8.1 OBSERVATIONS OF BOUNDARY LAYER DEPTH OVER AN URBAN/RURAL TRANSITION

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## 1. INTRODUCTION

In the U.K. the forecasting of air quality relies upon NAME, the UK Met Office's Lagrangian multi-particle random walk dispersion model. To comply with the Environment Act 1995, local air quality is also assessed using dispersion models, especially the ADMS and Airviro models. There are a number of parameters that are common to these models, such as the mixing height, stability, and various turbulence parameters. Measurements of many of the parameters are not routinely available over urban areas and the validation of urban models is thus hampered by a lack of observational data sets.

In 2003 two field campaigns were undertaken to investigate the behaviour of the boundary layer over a rural/urban transition region. This work was supported by HM Treasury under the Invest to Save programme (ISB52) and was a collaboration between the UK Met Office, the University of Salford, the University of Essex and QinetiQ, all in the UK. The goal of the project was to investigate the use of remote sensing instruments (two Doppler lidars) to measure wind flow and derive dispersion parameters for comparison with the UK Met Office NAME and ADMS models. This paper details the methods and results from boundary layer mixing height measurements from the summer field trial.

## 2. TRIAL DETAILS

### 2.1 SITE

The ISB52 summer field trial was carried out in July 2003 at RAF Northolt approximately 20 km west of Central London in the UK. The area surrounding the aerodrome to the east was mostly residential 2 storey housing and to the west was large areas of agricultural/park land as shown in figure 1.

Northolt aerodrome lies almost on the border between the greenbelt land to the west and the residential areas to the east. The topography of the aerodrome is flat. To the south and west there are gently rolling hills approximately +/- 10 m above the level of the aerodrome. Ten kilometres to the northwest the land rises to a ridge of hills, at their highest, being approximately 60m above the level of the aerodrome.

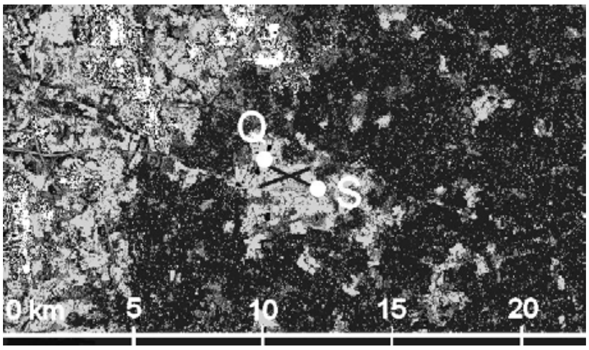


**Figure 1. Land use map for the area surrounding the field site. Darker areas are residential/urban, lighter areas are agricultural/rural, the X marks the aerodrome runways, Q denotes the QinetiQ lidar and S the Salford lidar.**

### 2.2 DATA

The instruments present at the trial consisted of two identical Doppler lidar systems belonging to QinetiQ and the University of Salford. Also present was an automatic weather station and a sonic anemometer set at a height 2m. Met data was also provided by the UK Met Office in various forms including NWP Mesoscale model data, NAME dispersion model output ADMS data and AMDAR. AMDAR is data taken from commercial aircraft. This includes temperature profiles as the aircraft take off and land. The AMDAR data was retrieved and processed by the UK Met Office.

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The primary variables measured using Doppler lidar are wind velocity along the direction of the lidar beam (radial velocity) and signal backscatter intensity. The measured wind velocities are volume averaged, where the volume is defined by the range gate length (112 m) and the width of the beam (0.5 m at a range of 4 km). Comparisons of these area averaged measurements with balloon-borne turbulence probes are shown in Bozier et al (2004). The maximum range of the lidar system is dependant on the signal backscatter intensity, but at high atmospheric aerosol concentrations it is up to 9 km. The lidar systems also have a minimum range of 700 m. The data is measured at a rate of 10 Hz, and processed to improve velocity estimation accuracy. Details of the processing procedure and velocity estimation error of the systems are outlined in Davies et al (2004). The data is subsequently stored at a rate of 0.2 Hz. The lidar systems can be scanned vertically and horizontally to retrieve data over an area of approximately 250 sq. km. The original lidar system, which has recently been upgraded, is discussed in Pearson and Collier (1999).

The signal backscatter intensity is a function of (amongst other parameters) the atmospheric aerosol concentration, the water vapour concentration and cloud droplet content. The primary local sources of aerosol are at the surface and concentrations are usually well mixed within the boundary layer. The mixed layer is capped by an entrainment zone, where there is a marked decrease of aerosol concentration, with much cleaner air above. The mixing height is therefore of primary importance within dispersion models as it determines the volume of air in which the pollution is contained. Methods to determine the mixing height from lidar signal backscatter profiles previously developed (Steyn et al 1999, Menut et al 1999, and Mok and Ruowicz 2004) will be used in this paper to determine the mixing height during the ISB52 summer trial.

### 2.3 WEATHER

The summer ISB52 field trial took place over a period of 3 weeks in July 2003. This period covered some of the hottest days ever recorded in north-western Europe. During the first week of the trial the UK was under anticyclonic high pressure conditions. There was little cloud cover. Both day and night temperatures were very high as was the humidity. The winds were light and from the east. There had been no rain for several days and the aerosol concentrations in the atmosphere were high. During the second week of the trial there were thunderstorms with heavy rainfall. In the third week the weather was back to more normal westerly winds with low pressure, cloudy conditions with the occasional shower. The aerosol concentrations were significantly lower than during the first week.

## 3. RESULTS

The analysis of two days of data will be discussed in this paper. The first day discussed will be from during the first week of the field trial and the second from the third week of the field trial.

### 3.1 9th JULY 2003

The weather on the 9th July was dominated by a high pressure system that had been stationary over the UK for several days. At the field site the winds were from an easterly direction and were very light as shown in the profiles in figure 2.

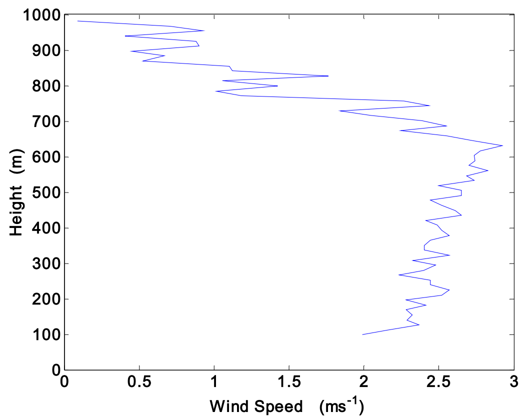


**Figure 2a. Wind speed derived from azimuth scan (PPI) using VAD analysis (Browning and Wexler 1968) at 07:50 UTC on 9th July 2003.**

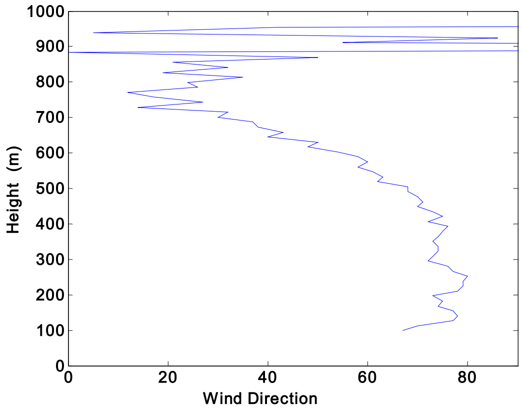


**Figure 2b. Wind direction (from north) derived from azimuth scan (PPI) using VAD analysis (Browning and Wexler 1968) at 07:50 UTC on 9th July 2003**.

At this time there had been no rain for several days and the concentration of aerosol in the atmosphere was relatively high. The signal backscatter intensity as measured by the lidar can be corrected for noise, range and atmospheric attenuation (set at 1 dB per km) to give a measurement for the backscatter coefficient. The backscatter coefficient is related to the aerosol concentration in the atmosphere, but not calibrated to give actual concentrations. The intensity corrected for noise and range for the 9th July at 07:50 is shown in figure 3a.

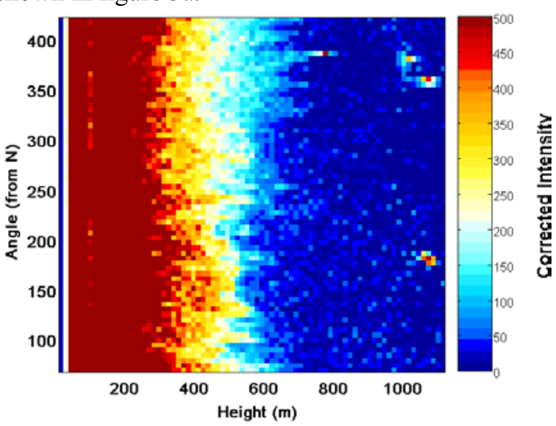


**Figure 3a. Corrected intensity for azimuth scan at 07:50 UTC on the 9th July 2003**.

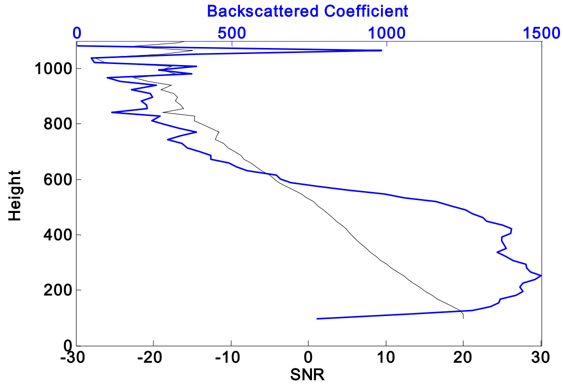


**Figure3b. Backscatter coefficient profile (blue line) and Signal to Noise ratio, SNR (black line) for data shown in figure 3a.**

Figure 3b shows the calculated average backscatter coefficient profile for the 360 degree azimuth scan at 07:50 UTC. There is a marked decrease of the backscatter coefficient at a height of approximately 410 m that marks the top of the mixed layer at this time.

In figure 3a there are a couple of spots of cloud which show up as high values of the backscatter coefficient at approximately 1100m. By 08:50 UTC there is a layer of patchy cloud which, as shown in figure 4, varies in height over the range of the scan.

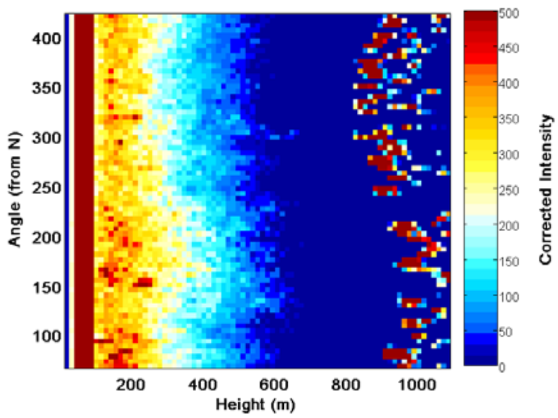


**Figure 4. Corrected intensity for azimuth scan at 08:50 UTC on the 9th July 2003.**

The highest point of the base of the cloud layer is at an angle 150 degrees from north which is in a south easterly direction over the 'urban' surface. The point where the cloud base is at its lowest is in the north-western 'rural' sector of the scan.

In a VAD analysis (Browning and Wexler, 1968) done at 14:07 (not shown) the wind speed had decreased to less than 0.5 m $s^{-1}$ at a height of 250 m and was south-westerly turning more westerly with height. At 1500 m it was approximately 1.5 m $s^{-1}$.

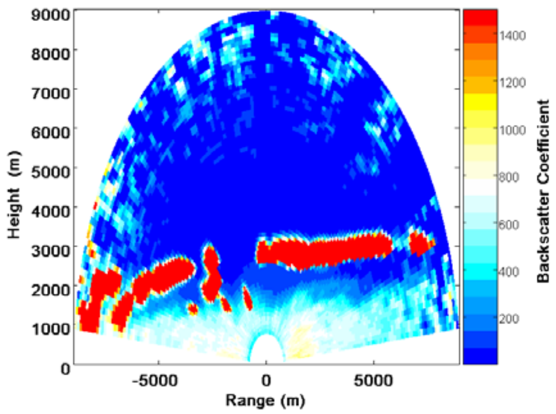


**Figure 5a. Elevation scan showing backscatter coefficient against height at 14:22 UTC on 9th July 2003. The scan has been carried out in an east – west plane. (i.e. positive ranges are due east of the lidar site).**

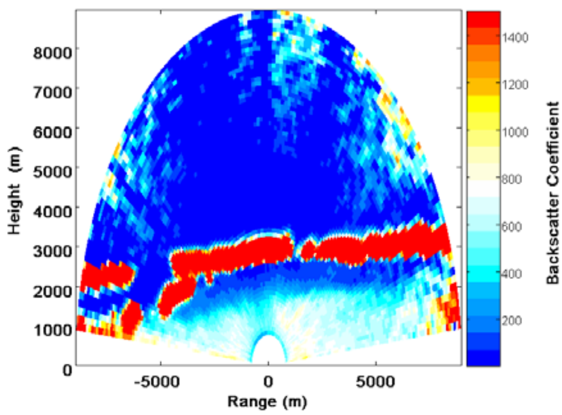


**Figure 5b. As figure 5a, except at 14:35.**

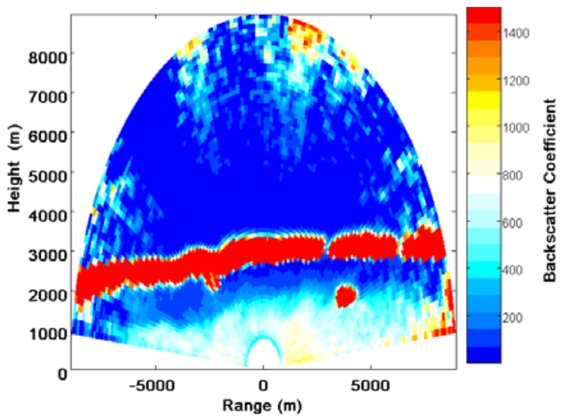


**Figure 5c. As figure 5a, except at 15:01 UTC.**

The series of figure 5a – c show 180 degree elevation scans from 14:22 to 15:01 UTC on the 9th July 2003. The figures show the backscatter coefficient plotted against height. The red bands show very high backscatter values denoting cloud bands.

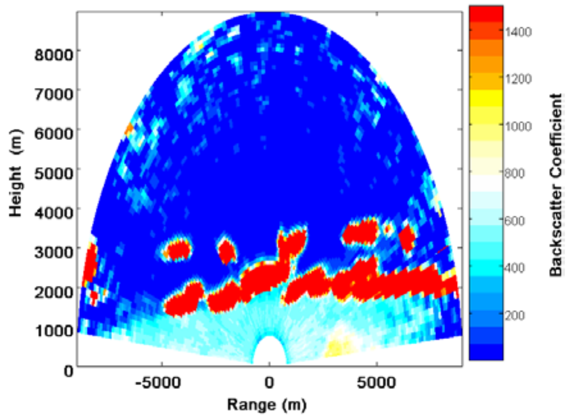


**Figure 6. As figure 5a, except at 16:50 UTC.**

The scans have been taken in an east west direction, so that positive ranges denote distance east of the lidar position. The figures show there is a marked increase in the height of the cloud base above the 'urban' surface. In figure 5c an isolated cloud can however be seen lower in the atmosphere. An elevation scan, figure 6, shows that later in the day the lower cloud layer is more continuous.

It can also be seen in figures 5a – c that the pale blue contours of backscatter coefficient are higher over the 'urban' surface than over the more 'rural' surface. Data was taken with the lidar beam stationary staring at an angle of 20 degrees due east and west of the lidar position and profiles of the backscatter coefficient are shown in figure 7a and b.

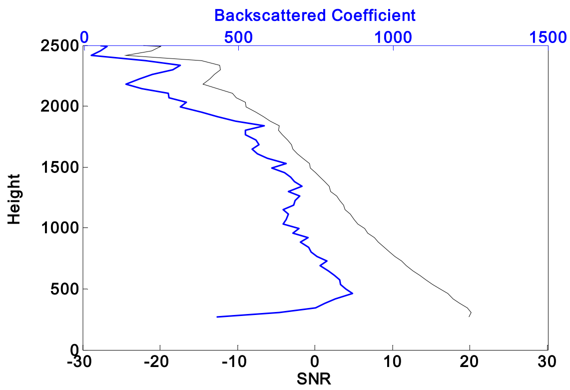


**Figure7a. Backscatter coefficient profile (blue line) and Signal to Noise ratio, SNR (black line) for stare data taken at 15:42 UTC, with the beam pointed due east over the 'urban' surface at an elevation angle of 20 degrees.**

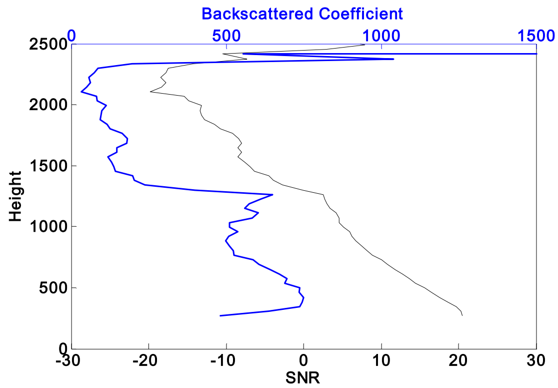


**Figure7b. As figure 7a except taken at 15:57 UTC, with the beam pointed due west over the 'rural' surface at an elevation angle of 20 degrees.**

Figure 7a and b show backscatter profiles for data at elevation angles of 20 degrees (a) due east, over the 'urban' surface and (b) due west over the 'rural' surface. The top of the mixed layer can be seen by visual inspection (Mok and Rudowicz 2004) as the point above which the backscatter coefficient decreases significantly. Over the 'urban' surface this is at a height of approximately 1750 m, and over the 'rural' surface it is at a height of 1300 m.

## 3.2 23rd JULY 2003

The weather on the 23rd July was dominated by low pressure and south westerly winds. There had been infrequent showers and the air was relatively clean of aerosols. The corrected backscattered intensity was therefore much reduced from that on the 9th July, see figure 8.

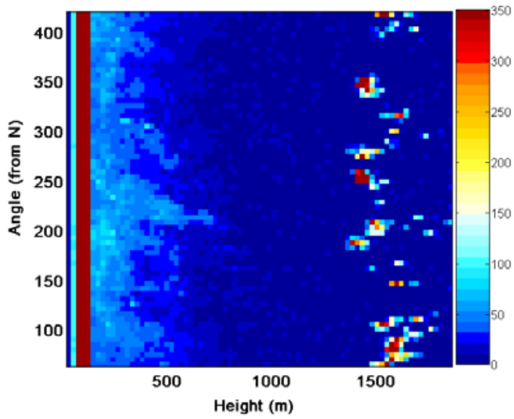


**Figure 8. Corrected intensity for azimuth scan at 14:05 UTC on the 23rd July 2003. Color-bar as for figure 3a.**

The azimuth scan taken at 14:05 UT,C shown in figure 8, displays no clear change of height of the cloud base, but does have a slight peak of corrected intensity close to the surface at approximately 200 degrees (i.e. due south). No systematic change in the cloud base was seen in any of the azimuth scans for this day.

The mixing layer height at this time, determined from the backscatter coefficient profile (not shown), was 1200 m. The wind speed above 300 m in height was a constant 10 m $s^{-1}$, with a bearing of 210 degrees, through the depth of the mixed layer.

An elevation scan taken at 12:35 UTC on the 23rd July is shown in figure 9.

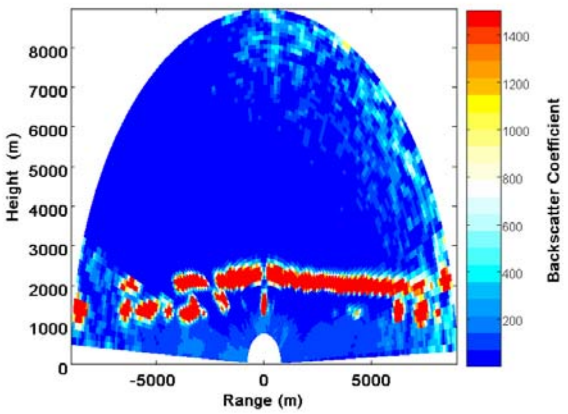


**Figure 9. Elevation scan of the backscatter coefficient at 12:35 UTC on the 23rd July. The scan is taken so that the positive ranges are at a bearing of 60 degrees from north, and east-north-east from the lidar position. The negative ranges are at an angle of 240 degrees from north, and west-south-west of the lidar position.**

Figure 9 shows again a tendency for there to be less low cloud over the more 'urban' surface (positive ranges). This is typical of the elevation scans takes on this day. The backscatter profiles shown in figure 10 agree with this. In figure 10 the cloud base over the 'urban' area is at 1500 m, while over 'rural' area it is at 1150 m.

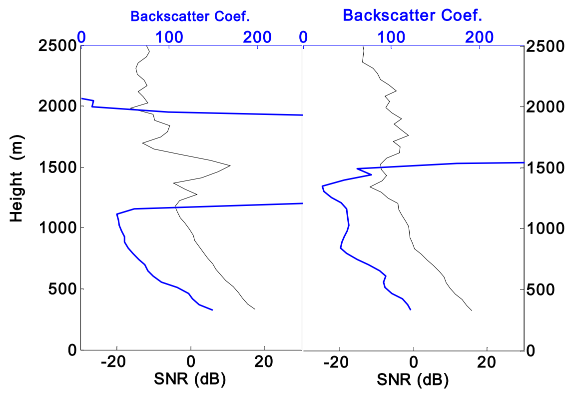


**Figure 10. Profiles of backscatter coefficient (blue line) and SNR (black line) for the rural sector (right) and for the urban sector (left) from the elevation scan shown in figure 9.**

The top of the mixed layer is more difficult to determine from the profiles shown in figure 10 since there is no one significant level of decrease of backscatter coefficient.

## 4. CONCLUSIONS

Examination of data from two separate days from the ISB52 summer field campaign has been carried out. The days had very different meteorological conditions. Both days showed similar behaviour in that the low layer cloud was less persistent above the more 'urban' surface. On the 23rd July this behaviour was only seen for a few hours in the afternoon. On the 9th July not only was the low layer cloud less evident above the 'urban' surface, but the cloud level itself was seen to change over the area of the azimuth scans. This behaviour was seen from approximately 08:30 UTC and lasted through the day.

Estimation of the height of the mixing layer was carried out using the method of Mok and Rudowicz (2004) and showed that at approximately 15:30 UTC on the 9th July there was a difference of approximately 450 m between the height over the 'urban' surface compared to the 'rural' surface. The distance between these two points was approximately 10 km.

## ACKNOWLEDGMENTS

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