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Observations of boundary-layer development during CSIP

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1 Introduction

The mechanisms responsible for the initiation of precipitating convection in the maritime climate of the United Kingdom are not well understood. Whilst much research has been undertaken in other parts of the world on the larger, long-lived convective systems, there has been little focus on the smaller but often locally intense systems experienced in the UK. These storms are capable of producing severe weather and a threat to life and property, as demonstrated by recent high-profile events e.g. the Boscastle flash flood on 16th August 2004 (Golding et al.) and the Birmingham tornado on 28th July 2005.

The goal of the Convective Storm Initiation Project (CSIP) is to understand why convective clouds form in a particular location and how they develop into showers and thunderstorms. The field campaign took place in the low undulating terrain of southern England. Detailed observational analysis of convection initiation cases is taking place and is being compared with output from the Met Office high resolution (1 km) numerical weather prediction model. This will enable validation and improvement of the model and lead to better forecasts.

The precise location of the initiation of convective cells is often controlled by spatial inhomogeneities in the evolving boundary layer. These perturbations include horizontal variations in temperature and moisture generated by land/sea contrasts and orographic features. In addition, fine-scale structures in the vertical profile can lead to variations in convective inhibition and affect cumulus development and the resultant precipitation. This study examines some of the boundary layer structures observed during CSIP and how they affected convection initiation and development.

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2 CSIP layout and key instruments

The field project was centred around the Chilbolton radar and was a collaborative project between institutions from the UK - the National Centre for Atmospheric Science (NCAS) Universities and the Met Office – and from Germany - the Institute for Meteorology and Climate Research (IMK) at the University of Karlsruhe, the Institute of Flight Guidance and Control (IFF) at the Technical University of Braunschweig and the National Research Centre for Geosciences, Potsdam (GFZ). The main project took place during June, July and August 2005 with a pilot project during July 2004. Figure 1 shows the location of the instruments that took part in the main project. The operations centre was based at the Chilbolton Observatory and the forecast centre was at the Joint Centre for Mesoscale Meteorology at the University of Reading, 40 km to the northeast.

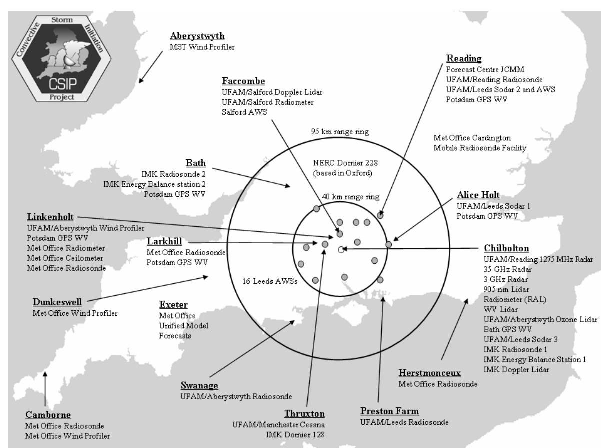

Fig. 1. Schematic map showing the locations of all the instruments involved in CSIP.

Datasets of particular value to this study are: 1-2 hourly soundings launched from five stations, at Larkhill, Reading, Bath, Swanage and Chichester, in addition to the operational stations operated by the Met Office; a network of 16 automatic weather stations deployed within 40 km range of Chilbolton; two instrumented aircraft – the University of Manchester Cessna 182-J and the University of Braunschweig Dornier 128; 15-minute high resolution imagery from the Meteosat Second Generation (MSG) satellite and sequences of scans from the Chilbolton radars.

The Chilbolton 25 m steerable antenna has two collocated radars, the **C**hilbolton **A**dvanced **M**eteorological **Ra**dar (CAMRa), a 3 GHz (S-Band) radar with dual polarization and Doppler capability, and the **A**dvanced **C**lear-Air **R**adar for **O**bserving the **B**oundary Layer **A**nd **T**roposphere (ACROBAT), a 1275 MHz (L-Band) Doppler radar. One of the unique aspects of CSIP was the ability to observe the clear-air convective field and shallow cumulus clouds with ACROBAT through the process of Bragg scatter. Variations in refractive index on the scale of half the wavelength, produced by gradients in temperature and humidity, cause a large signal to be returned to the radar. In range-height indicator (RHI) mode, thermals and cumulus clouds appear as "mantle" or "inverted cup" echoes surrounding a region of lower return. Low-level fields of refractivity were also retrieved from ACROBAT by implementing the Fabry technique (Fabry 1997), whereby changes in the phase of ground targets are related to the refractive index of the air. During the summer, the refractive index is dominated by humidity and therefore these maps can reveal inhomogeneities in surface moisture.

3 13 July 2005 Overview

A weak ridge of high pressure was positioned over the UK with two fronts, one over northern Scotland and the other over northern England (Fig. 2). Winds over the CSIP domain were very light and from the north northwest. There were mostly clear skies during the early morning and maximum temperatures reached 29^{o}C.

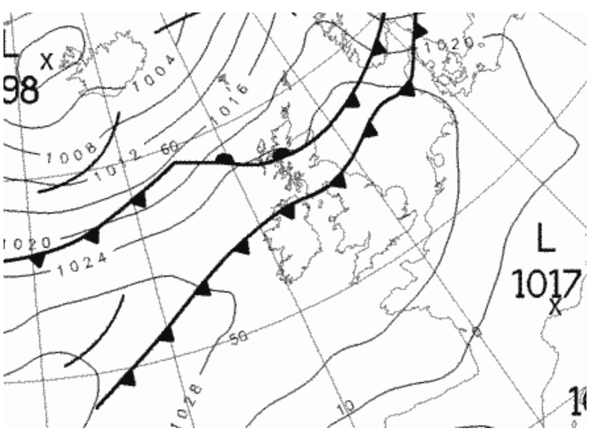

Fig. 2. Mean sea level pressure analysis with fronts at 1200 UTC on 13 July 2005.

The first cumulus clouds developed at 1100 UTC in a band orientated northeast to southwest with the edge of the band just to the north of Chilbolton by 1215 UTC (Fig. 3a). The band broadened with time and the cumulus clouds grew deeper. There was significant variation in the depth of convection within the band with maximum cloud tops at about 5 km.

Only a few of these deepest clouds produced precipitation and most of this was very light and brief. Visibility was quite poor as there were high aerosol concentrations, which probably affected the cloud microphysics. However, some heavier showers did develop to the northeast of the CSIP domain.

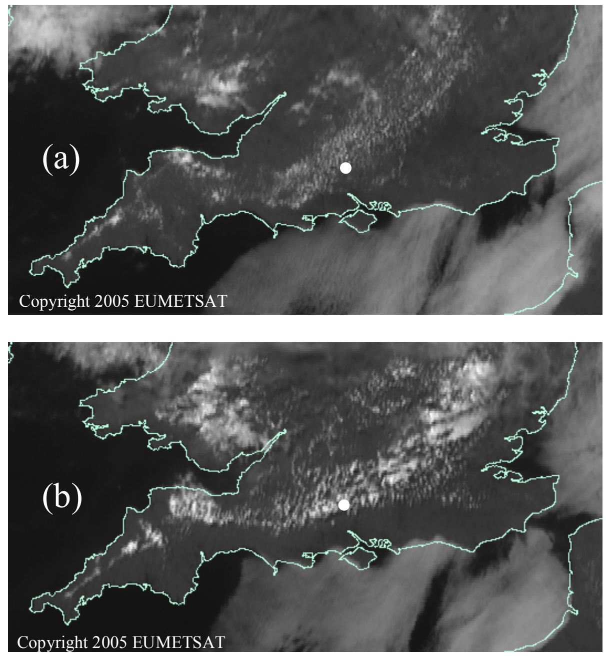

Fig. 3. MSG visible satellite images at (a) 1215 and (b) 1445 UTC on 13 July 2005. The white circle indicates the location of Chilbolton.

During the course of the day, a well-defined sea breeze developed along the south coast and moved inland, passing over Chilbolton at 1520 UTC (Fig. 3b). The sea breeze interacted with the band of cumulus clouds, possibly leading to some intensification of the convection.

4 Boundary layer features

There was a significant difference in boundary-layer moisture across the CSIP domain during the morning. Preliminary observations and model output suggest that there was a tongue of moisture lying NE-SW across the domain that led to the initial development of cumulus clouds in that location. This gradient in moisture was revealed by both refractivity measurements and soundings. Refractivity fields will be shown during the presentation.

There were six radiosonde stations located within the domain, four of which were in close proximity to the location of the cloud band (Fig. 5). Bath, Reading and Chilbolton launched soundings every hour and Larkhill launched every two hours. The mixing ratio profiles at 1000 UTC in the lowest kilometre clearly show the difference in moisture across the region (Fig. 6a). Reading and Larkhill had the highest values, averaging 10 g kg^{-1} and 11 g kg^{-1} respectively. Larkhill was in the centre of the band of clouds and Reading was close to the eastern edge. Bath was located in a clear region to the northwest and Chilbolton was just to the southeast of the band. Their mixing ratios were 9.7 g kg^{-1} and 9.5 g kg^{-1} respectively.

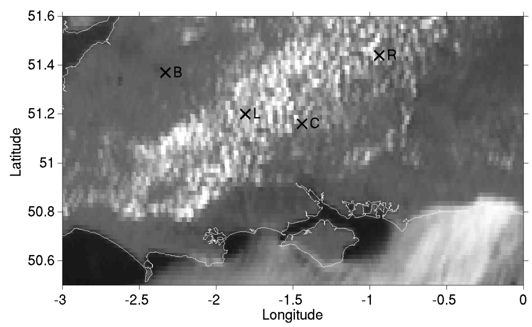

Fig. 5. MSG visible satellite image at 1215 UTC showing the four radiosonde locations closest to the band of cumulus clouds: B=Bath, L=Larkhill, C=Chilbolton and R=Reading.

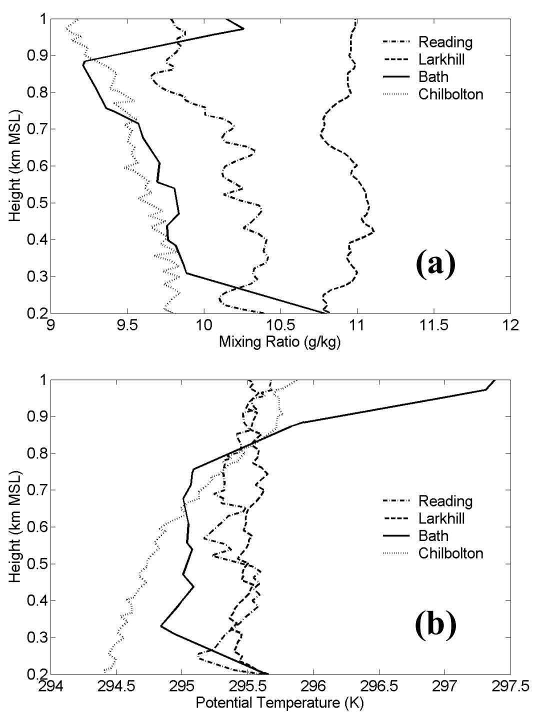

Fig. 6. Radiosonde profiles up to 1 km from Reading, Larkhill, Bath and Chilbolton at 1000 UTC showing (a) mixing ratio and (b) potential temperature.

The profiles of potential temperature show that the boundary layer in the vicinity of Larkhill and Reading was about 0.5 K warmer than at Bath and 1 K warmer than Chilbolton (Fig. 6b). It is likely that this difference also contributed to the earlier initiation of convection at these locations. Later soundings reveal several weak inversions and a significant dry layer at about 4 km height that probably played a large role in the variation in the depth of convection on this day.

ACROBAT performed a pre-determined sequence of PPI and RHI scans throughout the whole of the day. The evolution of thermals and cumulus clouds can be examined through this sequence of scans. In particular, the difference in the structure of the boundary layer within and outside of the region of higher moisture can be investigated. As an example, Fig. 7 shows a pair of RHI scans at about 1200 UTC, one towards the northwest and the other towards the south. The two regions are at different stages of development. The scan to the northwest shows cumulus clouds at several locations out to a range of 25 km. There is a particularly well-defined cloud at 11 km range with a top at approximately 2.3 km height. However, there are only a few shallow cumulus clouds visible to the south with tops up to about 1.7 km. The flatness of the features suggests there was an inversion at this height. The thin line of reflectivity at 2 km is also evidence of an inversion.

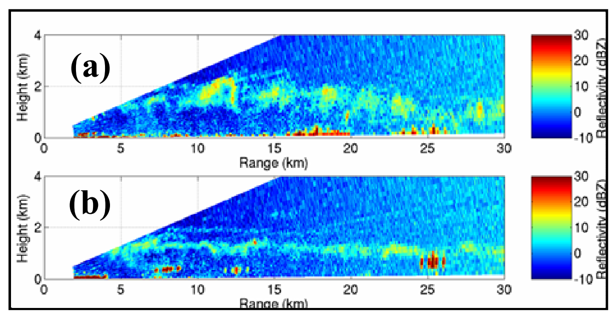

Fig. 7. ACROBAT RHI scans showing reflectivity at (a) 1150 and 310° azimuth and (b) 1203 and 189° azimuth.

5 Summary and future work

Vertical and horizontal variability in temperature and moisture on 13 July 2005 played a significant role in the evolution of the boundary layer and the development of clouds and deep convection. The synthesis of several datasets can be used to build a detailed description of the processes involved. This case study poses several questions which will be addressed through further analysis and comparison with model output: i) what caused the clouds to form in a band across the domain; what was the relative importance of the temperature and moisture variations, ii) what role did inversions and dry layers play in determining the depth of the convection, iii) how did the sea breeze interact with the convective field and iv) why were heavier showers able to develop in the north east portion of the domain.

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