

HUMIDITY EVALUATION USING GPS, RADIOMETER, WIND PROFILER AND UV LIDAR DURING CSIP ASSOCIATED WITH THUNDERSTORMS

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1. INTRODUCTION

The aim of the convective storm initiation project (CSIP) is to understand the mechanisms responsible for the initiation of precipitating convection in the maritime environment of southern England [Browning *et al.*, 2006]. The broad range of supporting instrumentation deployed in summer 2005 for this project and high-resolution NWP models provided an excellent opportunity to investigate the use of data from ground-based remote sensing systems. The studies allowed the changes in humidity to be tracked during a thunderstorm on 24 June 2005. This was done by measuring the integrated water vapour (IWV) using a combination of global positioning system (GPS) with a microwave radiometer. The smaller scale changes in humidity at the surface were also followed on this day using a wind profiler and UV lidar, resulting in the identification of the mechanism maintaining the thunderstorm. Atmospheric profiles were analysed during a thunderstorm on 29 June 2005 using a microwave radiometer and radiosondes. Small scale convective plumes feeding into the storm were identified using the wind profiler and the stability within these analysed using the radiometer. This investigation is important as it furthers the understanding of how various measurements can be integrated together when designing observational networks, and also how the data can then be assimilated into numerical weather prediction models.

2. INSTRUMENTATION

This report consists of data taken from several sites and instruments in close proximity to each other, within the CSIP area, Figure 1. A wind profiler and microwave radiometer were located at Linkenholt to provide time-height cross sections of temperature, humidity, wind speed and signal to noise ratio. A UV Raman Lidar was located at Chilbolton to provide time-height cross sections of humidity. Radiosondes were launched from Chilbolton, and also from Larkhill. GPS was also used to provide IWV data for this project. The UK GPS data network is processed by the Met Office / University of Nottingham system,

which is based in Exeter. The system is processed at fifteen minute resolution. For CSIP an additional five sites were installed and processed by GeoForschungZentrum (GFZ), Potsdam. These sites were processed at 30 minute resolution. Data from GPS sites at Newbury, Didcot, and Southampton were used to produce time-series of IWV.

3. COLD POOL CASE STUDY - 24 JUNE 2005

On the 24 June 2005 a synoptically forced event occurred throughout the southern UK and the Midlands. This event resulted in widespread thunderstorms and flash floods. From 1200-1800 UTC a trough moved across the CSIP area leading to increased cloud and precipitation. During this time a line of north-south thunderstorms crossed the entire CSIP area from west to east. The UV lidar at Chilbolton measured the humidity as the storm approached the region. At 1150 UTC a layer of high humidity occurred at the surface, (10-12 g kg⁻¹), and continued to deepen from 250-450 m as the storm approached. The IWV calculated by the UK GPS network measured ~40 kg m⁻² in the CSIP area at 1345 UTC as the storms were passing through. At 1400 UTC the thunderstorms had just passed over the CSIP area, shown by the rainrate measured by radar in Figure 2a. At this time the IWV calculated by the UK GPS network shows a dry pool to the west of the convective storm, Figure 2b. This dry (<34 kg m⁻²), cold pool behind the storm may be attributed to the downdraught behind the storm. Downdraught is formed via drag and evaporation of the precipitation. This cool air then spreads out at the surface and forces the warm air in the storm up over it, increasing the convection and enabling the storm to sustain itself. The radiometer retrieval showed that the surface cooled at this time, due to the evaporation of the precipitation. The wind profiler signal to noise ratio measurement showed a collapsed boundary layer top due to the cold pool. Between 1400 and 1600 UTC there was no rain, and the radiometer detected the clearance of mid-level cloud associated with the storm clearing from 1400-1440 UTC, with patchy mid-level cloud after 1500.

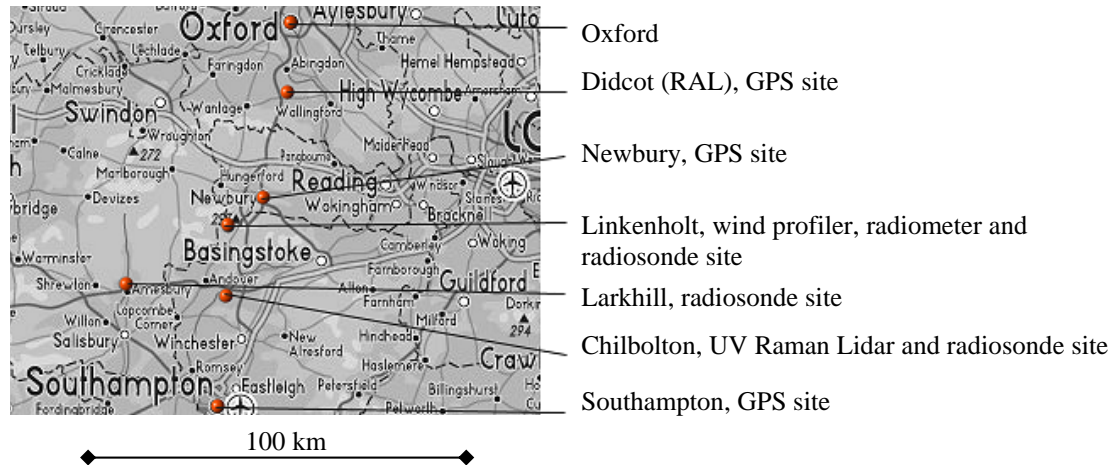


Figure 1 Map showing locations of instruments in the CSIP area used for this report.

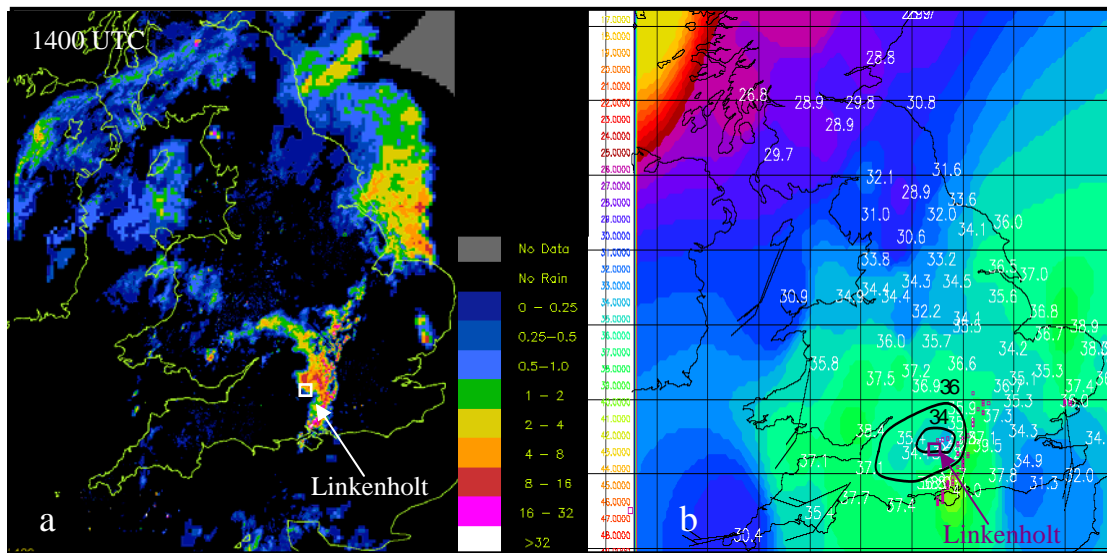


Figure 2 (a) Nimrod radar rainrate for 24 June 2005 at 1400 UTC. (b) GPS integrated water vapour processed by the Met Office/University of Nottingham system, 24 June 2005, 1400 UTC. Contours give values of IWV in kg m^{-2} calculated from individual sites. Colour legend gives linearly interpolated IWV in kg m^{-2} . Pink rectangles are lightning measured using arrival time difference (ATD). Winds barbs shown at 2 km.

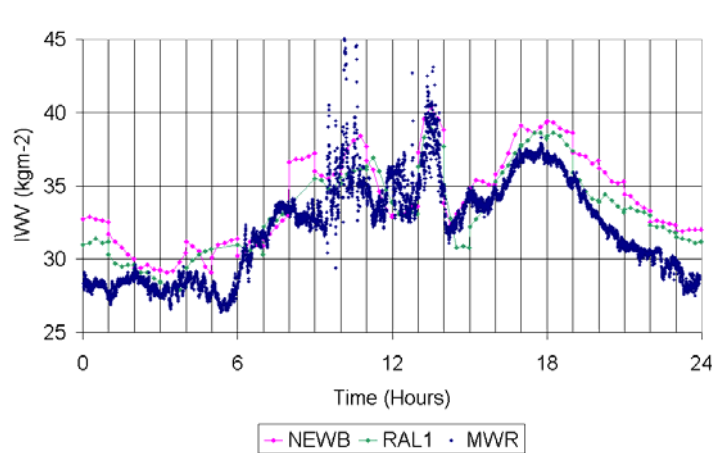


Figure 3 Integrated water vapour time series 24 June 2005 from GPS sensors at Newbury (NEWB), Didcot (RAL1) and microwave radiometer at Linkenholt (MWR).

A time-series was constructed for 24 June 2005 from the IWV calculated at the GPS sites at Newbury and Didcot and the IWV retrieved by the radiometer at Linkenholt. This is shown in Figure 3. The results from the GPS and the microwave radiometer show similar patterns, but time-shifted. The IWV measured by the radiometer has a very high temporal resolution (12 s). A sharp drop in IWV is seen after rain bands passed through at 1100 and 1400 UTC.

4. CONVECTIVE THERMALS CASE STUDY - 29 JUNE 2005

The 29 June 2005 was a convective day on which widespread showers occurred. In the CSIP area convective cells associated with upper level troughs formed in the late morning. A trough passed over the CSIP area between 1200 and 1500 UTC. The radiosonde at Larkhill had recorded an inversion at about 1.2 and 3.6 km at 1000 UTC. The clearance of upper cloud behind the trough may have initiated convection. Cumulus then formed due to convective cells building and reaching the lifting condensation level. By 1500 UTC convection from the surface had penetrated both of the lids, reaching the tropopause. A profile constructed from a radiosonde at Larkhill at 1600 UTC showed convective available potential energy of 289 J kg^{-1} . By 1500 UTC a well organised band of heavy showers and thunderstorms extended from mid-Wales to East Anglia, resulting in flash floods in Oxford (on the northern boundary of the CSIP area). Radar shows a rainfall rate of greater than 32 mm at 1400 UTC in Oxford. Lightning measured using arrival time difference (ATD) was detected in the same area as the band of rain. GPS IWV measurements showed dry air behind the line of thunderstorms ($<28 \text{ kg m}^{-2}$). The IWV was much lower over the UK on the 29 June 2005 ($\sim 21\text{-}30 \text{ kg m}^{-2}$) than on the 24 June 2005 ($\sim 26\text{-}45 \text{ kg m}^{-2}$). A time series of IWV was constructed from three GPS sensors at Newbury, Didcot, and Southampton, as well as the microwave radiometer at Linkenholt. The positions of these sites are shown in Figure 1. The fall in IWV after the storm passed through occurred at about 1600 UTC at Didcot, which is about 26 km south of Oxford.

Focusing on smaller scale convection, the wind profiler at Linkenholt enabled the identification of an updraught feeding into the cloud lasting between 5-10 minutes. The vertical wind speed measured on 29 June 2005 1600-1700 UTC shows ascent of about 0.5 m s^{-1} from the surface to about 1.3 km, Figure 4a. On either side of this updraught vertical

wind speed of about -0.6 m s^{-1} was measured in the downdraughts. Above the top of the thermal, the vertical winds speed was also negative as air from above was being funnelled into the downdraught. The signal to noise ratio produced by the wind profiler shows the change in humidity occurring between the boundary of the updraught and the surrounding downdraughts. A zoomed in diagram of the retrieval by the microwave radiometer at Linkenholt on the 29 June 2005 1600-1700 UTC is shown in Figure 4b. (Note the radiometer time was found to be 5 minutes 21 s slow with respect to the wind profiler by comparing the timing of the start of a rain shower on 29 June 2005). This plot helps to analyse the atmospheric conditions which lead to the convective plume, identified in Fig. 4a. The wind profiler plot, Fig. 4a, shows the plume initiated at 1628 UTC. The radiometer retrieval showed the surface temperature gradually increased from 18.2 to $19.3 \text{ }^\circ\text{C}$ at this time, which may have triggered the convection forming the updraught. The temperature profile in Fig. 4b(i) shows unstable conditions, a large temperature gradient, near the surface before the updraught. The temperature profile in Fig. 4b(i) then shows stable, well-mixed conditions, a small temperature gradient, during the warm updraught. The relative humidity was lower during the updraught (60-75 %), Fig. 4b(ii), due to its higher temperature. The conditions then remained stable until the end of the updraught. Comparisons between the radiometer temperature profile and the nearby radiosonde measured environmental profile at Larkhill supports the evidence of instability at the surface before the updraught and stability during the updraught, Fig. 5.

5. CONCLUSIONS

The integration of several instruments in close proximity allowed the identification of meteorological processes in convective storms. On 24 June 2005, the dense network of GPS sensors allowed the identification and tracking of areas of drier/colder air, which are associated with the lifecycle of thunderstorms. The wind profiler, radiometer and UV lidar enabled these changes in humidity to be studied in detail at the surface, leading to the identification of boundary layer growth and collapse. As a result of the use of the combination of instruments the mechanism sustaining the storm was identified; the cold pool sustained the updraught and hence the convection within the storm.

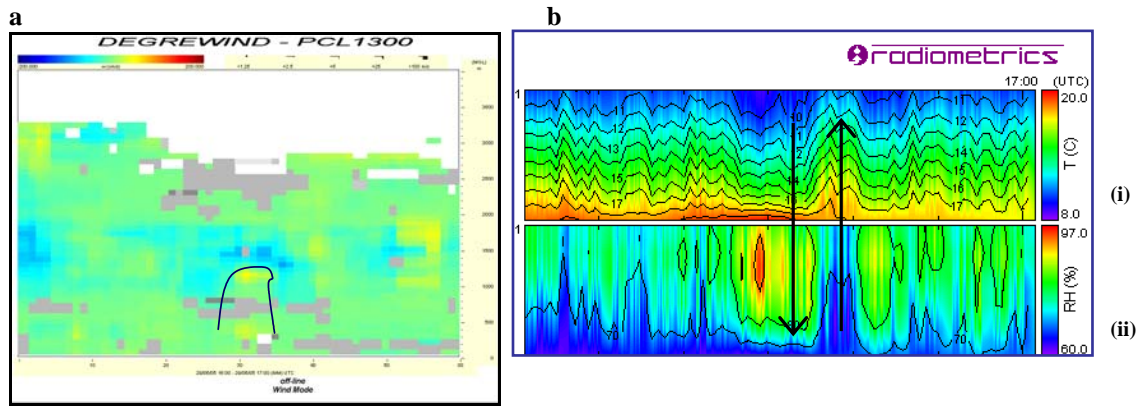


Figure 4 (a) Vertical speed and from wind profiler at Linkenholt 29 June 2005 1600-1700 UTC. (b) Microwave radiometer retrieval showing (i) temperature and (ii) relative humidity time-height cross sections for 0-2 km height, 29 June 2005, 1600-1700 UTC. Arrows show downdraught and updraught respectively.

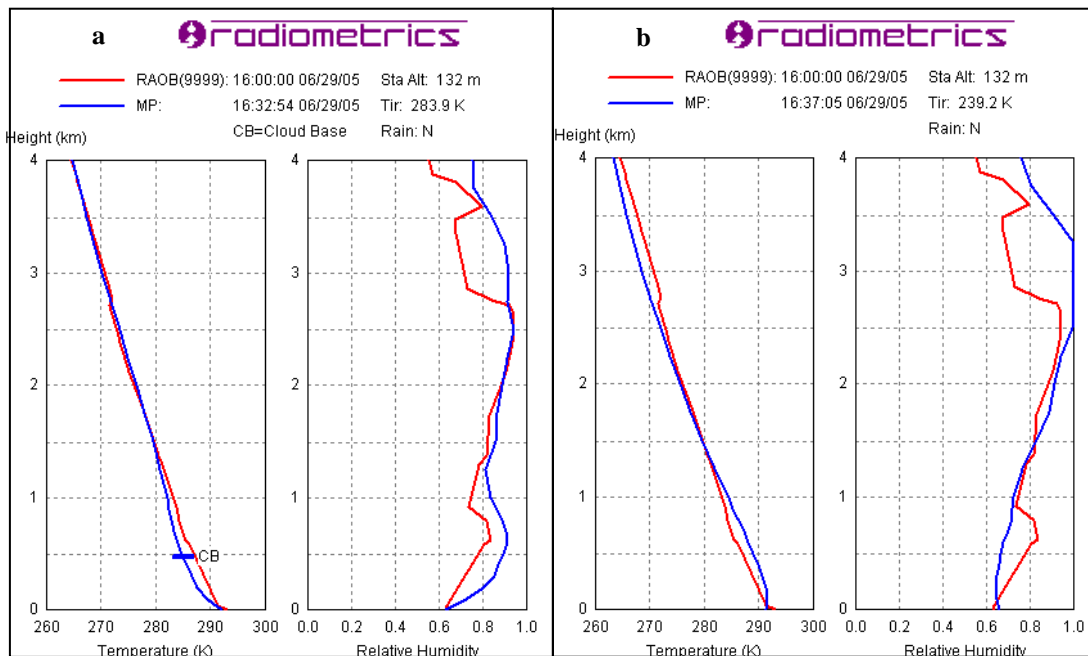


Figure 5 Atmospheric profiles of temperature and relative humidity measured by radiosondes launched from Larkhill (RAOB, red line) 29 June 2005 1600 UTC. Measurements retrieved by microwave radiometer at Linkenholt (MP, blue line) 29 June 2005 (a) 1633 UTC and (b) 1637 UTC.

On 29 June 2005 atmospheric profiles derived from the radiometer in combination with radiosondes lead to the identification of atmospheric lids prior to a thunderstorm. These lids were broken and the convective process taking place, forming the resulting thunderstorm, was studied in the lower 2 km of the atmosphere on a scale of minutes. The wind profiler and radiometer were used together to identify convective plumes, lasting about 5 - 10 minutes, feeding into the cloud. The thermal and humidity structure within these updraughts and downdraughts were shown.

GPS in combination with the radiometer allowed the tracking of IWV throughout both days, showing

a fall in IWV after the storms had passed through. The inter-comparison showed the radiometer IWV was in good agreement with most GPS sensors at high temporal resolution.

REFERENCE

Browning *et al.*, 2006: "The Convective Storm Initiation Project", Draft submitted to Bulletin of American Meteorological Soc., June 2006.