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Submitted by:	John Hirst
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FUTURE CHALLENGES AND OPPORTUNITIES

Response of the London Volcanic Ash Advisory Centre (VAAC) to the Eyjafjallajökull Eruption, April/May 2010

London VAAC Website can be found at http://www.metoffice.gov.uk/aviation/vaac/index.html

SUMMARY

This paper describes the response of the London VAAC to the recent Eyjafjallajökull volcanic eruption in Iceland which resulted in unprecedented closures of European and North Atlantic airspace. The paper outlines the events of this period, the new requirements for volcanic ash advisory products from the UK Civil Aviation Authority, and how current modelling and observing capabilities need to be further developed to meet likely future requirements from the aviation regulators. The Executive Council is invited to consider this information in preparing guidance on how WMO can respond to this significant future challenge and opportunity.

1. BACKGROUND

The VAACs were established in the mid 1990s as an integral component of the International Civil Aviation Organization (ICAO) International Airways Volcano Watch (IAVW). There are nine VAACs, these being London, Montreal, Washington, Anchorage, Toulouse, Buenos Aires, Darwin, Wellington and Tokyo. The formal responsibilities of the VAAC are outlined in ICAO Annex 3 Section 3.5 (see Annex). London VAAC is designated responsibility for the north-eastern Atlantic which of course includes Iceland.

When a volcanic eruption occurs the responsible State volcano observatory will notify the designated VAAC e.g. the Iceland Meteorological Office (IMO) notifies the London VAAC. The VAAC will then issue 18 hour volcanic ash advisories every 6 hours based on observational evidence and dispersion model guidance. The designated national Air Navigation Meteorological Service Provider e.g. Meteorological Watch Office (MWO) London, will then issue a volcanic ash SIGMET (aviation meteorological warning) based on the advisory and a further assessment of observational and forecast-based evidence. The designated national/regional Air Traffic Service (ATS) e.g. UK National Air Traffic services (NATS), will then issue a NOTAM (notification of aviation hazards) as appropriate to inform ATS users of the resultant airspace restrictions.

The VAAC Advisories are based on a ‘man-machine mix’ of ‘observed’ ash (primarily from satellite, pilot reports, LIDAR and enhanced ceilometer-based) and dispersion model output. For example, the London VAAC validates Met Office NAME dispersion model output both against observational evidence **and** against dispersion model output from VAAC Toulouse and VAAC Montreal as available.

It is worth noting that once a volcanic eruption has started it remains the mandated responsibility of the designated VAAC to produce the ‘official’ VAAC Advisory wherever the resultant ash is transported until such time as the eruption itself ceases. For example ash from the Eyjafjallajökull eruption was forecast by the London VAAC to spread into northern parts of the Toulouse VAAC area and into the eastern extremities of the Montreal VAAC area. On-going consultation with neighbouring VAACs is therefore an integral part of the process and for this particular event feedback has suggested that the London VAAC could initially have been more proactive. This has now been addressed.

2. EYJAFJALLAJÖKULL ERUPTION

Volcanologists had been observing an increase in seismological activity and other signs at the Eyjafjallajökull volcano for a number of months preceding April's 'major' eruption. The volcano had also been 'smouldering' for a few weeks before and, at 0600 UTC on the 14th April 2010, it erupted to around 35000 feet from a crater near the 5300 feet summit of the volcano. This major eruption persisted for around 30 hours before the volcano gradually 'settled down' to an eruption height of around 15000 feet by the 18th of April.

A slow-moving anticyclone over the northern Atlantic during the second half of April was responsible for maintaining a predominantly north or north-westerly airflow across much of northern Europe, which led to the transport of volcanic ash from the Eyjafjallajökull eruption towards European airspace. The anticyclone also resulted in largely fine, dry and stable weather conditions, ideal for the persistence of volcanic ash in the atmosphere.

Between the 18th April and the 23rd May, when the eruption 'paused' the Eyjafjallajökull volcano exhibited a further 3 active phases:

- 24 hour eruption to around 33000 feet on 5th/6th May;
- 12 hour eruption to around 30000 feet on 13th/14th May;
- 72 hour eruption to around 25000 feet between 16th and 19th May.

Experts from the British Geological Survey (BGS) have described the Eyjafjallajökull volcanic eruption as being an unusual and explosive mix of gas, magma, ice and water. The resultant volcanic ash plume has tended to be composed of a higher number of smaller, lighter particulates than has generally been observed in other volcanic eruptions around the world with a resultant increase in the persistence of the Eyjafjallajökull ash plumes.

3. AVIATION IMPACT OF THE EYJAFJALLAJÖKULL ERUPTION

The 'official' London VAAC Advisories consistently described volcanic ash affecting large parts of northern Europe between 15th and 21st April. Large areas of European airspace were subsequently closed resulting in widespread travel disruption. This unsurprisingly led to increasing pressure from the aviation industry and indeed governments for an urgent European review of the IAVW 'no ash' policy. The UK aviation regulator, the Civil Aviation Authority (CAA), after consultation with European Transport Ministers and advice from the airline engine manufacturers ultimately sanctioned the production of **supplementary** ash concentration charts on 20th April.

The supplementary ash concentration charts do **not** fall within the scope of the IAVW and have currently only been produced for the London VAAC responsibility area by the Met Office as requested by the UK CAA. The estimated volcano release rates for Eyjafjallajökull indicate that the IAVW 'no ash' limit equates to observed equivalent peak ash concentrations of $2x10^{-4}g/m^3$. This threshold is depicted by a 'red' zone on the supplementary charts and approximates to the areas depicted on the official VAAC London Advisories.

The engine manufacturers have quoted potentially hazardous engine ingestion rates equating to observed peak ash concentrations of $2x10^{-3} g/m^3$ and higher. This threshold was depicted by a 'black' zone on the supplementary charts but following directions from the UK CAA on the 18th May this zone is now depicted as grey and a 'new' black area depicting $4x10^{-3} g/m^3$ has been added. The 60 Nautical Mile 'buffer zone' which initially surrounded the 'black' zones was, on the basis of observational evidence, subsequently removed on 11th May.

Since 21st April there have been further occasional incursions of 'low' and 'higher' concentration ash over Western Europe. The resultant airspace closures have been shorter lived, less extensive and therefore less disruptive though still economically significant.

4. MODELLING VOLCANIC ASH DISPERSION AND TRANSPORT AT THE LONDON VAAC

The Met Office's capability to predict the transport and spread of pollution is delivered by the NAME (Numerical Atmospheric-dispersion Modelling Environment) computer model. The model began development following the Chernobyl accident in 1986 and since that time it has been used to model a wide range of atmospheric dispersion events, including previous volcanic eruptions and the Buncefield explosion in 2005. In addition to its role as an emergency response guidance tool the model is used for routine air quality forecasting and meteorological research activities. NAME provides a flexible modelling environment able to predict dispersion over distances ranging from a few kilometres to the whole globe and for time periods from minutes upwards.

The Eyjafjallajökull eruption has afforded us the opportunity of an on-going and ever evolving case study with which we have been able to demonstrate that the Met Office NAME model has performed remarkably well. The NAME model models natural ash deposition processes i.e. sedimentation, wet/dry deposition and is driven by the meteorology of the Met Office Unified Model (UM). It also retains ash from previous model runs that has not yet been deposited. NAME output has verified consistently well against VAAC Toulouse and VAAC Montreal dispersion model output and as the number of observational resources available to us has gradually grown we have also been increasingly able to validate NAME forecasts against 'real information'.

The **largest uncertainty** in the computer modelling of ash dispersion and transport is the ability to accurately reflect the status of the eruption at model initialization. This is less of a modelling issue and is much more a case of actually being able to accurately and safely observe what the volcano is doing in real time, in particular, the:

- Height, diameter and time variance of eruptive column;
- Assessment of ash concentration and particle size/distribution;
- Ash deposition close to the volcano i.e. ash that is not available to be transported.

The IMO has done a very good job in providing an ongoing assessment of the volcanic eruption but their ability to perform this role has been hampered by a lack of the necessary infrastructure e.g. 'state of the art' radar, suitably equipped aircraft etc. Support, in this regard, has been provided to the IMO from Members across Europe, notably Germany, Italy and the UK. The Met Office in collaboration with the UK National Centre for Atmospheric Science (NCAS) and the British Geological Survey (BGS) is working closely with the IMO to address these issues recently signing a Memorandum of Understanding with a view to developing a prioritised set of activities in Iceland.

The introduction of the ash concentration supplementary charts has, at least for the London VAAC area of responsibility (and also for the Toulouse VAAC as the London VAAC back-up) changed the requirement from forecasting 'ash, or no ash' to forecasting 'how much ash'. This has placed significant new demands on the NAME model and other operational dispersion models used at the VAACs. Verification has proved that NAME is very good at spatial forecasts of ash and there is some evidence that NAME also appears to have skill in modelling ash concentration levels. The ash concentration charts are though essentially and necessarily a raw model product and there is currently only very limited manual intervention that can be done. This means that if there is too much ash (and vice versa) at initiation then there will be too much ash (and vice versa) throughout the forecast. This now matters more than was previously the case with the introduction of the ash concentration thresholds.

5. MONITORING VOLCANIC ASH DISPERSION AND TRANSPORT

The Eyjafjallajökull eruption has highlighted limitations in our ability to effectively, consistently and spatially observe areas of volcanic ash. An integrated real time volcanic ash observing capability is vital to:

- Improve the initialization of dispersion models;
- Verify dispersion model output;
- Improve the forecaster's capability in 'adding value' to raw dispersion model outputs;
- Facilitate ongoing and future research and development.

The sub-headings below provide a summary of the various observing resources utilised by the Met Office, and other NMSs, during the Eyjafjallajökull eruption:

5.1 Satellite

The following satellite products are routinely generated in near real time and provide the basis for satellite detection:

- Products based on 15-minute SEVIRI data from Meteosat-9 including the following:
  - Two-channel BTD product based on 10.8μm – 12.0μm (thresholds kept under review to maximize useful signal);
  - Three-channel BTD product based on the two-channel version but using also SEVIRI 8.7μm data to further exclude false alarm pixels;
  - "Dust" RGB based on SEVIRI channels [(10-9), (9-7), 9]. Also a variant of this product, with some colour scale manipulation to allow better colour discrimination (following inputs from H-P Roesli, EUMETSAT);
  - HRV imagery, in particular at the dawn & dusk periods where low sun angles sometimes reveal the ash plume;
  - Cloud Top Temperature (CTT) and Cloud Top Height (CTH) based on multi-spectral analysis.

- Products based on AVHRR / MODIS direct broadcast data from polar orbiting satellites (satellites currently available are Metop-A, NOAA-15, -16, -17, -18, -19, FY-1D, TERRA, AQUA) including the following:
  - Two-channel BTD products based on the same theory as the SEVIRI product described above;
  - False colour RGB products (based on VIS channels) which sometimes shows the ash plume, especially if dense and especially at low sun angles.

- Products based on IASI global coverage data from Metop-A including the following:
    - o SO2 plume detection product.

In addition, products generated externally, most on an experimental or ad hoc basis, are routinely monitored to check their availability with appropriate timeliness, and also to check the information revealed by them, for possible future case studies and product improvements. These products include:

- Multi-spectral SEVIRI data analysis provided by Mike Pavolonis at CIMSS/SSEC at: http://cimss.ssec.wisc.edu/goes_r/proving-ground/geocat_ash/loops/iceland.html

- Expedited analysis of CALIPSO data from NASA LARC at: http://www-calipso.larc.nasa.gov/products/lidar/browse_images/production/

- Analysis of OMI data from AURA by NOAA/NESDIS at: http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2/iceland.html

Issues

- Satellite products are most useful where there are significant concentrations of volcanic ash, although for certain phases of the current event clear signals at long downwind ranges have also been readily detected;

- Further satellite application research is required to determine more accurate quantitative assessments of volcanic ash plume concentration levels;

- Satellite products can be affected by the presence of underlying, overlying or shrouding clouds, especially ice clouds.

5.2 Meteorological Research Aircraft

The UK has been operating 2 research aircraft. Germany (DLR) and France have also conducted intensive airborne research campaigns since mid-April. The aircraft have aerosol remote sensing instrumentation (LIDARs – see below) as well as aerosol sampling instruments to measure concentrations and particulate characteristics.

These aircraft have proved to be invaluable during the present Icelandic volcano eruption and have provided some of the most reliable, real-time information, of ash cloud extent and concentrations.

Issues

- Primarily research-based;

- Spatial coverage is compromised by the limited availability of these specialized and very expensive resources;

- Subject to the same aviation safety considerations (engine ingestion of volcanic ash).as other aircraft and therefore generally cannot fly into areas of high ash concentration;

- Further development of appropriate instrumentation necessary.

5.3 LIDARs (LIght Detection And Ranging)

Although generally operated by the research community and therefore not always available operationally, the most effective surface based measurement system for detecting the presence of volcanic plumes are suitably calibrated LIDAR systems. They emit pulses of laser light and detect the backscattered signal.

Issues

- Detect low and high level cloud as well as volcanic ash and other aerosols. Using different observing channels (and other observations) cloud and aerosol can be distinguished;
- LIDAR signals cannot penetrate through thick clouds so low level clouds can obscure detection of aerosol/ash plumes higher up in the atmosphere.

5.4 Laser Cloud Base Recorders

Laser cloud base recorders (LCBRs - also known as ceilometers) are simple, low power forms of LIDARs designed to measure the height of cloud bases. They can be retuned to measure changes in aerosol concentration and hence ash cloud.

Issues

- Usually 'tuned' to detect clouds but some models can be recalibrated to detect aerosol layers;
- As with LIDARs, LCBRs signals are unable to penetrate thick cloud layers;
- Evidence from recent Met Office experience suggests an effective ash layer detection height range of approximately 3km above the ground;
- Raw data currently requires interpretation by LCBR experts.

5.5 Lightning Location

The ash plumes from some volcanic eruptions produce frequent lightning discharges in the immediate vicinity of the volcano which are an indication that an eruption is taking place and generating ash clouds to sufficient altitude to trigger lightning events.

Issues

- Subjective information on the magnitude of some eruption activity only.

5.6 Aerosol Probes onboard Unmanned Aerial Vehicles

Particle measurement system (PMS) probes are frequently fitted to aircraft and can measure aerosol particle size from which it can be deduced whether the particle is volcanic ash or not. They can be mounted on UAV (Unmanned Aerial Vehicle) aircraft.

Issues

- Size distributions are derived in research mode requiring laboratory analysis.

5.7 Aerosol Sondes

Similarly, particle measurement system (PMS) probes have been developed which can fly together with balloon mounted meteorological radio-sondes. These can also measure aerosol particle characteristics from which it can be deduced whether the particle is volcanic ash or not and an estimate of the concentration levels calculated. **A drop-sonde version could potentially be an ideal way of obtaining accurate volcanic eruption source data for the initiation of dispersion models if dropped into the ash plume a nominal distance (100 KM) downwind of the volcano**

<u>Issues</u>

- Limited availability of the probes: development of the capability is ongoing and only a small number of the probes currently exist;

- A drop-sonde version, capable of being dropped from aircraft into volcanic ash plumes has, subject to confirmation, not yet been developed.

6. SUMMARY OF MET OFFICE ACTIONS

The Eyjafjallajökull eruption has presented a huge and ongoing challenge to the Met Office. The user requirements have evolved continually and the organization has had to react to these quickly and as effectively as possible whilst also coordinating or participating in other volcanic ash related activities in the UK, Europe and other parts of the world. The summary below is a top level overview of the priority actions undertaken by the Met Office during this event:

- Establishment of a Met Office cross-programme Volcanic Ash Steering Group to coordinate with and effectively respond to user/stakeholder needs and requirements;

- Significant diversion of resources to meet volcanic ash demands and consequences;

- Continual constructive dialogue with UK CAA and UK NATS;

- Enhancement of UK LIDAR and ceilometer observational availability;

- Enhanced UK science coordination e.g. with NCAS, BGS etc.;

- Accelerated development of NAME model science applications to meet changing user requirements;

- ‘Fast track’ development of new products and production/dissemination processes;

- Gradual move from crisis management to operational sustainability;

- Coordination of European research LIDAR observational availability;

- Daily VAAC tele-conferences with European NMS during VA episodes;

- Enhanced VA research flight campaigns in coordination with DWD and DLR;

- Enhanced coordination with Toulouse VAAC and IMO;

- Consultation with VAACs Montreal/Washington/ Darwin/Wellington and with WMO, ICAO, EUMETNET;

- Prioritization of and attendance at volcanic ash related meetings and workshops.

7. INTERNATIONAL REVIEW

The Met Office will be looking to play a full and active part in the proposed multi-disciplinary WMO inter-commission Scientific Advisory Group (EC-LXII/Doc. 4.2 refers) and the recently announced ICAO International Volcanic Ash Task Force (IVATF). The IVATF is tasked to undertake, in close coordination with the IAVWOPSG (IAVW Operations Study Group) and the ICAO EUR/NAT (Europe/North Atlantic) Operations Group the following tasks:

(i) Evaluation of the Icelandic eruption;

(ii) Revision of guidance on volcanic ash contingency plans;

(iii) Review of operational response to volcanic ash encounter;

(iv) Development of ash concentration thresholds;

(v) Improvement of ash detection systems;

(vi) Review of notification and warning for volcanic ash;

(vii) Improvement and harmonization of dispersion models; and

(viii) Improvement of visual volcanic ash advisory centre (VAAC) products.

Annex: 1

ANNEX – VAAC RESPONSIBILITIES

ICAO Annex 3 Section 3.5 describes the responsibilities of a VAAC as follows:

3.5.1 A Contracting State, having accepted, by regional air navigation agreement, the responsibility for providing a VAAC within the framework of the international airways volcano watch, shall arrange for that centre to respond to a notification that a volcano has erupted, or is expected to erupt or volcanic ash is reported in its area of responsibility, by arranging for that centre to:

a) Monitor relevant geostationary and polar-orbiting satellite data to detect the existence and extent of volcanic ash in the atmosphere in the area concerned;

b) Activate the volcanic ash numerical trajectory/dispersion model[1] in order to forecast the movement of any ash "cloud" which has been detected or reported;

[1] The numerical model may be its own or, by agreement, that of another VAAC.

c) Issue advisory information regarding the extent and forecast movement of the volcanic ash "cloud" to:

(i) *Meteorological watch offices, area control centres and flight information centres serving flight information regions in its area of responsibility which may be affected;*

(ii) *Other VAACs whose areas of responsibility may be affected;*

(iii) *World Area Forecast Centres, international OPMET data banks, international NOTAM offices, and centres designated by regional air navigation agreement for the operation of aeronautical fixed service satellite distribution systems; and*

(iv) *Airlines requiring the advisory information through the AFTN address provided specifically for this purpose;*

d) Issue updated advisory information to the meteorological watch offices, area control centres, flight information centres and VAACs referred to in c), as necessary, but at least every six hours until such time as the volcanic ash "cloud" is no longer identifiable from satellite data, no further reports of volcanic ash are received from the area, and no further eruptions of the volcano are reported.

3.5.2 Volcanic ash advisory centres shall maintain a 24-hour watch.

And the responsibility of 'State volcano observatories' as being:

3.6 Contracting States that maintain volcano observatories monitoring active volcanoes shall arrange that selected State volcano observatories, as designated by regional air navigation agreement, observing significant pre-eruption volcanic activity[1], a volcanic eruption and/or volcanic ash in the atmosphere shall send this information as quickly as practicable to its associated ACC, MWO and VAAC.

[1] Pre-eruption volcanic activity in this context means unusual and/or increasing volcanic activity which could presage a volcanic eruption.
