Institution: University of Manchester

Unit of Assessment: UoA 7 Earth Systems and Environmental Sciences

Title of case study:

Manchester atmospheric measurements had significant impact on UK response to the 2010 ash crisis

1. Summary of the impact

Technology developed at UoM on clouds and aerosols proved vital in deriving ash mass concentrations during the 2010 eruption of the Iceland volcano, verifying the Met Office model that was defining the airspace exclusion zone and predict ash loadings for the Civil Aviation Authority. The shutdown of airspace cost the airline industry worldwide an estimated $1.7bn, reaching $400m per day on April 19th. Reassurance provided by our verification allowed lifting of flight restrictions which had the immediate effect of re-opening airspace, relieving the impact on hundreds of thousands of people globally, leading to an estimated global saving to the industry of $10bn The approach has resulted in new long term airborne response capability at the Met Office.

2. Underpinning research

This research took place at The Centre for Atmospheric Sciences, University of Manchester since 2003. The key researchers were:

Professor Martin Gallagher (1993-) Professor of Atmospheric Physics

Dr Keith Bower (1993-) Senior Research Fellow

Professor Hugh Coe (1997-) Professor of Atmospheric Composition

Dr James Dorsey (2000-) Research Fellow

Dr Paul Connolly (2006-) Senior Lecturer

Professor Geraint Vaughan (2005-) Professor of Atmospheric Science

Over the past decade, research at Manchester's Centre for Atmospheric Sciences has established world-leading capability in measuring and interpreting cloud and aerosol properties from ground-based and airborne platforms. This was augmented by further research [4, 6] during the Eyafyallajökull eruption to address specific challenges relevant to ash detection. Key findings/insights were:

1. Better calibration techniques for cloud particle imager probes. These have enabled more accurate measurement of the sizes of cloud particles and improved our ability to image them correctly. For example, as cloud particles move through the imaging region their images may become blurred, leading to mis-sizing. Our work has developed methods for correcting and improving protocols for using these probes [1].
2. Improved analysis and interpretation methods for mixed-phase cloud data. Our team has developed improved ways of processing cloud microphysics data through efficient computational data analysis and the combination of very large, multi-dimensional data sets to more rigorously probe cloud microphysical phenomena from airborne platforms, as first evidenced during the EMERALD experiment [2]. These methods have been rigorously optimised and validated using cloud nucleation experiments at the EU AIDA large chamber facility e.g. [3].
3. Derivation of ash mass from airborne measurements during the Eyafyallajökull eruption using cloud microphysics probes. During the volcanic eruption, we deployed our cloud microphysics probes to measure ash particles. Ash has very different densities and refractive indices to cloud water or ice and our research during the eruption showed that the probes were capable of delivering reliable ash mass loading, which we validated using off-line analysis of filter samples [4].

4. Development of Raman LiDAR to measure aerosols and water vapour in the troposphere, in collaboration with European colleagues, and the application of Raman lidar measurements together with wind profiling radars to study atmospheric processes [5].
5. A method of deriving ash mass continuously using a combination of LiDAR and sun photometer. This research, conducted during the eruption, used the expertise developed by the Manchester LIDAR group, to provide a retrieval of the ash mass as a function of altitude [6]. Our work also showed that exploiting the ability of Raman LiDAR to separate measurements of optical depth and backscatter of the ash was particularly important in determining detailed measurements of particle properties.

3. References to the research

The research outputs have been published in influential international journals.

Key outputs:

1) Connolly, P. J., Flynn, M. J., Ulanowski, Z., Choularton, T. W., Gallagher, M. W., and Bower, K. N.: Calibration of the cloud particle imager probes using calibration beads and ice crystal analogs: The depth of field, J. Atmos. Ocean. Tech., 24, 1860–1879, 2007 [times cited: 26 (ISI)] doi:10.1175/JTECH2096.1

3) Connolly, P. J., O. Möhler, P. R. Field, H. Saathoff, R. Burgess, T. Choularton, and M. Gallagher, Studies of heterogeneous freezing by three different desert dust samples Atmos. Chem. Phys., 9, 2805-2824, 2009. [times cited 45 (ISI)] doi:10.5194/acp-9-2805-2009

4) 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:10.1029/2011JD016760. [times cited: 9 (ISI)]

Supporting outputs:

2) Gallagher, M. W., Connolly, P. J., Whiteway, J., Figueras-Nieto, D., Flynn, M., Choularton T. W., Bower, K. N., Cook, C., Busen, R., and Hacker, J.: An overview of the microphysical structure of cirrus clouds observed during EMERALD-1, Quart. J. Roy. Meteorol. Soc., 24, 1143-1169, 2005. [times cited 25 3.33 (ISI)] doi: 10.1256/qj.03.138

5) di Girolamo, P., D. Summa, M. Cacciani, E. G. Norton, G. Peters and Y. Dufournet. Lidar and radar measurements of the melting layer: observations of dark and bright band phenomena . Atmos. Chem. Phys., 12, 4143-4157, 2012. [times cited: 0 (ISI)] DOI: 10.5194/acp-12-4143-2012,

6) Devenish B.J., Thomson D.J., Marenco F., Leadbetter S.J., Ricketts H., and Dacre H.F., A study of the arrival over the United Kingdom in April 2010 of the Eyjafjallajökull ash cloud using ground-based lidar and numerical simulations, Atmos. Environ., Vol. 48, 152-164, 2012 [times cited: 13 (ISI)] doi 10.1016/j.atmosenv.2011.06.033

4. Details of the impact

"Without a doubt, the strong and close working relationship that exists between the University of Manchester and the Met Office was a significant benefit to the Met Office, the CAA, the aviation industry and the general public as it allowed swift state-of-the-art validation of model forecasts and satellite retrievals." *Dr Jim Haywood, Met Office supporting letter* [A]

Context

On April 14 2010, the eruption of Iceland's Eyafjallajökull volcano intensified and large quantities of ash began to be ejected into the atmosphere, reaching UK airspace on the morning of April 15. During this period, the Met Office's London Volcanic Ash Advisory Centre (VAAC) was tasked with delivering information on affected regions of the atmosphere to the Civil Aviation Authority (CAA) using numerical dispersion modelling. As a result of these model predictions, the International Civil Aviation Organization (ICAO) guidance, based on a zero threshold for ash in air, was that it would no longer support service to commercial air traffic into the affected region. As a result of the impact on the industry, the VAAC predictions became the subject of intense scrutiny from the airlines and it became imperative to verify the accuracy of the forecasts.

Pathways to Impact

The Centre for Atmospheric Sciences has a long track record of developing ground based and airborne instruments for sensing aerosol and cloud properties and it has applied these to a wide range of atmospheric research problems over the last decade and more. This leading research has meant CAS hosts the aerosol and cloud physics measurement capability for the NERC National Centre for Atmospheric Science (NCAS) on the FAAM aircraft in Manchester and was therefore central to the volcanic ash response during the eruption. The combination of the development of cloud physics probes and lidars and their application has placed this group as international leaders in the field and it is this research strength and experience that enabled the group to rapidly respond to the National Civil Emergency through the novel application of instrumentation and interpretation of the data and having the capability to develop the methods rapidly at the time of the crisis to apply them to a new research problem.

Prior to the deployment of the FAAM aircraft for the response, the first British detection of the ash cloud over the UK was from Manchester's LiDAR system at Cardington on 15 April [B]. The data was immediately relayed to the Met Office's London Volcanic Ash Advisory Centre. At the Capel Dewi field facility, the Raman and mobile DIAL lidars were operated by Manchester for NCAS [F] alongside a Met Office sun photometer to derive ash mass throughout the eruption. To verify the model predictions during the first week of the eruption, the NERC Dornier 228 aircraft was mobilised but initially did not have the measurement capability to detect ash particles. NERC asked Manchester's Centre for Atmospheric Sciences to install and operate its cloud physics probes for this purpose [F]. From April 16 until April 23 the Dornier flew five flights into the ash plume. These measurements provided initial verification of the Met Office model.

During the first week of the eruption there was no safe operating limit for ash and therefore the no-fly zone was extensive, severely restricting air traffic. On April 20 the Civil Aviation (CAA), in cooperation with engine manufacturers and regulators, was able to agree new procedures which allowed flights into areas of ash with concentrations predicted by VAAC to be below 2000 μgm^{-3}, with extended maintenance procedures to be applied for concentrations above 200 μgm^{-3}. The CAA technical report [C] details how the technical basis for the decision was significantly influenced by the data from Manchester's Centre for Atmospheric Science (CAS) airborne and LiDAR measurements.

The introduction of this safe operating limit set further challenges for the Met Office model, which from this point on needed to deliver accurate and verifiable ash mass forecasts. CAS performed intensive LiDAR monitoring from the Aberystwyth site throughout the period of the eruption. These measurements were used by the Met Office, in conjunction with its sun photometer, to deliver estimates of ash mass. This ultimately provided the main verification of the Met Office model, although as the methodology was indirect, direct measurements were still required to provide evidence that the approach was robust.

The Facility for Airborne Atmospheric Measurements (FAAM) had its aircraft operational by April 20 and flew five flights up until May 18. CAS, using the FAAM aircraft, delivered measurements of the size distribution of the ash particles and used this to develop a method with the Met Office of assessing ash mass. This data, coupled with shape analysis delivered by analysis of ash on filters by the Manchester researchers, was used to confirm the assumptions made using the ground based and satellite remote sensing retrievals of ash mass and so verify the Met Office model development. This work increased the model reliability and the CAA was able to vastly reduce the region of closed airspace, allowing commercial air traffic around northern Europe to be effectively re-routed and to return to near full operation.

Reach and Significance

Manchester data saves airline industry billions

The ability of CAS to rapidly respond and provide robust verification, allowed policy change to be implemented quickly, leading to a reduction in the number of days affected, the total financial losses and also disruption to the lives of UK nationals at home and overseas. The shutdown of airspace was estimated to cost the airline industry worldwide $400m per day at the height of the closures and caused a total loss of revenue to the industry of $1.7bn [D]. From April 20 onwards, the new procedures had the immediate effect of re-opening airspace and it remained substantially open up to the end of the eruption around 21 May except for a brief and predicted period between

3 and 5 May. It can be estimated that the implementation of the new ash thresholds produced a saving of up to $10bn to the global airline industry, based on extrapolating the average daily financial losses during the first 6 days before the new thresholds were introduced throughout the remaining active phase of the eruption. The University of Manchester measurements played a vital role by providing the Met Office with verification of their forecast model to allow such a threshold to be implemented.

Manchester team advises Government

Throughout this time Manchester provided advice directly to the Government as Professor Coe was a member of the Government Office for Science's Scientific Advisory Group in Emergencies (SAGE), which reported through the Chief Scientist to COBRA and the Cabinet Office throughout and following the event [E]. SAGE advised the Government of the issues and risks surrounding the on-going volcanic ash event, the necessary predictive capability at the time and in the future and sought to establish the risk of future events. Since June 2012, the responsibility for reviewing volcanic ash threat on behalf of the Government has passed to the Volcanic Ash Observation Review Group (VAORG), which reports to the Department for Transport. Professors Vaughan and Coe are members of VAORG. Professor Vaughan has also advised the Met Office on the specification of their lidar network and is evaluating the tenders as an external advisor.

Manchester measurement capability taken up by Met Office Volcano Response Aircraft Facility

An outcome of the SAGE reports was the need for a ground based lidar network and an airborne volcano response facility that was capable of delivering a similar response to that provided by the FAAM aircraft on a continuous, year on year basis. The Met Office has taken on this role and commissioned lidars and an aircraft for the purpose. The technologies employed are exactly those supplied by Manchester during the response and the developed capability is now being maintained operationally should further eruptions affect airspace over the UK VAAC region [A].

5. Sources to corroborate the impact

Corroborating information:

A. Letter from Aerosol Research Manager, Met Office, corroborates the link between Manchester research with cloud physics probes and LIDAR and their application to the Met Office response during the ash cloud event.

B. A pdf of a web document describing the initial airborne response to the ash cloud by the NERC aircraft, supported by Manchester Centre for Atmospheric Sciences, as part of the National Centre for Atmospheric Sciences contribution to the national response.

   http://www.ncas.ac.uk/index.php/en/currentnews/archived-news-2010/86-may-2010-ncas-response-to-the-eyjafjallajoekull-eruption-2010

C. A pdf of a summary of international teleconferences focused on revising the agreed safety position of engine manufacturers with respect to volcanic ash. Chaired by Padhraic Kelleher, Head of Airworthiness, UK CAA, 5 May 2010 http://www.caa.co.uk/docs/2011/Teleconferences%20log.pdf

D. IATA Economics Risk Analysis of the impact on industry operations and revenues from the eruption of Iceland's Eyjafjallajokull volcano in April 2010 (downloaded 18th Dec 2012) http://www.iata.org/whatwedo/Documents/economics/Volcanic-Ash-Plume-May2010.pdf

E. A pdf of publically available minutes of the Government Office for Science Scientific Advisory Group for Emergencies (SAGE), which met 4 times between 21st April and 24th June. http://www.bis.gov.uk/assets/goscience/docs/s/10-1371-sage-volcanic-ash-minutes-21-april-2010, http://www.bis.gov.uk/assets/goscience/docs/s/10-1372-sage-volcanic-ash-minutes-5-may-2010, http://www.bis.gov.uk/assets/goscience/docs/s/10-1373-sage-volcanic-ash-minutes-19-may-2010, http://www.bis.gov.uk/assets/goscience/docs/s/10-1374-sage-volcanic-ash-minutes-24-june-2010

F. Letter from National Centre for Atmospheric Science NCAS Director verifying that the NCAS and NERC aircraft activity do indeed relate to Manchester measurements.