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THE UK MET OFFICE OBSERVATIONS PROGRAMME RESPONSE TO THE EYJAFJALLAJÖKULL ERUPTION OF SPRING 2010

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1. INTRODUCTION

The Icelandic Eyjafjallajökull eruption of Spring 2010 resulted in volcanic ash clouds transported in the troposphere, affecting European and North Atlantic airspace.

There are a range of observational instruments and techniques at the disposal of the Met Office which can help in the monitoring of volcanic ash. These include satellite data, specialist instrumentation on research aircraft, aerosol sondes, eyewitness reports, lidars, and the main topic of this paper, operational laser cloud base recorders (LCBRs). During the Eyjafjallajökull eruption, the Met Office made extensive use of their own observational resources, as well as liaising with other organisations. Most of the proximal observational data, critical to dispersion model initialisation, was provided by the Icelandic Met Office. Following the Eyjafjallajökull eruption, much research has been carried out, or is currently in progress which may improve on proximal and distal monitoring of volcanic eruptions. One such study, using the Met Office ATDNet worldwide lightning detection system, found that lightning production as a result of the Eyjafjallajökull eruption was approximately proportional to plume height (Bennett *et al.,* 2010).

The Met Office currently operates 126 LCBRs, at fixed sites around the UK. LCBRs, also known as ceilometers, are a type of low-powered, single frequency lidar, and are used routinely at sites for cloud base height measurements. The HQ in Exeter receives minute resolution data for meteorological parameters from all Met Office surface stations. Prior to April 2010, a limited subset of data from LCBRs was sent back to HQ, comprising derived cloud base height and cloud amount. Raw output data is also generated by the LCBRs every 30 seconds, but was previously not sent back to HQ owing to communications limitations. This raw output consists primarily of profile information; that is an array describing the backscatter power at a large number of predetermined layers in the vertical, from near the surface to the maximum range of the sensor. The profile information is available at manned stations and is visualised for use by observers via manufacturer software, in the form of an individual backscatter power profile or a time-height display of backscatter power.

From mid-April 2010, with volcanic ash from the Eyjafjallajökull eruption reaching UK airspace, the Met Office Observations Programme reacted rapidly to investigate how their existing instrumentation might be used to help in the monitoring of volcanic ash. This paper describes the work undertaken to network and visualise LCBR data centrally during the volcanic crisis. Examples are presented which demonstrate the usefulness of this new capability, and also highlight some of the issues. We describe the transition of the new system into a more permanent operational monitoring capability and outline proposed future research and development.

2. EUROPEAN LIDAR AND LCBR NETWORKS

A number of lidar and LCBR networks exist worldwide, some operated by national meteorological services and others managed by research institutions. A key example of a research network is the European Aerosol Research Lidar Network (EARLINET), which currently operates 26 stations throughout Europe and has been used for a number of observations of stratospheric and tropospheric volcanic events. The instruments used within EARLINET are more powerful and have greater sensitivity than LCBRs, e.g. with the capability to estimate aerosol size distribution through multiple wavelength channels, and discriminate between volcanic ash and other aerosol via dual polarisation functionality. During the Eyjafjallajökull eruption, EARLINET stations followed the evolution of the volcanic ash cloud; however it remains that EARLINET is a research infrastructure, i.e. not an operational network, instruments are more costly and sparsely distributed.

At Met Office fixed LCBR sites, several types of instrument are in operation (Table 1).

Table 1. LCBRs used at Met Office sites, figures relate to operational setup within Met Office.

	Vaisala CT25k	Vaisala CL31	Jenoptik CHM 15k
Measurement range	7.5 km	7.5 km	15 km
Measurement resolution	30.5 m	20.0 m	15.0 m
Cloud layers	3	3	5
λ	905 nm	910 nm	1064 nm

These instruments are not as sensitive as research-grade lidars, with only single wavelength capability and with one receiving channel (backscatter), but it was found that they could be used to detect the presence of ash layers under certain favourable

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meteorological conditions. The dense spatial distribution and operational availability of the Met Office LCBRs furthered the view that they could provide a useful capability in monitoring volcanic ash in the atmosphere above the UK.

3. VOLCANIC ASH MONITORING USING LCBR PROFILES

3.1. Networking, Visualisation and Reporting of LCBR data

Of the 126 cloud reporting stations in the UK with operational LCBRs (Figure 1), approximately a third of these are manned sites. During the early days of the Eyjafjallajökull eruption in mid-April 2010, staff at manned sites were provided with new procedures requesting them to store the raw LCBR data and manually email this back to Exeter HQ at regular intervals. Once at HQ, data files were manually concatenated and read into manufacturer viewing software to provide time-height plots of backscatter intensity. Some adjustment of the backscatter colour scale was made to enhance weaker returns, such as those associated with aerosol layers.

The manual archiving, transfer and plotting of LCBR data proved time-consuming, so the need for an automated process soon became apparent. This involved, in many cases, the roll out of dedicated PC's to sites in the network, which were set up to automatically archive the raw LCBR data and send it back to HQ at hourly intervals. At HQ, an automated process was implemented to read the raw data and convert it into NetCDF format, resulting in a standard file format, since 3 types of LCBR are used within the network. Time-height backscatter intensity plots were automatically generated using programming software, taking the NetCDF files as input. Thus a number of visualisation products were readily available including daily plots appended to on an hourly basis; quicklook plots showing 3 hour, 24 hour and 3 day timescales with the ability to view multiple sites on one summary page; and access to archive plots. A clickable map was developed to create a user interface for single-site selection of various plots. A schematic of the LCBR data transfer from local cloud reporting stations to Exeter HQ, and generation of visualisation products, is available in the Appendix (Figure A.1).

Following rapid evolution of the LCBR networking and visualisation processes, plots were available for analysis from 30 sites within the first few weeks of the eruption, mostly through automated procedures. To make best use of the LCBR products, a daily reporting system was put in place from 17 April 2010. This was complemented by development of several key documents including guidance for identifying and interpreting aerosol signatures in LCBR and lidar profiles (Clark and Klugmann, 2010), and instructions for preparation of the daily reports (Clark, 2010). These instructions provided a standard format for daily reports and a method of categorising analysed data based on quality of data received, observing conditions and clarity or ambiguity of any aerosol layers detected.

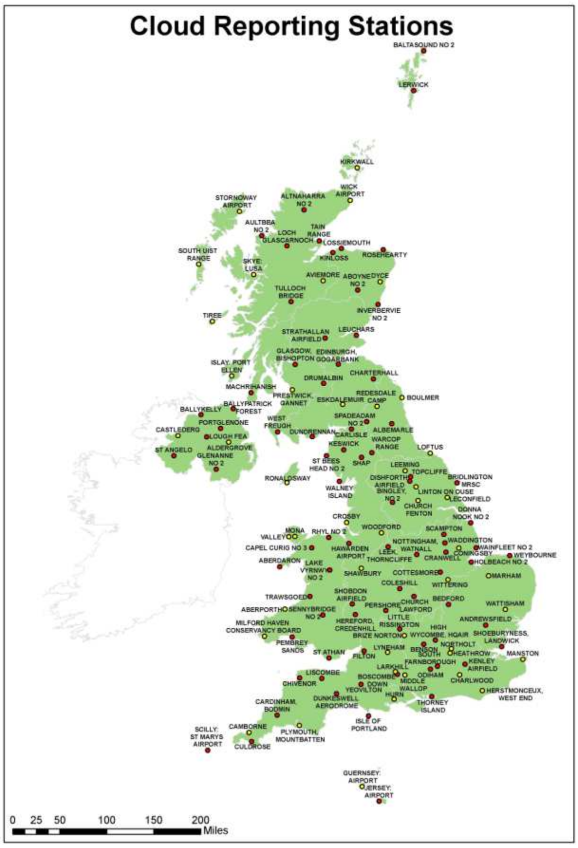

Figure 1: Met Office Cloud Reporting Stations (locations of LCBRs) in the United Kingdom.

Although there were many instances where aerosol layers could be identified in LCBR profiles with a high level of confidence, frequently ash could not be detected but this did not necessarily mean that there was no ash present; this negative result could be due to instrument limitations, for example ash layers at an altitude out of range of the sensor, or unfavourable meteorological conditions, for example thick cloud layers. Wherever possible, supporting evidence was used to corroborate findings. In addition, a volcanic ash observing instruction was produced and issued to site observers (Leitch and Green, 2010), including advice on how to use new synoptic codes to report volcanic ash layers. The completed daily report was distributed to the Volcanic Ash Coordination team within the Met Office, who collated information from relevant departments.

3.2. Examples of Detection and Interpretation

A. Eyjafjallajökull ash plume, 16th April 2010

Following an explosive eruption of Eyjafjallajökull on 14 April 2010, a volcanic ash plume clearly visible in satellite images extended over the northern isles of Scotland and into Scandinavia by the evening of 15 April. This plume then moved down over the North Sea region in a southerly and westerly direction and by 16:00 UTC on 16 April was located chiefly over northern Europe and the English Channel (Figure 2). At the same time, an ash layer is clearly visible above the boundary layer as detected by a Jenoptik CHM 15k LCBR at the Met Office, Exeter, in the south-west of England (Figure 3). The largely cloud-free conditions on 16 April enabled the ash plume to be detected very clearly by the LCBR, and provided good quality time-height data. In this case the LCBR provided a resolution of detail that was not easily discernable from the satellite image (Figure 2), where the ash plume appears quite diffuse over southern England and the western boundary difficult to resolve.

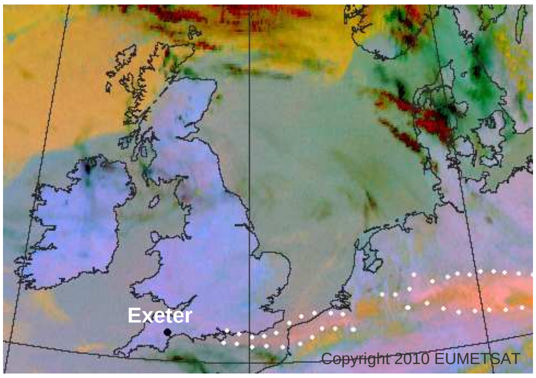

Figure 2: MSG Dust RGB satellite image showing the UK and parts of Northern Europe, 16:00 UTC on 16 April 2010. The northern and southern boundaries of the clearest signal for volcanic ash (pink/orange colour) are highlighted by white dots.

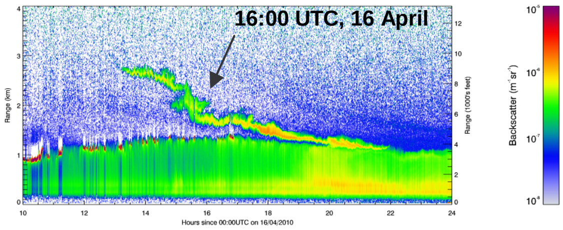

Figure 3: Time-height plot of backscatter intensity, as measured on 16 April 2010 by Jenoptik CHM 15k LCBR based at the Met Office, Exeter. Normal boundary layer aerosol can be seen up to an altitude of ~ 1.2 km, with patchy cloud at the top of this where strong backscatter (reds) are seen. A volcanic ash plume from the Eyjafjallajökull eruption is detected at an altitude of ~ 2.8 km from 13:00 UTC, apparently descending to the top of the boundary layer by 20:00 UTC. Enhanced backscatter (yellow) is visible within the boundary layer, as the ash layer mixes down rapidly due to turbulence.

B. Eyjafjallajökull ash with clouds, 18th May 2010

A significant eruptive phase of Eyjafjallajökull occurred mid-May 2010. With high pressure to the south of the UK and weak low pressure to the north, the bulk of the UK was under the influence of slack north to north-westerly winds, allowing ash aloft to be transported over parts of the country.

At mid-day on 18 May, an MSG Dust satellite image shows clear evidence of volcanic ash over the North Sea and into the Netherlands, while the UK is partly cloudy, especially southern and eastern England (Figure 4).

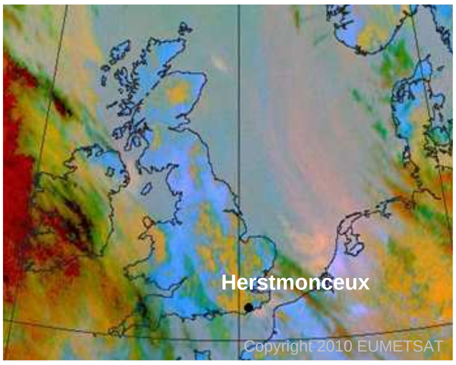

Figure 4: MSG Dust RGB satellite image showing the UK and parts of Northern Europe, 12:00 UTC on 18 May 2010. The clearest signal for volcanic ash (pink/orange colour) is visible over the North Sea, while cloud can be seen over parts of the UK (yellow colour), including over Herstmonceux.

An LCBR is located at Herstmonceux in the south-east of England, and the LCBR profile from the morning of 18 May (Figure 5) reveals several layers of enhanced backscatter. The lowest layer, up to ~ 2.8 km altitude, is the boundary layer, and where this is topped by cloud, it blocks higher altitude backscatter returns. Where there are breaks in the lower level cloud, enhanced layers of backscatter can be seen. At between ~ 3 and 4.5 km altitude, the layers of weak enhanced backscatter slowly descending toward the boundary layer are typical of volcanic ash layers observed in LCBR time-height cross section on a number of days during the Eyjafjallajökull eruption. The patchy areas of enhanced backscatter between ~ 5 and 6.5 km altitude proved more ambiguous in nature. Strong backscatter echoes were seen at this level, with some vertical structure, which is fairly typical of cirrus cloud where ice crystals produce strong returns. However, during the manual analysis on the day, there was still some question as to whether backscatter targets at this level were entirely ice cloud-related. As the day progressed, a 1230Z pilot report revealed that a 'dark ash cloud layer' had been spotted at flight level 170 (approximately 5.2 km altitude), at Bexhill, 10 km from Herstmonceux. Superimposing the location of this pilot observation on the time-height plot (Figure 5), and taking into account other available supporting information, there is evidence to suggest that some of the LCBR backscatter returns could be caused by the presence of volcanic ash clouds at this level.

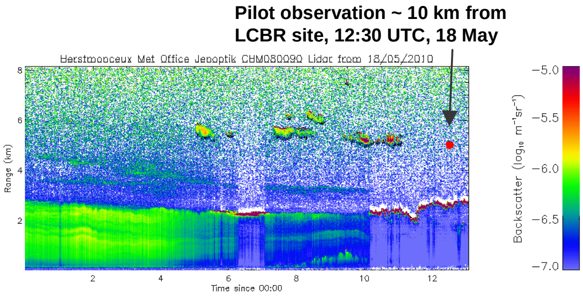
Pilot observation ~ 10 km from LCBR site, 12:30 UTC, 18 May

Figure 5: Time-height plot of backscatter intensity, as measured by Jenoptik CHM 15k LCBR based at Herstmonceux, on 18 May 2010, 00:00 to 13:00 UTC. Enhanced layers of backscatter, characteristic of aerosol, are visible at between ~ 3 and 4.5 km altitude, above the boundary layer. Patchy areas of enhanced backscatter are evident at between ~ 5 and 6.5 km altitude, with strong echoes in places. From satellite evidence and a report from a nearby pilot observation, there is possibly a mixture of cloud and volcanic ash at this level.

The mid-May case demonstrates the usefulness of LCBR profiles in providing a level of vertical resolution on layers of volcanic ash, clouds and boundary layer aerosol that would be difficult to determine from other sources. There is also evidence for the inhomogeneous nature of volcanic ash layers, and some of the difficulties of distinguishing ash and cloud in LCBR profiles are highlighted. A team using a ground-based lidar in Jülich, Germany, presented cases during the Eyjafjallajökull eruptive period in April of having observed volcanic ash with ice spots, and cirrus modified by volcanic ash (Rolf *et al.*, 2010). Microphysical modelling was used to simulate the development of induced cirrus clouds from calculated backward trajectories. The lidar depolarisation signal was analysed to distinguish between volcanic ash, natural cirrus cloud and cirrus cloud induced by volcanic ash particles i.e. where volcanic ash is likely to co-exist with cirrus cloud. For example, it was found that natural cirrus cloud created a higher depolarisation signal due to large aspheric ice particles, as opposed to the much smaller ice particles found in association with thin cirrus cloud forming on volcanic ash. This demonstrates the usefulness of multi-channel LCBRs/lidars, particularly with a depolarisation signal that assists in determining the nature of the backscatter targets. In support of LCBR/lidar plot analysis, the case for using additional sources of evidence is clear.

4. NON-VOLCANIC AEROSOL, 27TH JUNE 2010

Eruptions from Eyjafjallajökull diminished by the end of May 2010 and no significant new ash plumes were emitted from the volcano after this time. Despite this, it was interesting to discover that areas of enhanced backscatter, bearing similar characteristics to the volcanic ash layers seen previously, appeared in time-height plots at a number of LCBR stations throughout the UK on 26 to 27 June 2010. For example, at two sites in the north-east of England, Dishforth and Church Fenton (Figure 6 and Figure 7), the layer of enhanced backscatter is seen originating in the early hours of 27 June at an altitude of between 3.5 and 4 km. These sites are approximately 50 km apart from each other in horizontal distance.

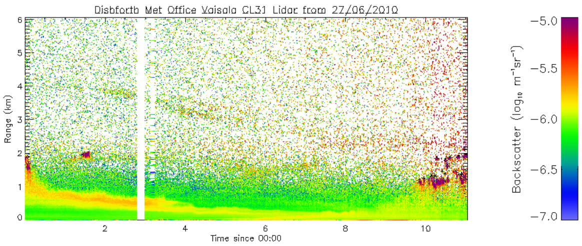

Figure 6: Time-height plot of backscatter intensity, as measured by Vaisala CL31 LCBR based at Dishforth on 27 June 2010, 00:00 to 11:00 UTC. An enhanced layer of backscatter, characteristic of aerosol, is visible from 01:00 UTC at an altitude of ~ 4 km, apparently slowly descending toward the boundary layer.

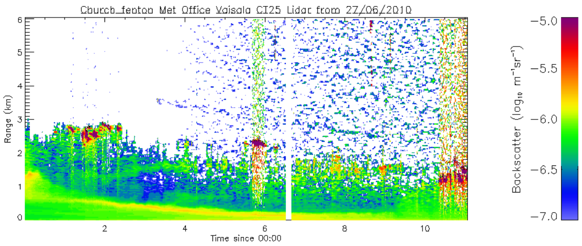

Figure 7: Time-height plot of backscatter intensity, as measured by Vaisala CT25k LCBR based at Church Fenton on 27 June 2010, 00:00 to 11:00 UTC. An enhanced layer of backscatter, characteristic of aerosol, is visible from 03:00 UTC at an altitude of ~ 3.5 km, apparently slowly descending toward the boundary layer.

By the evening of 27 June, the low sun angles facilitated a clearer view in satellite images of the cloud and possible aerosol in the region (Figure 8). It became apparent that other northern European organisations were detecting similar signatures in their lidar data at this time, which was identified as most likely aerosol layers.

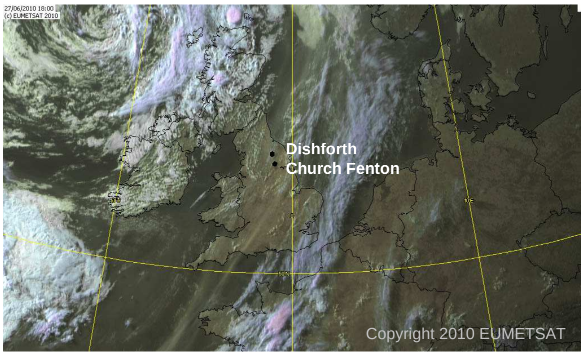

Figure 8: Meteosat MSG-2 satellite image for 27 June 2010, 18:00 UTC. The low sun angles reveals SW to NE trending "wispy" layers over the UK and Atlantic Ocean, between frontal systems associated with the depression to the north-west of the UK. Approximate locations of Dishforth and Church Fenton cloud reporting stations in the north-east of England are marked.

One suggestion as to the origin of this aerosol included Saharan dust – this is commonly transported over Europe in the summer season by southerly winds. Significant Saharan dust was observed in satellite imagery aloft over the Cape Verde Islands to the west of Africa on 20 June (NASA Earth Observatory). Another possibility was that the origin was biomass burning, from forest fires that were prevalent during June in the Canadian Northwest Territories. These produced large plumes of smoke which headed east toward the East Coast of the United States (UMBC, 2010).

From initial qualitative evidence, it was not a simple task to determine which aerosol source was the most probable, particularly as considerable cloud present over the Atlantic at this time obscured visual analysis of the full path of the aerosol from satellite imagery. Additional sources of evidence were consulted to try to resolve this question.

The Met Office NAME dispersion model was used to generate a 'back run', to determine the history of air pollutant at several points in the UK and Northern Europe where the aerosol layers had been observed on 26 and 27 June. The model was initiated with precise grid coordinates, times and altitudes of aerosol observations taken from the LCBR/lidar data available. The resulting maps from the back runs strongly indicated an air history originating from a westerly direction, across the Atlantic and into the United States and Canada. Following this, the NAME model was then used in forward mode starting from one week before the observations in the UK and northern Europe, using information available on the fires in Canada (e.g. Figure 9). The more specific source modelled was the Saskatchewan region where strong fires were known to be releasing large plumes of smoke at the time.

Assessing the NAME model results for the period, it appears that the air mass source from Canada was transported eastwards over eastern US, before circulating around a depression. This is seen clearly in both 27 June satellite imagery (Figure 8) and the NAME forward runs (e.g. Figure 9).

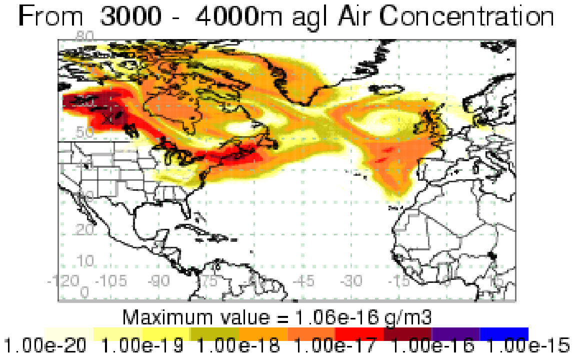

Figure 9: NAME model forward run, showing the 12 hour average air concentrations from 12:00 UTC on 26 June to 00:00 UTC on 27 June between 3-4 km altitude, assuming a continuous uniform release from 0-4 km above ground level, of an inert tracer from the Saskatchewan area of Canada since 20 June 2010. A nominal release value is used hence the predicted air concentrations should not be taken as true concentrations.

The forward model appears consistent with the observations, with the air from the Saskatchewan region reaching the LCBR/lidar locations at the correct time and altitude. Taking into account this and other evidence including upper air pressure patterns and winds, it seems probable that at least some proportion of the aerosol signatures observed on 27 June can be attributed to forest fires in Canada.

This case study demonstrates that more sophisticated analysis is required when classifying types of aerosol, as signatures from different types of aerosol may appear very similar when viewing plots from low-powered LCBRs with single backscatter channel, and it may not always be necessary to perform dispersion model runs. Aerosol classification can be assisted by lidars with a depolarisation channel, due to the differing mean lidar ratio against mean linear particle depolarisation ratio for different types of aerosol. Software products are being developed to automate aerosol classification, such as the 'aerosol mask'. A good example of this in practice was that on 26 June 2010, when the NASA Calipso satellite based lidar passed over the Atlantic Ocean on the south-west approaches to the UK, a separate layer at 4 km altitude was classified as a mixture of 'smoke' and 'polluted dust' (NASA, 2010). This corroborates well with the NAME modelling of the Canadian fire smoke. Similarly, researchers within EARLINET are building a non-standard aerosol product, a 4d profile aerosol mask (Pappalardo, 2010).

5. TRANSITION TO OPERATIONAL MONITORING CAPABILITY

The initial implementation of the enhanced LCBR monitoring capability was carried out in a Research and Development environment. As Icelandic volcanic activity is currently in a state of quiescence, the development work carried out to date is being transferred into an operational environment for extending the range of applications and in readiness for future incidents. A Network Specialist has been appointed to manage the transition and ensure continuity and maintainability once operational status has been achieved.

The transition to an operational monitoring capability for clouds and aerosol including volcanic ash will facilitate broad applicability and a more robust system in the event of future incidents. At the same time, the opportunity will be taken to enhance the initial work, including optimisation of visualisation products, automated detection and reporting of errors, and a review of existing documentation in light of experience gained during the Eyjafjallajökull eruption. There are also plans to improve spatial coverage of the networked LCBR data, extending the number of sites providing automated data collection from the current 30 sites to a total of approximately 60 sites.

A positive consequence of producing the new capability is that this has been welcomed for implementation into regular meteorological forecasting operations. Appropriate guidance and training is currently being developed to support this function.

6. FUTURE RESEARCH AND DEVELOPMENT

6.1. Automated Feature Detection Using Backscatter Gradient

With limited resources available to manually analyse backscatter as other tasks arise and the simultaneous increase in automated LCBR sites it becomes necessary to automate analysis where possible. Some products are derived from the backscatter profile by the instrument PC itself, for instance cloud base heights and for some instruments visibility estimates. However, these routines tend to be manufacturer specific which does not allow easy comparison between different LCBR systems.

As the name suggests, the principal use of LCBRs is to automatically derive cloud base heights. Since the backscatter signal from cloud is approximately an order of magnitude larger than backscatter from aerosol targets, a plot of backscatter signal against height will have a large gradient at cloud base. This feature can be used to designate a cloud base at a point on each profile where the gradient exceeds a certain magnitude. Development of an 'in-house' cloud detection algorithm rather than relying on the manufacturers software provides a first step in any target classification algorithms that may be developed in future.

Since atmospheric aerosols are significantly concentrated in the turbulently mixed boundary layer directly above the surface, they can be used as a tracer for its depth. This would be useful for nowcasting, forecast verification and for informing any future algorithms about inconsistencies in the humidity profile at a site. The actual process of deriving layers aloft from ceilometer data is relatively straightforward, using edge detection image processing techniques to identify in the gradient of backscatter. However the attribution of which detected layer is the top of the boundary layer is where significant work is required for these retrieval algorithms. Some recent work on this has focussed on describing a simple model using in situ sensible and latent heat flux observations to derive a simple model (Angelini *et al.*, 2010). This model can then inform the attribution of boundary layer depth to one of several derived options. Another suggested attribution technique would involve the use of model data, however this would be more useful for assimilation of the retrieval rather than for any validation purposes.

6.2. Feature Enhancement Using Image Processing

One of the difficulties with automated algorithms is they will always be less sophisticated than a human analyst in terms of pattern recognition in noisy data. This can lead to bad attribution of layers of enhanced backscatter when presented to the users. One way to minimize this problem is by applying techniques traditionally used in image processing to the backscatter data. Assuming that features are correlated in time as well as height, two dimensional diffusion will smooth noisy pixels to enhance features within the data. A step on from this has been investigated by Teschke *et al.* (2007) which uses anisotropic diffusion. This technique varies from isotropic diffusion in that information from each pixel does not bleed homogeneously into neighbouring pixels, but instead the direction of diffusion is a function of the gradient between the two pixels. Whenever a gradient is identified as having a certain pre-defined magnitude, the direction of diffusion changes to move along the gradient discontinuity.

6.3. Hardware improvements to UKMO network

It is planned to increase the number of LCBRs in the operational network to approximately 60. Upon achievement of this goal, about half of the LCBRs operated by the Met Office will be part of the operational network. This goal will be achieved by enhancing the communication infrastructure, e.g. rolling out dedicated PCs to further sites or the upgrade of communication lines.

The Met Office recently ordered additional 14 Jenoptik CHM 15k LCBRs with an extended maximum height range of 15 km. These systems will serve as anchor points with higher capability for the existing network. All systems will be embedded in the automated network, and most of them will be deployed on sites where one of the Vaisala systems is already operated. For the time being the new systems will not replace the Vaisala systems, but both systems will be operated co-located, if a Vaisala system is already on site.

The LCBRs with extended maximum height range of 15 km and enhanced detection threshold in the free troposphere above the boundary layer will be valuable sources of information for regular meteorological forecasting operations as well as for model initialisation and verification. They also enhance the maximum detection range of volcanic ash and the probability of detecting volcanic ash in the free troposphere in the case of a future volcanic eruption. In addition, the new systems can be extended by a second polarimetric channel, allowing for enhanced confidence in a number of applications like aircraft icing hazard detection and volcanic ash monitoring.

6.4. LCBR/Sun photometer combination

The combination of research lidars with Sun photometers has been investigated for some years now, and many articles (e.g. Wagner *et al.*, 2001, Müller *et al*., 2006, Tesche *et al*., 2007) have been published on this topic. However, to date the research has focused on the application of high capability research lidars usually featuring multiple transmission wavelengths and an extended number of receiving channels. This combination is for a number of reasons – costs of purchase and operation being among the most important – not suitable for setting up a network.

As opposed to the combination of research lidar and Sun photometer, setting up a network for the combination of LCBR and Sun photometer is affordable. Purchase and operation costs of a Sun photometer are comparable to those of an LCBR. Driven by the Eyjafjallajökull eruption of spring 2010, the Met Office and academic institutions in the UK started investigating the prospects of applying this instrument combination.

The simplest method consists of assessing the excess columnar mass load due to the aerosol source under investigation – e.g. volcanic ash – from a Sun photometer and distributing this over the depth – assessed from LCBR profiles – of the layer(s) presumably consisting of aerosol from this source, resulting in an estimate of the mass concentration. This method requires subtracting the normal extinction estimated over a properly selected time period adjacent to the occurrence of the aerosol under investigation and some educated assumptions on its 'mass concentration versus extinction' coefficient – which might be derived from measurements by enhanced Sun photometers directly. Examples of the excess mass load for selected days from the Met Office Sun photometer deployed at South Uist can be seen in Figure 10.

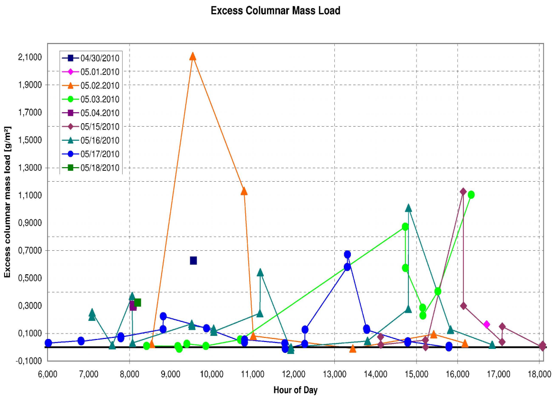

Figure 10: Time series of excess columnar mass load derived from the Met Office Sun photometer at South Uist for selected days. Further analysis is needed in order to help determine whether the excess columnar mass load detected is due to excess aerosol or the presence of cloud.

Figure 11 shows 15 min average and 90-percentile profiles from the co-located LCBR. By comparing both panels in this figure it becomes obvious that the narrow and weak backscatter peaks at higher altitudes (above 2000 m) cannot be detected in the averaged profile due to the background noise, but show up in the 90-percentile calculated from the 15 min data set. This example also highlights the principle weakness of the described method: Without additional information, or at least long term monitoring of the LCBR backscatter profiles, it is virtually impossible to decide which of the detected layers contain(s) the excess mass load, or whether the excess mass load might be (partially) attributed to cloud. Enhancing LCBR profiles as described in section 6.1 might provide valuable information for this purpose.

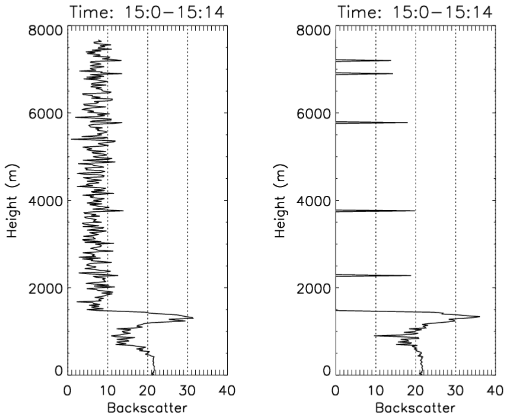

Figure 11: 15 min average (left panel) and 90-percentile (right panel) calculated from measurements on 6th May with the LCBR located at South Uist.

A method taking further advantage of the capabilities of multi-wavelengths Sun photometers is currently being investigated at Reading University in co-operation with further academic institutions and the Met Office (Hogan, 2010). However, selecting the proper layers containing the aerosol under investigation also remains difficult with this method. For the monitoring of volcanic ash, LCBRs equipped with a second polarimetric channel will provide important information in discriminating volcanic ash layers from normal aerosol layers.

7. SUMMARY

Laser cloud base recorders (LCBRs) are used routinely by the Met Office at sites across the UK for cloud base height measurements. Under certain favourable meteorological conditions, LCBRs are also capable of detecting aerosol layers in the atmosphere, and with supporting evidence these may be identified more specifically as volcanic ash. The Met Office now automatically collects and plots LCBR data centrally from a subset of its 126 cloud reporting stations, enabling near real-time analysis of volcanic ash signals. This monitoring capability is being made fully operational, providing a robust system in the event of future incidents. An additional 14 LCBRs with an extended maximum height range of 15 km will also be added to the network.

LCBRs produce mainly qualitative data, leading to more subjective analysis, therefore to have confidence in this analysis, experience and good-quality guidance is crucial. Also, the importance of using supporting information as far as possible, such as additional observations, modelling and meteorological analyses, has been demonstrated.

In this paper we have described some of the research the Met Office is undertaking in order to try and provide some automation of the LCBR plot analysis, which is currently a manual procedure, and also to better characterise and quantify aerosols detected including volcanic ash. We have also touched on some of the novel research being carried out by other organisations, for example cloud/aerosol interactions as evidenced from lidar profiles and automated aerosol classification from lidars.

Recommended wider activities include further investigation of LCBR/lidar synergies with other observational instruments and techniques, and also to maintain and build on National and International collaborations of meteorological services and research institutions.

8. ACKNOWLEDGEMENTS

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Appendix – Additional Figure

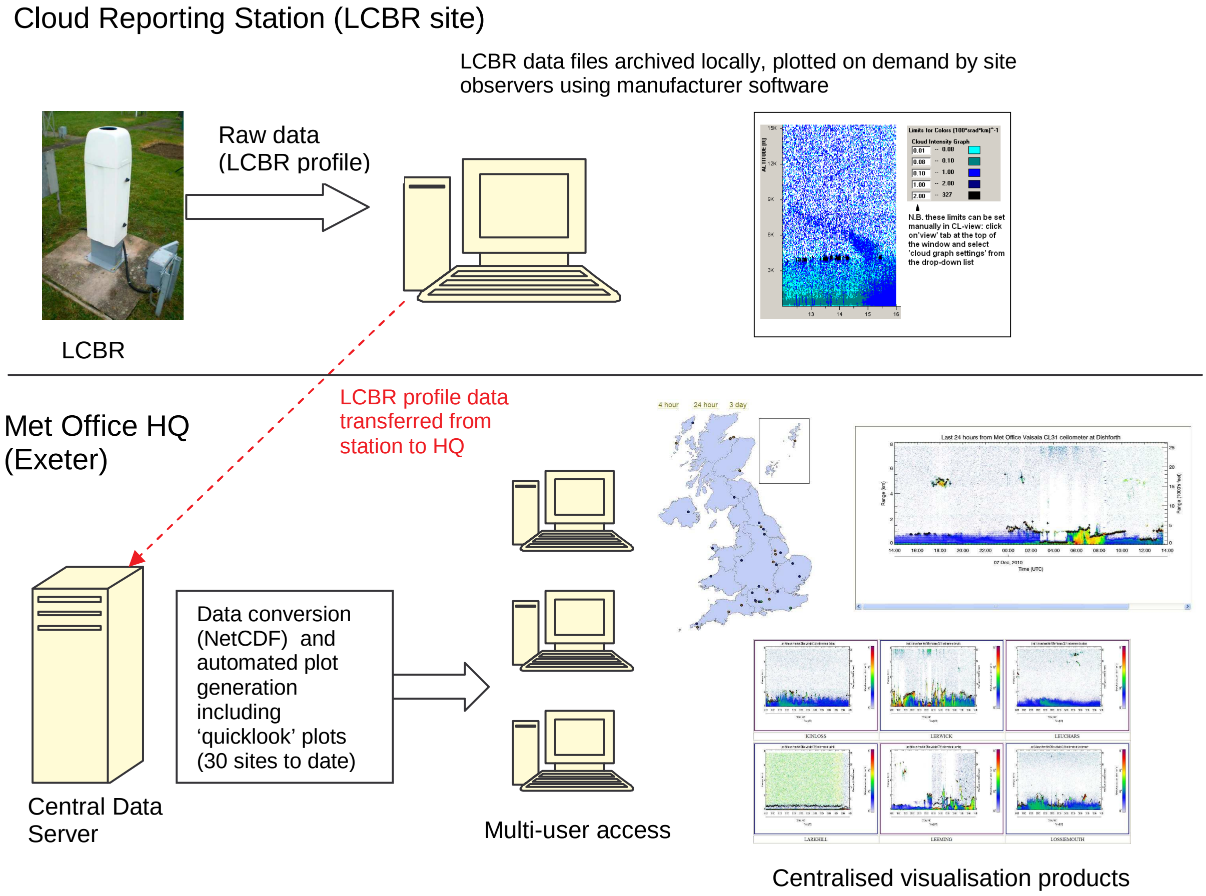

Figure A.1. Schematic showing the process of LCBR data transfer and visualisation. LCBR raw data is archived at local cloud reporting stations, then transferred to a central data server at Met Office HQ in Exeter, UK. Data files are converted to NetCDF file format standard then programming software is used to automatically generate visualisation products, e.g. a clickable map with locations of LCBR sites, and multi-site time-height plots of backscatter intensity (quicklooks) for varying time periods.