Wind Profilers and their integration with other remote sensing systems to investigate the structure of the boundary layer

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ABSTRACT

The UK Met Office has a network of ground based wind profilers which provide high resolution atmospheric vertical profiles of wind speed and direction. These wind profilers are part of an integrated wind observing network, also using winds from aircraft, radiosondes and Doppler weather radar. The wind profilers can be combined with other remote sensing systems, as will happen in the FUND testbed experiment [1], including cloud radar, ceilometer, radiometer and GPS water vapour measurements to provide a more complete representation of the structure of the boundary layer in both dry and wet conditions. This paper concentrates on analysis of warm and cold fronts in south west England, and identifies a low level jet in advance of the cold front and a narrow tongue of strong winds descending in colder air behind the cold front.

1. INTRODUCTION

The Met Office currently has a network of five wind profiler radar sites; two 915 MHz wind profilers situated at Camborne (Cornwall) and the Isle of Man, two 1290 MHz wind profilers at Dunkeswell (Devon) and Wattisham (Suffolk) and a 64 MHz wind profiler at South Uist (Outer Hebrides). Data is also used from the NERC MST wind profiler at Aberystwyth. Figure 1 shows the locations of wind profiler and velocity azimuth display (VAD) weather radar sites in the UK.

Figure 1. *Locations of UK wind profiler and weather radar sites.*

The UHF wind profilers are all operated in 2 modes. Typically, for the 915 and 1290 MHz wind profilers the first (low) mode samples the boundary layer to 1800 m using a 60 m resolution. The second (high) mode samples the lower troposphere to 8000 m with a 200 m resolution. Currently, winds are supplied to users at half hour resolution, whilst winds averaged at 15 minute intervals are under evaluation for operational implementation. To prepare for future exploitation of UHF wind profiler observations in the FUND Project, winds are also computed off-line at 5 minute temporal resolution, see Figures 3 – 5.

Active, remote sensing instrumentation (wind profilers, laser ceilometers and cloud radar) allows the atmosphere to be observed at high temporal and vertical resolution [2]. The case study presented here studies the temporal (and spatial) development of the wind fields associated with the passage of a cold front, associated with a rapidly deepening depression.

2. HIGH TEMPORAL RESOLUTION WIND MEASUREMENTS

2.1 Warm and cold front Case Study – 3rd March 2009

2.1.1 General Situation

At about 0600 UTC on 3 March 2009, a trailing cold front had moved to the south of the British Isles in the English channel and a wave was identified at 50ºN 20ºE, this wave moved eastwards so that at 1200 UTC the pressure had fallen from 1011 to 992 hPa and was centred off the south coast of south-west Ireland with the associated warm front remaining off the south coast of England. By 1800 UTC the low pressure had deepened further to 975 hPa and was centred in the Irish Sea, just south of the Isle of Man. South west England was in a warm sector with a cold front just crossing west Wales and Cornwall. The operational Met Office surface analysis for 1200 and 1800 UTC on 3rd March 2009 is shown in Figure 2. By 0000 UTC the depression had moved to eastern Scotland and had stopped developing with at a pressure of 969 hPa.

GPS water vapour measurements further illustrates the progression of the frontal system across the UK and shows the distinction between air masses, with integrated water vapour, IWV equal to 14 in the cold sector and 17 in the warm. Figure 3 presents the GPS water vapour observations at 1200 UTC and 1800 UTC on 3rd March 2009. At 1200 UTC the centre of the depression lies off the south-west coast of the UK and a warm front situated just off the south coast. Figure 10a indicates the surface warm front is still lying off the south coast of England, given there is no change IWV in this region at this time. At 1800 UTC the cold front is crossing south-west, bringing with it colder, drier (IWV approx 14) air, compared to the warm sector which is covering most of in the south consisting of warmer, moister (IWV approx 17) air.

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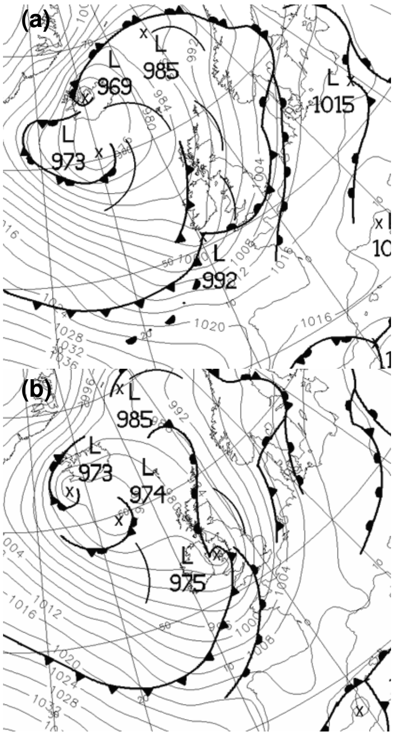

Figure 2. *Operational analysis for (a) 1200 UTC and (b) 1800 UTC on 3rd March 2009.*

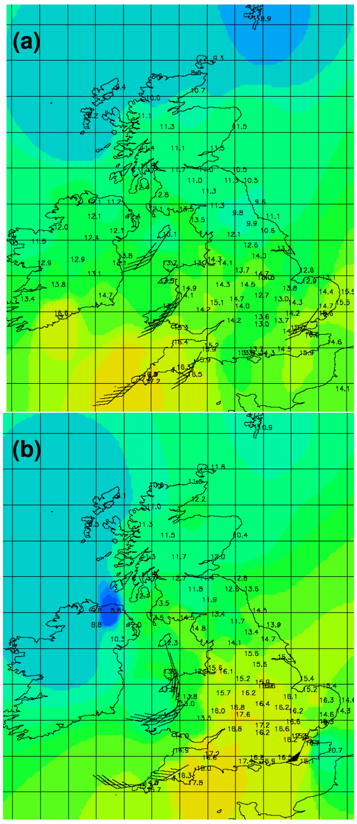

Figure 3 *Integrated water vapour (IWV) measurements at (a) 1200 UTC and (b) 1800 on 3rd March 2009. Wind barbs represent winds at 2km.*

2.1.2 Observations

Figure 4 presents the wind speed and direction in U, V, W components observed at Camborne at 5 minute resolution. Surface and weather radar analysis indicated the warm front passed Camborne at 1400 UTC. Associated with the passage of the warm front, westerly (U component) winds are initially stronger at 4 km and descend to below 1 km, as shown in Figures 4 and 5. Analysis of weather radar images confirmed these strong winds occur when the warm front passed over Camborne. Low-level winds increase with the passage of the warm front 1400 – 1500 UTC then again between 1530 – 1630 UTC, this structure is associated with two different rain bands passing over the site, observed by the weather radar in Figure 6. Low-level jets ahead of cold fronts observed (in the warm sector) have previously been observed using radiosonde and weather radar as described by Browning et al [3].

The passage of the cold front over Camborne is clearly evident in Figure 4 and 5 by the abrupt change in wind direction and the sudden decrease in the altitude of the melting layer, shown in the W component. The cold front passed Camborne at 1630 UTC and associated with it was a narrow tongue of strong winds at lower levels after the cold front passed, highlighted by the black-dotted line. This low-level jet was first seen by the 915 MHz wind profiler at Camborne, between 2 km at 1730 UTC and increasing with height until reaching 5 km at 2000 UTC on 3rd March 2009. The jet consists of strong (27 m/s in the U component) westerly winds. Above the jet are (25 m/s in V component) southerly winds and below weak (10 m/s in U component) westerly winds. In the region of the jet, enhanced fall velocities are observed from 1630 to 1700 UTC (W component) indicating the descent of strong winds to lower levels. Ice crystals within cumulus clouds have a fall speed of 1 m/s, however in the region of the jet the fall speed is enhanced to 2 m/s due to a combination of ice crystals and atmospheric motion

It is not clear that this type of low-level jet has been identified and observed, even though Browning presented a conceptual model to describe such a jet [4]. Assuming the frontal system is moving at 70 $kmhr^{-1}$ (estimated from weather radar analysis) the low-level jet persists for 1 hour, hence is 70 km across and is moving at a right angle from the rain-band, once the system velocity is subtracted.

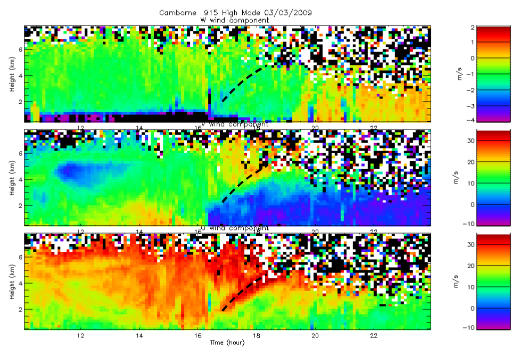

Figure 4*. Analysis of the W (top), V (middle) and U (bottom) wind components from the Camborne 915 MHz profiling radar on 3rd March 2009.*

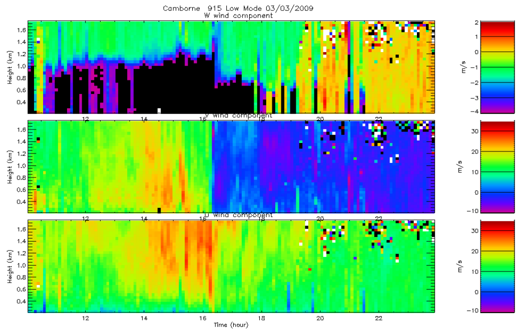

Figure 5. *Analysis of the W (top), V (middle) and U (bottom) wind components from the Camborne 915 MHz profiling radar operated in low mode on 3rd March 2009.*

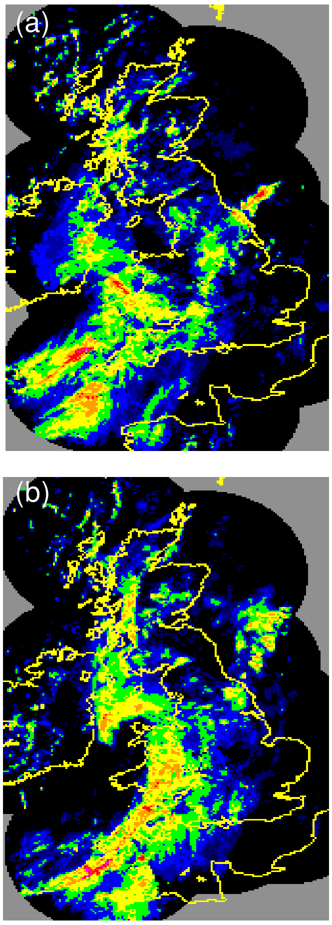

Figure 6 *Weather radar image, weak signals are blue-green and strong signals red-pink from (a) 1500 UTC and (b) 1700 UTC on 3rd March 2009.*

Similar structures are also seen by the 1290 MHz wind profiler at Dunkeswell between 1 km at 1830 UTC and 4.2 km at 2100 UTC. Figure 7 presents the wind speed and direction as U, V, W components observed by the Dunkeswell wind profiler, with the black-dotted line indicating the jet position. The strong westerly jet is seen in the U component, with weak westerly winds below the jet and strong southerly winds above the jet.

Figure 8 illustrates the wind speed and direction in the lower boundary layer, when the wind profiler is operated in low mode; here the jet can be clearly seen extending down below 1 km in the U component. It also illustrates how the jet is observed after the passage of the cold front, when there is a sharp decrease in the height of the melting layer from approximately 1.1 km to 0.8 km as indicated in the W component.

The jet is observed by both Camborne and Dunkeswell wind profilers at 1830 UTC; at Camborne the jets lowest observed altitude is 4.4 km at Dunkeswell it is 1.4 km. Given the sites are ~200 km away from each other, and the difference in jet heights is 3 km and the assumption that the jet is descending down the slope of the cold front this results in a cold front slope of 1:~67; a typical value for a cold front slope.

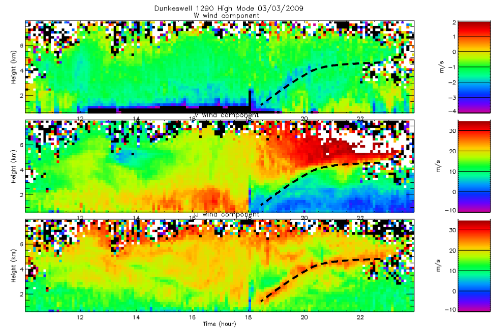

Figure 7. *Analysis of the W (top), V (middle) and U (bottom) wind components from the Dunkeswell 1290 MHz profiling radar on 3rd March 2009.*

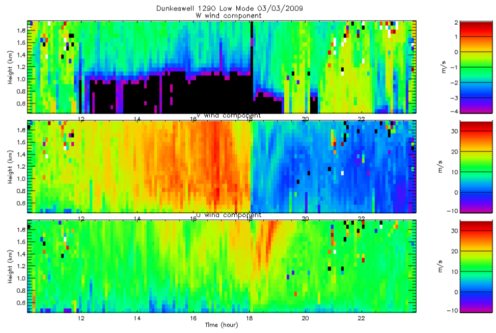

Figure 8. *Analysis of the W (top), V (middle) and U (bottom) wind components from the Dunkeswell 1290 MHz operated in low mode profiling radar on 3rd March 2009.*

Figure 9 presents the spectral width observations at Dunkeswell. High spectral widths are observed as a result of precipitation. Spectral width is also broadened in the region of the strong westerly jet and the region strong southerly winds above the jet most likely, due to increased shear and turbulence in this area.

The signal-to-noise ratio (SNR) measured by the Dunkeswell radar at this time is also shown in Figure 9. The strong SNR (red) region below 1.5 km decreasing to below 1km is a result of Rayleigh scattering from precipitation (also evident in the vertical velocity measurements in Figure 6 and 7). The strongest SNR signal is associated with the melting layer (also evident in Figure 6 and 7) and can be seen decreasing in height as the cold front passes over the profiler site. Bragg reflectivity's above this altitude were from the edges of cumulus clouds, an enhanced area of reflectivity is observed above the precipitation layer, this area is further enhanced in the region of the strong westerly jet.

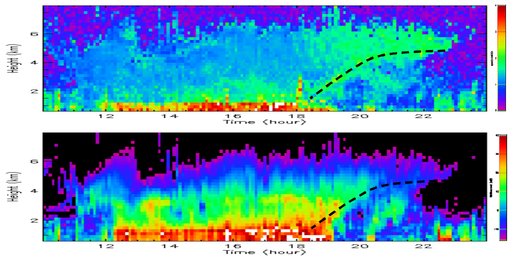

Figure 9. *Spectral width observations (top) and SNR (bottom) from the south-east (140 °) azimuth beam from the Dunkeswell 1290 MHz profiling radar on 3rd March 2009.*

Comparing the wind barb plots from Dunkeswell wind profiler radar with the wind barbs from the Cobbacombe Doppler weather radar winds shows a good degree of agreement between the two wind observing instruments as seen in Figure 11. Evident in both wind barb plots are the low-level jets observed in the warm sector, ahead of the cold front between 1430 and 1630 UTC. A region of enhanced winds from 2 – 4 km and 1800 - 2000 UTC is also observed in both wind barb plots and illustrates the low-level jet present behind the cold front.

Other weather radar wind barb plots from Dean Hill and Clee Hill (see Figure 11) show a similar structure with low-level jets observed ahead of the cold front, they do not show evidence of the low-level jet behind the cold front. Thus the jet is present in a limited area and is not persistent across the front, even though the line convection is still present when the front passes over Clee Hill and Dean Hill.

3. CONCLUSIONS AND FUTURE PLANS

Two different types of low-level jet structures, ahead and behind the passage of a cold front are observed with high temporal resolution in two wind profiler radars and by Doppler weather radar.

Two regions of strong low-level jets are observed ahead of the cold front, in the warm sector. These jets are associated with the passage of two distinct rain bands; the most intensive jet occurs just ahead of the surface cold front, this is also reported by [3].

The jet behind the cold front is composed of a strong westerly component, with only a weak southerly component, observed between 1.5 km and 5 km. The low-level jet is associated with a rapidly deepening depression and occurs behind the passage of a cold front. The strongest westerly winds descend behind the cold front, seen in the fall velocities (W component) and the backing of wind with height (U, V components) behind the front in Figures 4 and 7.

Similar jets have been observed by the UK Met Office wind profiling network, using the different profilers from the network. Jets which have been observed behind a frontal passage are associated with active cold fronts and deepening depressions.

A new 1290 MHz wind profiler is to be installed at Chilbolton Observatory later this year as part of the Met Office Future Upper Air Network (FUND). The Chilbolton wind profiler will add to the spatial resolution of the wind measurements in the southern UK. It is hoped, its use and comparison with existing instrumentation at Chilbolton will provide an invaluable asset to the UK network.

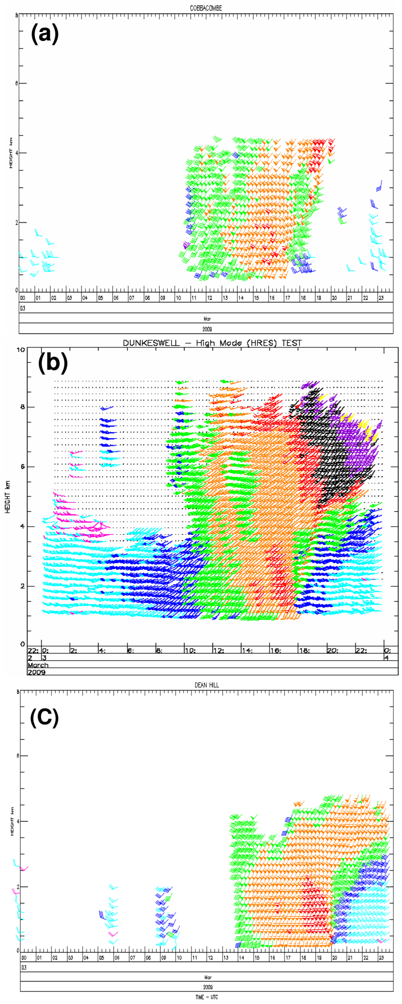

Figure 11. *Wind barb plots of wind speed and direction from (a) Cobbacombe Doppler weather radar winds and (b) Dunkeswell 1290 MHz wind profiler radar (c) Clee Hill Doppler weather radar on 3rd March 2009.*

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