P2.7 MEASUREMENTS OF CONVECTIVE TURBULENCE USING AN AUTONOMOUS DOPPLER LIDAR SYSTEM

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1. INTRODUCTION

The Convective and Orographically-Induced Precipitation Study, COPS was conducted in the Black Forest region of Germany during the summer of 2007. Its aim was to advance the quality of forecasts of orographically-induced convective precipitation by 4D observations and modeling. UFAM was funded through NERC to participate in the project. The University of Salford instrumentation included a 1.5 micron Doppler lidar system mounted in a mobile laboratory with a full hemispheric scanning capability, a 14 channel microwave radiometer and an automatic weather station (AWS). All Salford instruments were set up to run continuously from 13th June to 16th August 2007. The lidar, which was a Halo Photonics system was fully controlable over the internet and had been previously deployed during the Helsinki Testbed (Bozier et al 2007).

Figure1 Salford Autonomous lidar with antenna.

The Salford Autonomous Lidar System, operating at a wavelength of 1.5 microns, employs novel optical technology and the design approach has led to a new type of eye-safe Doppler lidar (class 1 or 1M) providing a high level of performance and exhibiting exceptional stability. The system has a modular design arranged in three separate units; the optical base unit, the weather-proof antenna and the signal processing and data acquisition unit. The base unit has approximate dimensions 56 cm x 54 cm x 18 cm (Figure 1) and contains the optical source, interferometer, receiver and electronics. The weather-proof antenna is attached to the base unit via an umbilical. The antenna can be deployed permanently outside whilst the base unit and data acquisition system are housed within a laboratory environment. The signal processing has been developed with a view to providing a high level of flexibility with respect to the data acquisition parameters. Users are able to set parameters such as the length of the range gate, maximum range and number of pulses accumulated for each measurement and the spectral resolution. Some lidar system parameters are given in table 1. The lidar system also has the capability to perform diagnostic tests in order to monitor and log the status of the system.

Parameter	Value
Operating wavelength	**1.5 μm**
Range gate length	**30 m**
Minimum range	**100 m**
Maximum range	**7 km**
Temporal resolution	**0.1 – 30 s**
Pulse Repetition Frequency	**20 kHz**

Table1: Autonomous Doppler lidar system parameters

The lidar was set to run 24/7 through the duration of the field trial. Measurements were only limited in heavy rain or foggy conditions when excess water collected on the antenna window and the two instrument down periods were caused by a lightening strike and a mains power failure. The system has now been updated to include a UPS and a dew blower.

2. MEASUREMENTS

Doppler lidar wind velocity measurements have been shown previously to correlate well with tethersonde instruments.(Bozier et al 2004) and the Salford lidar team have carried out successful dual Doppler lidar trials whose aim was the determination of a variety of meteorological parameters particularly important in dispersion modelling (Davies et al 2005).

During much of the field campaign the lidar system was set-up to run a particular series of scan patterns pre-programmed into the system software. On the hour and half hour the system carried out an azimuth scan for determination of profiles of wind speed and direction. The time taken was approximately 5 minutes. For the following 25 minutes, of the half hour duration, the lidar beam was fixed vertically. The vertical data was then spliced together to give a daily overview of boundary layer growth and turbulence behaviour.

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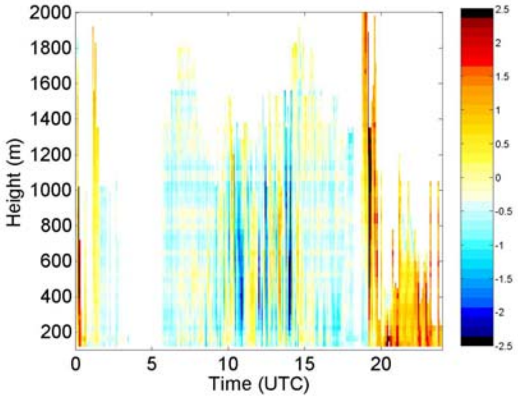

Figure 2 Vertical velocity lidar data from 17th June 2007.

The data from 17th June 2007 is shown in figure 2. The day was cloud free and thermal structures (updrafts and downdrafts) can be seen in the boundary layer from approximately 8 UTC through to 16 UTC. Above the boundary layer there is very little aerosol and the lidar is unable to measure any significant backscatter and the figure displays only noise above approximately 2 km during daylight hours.

This data can be used to determine a variety of meteorological products (Collier et al 2005) including, mixed layer height (Davies et al 2007) and turbulence statistics (Davies et al 2004). The aim of this work is to calculate the daily boundary layer structure for the whole duration of the field trial. As yet only a subset of this data has been analysed.

3. METHODOLOGY

The aim of this work is to formulate a robust set of analysis tools to automatically calculate the boundary layer turbulence behaviour. With this aim a comparison of different methodologies has been carried out. Using the half hourly sets of data spectral analysis has been done using two methods: Gal-Chen et al (1992) using the spatial data, and Champagne et al (1977) using the lidar temporal data.

The Gal-Chen method uses spectra calculated along the beam and averages over the duration of the data. The spectrum can be calculated from:

$$S(k) = 1.53\varepsilon^{\frac{2}{3}} k^{\frac{-5}{3}}$$

where $S(k)$ is the spectral energy of wavenumber *k* and ***ε*** is the dissipation rate.

The Champagne method uses the traditional method used for sonic data in the spectra are calculated along the timeseries and averaged over the height of the data. The spectrum can be calculated from:

$$nS(n) = 0.68\varepsilon^{\frac{2}{3}} \left(\frac{2\pi n}{U} \right)^{\frac{-2}{3}}$$

where $S(n)$ is the spectral energy of frequency *n*, and *U* is the mean wind speed.

These two methods are used for the derivation of the dissipation rate, ***ε***.

A third method for calculating ***ε*** is described in Davies et al (2004) following on from work detailed in Frehlich and Cornman, (2002). This involves the calculation of the Structure function:

$$D_w(s) = \left\langle \; [w(r_0) - w(r_0 + s)]^2 \; \right\rangle$$

where $D_w(s)$ is the structure function at separation, *s*, $w(r_0)$ is the vertical velocity at range, *r*.

By fitting a simple turbulence model to the lidar data:

$$D_w(s) = 2\sigma_w^2 \Lambda\left({}^{s}\!/_{Lo} \right)$$

where σ_w^2 is the variance of vertical velocity and $\Lambda\left[{}^{s}\!/_{Lo} \right]$ is the von Kármán model function at separation,*s*, and outer length scale of turbulence *Lo.*

The dissipation rate can then be calculated from:

$$\varepsilon = \frac{0.93\sigma_w^2}{Lo}$$

Using this methodology as detailed in Davies et al (2004) both the dissipation rate and outer length scale of turbulence can be measured. This third method also allows the lidar data to be corrected for both the spatial averaging effect of the lidar beam and the lidar estimation error.

These three methods can then be used to determine the turbulence behaviour in the growth and decay of the convective boundary layer throughout the daytime. It also means that a good comparison of the different methods for the data set is possible.

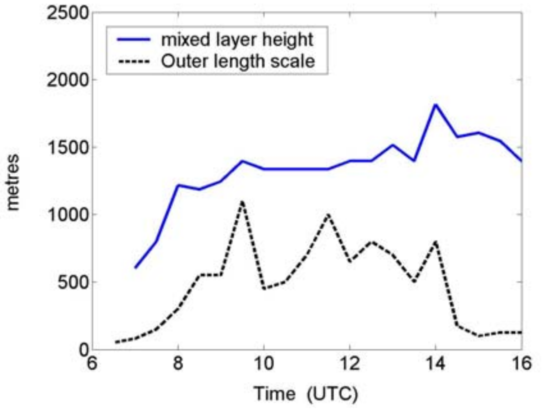

Figure 3 Mixed layer height and outer length scale of turbulence for 17/06/07

4. RESULTS

Following the three methods above calculations were carried out for data from the COPS campaign. Data from the 17th June 2007 was used. This day was cloud free and the vertical velocity data in figure 2 showed that the boundary layer was convective with vigorous thermals from 8 UTC through to 16 UTC. Figure 3 shows the mixed layer height as estimated from the lidar backscatter and compares it to the turbulence length scale. The outer length scale of turbulence is a measure of the characteristic size of the turbulent eddies within the boundary layer. It can be seen from figure 3 that the turbulent length scale increases quickly in the morning and rises to approximately half the size of the boundary layer depth, before decreasing quite suddenly at 14:30 UTC.

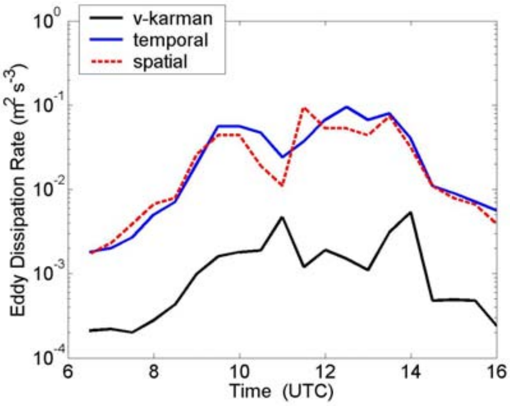

Figure 4. The eddy dissipation rates calculated for the three methods for 17th June 2007.

This behaviour agrees quite well with the dissipation rate timeseries in figure 4. The dissipation rate is seen to rise slowly through the morning hours and decrease more quickly after 14:30 UTC. The three curves are well correlated but the spectral and temporal spectral methods have much higher values of dissipation rate than the corrected von-Kármán method.

5. CONCLUSIONS

With the new development of autonomous Doppler lidar systems a new phase of software development will be needed. The Halo Photonics autonomous Doppler lidar system works 24/7 to provide continuous data day and night. This paper discusses the development of methodologies and software that can be applied to the lidar data to create views of the turbulent boundary layer that will allow us to better understand turbulent mixing and boundary layer behaviour. It is hoped that the software developed will allow constant automatic monitoring of the boundary layer turbulence.

In this paper I have shown preliminary results from the COPS experiment. It is hoped that the analysis of the whole dataset will give us some insight into the growth and decay of the turbulent boundary layer and the role of eddy size in the transport and mixing of surface fluxes.

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