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Observations of the development of the convective boundary layer using radar and Doppler lidar

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Abstract. One of the most difficult forecasting problems remains the identification of when and where convective cells develop. Observations are reported of the pre-storm environment over West London, England, made using data from an infrared scanning Doppler lidar within the coverage provided by a C-band weather radar located at Chenies to the north of London. A simple procedure is described which enables the lidar to be pointed in the direction, and at an elevation, appropriate to the direction of the ascending thermals. This involves calculation of the scale velocity of the convection, a function of the sensible heat flux and the boundary layer depth. The procedure is verified using data recorded on 8 July 2003. A further case study is described of a thunderstorm outflow observed on 16 July 2003 involving use of data from the lidar and from both the Chenies radar and the S-band radar located at Chilbolton, central southern England.

1 Introduction

Much work over many years has been carried out to investigate the structure of convective clouds and their mesoscale organisation. However, understanding remains incomplete regarding the initiation of new convective cells, and how that initiation may be forecast.

There are essentially two problems. Firstly how first-generation convective cells are triggered in an environment which has been previously quiescent for a period, but which becomes more and more unstable. Secondly, for convective cells that persist, how and where subsequent generations of cells are triggered by the propagation of cold outflows from the existing cells. In this paper we discuss examples of both these problems using data from a C-band weather radar (1 deg. beam width), a S-band weather radar (0.25 deg. beam width) and from an infrared scanning Doppler lidar.

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First generation convective cells may be triggered by orographic uplift dependent upon the steepness of the slope, hill aspect and strength of the wind (see for example Thielen and Gadian, 1997). The perturbation in the velocity field propagates upward depending upon wind speed and stability (Hunt et al., 1988). Alternatively, variations due to land surface heterogeneity, causing inhomogeneities in temperature and moisture fields (see for example Henry et al., 1988) may initiate the local ascent of thermals, and the formation of convective clouds. These clouds may pre-condition the boundary layer to further development triggered by the mesoscale structure of the lower atmosphere, which may cause the release of instability through areas of convergence.

2 Doppler lidar and weather radar

Data from two Doppler lidars, one operated by the University of Salford and the other by QinetiQ, Malvern, have been used to investigate the structure of the pre-convective boundary layer. These lidars operate in the infrared (10.6 microns), and their original design was described by Pearson and Collier (1999). However, the systems have been upgraded to use a Transverse Excitation Atmospheric (TEA) pressure carbon dioxide laser.

The performance of these systems has been discussed by Bozier et al. (2004) and Davies et al. (2003, 2004). Both systems have scanning mechanisms which allow PPI and RHI scans to be generated. These systems may make measurements in the boundary layer before rain occurs up to ranges of 10 km, although generally the range is somewhat less. The lidars cannot operate in rain as the lidar beam is strongly attenuated by the rain.

The lidar observations described later in this paper were made from sites at RAF Northolt, West London. This area is within the quantitative range of the Chenies C-band radar located just north of London. The radar, operated by the Met Office, has a 1 deg. beam width, and provides PPI scans at four elevations within a 5 min cycle. Observations of

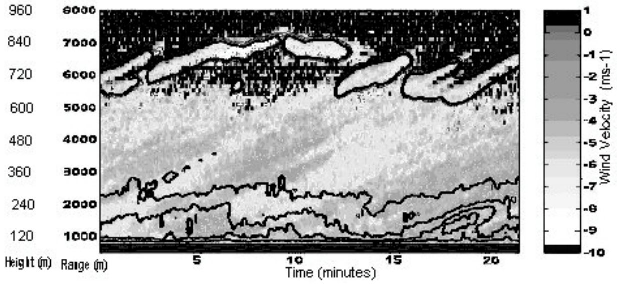

Fig. 1a. Example of a height-time plot (elevation 7 deg.) of radial velocity made using the QinetiQ Doppler lidar at Northolt, 12:30–12:52 UTC, 8 July 2003. Contours of the aerosol reflectivity are also shown.

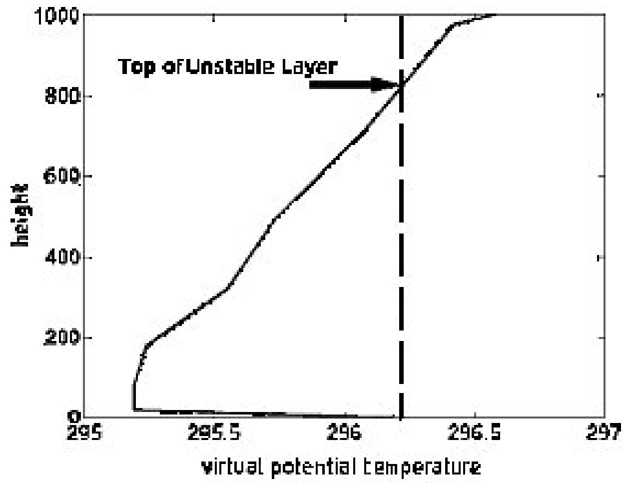

Fig. 1b. The vertical potential temperature profile from the Met Office NWP model.

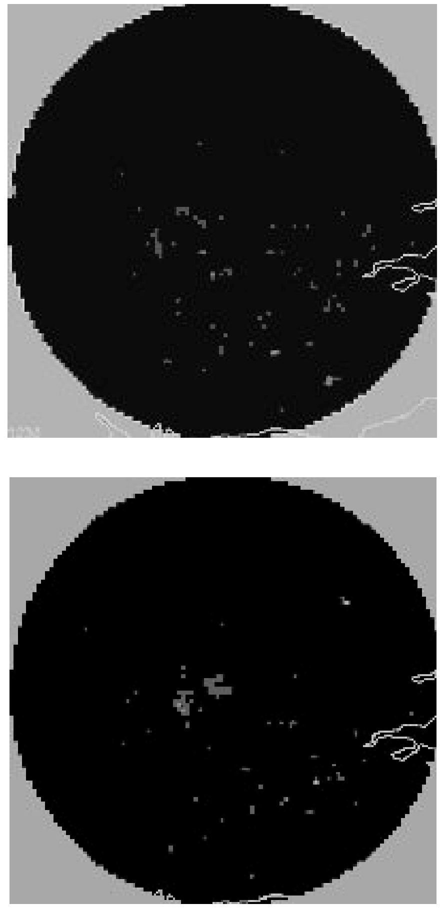

Fig. 2. PPI scans (2 km×2 km grid) from the Chenies radar at (a) 12:30 UTC and (b) 13:00 UTC on 8 July 2003. The position of Northolt is the centre of the image. The coastline of the Thames Estuary has been inserted. The rainfall rates in the convective cell are less than 1 mm h^{-1}. Other echoes are probably due to residual ground returns not removed in the processing. The maximum range is 75 km.

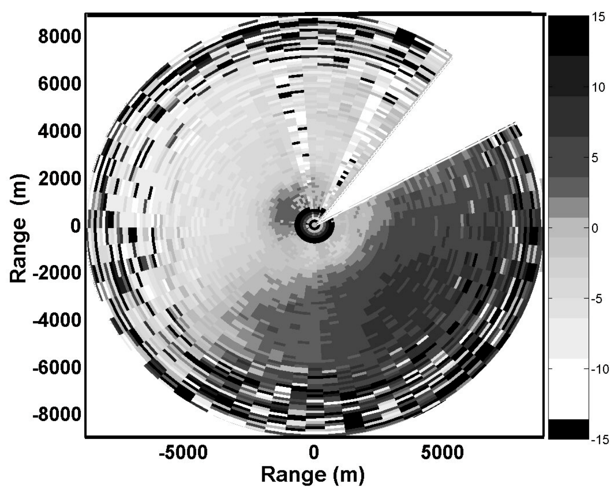

Fig. 3. Doppler lidar PPI showing radial velocities (positive towards the lidar site) at 8:50 UTC on 16 July 2003. Note the reversal of the wind direction at low levels, i.e. near to the lidar site. The elevation angle of the beam was 10 degrees.

reflectivity from this system are converted to estimates of rainfall rate (see for example Collier, 1996). Care must be taken in interpreting these radar data in heavy rainfall situations as in these cases the radar beam may be severely attenuated. The S-band radar, operated by the Rutherford Appleton Laboratory located to the south west of Chenies in central southern England, has a 0.25 deg. beam width, and does not suffer from attenuation in rain. This radar is a Doppler multi-parameter system, but has a slow scan speed due to the large size of its antenna (25 m diameter).

3 Observations of thermals by Doppler lidar

3.1 Line of sight (LOS) measurements

Key to the ability of a lidar system to make direct observations of thermals in the boundary layer is the selection of the line of sight (LOS) pointing angle. If the lidar is pointed vertically measurements are not possible for the first 500–700 m (see Bozier et al., 2004), and therefore this mode of operation is not practical. The LOS must be selected such

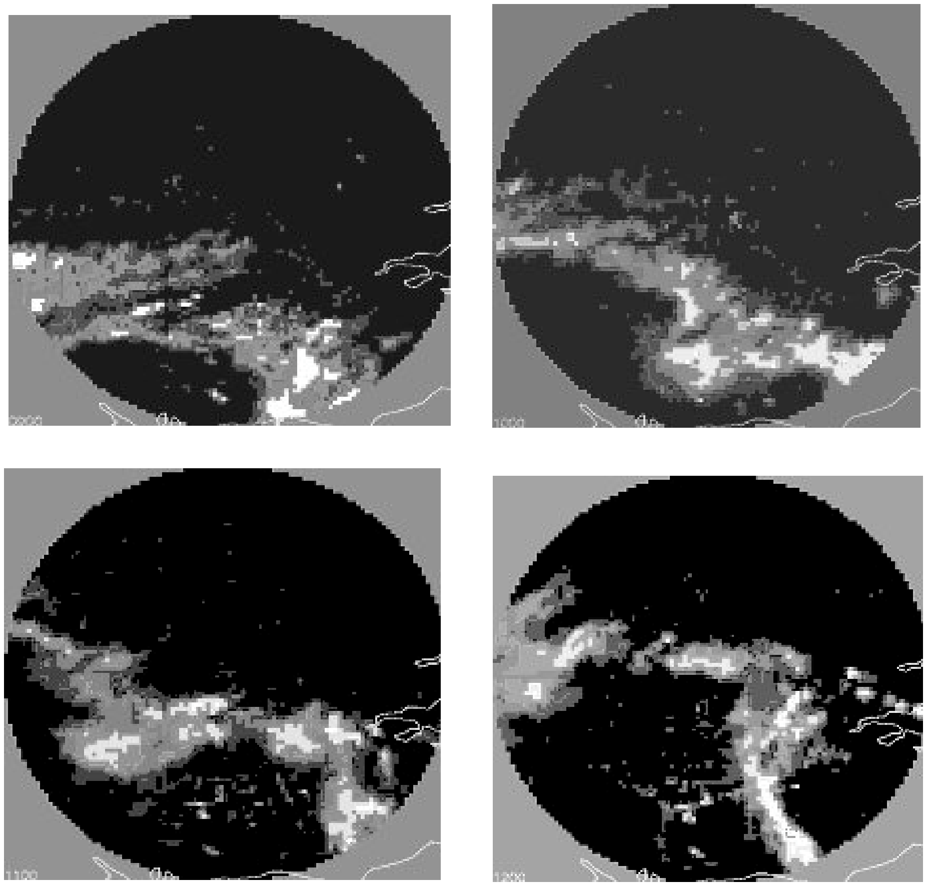

Fig. 4. Chenies radar images (a) 09:00 UTC, (b) 10:00 UTC, (c) 11:00 UTC, and (d) 12:00 UTC on 16 July 2003. Note the outflow boundary marked by the line of light broken echoes at 09:00 UTC. Dark grey: less than 1 mm h^{-1}; light grey: 1–2 mm h^{-1}; grey: 2–4 mm h^{1}; white: 4–8 mm h^{-1}; and grey: 8–16 mm h^{-1}. The grid square size is 2 km$\times$2 km. The maximum range is 75 km and the coastline has been inserted.

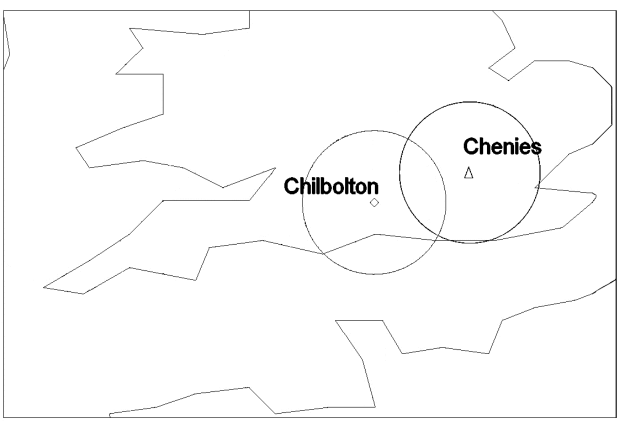

Fig. 5. Coverage shown by circles provided by the Chilbolton and Chenies radars over southern England.

that it is parallel to the direction of the ascending air in order that estimates may be made of the vertical velocity within the thermals. This may be achieved by evaluating the convective vertical velocity scale, a function of the sensible heat flux (see for example Troen and Mahrt, 1986) and the mean horizontal wind velocity. In general, the LOS elevation needs to be between 0 and 10 deg. For a mean wind speed of 1 m s^{-1}, a sensible heat flux of 200 watts m^{-2} and a boundary layer height of 1500 m, the beam elevation is 7 deg.

3.2 Case study

Figure 1 shows an example of a height-time plot of radial velocity made at Northolt using 7 degrees elevation. On this occasion thermals can be seen ascending along the beam direction. Contours of aerosol reflectivity are also shown in the figure. Aerosols are being moved from the surface upwards. Where the aerosol concentration is high convective cloud develops at the top of the boundary layer confirmed by the profile of potential temperature from the Met Office operational NWP model also shown in the figure. Figure 2 shows the radar data on the same day just after the lidar data were collected. A small rainfall cell is observed by the radar to form at 12:30 UTC just to the west of Northolt.

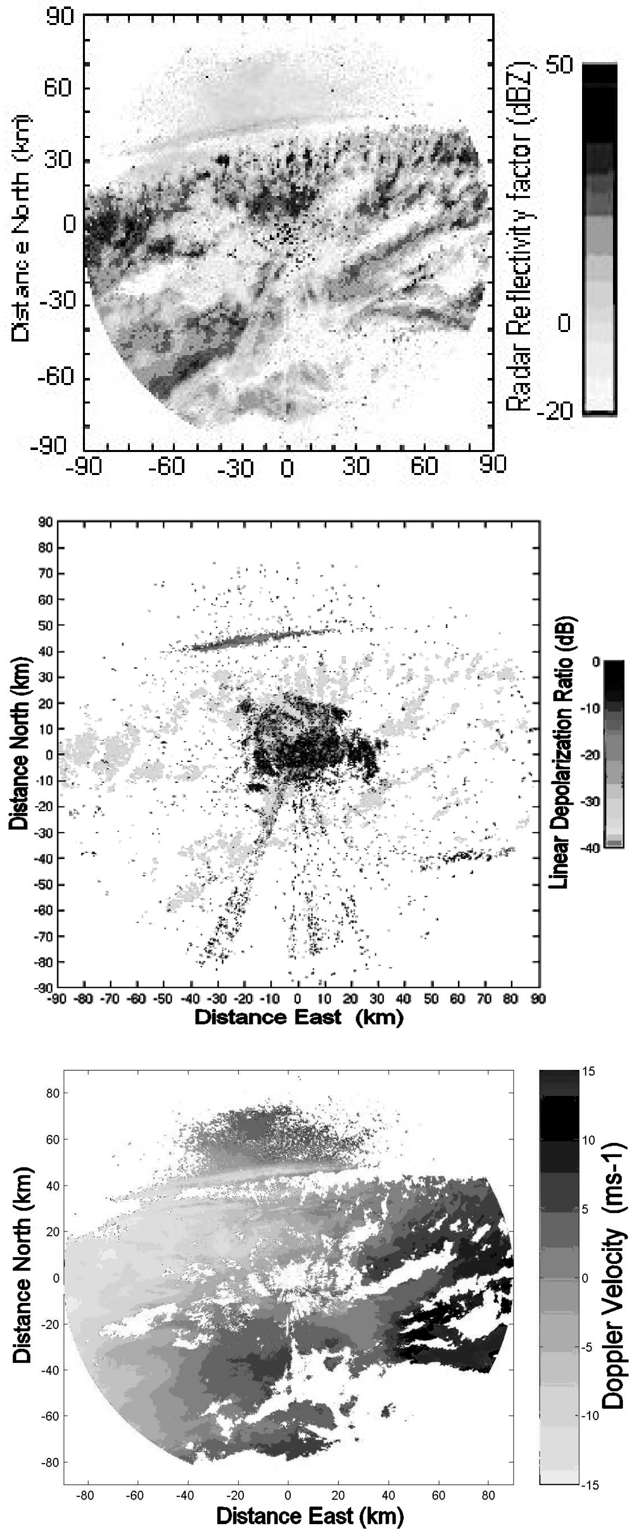

Fig. 6. Chilbolton radar images at 09:03 UTC on 16 July 2003 (a) reflectivity (dBz), (b) linear depolarisation ratio (dB) and (c) radial velocity (ms^{-1}). The resolution of the data is 300 m×0.25 deg.

4 Observations of the outflow from a thunderstorm

The outflow regions from thunderstorms may be manifest as density currents, often marked by cloud or radar echoes, moving within the boundary layer (see for example Bader et al., 1995). The lidar at Northolt was able to capture the motion of such an outflow region on 16 July 2003. The PPI shown in Fig. 3 indicates motion generally from the south easterly direction above a height of 380 m, at a speed of around 6 m s^{-1}. However, close to the lidar site, below 380 m in height, there is a region where the flow is reversed consistent with the outflow boundary shown in Fig. 4a.

The outflow boundary can be seen on the Chenies radar image shown in Fig. 4 at 09:00 UTC as a thin line of broken echoes about 12 km to the north and north east of the main area of convective rain. These echoes may be due to light rain perhaps evaporating before reaching the ground, the surface temperature was 21.7 deg C at 09:00 UTC, or due to chaff (grass / dust particles). Between 09:00 UTC and 10:00 UTC the outflow boundary moves more slowly northwards west of Northolt, but remains stationary to the south east. Later, as the main convergence line indicated by stronger convective echoes catches up with the old outflow boundary, the convection is invigorated.

Figure 5 shows the 2 km×2 km coverage provided from the Chenies radar site (maximum range 75 km), and the Chilbolton radar site (maximum range 90 km). Note the overlapping coverage. The reflectivity and the linear depolarisation ratio (LDR)observed by Chilbolton at 09:03 UTC corresponding to the Chenies rainfall rates in Fig. 4a are shown in Fig. 6. Values of the LDR higher than −20 dB are evident in the thin reflectivity band corresponding to the storm outflow boundary. This suggests that the radar targets are probably not raindrops, but may be particulate matter (straw, dust). Rain has LDR values generally below −30 dB (Illingworth, 2003). The Doppler radial velocities observed by Chilbolton at around this time, Fig. 6c, are consistent with the lidar measurements shown in Fig. 3.

5 Concluding remarks

The Doppler lidar and the weather radar data complement each other, each providing different types of data. The lidar is capable of observing the ascending air within thermals before first echoes become visible on the operational C-band radar. The overlapping lidar and radar radial velocities provide detailed measurements of air flow within the out flow region, the analysis of which is continuing.

Further studies of convective initiation using similar equipment are planned as part of the Natural Environment Research Council (NERC) funded Convective Storm Initiation Project (CSIP), the field campaign for which takes place June–August 2005.

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References

Bader, M. J., Forbes, G. S., Grant, J. R., Lilley, R. B. E., and Waters, A. J.: Images in Weather Forecasting. A practical guide for interpreting satellite and radar imagery, Cambridge University Press, 499pp, 1995.

Bozier, K. E., Pearson, G. N., Davies, F., and Collier, C. G.: Evaluating the precision of a TEA based CO_2 Doppler lidar system with in situ sensors, J. Optics A: Pure Appl. Opt., 6, 608–616, 2004.

Collier, C. G.: Applications of Weather Radar Systems. A guide to uses of radar data in meteorology and hydrology, 2nd Edition, Praxis Publ., John Wiley & Sons, Chichester/London, 390pp, 1996.

Davies, F., Collier, C. G., Bozier, K. E., and Pearson, G. N.: On the accuracy of retrieved wind information from Doppler lidar observations, Quart. J. R. Met. Soc., 129, 321–334, 2003.

Davies, F., Collier, C. G., Pearson, G. N., and Bozier, K. E.: Doppler lidar measurements of turbulent structure function over an urban area, J. Atmos. Ocean. Tech., in press, 2004.

Henry, J. A., Dicks, S. E., and Roguski, S. J.: Relationship of the urban fabric of Lawrence, Kansas with satellite-derived thermal infra-red data, Int. J. Biometeorol., 33, 181–187, 1988.

Hunt, J. C. R., Richards, K. J., and Brighton, P. W. M.: Stably stratified shear flow over low hills, Quart. J. R. Met. Soc., 114, 859–886, 1988.

Illingworth, A.: Improved precipitation rates and data quality by using polarimetric measurements, Chapter 5 in Weather Radar, Principles and Advanced Applications, publ. Springer, Berlin, 130–166, 2003.

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

Thielen, J. and Gadian, A.: Influence of topography and urban heat island effects on the outbreak of convective storms under unstable meteorological conditions: a numerical study, Meteor. Appl., 4, 139–149 1997.

Troen, I. B. and Mahrt, L.: A simple model of the atmospheric boundary layer: sensitivity to surface evaporation, Boundary-Layer Met., 37, 129–148 1986.