8B.4 STRUCTURE FUNCTION CALCULATIONS OF CONVECTIVE TURBULENCE DURING COPS

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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. The UK's University's Facility for Atmospheric Measurement, 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 Doppler lidar was controlled remotely via an internet link.

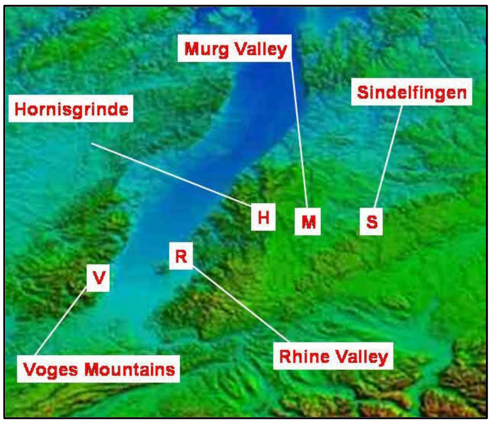

Figure 1: Orographic Map of the Five measurement 'supersites'. The sites were the bases for the COPS instrumentation. The supersites were on an east-west transect of the Black Forest mountains. The University of Salford instruments were based at the Rhine Valley supersite in Germany.

2. SALFORD AUTONOMOUS LIDAR SYSTEM

The Salford Autonomous Lidar System operates at a wavelength of 1.5 microns. It employs novel optical technology, provides a high level of performance and exhibits 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 contains the optical source, interferometer, receiver and electronics. The weather-proof antenna is attached to the base unit via an umbilical. 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.

Figure 2: Lidar Base Unit and Antenna

3. 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.

The data from 15th July 2007 is shown in figure 3. 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

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aerosol and the lidar is unable to measure any significant backscatter and the figure displays only noise above approximately 2 km during daylight hours.

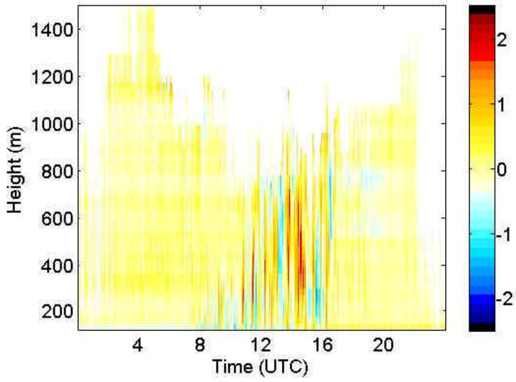

Figure 3: Vertical velocity composite through the day of the 15th July 2007. Colorbar shows upward velocities in red and downward velocities in blue.

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.

4. 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 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:

$$S(k) = 1.53\, e^{2/3}\ k^{-5/3} \qquad (1)$$

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

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

$$nS(n) = 0.68\, e^{2/3}\ (2pn/U)^{-2/3} \qquad (2)$$

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, *e*.

A third method for calculating *e* 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:

$$D\ w(s) = [\,w(ro) - w(ro + s)]^2 \qquad (3)$$

where *D w(s)* is the structure function at separation, *s*, *w(ro)* is the vertical velocity at range, *r*.

By fitting a simple turbulence model to the lidar data:

$$Dw(s) = 2\, s_w^{\,2}\ ?\ (s/Lo) \qquad (4)$$

where $s_w^{\,2}$ is the variance of vertical velocity and *? (s/Lo)* is the von Kármán model function at separation,*s*, and outer length scale of turbulence *Lo.* The dissipation rate can then be calculated from:

$$e = 0.93\, s_w^{\,2} /Lo. \qquad (5)$$

Using this methodology, as detailed in Davies et al (2004), both the dissipation rate and outer length scale of turbulence can be measured. This 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 calculation of dissipation rate from the data set is possible.

5. RESULTS

With the equations above the lidar data was used to calculate the dissipation rate from the temporal and spatial spectra, and from fitting the von Kármán model to the calculated structure function.

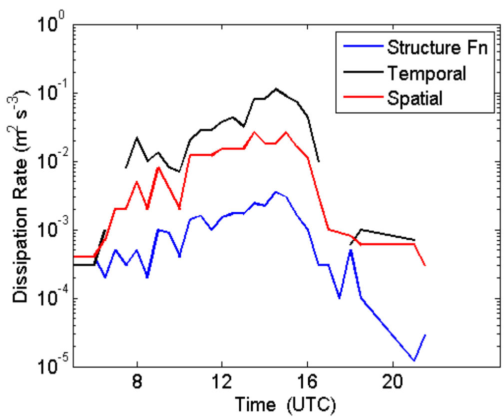

Figure 4: Dissipation rate for 15th July 2007.

Each half hourly dataset was used to calculate a spectrum using each method. Figure 4 shows the timeseries of the dissipation rate as calculated from the three methods discussed. The value of dissipation rate from the structure function method is significantly lower that the other two methods because it corrects for the velocity estimation error of the lidar processing and corrects for the spatial averaging of the lidar beam.

6. CONCLUSIONS

Both the dissipation rate and the turbulence length scales are important parameters in enabling us to understand the properties of the mixing and transport in the boundary layer. The dissipation rate is important in a practical sense in that it is a key parameter within NWP models. Current models include parameterizations to compensate for influence of energy from smaller scales onto resolved scales and a comprehensive set of dissipation rate measurements will enable us to improve these parameterizations. The turbulence length scale is important because it can tell us more about thermal development that leads to cloud formation and pre-storm conditions.

With the new development of autonomous Doppler lidar systems a new phase of software development will be needed. 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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