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IMPACT OF SURFACE HETEROGENEITY IN URBAN AND RURAL AREAS ON THE ATMOSPHERIC BOUNDARY LAYER USING DOPPLER LIDAR

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1. INTRODUCTION

Urban areas change profoundly the transport and mixing properties of the airflow, which has important applications in forecasting air quality and in emergency response to fires or toxic releases. These applications require understanding of the dynamical and thermodynamic interactions between the boundary layer and urban areas. Key questions requiring study are: What is the role of local advection and heterogeneity of both rural and urban surfaces in determining the structure of the ABL; What are the impacts of urban and rural areas on large scale weather?

Key components of modelling dispersion and air quality within the urban areas are the mixing and ventilation processes that set the concentrations and their fluctuations. These processes occur on a range of scales from street, to neighbourhood, to city. At the neighbourhood scale we need to understand what descriptors of the surface characterise the flow, mixing, and dispersion. Also on the city scale investigations are needed into the different roles played by tightly packed tall buildings in the city centre regions when compared to the low lying suburban regions in controlling transport, mixing, and ventilation in the urban boundary layer. Clarification is needed on how much of the understanding of plant canopies can be carried over to the urban canopy.

The research into those questions outlined in this paper is an integral part of the NERC National Centre for Atmospheric Science (NCAS) Universities Weather Research Network (UWERN) research programme. The work builds around both existing and planned scanning Doppler lidar data sets obtained in both urban and rural areas. The lidar system provides measurements on the scales from neighbourhood to city above the urban canopy layer to the top of the boundary layer and is therefore the ideal instrument with which to carry out this work. New urban measurements are to be made over Salford from SUBERB (Salford University Urban and Built Environment Research Base) and compared to existing rural data collected during both the NERC funded 2005 CSIP (Convective Storm Initiation Project (Browning, *et al*., 2007)) field campaign in Central-Southern England, and the 2006 Shoeburyness field trial to the East of London.

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2. LIDAR SYSTEM DESCRIPTION

The Salford scanning Doppler lidar system is a ground based, mobile instrument. The system operates at an eye safe wavelength of 10.6µm and has an (atmospheric dependent) range capable of 9km. The range and scanning capabilities of the Salford Doppler lidar system allows probing of the atmosphere throughout the boundary layer and over relatively large areas.

The lidar system is based around a pair of CO_2 lasers. The system is relatively compact, sitting upon an optical table measuring 1.2m x 0.75m, and requires little maintenance. One of the CO_2 lasers acts as a transmitter, sending a pulsed signal, whilst the other serves as a continuous wave (CW) local oscillator, used to reference the returning atmospheric signal. A schematic of the optical table layout is shown in figure 1.

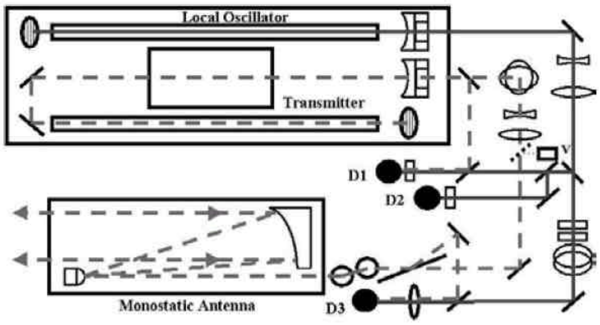

Figure 1 - A schematic drawing of the lidar optical layout. He rectangular base plate has dimensions 1.2 m × 0.75 m. The solid line traces the LO path, the dashed line traces the transmitter path, and V indicates a visible laser used for alignment purposes. The transmitter, local oscillator and monostatic antenna are labelled, and D1, D2 and D3 are the CdHgTe (mercury cadmium telluride) infrared detectors (Bozier, et al. 2004).

The original lidar specification for the Salford system required the system to operate safely in a variety of locations, within rural and urban environments. The Salford lidar system was designed, developed and upgraded by QinetiQ, Malvern, UK. Pearson and Collier (1999) detail the design and performance characteristics of the original Doppler lidar system (1998– 2001). In late 2001/early 2002 the lidar system received development to improve several aspects of the original design, although most of the components along with the signal processing were kept from the original system. The maximum range was increased to approximately 9 km (dependent on atmospheric conditions) by increasing the output pulse energy to approximately 50 mJ from 0.7 mJ by the inclusion of a transverse excitation atmospheric (TEA) pressure laser. The transmitter and local oscillator laser tubes were redesigned to improve their operating lifetimes, and a third liquid nitrogen cooled detector was added to assist in laser control. These improvements increase the reliability of the system and help to reduce the need for an operator to be permanently present. Improvements to the scanning mechanism included new higher specification mirrors to eliminate some of the signal loss, and the installation of a third mirror to enable vertical measurements.

Comparisons of the Doppler lidar radial velocities with those of a simple idealised mathematical model suggest how the surface influences the boundary layer structure. The paper will focus on the preliminary results of the rural field trials and give an overview of ongoing measurements at SUBERB project.

Parameters	**Description/value**
Operating wavelength	10.6 μm
System IF	12 MHz
Pulse length	0.6 μs
Energy/pulse	50 mJ
Spatial extent of lidar pulse	75 m
Nominal range gate	112 m
Telescope aperture	150 mm
Maximum range	9 km (dependent on atmospheric conditions)
Minimum range	500–700 m

Table 1 - Salford pulsed Doppler lidar parameters.

3. COMPUTER MODELLING DESCRIPTION

Using the equations in Wood and Brown (1986) as a guide, a simple computer model was produced that would create PPIs if a constant direction and speed were input. Table 2 lists the variables that can be changed by the user before each run of the model.

Parameters	**Description/value**
Elevation Angle of Scan:	0-90°
Scan Azimuth:	0-360°
Number of Range Gates:	80
Length of Range Gates:	112m
Turbulence:	0-100%
Wind Speed at Height z:	Any ms^{-1}
Wind Direction at Height z:	Any degree

Table 2 - Variables that can be changed by the user before each run of the model. For all of the runs the setup mimicked that of the Salford Doppler Lidar.

The results were compared to those of Wood and Brown (1986). Changing the model then allowed input of more complicated wind flow patterns, with variable speeds and directions at different heights. This was achieved by modifying the model equations that described the desired scenario. Again similar results were produced to those reported in Wood and Brown (1986). Data taken from the field can now be analysed using this model.

The model is used to analyse data collected by the Salford lidar. A theoretical PPI plot is generated using appropriate wind velocity input. This is compared to the actual scan. Any significant differences between the two would arise from local sources which are disturbing air flow.

The Salford lidar produces data that can be presented in the form of a PPI. VAD analysis can be carried out on the data, producing a mean wind speed and direction for each range gate height. A profile may be constructed of mean spd(h) and dir(h) from the surface through the ABL for any elevation angle. The profiles can then be used as inputs to the model, which outputs theoretical plots for a homogeneous surface.

There are difficulties in analysing the data in its present form. If the data from the model output is subtracted from the lidar data, only differences in wind speed due to surface heterogeneity will remain. This type of analysis should lead to data which shows either decreases or increases in wind speed, and can be easily represented numerically or visually in a difference model lidar (DML) PPI style plot (Figure 2).

With the ability represent areas of the scan with wind speeds higher or lower than the expected over a flat surface, it is possible to link the differences to specific features in the field-area. This is achieved through the use of aerial photography, topographic maps, and computer software. An advantage to analysing data in this manner is that past lidar data can be re-evaluated. Data for many different urban and rural situations is available for analysis using this method.

4. CSIP FIELD SITE

Recent field campaigns using the Salford Doppler lidar have been focused around rural sites, due to links with other projects such as CSIP (The Convective Storm Initiation Project).

CSIP used a large array of ground-based instruments, from the NCAS Universities' Facility for Atmospheric Measurement (UFAM), the UK Met Office and the Institute for Meteorology and Climate Research (IMK) Karlsruhe. These were deployed in southern England, over an area centred on the 3 GHz (CAMRa) and 1275 clear-air (ACROBAT) radars at Chilbolton. In addition, two aircraft complemented the ground-based instruments by mapping the temperature and dew point of the boundary layer. The main project was conducted from June to August 2005, whilst the pilot project took place during July 2004.

During CSIP the Salford Doppler lidar was positioned ten miles South-West of Newbury, over the hamlet of Faccombe. The area surrounding the site is made up of gently rolling hills, fields, forests, and to the North of the site a ridge running east-west. During the CSIP campaign in 2005 many PPI scans were taken at different elevation angles, and with differing flow conditions. This data is ideal for studying the effects of rural heterogeneity on flow within the ABL.

The pilot project data from 2004 is also useful for the same reason, although there are much fewer lower angle scans.

The majority of Urban data sets will be taken from the Salford University Urban and Built Environment Research Base (SUBERB) which is setup to the West of Salford. Here the lidar can take measurements over Salford and Manchester with varying flow directions and speeds. Due to the nature of the site data acquisition can occur at different times in the year so any seasonal differences that may occur can be detected.

5. PRELIMINARY RESULTS

Initial results have concentrated on the CSIP data set. Lots of data is available for this site. Importantly there are different elevation angles for similar wind flow scenarios which make analysis more comprehensive. Due to the decreasing effects of aerodynamic roughness with ABL height, lower angle scans are more likely to pick up any surface effects. However at higher elevations it may be possible to observe insects or target aerosol motion due to very local circulations. Figure 2 shows four DML plots from the 19/07/2005 CSIP field trial; they range between 5^{o} and 12.5^{o} in elevation, with a constant direction of 250^{o} and speed of 10-12ms^{-1} with height.

Ridge like structures are present in the lower elevation angle scans in figure 2, running south-west to the north-east. The undulating effect that can be seen is most likely related to the ridges and valleys that are present, creating patterns of flow separation such as those highlighted by Oke (1987). To the south-east of the lidar site, intermittent patchiness can be observed. On the surface below this area, there is a patchwork of villages, forests, and smaller topographical features, which in theory could create these differences. These effects will be the subject of further study.

One of the limitations of using the lidar, is that changes in wind direction created by surface topography are perceived as changes in speed. This is due to the way that the Doppler lidar uses the perceived speed of horizontal flow either towards or away from it. If an area of surface roughness directs flow away from the lidar it will be detected as a slowing of speed. The changing of direction through differences in aerodynamic roughness is a small effect in comparison to changes of speed due to the synoptic pressure field; but effects could be visible in lower angle scans. This will be looked at in future work.

Presently work is focused on more accurate linkage of surface topography with the patterns seen in the DML plots. This will be done by incorporating leading edge and fetch equations into the model. It is already possible to overlay a DML on an aerial photograph or topographic map, with different levels of transparency. This will allow users to instantly see links between surface topography and the DML, but only once the equations for fetch effects are put into the model.

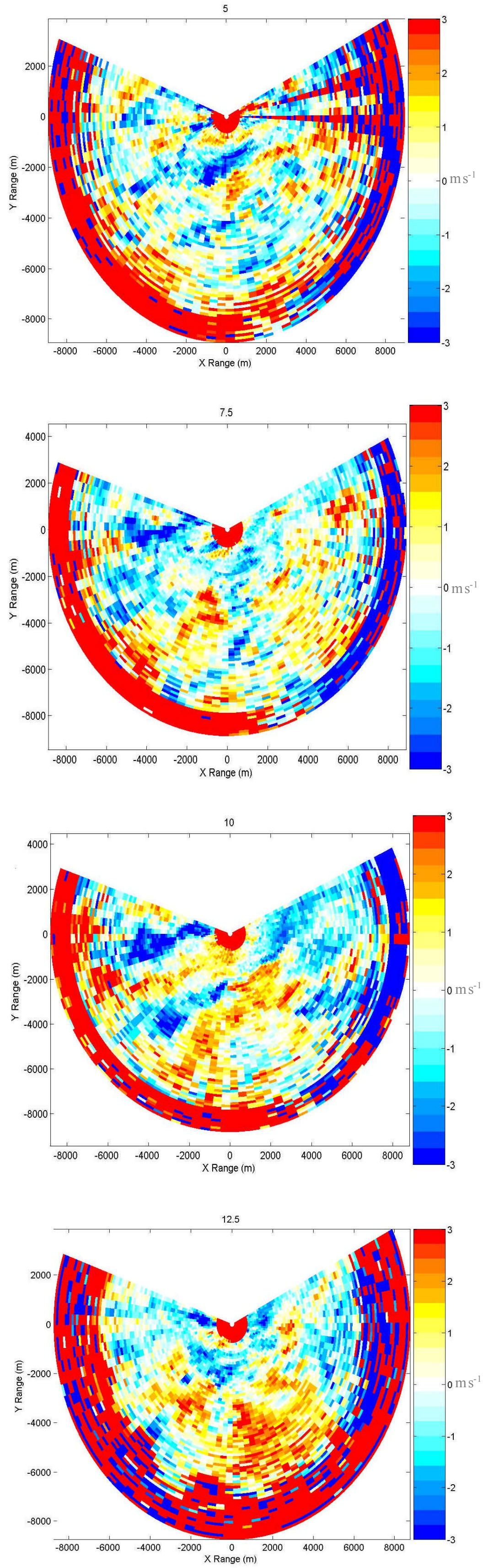

Figure 2 - Four DML plots from the 19/07/2005 (12:24:34 – 13:43:57 UTC) CSIP field trial; they range between 5^{o} and 12.5^{o} in elevation, with a constant direction of 250^{o} and speed of 10-12ms^{-1} with height. Distinct areas of quicker (red/yellow) and slower (blue) flow are present.

6. FUTURE WORK

There are several different areas in which further work will be undertaken. A substantial proportion of this work will involve the analysis of large amounts of previously collected lidar data using the DML model.

Once the equations for fetch of large scale objects (hills and valleys) have been put into the model, a spatially distorted DML will be produced for each lidar scan. This will move any differences in the DML to the point on the surface at which the disturbances originate. It would then be possible to drape the DML over a three dimensional topographic map. Using this technique it should be possible to pinpoint source areas, and look at the amount of change present at the same time.

Urban influences are the other major data sources that have not yet been looked at in this project. A field campaign is planned for this coming summer, with the City of Salford being the main target. The same techniques that were used for rural data sets will be applied.

Another area to concentrate on is expressing differences numerically, then deriving equations for some of the effects of surface heterogeneity on flow in the ABL. The aim would then be to then compare the field data with previously published theoretical numerical model output and wind tunnel experiments.

7. REFERENCES

Browning, et al., 2007. The Convective Storm Initiation Project. Submitted *Bull. Am. Met. Soc*.

Bozier, K. E., Pearson, G.N., Davies, F., and Collier, C.G., 2004. Evaluating the precision of a transverse excitation atmospheric based CO2 Doppler lidar system with *in situ* sensors. *J. Opt. A: Pure Appl. Opt.* **6**, pp 608 – 616

Oke, T. R., 1987. Boundary Layer Climates. *Routledge*, pp 182 – 189

Pearson, G.N., and Collier, C.G., 1999. A pulsed coherent CO2 lidar for boundary-layer meteorology. *Q. J. R. Meteorol. Soc.* **125** pp 2703 – 2721

Wood, V. T., and, Brown, R. A., 1986. Single Doppler velocity signature interpretation of nondivergent environmental winds. *J. Atmos. And Ocean. Tech.* Vol. **3**, pp 114 – 128