14.2 OBSERVATIONS OF THE DIURNAL VARIATION OF ENERGY DISSIPATION IN THE URBAN BOUNDARY LAYER USING DOPPLER LIDAR

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1. INTRODUCTION

Turbulent exchange in the lower part of the atmospheric boundary layer drives the exchange of heat, mass and momentum at the surface, thereby controlling the state of the whole boundary layer. Within a city, the nature and distribution of urban structures determine the airflow, with the aerodynamically rough and inhomogeneous surface modifying turbulent transfer and structure. The turbulent kinetic energy dissipation rate is one of the key parameters in atmospheric turbulence theory. It represents the rate of transfer of energy to smaller eddies in the inertial subrange of inhomogeneities, and the rate of conversion of kinetic energy of turbulence into heat in the viscous subrange, characterising the flow of energy in the atmosphere.

Estimates of turbulent kinetic energy dissipation rate and surface heat flux presented in this paper have been evaluated from Doppler lidar observations of airflow over the urban conurbation of Greater Manchester, northwest England, UK.

2. DESCRIPTION OF THE SALFORD LIDAR

The Remote Sensing and Hydrometeorology group at the University of Salford, UK, operate an infrared, pulsed Doppler lidar system described by Pearson and Collier (1999). The lidar detects backscatter of infrared laser light from naturally occurring aerosols that are advected with the wind field, providing radial (line of sight) wind and backscatter intensity measurements within the atmospheric boundary layer. To allow for operation within an urban environment, the system operates with an eye safe wavelength of 10.6 *m*m and a maximum power output of 0.7 mJ. The system is relatively compact and operates as a mobile unit equipped with an azimuth/elevation scanner. The system has a wind velocity accuracy of 0.5 ms^{-1} and a range resolution of 112 m with a theoretical maximum range of 4.6 km.

3. MEASUREMENT TECHNIQUES

Retrieval of the mean wind components, $\overline{u}$, $\overline{v}$ and $\overline{w}$ from Doppler lidar data relies on the pointing or scanning geometry of the lidar beam. Using scanning methods, the mean wind components can be calculated by performing range height indicator (RHI) or plan position indicator (PPI) scans. Following a method proposed by Gal-Chen *et al*. (1992), the mean wind, cross wind component, vertical velocity, second moments and associated momentum fluxes can be obtained from the radial wind velocities.

The nature of the energy spectra of turbulence depends upon the characteristic wavelength of the motions giving rise to the turbulence. For wavelengths less than the height above the surface, but larger than the Kolmogorov microscale, the energy spectrum is known as the inertial subrange. In this range, energy does not enter the system from the outside nor is any energy dissipated. Energy cascades from larger wavelengths (smaller wavenumbers) toward smaller wavelengths (larger wavenumbers). In the case of the velocity component, the energy leaves the inertial subrange at rate, ε, the rate at which it is then dissipated in the dissipation subrange. In the inertial range, one-dimensional spectral densities of velocity components depend only on the turbulent kinetic energy dissipation rate, ε and the wavenumber, κ.

Following the method used by Gal-Chen *et al.* (1992), the kinetic energy dissipation rate is found by examining the line spectra of the longitudinal velocity correlation. In the inertial subrange the expected relation is (Batchelor, 1956):

$$\overline{f}(k) = a e^{2/3} k^{-5/3}, \qquad (1)$$

where $\overline{f}(k)$ is the Fourier transformation of the longitudinal velocity correlation, the transform of $\overline{u'(x)u'(x+r)}$ or $\overline{v'(y)v'(y+r)}$ where u' and v' are the fluctuations of the u and v velocities. The range increment, r, along the beam is taken as a time increment and the universal spectra constant, α, has a value of 0.5. The kinetic energy dissipation is estimated from the spectra provided that an inertial $k^{-5/3}$ law is established.

An estimate of the surface heat flux first requires an estimate of the potential temperature-vertical velocity covariance, $\overline{w'q'}$. From Gal-Chen *et al.* (1992), the balance of vertical velocity fluctuations for horizontally homogenous turbulence are given by Wyngaard and Cote (1971) as:

$$\frac{\partial}{\partial z}\left(\frac{1}{2}\overline{w'^3}\right) = -\frac{1}{r_0}\left(\overline{w'\frac{\partial p'}{\partial z}}\right) - \frac{e}{3} + \frac{g}{q_0}\overline{w'q'}, \qquad (2)$$

where $\overline{w'^3}$ is the third moment of the vertical velocity, p¢ is the pressure fluctuation, r_0 is the air density at

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the surface, ε is the kinetic energy dissipation, g is the acceleration due to gravity, q_0 is the potential temperature at the surface, q' is the potential temperature perturbations and z is height.

Wyngaard and Cote (1971) found that under stable conditions, shear production and viscous dissipation are the dominant terms and are essentially in balance, and the turbulent transport is small. Under unstable conditions the pressure term near the surface is small compared to the other terms in equation 2 and can be neglected, reducing the equation to:

$$\overline{w'q'} = \left(\frac{\partial}{\partial z}\left(\frac{1}{2}\overline{w'^3}\right)+\frac{e}{3}\right)\frac{q_0}{g}\ . \qquad (3)$$

Since $\overline{w'q'}$ is the potential temperature-vertical velocity covariance then an estimate for the surface heat flux, H, may be obtained from:

$$H = r_0 C_p \overline{w'q'}\ , \qquad (4)$$

where C_p is the heat capacity of air at constant pressure.

4. DETAILS OF THE OBSERVATIONS AND MEASUREMENT SITE

The measurements discussed in this paper were gathered from two closely located sites at the University of Salford. One site (site A) had the lidar located at the top of a 30 m high building and the other site (site B, within 0.5 km) had the lidar located at ground level; both sites were situated on the edge of an urban park. In general, the terrain to the west is relatively flat consisting of low level (two storey) housing with a series of high rise tower blocks within 1 km. Approximately 1.6 km to the east is Manchester city centre consisting of high rise buildings (twenty storeys) rising above closely packed, five or six storey buildings. The area to the north, which rises at a gentle slope towards the west Pennine Moors, consists mainly of residential, low level housing, with a sparse scattering of high rise tower blocks. To the south, airflow is generally over buildings having similar form with several groups of high rise buildings a few kilometres to the southwest.

One set of observations were made on 27th August 1998 from site A, 1000 – 1600 hours, with results presented for the period 1100 – 1130 hours when the atmosphere was determined as being near neutral, $-z/L$ = 0.8. The dominant airflow was from the west with a mean wind of 3.6 ms^{-1} at 50 m, 18 °C maximum, mainly clear sky and 2/8ths cumulus at 1200 hours.

The second set of observations were made on 3rd April 2001 from site B, 1240 – 1530 hours, with near neutral atmospheric stability at 1240 hours, $-z/L$ = 0.2. Airflow was from the south/southwest with a mean wind of 6.4 ms^{-1} at 50 m. Temperature increased from 13 °C (1330 hours) to 15 °C (1515 hours), with convective cloud developing, distant showers and 4/8ths cloud cover.

5. RESULTS

The turbulent kinetic energy dissipation rates were evaluated from the Doppler lidar data by plotting the longitudinal power spectra of the *u* velocity against wavenumber.

Observation period (dd/mm/yy) (hours)	Estimate of turbulent kinetic energy dissipation rate x 10^{-3} (m^2s^{-3})
27/08/98 1100 – 1130	5.51
03/04/01 1240 – 1255	6.61
1320 – 1335	5.48
1400 – 1415	5.27
1440 – 1455	3.62

The surface heat flux was evaluated using equations 3 and 4, for three of the observation periods.

Observation period (dd/mm/yy) (hours)	Surface heat flux (Wm^{-2})
27/08/98 1100 – 1130	147
03/04/01 1240 – 1255	115
1440 – 1455	99

6. SUMMARY

The estimates of kinetic energy dissipation and surface heat flux obtained from wind velocity measurements are comparable to expected values. The lidar system is currently undergoing enhancement to improve reliability and allow the system to be operated with minimum supervision. Observations of airflow over larger areas, from a single location, made using the improved system should provide an extensive new database for studying a wide range of atmospheric boundary layer phenomena.

7. REFERENCES

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