Institution: University of Hertfordshire

Unit of Assessment: Panel B (9): Physics

Title of case study: First in situ measurements of ash spread from the 2010 Icelandic volcano eruption

1. Summary of the impact (indicative maximum 100 words)

Measurements made by unique radiosondes, conceived at and built by the university to count and size atmospheric aerosols, were used to validate UK Met Office models that forecast the amount and trajectory of the volcanic ash from the 2010 Eyjafjallajökull eruption. These first in situ measurements justified the authorities' cautious approach in grounding flights, thereby not jeopardising air passenger safety, despite huge pressure from commercial interests. The Met Office subsequently purchased further radiosondes for future deployment, and the underpinning particle detection technology is now licensed to a UK company for worldwide exploitation in areas of environmental monitoring, air quality and industrial safety.

2. Underpinning research (indicative maximum 500 words)

1) The University of Hertfordshire's Centre for Astrophysics Research (CAR) has a long tradition, supported by the UK Research Councils, of building and exploiting astronomical polarimeters. Facility instruments and private instruments were used at major observatories – the Anglo-Australian Telescope (AAT), Australia; United Kingdom Infrared Telescope (UKIRT), Hawaii; and the William Herschel Telescope (WHT), La Palma, Canary Islands.

A grant from the Particle Physics and Astronomy Research Council (now the Science and Technology Facilities Council (STFC)) supported the design and construction of a private polarimeter (PlanetPol) (Section 3, Ref. 1), commissioned in 2005, to detect the reflected (polarised) light from exoplanets – planets that orbit stars other than the Sun. This work was carried out by Professor James Hough (Director, Astronomy Research to 2010, now Research Professor) in collaboration with Dr Phil Lucas (Reader), and Dr Edwin Hirst (Senior Research Fellow). PlanetPol has a fractional polarisation sensitivity of 1 part per million, by far the highest ever achieved for a polarimeter used on a telescope.

During one set of astronomical observations (May 2005 on the WHT), some of the normally unpolarised standard stars were observed to have polarisations an order of magnitude larger than previously observed (Ref. 2). It became apparent that this coincided with a Saharan dust storm extending over the Canary Islands. Detailed calculations (Ref. 3) showed that the polarisation was produced by dichroic absorption in the dust layer over the islands resulting from the generally ellipsoidal dust grains being oriented vertically by the presence of electric fields (1–2 kVm^{-1}), with the field most likely generated by the presence of electrical charging of the dust itself.

That desert dust can be aligned by electric fields, an effect not hitherto observed, has implications for atmospheric models (and hence climate modelling), and for the accurate retrieval of data from sun photometers and from satellite observations. The STFC, recognising that an astronomy research project they had funded could have an impact on climate modelling, issued a news release to that effect.

2) The Centre for Atmospheric and Instrumentation Research (CAIR) specialises in the development of techniques and instruments for the detection, monitoring, characterisation, and analysis of airborne particulates in atmospheric, environmental, and security fields. Sponsors include EPSRC, NERC, dstl, the EU, NASA, NSF, NCAR, the Institute of Meteorology and Climate Research, Germany, and commercial companies in the UK, USA, and Europe. CAIR staff are named inventors on worldwide patents for particle monitoring and characterisation systems, and numerous commercial particle monitoring instrument systems have arisen from these.

Our theoretical work encompasses both direct and inverse scattering problems (i.e., computation of scattering from the knowledge of particle properties, and extraction of particle parameters such as size, shape and refractive index from scattering data, respectively) for particles of various geometries.

Following the discovery of the aligned dust grain phenomenon, NERC funded our development of the world's first low-cost atmospheric 'radiosondes'. These laser-optical devices attach to meteorological balloons and achieve in situ counting and sizing of individual atmospheric particles (Ref. 4). This work was led by Dr Zbigniew Ulanowski (Reader), and Dr Edwin Hirst. The probes were first used during a 2009 NERC-funded field campaign for taking airborne desert dust measurements in the Middle East (Ref. 5) and on Cape Verde Islands prior to the eruption of Eyjafjallajökull.

3. References to the research (indicative maximum of six references)

Bold type indicates University of Hertfordshire authorship; references that can be used as a measure of quality are indentified with an asterisk.

Peer-Reviewed Publications

*1. **Hough J.H.**, **Lucas P.W.**, Bailey J.A., Tamura M., **Hirst, E.**, **Harrison D.** and **Bartholomew-Biggs, M.** (2006), 'PlanetPol: A very high sensitivity polarimeter', *Publications of the Astronomical Society of the Pacific*, 118 (847), 1302–1318. DOI: 10.1086/507955

*2. Bailey J., **Ulanowski Z.**, **Lucas P.W.**, **Hough J.H.**, **Hirst M**. and Tamura M. (2008), 'The effect of airborne dust on astronomical polarization measurements', *Monthly Notices of the Royal Astronomical Society* 386 (2), 1016–1022. DOI: 10.1111/j.1365-2966.2008.13088.x

– REF2 Output

* 3. **Ulanowski Z.**, Bailey J.A., **Lucas P.W.**, **Hough J.H.** and **Hirst E.** (2007), 'Alignment of atmospheric mineral dust due to electric field', *Atmospheric Chemistry and Physics* 7 (24), 6161–6173. DOI: 10.5194/acp-7-6161-2007

4. **Ulanowski Z.**, **Hirst E.**, **Kaye P.**, **Harrison R.G.**, Nicoll K.A. and Rogers G. (2010), 'Radiosonde aerosol counter for vertical profiling of atmospheric dust', *European Geophysical Union General Assembly*, Vienna, 2–7 May, *Geophysical Research Abstracts* 12, EGU2010-13512 AS3.16.

5. **Ulanowski Z.**, Sabbah I., Harrison R.G., Nicoll K.A., **Hirst E.**, **Kaye P.H.**, Al-Abbadi N. and Rogers G. (2010), 'Atmospheric dust charging, vertical profiles, and optical properties measured in the Arabian Peninsula during the DREAME campaign', *Geophysical Research Abstracts* 12, EGU2010-13473.

Awards

In 2010, **Professor Hough** was awarded the Royal Astronomical Society's William Herschel Medal for his development and exploitation of astronomical polarimeters.

Grants

Following is a small selection of the grants related to the underpinning research described above:

PPARC award PPA/G/S/2001/00146 (PI Lucas), 'A high precision polarimeter for the direct detection and characterization of extra-solar planets', **£101,000**, 01/04/2002 to 31/03/2005.

NERC award NE/E011225/1 (PI Ulanowski), 'Aerosol interactions in mixed phase clouds', **£233,000**, 1/6/2007 to 31/5/2011.

NERC award NE/G007268/1 (PI Ulanowski), 'Dust radiation, electrification and alignment in the Middle East', **£68,000**, 21/1/2009 to 20/5/2010.

4. Details of the impact (indicative maximum 750 words)

In April 2010, just four days after the northern European airspace was closed in the wake of the Eyjafjallajökull eruption, Hertfordshire's unique radiosondes, built to count and size atmospheric aerosols, were used to validate Met Office models that forecast the amount and trajectory of the volcanic ash. There had been substantial pressure from the airlines and others to keep the skies open, but these first in situ measurements of the ash justified the authorities' decision to ground flights and avoid the potential risk to air passengers' lives.

The atmospheric ash from the 2010 eruption caused massive disruption to transatlantic and European air traffic. This had a significant economic impact on the air industry: almost 100,000 flights were cancelled and airlines had to compensate passengers for delays. The total impact on global GDP caused by the first week's disruption was estimated at $4.7 billion, and each additional day was costing European economies several hundred million dollars. There were also considerable concerns about disruptions to military air traffic, including supply, Medivac, repatriation and training flights linked to the Afghanistan conflict (Section 5, Refs 5.1–5.5).

Evidence already existed that aircraft were in considerable danger if they flew through volcanic ash, even at sub-visible concentrations, because of the engine damage that could result. For example, in June 1982, the Boeing 747 London to Auckland flight BA263 encountered an ash plume from the erupting Mount Galunggung in Java, resulting in all four engines failing. The plane managed to glide sufficiently out of the ash plume for three of the four engines to restart. Despite awareness of such evidence, airlines affected by Eyjafjallajökull queried the restrictions imposed on them, claiming that test flights through the so-called 'red zones' showed no evidence of any damage. This presented the authorities with a huge problem – namely, that identifying the prohibited air-space (red zones) relied on theoretical Met Office ash dispersion models that were unproven and therefore being brought into question. The only solution was to acquire in situ measurements of the ash clouds, but aircraft that would normally be used for atmospheric cloud particle studies, including the Met Office's FAAM instrumented research aircraft, were also grounded by the flight ban: a Catch-22 situation.

Fortunately, despite being developed for another purpose – i.e. the characterisation of atmospheric dust and its vertical profile (in turn following up the discovery of dust alignment during astronomical observations) – the radiosondes built by the university's researchers and described in section 2 were capable of characterising volcanic ash. The University of Hertfordshire led the NERC-funded radiosonde project and developed the aerosol counters; the University of Reading developed the electric charge sensors subsequently establishing that the ash particles carried a charge. As they were unaffected by the flight ban, the radiosondes could offer the most direct, quantitative and real-time data about the extent of the ash plumes, including the ash density and particle sizing. The Met Office was aware of the radiosondes through previous research collaborations with CAIR and, given the urgency of the situation, the fact that the sondes required no modification for ash measurements was extremely important.

This was how the first ever measurements of the Eyjafjallajökull volcanic ash came to be conducted using Hertfordshire radiosondes, at the request of the Met Office, by balloon launch in Scotland. The measurements were used to validate the models and justify the caution employed by the authorities, thereby preventing potential widespread aircraft damage or potential catastrophic failure had they capitulated to considerable commercial pressure and reopened the airspace prematurely. These radiosonde data were discussed during sessions of COBRA, the Cabinet Office emergency briefing forum, and special parliamentary committee meetings. They were also widely publicised in the media, including national radio (Refs 5.6–5.8).

The Met Office provided CAIR with an interim contract to build a further twenty 'reserve' radiosondes for use in further volcanic ash episodes. CAIR is also developing a version of the radiosondes that can be dropped from aircraft able to fly above the ash cloud layer. Further, a one-year NERC grant (£99,000) has been secured for a project that will run throughout 2014 and lead to commercialisation of the sonde system for measuring volcanic ash and other atmospheric aerosols.

The wider commercial opportunities of the 'low-cost' particle detection technologies born out of the radiosonde development has also been recognised. These technologies, the subject of international patenting, have been licensed to UK company Alphasense Ltd, for worldwide exploitation in areas of environmental monitoring, air quality and industrial safety. The licence guarantees minimum royalty payments [text removed for publication] over the first four years.

5. Sources to corroborate the impact (indicative maximum of 10 references)

Sources verifying economic and other disruption caused by volcanic ash

5.1 Oxford Economics 2010, 'The economic impacts of air travel restrictions due to volcanic ash', Report for Airbus, 25/5/2010. (Copy available on request.)

5.2 'Volcano crisis cost airlines $1.7 billion in revenue', IATA press release, 21 April 2010, <www.iata.org/pressroom/pr/Pages/2010-04-21-01.aspx>

5.3 'Volcanic ash diverts some wounded troops' flights', *CNN World*, 16 April 2010, <http://afghanistan.blogs.cnn.com/2010/04/16/volcanic-ash-diverts-some-military-flights-to-afghanistan/>

5.4 'Volcanic ash grounds Harrier jets', *BBC News*, 15 April 2010, <http://news.bbc.co.uk/1/hi/england/cambridgeshire/8622280.stm>

5.5 'Ash cloud: UK MoD suspends "airbridge" operation with Afghanistan', *Flightglobal News*, 19 April 2010, <www.flightglobal.com/news/articles/ash-cloud-uk-mod-suspends-airbridge-operation-with-afghanistan-340771/>

Sources corroborating use of University of Hertfordshire radiosondes to mitigate disruption

5.6 UK Parliament, 'Scientific advice and evidence in emergencies: Volcanic ash.' Science and Technology Committee meeting minutes, HC 498-ii, 3 November 2010 (Q148, response by Prof. Slingo), <www.publications.parliament.uk/pa/cm201011/cmselect/cmsctech/uc498-ii/uc49801.htm>

5.7 Met Office, 'Volcanic ash related development activities', 17 April 2012, <http://www.metoffice.gov.uk/aviation/volcanic-ash-development-activities>

5.8 *Material World*: two broadcasts of BBC Radio 4's former flagship science programme featured interviews with Dr Zbigniew Ulanowski about his work on measuring ash concentrations. Synopses and iPlayer recordings available at:

<www.bbc.co.uk/programmes/b00s0hn7#synopsis> (22 April 2010, 4:30pm)

<www.bbc.co.uk/programmes/b00sgbgs#synopsis> (27 May 2010, 4:30pm)

Institutional Corroboration

Contact details are supplied separately for representatives of the Met Office and Alphasense, who can corroborate the impact within their organisations.