5.25 EVALUATION OF DISPERSION MODEL PARAMETERS BY DUAL DOPPLER LIDARS OVER WEST LONDON, U.K.

Douglas R Middleton[1], Fay Davies[2]
[1]Met Office, FitzRoy Road, Exeter, Devon EX1 3PB, U.K.
[2]University of Salford, Salford, M5 4WT, U.K.

INTRODUCTION

Air quality forecasting in the U.K. is by the Met Office's Lagrangian multi-particle random walk dispersion model, NAME. Local air quality management for the Environment Act 1995 uses dispersion models, e.g. ADMS or Airviro, and screening models, e.g. Aeolius or DMRB. The COST 715 Action reviewed urban meteorology and its application to urban pollution problems: WG1 & 2 identified the need for measurements of the urban wind field, heat flux and mixing height. WG4 addressed urban meteorological stations, essentially instruments upon fixed structures. COST 715 identifies gaps in understanding or modelling, and suggests future research requirements, as discussed elsewhere in this meeting. Parameters such as mixing height, stability and turbulent fluxes, are not routinely measured in cities. Synoptic stations at airports ensure good exposure, whilst instruments placed on city buildings require careful evaluation for local effects. Masts can be difficult to place in cities. Validation of urban models is hampered by a lack of observational data sets. These requirements form the basis for our experimental study, Collier et al. (2004), using two pulsed Doppler lidars, with the overall aim of obtaining urban data for improving air quality forecasting. We explain the project and present some of our results.

SCANNED PULSED DOPPLER LIDAR

Lidar design, construction and signal processing are by Pearson and Collier (1999) at Qinetiq, Malvern. A powerful laser transmits pulse of light at 10.6 μm which is back-scattered by aerosol particles, cloud droplets, etc. in the beam. The Doppler shift of the returning light measures the velocity component of the scattering particle along the beam. This 'radial velocity' is our primary measured variable, following the horizontal and vertical motions of aerosol resolved in the beam direction. The system also measures the intensity of returning pulses, our other primary measured variable. Intensity is an indicator of the number of back-scattering particles, or aerosol concentration. The range, distance of the sensing point from the instrument, is determined from the time of flight, or 'range gate number', where each successive time gate in signal processing represents a distance of 112 m. Intensity of returning light decreases with increasing range. The signal to noise ratio, SNR decreases with range, until a point where meaningful information is lost. Similarly if the beam passes into very clean air, there may be so few scattering particles that the SNR becomes too small. If the beam encounters cloud layers, its intensity is attenuated, and SNR drops. As the pulse is emitted, it suffers reflections from optical components and back-scattering near the instrument, so the detector is saturated for the first few range gates: the instrument is unable to measure at points nearer than this. When the beam is vertical, up- and down-drafts are measured unambiguously, but our minimum range precluded data near the ground from this technique. These constraints play a significant role in deploying the lidars in the field, and interpreting data. The two instruments used here have a similar design, are pulsed at 10 Hz to accumulate data for 50 pulses, a data rate of 0.2 Hz. See www.qinetiq.com

Single Lidar Operation

The beam can be scanned in elevation and in azimuth. When measuring, step to a new position, sampling data every 112 m along the beam, between the inner saturation gate and the furthest useful level of SNR. In our experience the following scanning patterns were useful:

1. Fixed stand and stare, a time dependent view as the prevailing flow moves through the stationary inclined beam and convective cells rise through it. Colour coded radial velocity is plotted on successive inclined lines like a time series, with time horizontal and height vertical. Contours of intensity, or derived aerosol concentration, may be added. Figure 1 is a 20 minute period.

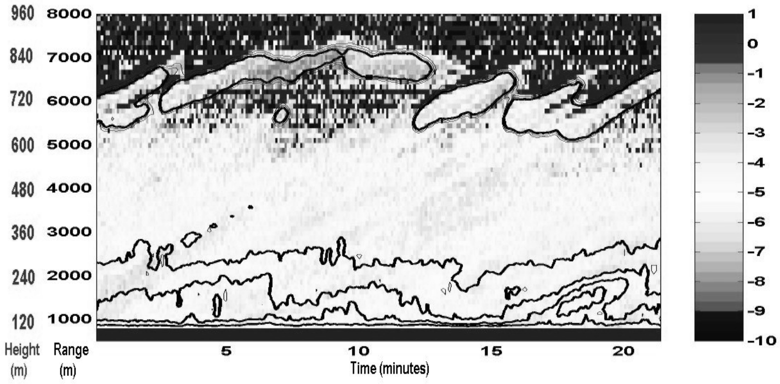
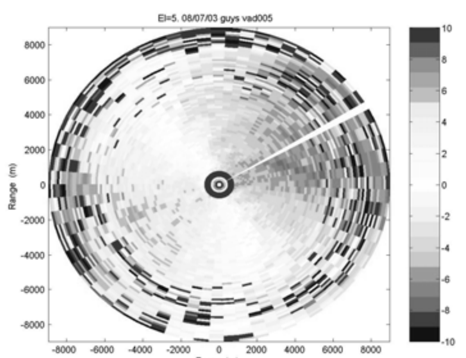


Figure 1. A 'Stand and Stare' plot, rather like a time series plot, colour coded for velocity with added contours indicative of intensity (aerosol number).

2. Velocity Azimuth Display, VAD: the inclined beam rotates about a vertical axis at the instrument and sweeps out an inverted cone. It quickly indicates mean wind direction, useful when deployed in the field. Colour-coded radial velocity is plotted on a polar plot as if seen from above. The mean wind direction is easily seen. Figure 2.
3. Range Height Indicator, RHI: the beam moves up or down in a vertical plane and sweeps out a vertical arc (in the Salford Scanner) or a full vertical semicircle (in the Malvern Scanner), according to the mechanical arrangement of the scanning mirrors. Colour coded radial velocity is plotted with axes height versus horizontal distance and appears as an arc or semicircle. Figure 3.



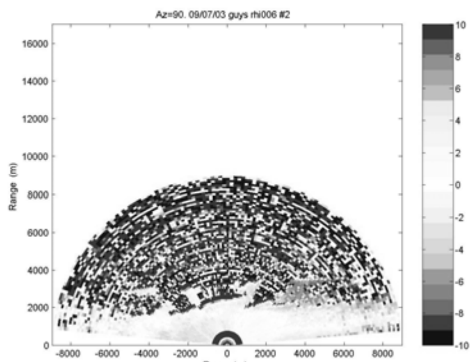


Figure 2. (left) showing a typical 'Azimuth Scan', by moving around a vertical axis, with flow from a south west direction. Figure 3 (right) shows a vertical scan with height vertical, range radial, and a rural to urban difference clearly evident.

Dual Lidar Operation

The advent of two similar lidars facilitated a key aim of this project, to operate them in a co-ordinated manner (Collier et al., 2004), yielding much more information than from a single lidar. The two beams were overlapped, so that fewer assumptions are invoked when analysing the lidar measurements. In particular, two measures of the velocities of aerosol within an intersection region are obtained, resolved into two beam directions. To map the flow, the two beams may be rotated in elevation and azimuth, subject to the geometric constraint that the beams cross. The geometry and alignment is calculated beforehand. For vertical profiles, which are of much interest to the urban meteorologist, the dual lidar beams were scanned as follows:

1. Intersecting points in a vertical column above a line AB joining the two instruments at A, B. For points between the lidars, this arrangement dictates that the lidars are further apart than twice their minimum range, a clear line of sight distance of over 1 km between them.
2. Intersecting points in a vertical column to either side of the line AB.

The development of this dual lidar concept, its assumptions and alignment on site, is described by Young et al. (2003a), Davies et al., (2003), Young et al., (2003b). Part of the work therefore provides a 'proof of concept', Collier et al., (2004), to obtain results in an urban boundary layer that yielded data for the dispersion parameters whilst testing the viability of a dual lidar measurement. We also sought to study questions on urban mixing heights and urban wind wield raised in COST715, seeking to record data to improve the urban boundary layer descriptions. Consequently we have used a site at RAF Northolt on the Western or prevailing wind side of London. We first conducted a trial at Malvern, Worcs, to assess equipment performance. Some validations of the single lidar (Salford) prototype were also conducted at Met Research Unit, Cardington using their tethered balloon. Full results of the trials will appear later as analyses are continuing. This paper presents some of the first observations.

DISPERSION MODEL PARAMETERS

Dispersion parameters describe the turbulent conditions in the atmosphere and are used to calculate the rate of advection and turbulent spread. Table 1 represents the parameters that, after much discussion of lidar characteristics, appear most amenable to measurement in the field by this technique. An important scientific goal of the work is to derive estimates of the parameters from the lidar data, to evaluate their uncertainty, and use them to improve the parameters in the modelling.

RESULTS

Trials were conducted in March 2003 at Malvern, a small rural town, and in July 2003 at RAF Northolt, on the Western edge of London. The work has been of great value in developing the methodology of operation and accompanying data processing software. Future work should focus on obtaining longer data-sets.

- Boundary layer heights have been inferred from the backscatter data and compared with AMDAR aircraft data and NWP model data.
- Mean wind speed and direction have been obtained from a VAD scan and represent an average over the layer enclosed in the sampling cone at each height.
- Turbulence parameters are being evaluated, both from the radial velocity data for a single lidar, and for dual beam intersections scanned in a vertical column. Mean horizontal wind, vertical wind, standard deviations in horizontal and vertical, and momentum flux have been evaluated. Other parameters have also been estimated.
- Work is in hand at Essex to analyse the errors inherent in the dual beam methodology, according to beam crossing geometry.

The field trials have provided data from single and dual operation, enabling the methodology to be developed and the results are now being processed and evaluated.

CONCLUSIONS

Fuller reports are in hand (Collier et al., 2004). Doppler lidar offers many advantages for urban science, and the work has demonstrated the potential value of dual lidars operated together. A striking feature of Doppler lidar remote sensing is its ability to survey over significant distances. Here the maximum range could be up to 10-12 km, or down to 6 km, according to conditions. In the talk we present some results from single and from dual intersecting beams. Having two lidars meant we could devise some other scanning patterns designed to look at rural and urban conditions simultaneously. The ability to scan the beams and reach out several km in either direction is a clear advantage when seeking to compare rural and urban boundary layers.

ACKNOWLEDGEMENTS

The work described here was funded by HM Treasury Invest to Save Project ISB 52 and by the Met Office's Government Meteorological and CORE Research Programmes. We also acknowledge JIF funding for upgrades to the Salford lidar facility. Lidar design, construction, and operating software by Guy Pearson and Dave Willetts with project management by Rob Young, all at Qinetiq, Malvern; data processing software by Fay Davies, University of Salford; dual lidar concept, data visualisation software and error analysis by Anthony Holt, Stefan Siemen and Graham Upton at University of Essex respectively; matching/comparisons with dispersion model parameters by Doug Middleton. We also are grateful for the help of colleagues in our institutes. Any views expressed here are those of the authors.

REFERENCES

Angevine, W.M., R.J. Doviak and Z. Sorbjan, 1994: Remote Sensing of Vertical Velocity Variance and Surface Heat Flux in a Convective Boundary Layer, *J. Appl. Meteor.,* **33**, 977 - 983

Collier, C.G., K.E. Bozier, F. Davies, A.R. Holt, D.R. Middleton, G.N. Pearson, S. Siemen, D V. Willetts, G.J.G. Upton, R.I. Young, 2004: Dual Doppler lidar measurements for improving dispersion models. *Paper in preparation for submission to BAMS.*

Davies, F., C.G. Collier, K.A. Bozier, D.R. Middleton, 2003: Identification of key parameters for dispersion models. Invest to Save Project Report ISB52-04. February 2003. QinetiQ, Malvern, Worcs, U.K. www.qinetiq.com

Davies, F, C. G. Collier, A. Holt, D.R. Middleton, G.N. Pearson, S. Siemen, D.V. Willetts 2003: Boundary layer measurements of dispersion model parameters using Dual Doppler Lidar at Malvern, UK. Invest to Save Project Report ISB52-06. July 2003. Qinetiq, Malvern, Worcs, U.K., www.qinetiq.com

Gal-Chen T., M. Xu and W.L. Eberhard, 1992: Estimations of atmospheric boundary layer fluxes and other turbulence parameters from Doppler lidar data. J. Geophys. Res., **97**, 18409 - 18423

Menut L., C. Flamant, J. Pelon., and P. H. Flamant, 1999: Urban boundary layer height determination from lidar measurements over the Paris area. Applied Optics, **38**, No. 4, 945 - 954

Pearson G.N. and C.G Collier, 1999: A pulsed coherent CO_2 lidar for boundary layer meteorology. *Q. J .R. Meteorol. Soc.,* 125, 2703 – 2721.

Young R.I., F. Davies, G.N. Pearson, D.V. Willetts, K.A. Bozier, 2003a: Description of the first ISB-52 Dual Doppler Lidar Trial. Project Report ISB52-05. March 2003. Qinetiq, Malvern, Worcs, U.K., www.qinetiq.com

Young R.I., G.N. Pearson, C.G. Collier, F. Davies, K.A. Bozier, 2003b: Description of the RAF Northolt ISB-52 Dual Doppler Lidar Trial. Project Report ISB52-07. August 2003. Qinetiq, Malvern, Worcs, U.K., www.qinetiq.com

Table 1. Summary of the data products and dispersion parameters potentially attainable using Doppler lidar data. An important scientific goal of this study is to evaluate their accuracy and usefulness for improving dispersion models. Adapted from Davies et al., (2003).

Variable	Symbol	Lidar Perspective
Boundary Layer Depth	h	Strength of back-scatter signal identifies aerosol layer(s). (Menut et al 1999)
Mean flow velocity (space or time average)	$\bar{u}, \bar{v}, \bar{w}$	VAD data yields mean $\bar{u}$ and $\bar{v}$. But $\bar{w}$ needs vertical beam or dual lidar.
Turbulence	$\sigma_u, \sigma_v, \sigma_w$	Dual lidar data can provide fluctuations u', v', w' to obtain $\sigma_u, \sigma_v, \sigma_w$. .
Local friction velocity derived from local Reynolds stress	u_* $\overline{u'w'}, \overline{v'w'}$	Dual lidar processing can yield Reynolds stress $\overline{u'w'}$, $\overline{v'w'}$ and friction velocity u_*
Log law for surface layer <u>mean</u> wind speed in neutral conditions	$\bar{u} = \frac{u_*}{k} \ln\left(\frac{z-d}{z_0}\right)$ Notation: Use d or z_d	Dual lidar data for $\overline{u(z)}$ to verify profiles and check u_*, k, z_0, d .
Urban roughness sub-scale height	z_* z_* is height to which roughness affects turbulence statistics or	Dual lidar data for Reynolds stress and friction velocity may shed light on the existence an urban roughness sub-layer
Eddy dissipation rate	ε	Lidar fluctuations processed to generate spectrum and estimate ε
Lagrangian integral timescale and Integral length scale	$\tau_L = \int_0^\infty R(\tau)d\tau$ $L_i = \int_0^\infty R(s)ds$	Decay time scales for auto correlation coefficient $R(\tau) = \frac{\overline{u'(t)u'(t+\tau)}}{\sigma_u^2}$ for lag τ , $R(s) = \frac{\overline{u'(x)u'(x+s)}}{\sigma_u^2}$ for lag s.
Sensible heat flux Flux of temperature fluctuation	H or Q $H = Q_H$ $= \rho C_p \overline{w'\theta'}$ $\overline{w'\theta'}$	Indirectly from lidar third moment $\overline{w'^3}$. (Gal-Chen et al 1992) Or from w_* as below.
Convective velocity scaling . Associated with speed of convection (unstable).	$w_* = \left[hg\frac{(\overline{w'\theta'})}{\theta}\right]^{\frac{1}{3}}$	From $\sigma_w^2 \approx \beta w_*^2$ (Angevine et al 1994) where $\beta \approx 0.4$ within $0.2 < z/h < 0.5$