMS-5 split-window infrared channels (4 and 5) due to the lower (8-bit) digitization of the signal. The next series of Japanese geostationary satellites, Multi Function Transport Satellites (MTSAT), however, has the full 10-bit digitization in the infrared channels. The two first satellites in this series have already been launched. The imager will have channels centred at: 0.7, 3.7, 6.7, 10.8, and 12.0 μm and will therefore provide data useful for volcanic ash monitoring.

16. U.G. Hartmann, R.H. Hertel, H.A. Roeder and J.O. Maloy, "GEO-TOMS: Total-Ozone Mapping Spectrometer for Ozone and Sulphur-Dioxide from a Geostationary Satellite", *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 341.
17. A.J. Krueger, "UV Detection of volcanic clouds from Satellites: Possibilities for an aviation hazard system", WMO/ICAO Workshop on Volcanic Ash, Toulouse, 1998.

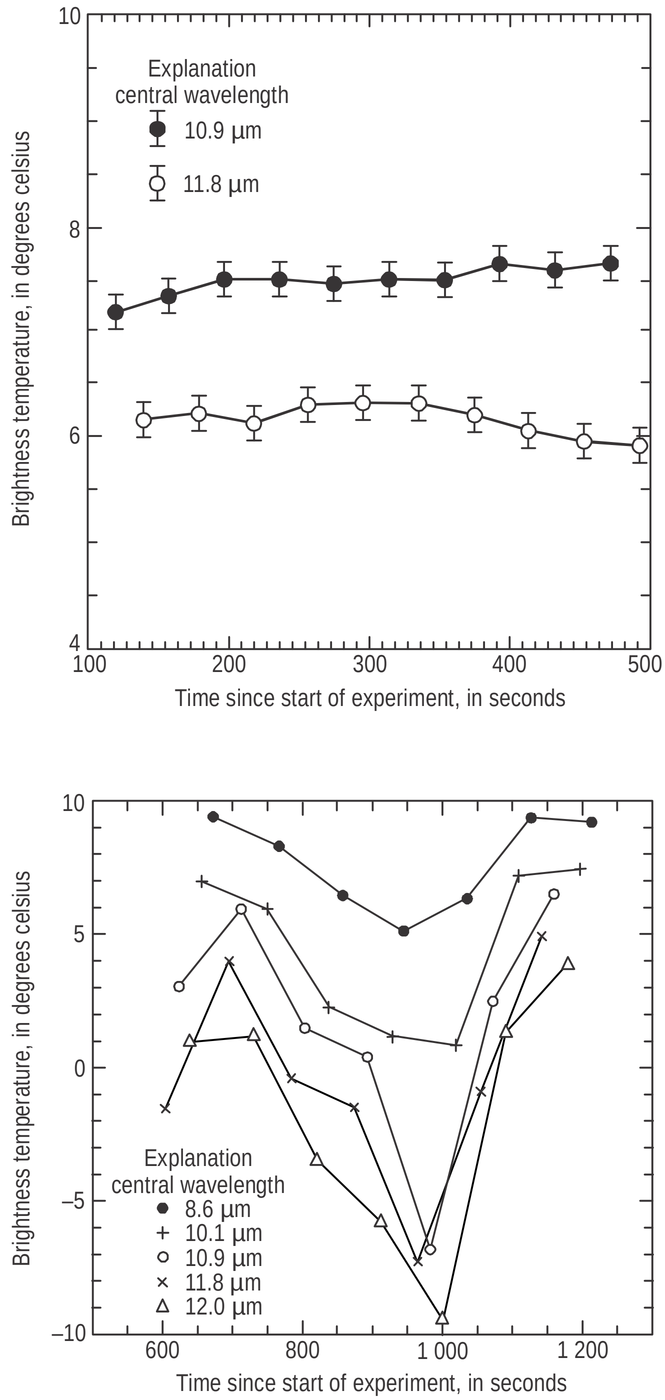

Figure I-3-6. (Top) Ground-based measurements of a cumulus cloud near Mt. Sakurajima, Japan, 10 March 1991, radiometer looking at an elevation of 21°. Vertical bars indicate measurement uncertainty. (Bottom) Ground-based measurements of volcanic ash cloud emanating from Mt. Sakurajima, Japan, 10 March 1991. Radiometer looking at an elevation of 13.5°. (from Prata and Barton)

3.4 FORECASTING THE MOVEMENT OF VOLCANIC ASH CLOUDS

3.4.1 The movement, spread and dispersion of volcanic ash clouds depend on a number of parameters, including the strength of the eruption and hence the altitude reached by the ash particles, particle concentration and size distribution, wind shear and stability of the atmosphere, and the scavenging of ash particles by precipitation. Regular images of a volcanic ash cloud can be derived from satellite data; however, this method alone is not adequate. A predictive scheme is necessary to provide an outlook on how airborne ash would move and spread in the prevailing winds. While in ideal conditions regular images of a volcanic ash cloud are available from satellite data (as described in 3.3), there are problems in coverage (frequency of data and spatial coverage) and in discrimination of the ash column from water vapour ice clouds. With a predictive capability based on numerical atmospheric transport prediction models, and in combination with whatever satellite imagery is available, pilots can be provided with information on the current and projected extent of ash hazards in a timely fashion. Some States had already done considerable research on forecasting the atmospheric transport and dispersion of pollutants, especially radioactive debris, using computer models, and it proved possible to use these models, or adapt them for use, in forecasting the evolution of volcanic ash clouds.

3.4.2 Computer models of varying complexity have been developed to forecast the evolution of volcanic ash clouds. The level of complexity ranges from very simple two-dimensional trajectory models to advanced three-dimensional transport/dispersion models. All of the models depend on the initial input of eruption data (e.g. location and time of eruption, height of column), analysed and forecast meteorological fields and, depending on the model, various assumptions of parameters such as particle mass loading. The typical output of the models provides two- or three-dimensional information of the volcanic ash cloud, depending on the complexity of the model used, at specific times in the future. An example of the output from one of the Montreal Volcanic Ash Advisory Centre's models showing the simulated transport and dispersion of volcanic ash from the Mt. Redoubt eruption on 14 December 1989 is shown in Figure I-3-7.

3.4.3 Another example of a dispersion model is the Met Office (UK) medium-to-long range atmospheric dispersion model called NAME. It has evolved into an all-purpose dispersion model capable of predicting the transport, transformation and deposition of a wide class of airborne materials, e.g. nuclear material, volcanic emissions, biomass smoke, chemical spills, foot-and-mouth disease. It is a Lagrangian particle dispersion model which predicts three-dimensional concentrations and deposition of airborne particles and covers horizontal scales from ~1 km to many 1 000s km. It uses detailed three-dimensional meteorology from the Met Office's Unified Model (horizontal resolution of 60 km globally and 12 km over northwest Europe and the United Kingdom).

3.4.4 During an eruption, forecasters run NAME to predict the dispersion of volcanic ash particles up to six days ahead. Where possible the plume height and release duration are derived from observations (e.g. satellite, radar or pilot reports). A release quantity of 1 g ash is used (1 g per six-hour period if the eruption continues for more than six hours). A look-up table based on summit and ash cloud height is used to determine the concentration corresponding to a "visual ash cloud". If good observational data are available then the release rate can be adjusted to provide a better match between observed and modelled visual ash clouds. An assumed particle size distribution is used, with a continuous distribution between 0.1-50 µm.

3.4.5 The output from NAME is a graphic showing the extent of the visible ash cloud at three levels: surface–FL200, FL200–FL350, FL350–FL550 for the next 24 hours at six-hour intervals. More detailed plots are available to forecasters, representing concentration maps over six layers. The NAME forecast forms the basis of the volcanic ash advisory issued by forecasters. They are validated by comparison in real-time with satellite observations. In addition to using NAME during volcanic events, the model is run twice daily to provide guidance to the Icelandic Meteorological Office (IMO) about the dispersion of ash from two volcanoes, Mt. Katla and Grímsvötn (Figure I-3-8).

3.4.6 Work is currently under way to combine the predictive capability of the atmospheric transport and dispersion models with the actual position of volcanic ash clouds as identified by satellite in data assimilation mode. This will not be an easy task, but if successful, should improve the three-dimensional estimate of the actual volcanic ash cloud and forecasts of its future position.

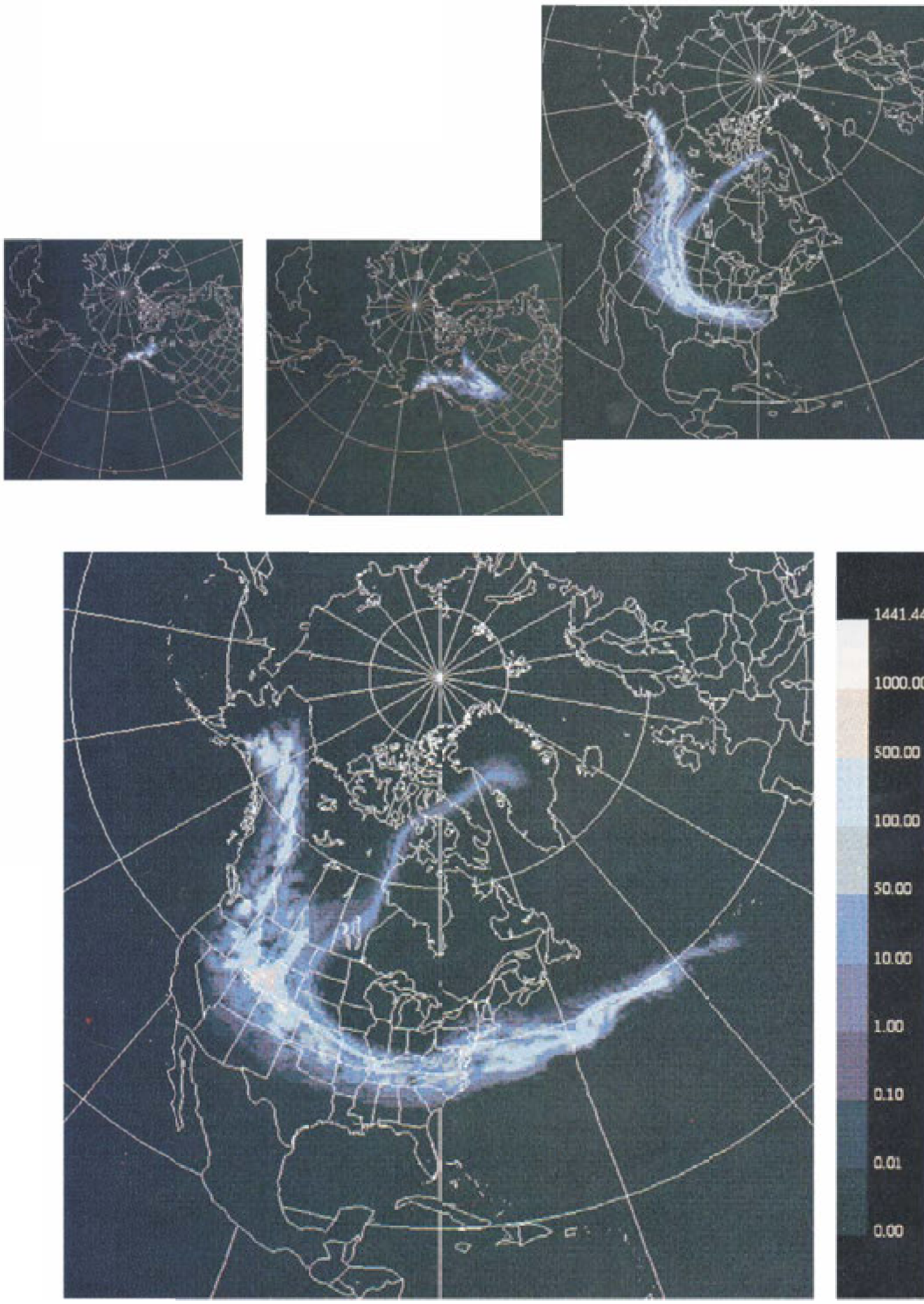

Figure I-3-7. Mt. Redoubt erupts. In this example of an output from the tracer model developed by the Atmospheric Environment Service of Canada, the four panels depict the simulated dispersion of volcanic ash cloud after the eruption of Mt. Redoubt at 1900 hours UTC on 14 December 1989. The concentrations are indicated in a logarithmic scale. The panels refer to the 250 hPa level and correspond to the situation at 12 hours, 24 hours, 36 hours and 48 hours after the eruption. (from ICAO Journal)

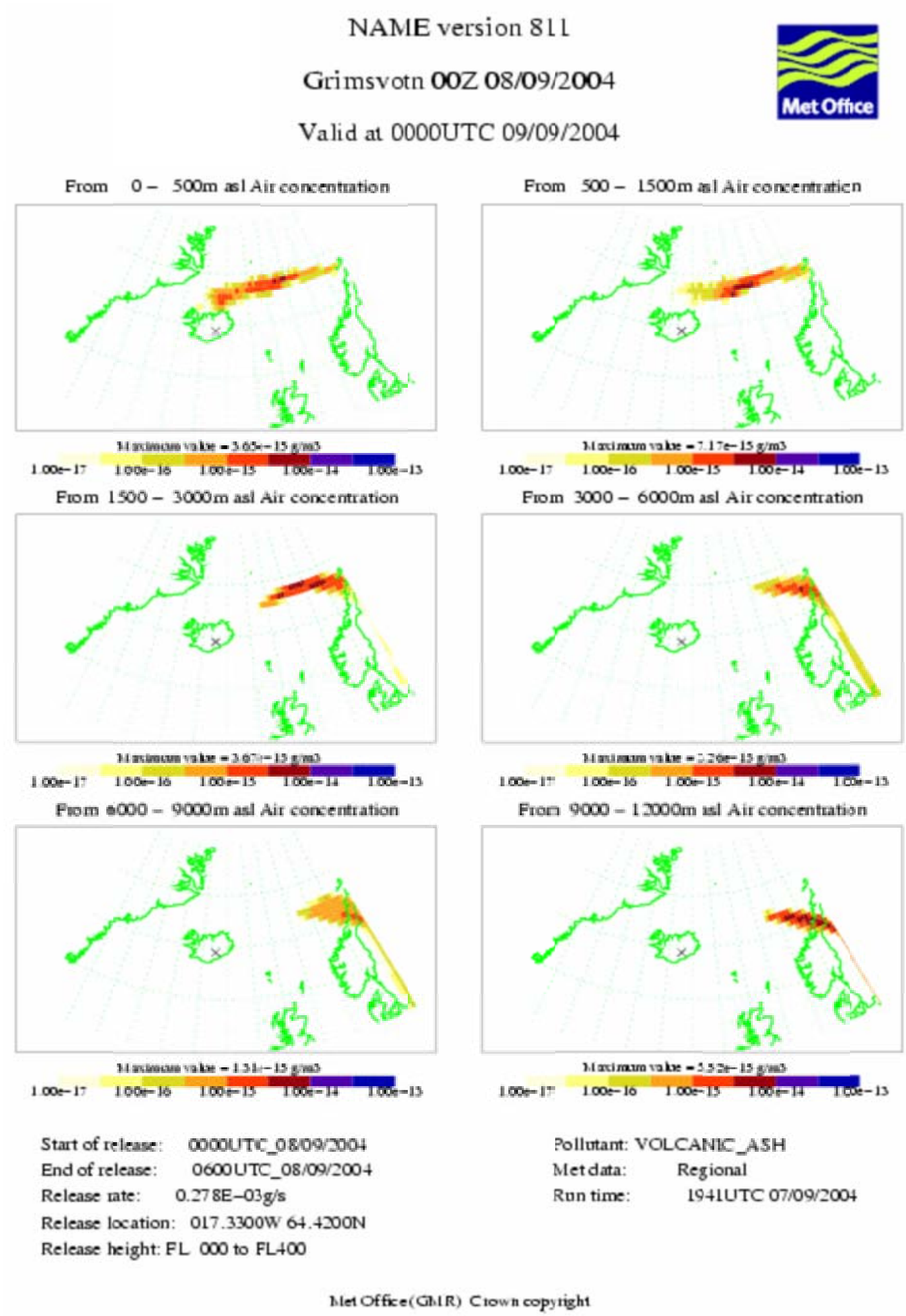

Figure I-3-8. NAME forecasted dispersion for a hypothetical eruption of Mt. Grimsvötn.

3.4.7 One of the purposes of producing such volcanic ash trajectory forecasts is to provide advisory information to airlines to enable them to take this information into consideration during the planning stage of flights (especially long haul flights). These operational aspects are addressed in Chapter 5, but it is sufficient to note here that the advisory information is issued in alphanumeric (message-type) format. Some VAACs also issue information in graphical format using the portable network graphics (PNG) format; when issued in binary format the BUFR code form should be used. The standardized volcanic ash advisory message format, which has been agreed globally, is given in Table A2-1 of Annex 3. The graphical format to be used is given in Appendix 1 to Annex 3.

3.4.8 Verification of volcanic ash transport and dispersion models, as well as the underlying forecast meteorological models, is an ongoing task.

3.5 VISIBLE AND DISCERNIBLE ASH

3.5.1 As a result of the work of the International Volcanic Ash Task Force (IVATF, 2010-2012), the IAVWOPSG fine-tuned the concepts of *visible ash* and *discernible ash*.

3.5.2 The IAVWOPSG developed the following definitions based on the above-mentioned concepts:

a) *Visible ash:* volcanic ash observed by the human eye (not be defined quantitatively by the observer); and

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

In accordance with agreed VAAC best practices, the "*discernible ash*" definition should be applied to delineate volcanic ash clouds on volcanic ash forecasts (including volcanic ash advisories in graphical format); otherwise, the definition of visible ash would be tactically useful for the flight crew while en route.

3.6 AIRCRAFT INSTRUMENTATION FOR CONDUCTING VOLCANIC ASH SAMPLING

3.6.1 The following recommendations for airborne sampling of ash plumes result from experience with the Eyjafjallajökull eruption[18].

a) It is important to perform airborne measurements in the eruption plume as soon as possible after the eruption to get early information on the source term and ash properties. Therefore, research aircraft with suitable instrumentation should be available at short notice (within 1-2 days). The aircraft should be capable of making measurements in the entire range of flight levels used by commercial air traffic,

18. Detailed scientific papers describing airborne sampling of the Eyjafjallajökull ash cloud include:
Schumann, U., et al. (2011) Airborne observations of the Eyjafjallajökull volcano ash cloud over Europe during airspace closure in April and May 2010, Atmos. Chem. Phys., 11, 2245-2279, doi: 10.5194/acp- 11 2245-2011. http://www.atmos-chem-phys.net/11/2245/2011/acp- 11 2245-2011.html
Johnson, B., et al. (2012) In situ observations of volcanic ash clouds from the FAAM aircraft during the eruption of Eyjafjallajökull in 2010, J. Geophys. Res., 117, D00U24, doi: 10.1029/2011JDO16760.
Turnbull, K., B. Johnson, F. Marenco, J. Haywood, A. Minikin, B. Weinzierl, H. Schlager, U. schumann, S. Leadbetter, and A. Woolley (2012). A case study of observations of volcanic ash from the Eyjafjallajökull eruption: 1. In situ airborne observations, J. Geophys. Res., 117, D00U12, https://www.agu.org/pubs/crossref/pip/2011JD016688.shtml

i.e. at altitudes up to 40 000 ft. It is recommended that experienced pilots and instrument operators conduct the missions. The crew on sampling flights should also carefully document their visual observations. The planning of the flights should be based on all information available including data from satellites, ground-based observing systems, and predictions from dispersion models.

b) The recommended instrumentation of the aircraft includes a combination of remote-sensing (Lidar, IR radiometer, DOAS) and in situ measurement systems for particles and gas-phase plume tracer. The Lidar provides information on the horizontal and vertical extent of the ash plume with qualitative information on the ash concentration and serves as pathfinder for the in situ measurements. For the in situ sampling, the ash plume is best intercepted using a combination of stacked flight runs and vertical profiles covering the entire vertical extent of the plume, thereby data are obtained that are best suited for comparison with satellite observations and dispersion models. Table I-3-3 provides a list of recommended instrument types and measurements that are currently available.

c) The mass concentration of ash cannot be measured directly but is determined from the particle number size distribution measured with the wing-mounted optical particle counter for given refractive index and density of the particles. Therefore, it is important to cover the entire size range of ash particles in the plume. The resultant uncertainty in ash mass concentration is about a factor of 2 (Schumann et al., ACP, 2011).

Table I-3-3. Aircraft instrumentation for volcanic ash cloud sampling

Instrumentation	*Measured quantity*
Remote sensing instruments	
Lidar (down, up or ahead viewing)	Aerosol backscatter ratio, depolarization
IR remote sensing	IR radiance at different wave-length
DOAS	SO_2 slant column density
In situ particle instruments	
Condensation particle counter (with heated and unheated channels) in aircraft cabin	Integral number of ultrafine particles ($0.005 < D_p < 2.5$ µm) and non-volatile fraction (sampled through inlet characterized for particle loss)
Optical particle counter (Grimm OPC 1.129) in aircraft cabin	Fine particles (0.25 µm $< D_p <$ 2.5 µm), (sampled through inlet characterized for particle loss)
PCASP-100X/UHSAS-A (wing mounted)	Fine particles, dry state (0.15 µm $< D_p <$ 3.0 µm)
FSSP-300/CAS (wing mounted)	Size distribution coarse mode, ambient state (1 µm $< D_p <$ 30/50 µm)
2D-C probe/CIP-15 (wing mounted)	Shape and size distribution of very large particles, water droplets and ice crystals (25 µm $< D_p <$ 800 µm)
Nephelometer	Particle scattering at three wavelength
Particle collection system (in cabin and wing mounted)	Chemical composition, particle size, shape, morphology (post-flight analysis)
Trace gas in situ instruments	
Chemical ionization mass spectrometer	SO_2 , HCl, HF, HNO_3 mixing ratios
UV absorption detector	O_3 mixing ratio
Vacuum UV fluorescence detector	CO mixing ratio
Chemiliminescence detector	NO, NOy mixing ratios
Meteorological data	
Standard probes	Position, temperature, pressure, humidity, wind

VOLCANIC ASH AND AIRCRAFT OPERATIONS

Chapter 4

EFFECT OF VOLCANIC ASH ON AIRCRAFT

4.1 GENERAL

Volcanic ash is mostly glass shards and pulverized rock, very abrasive and, being largely composed of siliceous materials, with a melting temperature below the operating temperature of jet engines at cruise thrust. The ash is accompanied by gaseous solutions of sulphur dioxide (sulphuric acid) and chlorine (hydrochloric acid). Given these stark facts, it is easy to imagine the serious hazard that volcanic ash poses to an aircraft which encounters it in the atmosphere. Volcanic ash damages the jet turbine engines, abrades cockpit windows, airframe and flight surfaces, clogs the pitot-static system, penetrates into air conditioning and equipment cooling systems and contaminates electrical and avionics units, fuel and hydraulic systems and cargo-hold smoke-detection systems. Moreover, the first two or three days following an explosive eruption are especially critical because high concentrations of ash comprising particles up to ~10 µm diameter could be encountered at cruise levels some considerable distance from the volcano. Beyond three days, it is assumed that if the ash is still visible by eye or from satellite data, it still presents a hazard to aircraft. The most serious threat to jet transport aircraft is the damaging effect volcanic ash has on the engines and this will be addressed first.

4.2 EFFECT ON JET ENGINES

4.2.1 The effect of volcanic ash on jet engines is now known in some detail, both from the results of strip-down inspection of jet engines which have been exposed to volcanic ash during flight and from ground tests of jet engines into which volcanic ash mixtures have been introduced through the fans. There are basically three effects which contribute to the overall engine damage. The first, and most critical, is the fact that volcanic ash has a melting point below jet engine operating temperatures with thrust settings above idle. As already mentioned in 2.1.2, the ash is made up predominantly of silicates with a melting temperature of 1 100°C, while at normal thrust the operating temperature of jet engines is 1 400°C. The ash melts in the hot section of the engine and fuses on the high pressure nozzle guide vanes and turbine blades as shown in Figure I-4-1. This drastically reduces the high pressure turbine inlet guide-vane throat area causing the static burner pressure and compressor discharge pressure to increase rapidly[1] which, in turn, causes engine surge. This effect alone can cause immediate thrust loss and possible engine flame-out. Earlier generations of jet engines, which operated at lower temperatures, were probably less susceptible to this effect. The general tendency, however, is to increase engine operating temperature as each successive family of jet engines is introduced, thereby increasing power but with improved specific fuel consumption. The melting/fusing effect of volcanic ash in jet engines will, therefore, continue to be a hazard in the future.

1. E. E. Campbell, "Recommended Flight-Crew Procedures if Volcanic Ash is Encountered", *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 153.

4.2.2 During the strip-down inspections, the fused volcanic ash deposits on the high-pressure nozzle guide vanes were found to be very brittle at room temperature and easily broke up and fell off the nozzle guide vanes. It seems clear that this can also happen when contaminated engines are shut down in flight and then restarted. The sudden thermal and pressure shocks of the ram air during the restart process, coupled with the cooling of the fused ash deposit when the engine is reduced to idle, seem to break off much of the deposit. Moreover, subsequent operation of the engines after restart, in the clearer air outside the ash cloud, also seems to further dislodge and evacuate some of the fused ash deposits.

4.2.3 The volcanic ash being abrasive also erodes compressor rotor paths and rotor blade tips (mostly high pressure section) as shown in Figure I-4-2, causing loss of high pressure turbine efficiency and engine thrust. The erosion also results in a decrease in the engine stall margin. The main factors that affect the extent of the erosion of the compressor blades are the hardness of the volcanic ash, particle size and concentration, the ash particle impact velocity, and thrust setting and core protection. Although this abrasion effect takes longer than the melting fusion of volcanic ash to shut down an engine, the abrasion damage is permanent and irreversible. Reduction of engine thrust to idle slows the rate of erosion of the compressor blades but cannot eliminate it entirely while the engine is still ingesting air contaminated by volcanic ash.

4.2.4 In addition to the melting/fusing of the volcanic ash and the blade erosion problems referred to above, the ash can clog flow holes in the fuel and cooling systems, although these particular effects appear to be rather variable. In ground tests of jet engines subjected to forced volcanic ash ingestion, a deposition of black carbon-like material was found on the fuel nozzles[2]. Analysis confirmed that the contaminating material was predominantly carbon, and although the main fuel nozzle appeared to remain clear, the swirl vanes which atomize the fuel were clogged. Such a condition would render engine restart very difficult if not impossible, because there seems to be no tendency for the material to break off during restart attempts. Strip-down of the engines involved in two flame-out incidents (British Airways B747, 1982, and KLM B747, 1989), however, did not in fact show such extreme clogging of fuel nozzles and cooling systems, possibly due to insufficient exposure time to produce this effect.

4.2.5 The following are observations and trends noted from the United States Government-funded Calspan testing of military engines in the 1980s and 1990s.

4.2.5.1 **Simulated volcanic ash environment.** The damage observed in the engines following exposure varied depending on the:

a) power setting at time of exposure (turbine inlet temperature);

b) amount of time of exposure to volcanic ash;

c) type of ash; and

d) concentration level of ash.

At lower power settings or lower turbine inlet temperatures, the predominate flow path damage condition was airfoil erosion. At higher power settings or higher turbine inlet temperatures, the predominate damage condition shifted from airfoil erosion to debris and glassification build-up in the combustor and turbine sections.

2. M.G. Dunn and D.P.Wade, "Influence of Volcanic Ash Clouds on Gas Turbine Engines", *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 107.

Figure I-4-1 a). Dark, glassy deposits of remelted volcanic ash on leading edge of stage-1 high-pressure-turbine nozzle guide vane. (from Przedpelski and Casadevall)

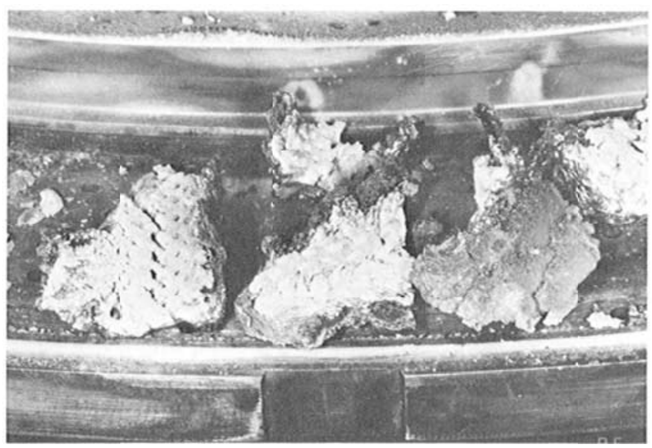

Figure I-4-1 b). Leading-edge deposits dislodged during disassembly of stage-1 high-pressure-turbine nozzle guide vanes. (from Przedpelski and Casadevall)

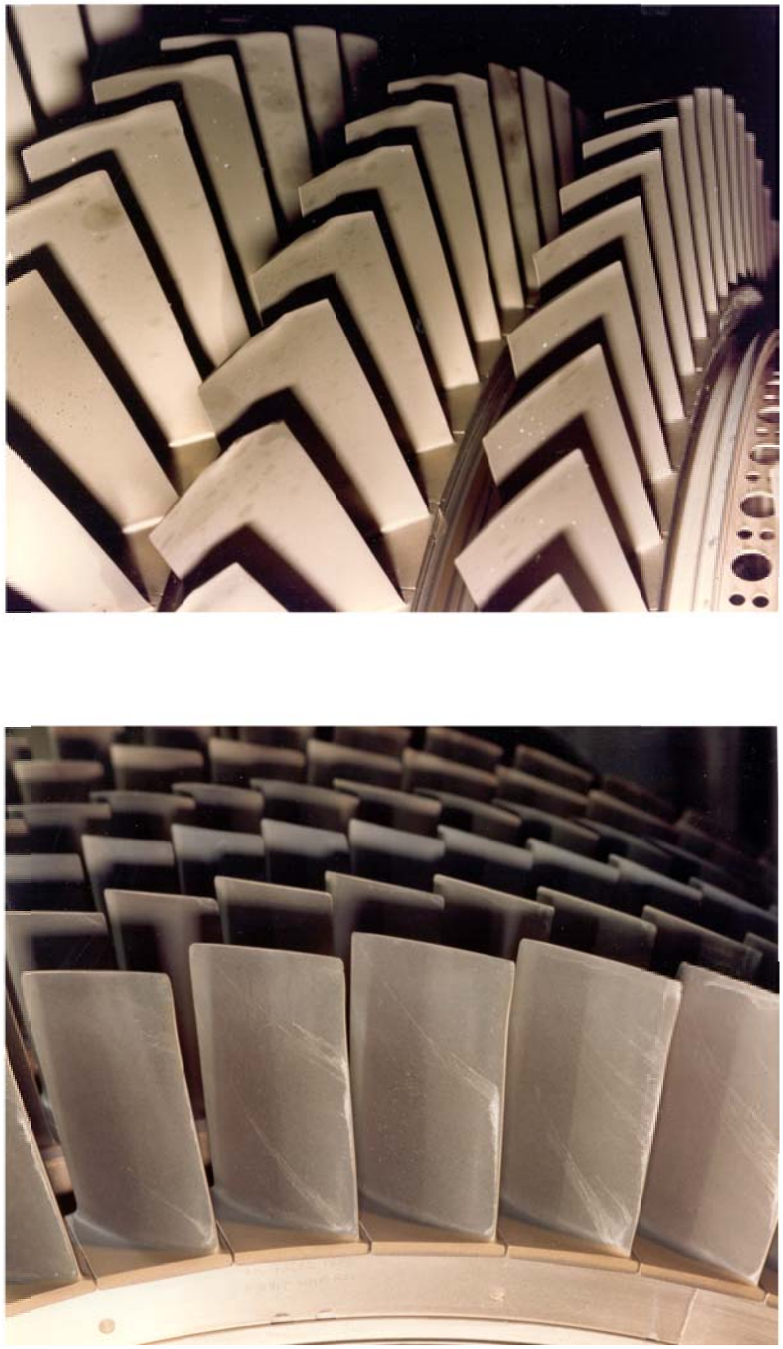

Figure I-4-2. (Top) IP compressor tip erosion. (Bottom) HP stage 1 compressor rotor hooking. (from Rolls-Royce)

4.2.5.2 **Simulated volcanic ash.** The damage observed varied depending on:

a) ash chemistry (melting point);

b) ash particle size distribution; and

c) ash concentration.

4.2.5.3 **Hot-section tests.** These tests demonstrated that:

a) the amount of build-up on a turbine nozzle guide vane was highly dependent on the chemistry of the dust ingested;

b) cooled nozzle guide vanes accumulated less debris than uncooled nozzle guide vanes; and

c) a reduction in nozzle guide vane cooling accelerated the rate of debris accumulation.

This testing included approximately six dust blends and ingested concentrations were varied between 200 and 1 000 mg/m^3.

4.2.5.4 **F107 small engine test series (first engine).** The following was observed:

a) moderate instabilities during the last quarter of testing (no conclusion as to the origin of instability was established);

b) significant (unserviceable) compressor erosion as well as opened compressor and turbine clearances (blade to casing); and

c) little, if any, glassification debris on combustor or turbine nozzles.

All ingestion testing was completed at steady state maximum power (i.e. engine transient performance was not evaluated). A 14-hour test with "earth mix" was ingested at moderate levels of 5 to 100 mg/m^3, with ingestions of 100 mg/m^3 for ~3 per cent of test time. Maximum TIT was 1 027ºC (1 880ºF). Ingested material size ranged from 40 to 250 microns (relatively large particles).

4.2.5.5 **F100 mid-size engine test series (second engine).** The following was observed:

a) the engine "purge" cycle, which is a reduction in power to idle then slow acceleration to maximum (dry) power, expelled a portion of the glassification debris on the nozzle guide vanes to recover some performance. Subsequent ingestion showed build-up at a more rapid rate than was originally observed;

b) significant compressor blade erosion and open tip clearance irreversibly degraded engine operability and performance; and

c) the overall engine condition was beyond economic repair at the end of this test.

All ingestion testing was completed at steady-state military power with TIT of ~1 371ºC (~2 500ºF) (i.e. engine transient performance was not evaluated). Total test duration was 20 minutes with a relatively high ingestion level of ~500 mg/m^3.

4.2.5.6 A general conclusion from the two F100 engine test series was that exposure to moderate level of volcanic ash ingestion would first be observable in the engine by erosion of the compressor airfoils, and exposure to higher levels of volcanic ash would first be observable by glassification build-up on the turbine nozzle guide vanes.

4.2.5.7 **YF101 mid-size engine test series.** The following was observed:

a) engine performance deterioration within the first 2.5 minutes of dust ingestion at a rate of 80 mg/m^3;

b) compressor erosion and nozzle guide vane debris accumulation following the first test series (10 minutes of operation);

c) mid-way through the testing, the engine was damaged to a point of not being airworthy from an operability standpoint; and

d) the engine condition was beyond economic repair at the end of this test.

All ingestion testing completed at steady-state military power (i.e. engine transient performance was not evaluated). Maximum TIT calculated to be ~1 404ºC (~2 560ºF). This testing included approximately four dust blends and ingestion concentrations were varied between 80 and 455 mg/m^3.

4.2.6 It is recognized that trace levels of volcanic ash can remain in the atmosphere for days, weeks and even months following a volcanic eruption. These trace levels, which are undetectable to the human senses (and not likely visible), do not pose an immediate hazard to safe flight. It is recognized, though, that even these trace levels of volcanic ash, as is the case with sand or dust, do cause irreversible economic damage to otherwise serviceable engines, leading to premature removal or reduced on-wing life. Additional insight into turbofan engine susceptibility has been gained from worldwide commercial operations in desert sand and dust. Manufacturers have worked to reduce engine susceptibility to desert sand and dust damage leading to premature removal or reduction of on-wing life. Specifically, such work relates to compressor airfoil erosion damage and turbine damage from sand and dust debris adhering to turbine nozzles and the loss of cooling to hot-section parts. Environmental air quality data have been used to assess particulate in the air to compare mass loading between regions to understand the impact of environmental air quality on engine durability. Environmental air quality data have been used to provide partial substantiation of an engine’s ability to safely operate in an environment contaminated by such low levels of volcanic ash. Based on environmental air quality, measurements for particulate matter and concentration levels provide some insight into the tolerability of an engine to volcanic ash from a safety hazard standpoint. It is recognized that the composition of typical sand and dust differs from volcanic ash. Exposure to a desert sand and dust environment is at relatively low altitude, whereas the volcanic ash environment is both at the surface and up to and including cruise altitudes. The exposure time can be significantly longer for the volcanic ash hazard. Additionally, it should be noted that for an equivalent airflow, the ingestion level increases with increased altitude as a result of reduced air density at altitude. A test conducted by an engine manufacturer exposed a ground test engine to a mixture of desert sand specifically formulated to assess hot-section vulnerability to desert sand ingestions. In this test, the engine was exposed to sand concentrations of approximately 750 mg/m^3, injected into the engine low pressure compressor for ten minutes to assess damage for a proposed design improvement. The engine successfully ran and produced thrust the entire ten minutes; however, at the end of the test, the engine’s operability was reduced to a negative operability margin. It was not determined how long the engine would have continued to run with a positive transient operability margin.

4.2.7 The test results summarized above are likely applicable to engines of similar construction and thermodynamic cycle parameters. However, modern engines have evolved both in material application and thermodynamic cycle to improve operating costs and reduce emissions in the environment. In the area of materials, many more recently certified engines have incorporated material changes to the airfoils to reduce erosion and have new materials and coatings that tolerate operation at higher temperatures. In the area of cycle changes, today’s high performance engines run higher combustion and turbine inlet temperatures to improve emissions and provide economies (e.g. fuel burn). The following general conclusions may be made with regard to these areas of change:

a) material changes to improve desert sand erosion should reduce the airfoils susceptibility to volcanic ash;

b) the coatings and material changes in the combustion and turbine section of the engine have an unknown impact on glassification of volcanic ash accumulation; and

c) the increases in combustor and turbine section temperatures will increase the engines susceptibility to volcanic ash.

Quantifying these susceptibilities such that a single volcanic ash concentration could be used universally for every volcanic eruption is not practicable. However, it should be assumed that modern jet engines will be at least as or more susceptible to volcanic ash as the engines referred to in 4.2.5.

4.3 EFFECT ON AIRFRAME AND EQUIPMENT

4.3.1 In addition to engine abrasion, volcanic ash abrades cockpit windows, the leading edges of the flight surfaces and the tailfin and can “sandblast” the paint from the airframe. Any parts protruding from the airframe such as antennas, probes, ice detectors and angle of attack vanes can be damaged and may be rendered inoperable. From the safety standpoint, the abrasion of the cockpit windows reduces the pilot’s forward visibility and can present a serious problem during landing, as was the case with the British Airways B747 which made an emergency landing at Jakarta in 1982 following its encounter with volcanic ash. Damage to the antennas can lead to a complete loss of high frequency (HF) communications and a degradation of very high frequency (VHF) communications[3]. Damage to the various sensors can seriously degrade the information available to the pilot through the cockpit instruments, thus rendering control of the aircraft more difficult.

4.3.2 The original equipment manufacturers do not recommend flight operations in visible volcanic ash clouds. Precaution must also be used when operating aircraft on the ground in areas contaminated with volcanic ash fallout. The following information provides general guidance and considerations for operations during a volcanic ash event. Operators should consult their appropriate original equipment manufacturer for the latest information regarding volcanic ash guidance.

4.3.3 Figure I-4-3 illustrates areas, in general, where an aircraft may be susceptible to volcanic ash. If the aircraft inadvertently or otherwise has had a volcanic ash encounter, the operator should conduct a volcanic ash conditional inspection in accordance with the original equipment manufacturer’s aircraft maintenance manual before the next flight. (See 4.5 for recommended flight crew procedures for instances where an aircraft has inadvertently encountered a volcanic ash cloud.)

3. Z.J. Przedpelski, “AIA Recommendations Aimed at Increased Safety and Reduced Disruption of Aircraft Operations in Regions with Volcanic Activity”, *Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety*, 1991, U.S. Geological Survey Bulletin 2047 (1994), p. 148.

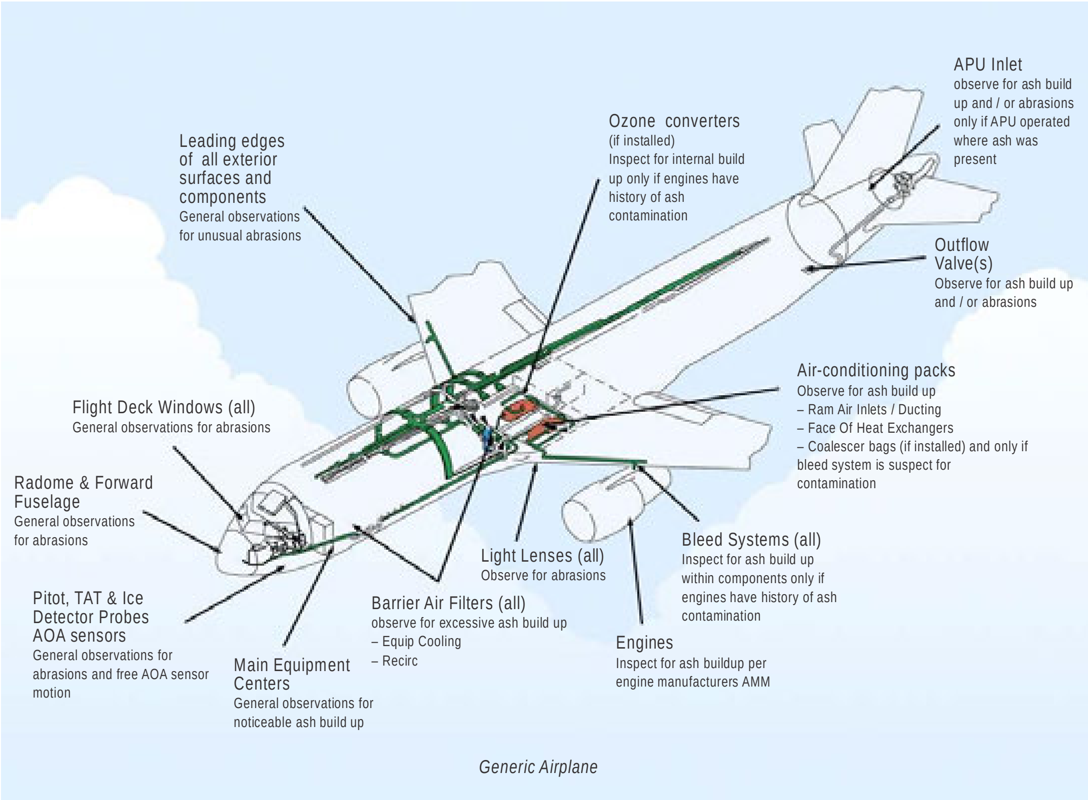

Figure I-4-3. Airframe and systems areas of observations for operations in vicinity of volcanic ash

4.3.4 If an operator is operating in low levels of volcanic ash concentration (i.e. not visible), the areas of the aircraft as illustrated in Figure I-4-3 should receive closer attention and potentially adjust their maintenance practices based upon their maintenance observations to prevent unscheduled maintenance. Observations should check for signs of unusual or accelerated abrasions and/or ash accumulation.

Note.— Flight operations in visible volcanic ash clouds are those which amount to a volcanic ash encounter as described in 3.2.2 and in Doc 9974 — Flight Safety and Volcanic Ash, *1.4. Flight operations in low levels of volcanic ash concentrations (not visible) are those which do not amount to a volcanic ash encounter as described in 3.2.2 and in Doc 9974, 1.4.*

4.3.5 The airframe, engines and systems can normally handle operations in low volcanic ash concentrations (not visible), without requiring unique or special subsequent inspections outside the normal operating and maintenance experience of individual airlines. Airframe, engines and systems degradation can occur at different rates, however, within many operating environments. Since this normal degradation occurs and varies between operating environments, airlines typically adjust their maintenance practices to ensure that aircraft degradation (plugged heat exchangers, filters, abrasions, etc.) does not cause unscheduled aircraft downtime. This same maintenance philosophy applies to operations in low levels of volcanic ash concentrations (not visible) where a flight crew has not reported a volcanic ash encounter.

General advice for aircraft maintenance inspection following operations in airspace contaminated by volcanic ash (for all turbine and piston powered aircraft, including rotorcraft)

4.3.6 Accomplish inspections following operations in airspace contaminated by volcanic ash to detect any erosion, accumulation of volcanic ash, or any aircraft and/or engine damage or system degradation. Turbine engines as well as piston engines operation can be adversely affected by volcanic ash on the ground or in the air. The inspections should include the following as a minimum:

a) wing leading edges;

b) navigation and landing lights, radomes;

c) landing gear;

d) horizontal stabiliser;

e) all extruding structure;

f) pitot tubes and static ports;

g) windows and windshields;

h) engine inlets and nacelles (turbine), induction air filter (piston);

i) engine cooling system components;

j) engine compressor and turbines;

k) engine oil systems;

l) fuel tank venting system;

m) rotor blades;

n) airplane ventilation and pressurization systems (air cycle machines, ozone converter, recirculation fans, HEPA filters, etc.); and

o) smoke detectors (detectors located in the cargo compartment, lavatory, electrical equipment bay, remote crew rest areas, etc.).

Based on the findings of these inspections, more detailed inspections (such as boroscope inspections of the engine, oil analysis, inspection of filters, cleaning of parts) may be necessary. Volcanic ash encounters and any relevant findings should be reported to the aircraft and engine type certificate holders, the State of Registry and volcanic ash advisory centres (VAACs) through the Service Difficulty Reporting System.

Ground operations at airports impacted by volcanic ash

4.3.7 The following provides general recommendations for aircraft ground operation at airports that are impacted by volcanic ash. Operators should contact their original equipment manufacturers for more specific advice for their aircraft and operations.

Protect the aircraft from ash. For ground operations originating at airports impacted by volcanic ash, original equipment manufacturers should advise operators to take special precautions to protect aircraft from the adverse effects of volcanic ash.

Remove ash from the aircraft prior to flight. Prior to flight, the operator must ensure that critical components such as inlets, probes and static ports are free of volcanic ash. Volcanic ash will be similar in appearance to talcum powder. If ash is detected on or in the vicinity of a parked aircraft, original equipment manufacturers suggest that operators clean the areas of the aircraft where ash is present, including the fuselage crown, horizontal surfaces, inlets and exposed chrome common to the landing gear, to remove all traces of ash. Original equipment manufacturers strongly advise against water or detergent washing of the engine gaspath, as this can cause accumulation of foreign material in the engine cooling flow passages. Operators should follow the engine manufacturer's recommendations for engine gaspath cleaning. Operators should pay special attention to the removal of volcanic ash from engine and APU inlets and areas around probes, ports, vents and drain holes as well as ram air ducts and all windows. Operators should be aware that aircraft washing processes without proper sealing of ports and tubes can introduce ash debris or water into pitot static systems. If there are no signs of volcanic ash, normal operations may be conducted.

Remove all covers and blanking material prior to flight. Flight crews should ensure that all materials used to mask or blank inlets, probes and ports are removed.

Determine safe ground routing. After an aircraft is free of any volcanic ash contamination, the operator should coordinate with the local airport authority to determine which ramps, taxiways and runways are clear of ash contamination. This information must be passed to flight crews prior to beginning ground operations.

Maintenance and ground personnel training. Operators should ensure that their maintenance and ground personnel are properly trained to inspect for signs of volcanic ash contamination and to know the proper techniques for removal of volcanic ash from aircraft.

Operator's recurrent flight crew training. An operator's recurrent flight crew training should review the airspeed unreliable, volcanic ash, single engine failure, dual/multiple engine failure and engine in-flight start non-normal checklists.

4.3.8 Preventing flight into potential volcanic ash environments requires planning in the following areas:

— Dispatch should provide flight crews with information about volcanic events, such as potentially active volcanoes and known ash sightings that could affect a particular route.

— Alternative routes should be identified or re-planned in order to avoid airspace containing a visible volcanic ash cloud.

— In the vicinity of a volcanic ash cloud, and where required, escape routes should be identified in the event of an unplanned descent due to an engine failure or cabin depressurization.

— Flights should be planned to remain upwind of volcanic ash or dust clouds, where possible.

— Flight crews should remember that airborne weather radar is ineffective in distinguishing ash.

Standard that has resulted in safe operations during volcanic eruptions

4.3.9 Since the introduction of the VAACs and the communication channels between them, the WMO and the aviation community, the number of significant in-flight volcanic ash encounters has diminished dramatically, even though the number of volcanic ash events has continued through the years. One key element that has enhanced operational safety (compared to the 1982 Galunggung volcano and 1989 Mt. Redoubt B747 events) has been the diligence and expertise of the VAACs and MWOs reporting on "observed" or "visible" volcanic ash clouds. These "observations" by the VAACs and MWOs have been primarily based on satellite imagery, either visual or infrared. This "observed" information has been used in correlation with dispersion models and meteorological expertise to forecast where a volcanic ash cloud will likely be several hours in the future. This use of a composite of all available information by meteorologists to forecast the location of a volcanic ash cloud has served aviation well. These observed reports and forecasts that are correlated to direct observations, along with operators avoiding flight planning or flights into "visible" or "observed" volcanic ash cloud, has resulted in safe and efficient operations in recent years. (It is important to note that there can be significant uncertainty in the forecast dispersion model predictions due to the inaccuracy of the source parameters (amount of debris ejected from the volcano, how high the debris was ejected, time since eruption, etc.) and the variation between forecast dispersion models used by different VAACs.)

4.3.10 The most significant hazard to an aircraft from a volcanic ash encounter is the impact on the engines and the potential consequent loss of all thrust. There are other significant hazards to the aircraft such as erroneous airspeed, but none of these hazards are catastrophic by themselves. Each of these other hazards can be mitigated through flight crew procedures or training that allows for continued safe flight and landing. As discussed in 4.2.5, today's jet engines have demonstrated capability in low levels of volcanic ash concentrations (not visible), provided that operation in visible ash is avoided. However, there are a number of variables including cloud thickness, particle size and ash concentration that affect whether the ash is visible. In order to ensure safe and efficient operations, such information should be taken into account in a flight operation risk assessment as described in Doc 9974. It should also be noted that even operations in low levels of ash concentration (not visible) can result in increased maintenance costs due to accelerated aircraft and engine degradation.

Volcanic ash communication process with original equipment manufacturers

4.3.11 Figure I-4-4 indicates the processes to be followed to obtain original equipment manufacturers' expert advice during times of volcanic eruption and the consequent potential disruption to aviation.

4.3.12 In the event of a volcanic eruption where the resulting volcanic ash affects adjacent airspace, airways or airfields, accessibility to accurate information from the (appropriate) original equipment manufacturer(s) or type certificate holder is a vital part of any regulatory accepted safety assessment process for the operator(s) in determining whether operations may or may not be continued. This information should be proactively sought by the operator before any such event to minimize air service disruptions.

4.3.13 It is recognized, that equally important is the information flow to the State regulators, air navigation services providers (ANSPs) and crisis centres among others. Regulating agencies that manage certification should contact their respective type certificate holder certification or safety offices for information related to operating recommendations, inspections and airworthiness. Other regulating agencies, ANSPs, and crisis centres should contact the appropriate regulating agency for a given type certificate holder for this type of information.

4.3.14 In the meantime, during periods of volcanic activity, each operator should set up a hotline to deal directly with calls for information from its associated regulator, ANSPs or nearby crisis centre to respond directly to the questions. The subsequent response (for information) may then from the operator. Every situation being different and unpredictable, this does not preclude direct communication between the regulator and the original equipment manufacturer.

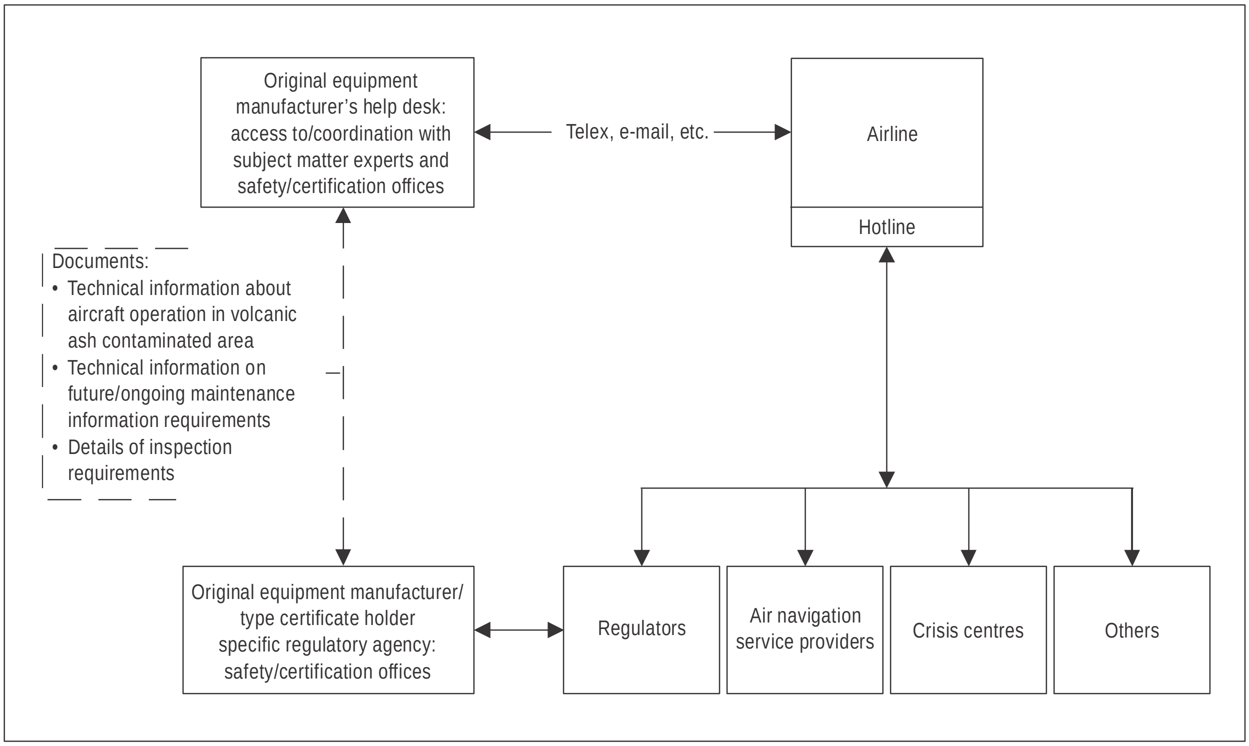

Figure I-4-4. Volcanic ash communication process

4.4 PRELIMINARY RECOMMENDATIONS FOR VOLCANIC ASH MATERIAL FOR USE IN JET ENGINE TESTING

4.4.1 Information about reported encounters of aircraft with volcanic ash clouds (1953-2009), including the type and severity of damage to engines and airframes, is given in Guffanti et al. (2010)[4]. Recently declassified technical reports on volcanic-ash engine tests funded by the Defense Nuclear Agency (now the Defense Threat Reduction Agency) and conducted at the facilities of the Calspan Corporation during the 1980s and early 1990s are available at http://www.dtra.mil/Info/FOIA/FrequentlyRequestedRecords.aspx. Those tests involved ash concentrations of tens to hundreds of milligrams per cubic metre, whereas current interest is directed at understanding the effects of lower concentrations that occur in distal parts of ash clouds several hundred kilometres or more from the volcanic sources.

4.4.2 The following paragraphs, developed by the Science Sub-Group of the International Volcanic Ash Task Force (IVATF) in 2011 and endorsed by the International Airways Volcano Watch Operations Group (IAVWOPSG), offer some ideas and initial recommendations about what kind of volcanic material would be most suitable for any new tests that may be undertaken to determine the effects of volcanic ash on jet engines.

4.4.3 Volcanic ash is a mixture of small fragments of rock, mineral and glassy material produced by explosive eruptions of volcanoes. During ash-producing eruptions, hot gas-charged magma abruptly depressurizes as it nears the Earth's surface and violently explodes out of a surface vent. The ejected magma is frothy with expanding gas and

4. Guffanti, Marianne, Casadevall, T.J., and Budding, K, 2010, Encounters of aircraft with volcanic ash clouds — A compilation of known incidents, 1953-2009: U.S. Geological Survey Digital Series 545. Online at http://pubs.usgs.gov/ds/545/

quickly cools in the air, fragmenting into pieces of pumice, glassy shards (not unlike pulverized window glass), and sharp-edged bits of minerals and rocks. The proportion of glass to minerals and rock material will vary from volcano to volcano. The mass of fragments (called tephra) — along with sulfur dioxide (SO_2) and other gases released from the decompressing magma — is entrained upward in a convecting, columnar mass. The larger pieces of tephra fall out of the column within minutes to hours and are deposited around the volcano, while the smallest particles (called ash) can remain suspended as volcanic clouds in the atmosphere for up to days.

4.4.4 Additionally, ash clouds can be produced from pyroclastic flows (hot, fast-moving, ground-hugging currents of gas and magmatic particles) when a mass of smaller particles rises convectively above the ground flow. On occasions, such ash clouds have reached altitudes of several kilometres.

4.4.5 The size of individual ash particles in volcanic clouds can range from less than one micron (a micron is a micrometer, 10^{-6} m) up to several hundred microns. In clouds >1 000 km from their source, particles typically are microns to tens of microns in diameter.

4.4.6 Magmatic gases such as SO_2, CO_2, H_2S, HCl and HF are erupted along with solid particles and react with water vapour in the erupting column and atmosphere. Of particular importance in a volcanic cloud is SO_2, some of which remains in that form in the atmosphere while some converts to sulphuric acid (H_2SO_4) which can be adsorbed onto volcanic ash particles.

4.4.7 The first-order compositional scheme for volcanic material, including ash, is based on silica content (reported as SiO_2). The scheme has three basic categories: mafic, intermediate and silicic. Mafic materials are relatively low in silica (<52 per cent SiO_2 as in basalt magma). Silicic material is relatively high in silica (>64 per cent SiO_2 as in dacites and rhyolites). Intermediate compositions are 52–63 SiO_2 as in andesites. The following relationships are important when considering tests:

a) mafic material has a higher melting temperature than more silicic material (e.g. ~1 200ºC for mafic minerals compared to ~800ºC for silicic minerals);

b) glass will melt at lower temperatures than minerals of the same composition (e.g. ~1 100ºC for mafic glass and ~650ºC for silicic glass); and

c) other parameters being equal, finer-grained ash will melt more easily than coarse grained ash because the entire finer particle can be heated more quickly.

4.4.8 Some initial volcanological recommendations about basic testing parameters are the following:

a) testing should use actual (authentic) volcanic ash. Synthetic mixtures created to simulate volcanic ash should not be used because doing so introduces yet more uncertainty into an already complex testing scheme;

b) ash for engine tests should be a mixture of fine-grained particles from about 10–100 microns, the size range expected in dispersed volcanic clouds beyond the vicinity of the volcanic source. It is not critical to have the ash be naturally pulverized; artificially pulverizing and sieving large-size tephra would produce virtually the same material. Ideally, the ash should be “fresh”, i.e. not consisting of hydrated glass (glass into which water has diffused) as one might find in geologically older, weathered ash;

c) tests should use volcanic ash in the compositional range of 56–64 per cent SiO_2, a common range for volcanic rock compositions worldwide that encompasses many andesites and some (lower silica) dacites. Candidate volcanoes for such material include those whose eruptions are known to have caused damage to aircraft in-flight:

— Mount St. Helens, Washington, 1980;

— Galunggung, Indonesia, 1982;

— Redoubt, Alaska, 1989–1990;

— Pinatubo, Philippines, 1991;

— Rabaul, Papua New Guinea, 2004;

— Soufriere Hills, Montserrat, 1995–present; and

d) testing should be started with dry samples, i.e. with no added volatiles components, such as water vapour or SO_2, in order to limit the number of complicated variables until test design can be re-evaluated.

4.4.9 Ash in sufficient bulk for testing likely will involve collection of several thousands of kilograms (several tonnes) of material. Depending on shipping concerns, the distance of a collection site to a testing site may be an issue.

4.4.10 Inclusion of volcano scientists familiar with explosive volcanism and its eruptive products in any industry development of test standards is recommended, to refine the recommendations presented here and answer questions as they arise. It also recommended that data from the previous Calspan tests (see 4.2.5) be carefully reviewed to determine if there are any important results regarding the type of volcanic materials that might be applicable to any future tests.

4.4.11 Original equipment manufacturers have the appropriate expertise to define the types of engines, or engine components to be used in testing.

4.4.12 These recommendations provide a starting point for what volcanic material to use, should a program to test jet engines with volcanic ash be formulated. Further recommendations about the engineering objectives and design of actual tests are best formulated by an industry standards group of experts.

4.5 RECOMMENDED GENERAL PROCEDURES TO MITIGATE THE EFFECT OF VOLCANIC ASH

4.5.1 The foregoing analysis of the effect of volcanic ash on aircraft should form the basis of the procedures recommended by aircraft manufacturers in the aircraft flight manual in instances where an aircraft has inadvertently encountered a volcanic ash cloud. Flight crews should always follow aircraft manufacturer procedures and recommendations under such circumstances. In the absence of specific procedures or recommendations, generic procedures which States may require flight crews to use are as follows:

a) taking into account airspace, terrain and traffic, if possible, *immediately reduce thrust to idle.* This will lower the exhaust-gas temperature (EGT), which in turn will reduce the fused ash build-up on the turbine blades and hot-section components. Volcanic ash can also cause rapid erosion and damage to the internal components of the engines;

b) *turn autothrottles off (if engaged).* The autothrottles should be turned off to prevent the system from increasing thrust above idle. Due to the reduced surge margins, limit the number of thrust adjustments and make changes with slow and smooth thrust-lever movements;

c) *exit volcanic ash cloud as quickly as possible.* Volcanic ash may extend for several hundred miles. The shortest distance/time out of the ash may require an immediate, descending 180-degree turn, terrain permitting. Setting climb thrust and attempting to climb above the volcanic ash cloud is not recommended due to accelerated engine damage/flame-out at high thrust settings;

d) *turn engine and wing anti-ice and all air conditioning packs on.* This further improves the engine stall margin by increasing the bleed-air flow. It may be possible to stabilize one or more engines at the idle thrust setting where the EGT will remain within limits. An attempt should be made to keep at least one engine operating at idle and within limits to provide electrical power and bleed air for cabin pressurization until clear of the volcanic ash;

e) *start the auxiliary power unit (APU), if available.* The APU can be used to power the electrical system in the event of a multiple-engine power loss. The APU may also provide a pneumatic air source for improved engine starting, depending on the aircraft model;

f) *put flight crew oxygen masks on at 100 per cent, if required.* If a significant amount of volcanic ash fills the cockpit or if there is a strong smell of sulphur, don an oxygen mask and select 100 per cent. Manual deployment of passenger oxygen masks is not recommended if cabin pressure is normal because the passenger oxygen supply will be diluted with volcanic ash-filled cabin air. If the cabin altitude exceeds 4 250 m (14 000 ft), the passenger oxygen masks will deploy automatically in most commercial aircraft;

g) *restart engine according to aircraft operations manual procedures.* If an engine fails to start, try again immediately. Successful engine start may not be possible until airspeed and altitude are within the air-start envelope. Monitor EGT carefully. If a hung start occurs, the EGT will increase rapidly. If the engine is just slow in accelerating, the EGT will increase slowly. Engines are very slow to accelerate to idle at high altitude, especially in volcanic ash — this may be interpreted as a failure to start or as a failure of the engine to accelerate to idle or as an engine malfunction;

h) *monitor airspeed and pitch attitude.* If unreliable airspeed is suspected, or if a complete loss of airspeed indication occurs (volcanic ash may block the pitot system), establish the appropriate pitch attitude dictated by the operations manual for “flight with unreliable airspeed.” If airspeed indicators are unreliable, or if loss of airspeed indication occurs simultaneously with an all-engine thrust loss, shutdown or flame-out, use the attitude indicator to establish an appropriate pitch attitude. Inertial ground speed may be used for reference if the indicated airspeed is unreliable or lost. Ground speed may also be available from approach control during landing;

i) *land at the nearest suitable airport* if volcanic ash has been encountered and aircraft damage is expected or abnormal engine operation occurs due to volcanic ash penetration;

j) *upon landing, use reversers as lightly as feasible.* If it appears that maximum reverse thrust will be needed, apply reverse thrust when the main landing gear touches down. Limit the use of reverse thrust as much as possible, because reverse flow may throw up ash, sand, dust and impair visibility;

k) if the autopilot system is operating satisfactorily, diversion to an airport where an autolanding can be accomplished and after landing, if forward visibility is restricted, having the aircraft towed to the parking gate should be considered. Because of the abrasive effects of volcanic ash on windshields and landing lights, visibility for approach and landing may be markedly reduced. Forward visibility may be limited to that which is available through the side windows; and

l) *if deemed necessary, consult a medical specialist.* Exposure to volcanic ash can create physical (sulphur, dust, deprivation of oxygen) and mental health (anxiety, stress) problems.

4.5.2 As mentioned in 4.5.1, pilots should always follow specific procedures in the aircraft operations manual, developed by aircraft operators for each aircraft type in their fleet, dealing with the particular aircraft engine combination concerned. Guidance on this is provided in Doc 9376 — *Preparation of an Operations Manual*, Chapter 8 and Attachment K, and in aircraft manufacturers' flight manual procedures for each of their aircraft types. Guidance should also be included in aircraft maintenance manuals regarding the necessary maintenance and/or inspections to be undertaken on an aircraft following an encounter with volcanic ash. Mention has already been made in Chapter 2 that for those airlines which operate aircraft regularly through regions of the world subject to frequent volcanic eruptions, the long-term consequences of frequent flights through even very low concentrations of volcanic ash may be increased maintenance costs. Certainly a number of airlines have found that cockpit and passenger windows needed to be re-polished or replaced rather more frequently than expected for the flight hours involved. At this stage it is not clear, however, if this is due more to newer types of plastic window materials used for passenger outer windows or if low concentrations of volcanic ash/acid droplets in the atmosphere are contributing to the problem.

4.5.3 Given that the most serious threat to an aircraft from volcanic ash is the risk of multiple-engine flame-out, it is extremely important to consider the ways and means of avoiding engine shut-down and improving the success of in-flight engine restarts contaminated by volcanic ash. Engine shut-downs or flame-outs in flight are rare events which many pilots will never be called upon to deal with in their entire careers except during simulator-based training. This is further complicated by the different procedures that are used for in-flight engine starts as compared to normal on-ground starts. The best solution is for pilots to be provided with a set of air-start procedures which also cover procedures in volcanic ash contaminated air and for simulator air-starts to be part of basic and recurrent pilot training.

Chapter 5

IMPACT OF VOLCANIC ASH ON AVIATION OPERATIONAL AND SUPPORT SERVICES

5.1 AERODROMES

5.1.1 General

5.1.1.1 Volcanic ash can also have a serious effect on aerodromes located downwind of a volcanic ash plume. The ash is deposited on and around the aerodrome, contaminating electronic, electrical and mechanical ground equipment and, if due care is not taken, aircraft parked or taxiing around the aerodrome. Problems caused by volcanic ash on the runways include a reduced runway friction coefficient for landing aircraft, especially when ash is wet, and severe deterioration in local visibility as the ash on the ground is disturbed by engine exhausts from aircraft taxiing, landing and taking off. In fact, it does not take that much ash to be deposited on an aerodrome (in fact as little as 1 mm) before the aerodrome may have to be closed completely to aircraft operations.

5.1.1.2 The effect of volcanic ash on electronic, electrical and mechanical equipment is very similar to the effects already described on aircraft equipment. Volcanic ash easily penetrates all but the most tightly sealed areas and this applies as much to small electronic components as to hangars and maintenance areas. Cooling, lubrication and filter systems are contaminated, often to the extent that the equipment is impossible to clean completely and has to be replaced. Moving parts in mechanical equipment, especially bearings, brakes and transmissions, are abraded rather quickly because the equipment filters and lubrication systems themselves become clogged and/or contaminated. Special problems can affect high voltage circuits and components, especially if the ash has been dampened by rain which renders it highly conductive electrically. This causes short circuits, arcing and flash-overs which can result in fires on electrical distribution system components. If the ash is subject to rain it can easily absorb considerable amounts of water reaching densities in excess of 1 400 kg/m^3 [1] or more. Such wet ash has the consistency of wet cement and when deposited on top of hangars can cause buildings to collapse, as happened at Clark U.S. Air Force Base in the Philippines during the Mt. Pinatubo eruption in 1991 (Figure I-5-1). Wet ash deposited on parked aircraft (especially rear-engined aircraft) can markedly shift the centre of gravity and cause the aircraft to tip over if not secured by a tail stick (Figure I-5-2).

5.1.1.3 Depending on the amount of ash fall on the aerodrome, the surface winds (which maintain ash in suspension in the air), and the occurrence of rainfall in the area (which assists settling out of the ash), varying degrees of medical problems may be reported. In heavy ash falls with very dry and windy conditions, such as occurred at aerodromes (and indeed large towns) in Argentina following the eruption of Mt. Hudson in eastern Chile in 1991, many medical problems were reported. The problems were mainly of a broncho-pulmonary and ophthalmic nature, and skin abrasions. In more humid conditions, and especially if there is rainfall and generally light winds, reports of medical problems tend to be fewer and less severe.

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1. J.R. Labadie , “Mitigation of Volcanic Ash Effects on Aircraft Operating and Support Systems”, *Proceedings of First International Symposium on Volcanic Ash and Aviation Safety*, 1991,U.S. Geological Survey Bulletin 2047 (1994), p. 125.

Figure I-5-1. Hangars at Clark Air Force Base, Philippines, before — see insert photo (10 June 1991) — and after (24 June 1991) major eruption on 15 June, 1991. (from Casadevall)

5.1.1.4 For airports which are considered likely to be under threat from volcanic ash fall, the problem can be viewed from the following aspects:

a) standing pre-eruption arrangements;

b) volcanic eruption, including initial ash fall over the airport through to airport closure; and

c) post-eruption clean-up and re-opening of the airport.

An exchange of views on the foregoing aspects and discussion on various examples of actual responses made by airport authorities during volcanic eruptions were conducted at a workshop on the "Impact of volcanic ash on airports" held in Seattle 1993[2].

2. T.J. Casadewall, "Volcanic ash and airports — Discussions and recommendations from workshop on the impact of volcanic ash on airport facilities — Seattle, Washington, April 1993" *US Geological Survey*, Open File Report 93-518.

Figure I-5-2. DC-10 on the ground at Cubi Point Naval Air Station, Philippines. (from Casadevall)

5.1.2 Standing pre-eruption arrangements

Arrangements to deal with volcanic ash fallout over the aerodrome could be included in that part of the airport emergency plan related to natural disasters[3] or could be developed as a separate document. In either case, the plan should comprise a comprehensive set of procedures which defines the role and responsibilities of all civil aviation staff and other agencies at and, where relevant, away from the airport in the event a volcanic eruption threatens to dump volcanic ash on the airport. Actions to be taken in order to ensure the airport can apply the emergency procedures quickly and effectively in such an emergency include:

a) pre-storage of minimum materials needed for covering/sealing openings on aircraft and engines, ground equipment, certain strategic buildings and electronic/computer equipment, etc. (e.g. duct-tape and plastic sheeting);

b) pre-arrangement of a source of cleaning materials (beyond usual storage), additional heavy equipment and large volumes of water for collecting/cleaning/dumping volcanic ash;

c) pre-arrangement of a suitable, approved area for dumping and covering, or at least stabilizing, volcanic ash away from the airport; and

d) pre-arrangement of a source of auxiliary power generators.

3. *Airport Services Manual*, Part 7. — *Airport Emergency Planning*, Doc 9137, International Civil Aviation Organization, Montréal, Canada, 1991.

5.1.3 During the volcanic eruption

5.1.3.1 From initial ash fall over the airport through to airport closure

On notification of an eruption which could cause volcanic ash to fall on the airport, protective measures should be initiated immediately, such as the storage of non-essential equipment, sealing/covering openings on aircraft and aircraft engines, ground equipment, strategic buildings and electronic/computer equipment, etc. A decision has to be taken by the airport authorities regarding the feasibility or necessity to continue aircraft operations at the airport. A number of sometimes conflicting considerations would weigh in this decision. It may be possible to dispatch many aircraft before the ash seriously affects airport operations. This reduces the number of aircraft and passengers stuck on the ground to be exposed to the ash fall. At some point, however, continued aircraft operations may risk damaging aircraft engines and/or cause such reduced local visibility by continually stirring up ash on the runways that further operations have to wait longer and longer before the ash settles. Maintaining ground support equipment operational in a volcanic ash-contaminated environment is extremely difficult because the equipment comprises turbines, compressors and air conditioners which normally use only minimal or coarse filtration. Ground support often fails before aircraft operations become impossible, thus grounding the aircraft anyway. In order to maximize the period during which restricted aircraft operations could, if necessary, continue at the airport, the following aircraft ground operating procedures[4] have been recommended:

a) during landings, limit reverse thrust. The use of maximum reverse thrust may impair visibility and ingest ash into the engines;

b) the presence of a light layer of ash that obliterates the markings on a runway could have a detrimental effect on braking. The effects of a heavy layer are unknown. Exercise caution when ash becomes wet because surfaces will be especially slippery and braking less effective;

c) brake wear will be accelerated; however, properly sealed bearings should not be affected;

d) avoid static operation of engines above idle power;

e) do not taxi with any engine shut down: use all engines for taxi; however, check the operation manual concerning specific aircraft/engine combinations;

f) thrust during taxi should be limited to that which is required to sustain a slow taxi speed;

g) avoid operation in visible airborne ash; ash should be allowed to settle prior to initiating a take-off roll;

h) use a rolling take-off procedure;

i) restrict ground use of the auxiliary power unit to engine starts; and

j) avoid the use of air conditioning packs on the ground if re-circulation fans will maintain an adequate comfort level. If air conditioning on the ground is necessary, operate at full cold setting if ash is visible and pre-condition at the terminal using a filtered ground cart if available. Use bleeds off for take-off if operating procedures permit the configuration. For air conditioning pack operation, consult the operations manual.

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4. Campbell, p. 151. (See note 1, p. I-5-1.)

5.1.3.2 While restricted aircraft operations continue, the sealing of openings on parked aircraft, unused ground equipment, certain strategic buildings and electronic/computer equipment, etc., should be completed. As aircraft operations decrease, more and more ground equipment can be withdrawn from service, cleaned, lubricating oils and filters replaced, and the equipment covered or stored. Eventually, it may be necessary to close the airport entirely. The worst situation is a protracted series of volcanic eruptions which could close the airport for weeks.

5.1.3.3 Post-eruption clean-up

The complexity and immensity of this task should not be underestimated. Depending on the extent of the ash fall, the sheer volume of ash to be removed from the airport can be staggering. It is essential that the ash be removed from the airport because it will not simply blow away or disappear, but will continually blow around and re-contaminate everything. To a limited extent, depending on the amount of ash and local climatological conditions, it may be possible to stabilize or plough under the ash cleared from runways along the adjacent grass strips but generally there is no alternative but complete removal of the ash from the airport. A set of recommended procedures for the protection and clean-up of the airport is provided in Appendix A which is based mainly on experience gained from the various ad hoc measures which have been used successfully by airport authorities during past volcanic eruptions.

5.2 AIR TRAFFIC MANAGEMENT

5.2.1 General

Volcanic eruptions and the resulting ash cloud can cause major disruptions in air traffic operations and in some circumstances result in life-threatening situations for aircraft en route. The purpose of this section is to describe the impact on air traffic services and especially area control centres (ACC) during a volcanic ash episode. The section is divided under four headings: detection and reporting of an event; coordination and alert process; air traffic procedures for an ACC; and radio and ground notification.

5.2.2 Detection and reporting of an event

5.2.2.1 With the coming of modern jet aircraft has volcanic ash become of great concern to aviation. As stated earlier in this manual, the potential to cause a major aircraft accident is real. In addition, there are economic costs associated not only with the rerouting of aircraft and delays in the system, but also with physical damage to the aircraft and its equipment. During the past twenty years vulcanologists, geophysical scientists, meteorologists, pilots, dispatchers and air traffic control specialists have been working toward development and improvement of worldwide standards for the notification of a volcanic eruption and ash cloud. The cumulative effort has resulted in the development of a series of messages used by aviation to notify all users of a volcanic eruption and subsequent ash cloud as part of the ICAO International Airways Volcano Watch (IAVW), which is described in detail in Chapter 6. These are as follows:

Aeronautical Information Services (AIS)

— NOTAM or ASHTAM (normally issued by AIS on the initiative of an ACC)

Meteorological Authority

— METAR/SPECI

— volcanic activity report

— information concerning en-route weather phenomena which may affect the safety of aircraft operations (SIGMET)

— information concerning volcanic ash deposition (aerodrome warning)

Vulcanological Agency

— volcanic activity report (may include volcano alert status colour code) or volcano observatory notice for aviation (VONA)

Note.— The template for VONA is included in the Handbook on the International Airways Volcano Watch (IAVW) *(Doc 9766), which is available on the ICAO IAVWOPSG website.*

Pilots

— special air-report of volcanic activity (special AIREP)

Volcanic Ash Advisory Centre (VAAC)

— volcanic ash advisory information (abbreviated plain-language message and graphical product)

5.2.2.2 The notification that an eruption has occurred or that volcanic ash in the atmosphere has been reported could reach air traffic services (ATS) units from one or more of the following sources and in a number of different formats:

— from the national vulcanological agency as a simple report (which may include a reference to the volcano alert status colour code) or a report using the VONA template;

— from the national MET service, the MWO or an aerodrome meteorological office;

— from an aircraft in flight as a special air-report of volcanic activity; and

— from a national service, such as police/military or forestry station.

5.2.3 Coordination and alert process

5.2.3.1 As mentioned in 5.2.2, the first report of the occurrence of a volcanic eruption and subsequent ash cloud can be from one or many sources. Unless the volcano is in a very remote part of the world there will more than likely be multiple reports of an eruption. The proliferation of reports can very quickly overwhelm the communication system as the public floods the local telecommunication networks to report and obtain information on the magnitude and danger of the eruption. Aviation agencies are not the only ones who have a vested interest in ascertaining the extent of the danger to their users. Governments will respond quickly to protect the general life and property of the public, with aviation interests being only one special focus.

5.2.3.2 In order for the ACC to make informed decisions regarding the effect that the eruption/ash cloud could have on the airspace under its jurisdiction, and for the MWO to prepare the SIGMET for volcanic ash, access to advice from experts is necessary. As indicated elsewhere in this document, ICAO has designated nine volcanic ash advisory centres (VAACs) for this purpose. The VAAC provides guidance on the trajectory of the ash cloud and the flight levels which are affected by the cloud. The MWO's responsibility is to use this information and other sources of data for the issuance of a SIGMET for volcanic ash. The same information provided to the MWO by the VAAC is customarily sent to the ACC for transmission to aircraft in flight and for the initiation of a NOTAM. In addition to the information on the volcanic activity, the NOTAM contains information on air routes affected by volcanic ash and guidance on alternative routes. Volcanic ash SIGMETs are issued by the MWO in accordance with the Standards and Recommended Practices of Annex 3 and are usually issued after the meteorologist has verified the reported information. SIGMETs are used by supervisors in the ACC for managing airspace under their area of responsibility including the closing of airspace and the rerouting of aircraft. The information contained in the SIGMET is also passed on to pilots by ATS so the pilots can avoid the ash cloud. All decisions on rerouting aircraft are a coordinated effort between ATS, the pilot and the flight dispatcher.

5.2.4 Air traffic procedures for an ACC

5.2.4.1 If a volcanic ash cloud is reported or forecast in the flight information region for which the ACC is responsible, from any of the foregoing sources, the following procedures are followed:

a) relay all information available immediately to pilots whose aircraft could be affected to ensure that they are aware of the ash cloud's position and the flight levels affected;

b) suggest appropriate rerouting to avoid area of known or forecast ash clouds;

c) remind pilots that volcanic ash clouds are not detected by airborne or air traffic radar systems. The pilot should assume that radar will not give them advanced warning of the location of the ash cloud;

d) if the ACC has been advised by an aircraft that it has entered a volcanic ash cloud and indicates that a distress situation exists:

   1) consider the aircraft to be in an emergency situation;

   2) do not initiate any climb clearances to turbine-powered aircraft until the aircraft has exited the ash cloud; and

   3) do not attempt to provide escape vectors without pilot concurrence.

Experience has shown that the recommended escape manoeuvre for an aircraft which has encountered an ash cloud is to reverse its course and begin a descent if terrain permits. The final responsibility for this decision, however, rests with the pilot.

5.2.4.2 Appendix B provides the U.S. Department of Transportation, Federal Aviation Administration, Anchorage Air Traffic Control Center Emergency Plan for Volcanic Eruptions in Alaska Airspace. The emergency plan is an example of the steps needed to be taken to provide a coordinated and controlled response for dealing with an event of this nature. Responsibilities are clearly denoted for the area manager in charge, area supervisor, traffic manager and controllers. The order also identifies the officials who need to be contacted, the type of messages that are to be created, and how to conduct business.

5.2.4.3 Appendix C provides the Australian Airservices Weather Deviation Procedures for Oceanic Controlled Airspace. These procedures provide an example of procedures to be followed for operations that require a deviation in the planned flight for avoiding severe weather, not unlike an event of encountering an ash cloud. These procedures are of particular use for areas outside the coverage of direct controller-pilot VHF communication. They describe actions to be followed by air traffic control and the responsibilities of pilots and pilot-controller communications.

5.2.4.4 Critical to the examples provided in Appendices B and C is the fact that each State needs to develop procedures that meet its circumstances and fulfil its obligations to ICAO to provide the necessary air traffic support to ensure safety of aircraft.

5.2.4.5 Controllers need to be trained and made aware that aircraft which encounter an ash cloud can suffer a complete loss of power to turbine engines and that extreme caution needs to be taken to avoid entering an ash cloud. Since there is no means to detect the density of the ash cloud and size distribution of the particles and their subsequent impact on engine performance and the integrity of the aircraft, controllers need to be aware of the serious consequences for an aircraft that may encounter an ash cloud. Chapters 4 and 5 of this document have described the damage that can result from ingesting volcanic ash in an engine and how ash can impair operations at an aerodrome. Some particular points of guidance are as follows:

a) ash clouds may extend for hundreds of miles horizontally and reach the stratosphere vertically, therefore pilots should not attempt to fly through or climb out of the cloud;

b) volcanic ash may block the pitot-static system of an aircraft, resulting in unreliable airspeed indications; and

c) braking conditions at airports where volcanic ash has recently been deposited on the runway will effect the braking ability of the aircraft. This is more pronounced on runways that have wet ash. Be aware of the consequences of ingesting the volcanic ash into the engines during landing and taxiing. When departing airports, it is recommenced that pilots avoid operating in visible airborne ash; instead they should allow sufficient time for the particles to settle before initiating a take-off roll, in order to avoid ingestion of ash particles into the engine.

5.2.5 Radio and ground notification

5.2.5.1 The ACC serves as the critical communication link between the pilot, dispatcher and meteorologists during a volcanic eruption. During episodes of volcanic ash clouds within their flight information region (FIR), the ACCs have two major communication roles. First and of greatest importance is their ability to communicate directly with aircraft en route which may encounter the ash cloud. Based on the information provided in the volcanic ash SIGMET and volcanic ash advisory message and working with MWO meteorologists, the air traffic controllers should be able to provide the pilot with the flight levels that are affected by the ash cloud and the projected trajectory and drift of the cloud. Through the use of radio communication, ACCs have the capability to coordinate with the pilot alternative routes which would route the aircraft away from the volcanic ash cloud.

5.2.5.2 Similarly, the ACC through the issuance of a NOTAM for volcanic activity or an ASHTAM can disseminate information on the status and activity of a volcano even for pre-eruption increases in volcanic activity. NOTAM, ASHTAM and SIGMETs together with special air reports (AIREPs) are critical to dispatchers for flight planning purposes. Airlines need as much advance notification as possible on the status of a volcano for strategic planning of flights and the safety of the flying public. Dispatchers need to be in communication with their pilots en route so that a coordinated decision can be made between the pilot, the dispatcher and air traffic control regarding the alternative air routes that are available. It cannot be presumed, however, that an aircraft which is projected to encounter an ash cloud will be provided the most desirable air route to avoid the cloud. Other considerations have to be taken into account such as existing traffic levels on other air routes and the amount of fuel reserve available for flights which may have to be diverted to other routes to allow for the affected aircraft to divert to that air route.

5.2.5.3 The NOTAM for volcanic activity and the ASHTAM provide information on the status of activity of a volcano when a change in its activity is, or is expected to be, of operational significance. They are issued by the ACC through the respective NOF based on the information received from any one of the observing sources and/or advisory information provided by the associated VAAC. In addition to providing the status of activity of a volcano, the NOTAM or ASHTAM also provides information on the location, extent and movement of the ash cloud and the air routes and flight levels affected. Complete guidance on the issuance of the NOTAM and ASHTAM is provided in Annex 15 — *Aeronautical Information Services*. Included in Annex 15 is a volcano level of activity colour code chart. The colour code chart alert may be used to provide information on the status of the volcano, with “red” being the most severe, i.e. volcanic eruption in progress with an ash column/cloud reported above flight level 250, and “green” at the other extreme being volcanic activity considered to have ceased and volcano reverted to its normal state. It is very important that NOTAM for volcanic ash and ASHTAM be cancelled as soon as the volcano has reverted to its normal pre-eruption status, no further eruptions are expected by vulcanologists and no ash cloud is detectable or reported from the FIR concerned.

5.2.5.4 It is essential that the procedures which the ACC personnel should follow during a volcanic eruption/ash cloud event described in the foregoing paragraphs are translated into the local staff instructions (adjusted to take account, as necessary, of local circumstances). It is also essential that these procedures/ instructions form part of the basic training for all air traffic services personnel whose jobs would require them to take action in accordance with the procedures. Background information to assist the ACC or flight information centre (FIC) in maintaining an awareness of the status of activity of volcanoes in their FIR(s) is provided in the monthly Scientific Event Alert Network Bulletin published by the U.S. Smithsonian Institution and sent free of charge to ACCs/FICs requesting it.

5.2.5.5 Some interesting work has been conducted by Stunder and Heffter on the probability of aircraft encountering volcanic ash (Ash Encounter Probabilities (AEP)) along particular air routes[5]. Examples of the output products are given in Figures I-5-3 a) and b).

5.2.5.6 As a result of the work of the ICAO International Volcanic Ash Task Force (IVATF) established by ICAO in 2010 to address the disruption caused in Europe by the Icelandic volcano Eyjafjallajökull, a template was developed to help the various ICAO regions in the contingency planning effort. This Air Traffic Management Volcanic Ash Contingency Plan Template was designed to assist the ICAO Planning and Implementation Regional Groups (PIRGs) for their use in preparing volcanic ash contingency plans for their respective regions.

5.3 METEOROLOGICAL SERVICES

5.3.1 General

Meteorological services located in those parts of the world that are affected by volcanic ash have a very important role to play in the IAVW. The extent that this affects a particular meteorological service depends upon the level of responsibility undertaken by the State concerned. These levels of responsibility for facilities and services are as follows:

— world area forecast centres (WAFCs)
— VAACs
— MWOs
— aerodrome meteorological offices
— aerodrome meteorological stations.

Some States have accepted the responsibility for providing all of the foregoing facilities and their related services, others for one or two of them.

5. B.J.B. Stunder and J.L. Heffter, “Volcanic Ash Encounter Probabilities”, Eighth Conference on Aviation, Range and Aerospace Meteorology, Dallas, 1999.

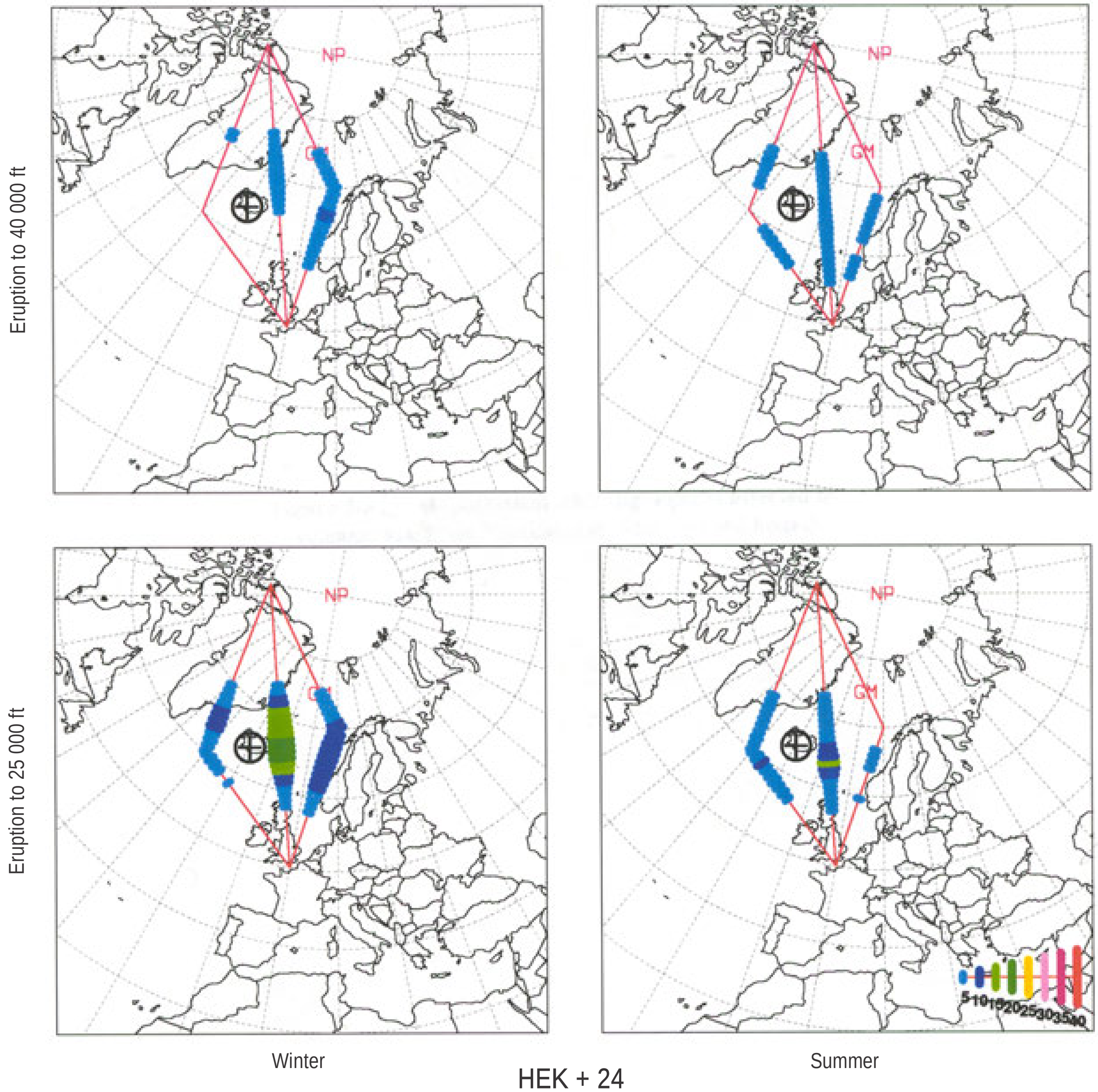

Figure I-5-3 a). Hypothetical AEP flight paths affected by volcanic ash from Kekla, Iceland (+24 hours). (from Stunder and Heffter)

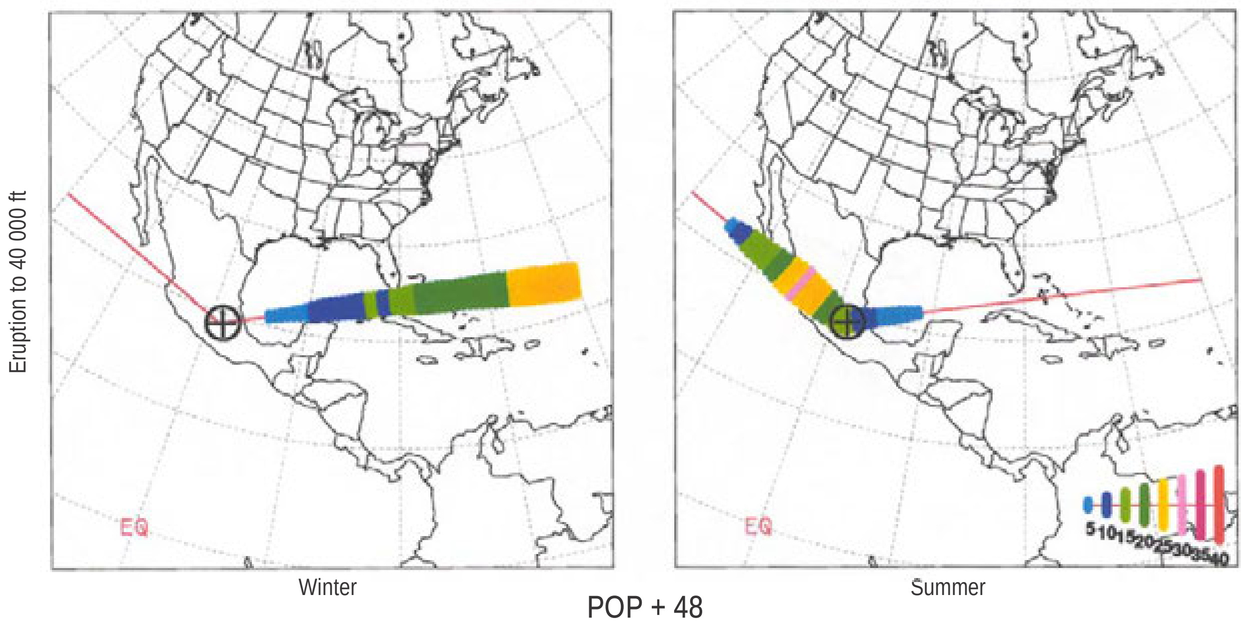

Figure I-5-3 b). Hypothetical AEP flight paths affected by volcanic ash from Popocatepetl, Mexico (+48 hours). (from Stunder and Heffter)

5.3.2 Observation of volcanic eruptions/ash cloud

Generally speaking, few aerodrome meteorological offices/stations are actually located within sight of an active volcano or groups of volcanoes. Nevertheless, those which are, e.g. Kagoshima airport near Mt. Sakurajima in Japan, and Anchorage within sight of a number of Alaskan volcanoes, are expected to issue volcanic activity reports in the event an eruption and/or ash cloud is observed. This information is passed up the chain of communications to the MWO which is responsible for maintaining a meteorological watch over the FIR concerned. If the volcanic ash in the atmosphere affects the visibility at the aerodrome, then it is also reported in the METAR/SPECI reports. Although less likely, if volcanic ash is affecting an aerodrome, the associated visibility reduction could also be forecast, i.e. at least the visibility values, not the occurrence of volcanic ash, in the terminal aerodrome forecast (TAF) for the aerodrome.

5.3.3 Warnings for volcanic ash

5.3.3.1 The next higher link in the chain of communication and responsibility is the MWO. The responsibility at this level focuses on the transformation of received "observed" information from any source into a warning to aviation i.e. a SIGMET. The SIGMET for volcanic ash is valid for a maximum period of six hours. In principle, in order for an MWO to discharge this responsibility, its meteorologists would need access to:

a) geostationary and AVHRR data; and

b) a computer model capable of forecasting volcanic ash trajectories in real time.

As many MWOs do not have access to such support, it was necessary for ICAO to designate VAACs having this capability and able to provide the necessary advisory information to MWOs.

5.3.3.2 Nine such centres have been designated to assist MWOs in an agreed area of responsibility (see Chapter 6). On receipt of information from any source that a volcano has erupted and/or volcanic ash has been reported, the MWO immediately informs its associated ACC/FIC so that aircraft which could be affected may be warned and diverted. Next, the MWO notifies its associated VAAC by telephone or fax seeking confirmation of ash clouds from satellite data and requesting trajectory forecasts based on initial information provided by the MWO. The initial information may, or may not, include confirmation that volcanic ash in the atmosphere is involved and the height the ash column has reached. If the reports do indicate that ash has definitely been observed, or the eruption was of the explosive type and ash can be inferred, an initial SIGMET should be issued while a trajectory forecast is awaited from the VAAC. A second SIGMET will be issued as soon as further confirmation is received regarding the existence and extent of the ash cloud and/or the first trajectory forecast is received from the VAAC. The SIGMETs should be updated as necessary, but at least every six hours.

5.3.3.3 It is important that the MWO maintains constant contact with its associated ACC to ensure that the contents of SIGMET and NOTAM/ASHTAM messages are mutually consistent. Depending on the arrangements made in States, the ACC may receive information directly from the VAAC at the same time the MWO receives it. Where possible this is the preferred method as it saves valuable time. This VAAC/ACC contact must be confirmed, and if it is not the case, the MWO must ensure that all such information is passed to the ACC immediately. Care should be taken to cancel SIGMETs when volcanic ash no longer affects the FIR concerned. In principle, this will be when the VAAC confirms that ash is no longer detectable from satellite data, no further reports of volcanic ash in the atmosphere have been received and the volcano has reverted to its pre-eruption status on the basis of expert vulcanological advice. In the latter context, the ACC should have access to vulcanological advice, and coordination of the cancellation of SIGMETs should be based on this advice. It should be noted that the NOTAM/ASHTAM may be issued before an actual eruption, or may be maintained after an eruption has ceased temporarily, based on vulcanological advice. The SIGMET, however, is only issued when volcanic ash in the atmosphere is reported or expected to exist.

5.3.4 Volcanic ash advisory service

5.3.4.1 Eight States have accepted responsibility for providing nine VAACs as part of the IAVW on a 24-hour basis. Each MWO should be aware to which VAAC it is associated and have readily to hand the VAAC 24-hour telephone and fax contact numbers. The VAAC has to be in a position to react to the receipt of information from any source that a volcano has erupted and/or volcanic ash has been reported. If the VAAC receives this information from *any source* other than an ACC/FIC or MWO (i.e. when the MWO is providing initial notification and request for trajectory advice), such as direct from a vulcanological agency or from their own satellite data, the VAAC should *immediately* inform the MWO and then issue a volcanic ash advisory.

5.3.4.2 If the VAAC receives the initial information of an eruption and/or ash cloud from an ACC/FIC or MWO, the first step is to monitor available satellite data to confirm the existence and extent of the volcanic ash cloud. Next, based on all information available (which may involve consultation with vulcanologists) the volcanic ash forecast transport and deposition model is activated and the resulting trajectory forecasts compiled into volcanic ash advisory information in an abbreviated plain language message and in graphical format. The former is transmitted to ACCs/FICs, MWOs and the two WAFCs by aeronautical fixed telecommunication network (AFTN), global telecommunication system (GTS) or facsimile, as necessary. The graphical format advisory information is transmitted to the London and Washington WAFCs by GTS or facsimile for uplink and availability on the WAFS Internet file service (WIFS) and the satellite distribution system for information relating to air navigation (SADIS) satellite broadcasts. This graphical format may of course be used to provide individual MWOs with advisory information in response to specific requests.

5.3.4.3 The VAAC should continue to monitor the situation in consultation with vulcanologists and the ACC/FIC, MWOs concerned. Advisory information should be issued as necessary but, if possible, at least every six hours to assist MWOs in updating their SIGMET information. The VAAC should maintain an awareness of the status of active and potentially explosive volcanoes in the FIRs which come under its area of responsibility. Assistance in this regard is provided in the monthly Scientific Event Alert Network Bulletin published by the U.S. Smithsonian Institution and sent free of charge to any ACC/FIC, MWO and VAAC requesting it.

5.3.5 World area forecast system (WAFS)

The two WAFCs in London and Washington have two responsibilities in respect of volcanic ash:

a) to include a reference to the occurrence of an eruption using the standard symbol on SIGWX forecast charts; together with a reminder to pilots to check SIGMETs for the area concerned;

b) to uplink volcanic ash advisory information (both abbreviated plain language and graphical format) on the satellite broadcasts.

The information provided in the SIGWX forecasts should be based on advice from the VAAC concerned, thereby ensuring consistency of information.

5.4 FLIGHT PLANNING, DISPATCH AND OPERATIONAL CONTROL

5.4.1 General

5.4.1.1 Volcanic ash cloud can cover a very wide area and move quickly from one region to another. Consequently, the accurate and timely availability of information is essential for safety of flight and to facilitate both the flight pre-planning stage as well as any consequential in-flight replanning. The options available include rerouting, unscheduled en-route technical stops, carriage of extra (contingency) fuel against possible en-route diversion or non-optimum flight altitudes, or cancellation. All of these materially affect load planning and crew preparation. All involve highly complex management decisions.

5.4.1.2 The overall situation can be further complicated when large numbers of passengers are involved. Carriage of additional fuel usually means loss of revenue payload. Offloading passengers or cargo close to departure time can bring additional complications. Technical stops are always costly and bring the additional risk of serious further delays due to flight crew duty time limitations being exceeded. Delayed or cancelled flights have a consequential effect on aircraft and crew availability for this and other sectors, beyond the immediate destination. For flights between Asia and Europe, curfews severely restrict the options to re-schedule flights. In fact, any interruption in the smooth and carefully planned operation of scheduled air services can lead to acute problems with serious financial penalties to the operator, and distress and frustration to the passenger.

5.4.1.3 The first consideration, however, must always be the safety of the aircraft and its occupants. The safety implications of an inadvertent ash encounter are already well documented and are addressed elsewhere in the manual. The aim is to avoid! Consequently, early knowledge of an event, however sketchy, will help airline operational staff make important planning decisions. Regular updates of information are essential.

5.4.2 Meteorological requirements

5.4.2.1 Annex 3

Specific user requirements for operational meteorological information (OPMET) are clearly stated in Annex 3.

5.4.2.2 Volcanic ash advisory messages

5.4.2.2.1 Airlines have identified a need for volcanic ash advisories to be available through the ICAO satellite broadcasts (international satellite communications system (ISCS) and satellite distribution system for information relating to air navigation (SADIS)) for immediate access. The advisories are also available through the International Society for Aeronautical Telecommunications (SITA) communications circuits and in the corresponding VAACs' websites. This information is required for flight planning, in particular for long-haul flights. It should be available at the flight planning stage as much as 15 hours before a possibly contaminated area is actually reached.

5.4.2.2.2 Additionally, airlines have identified a requirement for volcanic ash advisories in graphical format. When the volcanic ash advisory is provided in binary format, the BUFR code form should be used.

5.4.2.3 SIGMET and aerodrome warnings

5.4.2.3.1 SIGMET are to be valid for six hours. From a safety viewpoint, regular in-flight updates would be required, but important initial fuel and payload decisions would first need to have been taken. These include the availability of alternative routings and alternate en-route aerodromes as well as conditions at the destination. Dissemination of SIGMET to internationally agreed addresses well beyond the affected FIR is therefore an important factor. This will ensure the earliest possible notification of flights likely to be affected.

5.4.2.3.2 Unfortunately, the SIGMET is frequently the weakest link in the information chain. In the case of volcanic ash, forecasters at MWOs who issue SIGMET messages are encouraged to consider the impact of such a message on flight operations.

5.4.2.3.3 Meteorological and AIS staff should ensure the correct dissemination of SIGMET and NOTAM to internationally agreed addressees with particular attention to the ICAO four-letter FIR location indicator to ensure the longest possible warning and available preparatory time for airline operations staff and flight crews.

5.4.2.3.4 Aerodrome warnings for volcanic ash deposition have been identified as necessary by users. To that end, the meteorological office at the aerodrome is requested to issue such warnings if a forecast of impending ash deposition is available or as soon as the ash begins to accumulate at the aerodrome.

5.4.2.4 SIGWX

The inclusion of the volcanic eruption symbol on SIGWX charts is also an important warning to all users of the charts.

5.4.2.5 Flight planning/flight despatch

5.4.2.5.1 As airlines and other agencies progressively automate their OPMET and AIS databases, adherence to standard formats and communications headers for vital air safety messages becomes essential.

5.4.2.5.2 All available information on the nature, extent, altitude(s) and time of the eruption or cloud position and affected flight levels, as well as speed of movement, are important. If there has been an eruption in the vicinity of an airport, the operator needs to know whether any local alternates are also likely to be affected. The presence of ash cloud in the lower levels of the atmosphere may not be relevant to en-route operations but could be a considerable threat to climbing or descending traffic. No arbitrary limits can be established. Each situation will be unique and will require some degree of professional judgement.

5.4.2.5.3 Airspace congestion on many of the busier air routes can limit the available upper levels, leaving the pilot little operational flexibility. General messages (especially NOTAM) that effectively close airspace for long periods cause considerable difficulty to the user. Regular updates of SIGMETs and NOTAM are therefore essential.

5.4.2.5.4 Where an eruption is known or is believed to be of little operational impact (e.g. ash column of limited vertical extent), this should be stated in the SIGMET or NOTAM. Additionally, the SIGMET/ NOTAM should be cancelled immediately after the threat has past. This will minimize disruptions to air navigation and strengthen the credibility of the warning system.

5.4.2.5.5 An ASHTAM/NOTAM should be originated for volcanic ash deposition at an aerodrome if a forecast of impending ash deposition is available or as soon as the ash begins to accumulate at the aerodrome.

5.4.3 Centralized operational control/flight-following

5.4.3.1 Many airlines maintain operational control over their aircraft throughout their route network from a central location. Also, the aircraft flight and fuel plans are usually generated at a central location and disseminated to the point of departure. Increasingly, this requires near-global exchanges of OPMET messages and NOTAM, plus any other information relevant to the sector in question.

5.4.3.2 Widespread use of airline company communications and reporting systems provides airlines with a means of providing the pilot with the latest available information and assists in making difficult operational decisions, such as major re-routing or diversion. The option to uplink revised navigation flight plans to the pilot via company data link communications systems will increasingly be employed. Diversion aerodromes usually have to be carefully chosen both to accommodate the particular aircraft size and handling requirements and to minimize the potentially huge cost to an airline for an overnight stop with a full passenger load. Continuous situation updates are therefore required.

5.4.3.3 Close coordination between meteorological, vulcanological, ATS and AIS agencies is essential to ensure that the fullest and most recent information reaches the user as far ahead of the flight as possible.

5.5 VULCANOLOGICAL AGENCIES

5.5.1 Volcanoes under surveillance

5.5.1.1 There are approximately 560 volcanoes for which there is evidence of an eruption during the past 500 years. Only about 170 active volcanoes are under continuous surveillance by volcano scientists. The historically active volcanoes are concentrated around the margins of the Pacific Ocean basin and make up the circum-Pacific “ring of fire”. Each volcano has been identified by the numerical identifier used in the *Catalogue of Active Volcanoes of the World*, published by the International Association of Volcanology and Chemistry of the Earth’s Interior (IAVCEI) between 1950 and 1975, and in *Volcanoes of the World*, published by the Smithsonian Institution in 1981.

5.5.1.2 A convenient source to learn about which volcanoes are under surveillance is through the directory of the World Organization of Volcano Observatories (WOVO) (see Chapter 1, 1.5.8). The directory is available free on the Internet at: http://www.wovo.org

5.5.2 Techniques for monitoring volcanoes

The techniques used for monitoring the world's volcanoes are briefly described in Chapter 1, 1.5.

5.5.3 Agencies responsible for monitoring volcanoes

5.5.3.1 Typically volcanoes are monitored by scientists associated with organizations or departments of the national government. For example, in Japan, the Japanese Meteorological Agency maintains a network of approximately 83 volcano observatories and has the responsibility for reporting activity to government officials. In the United States, the United States Geological Survey — an agency of the United States Department of the Interior — has responsibility for monitoring United States volcanoes from four volcano observatories. In some countries local universities may have the responsibility for monitoring volcanoes, usually through an authorization or appropriation from the national government.

5.5.3.2 For the purposes of linking vulcanological agencies with aviation interests, ICAO has prepared the *Handbook on the International Airways Volcano Watch (IAVW) — Operational Procedures and Contact List* (Doc 9766) (available only in electronic format at www.icao.int/anb/iavwopsg), which *inter alia*, contains a detailed list of operational contact numbers in States concerned. This handbook is available only at the International Airways Volcano Watch Operations Group (IAVWOPSG) website and is under continuous updating due to the changing nature of some of the information contained therein. Effective channels of communication have to be established between the vulcanological agency and the civil aviation authority in those States subject to the effects of volcanoes. Normally, the civil aviation authority will seek assistance from the vulcanological agency first and thereafter coordination is arranged along the lines of the guidance given in the procedures contained in the IAVW Handbook (Doc 9766). In accordance with Annex 3, ICAO Contracting States shall make appropriate arrangements with selected State volcano observatories to monitor active or potentially active volcanoes and to send information on volcanic activity to their associated ACC, MWO and VAAC. This information will comprise significant pre-eruption volcanic activity (or a cessation thereof), volcanic eruptions (or a cessation thereof) and/or the presence of volcanic ash in the atmosphere.

5.5.4 Geological information relevant to aviation safety

5.5.4.1 Geologists who study erupting volcanoes can assist in mitigating the hazards of volcanic ash through their knowledge of the following topics:

a) nature of explosive vulcanism (dynamics of ash cloud formation and dispersal);

b) volcanic ash (size, composition, mineralogy, physical properties, gas content);

c) the prediction and warning of volcanic activity (monitoring volcanoes; communication with appropriate agencies);

d) geological history of local active volcanoes; and

e) the tracking and deposition of ash clouds.

5.5.4.2 When volcanic unrest is detected at an unmonitored volcano, scientists will respond quickly to evaluate the importance of that unrest. Such unrest may include an increase in the temperature and emissions of volcanic gases, the occurrence of earthquakes, changes in the shape of the volcano (volcano deformation), as well as other signs such as a change in the level of water in wells at a volcano, unusual melting of snow or ice, etc., as described in 1.5.

5.5.4.3 To evaluate unrest, scientists use a variety of instruments including temperature and gas detection samplers, seismometers and surveying instruments. Typically the information from such instruments will be collected at a central locale (the volcano observatory) where scientists can collectively evaluate the significance of their results.

5.5.4.4 If additional information about volcanoes is required, it is suggested that contact be made with the appropriate vulcanological agency in the State concerned as listed in the IAVW Handbook (Doc 9766).

5.5.5 Communications links from volcano observatories

In a typical volcano observatory, there will be various means of communicating information between the scientists and public officials. Communications may utilize telephone, fax, radio, email, printed statements and interviews with the local news media. At many observatories, there will be a prioritized list of agencies that must be contacted immediately when an eruption or other significant change occurs at the volcano under surveillance. Aviation authorities are typically at the top of such call-down lists.

5.5.6 Level of alert colour code

Many volcano observatories today utilize a level of alert colour code to convey in a shorthand form information about a volcano's state of unrest. The colour code recommended for use in providing information to aviation is given in the IAVW Handbook (Doc 9766). The classification of the level of activity for a volcanic eruption in terms of the colour code can only be done by experienced vulcanologists. In view of this, it is important for the civil aviation authority in a State in which there are active volcanoes to establish contact with the appropriate vulcanological agency and encourage the use of the aviation colour code when providing information to aviation. This ensures that the information provided may be included in the ASHTAM in terms of the colour code.

Chapter 6

THE INTERNATIONAL AIRWAYS VOLCANO WATCH (IAVW)

6.1 GENERAL

The definition of the IAVW given in Annex 3 is as follows:

International airways volcano watch (IAVW). International arrangements for monitoring and providing warnings to aircraft of volcanic ash in the atmosphere.

Note.— The IAVW is based on the cooperation of aviation and non-aviation operational units using information derived from observing sources and networks that are provided by States. The watch is coordinated by ICAO with the cooperation of other concerned international organizations.

Put in its simplest terms, the role of the IAVW is to keep aircraft in flight and volcanic ash in the atmosphere entirely separate. Nothing can be done to prevent volcanic ash erupting into the atmosphere and being carried by the upper winds across international air routes. The aviation community has the responsibility to ensure, as far as possible, that when this happens, the ash cloud is monitored, pilots concerned are advised and aircraft routed safely around it.

6.2 STRUCTURE OF THE IAVW

The IAVW consists of two parts, an observing part comprising observation sources, as follows:

a) observations from existing ground-based stations drawn from all known organized international observing networks regardless of their particular specialized function;

b) special air-reports; and

c) observations from satellites (meteorological and non-meteorological);

and an advisory warning part comprising advisory/ warning messages, as follows:

d) NOTAM or ASHTAM initiated by ACCs and issued by AIS units;

e) SIGMETs issued by MWOs; and

f) volcanic ash advisory messages issued by VAACs.

The overall structure of the IAVW is shown diagrammatically in Figure I-6-1 and in terms of the relevant international regulatory provisions in Figure I-6-2.

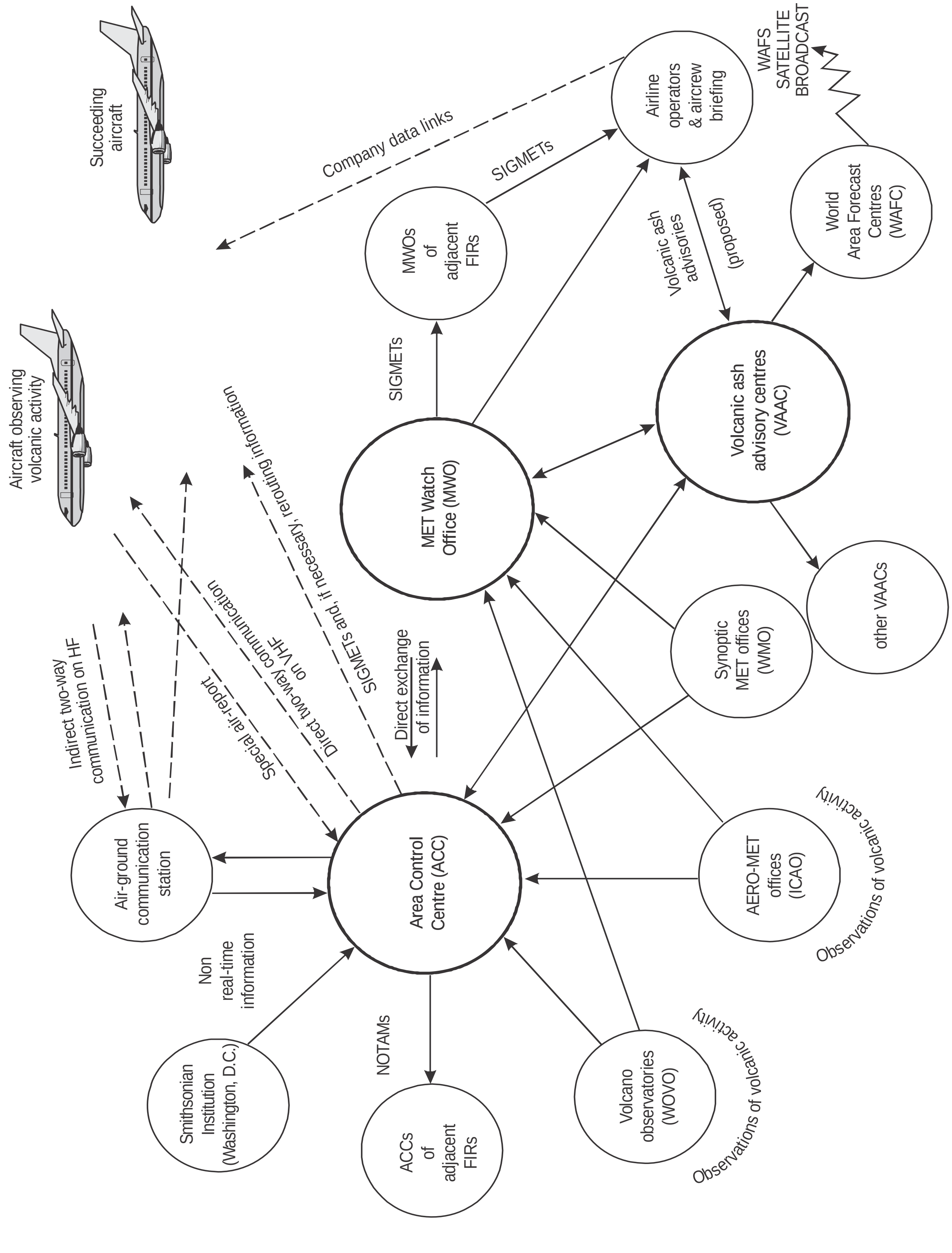

Figure I-6-1. Organization of the International Airways Volcano Watch.

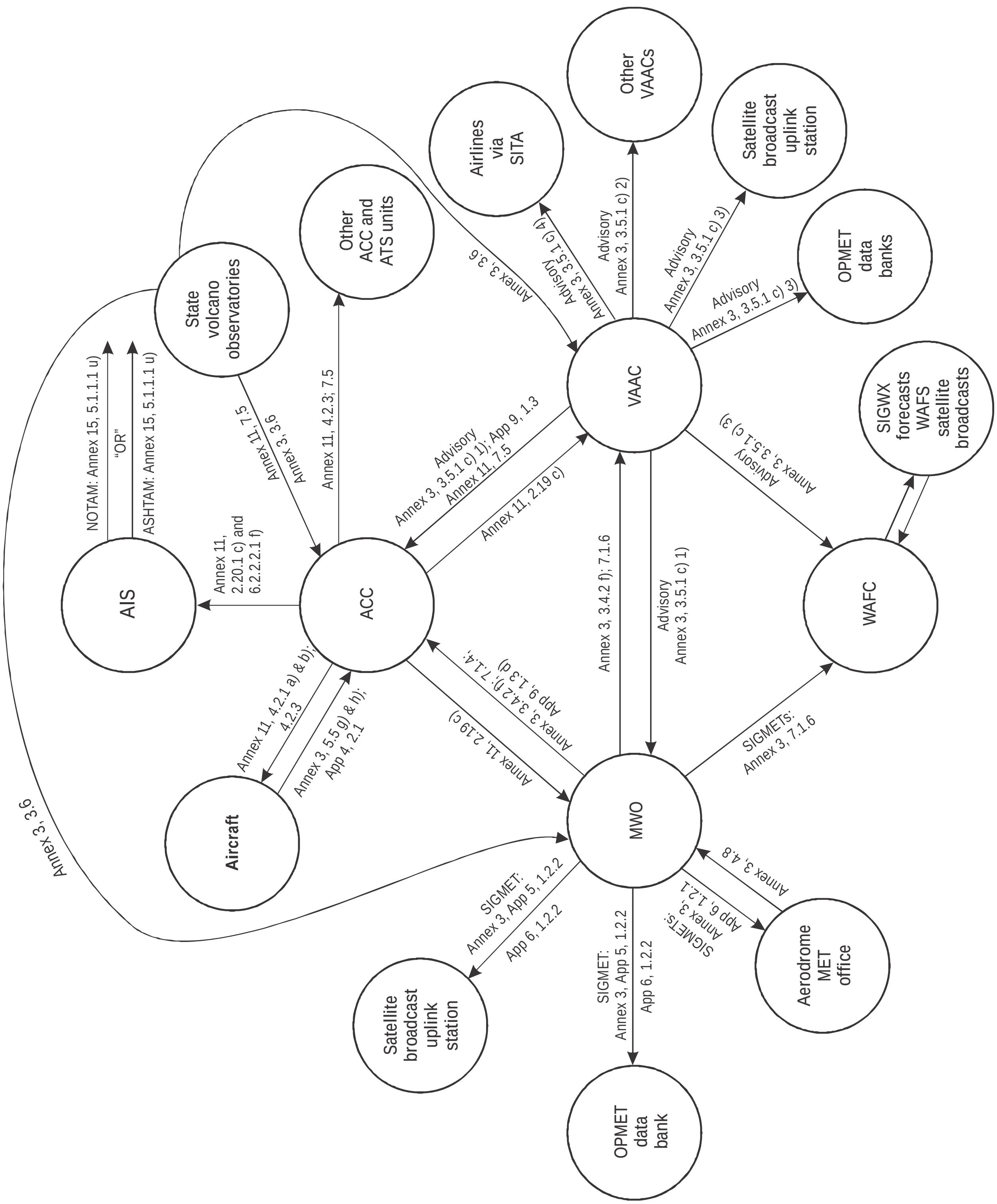

Figure I-6-2. International Airways Volcano Watch regulatory provisions (ICAO SARPs).

6.3 OBSERVING PART OF THE IAVW

6.3.1 Ground-based observing stations

Following a request from ICAO, a number of international organizations which coordinate existing international ground-based observing networks for various scientific or humanitarian purposes, and ICAO Contracting States, agreed to cooperate in the establishment of the IAVW. The organizations and the observing networks concerned were:

a) the World Organization of Volcano Observatories (WOVO):

— volcano observatories

— vulcanologists' internet

— seismological stations

b) the World Meteorological Organization (WMO):

— meteorological observatories (including those located at aerodromes)

— climatological stations

— hydrological and rainfall stations

— agricultural stations

— merchant ships

c) the United Nations Disaster Relief Organization (UNDRO):

— field relief stations (for volcanic eruptions)

d) ICAO Contracting States:

— general aviation

— police/military posts

— border customs/immigration posts

— forestry stations

— national park stations

— geological agencies

— inshore fishing fleets

e) the United Nations Comprehensive Nuclear Test Ban Treaty Verification Networks.

The relevant international regulatory and procedural documents which govern the work of the organized networks have been amended to indicate that, if their observing staff see or learn of a volcanic eruption or a volcanic ash cloud, the information must be sent immediately to the nearest area control centre or meteorological watch office through existing dedicated communications channels or by telephone, telex or facsimile.

6.3.2 Airborne observations

6.3.2.1 Mention was made in Chapter 1 that only a minority of active volcanoes is monitored on the ground, which means that pilots with their commanding view from the cockpit and regular travel over remote areas are often the first to observe a volcanic eruption or volcanic ash cloud, and therefore, may well be the first line of defence. In view of the danger volcanic ash presents to aircraft, however, it is appreciated that this is not an acceptable situation, and eventually must become the exception rather than the rule. Nevertheless, until such time as the world's active volcanoes are monitored more effectively, on many occasions pilots will continue to be the first to report volcanic activity.

6.3.2.2 In order to assist pilots in making these reports, volcanic activity, volcanic eruptions and volcanic ash clouds were included in the international regulatory documents as phenomena warranting the issuance of a special air-report. The international special air-report of volcanic activity reporting (VAR) format should be used. This format is given in Appendix 1 of the *Procedures for Air Navigation Services —Air Traffic Management* (PANS-ATM, Doc 4444) and its format was updated at the Third Meeting of the IAVWOPSG. A copy is provided in Figure I-6-3. The special air-report of volcanic activity (model VAR) is divided into two sections. Section 1 includes basic aircraft identification and position and the minimum information required immediately, i.e. the volcanic activity observed and wind/temperature at the flight level. This information is to be transmitted by radio to ATS units as soon as pilot workload permits. The wind/temperature information is included in the first section because it is of assistance to meteorologists in predicting the initial movement of the ash cloud at that flight level. When time permits, the pilot is encouraged to complete Section 2 of the message format giving additional details of the eruption, ash cloud and, if relevant, the effect on the aircraft. This information is handed in to ground personnel as a complete written post-flight special air-report at the next point of landing and is of assistance to vulcanologists in determining the type of eruption. The visual observation of pre-eruption volcanic activity and volcanic ash cloud by pilots is dealt with in 3.2.1 of this manual and the clues to warn the pilot that the aircraft has actually entered a volcanic ash cloud are discussed in 3.2.2. Aircraft engine and sensor anomalies which also assist the pilot in this latter regard are dealt with in 4.3. The requirements for pilots to report volcanic activity have been well publicized and supported throughout the aviation industry, due to the efforts of IATA and IFALPA, and there must be very few pilots by now who are unaware of these requirements.

6.3.3 Space-based observation

6.3.3.1 The final part of the IAVW observing triad comprises the observation of volcanic eruptions and ash cloud from satellites. The various satellites involved, the current data interpretation and analysis techniques used, and the expectations for future satellite sensors and systems are discussed in 3.3. For the most part, the satellites which are currently used for observing volcanic eruptions and volcanic ash cloud are polar-orbiting and geostationary meteorological satellites. These satellites form an integral part of the Global Observing System of the World Weather Watch which is coordinated and administered by WMO.

6.3.3.2 Other satellites and sensors which are of interest in the monitoring of volcanic eruptions and ash cloud, which are also discussed in Chapter 3, include environmental satellites, and sensors to detect stratospheric ozone which are currently operating on certain polar-orbiting meteorological satellites. These satellites and sensors also fall under the aegis of WMO in respect of their importance in environmental and climatological studies. It is the intention of WMO that the whole world will continue to be monitored by both polar-orbiting and geostationary meteorological satellites for the foreseeable future and, national budgets permitting, follow-on launches of replacement satellites for both series are planned at least through the current decade. WMO has committed itself to cooperating with ICAO in the development of satellite techniques in order to steadily improve the effectiveness of satellite data interpretation and analysis in monitoring volcanic eruptions and ash cloud. The VOLCAM-dedicated UV/IR camera package proposed by NASA to monitor volcanic eruptions and ash cloud from geostationary satellites described in 3.3.4.4 would, if it came to fruition, provide a quantum leap in the efficacy of the IAVW and the protection of aircraft.

6.4 ADVISORY AND WARNING PART OF THE IAVW

6.4.1 Area control centres and flight information centres

6.4.1.1 Airspace around the world is divided by regional agreement into FIRs throughout which flight information and alerting service is provided. Within these regions various control areas and zones are designated in which air traffic control service is provided for flights conducted under instrument flight rules, such as around airports and along air routes. ACCs are units established by States to provide air traffic control service to controlled flights in control areas under their jurisdiction. FICs are units established by States to provide flight information service and alerting service. The ACC and FIC are in radio contact with all aircraft in flight operating within and through their FIR via the aeromobile communications service. These units are, therefore, the critical interface between ground units and aircraft in flight. In addition to the air-ground communications through air traffic services units, most of the larger airline companies also maintain data link communications between their centralized operational control units on the ground and the company fleet of aircraft. The airlines transmit available operational information, including relevant meteorological information to their aircraft fleet in addition to specific “company” information.

6.4.1.2 Among its responsibilities, the ACC/FIC has to keep aircraft advised of operational information which could affect them. Such information may be exchanged between ACCs/FICs in adjacent FIRs by radio, telephone and by NOTAM. The NOTAM is a message in a specified format containing information concerning, *inter alia*, hazards, the timely knowledge of which is essential to personnel concerned with flight operations. NOTAM may be initiated by ACCs, for example for volcanic ash affecting certain air routes, and are exchanged on the aeronautical fixed telecommunication network (AFTN) between AIS units. In the case of information of immediate concern to aircraft, again volcanic ash would be a good example, the information received by an ACC in a NOTAM is transmitted immediately by radio to aircraft in flight concerned. NOTAM also form part of the briefing documentation for aircrew prior to take-off and at the flight planning stage. In addition to information on the volcanic eruption and/or volcanic ash cloud, the NOTAM would normally include information on the air routes closed and alternative routing to avoid the ash cloud. It is essential that NOTAM for volcanic eruptions/ash cloud are cancelled as soon as it is considered that the volcano has reverted to its normal state and the airspace is no longer contaminated by volcanic ash, otherwise vast volumes of airspace may be unnecessarily denied to aircraft, thereby causing considerable extra costs to the airlines. A special series NOTAM called the ASHTAM has been introduced specifically for volcanic activity. States may choose to use either format, but are encouraged to use the ASHTAM because the name immediately denotes its content and facilitates the routing of the information to the aircraft quickly.

6.4.2 Meteorological watch offices

6.4.2.1 Once an ICAO Contracting State accepts responsibility for providing air traffic services within an FIR or control area, it also has to establish an MWO for that FIR or control area, or arrange for another State to undertake this responsibility. The MWO maintains a watch over the meteorological conditions in the FIR or control area and issues SIGMET and AIRMET messages, as necessary, warning aircraft of specified observed or forecast en-route weather phenomena which may affect the safety of aircraft operations. The AIRMET message comprises information on weather phenomena of specific concern to low-level flights below flight level 100 (or 150 in mountainous areas) which has not already been included in the area forecasts provided for those low-level flights and/or a SIGMET (which may concern flights at any flight level). Volcanic ash is already included as a phenomenon which warrants issuance of a SIGMET (for whatever flight levels concerned) and, therefore, is not included in the list of phenomena warranting issuance of an AIRMET.

Special air-report of volcanic activity form (Model VAR)
MODEL VAR: to be used for post-flight reporting

VOLCANIC ACTIVITY REPORT

Air-reports are critically important in assessing the hazards which volcanic ash cloud presents to aircraft operations.

OPERATOR:			A/C IDENTIFICATION: (as indicated on flight plan)		
PILOT-IN-COMMAND:					
DEP FROM:	DATE:	TIME; UTC:	ARR AT:	DATE:	TIME; UTC:
ADDRESSEE			AIREP SPECIAL		
Items 1–8 are to be reported immediately to the ATS unit that you are in contact with.					
1) AIRCRAFT IDENTIFICATION			2) POSITION		
3) TIME			4) FLIGHT LEVEL OR ALTITUDE		
5) VOLCANIC ACTIVITY OBSERVED AT (position or bearing, estimated level of ash cloud and distance from aircraft)					
6) AIR TEMPERATURE			7) SPOT WIND		
8) SUPPLEMENTARY INFORMATION a) SO_2 detected Yes ☐ No ☐ b) Ash encountered Yes ☐ No ☐			Other ____________________ ____________________ ____________________ (Brief description of activity especially vertical and lateral extent of ash cloud and, where possible, horizontal movement, rate of growth, etc.)		
After landing complete items 9–16 then fax form to: (Fax number to be provided by the meteorological authority based on local arrangements between the meteorological authority and the operator concerned.)					
9) DENSITY OF ASH CLOUD	☐ (a) Wispy	☐ (b) Moderate dense	☐ (c) Very dense		
10) COLOUR OF ASH CLOUD	☐ (a) White ☐ (d) Black	☐ (b) Light grey ☐ (e) Other ____________	☐ (c) Dark grey		
11) ERUPTION	☐ (a) Continuous	☐ (b) Intermittent	☐ (c) Not visible		
12) POSITION OF ACTIVITY	☐ (a) Summit ☐ (d) Multiple	☐ (b) Side ☐ (e) Not observed	☐ (c) Single		
13) OTHER OBSERVED FEATURES OF ERUPTION	☐ (a) Lightning ☐ (d) Ash fallout	☐ (b) Glow ☐ (e) Mushroom cloud	☐ (c) Large rocks ☐ (f) All		
14) EFFECT ON AIRCRAFT	☐ (a) Communication ☐ (d) Pitot static	☐ (b) Navigation systems ☐ (e) Windscreen	☐ (c) Engines ☐ (f) Windows		
15) OTHER EFFECTS	☐ (a) Turbulence	☐ (b) St. Elmo's Fire	☐ (c) Other fumes		
16) OTHER INFORMATION (Any information considered useful.)					

Figure I-6-3. VAR Model

6.4.2.2 The SIGMET is issued for a validity period of from four to six hours, but in the special case of volcanic ash and tropical cyclones the validity period should normally be for the maximum period of six hours. An example of such a SIGMET is as follows:

SIGMET FOR VA

YUDD SIGMET 2 VALID 211100/211700 YUSO-
YUDD SHANLON FIR/UIR VA ERUPTION MT ASHVAL LOC S1500 E07348 VA CLD OBS AT 1100Z FL310/450 APRX 220KM BY 35KM S1500 E07348 – S1530 E07642 MOV SE 65KMH FCST 1700Z VA CLD APRX S1506 E07500 – S1518 E08112 – S1712 E08330 – S1824 E07836

Meaning: The second SIGMET message issued for the SHANLON* flight information region (identified by YUDD Shanlon area control centre) by the Shanlon/International* meteorological watch office (YUSO) since 0001 UTC; the message is valid from 1100 UTC to 1700 UTC on the 21st of the month; volcanic ash eruption of Mount Ashval* located at 15 degrees south and 73 degrees 48 minutes east; volcanic ash cloud observed at 1100 UTC between flight levels 310 and 450 in an approximate area of 220 km by 35 km between 15 degrees south and 73 degrees 48 minutes east, and 15 degrees 30 minutes south and 76 degrees 42 minutes east; the volcanic ash cloud is expected to move east-southeastwards at 65 kilometres per hour; at 1700 UTC the volcanic ash cloud is forecast to be located approximately in an area bounded by the following points: 15 degrees 6 minutes south and 75 degrees east, 15 degrees 18 minutes south and 81 degrees 12 minutes south, 17 degrees 12 minutes south and 83 degrees 30 minutes east, and 18 degrees 24 minutes south and 78 degrees 36 minutes east.

6.4.2.3 In the event that a volcanic eruption ejects volcanic ash into the atmosphere in a particular FIR, or volcanic ash is transported into the FIR from an adjacent FIR by the upper winds, the MWO responsible for that FIR is required to issue a SIGMET for volcanic ash. Issuance of the first SIGMET simply indicating the existence of a volcanic ash cloud (including volcano name, location, possible ash height and direction, if known) from a particular volcano is a straightforward matter for any MWO. Reference to Chapter 3, 3.3 and 3.4, however, indicates that substantial technical capabilities are required of an MWO in order to issue subsequent SIGMETs. As a minimum, the MWO should have reliable reception of polar-orbiting and geostationary satellites, including AVHRR satellite data and be in a position to manipulate, analyse and interpret the data in order to discriminate volcanic ash clouds from normal water/ice clouds. In addition, the MWO has to be able to forecast the trajectory of the volcanic ash cloud, which is a complex undertaking. It was appreciated from the beginning of the establishment of the IAVW that most MWOs do not have these capabilities. In view of this, ICAO has designated, on advice from WMO, nine VAACs whose responsibility it is to provide advice to MWOs and ACCs in their area of responsibility of the extent and forecast movement of the volcanic ash.

6.4.3 Volcanic ash advisory centres

6.4.3.1 The role of a VAAC is to provide expert advice on a 24-hour watch to ACCs/MWOs in its area of responsibility (see Figure I-6-4) regarding the extent and forecast movement of a volcanic ash cloud. This information is required by the MWOs in order to issue SIGMETs for volcanic ash. The VAACs monitor the volcanic ash cloud using the data received from various meteorological satellites and forecast the movement of the ash cloud using volcanic ash transport and dispersion computer models. The techniques employed by the VAACs are described in detail in Chapter 3.

* Fictitious locations.

6.4.3.2 The following VAACs have been designated by ICAO to provide advice to MWOs on the extent and forecast movement of volcanic ash within an agreed area of responsibility:

Anchorage, United States; Buenos Aires, Argentina; Darwin, Australia; London, United Kingdom; Montréal, Canada; Tokyo, Japan; Toulouse, France; Washington, United States; and Wellington, New Zealand.

The VAAC areas of responsibility as currently agreed, are shown in Figure I-6-4.

6.4.3.3 Under normal circumstances, a VAAC will be notified by one of its associated MWOs that a volcanic eruption has occurred in its FIR and at the same time the MWO will request advisory information. The VAAC immediately initiates the computer volcanic ash transport and dispersion model in order to provide advice on the forecast trajectory of the volcanic ash. The VAAC then checks the latest satellite information from all available sources to assess if the ash is discernible from satellite data and, if so, its extent. This information is passed immediately to the MWO and ACC/FIC together with the forecast volcanic ash trajectory if this is available at the same time. Initial confirmation that the volcanic ash is indeed detectable from satellite data and its extent is extremely important information for the MWO and ACC/FIC as it gives some initial measure of confidence for the ACC/FIC to reroute aircraft and/or activate, as necessary, ATC contingency arrangements. The VAAC concerned thereafter continues to monitor satellite data and provides regular volcanic ash trajectory forecasts to the MWO, ACC/FIC and airlines until such time as the eruption ceases and/or the airspace is no longer contaminated by ash. Arrangements have been made so that, if for any reason a VAAC is not in a position to provide the volcanic ash trajectory forecast, one of the other VAACs could be requested to do so.

6.4.3.4 In order to provide guidance to States, a set of IAVW procedures which reflect the foregoing responsibilities has been developed by ICAO and included in the IAVW Handbook (Doc 9766). In addition, the relevant ICAO Annexes (Annexes 3, 10 and 11) contain provisions concerning the role of the VAACs, based on the IAVW procedures.

6.5 COMMUNICATIONS AND COORDINATION IN THE IAVW

6.5.1 The communications links between the various entities in the IAVW are shown in Figure I-6-1. On the aviation side, the communications links between air traffic services, meteorological services and airlines are of long standing and should already be fully operational and reliable. Having said this, however, it should also be stated that in some instances, experience has shown that while the links themselves may be functional, the coordination necessary to make effective use of such links is sometimes lacking. This has been found to be particularly the case between ACCs/FICs and MWOs, with the result that there have been occasions when NOTAM were issued for volcanic ash, but no parallel SIGMET was issued for the same FIR, or information in the SIGMET and NOTAM was inconsistent. Effective coordination between the ACC/FIC and MWO is a two-way street and is fundamental to the entire SIGMET system, and especially critical for the IAVW which is unique in that it requires the issuance of both NOTAM and SIGMET for a "weather phenomenon". Although lack of effective coordination between the ACC/FIC and MWO has been the exception rather than the rule, it is emphasized here because just one lapse in attention to volcanic ash has the potential to cause a major aircraft accident. Therefore, no derogation whatever in the coordination between the ACC/FIC and MWO in this regard can be accepted, however infrequently it might occur. If the MWO learns of a volcanic eruption or volcanic ash cloud in its FIR or in adjacent FIRs, the ACC/FIC must be informed **immediately**, and *vice versa* if the ACC/FIC learns of the volcanic eruption or volcanic ash cloud first. Subsequent issuance of NOTAM and SIGMET must be the subject of continuous mutual coordination so that the information given therein is consistent.

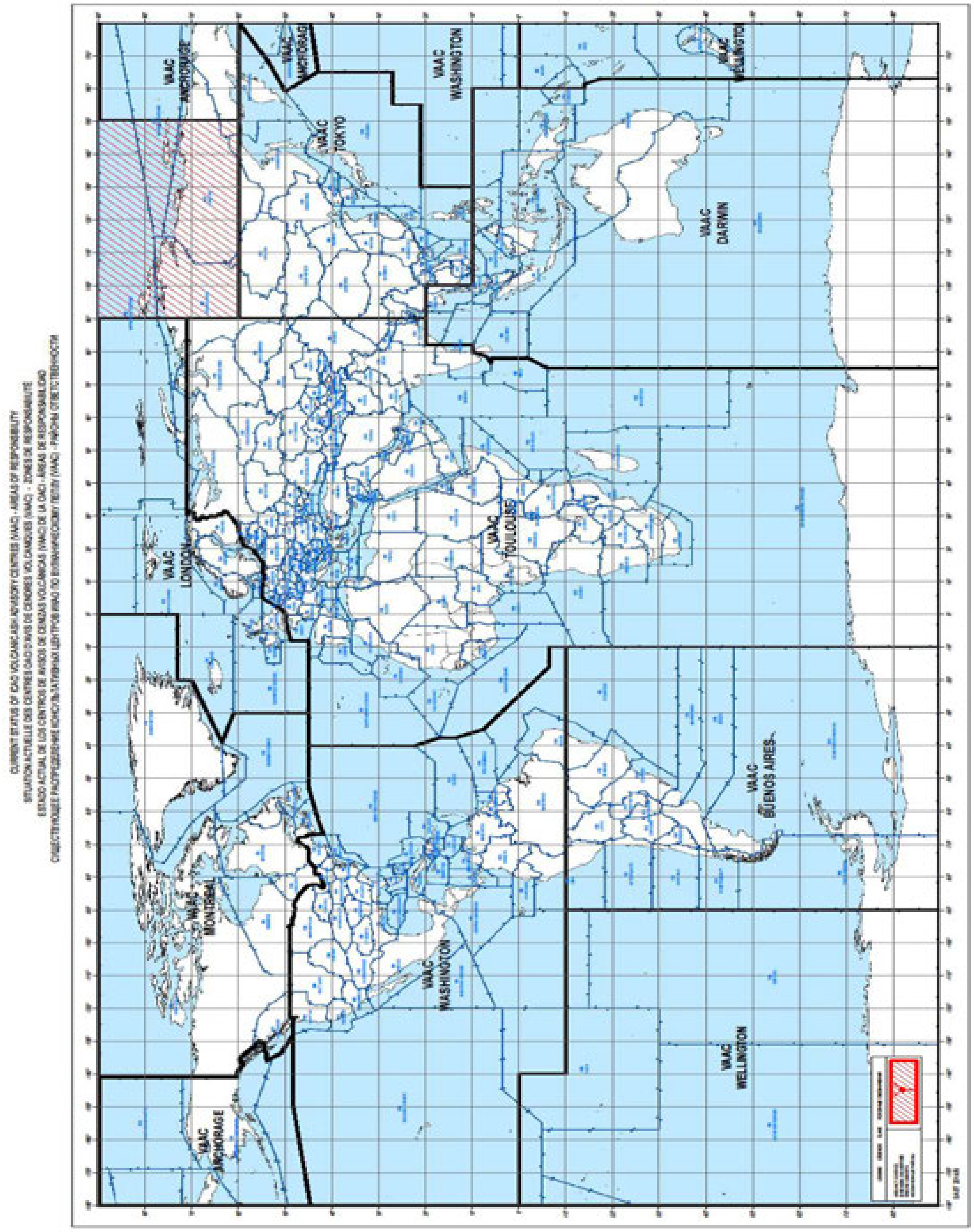

Figure I-6-4. Current status of ICAO Volcanic Ash Advisory Centres (VAACs) — Areas of responsibility

6.5.2 Mention was made in 6.5.1 that, at the time of the establishment of the IAVW, communication links between operational units in the aviation and meteorological communities were of long standing. There was no similar history of long-standing communications arrangements between the vulcanological agencies and the aviation community. This meant that these critical links had to be set up virtually from scratch by States whose FIRs contained active or potentially active volcanoes. Communications between volcano observatories (more often than not located in remote and mountainous areas) and the central vulcanological agency headquarters are the first link in the chain. These links have already been established for national volcano monitoring purposes and generally do not involve the aviation community. Communications are generally by telephone or radio, but in some cases this has to be done through third parties or at least using third-party equipment. As indicated in Chapter 1, only a minority of the world's active volcanoes is monitored continuously. The next link in the chain is between the vulcanological agency and the aviation community, and this is normally by telephone or fax. These links are established specifically to support the IAVW and, as volcanic ash in the atmosphere is of primary concern only to aviation, it is the civil aviation authority that should take the lead in establishing and maintaining effective links between the ACC/FIC, MWO and the vulcanological agency. The flow of vulcanological information from observatories is normally routed through the vulcanological headquarters or major field offices before it reaches the ACC/FIC or MWO, in order to ensure expert analysis of the information by a vulcanologist. To facilitate this communication, a requirement for the notification of volcanic activity from active or potentially active volcanoes from State volcano observatories was introduced in Annex 3 (3.6 refers). Subsequently, selected State Volcano Observatories are being included in the regional Air Navigation Plans (ANP) by the Planning and Implementation Regional Groups (PIRGs) concerned. To facilitate the provision of this information, a template called the *Volcano Observatory Notice for Aviation (VONA)* has been developed and included in Doc 9766. The same arrangement normally applies to vulcanological information provided by voluntary observing sources such as police/military, customs/immigration and forestry posts. Exceptions to this would be vulcanological information provided by domestic aircraft and the various meteorological observatories, all of which are able to make contact with the ACC/FIC or MWO directly (with one or through the other).

Note.— In order to enhance links, coherence and integration with States' disaster risk reduction units, Contracting States are encouraged to return to States' volcano observatories any relevant information regarding volcanic ash to an extent and in a form agreed between the VAAC and the volcano observatory concerned. The sample letter of agreement, along the lines of the one included in Appendix A of Doc 9766, could be used to document such agreements.

6.5.3 A list of operational contact points in the IAVW between vulcanological agencies, MWOs and ACCs is included in Doc 9766. The list contains telephone, fax numbers and email addresses of the contact points in each State involved in the IAVW, which enables interested parties outside a State to contact key personnel, as necessary, in the event information is required concerning a volcanic eruption or volcanic ash cloud.

6.6 NON-REAL-TIME SUPPORT TO THE IAVW

6.6.1 The Smithsonian Institution, Washington, D.C.

6.6.1.1 This institution maintains a global database of volcanoes and volcanic eruptions and operates the Global Volcanism Network. This database is accessible by electronic means and is also available in book form under the title *Volcanoes of the World*. A monthly bulletin is published which provides an analysis by vulcanologists of recent volcanic activity around the world. In order to provide background information on the global status of volcanoes to ACCs/FICs, MWOs and VAACs, the Smithsonian Institution kindly agreed to send copies of the bulletin to ACCs/ FICs, MWOs and VAACs requiring it. This arrangement was made on the understanding that reports of volcanic activity received by the aviation community, such as in special air-reports, would be forwarded to the Smithsonian Institution to assist them in updating their global vulcanism database. These arrangements have worked well and the ACCs/FICs, MWOs and VAACs are receiving the bulletin regularly.

6.6.1.2 In addition to the foregoing, arrangements have been made for regular consultations to be conducted between VAACs and the Smithsonian Institution by conference telephone and email in order for VAACs to maintain currency with the activity status of volcanoes around the world.

6.7 TRAINING AND AUDIO-VISUAL AIDS

6.7.1 As is the case with all operational fields, the importance of the training of operational personnel cannot be over-emphasized. In particular, in the case of volcanic ash, its incidence in any one FIR is likely to be infrequent, and the familiarity of operational personnel with the relevant local staff instructions over time may diminish. In certain FIRs, although dangerous volcanoes exist, there could be many decades between eruptions, and unless the volcanic ash procedures form an integral part of initial and refresher training courses for pilots, flight dispatchers, ATC, MET and vulcanological personnel, the procedures are less likely to be applied effectively when they are needed. In many cases, to an extent, it may be possible to treat volcanic ash as any other en-route hazard, so that the local staff instructions and contingency arrangements are more general and cover all hazards. This approach is illustrated in the case of the "weather deviation procedures for oceanic controlled airspace" used by the Civil Aviation Authority in Australia and described in Part I, Chapter 5, 5.2.4.3, and Appendix C.

6.7.2 ICAO has also produced French, Russian and Spanish versions of the video "Volcanic Ash Avoidance" originally produced in English by the Boeing Airplane Company. A world map of volcanoes and principal aeronautical features produced by Jeppesen, Sanderson Inc. and the U.S. Geological Survey, with the assistance of other organizations including ICAO, was distributed to States in English with explanatory text in French, Russian and Spanish by ICAO and WMO. A video has also been issued by the United States Federal Aviation Administration (in English) providing a briefing for air traffic controllers on the hazards of volcanic ash to aviation. Additionally, a video prepared by the International Federation of Air Line Pilots' Associations (IFALPA) titled "volcanic ash, an aviation hazard of explosive proportions" is available on the ICAO IAVWOPSG website.

6.7.3 A number of ICAO/WMO workshops and seminars have been organized in those ICAO regions most concerned with volcanic activity, including the African, Asian, European, Caribbean and South American regions.

6.8 OPERATION OF THE IAVW

6.8.1 The average frequency of Plinian volcanic eruptions is discussed in general terms in Chapter 1, but it is instructive to look at the real picture over the past twenty years in order to gauge how often aviation had cause for concern. In Appendix D is a list of reported volcanic eruptions since 1980 which were assessed as having a volcanic explosivity index (VEI) of 3 or more, and also those of lesser VEI but which could still cause difficulties for aviation due to the presence of volcanic ash in the atmosphere. Those which were known to have had an impact on aviation, most of which involved activation of the IAVW, are denoted by an asterisk. In Appendix E is the list of volcanoes contained on the world map of volcanoes and principal aeronautical features referred to in 6.7.2. In addition, a database and analysis of actual aircraft encounters with volcanic ash since 1980 compiled by the USGS with the cooperation of aircraft and engine manufacturers is provided in Appendix F.

6.8.2 Reference to these appendices shows clearly that there have been numerous eruptions of direct concern to aviation in the last twenty years and the number of actual aircraft encounters with volcanic ash has been worryingly high. States and international organizations have expended much effort and many resources to mitigate the problem, and the activation of the IAVW has become more frequent and more effective over the period as the system gradually became established and operational units became increasingly familiar with their responsibilities. The designation by ICAO of nine VAACs to provide volcanic ash advisory information to MWOs and ACCs/FICs, which was completed at the end of 1996, provided a marked overall improvement in the efficacy of the IAVW as each VAAC gained experience and this experience was shared among all VAACs.

PART II

Radioactive Materials and Toxic Chemicals in the Atmosphere and Aircraft Operations

INTRODUCTION TO PART II

The accident which occurred at the Chernobyl nuclear reactor in the Ukraine in April 1986 produced a cloud of radioactive materials and debris that was reported to have reached an altitude of at least 3 or 4 km. The potential danger this type of cloud posed for civil aviation prompted the International Federation of Air Line Pilots' Associations (IFALPA) to request ICAO to develop the necessary arrangements to ensure that information on the extent and movement of such clouds be provided in a timely manner to aircraft and aerodromes likely to be affected. In addition to the problem of radioactive materials in the atmosphere, IFALPA also requested similar action in respect of the hazard posed to civil aviation by the release of toxic chemicals into the atmosphere following industrial or transport accidents.

The Air Navigation Commission (ANC) acceded to these requests and an appropriate task was introduced into the technical work programme.

It was noted at the time that, at least from the operational standpoint, there were similarities between these problems and the problem of volcanic ash in the atmosphere. Accordingly, the ANC instructed the Secretariat to develop the necessary arrangements and procedures for the monitoring and provision of warnings to aircraft of radioactive materials and toxic chemicals in the atmosphere with the assistance of the Volcanic Ash Warnings Study Group. In this regard, the group was strengthened by the addition of a member nominated by the International Atomic Energy Agency (IAEA). Since 2002, this task has been progressed with the assistance of the International Airways Volcano Watch Operations Group (IAVWOPSG).

In formulating the task, it was acknowledged that most States already had, or should have had, national emergency procedures to deal with a nuclear accident originating in their State or clouds of radioactive materials drifting across national boundaries. In the case of toxic chemicals, at least some States were known to have taken this particular hazard into account in their national emergency procedures. ICAO, therefore, wished specifically to focus on aircraft in flight to ensure that such aircraft were not "overlooked" in emergency procedures and to explore the possibility of minimizing the time for the notification of pilots about a cloud of radioactive material by arranging for direct contact between the IAEA and ACCs/FICs.

The introduction, by Amendment 75 to Annex 3, of a requirement for a worldwide centre for direct notification to the ACC of areas affected by the release of radioactive materials, which in turn notifies the aircraft in flight, completed the foregoing task. At that time, it was thought that only reviews remained of the implementation and improved procedures were necessary.

However, the events in Japan in March 2011, when an earthquake of 9.0 magnitude struck Japan's east coast and triggered a tsunami which in turn devastated northern parts of the country and caused a nuclear accident at the Fukushima Nuclear Power Plant, changed drastically the urgency regarding the completion of the task. The release of the radioactive material is now considered an ongoing task even with the necessary arrangements and procedures to deal with this emergency in place.

Chapter 1

RELEASE INTO THE ATMOSPHERE OF RADIOACTIVE MATERIALS AND TOXIC CHEMICALS FOLLOWING INDUSTRIAL ACCIDENTS

1.1 RADIOACTIVE MATERIALS

1.1.1 The attention of the world was focused on this problem in April 1986 when radioactive debris was released into the atmosphere from reactor 4 of the Chernobyl nuclear power plant in the Ukraine. The release of radioactive debris was the result of explosions following an experiment to test the safety of the reactors if two breakdowns were to occur simultaneously. Debris released in the early period of the accident, while the core and the expelled debris were still extremely hot, rose to 1 or 2 km[1]. Subsequent emissions were much cooler and tended to travel over long distances in the boundary layer, except when advected upwards to 3 or 4 km in frontal and convective clouds.

1.1.2 The radioactive debris comprised numerous radionuclides from the reactor. The most important from the health standpoint were iodine-131 (a short-lived isotope which contaminates grass and thereby cow's milk and thence human thyroid glands and may be inhaled directly); caesium-134 (half-life of two years); and caesium-137 (half-life of thirty years). All of the foregoing can accumulate in the human body and have been implicated in causing cancer. Iodine-131 debris can be in gaseous and particulate form. The transport of the radioactive debris in the atmosphere is controlled on the one hand by atmospheric winds including wind shear and instability (frontal and convective clouds), and on the other hand by the dry deposition of the larger particles due to gravity and wet deposition due to scavenging of gaseous and industrial particulate matter by rainfall.

1.2 TOXIC CHEMICALS

1.2.1 In the case of accidents involving chemicals, these have tended to be on a much smaller, usually local, scale. These accidents have been caused by explosions in factories where industrial chemicals are made; as a result of fires in chemical factories; due to railway/road accidents during the transport of industrial chemicals; or due to leaks/ explosions at natural gas wells and storage facilities. The toxic chemical clouds are more often than not in gaseous form and, unless opaque, are very difficult to track. Fortunately, being on a local scale, such clouds tend to drift mainly in the boundary layer near the ground and dissipate quickly.

1.2.2 A number of accidents involving toxic chemicals have been reported which affected aircraft operations. One example concerned a leak which occurred on 25 September 1989 in Europe's largest underground natural gas storage caverns near Chemery, France. The natural gas leaked into the atmosphere at a rate of over 5 million ft^3/hour, and local air traffic operating into a nearby aerodrome had to be diverted. The leak was finally plugged on 27 September 1989.

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1. F.B. Smith, "Lessons from the dispersion and deposition of debris from Chernobyl", *Meteorological Magazine*, Vol. 117, Meteorological Society, London, 1988.

1.2.3 One of the fundamental difficulties in dealing with accidents involving toxic chemicals is the huge number of potential chemicals involved. Any gas which totally replaces the oxygen in the air in the cockpit has the potential to incapacitate the flight crew. For example, nitrogen or carbon dioxide are not specifically toxic, in fact they are breathed constantly, but if a high concentration of these gases excluded sufficient oxygen from the cockpit, it would of course become lethal to the aircrew. This means that the effect of toxic gases in the cockpit could be the immediate incapacitation of the flight crew and the loss of the aircraft and passengers.

1.2.4 One of the latest developments in this field was the agreement reached within the IAVW regarding the future policy on how to deal with the release of toxic chemicals into the atmosphere. In this regard it was agreed that the atmospheric dispersion of the release of chemicals into the atmosphere is largely a local problem because the material released generally remains close to the surface, near the location of the release and is short lived. Therefore rapid response times are considered critical and local arrangements within the State concerned are most effective in advising on the transport and dispersion of hazardous materials. In case of an event of this nature, States should issue a NOTAM for toxic chemicals (Annex 15, *Aeronautical Information Services*, 5.1.1.1 v) refers). In the future, an amendment to Annex 3 stipulating the inclusion of information related to toxic chemical clouds in aerodrome warnings will be developed.

Chapter 2

EFFECT ON AIRCRAFT OPERATIONS

2.1 EFFECT OF RADIOACTIVE MATERIALS

2.1.1 If an aircraft encountered a cloud of radioactive materials in the atmosphere from a nuclear event, the aircrew and passengers would be unlikely to be affected immediately and, therefore, the aircrew would not be incapacitated. The hazard is more of a long-term effect on the health of those inhaling or ingesting the radioactive materials (breathing or eating). The air conditioning filters on board aircraft are too coarse to filter out radionuclide particles in a radioactive cloud, hence these would pass more or less unmodified into the aircraft air circulation system. The exception to the foregoing scenario would be the unlikely case of an aircraft flying at low altitude directly above the reactor at the time of the accident and being affected by the blast itself and/or the intense but short-range radiation produced in the initial explosion. Areas around nuclear facilities are usually designated by States as danger areas, expressly to ensure that such facilities are not overflown by aircraft.

2.1.2 While the potential danger of the radioactive cloud to aircraft in flight is clear, there is also the effect on the "collective mind" of the travelling public to be considered. Unless extreme care is taken regarding the wording of public information and the timeliness of its issuance, a negative (and likely exaggerated) impression may be gained. This can have a widespread ripple effect throughout the air travel industry causing problems for the travel agencies through to the airline ticket counters. The manner in which information on emergency situations is handled varies considerably from one State to another, although guidance in the case of nuclear accidents is provided by the IAEA[1].

2.1.3 The effect on aerodrome operations depends on whether or not the aerodrome is in the path of the radioactive cloud. If so, the aerodrome and facilities would come under the State emergency plan in the same way as other public facilities. When the aerodrome is not directly affected by the radioactive cloud but air traffic is scheduled to transit the affected area, the situation is more complicated. In this case, the indirect effect of air traffic diversions and delays on the aerodrome operations can be considerable, but the travelling public, receiving information from numerous official and unofficial (media) sources, may have a totally confused appreciation of the situation. The prognosis and the replanning of travel arrangements are likely to be rather more difficult than for delays due to weather, which at least are well understood.

2.2 EFFECT OF TOXIC CHEMICALS

It was indicated in the previous chapter that the release of a cloud of toxic chemicals, although usually of a local nature, if encountered by an aircraft could cause the immediate incapacitation of the aircrew. Generally speaking, the risk is likely to be highest for aircraft operating at low level, e.g. landing, taking-off or circling at an aerodrome. The emergency is usually local, low-level, and short-lived because of the speed with which emergency personnel work to contain or extinguish such accidents or fires.

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1. "Guidance on International Exchange of Information and Data following a major nuclear accident on Radiological Emergency", International Atomic Energy Agency, Publication STI/PUB/914, Vienna, 1992.

Chapter 3

NATIONAL AND INTERNATIONAL ARRANGEMENTS AND PROCEDURES TO DEAL WITH THE HAZARD TO AIRCRAFT

3.1 RELEASE OF RADIOACTIVE MATERIALS AND TOXIC CHEMICALS INTO THE ATMOSPHERE

3.1.1 The provision of national information on events in which radioactive materials or toxic chemicals are released into the atmosphere normally forms part of a State's emergency plan. On this assumption, appropriate provisions have been introduced into the relevant ICAO regulatory documents (Annex 11 — *Air Traffic Services*, Annex 15 — *Aeronautical Information Services*, the *Procedures for Air Navigation Services — ICAO Abbreviations and Codes* (PANS-ABC, Doc 8400) and the *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444)) requiring that any information on such accidents available nationally should be provided by the responsible ACC to aircraft in flight likely to be affected in the FIR concerned. A specific designator "WR" is provided for in the NOTAM format used to disseminate information among aeronautical information services units, and then to air traffic services personnel, e.g. the ACC.

3.1.2 The problem becomes more complex when a nuclear or chemical accident occurs in a neighbouring State. Such information should be passed by radio, telephone and NOTAM from the ACC responsible for the FIR in which the accident occurred to the ACCs of adjacent FIRs. This ensures that aircraft in flight or about to depart for the affected FIR are advised of the situation in time to take the necessary action.

3.1.3 The requirement for States to notify other States of a nuclear accident is derived from the United Nations *Convention on Early Notification of a Nuclear Accident*. A parallel instrument, the *Convention on Assistance in Case of a Nuclear Accident or Radiological Emergency*, ensures that the State affected may seek and be provided with assistance from other States in order to minimize the consequences of the accident. Both of these conventions were adopted by the IAEA in 1986/1987 in the aftermath of the Chernobyl accident in April 1986.

3.1.4 In order to give practical effect to these conventions, the IAEA, together with other interested international organizations, have developed through the United Nations Inter-Agency Committee for Response to Nuclear Accidents, a set of internationally-agreed procedures (referred to as the "Convention Information Structure (CCI)"). Of particular interest to aviation is the specific set of procedures agreed between the IAEA and the WMO. The initial notification of the accident (an example is provided in Appendix G) comprises the following information:

- statement that an accident has occurred;
- nature of the accident;
- time of occurrence; and
- exact location of the accident.

Following notification, States which may be physically affected are provided by the IAEA with information regarding trajectory forecasts for the radioactive materials released into the atmosphere. In order to provide this, the WMO has designated a number of Regional Specialized Meteorological Centres (RSMCs) with the responsibility of providing forecast charts (output products) for the trajectory and deposition of radioactive material released into the atmosphere. The RSMCs designated are: Beijing, Exeter, Melbourne, Montréal, Obninsk, Tokyo, Toulouse and Washington. Examples of the output products from one RSMC for a hypothetical release of radioactive materials are given in Figures II-3-1 a) and b). Moreover, the inclusion of a symbol indicating “radioactive material in the atmosphere” on WAFS SIGWX charts in a similar manner to the inclusion of the “volcanic activity” symbol mentioned in 5.3.5 is intended to warn crew at a pre-flight stage. The ICAO regulatory provisions governing these procedures are shown diagrammatically in Figure II-3-2.

3.1.5 The foregoing paragraphs describe the internationally agreed procedures for notifying and exchanging information on the release of radioactive materials into the atmosphere. There are equivalent conventions and associated procedures governing the release of toxic chemicals. This is currently treated as a purely national matter and, as indicated above, from the aviation standpoint aircraft in flight are to be provided with information available nationally concerning the release into the atmosphere of toxic chemicals. The United Nations Department of Humanitarian Affairs in 1995 raised the issue of toxic chemical accidents and this has been addressed by ICAO with the assistance of WMO. Within WMO the work has been progressed with the assistance of the Emergency Response Activities (ERA) programme (in the non-nuclear area). The following WMO annexes contain relevant information and are under continuous update by the ERA programme.

— *Definition of Requirements Concerning Chemical Incidents*

ftp://ftp.wmo.int/Documents/PublicWeb/www/era/TD778_newSec5_Annex8(cbs-ext06).pdf

— *Role of National Meteorological Services (NMSs)*

ftp://ftp.wmo.int/Documents/PublicWeb/www/era/TD778_newSec5_Annex9(cbs-ext06).pdf

— *Guidance for Development of the Interface Between an NMS and Other Emergency Response Agencies in Case of Chemical Incidents*

ftp://ftp.wmo.int/Documents/PublicWeb/www/era/TD778_newSec5_Annex10(cbs-ext06).pdf

Basically, airborne “toxic chemicals” are highly localized effects, and the associated hazards are usually sudden onset and are short-lived in nature. The CBS ET has stated that such incidents have to be deal with efficiently, i.e. by the local authorities, and of course the emergency related decisions have to be consistent across the population and activities. Advice on meteorological aspects should come from the NMS. As a result of this work, it has been confirmed that the atmospheric dispersion of the release of chemicals into the atmosphere is largely a local problem since the material generally remains on the surface and near the location of release. Since the main potential impact would be at aerodromes if the source of the release is nearby, local arrangements within a State are considered as the most effective. Therefore, a requirement for aerodrome warnings for the release of toxic chemicals into the atmosphere has been included in Annex 3. This warning should be in accordance with the format provided in Annex 3, Appendix 5, Table A6-2 — *Template for aerodrome warnings*. Additionally, a NOTAM for toxic chemicals should be issued in accordance with Annex 15, 5.1.1.1 v) (3.1.1 above, refers).

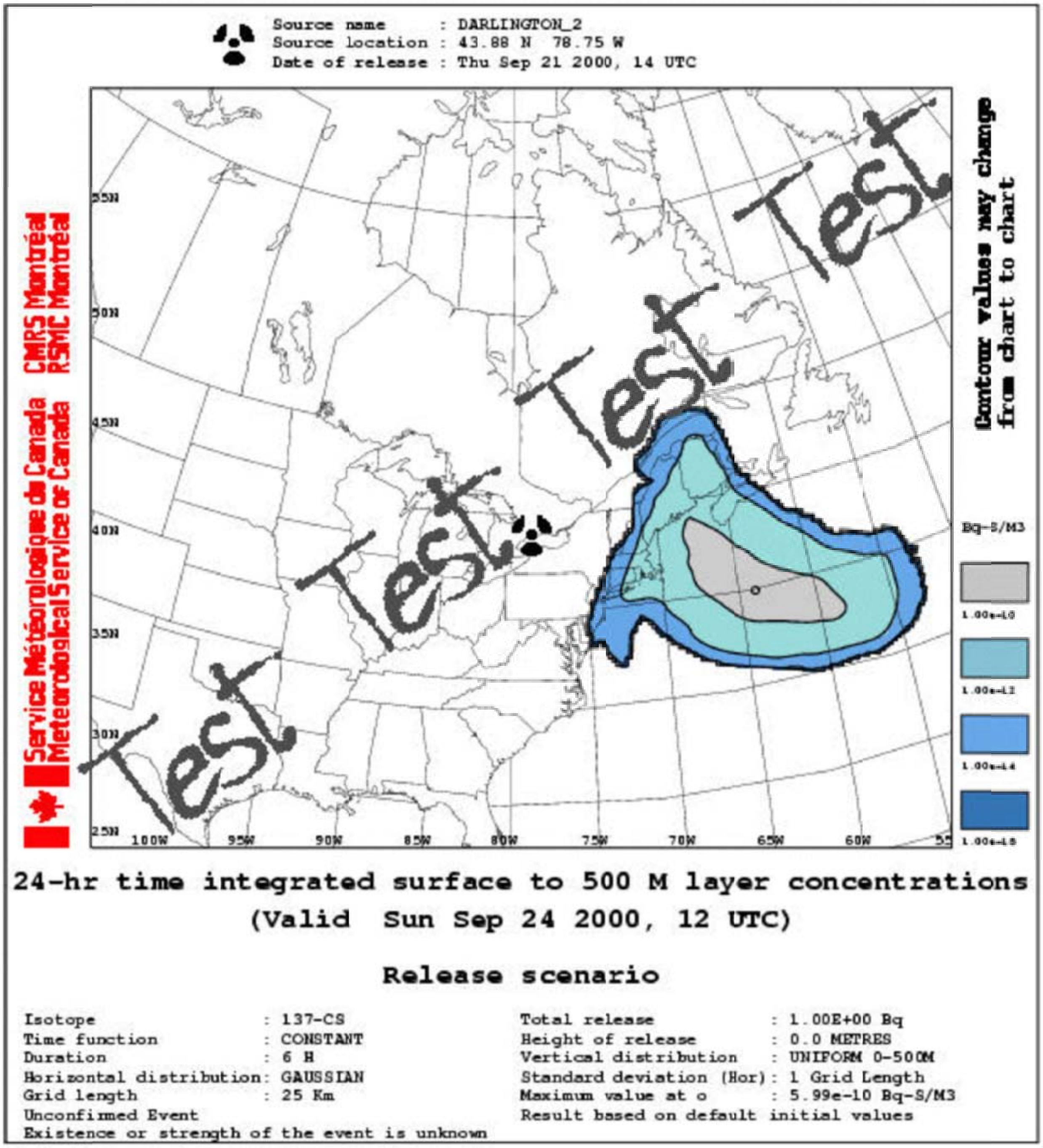


Figure II-3-1a). Integrated radionuclide concentration to 500 m.
(courtesy of Meteorological Service of Canada)

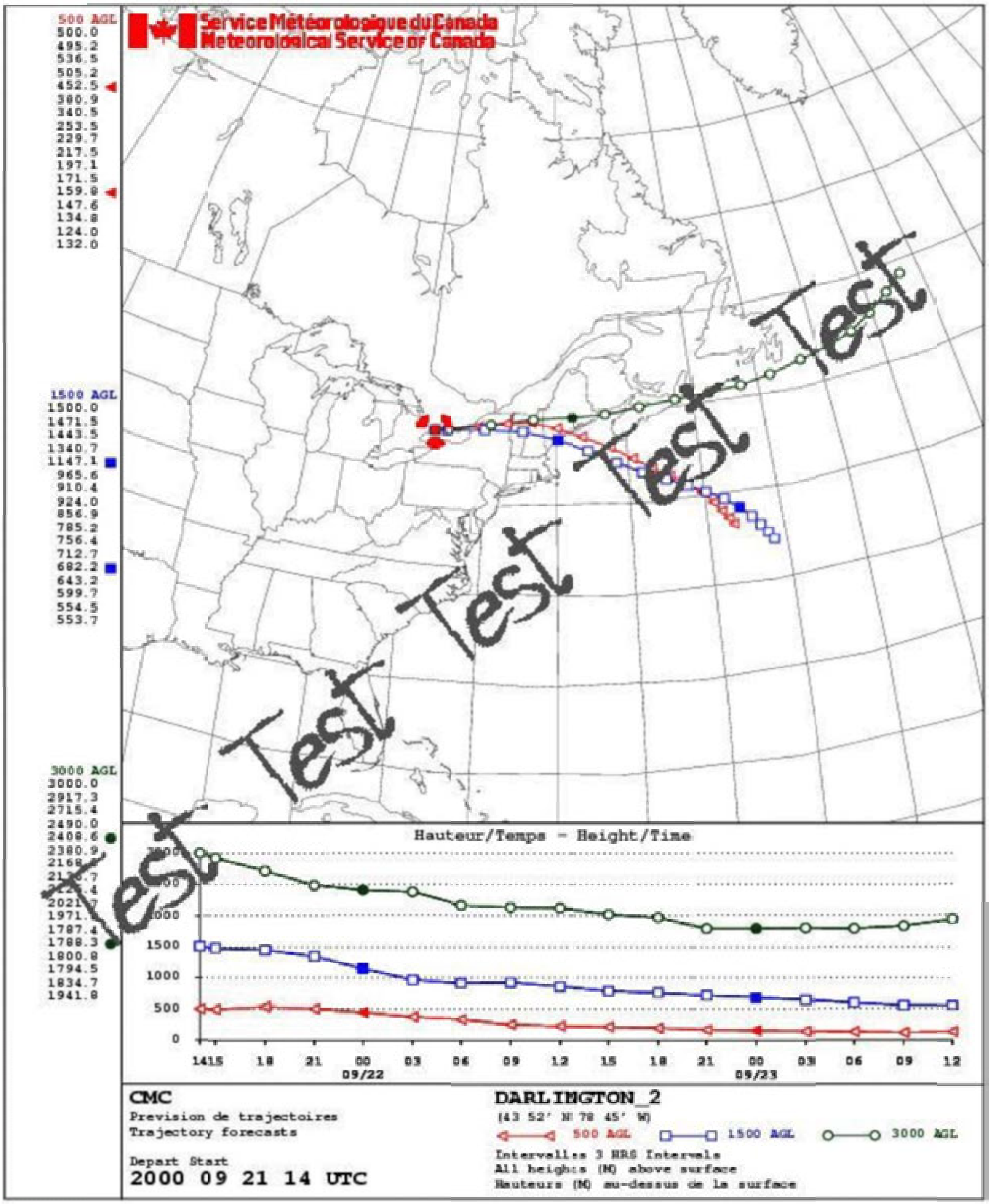
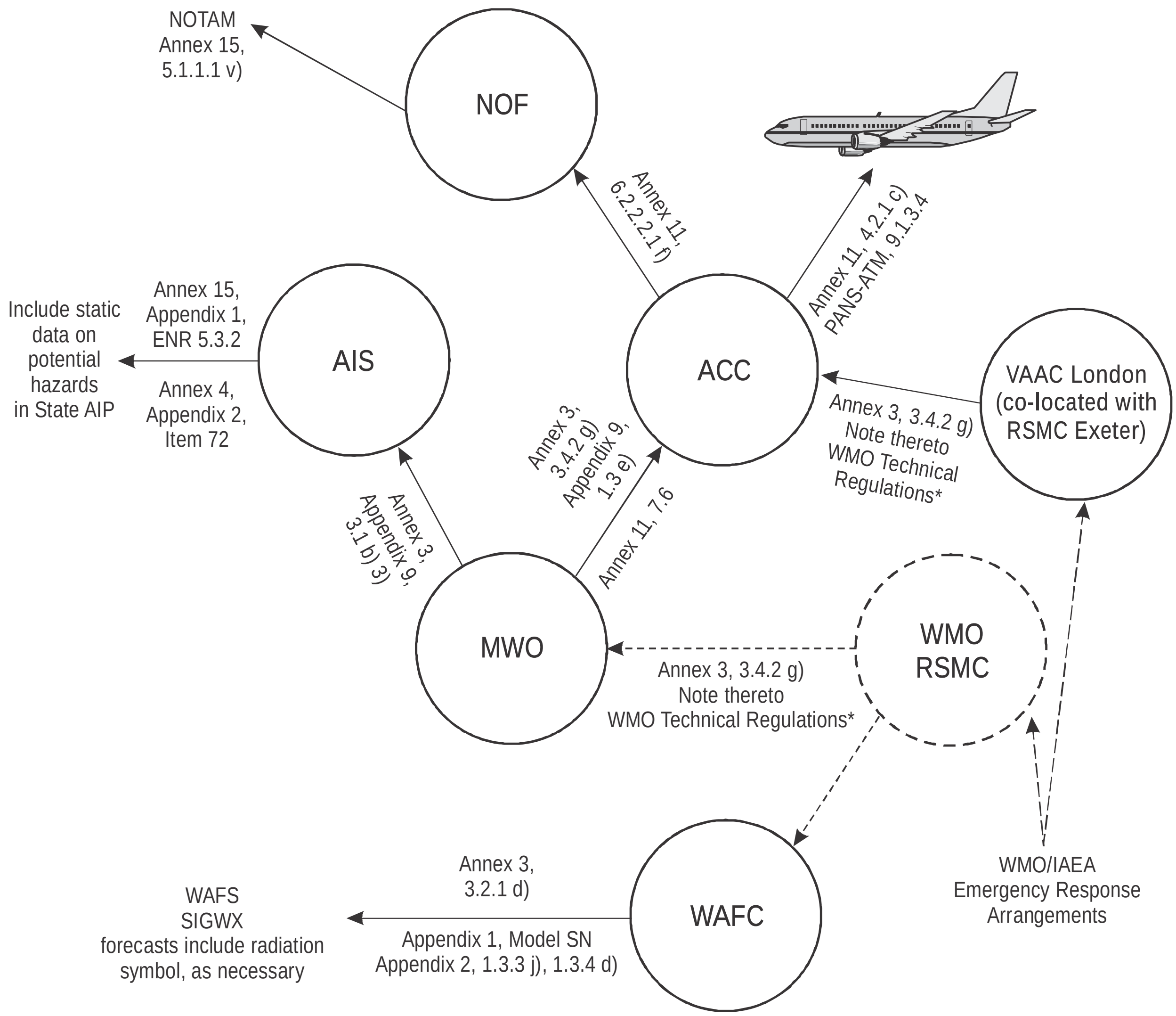


Figure II-3-1b). Forecast trajectories at 500 m, 1 400 m and 3 000 m. (courtesy of Meteorological Service of Canada)



*In practice, this information is disseminated to MWOs through NMCs.

Figure II-3-2. Provision of information to pilots of the release of radioactive materials into the atmosphere. (Dotted lines refer to non-ICAO systems.)

3.1.6 Although the necessary international provisions are in place to ensure that aircraft in flight are notified of the release of radioactive materials into the atmosphere, there is an unavoidable built-in delay in such information reaching the pilot if the notification to adjacent States has to first pass through the States' emergency focal points. Bearing in mind that jet aircraft cruise at more than 800 km/h, any delay in receipt of such information could have serious consequences. Therefore, international arrangements for the direct notification of ACCs by the IAEA of a nuclear accident have been established. These arrangements stipulate that VAAC London will be in charge of the provision of information, received from the IAEA to ACCs concerned, about an release of radioactive material. ACCs will in turn notify aircraft flying in affected areas. The notification by VAAC London will be made by including the information received from the IAEA through RSMC Exeter (co-located with VAAC London) in the *Template for nuclear emergency messages* (Appendix H) developed by ICAO.

3.1.7 Another aspect of the problem concerns the monitoring and decontamination of persons and property exposed to radiation, which would include effected aircraft, passengers and crew. The techniques to accomplish this would also form part of the national emergency procedures and are, therefore, not considered to be the direct concern of ICAO.

General References for Figures and Tables

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Appendix A

RECOMMENDED PROCEDURES FOR THE MITIGATION OF THE EFFECT OF VOLCANIC ASH ON AIRPORTS

taken from
"Mitigation of Volcanic Ash Effects on Aircraft Operating and Support Systems"
by J.R. Labadie
Proceedings of the First International Symposium on Volcanic Ash and Aviation Safety
(Part I, Chapter 5, 5.1.3.3 refers)

1. INTRODUCTION

1.1 Techniques for reducing the effects of volcanic ash can be grouped into three broad categories: (1) keeping the ash out, (2) controlling what gets in, and (3) disposing of the ash. These categories are more illustrative than discrete, and some mitigation techniques will apply in all three cases. Mitigation actions will be required on a continuous basis as long as ash is present. Settled ash is easily re-entrained into the atmosphere, and a 2-mm layer can be as troublesome as a 50-mm layer.

1.2 The most effective technique for reducing ash-related damage or upset to equipment is to avoid using the equipment: shut down, close up, keep inside, or seal the area until the ash can be removed. This tactic is acceptable only for short periods of time because operations must be resumed at some point. In any case, disposal techniques will not eliminate all of the ash. A residue will remain on the ground and will be blown into the air by wind, passing vehicles and aircraft take-offs. Thus, an accelerated and intensive program of inspection, maintenance, cleaning and monitoring will be necessary during and after the main part of ash deposition.

1.3 Cleaning the ambient air — and keeping it clean — is the key to reducing operation and maintenance problems. Blowing ash off of a circuit board is useless if the ash is fine enough to remain suspended for several minutes. The difficulty of attempting to perform maintenance tasks in an already ash-contaminated atmosphere is obvious. "Clean-room" procedures can be used to isolate an area and keep it free of ash, but only under ideal circumstances. Some equipment — aircraft engines, for example — are too large for such treatment. Tents or tarps can be used to reduce gross contamination. However, the fine particles of volcanic ash can penetrate very small openings and seams; it is this property that makes volcanic ash so damaging to critical equipment.

1.4 Some mitigation procedures may cause additional problems or may actually be counterproductive, depending on the circumstances. For example, adding filtration to a computer system will reduce the amount of ash contamination, but it will also decrease the air flow. The resulting rise in temperature may change the operating characteristics of sensitive components or even cause damage. Adding a larger fan would increase the air flow, but not all computers, especially smaller units, can be easily modified. Another example is the use of moisture to control ash. Wetting carpets will increase relative humidity and help to keep the ash down; however, wet or even damp volcanic ash is conductive.

1.5 No single technique will be absolutely effective; a combination of techniques has been found to provide the best results for managing volcanic ash. Constant monitoring and reassessment of ash effects and the mitigation process will be required to achieve the most effective balance between operational requirements and the desired level of damage limitation. The following sections summarize ash mitigation techniques for selected aircraft and support systems.

2. AIRCRAFT SYSTEMS

2.1 The basic mitigation tactic to protect aircraft systems is avoidance of exposure to ash. The airports and airfields surveyed after the Mt. St. Helens eruption simply shut down for the duration of the ash problem or until the ash had been removed. Airlines rerouted traffic away from ash-impacted airports.

2.2 Sealing aircraft seams, ports, vents and other openings with duct tape will keep out the bulk of the ash, especially if the aircraft is under cover. Maintaining positive pressure within aircraft components would help to keep ash out, but it is difficult, if not impossible, to pressurize an aircraft on the ground without damaging ground equipment. Techniques include:

a) blow or vacuum ash before washing, otherwise, ash tends to flow into ports, vents or control surfaces;

b) flush or wash residue, do not scrub or sweep;

c) wash gear, underside, air-conditioning intakes and engines;

d) check pH of aircraft/engine surfaces for acidity; and

e) neutralize acidic residue by adding petroleum-based solvent to the wash water.

2.3 All of the above techniques require large amounts of time, manpower and equipment. All have significant effects on the level and scope of continued operations. These techniques were tried under conditions of greatly reduced operating levels; however, there is some question as to their effectiveness during normal (or near-normal) operations. For example:

a) sealing an aircraft would take 4-5 hours, and removing all seals and tape would take 1-2 hours. It is very hard to seal an aircraft completely because of numerous ports, vents, seams and joints;

b) ash buildup in or around hatch seals could cause pressurization problems; and

c) fuel tank vents must be open during loading, unloading and transfer of fuel. If vents are plugged with ash, or if sealed, the tank could collapse. A 4-5 Psi vacuum is sufficient to cause collapse.

3. RUNWAYS

If aircraft operations are not suspended, runways must be continually cleaned as ash is resuspended by wind, aircraft take-off and ground vehicle movement. There is some disagreement on the proper use of water in cleaning runways. Some sources felt that water turns the ash to sludge (or causes it to harden), whereas others found it impossible to control the ash without wetting it first. Open-graded (popcorn surface) runways are to some extent self-cleaning because the engine blast on take-off will blow ash out of crevices. Basic techniques include:

a) wet ash with water trucks;

b) blade into windrows;

c) pick up with belt or front-end loaders;

d) haul to dump areas;

e) sweep and flush residue;

f) sweep/vacuum ash first, then flush with water (best for ramps, etc.);

g) push ash to runway edge and plow under or cover with binder such as Coherex or liquid lignin;

h) install sprinklers along edges of runway to control resuspension of ash from aircraft engine blast or wing-tip vortices; and

i) keep residue wet on taxiways and ramps.

Note.— The slippery nature of wet ash should be taken into account by pilots manoeuvring aircraft on the ground and during landing and take-off.

4. LANDING AIDS AND AIR TRAFFIC CONTROL

Protection of landing aids and air traffic control systems will require periodic cleaning, maintenance and monitoring. Also, turning off unnecessary equipment will reduce exposure. Exposed light and indicator systems, radar antennas and any equipment that requires cooling air are especially vulnerable to ash contamination and damage. Interruption of commercial power supplies will require backup generators, which are also vulnerable to ash damage. Techniques include:

a) replace antennas that have Teflon insulators. Because ash is hard to remove and will cause shorting, ceramic insulators should be used;

b) seal relay boxes and remove indicator units and light systems to prevent ash entry;

c) increase cleaning and maintenance of systems that cannot be sealed or that require cooling air;

d) vacuum or blow ash out and clean relays with contact cleaner;

e) use high-pressure water wash on exposed antenna rotor bearings and then relubricate;

f) cover exposed joints, seams and bearings;

g) seal buildings, control access, vacuum shoes and clothes; and

h) reduce operating levels: shut down unused equipment, reduce broadband displays to a minimum, and reduce cooling and power consumption.

5. GROUND SUPPORT EQUIPMENT

5.1 The consensus is that ground support equipment is the key to flight operations. If ground support equipment is unserviceable because of ash, aircraft cannot be operated. Unfortunately, there are more problems than solutions in the ash contamination of ground equipment.

5.2 Gas turbines, air compressors and air conditioners operate by ingesting large volumes of air. This equipment has only coarse filtration (or none at all), and extra filtration cannot be added without affecting operation. Using air conditioners to pressurize aircraft compartments would only blow ash into the aircraft and ruin the air conditioners in the process. Techniques include:

a) constant cleaning and maintenance;

b) do not wash equipment, because water turns ash to sludge and washes it into the equipment;

c) vacuum equipment;

d) change oil and filters more often; and

e) change design to include better filtration.

6. COMPUTER SYSTEMS

The most widely advised damage-prevention tactic is to shut down all computer and electronic systems until the ash has been completely removed from the area and from the equipment. Computer heads and disks, and any high-voltage circuits, are especially vulnerable to ash upset and damage. Ash on digital circuits will not cause much of a problem because of the low voltages involved. High-voltage or high-impedance circuits are very vulnerable to leakage caused by semi-conductive ash. Ash that is acidic is conductive as well as corrosive. Continual cleaning and aggressive protection of computer systems should allow for continued operation in all but the heaviest ash fallout. Techniques include:

a) clean and condition surrounding air to keep ash out of equipment;

b) cotton mat filters used in clean rooms were found to be best for filtering particles, but they reduce air flow. A solution is to use larger fans to maintain required air flow. Rack-mounted equipment can be modified to add a larger fan, but smaller instruments or components with a built-in fan would require a design change to increase fan capacity;

c) use fluted filters as a compromise, this increases surface area but reduces air flow by only about 20 per cent;

d) humidifying ambient air (e.g. wetting carpets) will help to control ash re-entrainment;

e) ash on equipment can be blown out with compressed air. If the air is too dry, static discharge could damage sensitive components (e.g. integrated circuits). If the air is too damp, the ash will stick. Relative humidity of 25-30 per cent is best for compressed air;

f) cleaning with a pressurized mixture of water and detergent and using a hot-water rinse is quite effective, however, this process requires at least partial disassembly;

g) ash may have a high static charge and be hard to dislodge, thus requiring brushing to dislodge particles;

h) accelerate filter change, use prefilters;

i) change to absolute filters, these will keep out particles down to 1 µm and smaller;

j) keep computer power on for filtration, but do not operate, especially disk drives;

k) maintain room-within-a-room configuration, restrict access, re-circulate air and accelerate cleaning of the critical area.

7. RADAR AND OPTICAL SYSTEMS

Most radar equipment in the heaviest ash-fall areas has to be shut down for the duration of severe ash contamination. Thus, few problems are likely aside from clean-up and control of residual ash. The simplest mitigation tactic is to cease operations. Clean-up techniques include:

a) repair and clean high-voltage circuits;

b) wash antenna rotor bearings, re-lubricate, and cover exposed bearings;

c) ash on optical components should be blown away or washed with copious amounts of water. Do not wipe, brush or nib, as this will abrade the optics;

d) take care not to wash ash into optical-instrument mounts on aircraft (e.g. sextant);

e) turn off non-essential radar equipment to reduce cooling load and power requirements;

f) transfer radar coverage to other facilities, combine sectors;

g) remove and replace camera bearings and clean gear drives; and

h) protect video tape from ash because it will cause “drop-outs” and scratches.

8. PLANNING FOR ASH MITIGATION

Techniques for reducing the impacts of volcanic ash are basically “low tech” and depend more on procedural approaches than on technical fixes. Also, they are quite labour and resource intensive. Normal stock of daily-use items such as filters, lubricants, spare parts, cleaning supplies, etc., may be expended much faster than they can be replaced through the normal reordering process. Prior planning is necessary to reduce the severity of ash effects. Planning actions include:

a) conduct a vulnerability analysis of equipment and facilities to determine which would be most impacted by ash, which are adequately protected, and which need long-term or expedient modification;

b) develop a priority list of facilities that must be kept in operation versus those that can be closed or shut down for the duration of ash fall;

c) ensure hazard-alert and information channels are properly maintained with the vulcanological/ geological agencies, and the meteorological service, local news media, and State and local governments;

d) establish plans and procedures for alerting and notification, reduced operations, accelerated maintenance, protection of critical facilities, and clean-up and disposal;

e) alert air traffic controllers and airport operations personnel to notify aircraft as soon as volcano “watch” and “warning” notices are received. Normal air traffic and weather radars cannot detect volcanic ash; therefore, relatively large “keep-out zones” should be established at night or during bad weather once the warning notice is issued. Personnel should also be alerted to the existence of fall-out beneath the clouds and lightning conditions, etc.;

f) stockpile spare parts for critical equipment, filters, sealing, cleaning and disposal equipment;

g) plan for extended clean-up and maintenance activities including 24-hour operations, augmentation of the work force, and training of clean-up crews; and

h) ensure that sufficient water and back-up power is available to support clean-up operations, should normal supply sources fail.

Ash clean-up operations may continue for weeks or months if multiple eruptions occur. Effective mitigation of volcanic ash effects depends on prior planning and preparation, mobilization of resources, and persistence.

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Appendix B

EMERGENCY PLAN FOR VOLCANIC ERUPTIONS IN ALASKAN AIRSPACE

U.S. Department of Transportation, Federal Aviation Administration
(Part I, Chapter 5, 5.2.4.2 refers)

1. PURPOSE. This Order revises procedures established by ZAN Order 1900.2D, Emergency Plan for Volcanic Eruptions in Alaskan Airspace. The Order establishes the notification procedures in the event of increased volcanic activity.

2. DISTRIBUTION. This Order is distributed to all managers, operations supervisors, NATCA, NAGE, CWSU, the air traffic managers' library and the watch desk library.

3. CANCELLATION. This Order cancels ZAN Order 1900.2D, effective June 9, 1993.

4. EFFECTIVE DATE. September 15, 2002.

5. BACKGROUND. Volcanic eruptions and subsequent ash drift/fallout have previously caused delays and damage to aircraft and equipment. There is a continuing possibility of further eruptions, particularly in the Cook Inlet and Aleutian Chain areas of Alaska. Notifications could be received by several sources which include the Alaska Volcano Observatory (AVO), Regional Operations Center (ROC), Regional Air Operations Center (RAOC), pilot report or another FAA facility or the general public.

6. RESPONSIBILITIES. Upon receiving notification of an eruption or possible eruption:

a) the Supervisory Traffic Management Controller in Charge (STMCIC) shall:

1) verify the occurrence of volcanic activity with AVO. If after normal duty hours, call the AVO Scientist-in-Charge. Contact number can be found in the Alaska Interagency Operating Plan for Volcanic Ash Episodes;

Note.— If AVO notifies ZAN of increased seismic activity which is predicted to result in a volcanic eruption, issue an FDC Advisory NOTAM (Appendix A[1]) and notify personnel and facilities listed in 6 b) 1) of this order. Once notified, a traffic management coordinator will respond to provide assistance as required.

2) notify the traffic management unit (TMU)/weather coordinator (WC).

1. Appendices are not included as the contain information of only local interest.

b) if a volcanic eruption is verified, the STMCIC shall take the following action:

1) notifiy the following:

i) the Center Weather Service Unit (CWSU) Meteorologist who will issue an urgent pilot report (UUA) (see Appendix B). If an eruption occurs when the CWSU meteorologist is not on duty, the STMCIC/WC shall issue the UUA, contact the Alaska Aviation Weather Unit (AAWU) and; if required, contact a CWSU meteorologist to report immediately to Anchorage ARTCC.

ii) operations supervisor in charge (OSIC)/controller-in-charge (CIC);

iii) regional operations center (ROC);

iv) Anchorage ARTCC air traffic manager;

v) traffic management officer;

vi) watch supervisor of the FSS nearest to volcanic activity;

vii) Anchorage approach watch supervisor;

viii) maintenance control center (MCC);

ix) air traffic control system command center (ATCSCC);

x) Elmendorf AFB operations; and

2) as soon as possible, issue an FDC (TFR) flight restriction NOTAM (see Appendix A);

3) designate a weather coordinator, if necessary;

4) when information is known about the extent and drift of the ash cloud, issue an FDC/international volcano advisory NOTAM (see Appendix A);

5) ensure that the following is sent via multi-fax:

i) time of volcano eruptions and color codes when assigned. (See Appendix C for color code classifications); and

ii) volcano meteorological impact statements (MIS) prepared by the ZAN CWSU;

6) when requested by AVO, assist them in relaying and/or obtaining information from the Kamchatkan Volcanic Eruption Response Team (KVERT) in Petropavlovsk-Kamchatsky through coordination with Petropavlovsk-Kamchatsky ACC;

c) OSIC/CIC shall:

1) ensure that PIREP's are solicited by controllers and recorded on the volcanic activity report form (VAR);

2) disseminate the NOTAM, PIREP, current conditions and TFR’s to controllers on duty;

d) traffic management shall:

1) review the areas affected by the volcanic activity to determine if any traffic management initiatives (TMIs) are required;

2) prior to initiating traffic management initiatives, advise the STMCIC and OSIC/CIC;

3) coordinate TMIs with affected facilities and ATCSCC;

4) monitor the new routings and affected areas;

e) controllers shall:

1) ensure that all aircraft in the affected area are aware of the most current information available concerning ash cloud position/altitude;

2) with pilot’s concurrence, suggest headings or reroutes around known ash or possible ash areas/ concentrations;

3) assist VFR aircraft to the extent possible in avoiding ash cloud areas/concentrations;

4) solicit PIREP’s and record on the volcanic activity report form. Forward these reports to the operations supervisor; and

5) when requested, broadcast information received relating to volcanic ash drift.

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Appendix C

WEATHER DEVIATION PROCEDURES FOR OCEANIC CONTROLLED AIRSPACE

Airservices Australia

(Part I, Chapter 5, 5.2.4.3 refers)

1. GENERAL

1.1 Airservices Australia, in conjunction with other regional ATS providers and airspace users, have developed contingency procedures for weather deviations applicable in oceanic airspace, particularly outside the coverage of direct controller-pilot VHF communication.

1.2 This SUP describes weather deviation procedures applicable in those portions of the Australian FIRs designated as Oceanic Control Areas (OCA). These procedures are intended to enhance ICAO *Regional Supplementary Procedures* (Doc 7030). All possible circumstances cannot be covered. The pilot's judgement shall ultimately determine the sequence of actions taken and ATC shall render all possible assistance.

1.3 If an aircraft is required to deviate from track to avoid weather and prior clearance cannot be obtained, an ATC clearance must be obtained at the earliest possible time. In the meantime, the aircraft must broadcast its position (including the ATS route designator or the track code, as appropriate) and intentions on frequency 121.5 MHz, at suitable intervals, until ATC clearance is received.

1.4 The pilot must advise ATC when weather deviation is no longer required, or when a weather deviation has been completed and the aircraft has returned to its cleared track.

2. OBTAINING ATC PRIORITY WHEN WEATHER DEVIATION IS REQUIRED

2.1 When the pilot initiates communications with ATC, rapid response may be obtained by stating "WEATHER DEVIATION IS REQUIRED" to indicate that priority is desired on the frequency and for ATC response.

2.2 The pilot also retains the option of initiating the communication using the urgency call "PAN-PAN" three times to alert all listening parties of a special handling condition which will receive ATC priority for issuance of a clearance or assistance.

3. ACTIONS TO BE TAKEN — PILOT-CONTROLLER

3.1 Communications established

3.1.1 When two-way pilot-controller communications are in effect, and a pilot identifies the need to deviate from track to avoid weather, the pilot must notify ATC and request clearance to deviate from track, advising, where possible, the extent of the deviation expected.

3.1.2 ATC will then take one of the following actions:

a) if there is no conflicting traffic in the lateral dimension, ATC shall issue clearance to deviate from track;

b) if there is conflicting traffic in the lateral dimension, ATC shall separate aircraft by establishing vertical separation (2 000 ft above FL290 or 1 000 ft below FL290) and issue a clearance to deviate from track; and

c) if there is conflicting traffic in the lateral dimension and ATC is unable to establish vertical separation, ATC shall advise the pilot and provide information on all other aircraft with which the aircraft could potentially conflict.

3.1.3 The pilot must comply with the ATC clearance issued for the deviation, or, if ATC is unable to issue a revised clearance, and after evaluating the circumstances of the situation, the pilot must execute the procedures detailed in 3.2 below. The pilot must immediately inform ATC of intentions and ATC will issue Essential Traffic Information to all affected aircraft.

3.1.4 The pilot must at regular intervals, update ATC of the extent and progress of the deviation to ensure separation applied is not infringed, or to enable ATC to update essential traffic information.

3.2 Communication not established or revised ATC clearance not available

3.2.1 If contact cannot be established, or a revised ATC clearance is not available and deviation from track is required to avoid weather, the pilot must take the following actions:

a) deviate away from an organised track or route system, if possible;

b) broadcast aircraft position and intentions on frequency 121.5 MHz at suitable intervals stating:

   1) flight identification (operator call sign);

   2) flight level;

   3) track code or ATS route designator; and

   4) extent of deviation expected;

c) watch for conflicting traffic both visually and by reference to TCAS (if equipped);

d) turn on aircraft exterior lights;

e) when the aircraft is approximately 10 NM off-track, start a descent to and maintain:

1) a flight level 1 000 ft below that assigned when operating above FL290; or

2) a flight level or altitude 500 ft below that assigned when operating at, or below, FL290; and

f) when returning to track, be established at the assigned flight level or altitude, when the aircraft is within approximately 10 NM of track;

3.2.2 If contact was not established prior to deviating, continue to attempt to contact ATC to obtain a clearance. If contact was established, continue to keep ATC advised of intentions and obtain essential traffic information.

4. CANCELLATION

This SUP remains current until its provisions have been incorporated in the appropriate documents.

5. DISTRIBUTION

All AIP holders	last issue H12/96
All MATS holders	last issue H11/96

Appendix D

VOLCANIC ERUPTIONS PRODUCING ASH PLUME OF CONCERN TO CIVIL AVIATION, 1980–2004

(Part I, Chapter 6, 6.8.1 refers)

Year	*Date*	*Volcano*	*Location*
1980	January	Langila	Papua New Guinea
		Kliuchevskoi	Kamchatka (Russian Federation)
	30 January	Nyamuragira	Dem. Rep. of the Congo
	2 February	Bulusan	Philippines
	15 April	Lopevi	Vanuatu
	18 April	Bezymianny	Kamchatka (Russian Federation)
	18, 26 May	St. Helens*	United States
	12 June	St. Helens*	United States
	22 July	St. Helens*	United States
	23 July	Ambrym	Vanuatu
	31 July	Gorely	Kamchatka (Russian Federation)
	17 August	Hekla	Iceland
	1 September	Etna	Italy
	6 October	Ulawun	New Britain
	16 October	St. Helens	United States
	11 November	Pavlof	United States
1981	9 April	Bulusan	Philippines
	27 April	Alaid*	Kurile Is. (Russian Federation)
	30 April	Alaid	Kurile Is. (Russian Federation)
	8 May	Ambrym*	Vanuatu
	15 May	Pagan*	Mariana Is. (United States)
	12 June	Bezymianny	Kamchatka (Russian Federation)
	25 September	Pavlof	United States
	25 December	Nyamuragira	Dem. Rep. of the Congo
1982	15 January	Gareloi	Aleutian Is. (United States)
	13 February	Langila	Papua New Guinea
	19 March	St. Helens	United States
	27 March	Manam	Papua New Guinea
	29 March	El Chichon*	Mexico
	5 April	Galunggung	Indonesia
	17 May	Galunggung	Indonesia
	24 June	Galunggung*	Indonesia
	13 July	Galunggung*	Indonesia
	18 July	Raung	Indonesia
	27 August	Soputan*	Indonesia
1983	18 April	Langila	Papua New Guinea
	17 June	Langila	Papua New Guinea
	22 May	Bezymianny	Kamchatka (Russian Federation)
	2 June	Veniaminof	United States
	23 July	Colo*	Indonesia
	9 August	Gamalama	Indonesia
	3 October	Miyake-jima*	Japan
	14 November	Pavlof	United States
1984	7 January	Langila	Papua New Guinea
	February	Manam	Papua New Guinea
	25 May	Soputan*	Indonesia
	15 June	Merapi	Indonesia
	31 August	Soputan	Indonesia
	5 September	Krafla*	Iceland (VEI<3)
	5 September	Karangetang	Indonesia
	9 September	Mayon	Philippines
	13 October	Bezymianny	Kamchatka (Russian Federation)
	13 November	Kliuchevskoi	Kamchatka (Russian Federation)
		Augustine*	United States
1985	29 January	Langila	Papua New Guinea
	29 June	Bezymianny	Kamchatka (Russian Federation)
	30 June	Sangeang Api	Indonesia
	13 November	Ruiz	Colombia
	20 November	Ulawun	Papua New Guinea
	2 December	Kliuchevskoi	Kamchatka (Russian Federation)
1986	27 March	Augustine	United States
	18 April	Pavlof	United States
	4 August	Sheveluch	Kamchatka (Russian Federation)
	16 September	Lascar	Chile
	20 November	Chikurachki	Kurile Is. (Russian Federation)
	21 November	Oshima	Japan
	16 December	Bezymianny	Kamchatka (Russian Federation)
1987	21 January	Pacaya	Guatemala
	6 February	Karangetang	Indonesia
	19 February	Kliuchevskoi	Kamchatka (Russian Federation)
	10 June	Pacaya	Guatemala
	19 July	Sheveluch	Kamchatka (Russian Federation)
	28 August	Cleveland	Aleutian Is. (United States)
	16 November	Oshima	Japan
1988	13 January	Ranakah, Gunung	Indonesia
	12 February	Ambrym	Vanuatu

Year	*Date*	*Volcano*	*Location*
	14 March	White Island	New Zealand
	29 July	Makian	Indonesia
	27 December	Lonquimay	Chile
1989	7 March	Pacaya	Guatemala
	24 April	Nyamuragira	Dem. Rep. of the Congo
	19 July	Santa Maria	Guatemala
	15 December	Redoubt*	United States
1990	2 January	Redoubt	United States
	8 January	Redoubt*	United States
	1 February	Kliuchevskoi	Kamchatka (Russian Federation)
	20 February	Lascar	Chile
	21 and 28 February	Redoubt*	United States
	10 March	Bezymianny	Kamchatka (Russian Federation)
	11 March	Sakurajima*	Japan
	25 April	Gamalama	Indonesia
	5 June	Sabancaya	Peru
	13 July	Santa Maria	Guatemala
	4 August	Sheveluch	Kamchatka (Russian Federation)
1991	13 January	Avachinsky	Kamchatka (Russian Federation)
	17 January	Hekla	Iceland
	8 April	Sheveluch	Kamchatka (Russian Federation)
	16 April	Colima*	Mexico
	15 June	Pinatubo	Philippines
	27 July	Pacaya	Guatemala
	8 August	Hudson*	Chile
	12 August	Hudson	Chile
	16 September	White Island	New Zealand
	15 October	Nyamuragira	Dem. Rep. of the Congo
	24 October	Lokon*	Indonesia (VAI 2)
	29 November	Westdahl	Aleutian Is. (United States)
1992	9 April	Cerro Negro*	Nicaragua
	6 June	Sakurajima*	Japan
	27 June	Spurr	United States
	6 July	Bogoslof	Aleutian Is. (United States)
	18 August	Spurr*	United States
	31 August	Manam	Papua New Guinea
	17 September	Spurr	United States
	19 April	Lascar*	Chile
1993	22 April	Sheveluch*	Kamchatka (Russian Federation)
	7 June	Galeras*	Colombia
	14 June	Myanan	Papua New Guinea
	21 October	Bezymianny	Kamchatka (Russian Federation)
1994	4 January	Bezymianny*	Kamchatka (Russian Federation)
	5 January	Manam	Papua New Guinea
	January	Langila	Papua New Guinea
	10 May	Cleveland*	Aleutian Is. (United States)
	17 May	Llaima*	Chile
	3 June (and July)	Rinjani*	Indonesia
	29 June	Veniaminof	United States
	5-10 July	Nyamuragira	Dem. Rep. of the Congo
	7 July	Sheveluch	Kamchatka (Russian Federation)
	26 July	Lascar*	Chile
	5 August	Gamalama	Indonesia
	18 August	Kanaga*	Aleutian Is. (United States)
	22 August	Poas*	Costa Rica
	12 September (and 1 October)	Kliuchevskoi	Kamchatka (Russian Federation)
	19 September	Rabaul*	Papua New Guinea
	26 December	Popocatepetl*	Mexico
	1 December	Dukono	Indonesia
1995	7 January	Dukono*	Indonesia
	13 February	Popocatepetl	Mexico
	14 March	Barren Islands*	Andaman Is. (India)
	10 May	Sabancaya*	Peru
	1 June	Pacaya*	Guatemala
	15 August	Raung*	Indonesia
	12 September	Rinjani*	Indonesia
	25 September	Dukono*	Indonesia
	12 October	Ruapehu*	New Zealand
	7 November	Soputan*	Indonesia
	19 November	Cerro Negro*	Nicaragua
	23 December	Shishaldin*	Aleutian Is. (United States)
1996	3 January	Karymsky	Kamchatka (Russian Federation)
	10 March	Popocatepetl*	Mexico
	5 May	Semeru*	Indonesia
	2 June	Suwanose-Jima*	Japan
	10 June	Soputan*	Indonesia
	17 June	Ruapehu	New Zealand
	27 June	Ruang*	Indonesia
	29 June	Atka*	Aleutian Is. (United States)
	July	Karymsky	Kamchatka (Russian Federation)
	10 August	Can laon	Philippines
	13 September	Merapi*	Indonesia
	17 September	Soufriere Hills*	Montserrat (United Kingdom)
	27 September	Gareloi	United States
	29 September	Krakatau*	Indonesia
	2 October	Vatnajökull*	Iceland
	October	Rabaul*	Papua New Guinea
	28 October and 25 December	Popocatepetl*	Mexico
	3 December	Alaid	Kurile Is. (Russian Federation)
	11 December	Pavlof*	United States
1997	1-20 January	Kliuchevskoi	Kamchatka (Russian Federation)
	5 January	Heard Is.*	Antarctica
	16 January	Kavachi*	Solomon Islands
	5 February, 30 June, 12 August	Popocatepetl*	Mexico

*IAVW was activated.

Year	*Date*	*Volcano*	*Location*
	11-12 February, 22 March and 14 September	Langila*	Papua New Guinea
	12 April	Rabaul*	Papua New Guinea
	14 April	Karymsky*	Kamchatka (Russian Federation)
	9 May and 5-7 December	Bezymianny*	Kamchatka (Russian Federation
	13 May and 26 December	Soufriere Hills*	Montserrat (United Kingdom)
	19-20 May	San Cristobal	Nicaragua
	22 May	Langila*	Papua New Guinea
	24-27 May	Popocatepetl*	Mexico
	21 March to 30 May, August, October and November	Semeru*	Indonesia
	1 June	Raung*	Indonesia
	7 June	Barren Islands	Indian Ocean
	31 July	Sheveluch	Kamchatka (Russian Federation)
	11 August and 14 November	Pacaya	Guatemala
1998	26 January, 21 April and 24 November	Karymsky	Kamchatka (Russian Federation)
	3 February, May and 20 August	Rabaul	Papua New Guinea
	15 February	Sakurajima	Japan
	7-22 April	Langila	Papua New Guinea
	27 April	Peuet Sague*	Indonesia
	20 May	Pacaya*	Guatemala
	30 May	Sheveluch	Kamchatka (Russian Federation)
	30 June	Korovin	Kamchatka (Russian Federation)
	11 July	Merapi*	Indonesia
	2 September	Kliuchevskoi*	Kamchatka (Russian Federation)
	22 September, 17 October and 26 November	Popocatepetl*	Mexico
	3 November	Guagua Pichincha*	Ecuador
	18 December	Grimsvotn*	Iceland
1999	27-29 January and 8 March	Popocatepetl*	Mexico
	10 February	Karymsky*	Kamchatka (Russian Federation)
	25 February	Bezymianny*	Kamchatka (Russian Federation)
	19 April and 24 May	Shishaldin*	Aleutian Is. (United States)
	19 April, 13 June, 9 July, 16 July, 5 August, and 23 August	Semeru*	Indonesia
	10 May and 17 July	Colima*	Mexico
	21 May	Pacaya	Guatemala
	11 June	Guagua Pichincha	Ecuador

Year	*Date*	*Volcano*	*Location*
	18-26 June, 12-18 July and 29 November	Kliuchevskoi*	Kamchatka (Russian Federation)
	22 June	Mayon*	Philippines
	21-29 July	Fuego*	Guatemala
	5 August	Cerro Negro*	Nicaragua
	August and October	Poas	Costa Rica
	4 September	Etna*	Italy
	21-30 September	Langila	Papua New Guinea
	28 September	Rabaul	Papua New Guinea
	1, 31 October	Tungurahua	Ecuador
	3 October	Popocatepetl*	Mexico
	5 October, 18 November and 11 December	Guagua Pichincha*	Ecuador
	12 October, 1st two weeks in November	Colima	Mexico
	27 November and 2 December	Sheveluch	Kamchatka (Russian Federation)
	10 December	Ambrym	Vanuatu
	29 December	Telica	Nicaragua
2000	12, 15, 17, 30 January and 3, 8, 12, 18 February	Tungurahua*	Ecuador
	16 January	Pacaya*	Guatemala
	16 January and 28 February	Guagua Pichincha*	Ecuador
	19, 24-25 January	Fuego*	Guatemala
	23 January	Santa Maria*	Guatemala
	Late January, early March, early May and mid June	Tungurahua*	Ecuador
	3 February, 28 July and 22 September	Kliuchevskoi*	Russian Federation
	3, 18, 19 February, 22 March, and 24 April	Lopevi*	Vanuatu
	7, 15 February, 16, 26 April, 15 May, 18 August, 19, 22, 23 September and 14, 29 October	Etna*	Italy
	7 February, 9,17 March, 30 June and 1 July 23, 28, 29 August	Sheveluch*	Kamchatka (Russian Federation)
	20, 21 February	Karymsky*	Kamchatka (Russian Federation)
	21 February	San Cristobal*	Nicaragua
	24, 29 February and 1 Marchs	Mayon	Philippines
	26, 29 February and 8March	Hekla*	Iceland
	29 February	Pacaya*	Guatemala
	11, 12 March 13, 14, 16 April and 5 June	Marapi	Indonesia

*IAVW was activated.

Year	*Date*	*Volcano*	*Location*
	14, 18 March and 2, 3 November	Bezymianny*	Kamchatka (Russian Federation)
	20 March	Soufriere Hills*	Montserrat (United Kingdom)
	31 March and 1April	Usu*	Japan
	1, 15, 26 April, 5,17 May, and 1, 5, 14, 24 June	Etna*	Italy
	5, 9 April	Langila	Papua New Guinea
	22, 23 April, 2 May 12, 22 July	White Island*	New Zealand
	3 June	Manam	Papua New Guinea
	2, 9, 12 June and 23-24 July	Guagua Pichincha*	Ecuador
	9 eruptions between 13 June and 20 August, 15 August- 4 September 12-25 September 10-16 October 31 October- 16 November 26 December	Semeru*	Indonesia
	1, 25 July	Copahue*	Argentina
	3, 14 July, 4, 10, 23 August and 24 December	Popocatepetl*	Mexico
	8 July and 10, 18, 28, 29 August	Miyake-Jima*	Japan
	9 July	Raung*	Indonesia
	20-21 July	Lascar*	Chile
	25, 26 July	Soputan*	Indonesia
	19, 21, 23 August	Copahue	Chile
	29 August and 8 September	Rabaul	Papua New Guinea
	29 September	Ulawun*	Papua New Guinea
	7 October	Sakura-jima*	Japan
	29 October, 2 November and 7 December	Fuego	Guatemala
	15-25 December	Karangetang	Indonesia
2001	2 January	Karangetang	Indonesia
	27 January and 10 February	Merapi*	Indonesia
	1, 13 February	Karymsky*	Kamchatka (Russian Federation)
	15 eruptions between 1 February to 17 August	Popocatepetl*	Mexico
	19-21 February and 11, 19 March	Cleveland*	United States
	7 March, 19 July 30 September and 1 October	Sheveluch*	Kamchatka (Russian Federation)
	13, 15, 16, 22, 23, 29 March, 2, 25 April, 15, 17, 19, 26, 31 May, 5, 17, 22, 28 June, 5, 12, 20, 25 July and 5, 6, 13, 14, 15 August (30 eruptions between August-December)	Tungurahua*	Ecuador
	18, 31 March and 25 May	Guagua Pichincha	Ecuador
	19 March, 27 May, 26, 27 September and 16 October	Miyake-Jima*	Japan
	26 March 20 May and 18 August	Lokong-Empung	Indonesia
	31 March to 3 April	Usu	Japan
	30 April	Ulawun*	Papua New Guinea
	11 May and 26 July	Suwanose-Jima	Japan
	8 June	Lopevi*	Vanuatu
	1, 2, 6, 14, 18, 19 June and 28 August	Rabaul	Papua New Guinea
	11, 22, 24, 29 June 4, 13, 21, 23, 18 July and 1 August	Etna*	Italy
	18 June and 29 August	Suwanose-Jima	Japan
	21 June	San Cristobal	Nicaragua
	24 June	Mayon	Philippines
	8, 9 July	Semeru*	Indonesia
	15 July	Ijen	Indonesia
	22, 27 July	Etna*	Italy
	31 eruptions between 26 August to 29 December and 30 October	Soufriere Hills*	Montserrat (United Kingdom)
	7 August and 16 December	Bezymianny*	Kamchatka (Russian Federation)
	25 October 10, 21 November and 11, 17, 18, 22 December	Popocatepetl*	Mexico
2002	7, 11, 13, 23 January, 23 February, 21 May, 17, 27, 29 June and 1, 2 July	Popocatepetl*	Mexico
	8 January and 1 February	Fuego*	Guatemala
	Mid-January	Nyiragongo*	Central Africa

*IAVW was activated.

Year	*Date*	*Volcano*	*Location*
	End of January to first half of February, 21 February, 30, 31 March, 10, 15, 20 April, 5, 8, 10, 12, 16, 17, 21 May, 1, 2, 7 June, 6, 8 10 July, 6, 7 August and 8, 9 September	Sheveluch*	Kamchatka (Russian Federation)
	10 January and 11 March	Santa Maria*	Guatemala
	13 January and 15, 17, 20, 22, 27 March	Manam*	Indonesia
	January, 14, 24 February, Last week-March, 22, 23 April, 13, 28-30 May, First weeks of July and 13-21 September	Tungurahua*	Ecuador
	9 February	Lokong-Empung	Indonesia
	8, 25 March	Colima*	Mexico
	15 April, 10 May and 9 July	Karymsky*	Kamchatka (Russian Federation)
	30 May and 5 July	Pacaya*	Guatemala
	2 June and 9 July	Raung*	Indonesia
	3, 26 June, 5-7 July, and 26 October to 1 November	Etna*	Italy
	11 July	Langila*	Papua New Guinea
	25, 26 July	Nyamuragira	Central Africa
	3, 5, 14 August and 7 September	Pago	Papua New Guinea
	22, 27, 28 August, 12, 19, 28 September and 2, 16 October	Ulawun*	Papua New Guinea
	1 September	Semeru*	Indonesia
	25 September	Ruang*	Indonesia
	20 October, 30 November and 3 December	Rabaul*	Papua New Guinea
	27 October	Lascar	Chile
	31 October	Manam*	Papua New Guinea
	3-7 November	Reventador	Ecuador
	3 November, 7 December	Guagua Pichincha	Ecuador
	14, 15, 17, 20, 25, 26 November	Papandayan*	Indonesia
2003	18 January	Langila	Papua New Guinea
	20, 26 January, 5-24 February, 7-12 May, and 29 August to 11 September	Rabaul	Papua New Guinea
	February, 8 June and 8 December	Dukono*	Indonesia
	16 February, 23 July, 14 August and 21, 24 October	Santa Maria*	Guatemala
	9 March, 7, 16 April, 6, 27 June, 27 August and 28 December	Tungurahua*	Ecuador
	20, 25 March, 22 April and 1 May	Soufriere Hills*	Montserrat (United Kingdom)
	30 March	Pacaya*	Guatemala
	April, 25 September and 9 November	Etna*	Italy
	11 April to 22 July (several eruptions)	Ulawun*	Papua New Guinea
	18 April, 5 to 29 May (several eruptions) and 6, 9 June	Chikurachki*	Kuril Islands (Russian Federation)
	21 April, 10 to 16 May, 16 October, 28 November to 5 December and 16 December	Karymsky*	Kamchatka (Russian Federation)
	28 April, 29 June, 9 July and 28 September	Fuego*	Guatemala
	6, 9, 14, 15 May	Nyiragongo*	Central Africa
	10, 11, 21 May and 14, 16 June	Anatahan*	Mariana Islands (United States)
	8, 14 June	Lopevi*	Vanuatu
	26 June and 26 July	Bezymianny*	Kamchatka (Russian Federation)
	28 June and 4, 6, 15, 16 July	Sheveluch*	Kamchatka (Russian Federation)
	12, 13 July	Soufriere Hills*	Montserrat (United Kingdom)
	17 July and 2 August	Popocatepetl*	Mexico
	18 July	Karangetang*	Indonesia
	29 July	Leroboleng*	Indonesia
	6 September, 16, 18 October, 18 November and 1, 2 December	Colima*	Mexico
	8 September and 24 October	Kliuchevskoy*	Kamchatka (Russian Federation)
	9 September	Semeru*	Indonesia
	31 October and 17 November	Santa Maria	Guatemala
	7, 8 November and 15, 21, 27, 28 December	Suwanose-Jima*	Japan
	7, 11 November and 10 December	Stromboli	Italy
	3 December	Sakurajima	Japan
2004	January to mid April	Karymsky*	Kamchatka (Russian Federation)
	1 January to 9 April and 10 May	Sheveluch*	Kamchatka (Russian Federation)
	2, 4, 21, 22 January	Suwanose-Jima*	Japan

*IAVW was activated.

Year	*Date*	*Volcano*	*Location*
	1 to 17 February	Rabaul	Papua New Guinea
	10 February	Stromboli*	Italy
	12 to 14 February	Etna*	Italy
	19 February	Veniaminof*	Alaska
	Mid March to April	Kliuchevskoy*	Kamchatka (Russian Federation)
	3, 15 March	Soufriere Hills*	Montserrat (United Kingdom)
	3 April	Ambrym	Vanuatu
	12, 13, 14 April	Ulawun*	Papua New Guinea
	20 April and 23 May	Semeru*	Indonesia

Year	*Date*	*Volcano*	*Location*
	24 April 7, 8 June and 3, 24 July	Anatahan	Mariana Islands (United States)
	21 May	Nyiragongo*	Central Africa
	8 June	Awu*	Indonesia
	8 June	Bromo*	Indonesia
	12 June	Colima*	Mexico
	14, 19 June	Bezymianny*	Kamchatka (Russian Federation)
	22 June and 24, 31 July	Kerinci*	Indonesia
	1 September	Asama*	Japan

*IAVW was activated.

Appendix E

CROSS-REFERENCE LIST OF VOLCANOES AND NAVIGATION AIDS

(Part I, Chapter 6, 6.8.1 refers)

Note.— The information contained in this appendix regarding volcano number may differ from the information contained in the List of Volcanoes of the World for VAAC Use *database at http://www.volcano.si.edu/projects/vaac-data/ maintained by the Global Volcanism Program of the Smithsonian Institution. In case of discrepancy, the information contained in the latter should be used.*

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
EUROPE-AFRICA-MIDDLE EAST-INDIAN OCEAN						
ALAYTA	ETHIOPIA	201-112	N12 52.5	E040 33.4	297°/168NM	DJIBOUTI (DTI) VOR/DME
ARDOUKOBA	DJIBOUTI	201-126	N11 36.4	E042 27.4	274°/37NM	DJIBOUTI (DTI) VOR/DME
CAMPI FLEGREI	ITALY	101-01	N40 49.4	E014 08.2	327°/17NM	SORRENTO (SOR) VOR/DME
CAMPI FLEGREI MAR SICILY	ITALY	101-07	N37 06.0	E012 42.0	064°/39NM	PANTELLERIA (PAN) VOR/DME
CHYULU HILLS	AFRICA-E	202-13	S02 40.5	E037 52.5	269°/17NM	MTITO ANDEI (MTA) VOR/DME
DALLOL	ETHIOPIA	201-041	N14 14.3	E040 18.0	124°/102NM	ASMARA (ASM) VOR/DME
DAMA ALI	ETHIOPIA	201-141	N11 16.3	E041 37.3	258°/88NM	DJIBOUTI (DTI) VOR/DME
DJEBEL TEYR	RED SEA	201-01	N15 42.0	E041 44.3	212°/86NM	JAZAN (GIZ) VORTAC
DUBBI	ETHIOPIA	201-10	N13 34.5	E041 48.3	222°/99NM	HODEIDAH (HDH) VOR/DME
EMURUANGOGOLAK	AFRICA-E	202-051	N01 30.0	E036 19.5	155°/105NM	LODWAR (LOV) VOR/DME
ERTA ALE	ETHIOPIA	201-08	N13 36.0	E040 40.1	131°/144NM	ASMARA (ASM) VOR/DME
ES SAFA	SYRIA	300-05	N33 04.5	E037 09.0	113°/38NM	DAMASCUS (DAM) VOR/DME
ETNA	ITALY	101-06	N37 44.0	E015 00.1	004°/16NM	CATANIA (CAT) VOR/DME
FENTALE	ETHIOPIA	201-19	N08 58.3	E039 55.5	087°/67NM	ADDIS (ADS) VOR/DME
HARRAS OF DHAMAR	ARABIA-S	302-06	N14 34.1	E044 40.1	029°/60NM	TAIZ (TAZ) VOR/DME
HEARD VOLCANO	INDIAN OCEAN-S	304-01	S53 06.2	E073 30.4	181°/2091NM	PLAISANCE (MAURITIUS) (PLS) VOR/DME
JABAL YAR	ARABIA-S	302-01	N17 03.0	E042 49.5	058°/16NM	JAZAN (GIZ) VORTAC
JEBEL ZUBAYR	RED SEA	201-02	N15 04.5	E042 09.4	289°/51NM	HODEIDAH (HDH) VOR/DME
KARTHALA	INDIAN OCEAN-W	303-01	S11 45.0	E043 22.5	161°/15NM	MORONI (HAI) VOR
KIEYO	AFRICA-E	202-17	S09 13.5	E033 46.5	355°/43NM	KARONGA (VKA) VOR/DME
KONE	ETHIOPIA	201-20	N08 48.0	E039 41.3	099°/54NM	ADDIS (ADS) VOR/DME
LONGONOT	AFRICA-E	202-10	S00 55.1	E036 27.0	308°/37NM	NAIROBI (NV) VOR/DME
MANDA-INAKIR	ETHIOPIA	201-122	N12 22.5	E042 12.0	313°/72NM	DJIBOUTI (DTI) VOR/DME
MARION ISLAND	INDIAN OCEANS	304-08	S46 54.0	E037 45.0	177°/947NM	EAST LONDON (ELV) VOR/DME
MERU	AFRICA-E	202-16	S03 15.0	E036 45.0	297°/23NM	KILIMANJARO (KV) VOR/DME
METHANA	GREECE	102-02	N37 36.5	E023 20.1	033°/9NM	DIDIMON (DDM) VOR/DME
MOUNT CAMEROON	AFRICA-W	204-01	N04 12.1	E009 10.1	293°/36NM	DOUALA (DLA) VOR/DME
NISYROS	GREECE	102-05	N36 34.5	E027 10.5	200°/45NM	MILAS (BODRUM) (GML) VOR/DME
NYAMURAGIRA	AFRICA-C	203-02	S01 24.3	E029 12.0	354°/16NM	GOMA (GOM) VOR/DME
NYIRAGONGO	AFRICA-C	203-03	S01 31.1	E029 15.0	006°/9NM	GOMA (GOM) VOR/DME
OKU VOLCANO FIELD	AFRICA-W	204-003	N06 15.0	E010 30.0	065°/25NM	BAMENDA (BND) VOR/DME
OL DOINYO LENGAI	AFRICA-E	202-12	S02 45.0	E035 54.1	300°/82NM	KILIMANJARO (KV) VOR/DME
OLKARIA	AFRICA-E	202-09	S00 54.1	E036 17.3	302°/46NM	NAIROBI (NV) VOR/DME
PANTELLERIA	ITALY	101-071	N36 45.4	E012 00.4	147°/3NM	PANTELLERIA (PAN) VOR/DME
PITON DE FOURNAISE	INDIAN OCEAN-W	303-02	S21 13.4	E055 42.5	171°/24NM	ST DENIS (SDG) VOR/DME
SANTA ISABEL	AFRICA-W	204-02	N03 34.3	E008 45.0	175°/11NM	MALABO (MBO) VOR/DME
SANTORINI	GREECE	102-04	N36 24.1	E025 23.5	113°/47NM	MILOS (MIL) VOR/DME
SOUTH ISLAND	AFRICA-E	202-02	N02 37.3	E036 36.0	115°/66NM	LODWAR (LOV) VOR/DME
ST PAUL	INDIAN OCEAN-S	304-03	S38 42.4	E077 31.5	159°/1502NM	PLAISANCE (MAURITIUS) (PLS) VOR/DME

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
STROMBOLI	ITALY	101-04	N38 47.2	E015 12.5	271°/54NM	CARAFFA (CDC) VORTAC
THE BARRIER	AFRICA-E	202-03	N02 19.1	E036 34.1	129°/74NM	LODWAR (LOV) VOR/DME
TULLU MOJE	ETHIOPIA	201-25	N08 09.3	E039 07.5	155°/52NM	ADDIS (ADS) VOR/DME
VESUVIO	ITALY	101-02	N40 49.2	E014 25.3	015°/14NM	SORRENTO (SOR) VOR/DME
VISOKE	AFRICA-C	203-05	S01 28.1	E029 29.3	051°/20NM	GOMA (GOM) VOR/DME
VULCANO	ITALY	101-05	N38 24.1	E014 57.4	358°/56NM	CATANIA (CAT) VOR/DME

NEW ZEALAND-SOUTHWEST PACIFIC

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
AMBRYM	VANUATU-SW PACIFIC	507-04	S16 15.0	E168 07.1	343°/84NM	PORT VILA (VLI) VOR/DME
AOBA	VANUATU-SW PACIFIC	507-03	S15 24.0	E167 49.5	338°/137NM	PORT VILA (VLI) VOR/DME
AUCKLAND FIELD	NEW ZEALAND	401-02	S36 54.0	E174 52.1	003°/6NM	AUCKLAND (AA) VOR/DME
BAGANA	BOUGAINVILLE-SW PACIFIC	505-02	S06 08.2	E155 11.4	114°/198NM	TOKUA (TOK) VOR/DME
BAM	NEW GUINEA-NE OF	501-01	S03 36.0	E144 51.0	085°/70NM	WEWAK (WK) VOR/DME
BAMUS	NEW BRITAIN-SW PACIFIC	502-11	S05 12.0	E151 13.5	225°/86NM	TOKUA (TOK) VOR/DME
BILLY MITCHELL	BOUGAINVILLE-SW PACIFIC	505-011	S06 05.3	E155 13.3	113°/198NM	TOKUA (TOK) VOR/DME
BRIMSTONE ISLAND	KERMADEC IS	402-02	S30 13.5	W178 54.4	022°/508NM	WHENUAPAI (AUCKLAND) (WP) VORTAC
CURACOA	TONGA-SW PACIFIC	403-101	S15 36.4	W173 39.4	210°/143NM	FALEOLO (UPOLU I.) (FA) VOR/DME
DAKATAUA	NEW BRITAIN-SW PACIFIC	502-04	S05 03.2	E150 06.3	244°/143NM	TOKUA (TOK) VOR/DME
EAST EPI	VANUATU-SW PACIFIC	507-06	S16 40.5	E168 22.1	355°/59NM	PORT VILA (VLI) VOR/DME
FALCON ISLAND	TONGA-SW PACIFIC	403-05	S20 18.4	W175 24.4	331°/57NM	FUA'AMOTU (TBU) VOR/DME
FONUALEI	TONGA-SW PACIFIC	403-10	S18 00.4	W174 19.3	359°/198NM	FUA'AMOTU (TBU) VOR/DME
GAUA	VANUATU-SW PACIFIC	507-02	S14 16.1	E167 30.0	336°/207NM	PORT VILA (VLI) VOR/DME
HOME REEF	TONGA-SW PACIFIC	403-08	S18 59.3	W174 46.3	354°/136NM	FUA'AMOTU (TBU) VOR/DME
HUNTER ISLAND	SW PACIFIC	508-02	S22 24.0	E172 03.0	099°/285NM	LIFOU (LFU) VOR
KARKAR	NEW GUINEA-NE OF	501-03	S04 38.6	E145 57.5	011°/34NM	MADANG (MD) VOR/DME
KAVACHI	SOLOMON IS-SW PACIFIC	505-06	S09 01.1	E157 57.0	272°/125NM	HONIARA (HN) VOR/DME
KUWAE	VANUATU-SW PACIFIC	507-07	S16 49.4	E168 32.1	007°/52NM	PORT VILA (VLI) VOR/DME
LAMINGTON	NEW GUINEA	503-01	S08 57.0	E148 09.0	055°/63NM	PORT MORESBY (PY) VOR/DME
LANGILA	NEW BRITAIN-SW PACIFIC	502-01	S05 31.3	E148 25.1	052°/119NM	NADZAB (NZ) VOR/DME
LATE	TONGA-SW PACIFIC	403-09	S18 48.2	W174 39.0	357°/148NM	FUA'AMOTU (TBU) VOR/DME
LOLOBAU	NEW BRITAIN-SW PACIFIC	502-13	S04 55.1	E151 09.3	237°/81NM	TOKUA (TOK) VOR/DME
LONG ISLAND	NEW GUINEA-NE OF	501-05	S05 21.3	E147 07.1	012°/76NM	NADZAB (NZ) VOR/DME
LOPEVI	VANUATU-SW PACIFIC	507-05	S16 30.3	E168 20.5	353°/69NM	PORT VILA (VLI) VOR/DME
MANAM	NEW GUINEA-NE OF	501-02	S04 06.0	E145 03.4	321°/79NM	MADANG (MD) VOR/DME
MATTHEW ISLAND	SW PACIFIC	508-01	S22 19.5	E171 19.1	100°/246NM	LIFOU (LFU) VOR
METIS SHOAL	TONGA-SW PACIFIC	403-07	S19 10.5	W174 51.4	353°/124NM	FUA'AMOTU (TBU) VOR/DME
MONOWAI SEAMOUNT	KERMADEC IS	402-05	S25 53.2	W177 11.2	187°/299NM	FUA'AMOTU (TBU) VOR/DME
MOUNT EGMONT	NEW ZEALAND	401-03	S39 18.0	E174 03.4	176°/18NM	NEW PLYMOUTH (NP) VOR/DME
NIUAFO'OU	TONGA-SW PACIFIC	403-11	S15 36.0	W175 37.5	154°/144NM	HIHIFO (UVEA I., WALLIS IS.) (HOI) VOR/ DME
OFU-OLOSEGA	SAMOA-SW PACIFIC	404-01	S14 10.3	W169 37.1	069°/64NM	PAGO PAGO (TUT) VORTAC
PAGO WITORI	NEW BRITAIN-SW PACIFIC	502-08	S05 34.5	E150 31.1	228°/134NM	TOKUA (TOK) VOR/DME
RABAUL	NEW BRITAIN-SW PACIFIC	502-14	S04 16.2	E152 12.1	283°/12NM	TOKUA (TOK) VOR/DME
RAOUL ISLAND	KERMADEC IS	402-03	S29 15.4	W177 54.4	182°/502NM	FUA'AMOTU (TBU) VOR/DME
RITTER ISLAND	NEW GUINEA-NE OF	501-07	S05 31.1	E148 07.2	047°/105NM	NADZAN (NZ) VOR/DME
RUAPEHU	NEW ZEALAND	401-10	S39 16.5	E175 34.1	186°/78NM	ROTORUA (RO) VOR/DME
RUMBLE III	NEW ZEALAND	401-13	S35 44.4	E178 28.4	017°/175NM	ROTORUA (RO) VOR/DME
SAVAI'I	SAMOA-SW PACIFIC	404-04	S13 36.4	W172 31.3	280°/33NM	FALEOLO (UPOLU I.) (FA) VOR/DME
SAVO	SOLOMON IS-SW PACIFIC	505-07	S09 07.5	E159 49.1	318°/22NM	HONIARA (HN) VOR/DME
SORETIMEAT	VANUATU-SW PACIFIC	507-01	S13 48.0	E167 28.1	337°/235NM	PORT VILA (VLI) VOR/DME
ST ANDREW STRAIT	ADMIRALTY IS-SW PACIFIC	500-01	S02 22.5	E147 21.0	024°/192NM	MADANG (MD) VOR/DME
TARAWERA	NEW ZEALAND	401-06	S38 13.4	E176 30.3	108°/11NM	ROTORUA (RO) VOR/DME
TINAKULA	SANTA CRUZ IS-SW PAC	506-01	S10 22.5	E165 48.0	090°/346NM	HONIARA (HN) VOR/DME

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
TOFUA	TONGA-SW PACIFIC	403-06	S19 45.0	W176 04.5	315°/103NM	FUA'AMOTU (TBU) VOR/DME
TONGARIRO	NEW ZEALAND	401-08	S39 07.5	E175 38.3	187°/68NM	ROTORUA (RO) VOR/DME
TRAITOR'S HEAD	VANUATU-SW PACIFIC	507-09	S18 45.0	E169 13.5	126°/86NM	PORT VILA (VLI) VOR/DME
ULAWUN	NEW BRITAIN-SW PACIFIC	502-12	S05 03.0	E151 19.5	228°/76NM	TOKUA (TOK) VOR/DME
UNNAMED	TONGA-SW PACIFIC	403-01	S21 27.3	W175 46.1	235°/37NM	FUA'AMOTU (TBU) VOR/DME
UNNAMED	TONGA-SW PACIFIC	403-03	S20 51.0	W175 31.5	303°/32NM	FUA'AMOTU (TBU) VOR/DME
UNNAMED	TONGA-SW PACIFIC	403-04	S20 33.4	W175 22.5	328°/42NM	FUA'AMOTU (TBU) VOR/DME
UNNAMED	SW PACIFIC	508-03	S25 46.5	E168 37.5	356°/199NM	NORFOLK I. (NF) VOR/DME
UNNAMED	ADMIRALTY IS-SW PACIFIC	500-03	S03 01.5	E147 46.5	037°/176NM	MADANG (MD) VOR/DME
UNNAMED	KERMADEC IS	402-04	S29 10.5	W177 52.1	182°/497NM	FUA'AMOTU (TBU) VOR/DME
VICTORY	NEW GUINEA	503-03	S09 12.0	E149 04.1	304°/101M	GURNEY (GNY) VOR/DME
WAIOWA	NEW GUINEA	503-04	S09 34.1	E149 04.3	293°/88NM	GURNEY (GNY) VOR/DME
WHITE ISLAND	NEW ZEALAND	401-04	S37 31.1	E177 10.5	029°/54NM	ROTORUA (RO) VOR/DME
YASUR	VANUATU-SW PACIFIC	507-10	S19 31.1	E169 25.3	136°/129NM	PORT VILA (VLI) VOR/DME

INDONESIA

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
AGUNG	LESSER SUNDA IS	604-02	S08 20.3	E115 30.3	039°/31NM	BALI (DEN PASAR) (BLI) VOR/DME
AMBANG	SULAWESI-INDONESIA	606-02	N00 45.0	E124 25.1	218°/45NM	MANADO (TDO) VOR/DME
API SIAU	SANGIHE IS- INDONESIA	607-02	N02 46.5	E125 28.5	022°/80NM	MANADO (MNO) VOR/DME
ARJUNO-WELIRANG	JAVA	603-29	S07 43.3	E112 34.5	210°/24NM	SURABAYA (SBY) VOR/DME
AWU	SANGIHE IS- INDONESIA	607-04	N03 40.1	E125 30.0	013°/130NM	MANADO (MNO) VOR/DME
BANDA API	BANDA SEA	605-09	S04 31.3	E129 52.2	116°/114NM	AMBON (AMN) VOR/DME
BANUA WUHU	SANGIHE IS- INDONESIA	607-03	N03 08.2	E125 29.3	017°/100NM	MANADO (MNO) VOR/DME
BARREN ISLAND	ANDAMAN IS-IND OCEAN	600-01	N12 15.0	E093 49.5	061°/73NM	PORT BLAIR (PPB) VOR/DME
BATU TARA	LESSER SUNDA IS	604-26	S07 47.3	E123 34.4	288°/124NM	DILI (DIL) VOR/DME
BATUR	LESSER SUNDA IS	604-01	S08 14.3	E115 22.3	021°/32NM	BALI (DEN PASAR) (BLI) VOR/DME
BUR NI TELONG	SUMATRA	601-05	N04 45.4	E096 48.3	233°/33NM	LHOK SUKON (LSN) VOR
CEREME	JAVA	603-17	S06 53.3	E108 24.0	174°/35NM	INDRAMAYU (IMU) VOR/DME
COLO UNA UNA	SULAWESI-INDONESIA	606-01	S00 10.1	E121 36.3	066°/111NM	PALU (PAL) VOR/DME
DEMPO	SUMATRA	601-23	S04 01.5	E103 07.5	232°/114NM	PALEMBANG (PLB) VOR/DME
DIENG VOLCANO COMPLEX	JAVA	603-20	S07 12.0	E109 55.1	242°/30NM	ACHMAD YANI (SEMARANG) (ANY) VOR/ DME
DUKONO	HALMAHERA-INDONESIA	608-01	N01 42.0	E127 52.1	085°/177NM	MANADO (MNO) VOR/DME
EBULOBO	LESSER SUNDA IS	604-10	S08 48.3	E121 10.5	296°/168NM	KUPANG (KPG) VOR/DME
EGON	LESSER SUNDA IS	604-16	S08 39.4	E122 27.0	319°/115NM	KUPANG (KPG) VOR/DME
GALUNGGUNG	JAVA	603-14	S07 15.0	E108 03.0	123°/38NM	BANDUNG (BND) VOR/DME
GAMALAMA	HALMAHERA-INDONESIA	608-06	N00 48.0	E127 19.3	101°/148NM	MANADO (TDO) VOR/DME
GAMKONORA	HALMAHERA-INDONESIA	608-04	N01 22.3	E127 31.1	091°/156NM	MANADO (MNO) VOR/DME
GEDE	JAVA	603-06	S06 46.5	E106 58.5	169°/30NM	HALIM (JAKARTA) (HLM) VOR/DME
GUNTUR	JAVA	603-13	S07 07.5	E107 49.5	127°/24NM	BANDUNG (BND) VOR/DME
GUNUNG BESAR	SUMATRA	601-25	S04 25.5	E103 39.4	298°/104NM	BANDAR LAMPUNG (TKG) VOR/DME
GUNUNG RANAKAH	LESSER SUNDA IS	604-071	S08 37.1	E120 31.1	294°/207NM	KUPANG (KPG) VOR/DME
GUNUNGAPI WETAR	BANDA SEA	605-03	S06 38.3	E126 39.0	027°/131NM	DILI (DIL) VOR/DME
IBU	HALMAHERA-INDONESIA	608-03	N01 28.5	E127 37.5	089°/162NM	MANADO (MNO) VOR/DME
IJEN	JAVA	603-35	S08 03.3	E114 14.3	306°/68NM	BALI (DEN PASAR) (BLI) VOR/DME
ILIBOLENG	LESSER SUNDA IS	604-22	S08 20.3	E123 15.3	345°/111NM	KUPANG (KPG) VOR/DME
ILIWERUNG	LESSER SUNDA IS	604-25	S08 32.2	E123 35.2	355°/97NM	KUPANG (KPG) VOR/DME
INIELIKA	LESSER SUNDA IS	604-09	S08 43.5	E120 58.5	296°/180NM	KUPANG (KPG) VOR/DME
IYA	LESSER SUNDA IS	604-11	S08 52.5	E121 37.5	300°/142NM	KUPANG (KPG) VOR/DME
KABA	SUMATRA	601-22	S03 30.4	E102 36.4	209°/128NM	JAMBI (JMB) VOR/DME
KELIMUTU	LESSER SUNDA IS	604-14	S08 45.3	E121 49.5	305°/137NM	KUPANG (KPG) VOR/DME
KELUT	JAVA	603-28	S07 55.5	E112 18.3	220°/43NM	SURABAYA (SBY) VOR/DME
KERINCI	SUMATRA	601-17	S01 41.3	E101 15.4	132°/73NM	PADANG (PDG) VOR/DME
KIARABERES-GAGAK	JAVA	603-03	S06 43.5	E106 39.0	168°/26NM	BUDIARTO (TANGERANG) (BTO) VOR/ DME

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
KRAKATAU	INDONESIA	602-00	S06 06.1	E105 25.2	164°/52NM	BANDAR LAMPUNG (TKG) VOR/DME
LAMONGAN	JAVA	603-32	S08 00.0	E113 20.3	137°/49NM	SURABAYA (SBY) VOR/DME
LEREBOLENG	LESSER SUNDA IS	604-20	S08 21.3	E122 50.3	333°/118NM	KUPANG (KPG) VOR/DME
LEWOTOBI	LESSER SUNDA IS	604-18	S08 31.5	E122 46.3	329°/110NM	KUPANG (KPG) VOR/DME
LEWOTOLO	LESSER SUNDA IS	604-23	S08 16.2	E123 30.2	353°/113NM	KUPANG (KPG) VOR/DME
LOKON-EMPUNG	SULAWESI-INDONESIA	606-10	N01 21.3	E124 47.3	283°/7NM	MANADO (TDO) VOR/DME
MAHAWU	SULAWESI-INDONESIA	606-11	N01 21.3	E124 51.3	297°/3NM	MANADO (TDO) VOR/DME
MAKIAN	HALMAHERA-INDONESIA	608-07	N00 19.1	E127 24.O	110°/161NM	MANADO (TDO) VOR/DME
MARAPI	SUMATRA	601-14	S00 22.5	E100 28.2	013°/30NM	PADANG (PDG) VOR/DME
MERAPI	JAVA	603-25	S07 32.3	E110 26.3	026°/17NM	YOGYAKARTA (JOG) VOR/DME
MERBABU	JAVA	603-24	S07 27.0	E110 25.5	279°/22NM	SOLO (SLO) VOR/DME
NILA	BANDA SEA	605-06	S06 43.5	E129 30.0	152°/198NM	AMBON (PMA) VOR/DME
PALUWEH	LESSER SUNDA IS	604-15	S08 19.1	E121 42.3	311°/159NM	KUPANG (KPG) VOR/DME
PAPANDAYAN	JAVA	603-10	S07 18.4	E107 43.5	152°/28NM	BANDUNG (BND) VOR/DME
PEUET SAGUE	SUMATRA	601-03	N04 55.3	E096 19.5	260°/56NM	LHOK SUKON (LSN) VOR
RAUNG	JAVA	603-34	S08 07.3	E114 02.3	298°/76NM	BALI (DEN PASAR) (BLI) VOR/DME
RINJANI	LESSER SUNDA IS	604-03	S08 24.4	E116 27.4	067°/24NM	MATARAM (MTM) VOR/DME
RUANG	SANGIHE IS- INDONESIA	607-01	N02 16.5	E125 25.3	032°/52NM	MANADO (MNO) VOR/DME
SALAK	JAVA	603-05	S06 42.4	E106 43.5	157°/26NM	BUDIARTO (TANGERANG) (BTO) VOR/ DME
SANGEANG API	LESSER SUNDA IS	604-05	S08 10.5	E119 03.3	081°/178NM	MATARAM (MTM) VOR/DME
SEMERU	JAVA	603-30	S08 06.3	E112 55.1	169°/44NM	SURABAYA (SBY) VOR/DME
SERUA	BANDA SEA	605-07	S06 18.0	E130 00.0	141°/192NM	AMBON (PMA) VOR/DME
SIBAYAK	SUMATRA	601-07	N03 12.3	E098 28.1	207°/19NM	MEDAN (MDN) VOR/DME
SIRUNG	LESSER SUNDA IS	604-27	S08 30.4	E124 08.5	268°/82NM	DILI (DIL) VOR/DME
SLAMET	JAVA	603-18	S07 14.3	E109 12.3	023°/26NM	CILACAP (CLP) VOR/DME
SOPUTAN	SULAWESI-INDONESIA	606-03	N01 06.3	E124 43.3	219°/17NM	MANADO (TDO) VOR/DME
SORIKMARAPI	SUMATRA	601-12	N00 41.1	E099 32.1	026°/112NM	ESMERALDAS (TACHINA) (ESV) VOR/DME
SUMBING	SUMATRA	601-18	S02 24.4	E101 43.5	138°/123NM	PADANG (PDG) VOR/DME
SUMBING	JAVA	603-22	S07 22.5	E110 03.3	328°/29NM	YOGYAKARTA (JOG) VOR/DME
SUNDORO	JAVA	603-21	S07 18.0	E109 59.3	228°/30NM	ACHMAD YANI (SEMARANG) (ANY) VOR/ DME
SUOH	SUMATRA	601-27	S05 15.0	E104 15.4	270°/55NM	BANDAR LAMPUNG (TKG) VOR/DME
TALANG	SUMATRA	601-16	S00 58.4	E100 40.4	161°/142NM	AMBATO (AMB) VOR/DME
TAMBORA	LESSER SUNDA IS	604-04	S08 15.0	E118 00.0	079°/116NM	MATARAM (MTM) VOR/DME
TANDIKAT	SUMATRA	601-15	S00 25.6	E100 19.0	355°/26NM	PADANG (POG) VOR/DME
TANGKUBANPARAHU	JAVA	603-09	S06 46.1	E107 36.0	037°/8NM	BANDUNG (BND) VOR/DME
TENGGER CALDERA	JAVA	603-31	S07 56.3	E112 57.0	163°/34NM	SURABAYA (SBY) VOR/DME
TEON	BANDA SEA	605-05	S06 54.4	E129 07.3	160°/200NM	AMBON (PMA) VOR/DME
TONGKOKO	SULAWESI-INDONESIA	606-13	N01 31.1	E125 12.0	095°/16NM	MANADO (MNO) VOR/DME
WURLALI	BANDA SEA	605-04	S07 07.3	E128 40.3	062°/205NM	DILI (DIL) VOR/DME

PHILIPPINES-JAPAN-MARIANAS-SOUTHEAST ASIA

ADATARA	HONSHU-JAPAN	803-17	N37 37.1	E140 16.5	349°/24NM	FUKUSHIMA (FKE) VOR/DME
AGRIGAN	MARIANA IS-C PACIFIC	804-16	N18 46.1	E145 40.1	007°/322NM	NIMITZ (UNZ) VORTAC
AKAGI	HONSHU-JAPAN	803-13	N36 31.5	E139 10.5	256°/44NM	NASU (NZE) VOR/DME
AKAN	HOKKAIDO-JAPAN	805-07	N43 22.5	E144 01.1	347°/22NM	KUSHIRO (KSE) VOR/DME
AKITA-KOMAGA-TAKE	HONSHU-JAPAN	803-23	N39 45.0	E140 48.0	328°/24NM	HANAMAKI (HPE) VOR/DME
AKITA-YAKE-YAMA	HONSHU-JAPAN	803-26	N39 58.1	E140 46.1	134°/23NM	ODATE-NOSHIRO (ODE) VOR/DME
ALAMAGAN	MARIANA IS-C PACIFIC	804-18	N17 36.0	E145 49.5	012°/255NM	NIMITZ (UNZ) VORTAC
AOGA-SHIMA	IZU IS-JAPAN	804-06	N32 27.0	E139 46.1	187°/39NM	HACHIJO JIMA (HCE) VOR/DME
ASAMA	HONSHU-JAPAN	803-11	N36 24.0	E138 31.5	070°/33NM	MATSUMOTO (MBE) VOR/DME
ASO	KYUSHU-JAPAN	802-11	N32 52.5	E131 06.0	084°/13NM	KUMAMOTO (KUE) VOR/DME
ASUNCION	MARIANA IS-C PACIFIC	804-15	N19 39.4	E145 24.0	004°/372NM	NIMITZ (UNZ) VORTAC
AZUMA	HONSHU-JAPAN	803-18	N37 43.5	E140 15.0	196°/27NM	ZAO-YAMADA (ZMO) VOR
BABUYAN CLARO	LUZON IS-N OF	704-03	N19 31.2	E121 56.2	044°/113NM	LAOAG (LAO) VOR/DME
BANDAI	HONSHU-JAPAN	803-16	N37 36.0	E140 04.5	329°/28NM	FUKUSHIMA (FKE) VOR/DME
BAYONNAISE ROCKS	IZU IS-JAPAN	804-07	N31 55.1	E139 55.1	180°/71NM	HACHIJO JIMA (HCE) VOR/DME
BILIRAN	PHILIPPINES-C	702-08	N11 31.2	E124 32.0	133°/73NM	MASBATE (MBT) VOR
BUD DAJO	SULU IS-PHILIPPINES	700-01	N05 57.0	E121 04.1	224°/82NM	ZAMBOANGA (ZAM) VOR/DME
BULUSAN	LUZON-PHILIPPINES	703-01	N12 46.1	E124 03.0	140°/29NM	LEGAZPI (LP) VOR/DME

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
CALAYO	MINDANAO-PHILIPPINES	701-07	N07 52.4	E125 04.1	139°/42NM	CAGAYAN DE ORO (CGO) VOR/DME
CAMIGUIN DE BABUYANE	LUZON IS-N OF	704-01	N18 49.5	E121 51.4	006°/71NM	TUGUEGARAO (TUG) VOR
CANLAON	PHILIPPINES-C	702-02	N10 24.4	E123 07.6	116°/39NM	ILOILO (IOO) VOR/DME
CHOKAI	HONSHU-JAPAN	803-22	N39 04.5	E140 01.5	041°/19NM	SHONAI (YSE) VOR/DME
DIDICAS	LUZON IS-N OF	704-02	N19 04.3	E122 12.0	018°/90NM	TUGUEGARAO (TUG) VOR
E-SAN	HOKKAIDO-JAPAN	805-012	N41 48.0	E141 09.4	091°/14NM	HAKODATE (HWE) VOR/DME
FARALLON DE PAJAROS	MARIANA IS-C PACIFIC	804-14	N20 31.5	E144 54.0	359°/422NM	NIMITZ (UNZ) VORTAC
FUJI	HONSHU-JAPAN	803-03	N35 21.0	E138 43.5	283°/42NM	YOKOSUKA (HYE) VOR/DME
FUKUJIN	VOLCANO IS-JAPAN	804-133	N21 55.3	E143 26.3	350°/511NM	NIMITZ (UNZ) VORTAC
GUGUAN	MARIANA IS-C PACIFIC	804-19	N17 18.4	E145 51.0	013°/239NM	NIMITZ (UNZ) VORTAC
HACHIJO-JIMA	IZU IS-JAPAN	804-05	N33 07.5	E139 46.1	321°/1NM	HACHIJO JIMA (HCE) VOR/DME
HAKU-SAN	HONSHU-JAPAN	803-05	N36 09.0	E136 46.5	135°/23NM	KOMATSU (KMC) VORTAC
HIBOK-HIBOK	MINDANAO-PHILIPPINES	701-08	N09 12.1	E124 40.2	003°/46NM	CAGAYAN DE ORO (CGO) VOR/DME
IBUSUKI VOLCANO FIELD	KYUSHU-JAPAN	802-07	N31 13.1	E130 34.1	187°/28NM	KAGOSHIMA (HKC) VORTAC
ILE DES CENDRES	SE ASIA	705-06	N10 09.3	E109 00.5	129°/72NM	PHANTHIET (PTH) VOR/DME
IRIGA	LUZON-PHILIPPINES	703-041	N13 27.3	E123 27.3	319°/24NM	LEGAZPI (LP) VOR/DME
IRIOMOTE-JIMA	RYUKYU IS	802-01	N24 33.3	E124 00.0	326°/16NM	ISHIGAKI (GKE) VOR/DME
IWAKI	HONSHU-JAPAN	803-27	N40 39.0	E140 18.0	262°/19NM	AOMORI (MRE) VOR/DME
IWATE	HONSHU-JAPAN	803-24	N39 51.0	E141 00.0	353°/25NM	HANAMAKI (HPE) VOR/DME
IO-TO	VOLCANO IS-JAPAN	804-12	N24 45.0	E141 19.5	175°/507NM	HACHIJO JIMA (HCE) VOR/DME
IZU-TOBU	HONSHU-JAPAN	803-01	N34 55.1	E139 07.1	316°/19NM	OSHIMA (XAC) VORTAC
KAITOKU SEAMOUNT	VOLCANO IS-JAPAN	804-10	N26 03.2	E141 07.1	176°/428NM	HACHIJO JIMA (HCE) VOR/DME
KIKAI	RYUKYU IS	802-06	N30 46.5	E130 16.5	325°/31NM	YAKUSHIMA (YKE) VOR/DME
KIRISHIMA	KYUSHU-JAPAN	802-09	N31 55.5	E130 52.1	048°/10NM	KAJIKI (KAGOSHIMA) (KGE) VOR/DME
KITA-IO-TO	VOLCANO IS-JAPAN	804-11	N25 25.5	E141 13.5	176°/466NM	HACHIJO JIMA (HCE) VOR/DME
KOMAGA-TAKE	HOKKAIDO-JAPAN	805-02	N42 04.1	E140 40.5	347°/19NM	HAKODATE (HWE) VOR/DME
KUCHINOERABU-JIMA	RYUKYU IS	802-05	N30 25.5	E130 13.1	282°/23NM	YAKUSHIMA (YKE) VOR/DME
KUJU GROUP	KYUSHU-JAPAN	802-12	N33 04.5	E131 15.0	255°/24NM	OITA (TAE) VOR/DME
KURIKOMA	HONSHU-JAPAN	803-21	N38 57.0	E140 46.5	218°/33NM	HANAMAKI (HPE) VOR/DME
KUSATSU-SHIRANE	HONSHU-JAPAN	803-12	N36 37.1	E138 33.0	054°/41NM	MATSUMOTO (MBE) VOR/DME
KUTTARA	HOKKAIDO-JAPAN	805-034	N42 30.0	E141 10.5	251°/25NM	CHITOSE (CHE) VOR/DME
MALINAO	LUZON-PHILIPPINES	703-04	N13 25.2	E123 35.5	334°/17NM	LEGAZPI (LP) VOR/DME
MAYON	LUZON-PHILIPPINES	703-03	N13 15.3	E123 41.1	338°/6NM	LEGAZPI (LP) VOR/DME
MINAMI-HIYOSHI	VOLCANO IS-JAPAN	804-131	N23 30.2	E141 54.2	174°/585NM	HACHIJO JIMA (HCE) VOR/DME
MIYAKE-JIMA	IZU IS-JAPAN	804-04	N34 04.5	E139 31.5	152°/2NM	MIYAKEJIMA (MJE) VOR/DME
MOUNT PAGAN	MARIANA IS-C PACIFIC	804-17	N18 07.5	E145 48.0	010°/286NM	NIMITZ (UNZ) VORTAC
MOUNT PINATUBO	LUZON-PHILIPPINES	703-083	N15 07.5	E120 21.0	255°/12NM	CLARK (ANGELES (CIA) VOR/DME
NAKANO-SHIMA	RYUKYU IS	802-04	N29 51.0	E129 52.1	237°/52NM	YAKUSHIMA (YKE) VOR/DME
NASU	HONSHU-JAPAN	803-15	N37 07.1	E139 58.1	357°/20NM	NASU (NZE) VOR/DME
NIIGATA-YAKE-YAMA	HONSHU-JAPAN	803-09	N36 55.1	E138 01.5	075°/43NM	TOYAMA (TOE) VOR/DME
NIKKO-SHIRANE	HONSHU-JAPAN	803-14	N36 48.0	E139 22.5	278°/31NM	NASU (NZE) VOR/DME
NIPESOTSU-UPEPESANKE	HOKKAIDO-JAPAN	805-051	N43 27.0	E143 01.5	126°/28NM	ASAHIKAWA (AWE) VOR/DME
NISHINO-SHIMA	VOLCANO IS-JAPAN	804-092	N27 14.4	E140 52.4	176°/356NM	HACHIJO JIMA (HCE) VOR/DME
OKINAWA-TORI-SHIMA	RYUKYU IS	802-02	N27 51.0	E128 15.0	279°/33NM	TOKUNOSHIMA (TKE) VOR/DME
ON-TAKE	HONSHU-JAPAN	803-04	N35 54.0	E137 28.5	241°/26NM	MATSUMOTO (MBE) VOR/DME
OSHIMA	IZU IS-JAPAN	804-01	N34 43.5	E139 22.5	308°/2NM	OSHIMA (XAC) VORTAC
OSHIMA-OSHIMA	HOKKAIDO-JAPAN	805-01	N41 30.0	E139 22.1	194°/34NM	OKUSHIRI (ORE) VOR/DME
OSORE-YAMA	HONSHU-JAPAN	803-29	N41 19.1	E141 04.5	165°/29NM	HAKODATE (HWE) VOR/DME
RAGANG	MINDANAO-PHILIPPINES	701-06	N07 40.1	E124 30.0	029°/34NM	COTABATO (DINAIG) (COT) VOR/DME
RUBY	MARIANA IS-C PACIFIC	804-201	N15 36.4	E145 33.4	018°/137NM	NIMITZ (UNZ) VORTAC
SAKURA-JIMA	KYUSHU-JAPAN	802-08	N31 34.5	E130 40.1	153°/8NM	KAGOSHIMA (HKC) VORTAC
SHIN-IO-TO	VOLCANO IS-JAPAN	804-13	N24 16.5	E141 31.1	175°/536NM	MIYAKEJIMA (MJE) VOR/DME
SHIRETOKO-IO-ZAN	HOKKAIDO-JAPAN	805-09	N44 07.5	E145 10.1	025°/34NM	NAKASHIBETSU (NSE) VOR/DME
SMITH ROCK	IZU IS-JAPAN	804-08	N31 16.5	E139 46.1	186°/109NM	HACHIJO JIMA (HCE) VOR/DME
SUPPLY REEF	MARIANA IS-C PACIFIC	804-142	N20 07.5	E145 06.0	001°/399NM	NIMITZ (UNZ) VORTAC
SUWANOSE-JIMA	RYUKYU IS	802-03	N29 31.5	E129 43.1	011°/65NM	AMAMI (ALC) VORTAC
TAAL	LUZON-PHILIPPINES	703-07	N14 00.1	E120 59.4	288°/8NM	LIPA (LIP) VOR
TARUMAI	HOKKAIDO-JAPAN	805-04	N42 40.5	E141 22.5	274°/13NM	CHITOSE (CHE) VOR/DME
TATE-YAMA	HONSHU-JAPAN	803-08	N36 34.1	E137 36.0	110°/20NM	TOYAMA (TOE) VOR/DME
TENGCHONG	CHINA-S	705-11	N25 18.4	E098 27.4	292°/41NM	BAOSHAN (BSD) VOR

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
TOKACHI	HOKKAIDO-JAPAN	805-05	N43 25.1	E142 40.5	155°/17NM	ASAHIKAWA (AWE) VOR/DME
TORI-SHIMA	IZU IS-JAPAN	804-09	N30 28.5	E140 19.1	176°/160NM	HACHIJO JIMA (HCE) VOR/DME
UNNAMED	LUZON IS-N OF	704-05	N20 19.5	E121 45.0	153°/108NM	HENGCHUN (HCN) VORTAC
UNNAMED	TAIWAN-E OF	801-02	N21 49.5	E121 10.5	109°/19NM	HENGCHUN (HCN) VORTAC
UNNAMED	TAIWAN-E OF	801-03	N24 00.0	E121 49.5	099°/10NM	HUALIEN (HLN) VOR/DME
UNNAMED	TAIWAN-N OF	801-04	N25 24.4	E122 19.5	075°/46NM	ANPU (TAIPEI) (APU) VOR/DME
UNZEN	KYUSHU-JAPAN	802-10	N32 45.0	E130 18.0	121°/21NM	NAGASAKI (OLE) VOR/DME
USU	HOKKAIDO-JAPAN	805-03	N42 31.5	E140 49.5	264°/39NM	CHITOSE (CHE) VOR/DME
YAKE-DAKE	HONSHU-JAPAN	803-07	N36 13.1	E137 34.5	290°/16NM	MATSUMOTO (MBE) VOR/DME
ZAO	HONSHU-JAPAN	803-19	N38 09.0	E140 27.0	121°/5NM	ZAO-YAMADA (ZMO) VOR
ZENGYU	TAIWAN-N OF	801-05	N26 10.5	E122 27.3	043°/78NM	ANPU (TAIPEI) (APU) VOR/DME

MAINLAND ASIA-KURILES-KAMCHATKA PENINSULA

ALAID	KURIL IS	900-39	N50 48.0	E155 30.0	050°/610NM	NAKASHIBETSU (NSE) VOR/DME
ANJUISKY	RUSSIA	1001-02	N67 10.1	E165 12.0	286°/639NM	KUKULIAK (SAVOONGA) (ULL) VOR/DME
ATSONUPURI	KURIL IS	900-05	N44 49.1	E147 07.3	059°/119NM	NAKASHIBETSU (NSE) VOR/DME
AVACHINSKY	KAMCHATKA PENINSULA	1000-10	N53 15.0	E158 51.0	276°/551NM	SHEMYA (SYA) VORTAC
BAITOUSHAN	CHINA-E	1005-07	N41 58.5	E128 04.5	236°/83NM	YANJI (YNJ) VOR/DME
BALAGAN-TAS	RUSSIA	1001-03	N66 25.5	E143 43.5	048°/780NM	CHULMAN (NERUNGRI) (NRG) VOR/DME
BARANSKY	KURIL IS	900-08	N45 06.0	E148 01.5	063°/161NM	NAKASHIBETSU (NSE) VOR/DME
BEZYMIANNY	KAMCHATKA PENINSULA	1000-25	N55 58.1	E160 36.0	294°/510NM	SHEMYA (SYA) VORTAC
CHIKURACHKI-TATARINO	KURIL IS	900-36	N50 19.3	E155 27.3	052°/591NM	NAKASHIBETSU (NSE) VOR/DME
CHIRINKOTAN	KURIL IS	900-26	N48 58.5	E153 28.5	053°/480NM	NAKASHIBETSU (NSE) VOR/DME
CHIRIP PENINSULA GROUP	KURIL IS	900-09	N45 22.5	E147 55.1	057°/167NM	NAKASHIBETSU (NSE) VOR/DME
CHIRPOI	KURIL IS	900-15	N46 31.3	E150 52.3	061°/307NM	NAKASHIBETSU (NSE) VOR/DME
EBEKO	KURIL IS	900-38	N50 40.1	E155 55.5	051°/618NM	NAKASHIBETSU (NSE) VOR/DME
EKARMA	KURIL IS	900-27	N48 57.0	E153 56.3	055°/493NM	NAKASHIBETSU (NSE) VOR/DME
FUSS PEAK	KURIL IS	900-34	N50 13.1	E155 12.0	051°/579NM	NAKASHIBETSU (NSE) VOR/DME
GOLOVNIN	KURIL IS	900-01	N43 48.4	E145 33.0	070°/29NM	NAKASHIBETSU (NSE) VOR/DME
GORELY	KAMCHATKA PENINSULA	1000-07	N52 33.3	E158 01.5	272°/584NM	SHEMYA (SYA) VORTAC
GORIASCHAIA SOPKA	KURIL IS	900-17B	N46 49.5	E151 45.0	062°/348NM	NAKASHIBETSU (NSE) VOR/DME
GROZNY GROUP	KURIL IS	900-07	N45 01.1	E147 52.1	063°/152NM	NAKASHIBETSU (NSE) VOR/DME
HARIMKOTAN	KURIL IS	900-30	N49 03.0	E154 25.5	055°/512NM	NAKASHIBETSU (NSE) VOR/DME
ILYINSKY	KAMCHATKA PENINSULA	1000-03	N51 30.0	E157 12.0	267°/626NM	SHEMYA (SYA) VORTAC
KARPINSKY GROUP	KURIL IS	900-35	N50 09.0	E155 22.1	052°/581NM	NAKASHIBETSU (NSE) VOR/DME
KARYMSKY	KAMCHATKA PENINSULA	1000-13	N54 04.5	E159 25.5	281°/530NM	SHEMYA (SYA) VORTAC
KETOI	KURIL IS	900-20	N47 21.0	E152 28.3	060°/389NM	NAKASHIBETSU (NSE) VOR/DME
KIKHPINYCH	KAMCHATKA PENINSULA	1000-18	N54 28.5	E160 13.5	284°/504NM	SHEMYA (SYA) VORTAC
KIZIMEN	KAMCHATKA PENINSULA	1000-23	N55 09.4	E160 31.5	289°/500NM	SHEMYA (SYA) VORTAC
KLIUCHEVSKOI	KAMCHATKA PENINSULA	1000-26	N56 03.3	E160 38.2	295°/510NM	SHEMYA (SYA) VORTAC
KOLOKOL GROUP	KURIL IS	900-12	N46 03.0	E150 03.3	063°/263NM	NAKASHIBETSU (NSE) VOR/DME
KORYAKSKY	KAMCHATKA PENINSULA	1000-09	N53 18.4	E158 42.4	276°/556NM	SHEMYA (SYA) VORTAC
KOSHELEV	KAMCHATKA PENINSULA	1000-02	N51 21.0	E156 43.5	266°/645NM	SHEMYA (SYA) VORTAC
KRASHENINNIKOV	KAMCHATKA PENINSULA	1000-19	N54 36.0	E160 16.5	285°/503NM	SHEMYA (SYA) VORTAC
KRONOTSKY	KAMCHATKA PENINSULA	1000-20	N54 45.0	E160 31.5	286°/496NM	SHEMYA (SYA) VORTAC
KSUDACH	KAMCHATKA PENINSULA	1000-05	N51 48.0	E157 31.5	268°/610NM	SHEMYA (SYA) VORTAC
KUNLUN VOLCANO GROUP	CHINA-W	1004-03	N35 30.4	E080 12.0	167/92NM	SHACHE (SCH) VOR/DME
LONGGANG GROUP	CHINA-E	1005-06	N42 19.5	E126 30.0	157°/110NM	CHANGCHUN (CGQ) VOR/DME
MALY SEMIACHIK	KAMCHATKA PENINSULA	1000-14	N54 07.5	E159 40.5	282°/522NM	SHEMYA (SYA) VORTAC

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
MEDVEZHIA	KURIL IS	900-10	N45 22.5	E148 48.0	064°/197NM	NAKASHIBETSU (NSE) VOR/DME
MENDELEEV	KURIL IS	900-02	N43 54.0	E145 42.0	068°/37NM	NAKASH BETSU (NSE) VOR/DME
MUTNOVSKY	KAMCHATKA PENINSULA	1000-06	N52 27.0	E158 10.5	271°/580NM	SHEMYA (SYA) VORTAC
NEMO PEAK	KURIL IS	900-32	N49 33.4	E154 48.3	054°/542NM	NAKASHIBETSU (NSE) VOR/DME
OPALA	KAMCHATKA PENINSULA	1000-08	N52 32.4	E157 20.1	272°/610NM	SHEMYA (SYA) VORTAC
PREVO PEAK	KURIL IS	900-19	N47 00.4	E152 06.4	062°/366NM	NAKASHIBETSU (NSE) VOR/DME
RAIKOKE	KURIL IS	900-25	N48 15.0	E153 15.0	057°/446NM	NAKASHIBETSU (NSE) VOR/DME
RASSHUA	KURIL IS	900-22	N47 46.1	E153 01.1	059°/422NM	NAKASHIBETSU (NSE) VOR/DME
SARYCHEV PEAK	KURIL IS	900-24	N48 05.3	E153 12.0	058°/439NM	NAKASHIBETSU (NSE) VOR/DME
SHEVELUCH	KAMCHATKA PENINSULA	1000-27	N56 39.0	E161 21.0	300°/500NM	SHEMYA (SYA) VORTAC
SINARKA	KURIL IS	900-29	N48 52.3	E154 10.3	056°/498NM	NAKASHIBETSU (NSE) VOR/DME
TAO-RUSYR CALDERA	KURIL IS	900-31	N49 21.3	E154 42.3	054°/532NM	NAKASHIBETSU (NSE) VOR/DME
TIATIA	KURIL IS	900-03	N44 21.0	E146 15.0	059°/72NM	NAKASHIBETSU (NSE) VOR/DME
TOLBACHIK	KAMCHATKA PENINSULA	1000-24	N55 49.5	E160 19.5	293°/516NM	SHEMYA (SYA) VORTAC
UNNAMED	KURIL IS	900-23	N48 04.5	E153 19.5	058°/443NM	NAKASHIBETSU (NSE) VOR/DME
UNNAMED	KURIL IS	900-16	N46 30.0	E151 00.0	062°/311NM	NAKASHIBETSU (NSE) VOR/DME
USHISHIR CALDERA	KURIL IS	900-21	N47 30.4	E152 48.4	060°/406NM	NAKASHIBETSU (NSE) VOR/DME
USHKOVSKY	KAMCHATKA PENINSULA	1000-261	N56 06.4	E160 30.4	295°/515NM	SHEMYA (SYA) VORTAC
VEER	KAMCHATKA PENINSULA	1000-102	N53 37.5	E158 34.5	278°/560NM	SHEMYA (SYA) VORTAC
WUDALIANCHI	CHINA-E	1005-04	N48 42.4	E126 06.4	054°/124NM	QIQIHAER (NDG) VOR
XIANJINDAO	KOREA	1006-01	N41 19.5	E128 00.0	223°/116NM	PYONGYANG (SUNAN) (GK) VOR/DME
ZAVARITZKI CALDERA	KURIL IS	900-18	N46 55.3	E151 57.0	062°/358NM	NAKASHIBETSU (NSE) VOR/DME
ZHELTOVSKY	KAMCHATKA PENINSULA	1000-04	N51 34.1	E157 15.0	267°/623NM	SHEMYA (SYA) VORTAC
ZHUPANOVSKY	KAMCHATKA PENINSULA	1000-12	N53 35.2	E159 08.5	278°/540NM	SHEMYA (SYA) VORTAC

ALEUTIANS-PACIFIC-NORTH AMERICA

AKUTAN	ALEUTIAN IS	1101-32	N54 07.5	W165 58.1	222°/130NM	COLD BAY (COB) VORTAC
AMAK	ALEUTIAN IS	1101-39	N55 24.4	W163 09.0	286°/15NM	COLD BAY (CDB) VORTAC
AMUKTA	ALEUTIAN IS	1101-19	N52 30.0	W171 15.0	227°/343NM	COLD BAY (COB) VORTAC
ANIAKCHAK	ALASKA PENINSULA	1102-09	N56 52.5	W158 09.0	086°/16NM	TURNBULL (PORT HEIDEN) (PTH) VOR/ DME
ATKA	ALEUTIAN IS	1101-16	N52 22.5	W174 09.0	085°/431NM	SHEMYA (SYA) VORTAC
AUGUSTINE	ALASKA-SW	1103-01	N59 21.4	W153 24.4	227°/63NM	HOMER (HOM) VORTAC
BOGOSLOF	ALEUTIAN IS	1101-30	N53 55.5	W168 01.5	231°/200NM	COLD BAY (CDB) VORTAC
CARLISLE	ALEUTIAN IS	1101-23	N52 54.0	W170 03.0	227°/293NM	COLD BAY (CDB) VORTAC
CHIGINAGAK	ALASKA PENINSULA	1102-11	N57 07.5	W157 00.0	060°/54NM	TURNBULL (PORT HEIDEN) (PTH) VOR/ DME
CLEVELAND	ALEUTIAN IS	1101-24	N52 48.4	W169 57.0	225°/293NM	COLD BAY (CDB) VORTAC
FISHER	ALEUTIAN IS	1101-35	N54 39.4	W164 21.0	219°/65NM	COLD BAY (CDB) VORTAC
GARELOI	ALEUTIAN IS	1101-07	N51 46.5	W178 48.0	096°/269NM	SHEMYA (SYA) VORTAC
GLACIER PEAK	USA-WASHINGTON	1201-02	N48 06.4	W121 06.4	027°/63NM	SEATTLE (SEA) VORTAC
GREAT SITKIN	ALEUTIAN IS	1101-12	N52 04.5	W176 07.5	089°/362NM	SHEMYA (SYA) VORTAC
HALEAKALA	HAWAIIAN IS	1302-06	N20 42.3	W156 15.0	127°/15NM	MAUI (KAHULUI) (OGG) VORTAC
HUALALAI	HAWAIIAN IS	1302-04	N19 41.3	W155 51.4	065°/9NM	KONA (KAILUA-KONA) (IAI) VORTAC
ILIAMNA	ALASKA-SW	1103-02	N60 01.5	W153 04.5	268°/52NM	HOMER (HOM) VORTAC
ISANOTSKI	ALEUTIAN IS	1101-37	N54 45.0	W163 43.5	210°/45NM	COLD BAY (CDB) VORTAC
ISKUT-UNUK RIVER GROUP	CANADA	1200-10	N56 34.5	W130 33.0	056°/84NM	LEVEL ISLAND (LVD) VOR/ DME
KAGAMIL	ALEUTIAN IS	1101-26	N52 57.4	W169 42.4	226°/281NM	COLD BAY (CDB) VORTAC
KANAGA	ALEUTIAN IS	1101-11	N51 54.4	W177 09.4	092°/326NM	SHEMYA (SYA) VORTAC
KASATOCHI	ALEUTIAN IS	1101-13	N52 10.5	W175 30.0	087°/384NM	SHEMYA (SYA) VORTAC
KATMAI	ALASKA PENINSULA	1102-17	N58 16.1	W154 58.5	094°/62NM	KING SALMON (AKN) VORTAC
KILAUEA	HAWAIIAN IS	1302-01	N19 25.3	W155 17.3	211°/23NM	HILO (ITO) VORTAC
KISKA	ALEUTIAN IS	1101-02	N52 06.0	E177 36.0	101°/135NM	SHEMYA (SYA) VORTAC
KUPREANOF	ALASKA PENINSULA	1102-06	N56 00.4	W159 48.0	196°/68NM	TURNBULL (PORT HEIDEN) (PTH) VOR/ DME
LASSEN	USA-CALIFORNIA	1203-07	N40 29.3	W121 30.3	036°/40NM	RED BLUFF (RBL) VORTAC
LITTLE SITKIN	ALEUTIAN IS	1101-05	N51 57.0	E178 31.5	100°/170NM	SHEMYA (SYA) VORTAC
MACDONALD	PACIFIC-C	1303-07	S28 58.5	W140 15.0	176°/436NM	MURUROA (MRA) VOR/DME

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
MAGEIK	ALASKA PENINSULA	1102-15	N58 12.0	W155 15.0	102°/56NM	KING SALMON (AKN) VORTAC
MAKUSHIN	ALEUTIAN IS	1101-31	N53 54.0	W166 55.5	225°/166NM	COLD BAY (CDB) VORTAC
MARTIN	ALASKA PENINSULA	1102-14	N58 09.4	W155 21.0	105°/55NM	KING SALMON (AKN) VORTAC
MAUNALOA	HAWAIIAN IS	1302-02	N19 28.3	W155 36.3	103°/25NM	KONA (KAILUA-KONA) (IAI) VORTAC
MEDICINE LAKE	USA-CALIFORNIA	1203-02	N41 31.5	W121 31.5	149°/38NM	KLAMATH FALLS (LMT) VORTAC
MONO LAKE VOLCANO FIELD	USA-CALIFORNIA	1203-11	N38 01.5	W119 00.4	218°/56NM	MINA (MVA) VORTAC
MOUNT BAKER	USA-WASHINGTON	1201-01	N48 47.1	W121 48.4	087°/31NM	BELLINGHAM (BLI) VORTAC
MOUNT HOOD	USA-OREGON	1202-01	N45 21.4	W121 42.0	209°/33NM	KLICKITAT (THE DALLES) (LTJ) VORTAC
MOUNT RAINIER	USA-WASHINGTON	1201-03	N46 51.4	W121 45.3	124°/41NM	SEATTLE (SEA) VORTAC
MOUNT SHASTA	USA-CALIFORNIA	1203-01	N41 24.0	W122 10.5	187°/49NM	KLAMATH FALLS (LMT) VORTAC
MOUNT ST HELENS	USA-WASHINGTON	1201-05	N46 12.0	W122 10.5	011°/32NM	BATTLE GROUND (BTG) VORTAC
MOUNT WRANGELL	ALASKA-E	1105-02	N62 00.0	W144 00.4	074°/41NM	GULKANA (GKN) VORTAC
NOVARUPTA KATMAI	ALASKA PENINSULA	1102-18	N58 16.1	W155 09.4	096°/57NM	KING SALMON (AKN) VORTAC
OKMOK	ALEUTIAN IS	1101-29	N53 24.4	W168 07.5	224°/218NM	COLD BAY (CDB) VORTAC
PAVLOF	ALASKA PENINSULA	1102-03	N55 25.1	W161 54.0	055°/31NM	COLD BAY (CDB) VORTAC
PAVLOF SISTER	ALASKA PENINSULA	1102-04	N55 27.0	W161 51.4	053°/33NM	COLD BAY (CDB) VORTAC
PROSPECT PEAK	USA-CALIFORNIA	1203-08	N40 33.0	W121 19.1	039°/50NM	RED BLUFF (RBL) VORTAC
REDOUBT	ALASKA-SW	1103-03	N60 28.5	W152 45.0	235°/46NM	KENAI (ENA) VOR/DME
SEGUAM	ALEUTIAN IS	1101-18	N52 18.4	W172 30.4	229°/388NM	COLD BAY (CDB) VORTAC
SEMISOPOCHNOI	ALEUTIAN IS	1101-06	N51 55.5	E179 36.0	097°/209NM	SHEMYA (SYA) VORTAC
SHISHALDIN	ALEUTIAN IS	1101-36	N54 45.0	W163 57.4	216°/51NM	COLD BAY (CDB) VORTAC
SOUTH SISTER	USA-OREGON	1202-08	N44 06.0	W121 45.4	227°/21NM	DESCHUTES (REDMOND) (DSD) VORTAC
SPURR	ALASKA-SW	1103-04	N61 18.0	W152 15.0	298°/51NM	KENAI (ENA) VOR/DME
TANAGA	ALEUTIAN IS	1101-08	N51 52.5	W178 07.5	093°/291NM	SHEMYA (SYA) VORTAC
TRIDENT	ALASKA PENINSULA	1102-16	N58 13.5	W155 04.5	097°/60NM	KING SALMON (AKN) VORTAC
TSEAX RIVER CONE	CANADA	1200-12	N55 06.4	W128 51.4	273°/86NM	HOUSTON (SMITHERS) (YYD) VOR/DME
UGASHIK-PEULIK	ALASKA PENINSULA	1102-13	N57 45.0	W156 21.4	146°/59NM	KING SALMON (AKN) VORTAC
UKINREK MAARS	ALASKA PENINSULA	1102-13	N57 49.5	W156 30.4	150°/54NM	KING SALMON (AKN) VORTAC
UNNAMED	PACIFIC-C	1303-01	N09 49.1	W104 18.0	198°/107NM	PHNOM PENH (PNH) VOR/DME
UNNAMED	PACIFIC-N	1301-02	N45 01.5	W130 12.0	259°/263NM	NEWPORT (ONP) VORTAC
UNNAMED	PACIFIC-N	1301-01	N46 33.0	W129 34.3	246°/225NM	HOQUIAM (HQM) VORTAC
UNNAMED	HAWAIIAN IS	1302-09	N23 34.5	W163 49.5	282°/258NM	SOUTH KAUAI (SOK) VORTAC
VENIAMINOF	ALASKA PENINSULA	1102-07	N56 09.4	W159 22.5	189°/53NM	TURNBULL (PORT HEIDEN) (PTH) VOR/ DME
VSEVIDOF	ALEUTIAN IS	1101-27	N53 07.5	W168 40.5	223°/244NM	COLD BAY (CDB) VORTAC
WESTDAHL	ALEUTIAN IS	1101-34	N54 30.0	W164 39.0	218°/79NM	COLD BAY (CDB) VORTAC
YUNASKA	ALEUTIAN IS	1101-21	N52 37.5	W170 37.5	226°/320NM	COLD BAY (CDB) VORTAC

MEXICO-CENTRAL AMERICA

ACATENANGO	GUATEMALA	1402-08	N14 30.0	W090 52.3	251°/20NM	LA AURORA (GUAT. CITY) (AUR) VOR/ DME
ALMOLONGA	GUATEMALA	1402-04	N14 48.4	W091 28.5	083°/52NM	TAPACHULA (TAP) VOR/DME
ARENAL	COSTA RICA	1405-033	N10 27.5	W084 42.1	313°/39NM	EL COCO (SAN JOSE) (TIO) VOR/DME
ATITLAN	GUATEMALA	1402-06	N14 34.6	W091 11.1	265°/38NM	LA AURORA (GUAT. CITY) (AUR) VOR/ DME
BARCENA	MEXICO-IS	1401-02	N19 15.4	W110 48.0	185°/240NM	CABOS (SAN JOSE DEL CABO) (SJD) VOR/ DME
BARU	PANAMA	1407-01	N08 48.0	W082 33.3	342°/25NM	DAVID (DAV) VOR/DME
BARVA	COSTA RICA	1405-05	N10 08.1	W084 06.0	040°/12NM	EL COCO (SAN JOSE) (TIO) VOR/DME
CERRO NEGRO	NICARAGUA	1404-07	N12 30.2	W086 42.1	157°/96NM	TONCONTIN (TEGUCIGALPA) (TNT) VOR/ DME
COLIMA VOLCANO COMPLEX	MEXICO	1401-04	N19 30.5	W103 37.1	342°/14NM	COLIMA (COL) VOR/DME
CONCEPCION	NICARAGUA	1404-12	N11 32.2	W085 37.2	353°/56NM	LIBERIA (LIB) VOR/DME
CONCHAGUITA	EL SALVADOR	1403-12	N13 12.4	W087 45.5	209°/58NM	TONCONTIN (TEGUCIGALPA) (TNT) VOR/ DME
COSIGUINA	NICARAGUA	1404-01	N12 58.5	W087 33.4	193°/65NM	TONCONTIN (TEGUCIGALPA) (TNT) VOR/ DME
EL CHICHON	MEXICO	1401-12	N17 21.4	W093 13.4	005°/36NM	TUXTLA (TUXTLA GUTIERREZ) (TGZ) VOR/DME
FUEGO	GUATEMALA	1402-09	N14 28.2	W090 52.5	247°/21NM	LA AURORA (GUAT. CITY) (AUR) VOR/ DME
ILOPANGO	EL SALVADOR	1403-06	N13 40.2	W089 03.1	102°/3NM	ILOPANGO (SAN SALVADOR) (YSV) VOR/ DME
IRAZU	COSTA RICA	1405-06	N09 58.4	W083 51.1	089°/22NM	EL COCO (SAN JOSE) (TIO) VOR/DME
IZALCO	EL SALVADOR	1403-03	N13 48.4	W089 37.6	280°/31NM	ILOPANGO (SAN SALVADOR) (YSV) VOR/ DME

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
LA YEGUADA	PANAMA	1407-02	N08 31.2	W080 54.4	004°/26NM	SANTIAGO (STG) VOR
LAGUNA VERDE	EL SALVADOR	1403-01	N13 53.3	W089 47.1	283°/40NM	ILOPANGO (SAN SALVADOR) (YSV) VOR/ DME
LAS PILAS	NICARAGUA	1404-08	N12 29.4	W086 41.2	156°/96NM	TONCONTIN (TEGUCIGALPA) (TNT) VOR/ DME
MASAYA	NICARAGUA	1404-10	N11 59.0	W086 09.4	334°/90NM	LIBERIA (LIB) VOR/DME
MICHOACAN-GUANAJUATO	MEXICO	1401-06	N19 28.5	W102 15.0	285°/12NM	URUAPAN (UPN) VOR/DME
MIRAVALLES	COSTA RICA	1405-03	N10 44.5	W085 09.1	066°/25NM	LIBERIA (LIB) VOR/DME
MOMOTOMBO	NICARAGUA	1404-09	N12 25.2	W086 32.2	153°/104NM	TONCONTIN (TEGUCIGALPA) (TNT) VOR/ DME
PACAYA	GUATEMALA	1402-11	N14 22.5	W090 36.0	194°/13NM	LA AURORA (GUAT. CITY) (AUR) VOR/ DME
PICO DE ORIZABA	MEXICO	1401-10	N19 01.5	W097 16.1	256°/61NM	VERACRUZ (VER) VOR/DME
PINACATE PEAKS	MEXICO	1401-001	N31 46.2	W113 29.5	349°/25NM	PENASCO (PUNTA PENASCO) (PPE) VOR/ DME
POAS	COSTA RICA	1405-04	N10 12.0	W084 13.6	360°/12NM	EL COCO (SAN JOSE) (TIO) VOR/DME
POPOCATEPETL	MEXICO	1401-09	N19 01.2	W098 37.2	233°/16NM	PUEBLA (PBC) VOR/DME
RINCON DE LA VIEJA	COSTA RICA	1405-02	N10 49.5	W085 19.3	040°/19NM	LIBERIA (LIB) VOR/DME
SAN CRISTOBAL	NICARAGUA	1404-02	N12 42.1	W087 00.1	166°/80NM	TONCONTIN (TEGUCIGALPA) (TNT) VOR/ DME
SAN MIGUEL	EL SALVADOR	1403-10	N13 25.5	W088 16.2	087°/45NM	EL SALVADOR (SAN SALVADOR) (CAT) VOR/DME
SAN SALVADOR	EL SALVADOR	1403-05	N13 44.1	W089 17.1	282°/10NM	ILOPANGO (SAN SALVADOR) (YSV) VOR/ DME
SANTA ANA	EL SALVADOR	1403-02	N13 51.1	W089 37.5	284°/31NM	ILOPANGO (SAN SALVADOR) (YSV) VOR/ DME
SANTA MARIA	GUATEMALA	1402-03	N14 45.2	W091 33.1	087°/47NM	TAPACHULA (TAP) VOR/DME
SOCORRO	MEXICO-IS	1401-021	N18 45.0	W110 57.0	184°/271NM	CABOS (SAN JOSE DEL CABO) (SJD) VOR/ DME
TACANA	MEXICO	1401-13	N15 07.5	W092 06.5	032°/25NM	TAPACHULA (TAP) VOR/DME
TELICA	NICARAGUA	1404-04	N12 36.1	W086 50.4	161°/88NM	TONCONTIN (TEGUCIGALPA) (TNT) VOR/ DME
TRES VIRGENES	MEXICO	1401-01	N27 28.1	W112 35.3	289°/19NM	ROSALIA (SANTA ROSALIA) (SRL) VOR/ DME
TURRIALBA	COSTA RICA	1405-07	N10 01.5	W083 46.1	083°/27NM	EL COCO (SAN JOSE) (TIO) VOR/DME
VOLCANO CEBORUCO	MEXICO	1401-03	N21 07.3	W104 30.0	124°/25NM	TEPIC (TNY) VOR/DME
VOLCANO DE SAN MARTIN	MEXICO	1401-11	N18 34.2	W095 10.1	304°/43NM	MINATITLAN (MTT) VOR/DME

SOUTH AMERICA-CARIBBEAN

ANTISANA	ECUADOR	1502-03	S00 28.5	W078 08.2	047°/39NM	LATACUNGA (LTV) VOR/DME
ANTUCO	CHILE-C	1507-08	S37 24.2	W071 20.6	081°/51NM	LOS ANGELES (MAD) VOR
ARACAR	ARGENTINA	1505-107	S24 16.1	W067 46.1	152°/122NM	EL LOA (CALAMA) (LOA) VOR/DME
CALBUCO	CHILE-S	1508-02	S41 18.4	W072 36.0	061°/23NM	PUERTO MONTT (MON) VOR/DME
CALLAQUI	CHILE-C	1507-081	S37 54.4	W071 24.4	113°/57NM	LOS ANGELES (MAD) VOR
CARRAN-LOS VENADOS	CHILE-C	1507-14	S40 21.0	W072 04.1	239°/48NM	SAN MARTIN DE LOS ANDES (CHP) VOR/ DME
CERRO QUIZAPU AZUL	CHILE-C	1507-06	S35 39.1	W070 45.4	144°/46NM	CURICO ([CO) VOR/DME
CERRO AZUL	GALAPAGOS	1503-06	S00 54.0	W091 25.1	274°/631NM	SALINAS (SAV) VOR/DME
CERRO BRAVO	COLOMBIA	1501-011	N05 05.3	W075 18.0	255°/23NM	MARIQUITA (MQU) VOR
CERRO HUDSON	CHILE-S	1508-057	S45 54.0	W072 58.1	137°/50NM	PUERTO (PAR) VOR/DME
CERRO YANTELES	CHILE-S	1508-051	S43 25.1	W072 49.3	236°/82NM	ESQUEL (ESQ) VOR
CHACANA	ECUADOR	1502-022	S00 22.3	W078 15.0	033°/39NM	LATACUNGA (LTV) VOR/DME
CORCOVADO	CHILE-S	1508-05	S43 10.5	W072 48.0	246°/76NM	ESQUEL (ESQ) VOR
CORDON CAULLE	CHILE-C	1507-141	S40 30.4	W072 12.0	232°/57NM	SAN MARTIN DE LOS ANDES (CHP) VOR/ DME
COTOPAXI	ECUADOR	1502-05	S00 40.4	W078 26.1	036°/18NM	LATACUNGA (LTV) VOR/DME
CUMBAL	COLOMBIA	1501-10	N00 58.5	W077 52.5	236°/43NM	PASTO (PST) VOR/DME
DESCABEZADO GRANDE	CHILE-C	1507-05	S35 34.5	W070 45.0	141°/43NM	CURICO (ICO) VOR/DME
DONA JUANA	COLOMBIA	1501-07	N01 28.1	W076 55.1	085°/22NM	PASTO (PST) VOR/DME
EL MISTI	PERU	1504-01	S16 17.4	W071 24.3	079°/11NM	AREQUIPA (EQU) VOR/DME
FERNANDINA	GALAPAGOS	1503-01	S00 22.1	W091 33.0	266°/76NM	GALAPAGOS (ISLA BALTRA) (GLV) VOR/ DME
GALERAS	COLOMBIA	1501-08	N01 13.1	W077 22.1	204°/11NM	PASTO (PST) VOR/DME
GUAGUA PICHINCHA	ECUADOR	1502-02	S00 10.2	W078 35.5	001°/45NM	LATACUNGA (LTV) VOR/DME

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
GUALLATIRI	CHILE-N	1505-02	S18 25.1	W069 10.1	107°/67NM	TACNA (TCA) VOR/DME
HUAYNAPUTINA	PERU	1504-03	S16 36.3	W070 51.0	111°/46NM	AREQUIPA (EQU) VOR/DME
HUEQUI	CHILE-S	1508-03	S42 21.4	W072 34.5	146°/601NM	PUERTO MONTT (MON) VOR/DME
HUILA	COLOMBIA	1501-05	N02 55.1	W076 03.0	1465°/36NM	CALI (CLO) VOR/DME
ISLUGA	CHILE-N	1505-03	S19 09.0	W068 49.5	12019°/98NM	ARICA (ARI) VOR/DME
KICK-'EM-JENNY	W INDIES	1600-16	N12 18.0	W061 37.5	040°/20NM	POINT SALINES (ST GEORGE'S) (GND) VOR/DME
LASCAR	CHILE-N	1505-10	S23 22.1	W067 43.5	131°/82NM	EL LOA (CALAMA) (LOA) VOR/DME
LAUTARO	CHILE-S	1508-06	S49 00.4	W073 33.0	128°/95NM	ISLOTE SAN PEDRO (ISP) VOR/DME
LLAIMA	CHILE-C	1507-11	S38 42.0	W071 42.0	075°/43NM	TEMUCO (TCO) VOR/DME
LLULLAILLACO	CHILE-N	1505-11	S24 43.1	W068 31.5	125°/129NM	ANTOFAGASTA (FAG) VOR/DME
LONQUIMAY	CHILE-C	1507-10	S38 22.1	W071 34.5	055°/54NM	TEMUCO (TCO) VOR/DME
MAIPO	CHILE-C	1507-021	S34 09.4	W069 49.4	127°/58NM	LOS CERRILLOS (SANTIAGO) (SCL) VOR/ DME
MARCHENA	GALAPAGOS	1503-08	N00 19.5	W090 28.1	046°/497NM	BANDA ACEH (BAC) VOR/DME
MICOTRIN	W INDIES	1600-10	N15 19.5	W061 19.5	351°/47NM	FORT DE FRANCE (FOF) VOR/DME
MINCHINMAVIDA	CHILE-S	1508-04	S42 46.5	W072 25.5	265°/58NM	ESQUEL (ESQ) VOR
MOCHO-CHOSHUENCO	CHILE-C	1507-13	S39 55.4	W072 01.5	270°/43NM	SAN MARTIN DE LOS ANDES (CHP) VOR/ DME
MONTAGNE PELEE	W INDIES	1600-12	N14 49.1	W061 10.1	341°/16NM	FORT DE PRANCE (FOF) VOR/DME
MONTE BURNEY	CHILE-S	1508-07	S52 19.5	W073 24.0	208°/50NM	PUERTO NATALES (PNT) VOR/DME
MORNE PATATES	W INDIES	1600-11	N15 13.1	W061 22.1	344°/42NM	FORT DE FRANCE (FOF) VOR/DME
MOUNT LIAMUIGA	W INDIES	1600-03	N17 22.1	W062 48.0	167°/43NM	SAINT MAARTEN (PJM) VOR/DME
NEGRO DE MAYASQUER	COLOMBIA	1501-11	N00 49.4	W077 57.3	262°/17NM	IPIALES (IPI) VOR
NEVADOS DE CHILLAN	CHILE-C	1507-07	S36 51.5	W071 22.3	110°/36NM	CHILLAN (CHI) VOR/DME
OLCA-PARUMA	CHILE-N	1505-05	S20 55.5	W068 28.5	015°/96NM	EL LOA (CALAMA) (LOA) VOR/DME
OSORNO	CHILE-S	1508-01	S41 06.0	W072 30.0	042°/33NM	PUERTO MONTT (MON) VOR/DME
PINTA	GALAPAGOS	1503-07	N00 34.5	W090 45.0	328°/67NM	BANDA ACEH (BAC) VOR/DME
PLANCHON-PETEROA	CHILE-C	1507-04	S35 14.2	W070 34.1	110°/35NM	CURICO (ICO) VOR/DME
PUNTIAGUDO-CORDON CEN	CHILE-C	1507-16	S40 57.0	W072 15.4	042°/47NM	PUERTO MONTT (MON) VOR/DME
PURACE	COLOMBIA	1501-06	N02 18.0	W076 24.0	058°/54NM	MERCADERES (MER) VOR
PUTANA	CHILE-N	1505-09	S22 33.4	W067 51.4	095°/56NM	EL LOA (CALAMA) (LOA) VOR/DME
QUALIBOU	W INDIES	1600-14	N13 49.5	W061 03.0	336°/7NM	HEWANORRA (SAINT LUCIA) (BNE) VOR/ DME
QUILOTOA	ECUADOR	1502-06	S00 51.0	W078 54.0	284°/17NM	LATACUNGA (LTV) VOR/DME
REVENTADOR	ECUADOR	1502-01	S00 04.4	W077 39.2	048°/76NM	LATACUNGA (LTV) VOR/DME
ROBINSON CRUSOE	CHILE-IS	1506-02	S33 39.2	W078 51.0	292°/340NM	CONCEPCION (CAR) VOR/DME
RUIZ	COLOMBIA	1501-02	N04 53.4	W075 19.2	234°/30NM	MARIQUITA (MQU) VOR
SABA	W INDIES	1600-01	N17 37.5	W063 13.5	206°/25NM	SAINT MAARTEN (PJM) VOR/DME
SABANCAYA	PERU	1504-003	S15 46.5	W071 51.0	338°/36NM	AREQUIPA (EQU) VOR/DME
SAN JOSE	CHILE-C	1507-02	S33 46.6	W069 53.5	107°/43NM	LOS CERRILLOS (SANTIAGO) (SCL) VOR/ DME
SAN PEDRO	CHILE-N	1505-07	S21 52.5	W068 24.0	037°/45NM	EL LOA (CALAMA) (LOA) VOR/DME
SANGAY	ECUADOR	1502-09	S02 01.5	W078 19.5	210°/36NM	PASTAZA (SHELL MERA) (PAV) VOR/DME
SANTIAGO	GALAPAGOS	1503-09	S00 13.1	W090 46.1	287°/31NM	GALAPAGOS (ISLA BALTRA) (GLV) VOR/ DME
SIERRA NEGRA	GALAPAGOS	1503-05	S00 49.5	W091 10.1	275°/617NM	SALINAS (SAV) VOR/DME
SOUFRIERE GUADELOUPE	W INDIES	1600-06	N16 03.0	W061 40.1	224°/15NM	POINTE A PITRE (PPR) VOR/DME
SOUFRIERE HILLS	W INDIES	1600-05	N16 43.1	W062 10.5	235°/32NM	V.C. BIRD (SAINT JOHNS) (ANU) VOR/DME
SOUFRIERE ST VINCENT	W INDIES	1600-15	N13 19.5	W061 10.5	219°/26NM	HEWANORRA (SAINT LUCIA) (BNE) VOR/ DME
SUMACO	ECUADOR	1502-04	S00 33.4	W077 39.0	021°/60NM	PASTAZA (PAV) VOR/DME
TINGUIRIRICA	CHILE-C	1507-03	S34 48.5	W070 21.1	071°/43NM	CURICO (ICO) VOR/DME
TOLIMA	COLOMBIA	1501-03	N04 40.1	W075 19.5	324°/21NM	IBAGUE (BG) VOR/DME
TUNGURAHUA	ECUADOR	1502-08	S01 27.6	W078 26.3	149°/12NM	AMBATO (AMV) VOR/DME
TUPUNGATITO	CHILE-C	1507-01	S33 24.0	W069 48.0	077°/45NM	LOS CERRILLOS (SANTIAGO) (SCL) VOR/ DME
TUTUPACA	PERU	1504-04	S17 01.3	W070 21.3	359°/65NM	TACNA (TCA) VOR/DME
UBINAS	PERU	1504-02	S16 21.2	W070 54.1	093°/39NM	AREQUIPA (EQU) VOR/DME
VILLARRICA	CHILE-C	1507-12	S39 25.0	W071 56.0	132°/50NM	TEMUCO (TCO) VOR/DME
VOLCANO ALCEDO	GALAPAGOS	1503-04	S00 25.5	W091 07.1	264°/50NM	GALAPAGOS (ISLA BALTRA) (GLV) VOR/ DME
VOLCANO VIEDMA	CHILE-S	1508-061	S49 25.1	W073 16.5	131°/121NM	ISLOTE SAN PEDRO (ISP) VOR/DME
VOLCANO WOLF	GALAPAGOS	1503-02	N00 01.1	W091 21.0	052°/524NM	GALAPAGOS (ISLA BALTRA) (GLV)

Volcano Name	Country/State Region	Volcano number	Volcano lat-long		Radial (MAG BRG) and distance from reference Navigation Aid	
						VOR/ DME
YUCAMANE	PERU	1504-05	S17 10.5	W070 12.0	007°/56NM	TACNA (TCA) VOR/DME

ICELAND-ATLANTIC-ANTARCTICA

AGUA DE PAU	AZORES	1802-09	N37 46.1	W025 28.1	120°/14NM	SAN MIGUEL (VMG) VORTAC
ASKJA	ICELAND-NE	1703-06	N65 01.5	W016 45.0	162°/54NM	AKUREYRI (AKI) VOR/DME
BARDARBUNGA	ICELAND-NE	1703-03	N64 37.5	W017 31.5	352°/55NM	INGO (ING) VOR/DME
BOUVET	ATLANTIC-S	1806-02	S54 24.4	E 003 21.0	227°/1385NM	CAPE TOWN (CTV) VOR/DME
BRISTOL ISLAND	ANTARCTICA	1900-08	S59 01.5	W026 34.5	072°/905NM	MARAMBIO (MBI) VOR/DME
BUCKLE ISLAND	ANTARCTICA	1900-01	S66 48.0	E163 15.0	160°/1236NM	INVERCARGILL (NV) VOR/DME
CANDLEMAS ISLAND	ANTARCTICA	1900-10	S57 04.5	W026 42.4	066°/970NM	MARAMBIO (MBI) VOR/DME
DECEPTION ISLAND	ANTARCTICA	1900-03	S62 58.1	W060 39.0	211°/65NM	ISLA REY JORGE (IRJ) VOR/DME
DON JOAO DE CASTRO BANK	AZORES	1802-07	N38 13.5	W026 37.5	159°/40NM	LAJES (LM) VOR
ESJUFJOLL	ICELAND-SE	1704-02	N64 16.1	W016 34.1	020°/28NM	INGO (ING) VOR/DME
EYJAFJOLL	ICELAND-S	1702-02	N63 37.5	W019 36.4	280°/80NM	INGO (ING) VOR/DME
FAYAL	AZORES	1802-01	N38 36.0	W028 43.5	326°/7NM	HORTA (VFL) VORTAC
FOGO	CAPE VERDE IS	1804-01	N14 57.0	W024 21.0	230°/134NM	SAL (CVS) VOR/DME
FREMRINAMUR	ICELAND-NE	1703-07	N65 25.3	W016 39.0	139°/39NM	AKUREYRI (AKI) VOR/DME
FURNAS	AZORES	1802-10	N37 46.1	W025 19.1	114°/21NM	SAN MIGUEL (VMG) VORTAC
GRIMSVOTN	ICELAND-NE	1703-01	N64 25.1	W017 19.5	351°/41NM	INGO (ING) VOR/DME
HEKLA	ICELAND-S	1702-07	N63 58.5	W019 42.0	110°/77NM	KEFLAVIK (KEF) VORTAC
HIERRO	CANARY IS	1803-02	N27 43.5	W018 00.0	265°/71NM	TENERIFE-SOUTH (TFS) VOR/DME
JAN MAYEN	ATLANTIC-N	1706-01	N71 04.5	W008 10.1	048°/386NM	AKUREYRI (AKI) VOR/DME
KATLA	ICELAND-S	1702-03	N63 37.5	W019 01.5	278°/64NM	INGO (ING) VOR/DME
KOLBEINSEY RIDGE	ICELAND-N OF	1705-01	N67 07.1	W018 36.0	009°/83NM	AKUREYRI (AKI) VOR/DME
KRAFLA	ICELAND-NE	1703-08	N65 43.5	W016 46.5	111°/30NM	AKUREYRI (AKI) VOR/DME
KRAKAGIGAR	ICELAND-S	1702-09	N64.00.4	W019 27.4	297°/75NM	INGO (ING) VOR/DME
KVERKFJOLL	ICELAND-NE	1703-05	N64 39.0	W016 43.1	014°/51NM	INGO (ING) VOR/DME
LA PALMA	CANARY IS	1803-01	N28 34.5	W017 49.5	308°/69NM	TENERIFE-SOUTH (TFS) VOR/DME
LANZAROTE	CANARY IS	1803-06	N29 01.5	W013 37.5	359°/5NM	LANZAROTE (LT) VOR/DME
LOKI-FOGRUFJOLL	ICELAND-NE	1703-02	N64 28.3	W017 48.0	340°/50NM	INGO (ING) VOR/DME
MONACO BANK	AZORES	1802-11	N37 36.0	W025 52.5	213°/15NM	SAN MIGUEL (VMG) VORTAC
MOUNT EREBUS	ANTARCTICA	1900-02	S77 31.5	E167 10.1	155°/1872NM	INVERCARGILL (NV) VOR/DME
MOUNT MELBOURNE	ANTARCTICA	1900-015	S74 21.0	E164 42.0	157°/1683NM	INVERCARGILL (NV) VOR/DME
MOUNT MICHAEL	ANTARCTICA	1900-09	S57 46.5	W026 27.0	069°/951NM	MARAMBIO (MBI) VOR/DME
MUNDAFELL	ICELAND-S	1702-08	N63 58.5	W019 33.0	296°/78NM	INGO (ING) VOR/DME
ORAEFAJOKULL	ICELAND-SE	1704-01	N64 00.0	W016 39.0	015°/11NM	INGO (ING) VOR/DME
PENGUIN	ANTARCTICA	1900-031	S62 06.0	W057 55.5	068°/30NM	ISLA REY JORGE (IRJ) VOR/DME
PICO	AZORES	1802-02	N38 27.4	W028 24.0	121°/11NM	HORTA (VFL) VORTAC
PROTECTOR SHOAL	ANTARCTICA	1900-14	S55 54.4	W028 04.5	061°/981NM	MARAMBIO (MBI) VOR/DME
REYKJANES	ICELAND-SW	1701-02	N63 52.3	W022 30.0	175°/7NM	KEFLAVIK (KEF) VORTAC
REYKJANESHRYGGUR	ICELAND-SW	1701-01	N63 40.1	W023 19.3	244°/26NM	KEFLAVIK (KEF) VORTAC
SAN JORGE	AZORES	1802-03	N38 39.0	W028 04.5	085°/26NM	HORTA (VFL) VORTAC
SEAL NUNATAKS GROUP	ANTARCTICA	1900-05	S65 01.5	W060 03.0	229°/100NM	MARAMBIO (MBI) VOR/DME
SETE CIDADES	AZORES	1802-08	N37 52.1	W025 46.5	336°/1NM	SANTA MARIA (VMG) VORTAC
TENERIFE	CANARY IS	1803-03	N28 16.2	W016 38.3	016°/16NM	TENERIFE-SOUTH (TFS) VOR/DME
TERCEIRA	AZORES	1802-05	N38 43.5	W027 18.4	266°/10NM	LAJES (LM) VOR
TJORNES FRACTURE ZONE	ICELAND-N OF	1703-10	N66 18.0	W017 06.0	052°/39NM	AKUREYRI (AKI) VOR/DME
TRISTAN DA CUNHA	ATLANTIC-S	1806-01	S37 05.3	W012 16.5	276°/1508NM	ROBBEN ISLAND (RIV) VOR/DME
UNNAMED	ARCTIC OCEAN	2001-01	N88.15.4	W065 36.0	066°/706NM	THULE (THT) VORTAC
UNNAMED	AZORES	1802-081	N37 46.5	W025 40.1	145°/5NM	SAN MIGUEL (VMG) VORTAC
UNNAMED	ATLANTIC-N	1801-02	N49 00.0	W034 30.0	001°/589NM	FLORES (FRS) VOR/DME
UNNAMED	ATLANTIC-N	1801-04	N38 45.0	W038 04.5	279°/323NM	FLORES (FRS) VOR/DME
UNNAMED	ATLANTIC-C	1805-03	S00 34.5	W015 49.5	007°/449NM	ASCENSION AUX (ASI) VORTAC
VESTMANNAEYJAR	ICELAND-S	1702-01	N63 27.4	W020 28.5	138°/6570NM	KEFLAVIK (KEF) VORTAC
ZAVODOVSKI	ANTARCTICA	1900-13	S56 18.0	W027 33.4	063°/978NM	MARAMBIO (MBI) VOR/DME

Appendix F

DATABASE FOR ENCOUNTERS BETWEEN AIRCRAFT AND ASH CLOUDS

United States Geological Survey

(Part I, Chapter 6, 6.8.1 refers)

DATABASE OF ENCOUNTERS

All available information describing the 83 encounters between aircraft and volcanic ash is given in Table F-2. The database is tabulated chronologically beginning in 1935. The severity-of-encounter class given for each incident is based on the ash-encounter severity index outlined in Table F-1. In the event the aircraft was damaged while parked at an airport, an aircraft on ground (AOG) designation has been assigned for the severity of the incident. Encounter numbers 91-16 and 91-20 have been given AOG-2 ratings for severity, because the Class-2 damage was incurred when the aircraft was grounded. Encounter number 91-04 has been given a severity rating of 1 (3*) because the Class-1 damage was incurred while the aircraft was airborne and the Class-3 damage was not discovered until the aircraft attempted to depart seven days after the date of the encounter. Encounters 91-03 and 91-14 have been given a severity index of insufficient data (ISD) because the extent of damage resulting from the encounter could not be determined from the available data.

SUMMARY

The severity index criteria (from the ash-encounter severity index, Table F-1) reported for each of the 83 encounters, along with an assigned class of ash-encounter severity, are given in Table F-2. Table F-3 summarizes some key facts, where known, for all the reported incidents, and Table F-4 summarizes selected information for those incidents with a Class-4 rating. A number of observations can be made from analysing these data.

Of the eight incidents with a severity encounter rating of 4, signifying an in-flight loss of jet engine power, two of these occurred in the United States: one after the 1980 eruption of Mt. St. Helens in Washington, and the other in 1989 after the Mt. Redoubt eruption in Alaska (Table F-4). In two instances there were two Class-4 encounters associated with a single eruption: two incidents in 1982 after the eruption of Mt. Galunggung in Indonesia and two incidents in 1991 associated with the eruption of Mt. Pinatubo in the Philippines. A third incident occurred in 1982 as a result of a later eruption of Mt. Galunggung. The most recent Class-4 incident occurred in Japan after the eruption of Mt. Unzen in June of 1991.

Figure F-1 shows the distribution of severity index classes for 81 encounters. Two incidents, for which there are insufficient data, were not included. The statistics were calculated using a severity index of Class 1 for incident 91-04 and are based on an AOG severity rating for four of the incidents (see Table F-2). Just over half of the total incidents reported incurred damage of Class-2 severity. Within this class, frosting or breaking of windows due to the impact of ash is the most commonly occurring criterion (comprising 54 per cent of the total number of Class-2 factors cited), followed by abrasion damage to the exterior surface of the aircraft which comprises 28.6 per cent of the Class-2 factors cited. Abrasion to the engine inlet or compressor fan blades was noted in 9.5 per cent of the Class-2 incidents. Most of the aircraft involved in Class-0 encounters did not receive any notable damage (61.1 per cent of Class-0 criteria).

Electrostatic discharge producing St. Elmo's fire is reported in 27.8 per cent of the cases, and acrid odour within the aircraft was present in 11.1 per cent of the Class-0 cases. The most common criterion in the Class-3 category is general engine damage comprising 61.5 per cent of the total number of Class-3 factors, followed by the contamination of engine oil hydraulic system fluids which makes up 23 per cent of the factors in this class. Of the three incidents of Class-1 severity, two reported light dust in the aircraft cabin during the encounter, and in one incident there were fluctuations in exhaust gas temperatures with return to normal values.

Figure F-2 shows the total number of jet-powered aircraft/volcanic ash encounters that occurred each reported year between 1970 and 1995. The plot is based on a total of 83 encounters. The high number (25) of reported encounters in 1991 is largely due to the eruption of Mt. Pinatubo which was responsible for 18 of the incidents. All eight encounters in 1980 resulted from the eruptions at Mt. St. Helens, and all seven encounters in 1982 were related to two eruptions of Mt. Galunggung. Three of the six ash/air encounters in 1977 were caused by Mt. Sakurajima, Japan, but occurred on three different dates. The remaining three encounters in 1977 were from an eruption at Mt. Usu, Japan. Four of the six encounters in 1986 resulted from the eruption of Mt. Izu-Oshima in Japan. All five encounters in 1976 are attributed to the eruption of Mt. Augustine, United States, and the four encounters in 1979 occurred over a five-week period resulting from activity at Mt. Sakurajima.

The number of aircraft/volcanic ash encounters versus the volcano producing the eruption is shown in Table F-5. The graph is based on 82 encounters because the source volcano for incident 89-01 is not known. The volcanoes commonly responsible for producing ash clouds that interfere with established airline routes are Mt. Pinatubo (19 encounters), Mt. Sakurajima (13), Mt. St. Helens (8), Mt. Augustine and Mt. Redoubt (6 each), Mt. Galunggung (5), and Mt. Izu-Oshima (4).

Encounters related to eruptions at Mt. Sakurajima all involved Class-2 damage to the aircraft. Frosting or breaking of the windows from ash impact was the sole damage reported in 12 out of the 13 encounters. The aircraft in incident 91-01 suffered some additional Class-2 damage. Class-2 damage was also the most common ramification found in aircraft encountering ash from eruptions at Mt. Augustine, Mt. Izu-Oshima and Mt. Usu. Aircraft damage as a consequence of activity at Mt. St. Helens falls largely into the Class-3 category. The widespread damage to aircraft incurred after the Mt. Pinatubo eruptions is almost evenly divided among Classes 0 through 4. The Mt. Redoubt eruptions produced a wide range of aircraft damage, with incidents of Class 0, 2 and 4 reported. Damage associated with the 1982 eruptions at Mt. Galunggung was severe causing Class-2 and -4 damage. More Class-4 damage, temporary engine failure, has resulted from volcanic activity at Mt. Galunggung (three out of eight incidents) than at other volcanoes producing eruptions that have affected air traffic.

EXPLANATION OF ASH-ENCOUNTER SEVERITY INDEX

The ash encounter severity index (Table F-1) was formulated in order to quantify the effects of the damage incurred as a result of encounters between aircraft and volcanic ash. The criteria that define each class in the severity index are based on the types of damage that have been reported, or describe the conditions that have reportedly occurred, during actual aircraft/ash encounters.

SOURCES OF INFORMATION

The published references used as sources of information for each volcanic ash and aircraft encounter described in the database are cited under the heading “Sources” in each incident description and are listed in the references at the end of this paper. In addition, there were numerous other unpublished sources of valuable information used to compile this database. We would like to acknowledge the following people or organizations for their assistance in providing encounter information.

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ACRONYMS

AOG	Aircraft on ground
AS	Naval air station
ATC	Air Traffic control
A.U.	auxiliary power unit
GMT	Greenwich mean time
IAVCEI	International Association of Volcanolgy and Chemistry of the Earth's Interior
ICAO	International Civil Aviation Organization
ISD	insufficient data
JA	Japan Airlines
JAS	Japan Air System
LE	leading edge
NM	nautical miles
NOTAM	notices to airmen
PIREPs	Pilot report (North America version of AIREP)
SEAN Bulletin	Smithsonian Institution's Scientific Event Alert Network Bulletin
UTC	coordinated universal time
VHF	very high frequency

SELECTED GLOSSARY OF VOLCANOLOGY

active volcano — A volcano that is erupting or has erupted in recorded history.

ash — Finely fragmented particles of rocks and minerals less than 2 mm in diameter (less than 0.063 mm diameter for fine ash) produced by explosive volcanic eruption. Also see tephra, pyroclast and ejecta.

ash cloud — A cloud of volcanic ash and pyroclastic fragments, often with gases and aerosols of volcanic origin, formed by volcanic explosion that is carried by winds away from an eruption column. Ash clouds are often dark-coloured brown to gray. Ash clouds may drift for hundreds to thousands of kilometres from their volcanic source. As ash clouds become more diluted, they may be difficult to distinguish from meteorological clouds. Also see eruption cloud.

ash flow — A mixture of hot gases and ash, which may move down the flanks of a volcano or along the ground surface at high speed. Also see pyroclastic flow.

composite volcano — A steep-sided volcano composed of many layers of volcanic rocks, usually lava flows and ash and pyroclastic deposits; also known as stratovolcano.

dormant volcano — A volcano that is not presently erupting but is considered likely to do so in the future.

ejecta — General term for material thrown out by a volcano. Also see pyroclast.

eruption cloud — A cloud of volcanic ash and other pyroclastic fragments, and volcanic gases and aerosols, that forms by volcanic explosion. Eruption clouds are often dark-coloured brown to gray. Often used interchangeably with plume or ash cloud.

eruption column — The vertical pillar of ash and gas which forms above the volcano at the time of eruption. Eruption columns from energetic eruptions may rise to altitudes in excess of 100 000 ft (30 km).

fumarole — A vent on a volcano from which gases and vapours are emitted.

Hawaiian eruption — An eruption characterized by the non-explosive eruption of fluid lava of basaltic composition. Hawaiian eruptions generally pose no threat to aviation safety.

lapilli — Pyroclastic fragments with diameters between 2 and 64 mm.

lava — Molten rock that erupts from a volcano.

magma — Naturally occurring molten rock, generated within the Earth that can be erupted as lava or pyroclasts.

mudflow — A general term for a flowing mass of predominantly fine-grained earth material mixed with water and possessing a high degree of fluidity during movement. The Indonesian term lahar is often used interchangeably with mudflow.

phreatic eruption — A volcanic eruption or explosion of steam, mud or other non-juvenile material, generally caused by the heating and expansion of ground water due to underlying magma.

Plinian eruption — A large explosive eruption that ejects a steady, turbulent stream of fragmented magma and magmatic gas to form an eruption column that may reach altitudes in excess of 100 000 feet (30 km).

plume — Term often used to describe the elongated, downwind dispersed portion of an eruption cloud and ash-cloud.

pyroclast — An individual volcanic particle ejected during an eruption. For example, ash, lapilli and volcanic bombs are pyroclasts.

pyroclastic flow — A turbulent flowing mass of fragmental volcanic materials mixed with hot gases which may move downhill at high speed. Pyroclastic flows may result from the collapse of tall eruption columns or from spillover of ejected materials from erupting vents. Also see ash flow.

stratovolcano — A volcano that is constructed of alternating layers of lava and pyroclastic deposits. Also known as a composite volcano.

Strombolian eruption — An eruption consisting of short, discrete explosions which may eject pyroclasts for a few tens to a few hundreds of feet into the air. Each explosion may last for only a few seconds and there may be pauses of tens of minutes between explosions.

tephra — A collective term for all violently ejected materials from craters or vents during volcanic eruptions. These materials are airborne momentarily or for a longer period of time depending primarily on the vigour of the eruption and the size of ejected fragments. Generally, coarser tephra are deposited closer to the erupting crater or vent and the finer tephra are deposited farther away. Tephra includes volcanic dust, ash, cinder, lapilli, bombs and blocks. Also see ejecta.

volcanic gas — Volatile material, released during a volcanic eruption, that was previously dissolved in the magma. The principal volcanic gases include water vapour, carbon dioxide and sulfur dioxide.

volcano — A vent or opening at the surface of the Earth through which magma erupts, also the landform that is produced by the erupted material accumulated around the vent.

Vulcanian eruption — A type of volcanic eruption characterized by the short duration, violent explosive ejection of fragments of lava. Vulcanian eruption columns may attain heights of 45 000 ft (14 km) or more.

Table F-1. Ash-encounter severity index

Class	*Criteria*
0	+ sulphurous odour noted in cabin + electrostatic discharge (St. Elmo's fire) on windshield, nose or engine cowl + ash reported or suspected but no other effects or damage noted
1	+ light dust observed in cabin + ash deposits on exterior of aircraft + fluctuations in exhaust gas temperature (EGT) with return to normal values
2	+ heavy cabin dust ("dark as night") in cabin + contamination of air handling and air conditioning systems requiring use of oxygen + abrasion damage to exterior surfaces, engine inlet and compressor fan blades + pitting, frosting or breaking of windscreen or windows + minor plugging of pitot-static system, insufficient to affect instrument readings + deposition of ash in engine
3	+ vibration or surging of engine(s) + plugging of pitot-static system to give erroneous instrument readings + contamination of engine oil hydraulic system fluids + damage to electrical computer systems + engine damage
4	+ temporary engine failure requiring in-flight restart of engine
5	+ engine failure or other damage leading to crash

Table F-2. Severity index factors and encounter severity, for incidents occurring 1953-2008.

	CLASS 0			CLASS 1		CLASS 2						CLASS 3					CLASS 4	CLASS 5	
Incident number	Acrid odour	Electro-static discharge	No notable damage	Light cabin dust	EGT fluctuations with return to normal	Heavy cabin dust	Contami-nation of air handling systems	Exterior abrasion damage	Abrasion to engine inlet or compressor fan blades	Frosting or breaking of windows	Deposition of ash in engine	Engine vibration or surging	Plugging of pitot-static system	Contami-nation of engine oil, hydraulic-system fluids	Damage to electrical system	Engine damage	Engine failure	Engine failure leading to crash	Severity
1953-01								X		X									2
1963-01										X									2
1973-01										X									2
1975-01										X									2
1976-01						X		X		X									2
1976-02						X		X		X									2
1976-03				X				X		X									2
1976-04				X				X											2
1976-05				X				X											2
1977-01										X									2
1977-02										X									2
1977-03										X									2
1977-04										X									2
1977-05										X									2
1977-06										X									2
1978-01										X									2
1978-02	X							X		X									2
1979-01										X									2
1979-02										X									2
1979-03										X									2
1979-04										X									2
1980-01	X							X	X	X				X					3
80-02 deleted																			
1980-03	X					X	X	X	X	X		X	X			X	X		4
1980-04	X								X							X			3

	CLASS 0			CLASS 1		CLASS 2						CLASS 3					CLASS 4	CLASS 5	
Incident number	Acrid odour	Electro-static discharge	No notable damage	Light cabin dust	EGT fluctuations with return to normal	Heavy cabin dust	Contami-nation of air handling systems	Exterior abrasion damage	Abrasion to engine inlet or compressor fan blades	Frosting or breaking of windows	Deposition of ash in engine	Engine vibration or surging	Plugging of pitot-static system	Contami-nation of engine oil, hydraulic-system fluids	Damage to electrical system	Engine damage	Engine failure	Engine failure leading to crash	Severity
1980-05	X															X			3
1980-06														X					3
1980-07								X		X	X								2
1980-08								X	X	X				X					3
1980-09										X									2
1982-01										X									2
1982-02										X									2
1982-03	X	X				X	X	X	X	X	X	X	X	X	X	X	X		4
1982-04								X		X		X				X	X		4
1982-05				X							X								2
1982-06		X			X			X	X		X	X		X		X	X		4
1982-07										X									2
1983-01	X	X																	0
1983-02			X																ISD
1985-01		X				X				X		X				X			3
1985-02	X					X				X									2
1986-01									X	X									2
1986-02										X									2
1986-03	X	X																	0
1986-04	X			X															1
1986-05		X						X			X								2
1986-06								X	X	X									2
1987-01								X		X									2
1989-01								X	X	X									2
1989-02								X		X	X								2
1989-03	X	X						X		X									2

	CLASS 0			CLASS 1		CLASS 2						CLASS 3					CLASS 4	CLASS 5	
Incident number	Acrid odour	Electro-static discharge	No notable damage	Light cabin dust	EGT fluctuations with return to normal	Heavy cabin dust	Contami-nation of air handling systems	Exterior abrasion damage	Abrasion to engine inlet or compressor fan blades	Frosting or breaking of windows	Deposition of ash in engine	Engine vibration or surging	Plugging of pitot-static system	Contami-nation of engine oil, hydraulic-system fluids	Damage to electrical system	Engine damage	Engine failure	Engine failure leading to crash	Severity
1989-04								X		X									2
1989-05	X	X				X	X	X	X	X	X	X	X	X	X	X	X		4
1989-06										X									2
1989-07			X																0
1990-01								X		X									2
1991-01								X	X	X									2
1991-02			X																0
1991-03																			ISD
1991-04	X			X								X			X				3
1991-05		X																	0
1991-06	X	X																	0
1991-07		X																	0
1991-08	X	X		X				X		X	X		X			X			3
1991-09		X																	0
1991-10				X															1
1991-11		X	X		X														1
1991-12								X	X		X								2
1991-13									X							X			3
1991-14																			ISD
1991-15								X								X			3
91-16 DELETED																			
1991-17												X				X	X		4
1991-18											X						X		4
1991-19				X				X	X										2
91-20 DELETED																			
1991-21		X		X								X					X		4

	CLASS 0			CLASS 1		CLASS 2						CLASS 3					CLASS 4	CLASS 5	
Incident number	Acrid odour	Electro-static discharge	No notable damage	Light cabin dust	EGT fluctuations with return to normal	Heavy cabin dust	Contami-nation of air handling systems	Exterior abrasion damage	Abrasion to engine inlet or compressor fan blades	Frosting or breaking of windows	Deposition of ash in engine	Engine vibration or surging	Plugging of pitot-static system	Contami-nation of engine oil, hydraulic-system fluids	Damage to electrical system	Engine damage	Engine failure	Engine failure leading to crash	Severity
1991-22										X									2
91-23 DELETED																			
1991-24	X																		0
91-25 DELETED																			
1992-01			X																0
1993-01																X			3
1993-02		X		X															1
1993-03									X	X									2
1994-01																			ISD
1994-02																			ISD
1995-01																			ISD
1995-02																			ISD
1995-03																			ISD
1996-01			X																0
1996-02			X																0
1996-03	X	X		X					X	X									2
1997-01	X		X																0
1997-02										X									2
1998-01										X									2
1998-02																			ISD
1998-03																			ISD
1998-04																			ISD
1999-01																			ISD
1999-02		X					X	X		X					X	X			3
1999-03																			ISD
1999-04																			ISD

Incident number	CLASS 0			CLASS 1		CLASS 2						CLASS 3					CLASS 4	CLASS 5	Severity
	Acrid odour	Electro-static discharge	No notable damage	Light cabin dust	EGT fluctuations with return to normal	Heavy cabin dust	Contami-nation of air handling systems	Exterior abrasion damage	Abrasion to engine inlet or compressor fan blades	Frosting or breaking of windows	Deposition of ash in engine	Engine vibration or surging	Plugging of pitot-static system	Contami-nation of engine oil, hydraulic-system fluids	Damage to electrical system	Engine damage	Engine failure	Engine failure leading to crash	
1999-05																			ISD
2000-01									X		X								2
2000-02										X									2
2000-03						X		X	X	X			X		X	X			3
2000-04										X						X			3
2000-05		X																	0
2000-06	X																		0
2001-01	X			X															1
2001-02																	X		4
2001-03		X																	ISD
2002-01	X	X							X		X								2
2002-02	X																		0
2003-01			X																0
2003-02	X																		0
2003-03																			ISD
2003-04									X	X									2
2005-01	X																		0
2006-01	X																		0
2006-02		X		X															1
2006-03											X						X		4
2008-01																X			3
2008-02																X			3
2008-03											X								2
2008-04	X			X															1
2008-05				X															1
2008-06										X						X			3

	CLASS 0			CLASS 1		CLASS 2						CLASS 3					CLASS 4	CLASS 5	
Incident number	Acrid odour	Electro-static discharge	No notable damage	Light cabin dust	EGT fluctuations with return to normal	Heavy cabin dust	Contami-nation of air handling systems	Exterior abrasion damage	Abrasion to engine inlet or compressor fan blades	Frosting or breaking of windows	Deposition of ash in engine	Engine vibration or surging	Plugging of pitot-static system	Contami-nation of engine oil, hydraulic-system fluids	Damage to electrical system	Engine damage	Engine failure	Engine failure leading to crash	Severity
2008-07		X		X															1
2008-08	X			X															1

ISD = insufficient data to assign severity index.

Table F-3. Summary of in-flight encounters of aircraft with volcanic ash, 1953-2008

Incident ID	*Encounter severity*	*Encounter date*	*Eruption date*	*Source volcano, country*	*Aircraft type*
1953-01	2	9 July 1953	9 July 1953	Spurr, United States	F-94
1963-01	2	1963	1963-1965	Irazu, Costa Rica	DC6
1973-01	2	3 February 1973	1 February - 24 May 1973	Asama, Japan	DC8
1975-01	2	8 April 1975	8 April 1975	Sakurajima, Japan	L1011
1976-01	2	22 January 1976	22-26 January 1976	Augustine, United States	F-4E Phantom
1976-02	2	22 January 1976	22-26 January 1976	Augustine, United States	F-4E Phantom
1976-03	2	25 January 1976	22-26 January 1976	Augustine, United States	DC8 cargo
1976-04	2	25 January 1976	22-26 January 1976	Augustine, United States	B747
1976-05	2	25 January 1976	22-26 January 1976	Augustine, United States	DC8
1977-01	2	7 August 1977	uncertain	Sakurajima, Japan	L1011
1977-02	2	7 August 1977	7 August 1977	Usu, Japan	DC8
1977-03	2	7 August 1977	7 August 1977	Usu, Japan	DC8
1977-04	2	7 August 1977	7 August 1977	Usu, Japan	L1011
1977-05	2	19 November 1977	uncertain	Sakurajima, Japan	DC8
1977-06	2	25 December 1977	25 December 1977	Sakurajima, Japan	L1011
1978-01	2	4 December 1978	4 December 1978	Sakurajima, Japan	L1011
1978-02	2	9 May 1978	9 May 1978	Ulawun, Papua New Guinea	F27
1979-01	2	18 November 1979	18 November 1979	Sakurajima, Japan	L1011
1979-02	2	18 November 1979	18 November 1979	Sakurajima, Japan	L1011
1979-03	2	18 December 1979	18 December 1979	Sakurajima, Japan	L1011
1979-04	2	24 December 1979	24 December 1979	Sakurajima, Japan	YS11
1980-01	3	18 May 1980	18 May 1980	Mt. St. Helens, United States	DC9-30
1980-03	4	25 May 1980	25 May 1980	Mt. St. Helens, United States	C130 Hercules (L382)
1980-04	3	26 May 1980	25 May 1980	Mt. St. Helens, United States	B727 tri-jet transport
1980-05	3	26 May 1980	25 May 1980	Mt. St. Helens, United States	B727 tri-jet transport
1980-06	3	15 June 1980	12 June 1980	Mt. St. Helens, United States	DC8-52
1980-07	2	1980	uncertain	Mt. St. Helens, United States	Cessna 182
1980-08	3	1980	uncertain	Mt. St. Helens, United States	B737
1980-09	2	25 May 1980	25 May 1980	Mt. St. Helens, United States	F111
1982-01	2	1982	March - April 1982	El Chichon, Mexico	B747
1982-02	2	5 April 1982	5 April 1982	Galunggung, Indonesia	DC9
1982-03	4	24 June 1982	24 June 1982	Galunggung, Indonesia	B747
1982-04	4	24 June 1982	24 June 1982	Galunggung, Indonesia	B747
1982-05	2	24 June 1982	24 June 1982	Galunggung, Indonesia	B747
1982-06	4	13 July 1982	13 July 1982	Galunggung, Indonesia	B747-200B
1982-07	2	23 November 1982	23 November 1982	Sakurajima, Japan	B727-95
1983-01	0	23 July 1983	21-23 July 1983	Colo, Una Una Is., Celebes	B747-136

Incident ID	*Encounter severity*	*Encounter date*	*Eruption date*	*Source volcano, country*	*Aircraft type*
1983-02	ISD	24 July 1983	21-23 July 1983	Colo, Una Una Is., Celebes	
1985-01	3	19 May 1985	19 May 1985	Soputan, Indonesia	B747
1985-02	2	13 November 1985	13 November 1985	Nevado del Ruiz, Colombia	DC8 cargo
1986-01	2	29 March 1986	27-31 March 1986	Augustine, United States	DC10
1986-02	2	24 June 1986	24 June 1986	Sakurajima, Japan	DC9
1986-03	0	21 November 1986	21 November 1986	Oshima, Japan	B747
1986-04	1	21 November 1986	21 November 1986	Oshima, Japan	DC8
1986-05	2	21 November 1986	21 November 1986	Oshima, Japan	DC10
1986-06	2	21 November 1986	21 November 1986	Oshima, Japan	B747 freighter
1987-01	2	25 January 1987	25 January 1987	Pacaya, Guatemala	B737-2A3
1989-01	2	7 March 1989	7-10 March 1989	Pacaya, Guatemala	B737-300
1989-02	2	10 September 1989	10 September 1989	Etna, Italy	CT-39G Sabreliner
1989-03	2	15 December 1989	15 December 1989	Redoubt, United States	B737-2X6C freighter
1989-04	2	15 December 1989	15 December 1989	Redoubt, United States	B727
1989-05	4	15 December 1989	15 December 1989	Redoubt, United States	B747-400
1989-06	2	16 December 1989	14-19 December 1989	Redoubt, United States	B737
1989-07	0	17 December 1989	14-19 December 1989	Redoubt, United States	C9B
1990-01	2	21 February 1990	21 February 1990	Redoubt, United States	B727
1991-01	2	3 June 1991	uncertain	Sakurajima, Japan	DC9-81 (MD80)
1991-02	0	3 June 1991	3 June 1991	Unzen, Japan	A300
1991-03	ISD	12 June 1991	12 June 1991	Pinatubo, Philippines	B747-400
1991-04	3	12 June 1991	12 June 1991	Pinatubo, Philippines	B747-300
1991-05	0	12 June 1991	12 June 1991	Pinatubo, Philippines	DC10 series 40
1991-06	0	15 June 1991	15-16 June 1991	Pinatubo, Philippines	B747-SP
1991-07	0	15 June 1991	15-16 June 1991	Pinatubo, Philippines	DC10 series 40
1991-08	3	15 June 1991	15-16 June 1991	Pinatubo, Philippines	B747-400
1991-09	0	15 June 1991	15-16 June 1991	Pinatubo, Philippines	DC10 series 40
1991-10	1	15 June 1991	15-17 June 1991	Pinatubo, Philippines	B747-200 freighter
1991-11	1	15 June 1991	15-16 June 1991	Pinatubo, Philippines	B747-251
1991-12	2	15 June 1991	15-16 June 1991	Pinatubo, Philippines	DC10 series 30
1991-13	3	15 June 1991	15-16 June 1991	Pinatubo, Philippines	B747-300
1991-14	ISD	15 June 1991	15-16 June 1991	Pinatubo, Philippines	B747-200B
1991-15	3	15 June 1991	15-16 June 1991	Pinatubo, Philippines	B747-428
1991-17	4	15 June 1991	15-16 June 1991	Pinatubo, Philippines	B747-200B
1991-18	4	15 June 1991	15-16 June 1991	Pinatubo, Philippines	DC10
1991-19	2	15 June 1991	15-16 June 1991	Pinatubo, Philippines	B737-200 freighter
1991-21	4	27 June 1991	27 June 1991	Unzen, Japan	DC10
1991-22	2	5 August 1991	5 August 1991	Sakurajima, Japan	B737
1991-24	0	20 August 1991	14-15 August 1991	Hudson, Chile	Airbus

Incident ID	*Encounter severity*	*Encounter date*	*Eruption date*	*Source volcano, country*	*Aircraft type*
91-25 DELETED					
1992-01	0	21 August 1989	18 August 1989	Spurr, United States	
1993-01	3	10 January 1993	10 January 1993	Pacaya, Guatemala	
1993-02	1	14 July 1993	14 July 1993	Manam, Papua New Guinea	Fokker F28
1993-03	2	19 August 1993	19 August 1993	Pinatubo, Philippines	B747-276
1994-01	ISD	September 1994	September 1994	Kliuchevskoi, Russia	
1994-02	ISD	November 1994	November 1994	Sakurajima, Japan	
1995-01	ISD	March 1995	March 1995	Rabaul, Papua New Guinea	
1995-02	ISD	March 1995	March 1995	Rabaul, Papua New Guinea	
1995-03	ISD	March 1995	March 1995	Rabaul, Papua New Guinea	
1996-01	0	20 June 1996	June 1996	Ruapehu, New Zealand	Saab Metroliner
1996-02	0	21 June 1996	June 1996	Ruapehu, New Zealand	Aztec
1996-03	2	18 September 1996	18 September 1996	Soufriere Hills, Montserrat, United Kingdom	A320
1997-01	0	12 February 1997	12 February 1997	Langila, Papua New Guinea	B747
1997-02	2	30 June 1997	30 June 1997	Popocatepetl, Mexico	
1998-01	2	20 May 1998	20 May 1998	Pacaya, Guatemala	
1998-02	ISD	November 1998	November 1998	Popocatepetl, Mexico	
1998-03	ISD	November 1998	November 1998	Popocatepetl, Mexico	
1998-04	ISD	November 1998	November 1998	Popocatepetl, Mexico	
1999-01	ISD	21 May 1999	21 May 1999	Fuego (or Pacaya), Guatemala	
1999-02	3	21 May 1999	21 May 1999	Fuego, Guatemala	737-NexGen
1999-03	ISD	December 1999	December 1999	Tungurahua, Ecuador	
1999-04	ISD	December 1999	December 1999	Pichincha, Ecuador	
1999-05	ISD	December 1999	December 1999	Pichincha, Ecuador	
2000-01	2	28 February 2000	26 February 2000	Hekla, Iceland	DC8 research
2000-02	2	26 April 2003	26 April 2000	Etna, Italy	A320
2000-03	3	18 August 2000	18 August 2000	Miyakejima, Japan	B737-800
2000-04	3	18 August 2000	18 August 2000	Miyakejima, Japan	B747
2000-05	0	18 August 2000	18 August 2000	Miyakejima, Japan	B747
2000-06	0	18 August 2000	18 August 2000	Miyakejima, Japan	B747
2001-01	1	22 February 2000	19 February 2001	Cleveland, United States	B747
2001-02	4	29 July 2001	uncertain	Soufriere Hills, Montserrat, United Kingdom	767-400
2001-03	ISD	29 July 2001	uncertain	Soufriere Hills, Montserrat, United Kingdom	B727
2002-01	2	23 November 2002	3-5 November 2002	Reventador, Ecuador	A340
2002-02	0	24 November 2002	3-5 November 2002	Reventador, Ecuador	
2003-01	0	8 March 2003	6 March 2003	Rabaul?, Papua New Guinea	

Incident ID	*Encounter severity*	*Encounter date*	*Eruption date*	*Source volcano, country*	*Aircraft type*
2003-02	0	13 May 2003	10-11 May 2003	Anatahan, N. Mariana Is., United States	B767-319
2003-03	ISD	12 July 2003	12-13 July 2003	Soufriere Hills, Montserrat, United Kingdom	B767
2003-04	2	12 July 2003	12-13 July 2003	Soufriere Hills, Montserrat, United Kingdom	Airbus
2005-01	0	30 January 2005	27 January 2005	Manam, Papua New Guinea	Embraer E120
2006-01	0	14 January 2006	13-14 January 2006	Augustine, United States	B737-400
2006-02	1	3 February 2006	27 January – 3 February 2006	Augustine, United States	Jayhawk helicopter HH-60
2006-03	4	17 July 2006	17 July 2006	Manam?, Papua New Guinea	Gulfstream II
2008-01	3	5 May 2008	2-8 May 2008	Chaiten, Chile	F28
2008-02	3	5 May 2008	2-8 May 2008	Chaiten, Chile	
2008-03	2	6 May 2008	2-8 May 2008	Chaiten, Chile	A320
2008-04	1	7 May 2008	2-8 May 2008	Chaiten, Chile	B727-200
2008-05	1	9 May 2008	2-8 May 2008	Chaiten, Chile	
2008-06	3	21 May 2008	21 May 2008	Chaiten, Chile	Bolkow helicopter
2008-07	1	15 July 2008	12 July 2008	Okmok, United States	777
2008-08	1	11 August 2008	7-9 August 2008	Kasatochi, United States	757

ISD = insufficient data to assign severity index.

Deleted from 2001 ICAO compilation: 1935-01 involved lava ejecta at airstrip, not ash cloud; 1944-01, 1980-02, 1991-16, 1991-20, 1991-23 involved aircraft on the ground and were moved to the airports database (Guffanti, M., Mayberry, G. C., Casadevall, T. J., and Wunderman, R., 2009, Volcanic hazards to airports, Natural Hazards, v. 51, pp. 287-302. Online at http://www.springerlink.com/content/v3236p5733245713/).

Table F-4. Summary of Class-4 encounters

Incident Number	*Source volcano*	*Encounter date*	*Encounter altitude*	*Encounter duration*	*Aircraft type*	*Number of failed engines*	*Exterior damage to aircraft*
1980-03	Mount St. Helens, United States	25 May 1980	15 000-16 000 ft 4.6-4.9 km	~ 4 minutes	C-130 turboprop	2 of 4	yes
1982-03	Galunggung, Indonesia	24 June 1982	37 000 ft 11.3 km	13 minutes	B747-200B	4 of 4	yes
1982-04	Galunggung, Indonesia	24 June 1982	33 000-35 000 ft 10.1-10.7 km	unknown	B747	3 of 4	yes
1982-06	Galunggung, Indonesia	13 July 1982	33 000 ft 10.1 km	unknown	B747-200B	3 of 4 plus 1 to idle	yes
1989-05	Redoubt, United States	15 December 1989	25 000 ft 7.6 km	~8 minutes	B747-400	4 of 4	yes
1991-17	Pinatubo, Philippines	17 June 1991	37 000 ft 11.3 km	2 minutes	B747-200B	2 of 4	no
1991-18	Pinatubo, Philippines	17 June 1991	unknown	unknown	DC-10	3 of 3	no
1991-21	Unzen?, Japan	27 June 1991	37 000 ft 11.3 km	unknown	DC-10	2 of 3	no
2001-02	Soufriere Hills, Montserrat, United Kingdom	29 July 2001	unknown	unknown	B767-400	1 of 2	unknown
2006-03	Manam?, Papua New Guinea	17 July 2006	39 000 ft 11.9 km	7 minutes	Gulfstream II	2 of 2	no

Table F-5. Number of encounters for each source volcano

Volcano, Country	*Number of encounters*
Anatahan, United States	1
Asama, Japan	1
Augustine, United States	8
Cerro Hudson, Chile	1
Chaiten, Chile	6
Cleveland, United States	1
Colo, Indonesia	2
El Chichon, Mexico	1
Etna, Italy	2
Fuego, Guatemala	2
Galunggung, Indonesia	5
Guagua Pichincha, Ecuador	2
Hekla, Iceland	1
Irazu, Costa Rica	1
Kasatochi, United States	1
Kliuchevskoi, Russia	1
Langila, Papua New Guinea	1

Volcano, Country	*Number of encounters*
Manam, Papua New Guinea	3
Mijakejima, Japan	4
Okmok, United States	1
Oshima, Japan	4
Pacaya, Guatemala	4
Pinatubo, Philippines	17
Popocatepetl, Mexico	4
Rabaul, Papua New Guinea	4
Redoubt, United States	6
Reventador, Ecuador	2
Ruapehu, New Zealand	2
Ruiz (Nevado del), Colombia	1
Sakurajima, Japan	14
Soputan, Indonesia	1
Soufriere Hills, United Kingdom	5
Spurr, United States	2
St. Helens, United States	8
Tungurahua, Ecuador	1
Ulawun, Papua New Guinea	1
Unzen, Japan	2
Usu, Japan	3

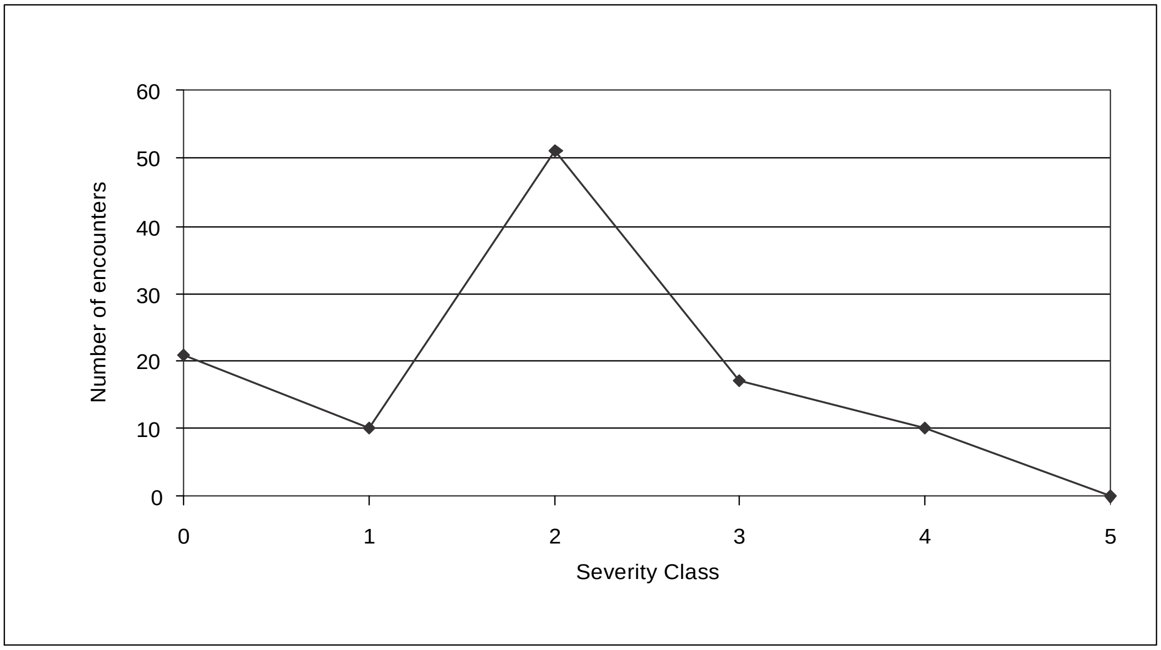

Figure F-1. Plot of number of encounters in each severity class on a scale of 0 to 5

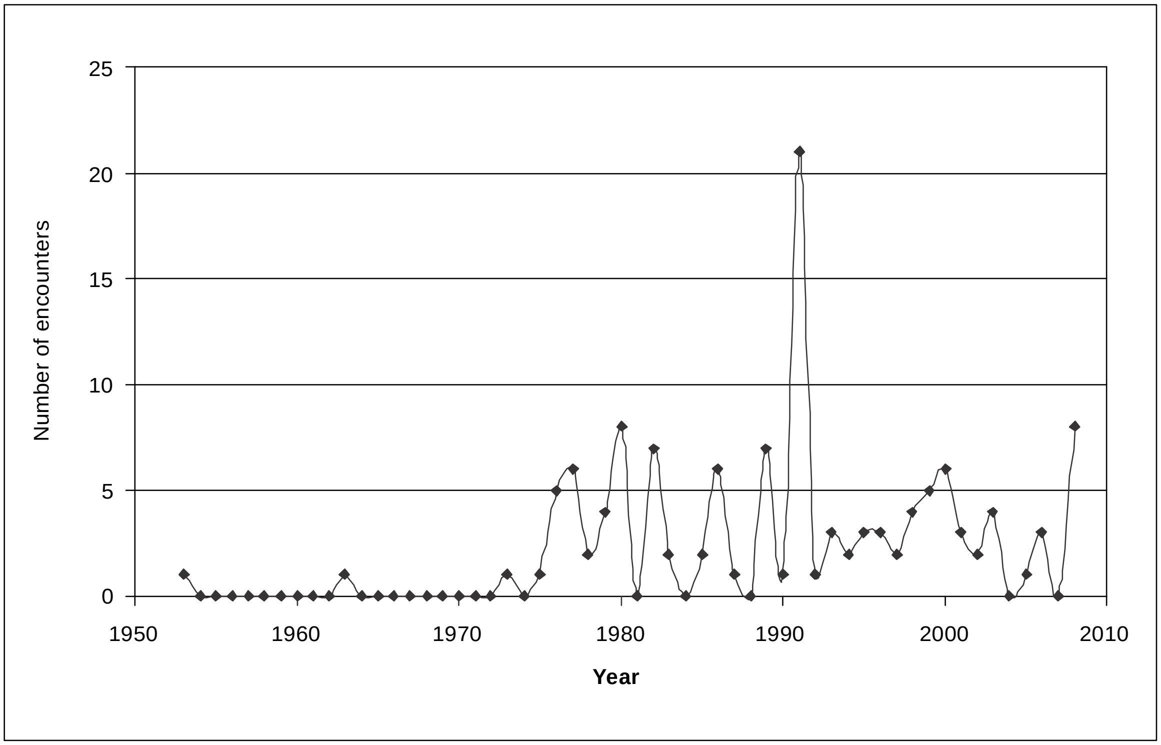

Figure F-2. Plot of annual frequency of encounters, 1953-2008.

Appendix G

EXAMPLE OF NOTIFICATION FROM IAEA REGARDING THE RELEASE OF RADIOACTIVE MATERIAL IN THE ATMOSPHERE

To: ☒ IAEA (ERC) ☐ MESSAGE No. ______
☐ ☐ ☐ For authority use only
☐ ☐ ☐ Free for publication ☐ instantly ☐ after ____ hours
☐ ☐

EXERCISE EMERCON GENERAL EMERGENCY

BASIC INFORMATION

1 Notifying STATE: Number of pages 1 + ___

2 Is this an official Notification under the **Early Notification Convention** of an actual or potential **transboundary** release that is or may be of radiological significance for another State? ☐ **Yes** ☐ **No**

3 Competent authority:
Tel: + Email:
Fax: + URL:
Contact person (official position):

4 Installation name/location: Coordinates: latitude (deg · dec) ____ . ____° ☐ N ☐ S
Installation type: longitude (deg · dec) ____ . ____° ☐ E ☐ W
Normal power: ______ **MWthermal**

5 General Emergency declared at: yyyy/mm/dd 20 ___ / ___ / ___ (24 hour clock) hh:mm ___ : ___ UTC
Basis for declaration:

6 Information VALID at: yyyy/mm/dd 20 ___ / ___ / ___ (24 hour clock) hh:mm ___ : ___ UTC

7 CRITICALITY
☐ Continuing
☐ Stopped on ___ / ___ at ___ : ___ (UTC)
☐ Unknown
TREND IN PLANT CONDITIONS
☐ Getting better ☐ Stable
☐ Getting worse ☐ Unknown

SEVERE DAMAGE TO FUEL
☐ Unknown mm/dd hh:mm
☐ Has not occurred and unlikely to occur
☐ Likely to occur on/ ☐ Has occurred on ___ / ___ at ___ : ___ (UTC)
Fuel damage indicated by:

8 ACTUAL OR PROJECTED RELEASE INFORMATION
☐ Unknown
☐ Has not occurred and unlikely to occur
☐ Release to atmosphere:
Effective release height
☐ > 1 km ☐ < 1 km ☐ Unknown
☐ Release to water: Body affected:

Description of actual or projected release conditions

Actual or projected release times: m m / d d h h : m m
Start time ___ / ___ ___ : ___ (UTC)
End time ___ / ___ ___ : ___ (UTC)
at ___ / ___ ___ : ___ (UTC)

9 METEOROLOGY at ___ / ___ ___ : ___ (UTC)
Wind from ____ degrees
(e.g. 90 deg. means wind blows from E to W)
Wind speed: ____ metres/second
Pasquill stability class (A-G) ___
Local precipitation: ☐ Yes ☐ No

Forecast:

Areas likely affected:

10	PROTECTIVE ACTIONS ORDERED?	☐ None until now How far?	☐ Stable iodine ____ km	☐ Sheltering ____ km	☐ Evacuation ____ km
	☐ Others				
11	MEDIA INFORMATION Media contact tel: +	Provisional INES Rating ____ URL of public website:	Press release	☐ attached	☐ see website
12	Other relevant information:				

☐ Further information in attachment ☐ Final message

☐ Further information web:

EMERCON FORM GENF Ver 1.1p (Feb 2003) For reporting on a 'general emergency' at a nuclear installation

———————————

Appendix H

TEMPLATE FOR NUCLEAR EMERGENCY MESSAGES

Element	*Detailed content*	*Template*	*Examples*
1. Identification of the type of message (M)	Type of message	NUCLEAR EMERGENCY	NUCLEAR EMERGENCY
2. Time of origin (M)	Year, month, day of month, time in UTC	DTG: nnnnnnnn/nnnnUTC	DTG: 20080317/1425UTC
3. Originator (M)	Name of VAAC	ORIGIN: VAAC LONDON	ORIGIN: VAAC LONDON
4. Information source (M)	Information source	INFO SOURCE: IAEA	INFO SOURCE: IAEA
5. Status (M)	Emergency or exercise	STATUS: nnnnnnnnnn	STATUS: EXERCISE
6. Name of release site and country (M)	Site and country	SITE: nnnnnnnnnn	SITE: BILIBINO RUSSIA
7. Geographic location (M)	Location of release in decimal degrees	LOCATION: Nnnnn or Snnnn Wnnnnn or Ennnnn or UNKNOWN	LOCATION: N6805 E16645 N5100 W00130
8. Start of release (M)	Year, month, day of month, time in UTC	START OF RELEASE: nnnnnnnn/nnnnUTC	START OF RELEASE: 20080317/1300UTC
9. Duration or end of release (M)	Duration in days, hours and minutes or End date/time or not known.	DURATION: n[nn] DAYS n[nn] HOURS n[nn] MINUTES or UNKNOWN or END OF RELEASE: nnnnnnnn/nnnnUTC or UNKNOWN	DURATION: 0 DAYS 3 HOURS 30 MINUTES END OF RELEASE: 20080317/1800UTC UNKNOWN
10. FIR name(s) affected (M)	Name of FIR(S)	FIR NAME(S): nnnnnnnnnn	FIR NAME(S): PEVEK
11. FIR code(s) (M)	ICAO FIR code(S)	FIR CODE(S): nnnn nnnn nnnn	FIR CODE(S): UHMP
12. Additional information (O)	Additional information provided by IAEA using free text only (up to 256 characters)	ADDITIONAL INFO: nnnnnnnnnn	ADDITIONAL INFO: NOT AVAILABLE NEXT UPDATE EXPECTED AT 17/1800UTC

M = inclusion mandatory
O = inclusion optional

Example of a nuclear emergency message for distribution via the AFTN

GG UHMPZQZX
170425 EGRRYMYX
NNXX01 EGRR 170425

NUCLEAR EMERGENCY

DTG: 20080317/1425UTC
ORIGIN: VAAC LONDON
INFO SOURCE: IAEA
STATUS: EXERCISE
SITE: BILIBINO RUSSIA
LOCATION: N6805 E16645
START OF RELEASE: 20080317/1300UTC
END OF RELEASE: 20080317/1800UTC
FIR NAME(S): PEVEK
FIR CODE(S): UHMP
ADDITIONAL INFO: NEXT UPDATE EXPECTED AT 17/1800UTC

Note.— The highlighted items will change with each issuance. The other elements are fixed.

— END —

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