Integrated profiling stations for High Resolution Numerical Weather Prediction

Catherine Gaffard[1] and John Nash[2]

[1]Met Office, Observation R&D, Reading, RG6 6BB, UK, catherine.gaffard@metoffice.gov.ukl
[2]Met Office , Observation R&D, Exeter, EX1 3PB, UK, john.nash@metoffice.gov.uk

ABSTRACT

The UK Met Office is currently working on the development of the terrestrial based component of a new upper air observing network to meet user needs in future High resolution numerical weather prediction [NWP] model. One type of instrument can not provide the spatial and temporal continuity needed for a high resolution model, only a combination of different types of instruments can meet the user need. The south east of UK is going to be equipped with a dense network of integrated profiling stations including wind profiler, cloud radar, ceilometer and radiometer. Used together with other observations like AMDAR, Weather radar, auto-sonde, the network will be able to provide continuously 3D information with a spatial horizontal grid around 50 km and with a vertical resolution of around 200m to 300m for winds, temperature and humidity, in the first 2 km. This paper describes what can be expected from integrated profiling systems to give improved atmospheric profile information in future.

1. INTRODUCTION

The Met Office has implemented a 1.5 km resolution numerical weather prediction model in 2009. If the performance of this model is to be optimized over the British Isles, especially for high impact weather, more observations of wind, cloud, atmospheric temperature and humidity [both in space and in time] are required. It is proposed that these requirements, especially in the boundary layer will be met primarily by terrestrially based measurements, including AMDAR and weather radar. The measurements will be used as:-

- input for NWP data assimilation,
- verification of NWP results,
- testing the forecasting of specific problems, e.g. lee waves, wintertime stratus cloud
- data sets for climate services and research,
- data visualized to match forecaster requirements, particularly in the boundary layer.

The Met Office FUND Project will coordinate the development and implementation of the enhanced Upper-air Observing Network. The plans for this project were revised this year, to deliver new information to the users more quickly. Some changes involving the introduction of additional wind profilers and high performance laser ceilometers are proposed to start in 2010/11. Whilst the full set of equipment to provide integrated profiling capability needs to be identified by late 2011, ready for implementation to start the following year. The network will be designed to complement information available from satellite observing systems and needs to provide a wider range of observations at an increased frequency, spatial density and reduced unit cost. In the mean time, development and evaluation of other new technologies will continue.The remote sensing discussed in this paper is expected to be supplemented by the continued use of radiosondes, probably at more launch sites across the UK, but with the total number launched kept to a total slightly lower than those used in 2009.

The implementation of the integrated profiling contribution to the new network requires:-

1. Optimization and validation of products from wind profilers, completion of the development of fmcw cloud radars [and, transition of microwave radiometers to operationally stable systems if they are to be used.]

2. Development of improved quality control procedures for individual instruments and also error characterization for the measurements.

3. Development of integrated products from collocated groups of observing systems, hence improving the information content and data quality from the profiling network.

4. Improved delivery of profiling information from existing systems such as current wind profilers and laser ceilometer networks and AMDAR.

5. Examination of the added information content of the profiling observations relative to NWP plus preparations for assimilation of the data into the NWP models,

6. Completion of an extended test bed experiment around London, demonstrating the performance of integrated profiling sites, and how the measurements can be combined with aircraft measurements, and weather radar winds to observe significant weather events on a horizontal scale of about 50 km.

7. Evaluation of the cost effectiveness of different combination of observations, to provide costs and benefits of different network design options.

2. PROGRESS WITH TESTBED IMPLEMENTATION

The testbed installations expected around London in early 2010 are shown in Figure1.The integrated profiling part of the network (Wattisham and Chilbolton) will be in operation by January 2010, now that planning permission has been granted for the installations at Chilbolton

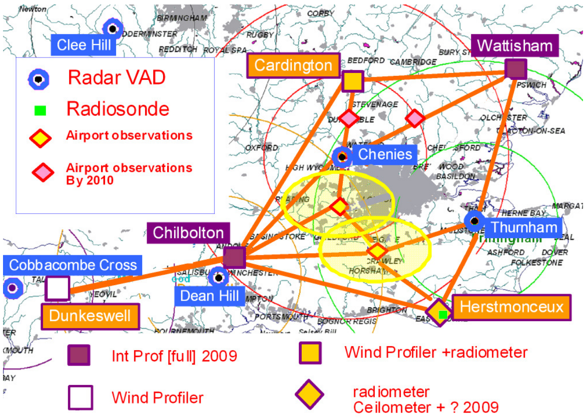

Figure 1. *Initial UK testbed deployments in 2010 around London, based on cooperation with Met Office Observation Based Research at Cardington and co-operation with research councils and universities at Cardington and Chilbolton The first and second circles around each weather radar are at 50 and 100 km radius.*

This testbed is intended to examine the provision of vertical profiles of wind and temperature and integrated water vapour, with network spacing less than 100km, and detailed cloud profiles at sites 200km apart. A new wind profiler with narrow vertical beam to minimize ground clutter and measure vertical velocities at high temporal resolution is to be installed at Chilbolton. FUND will also benefit from the UFAM (Universities Facility for Atmospheric measurements) wind profiler when it is operated at Cardington to the north of London. The existing wind profiler at Wattisham to the north east of London will be complemented by a high performance ceilometer and FMCW cloud radar.

FUND sites such as Chilbolton and Cardington will have a wide range of measurements from more instrumentation than could normally be afforded at individual Met Office profiling sites. So these extra measurements will allow the effectiveness and accuracy of various combinations to be tested. E.g. how much difference in cloud properties product is there between using a cheap microwave radiometer or the 12 channel radiometers?

Case studies will be used to compare the usefulness of different observing networks in observing significant weather events, and identifying those systems which work well in significant weather conditions and those which do not function well

The density of testbed observations around London, is too expensive to implement all over the UK, but is merited by the number of customers in this area and the need to support forecasting for severe weather and various types of emergency within the region. The output from all the profiling sites, plus additional radiosondes for special test periods should allow detailed observations of the actual atmospheric structure on a scale significantly lower than 100 km. Improving knowledge of the structure on these scales is important for future decisions on the network options for additional equipment to support wind profilers + weather radar + aircraft in the upper air network.

Current daytime availability of winds in southern England is illustrated on a day with significant initiation of thunderstorms in southern England; see weather radar composite from 17.07.09 showing the line of storms in southern England, Figure 2, and the associated wind plots at 500m and 2 km in Figure 3.

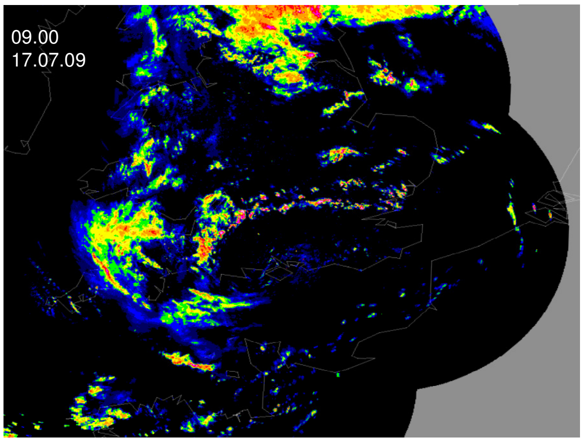

Figure 2. *Weather radar composite for 09.00 on 17.07.09, with a line of storms just forming insitu over central southern England, with their location marked in Figure 3 by the red dashed line/ white Red is very high intensity returns and green/ blue are weak.*

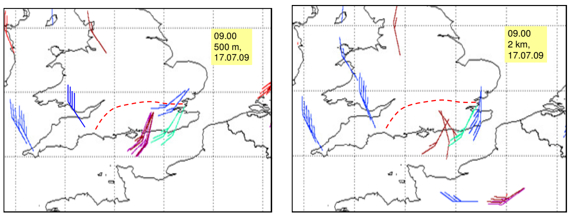

Figure 3. *Upper wind measurements at 500m and 2 km respectively available within ± 30 minutes of 09.00 UTC. Blue measurements from wind profiler, maroon from AMDAR aircraft below nominal height and purple above nominal height, and bluegreen from radiosondes [here, from a non-Met Office site, Shoeburyness*].

On this day weather radar VAD did not provide any winds in southern England. A surface low was located over the sea in the northeast. The wind measurements at 2 km suggest a low circulation at 2 km centred over southern England near the centre of the line of thunderstorms. The additional testbed wind profilers would fill the gap between the London airports and the western wind profilers and would provide another site to the north of the line of convection and the current airport measurements. 24 hour time series of the wind measurements at 5 minute resolution from the eastern UK wind profiler Wattisham are shown In Figure. 4.

The thunderstorms shown on the weather radar had moved northwards over the site by about 09.30. Whilst the melting level on this day was at about 2 km , there were extremely strong fall speeds at higher levels in the storm at 10.00, indicating the growth of hail in this storm. In advance of the storm and during the storm there was a shallow layer [below 1 km] of weak westerly winds near the surface, followed by stronger southerly winds after the passage of the storm. The second storm at 18.00 was associated with the passage of the trough over Wattisham, seen earlier in the centre of the UK at 09.00 UTC, followed by strong northwesterly winds. Data from all the FUND sites will be archived in similar detail in order to facilitate case study work, and the development of error analysis and quality control. Vertical stripes of anomalous winds can be clearly identified in Figure 4 between 10 and 15 UTC and would need to be eliminated for future operational use.

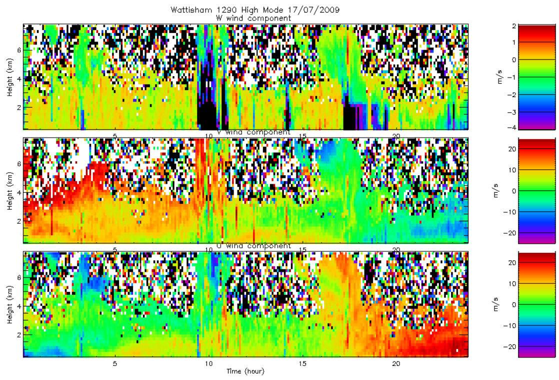

Figure 4. Time series of orthogonal horizontal wind components, u and v, and w, vertical velocity at 5 minute temporal resolution observed by the operational Wattisham profiler in high mode, vertical resolution 200m, and stored in the FUND Data archive.

Observations need to be compared with model background fields and also with the analyses once data are assimilated to understand what scales of motion are being accepted and those which are not being represented in the model, especially if the observations are reliable but are being rejected in the data assimilation process.

Within the EG_Climet COST Action data will be made available for analysis. FUND will also benefit from access to other new field experiments done in Europe. e.g. with water vapour Raman lidar, GPS water vapour tomography, and the HYMEX experiment run by Meteo France developing integrated profiling methods.

It may also prove possible to deploy additional instrumentation offered by COST partners within the UK Testbed in 2010-11.

3. INTEGRATED PROFILING FOR FUND

The recent review of FUND progress has led to a decision to prioritise the delivery of wind profiles and cloud profiles this year, with targets for other information to be set for the following years of the project.

FUND will prioritise on measurements in the boundary layer and lower troposphere where ground-based remote sensing is likely to have most impact complementing what is available from satellite remote sensing. However, each remote sensing instrument used on its own has some weakness, like target ambiguity (cloud drop, drizzle, clear air or aerosol) for cloud radar and wind profiler and laser ceilometer and lack of vertical resolution for microwave radiometer.

Several works (Westwater 1983[1], Bianco et al 2005[2], CLOUDNET project[3]) have shown that more reliable meteorological variables can be extracted when collocated observations from different systems are used together. The operational combinations considered for evaluation in FUND are various combinations of wind profiler, laser ceilometer, cloud radar, and radiometer measurements. Gaffard and Nash, 2008 [4] have already discussed some of the information content from the individual instruments

Cloud properties have already been derived in CLOUDNET for pulsed cloud radars combined with ceilometers, and so the transition to using fmcw cloud radar requires some work which is in progress, with the fmcw cloud radar temporarily located at Chilbolton.

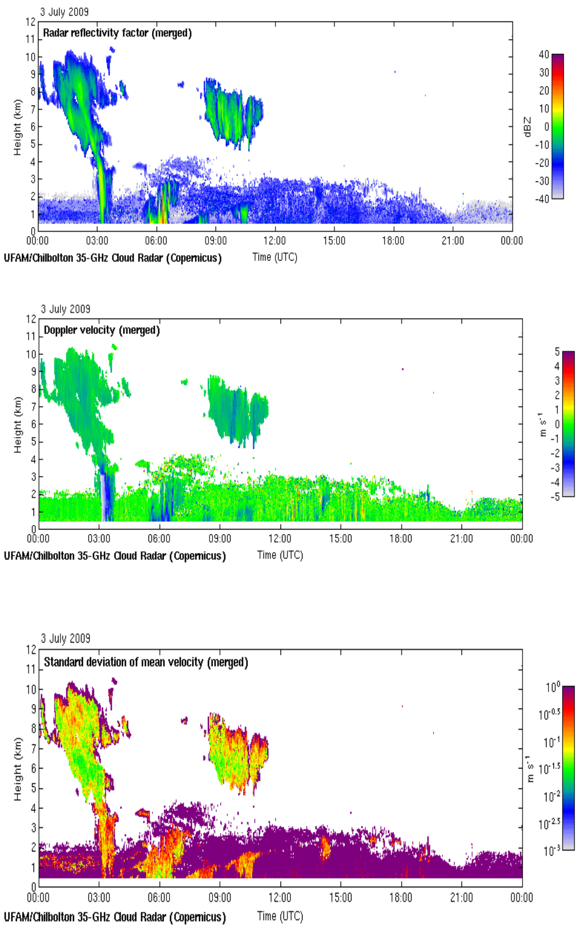

Figure 5. *24 hour plot of pulsed cloud radar returns measured at Chilbolton, courtesy of Reading University. The cloud radar has to be combined with laser ceilometer data to identify cloud base unambiguously*.

CLOUDNET data products can be viewed at reference [3].

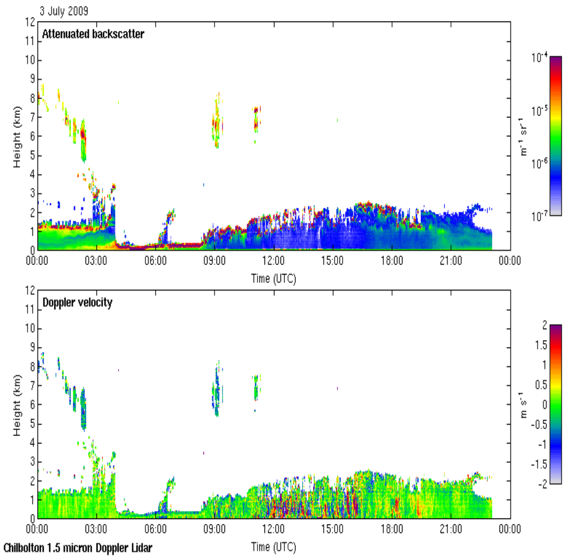

Figure 6. *24 hour plot of Halo Photonics lidar returns measured at Chilbolton, courtesy of Reading University. The red backscatter would correspond to cloud base, green and blue returns would be from aerosol.*

Comparing Figure 5 with Figure 6 shows low cloud for most of the time between 04.00 and 08.00 which is not obvious from the cloud radar returns. The thin clouds at the top of the boundary layer shown by the lidar between 09.00 and 16.00 are sometimes seen, but not always by the cloud radar. The lidar aerosol signals between 00 and 03 UTC clearly show differing layers of aerosol, with the low blue values likely to be in a much drier layer than the green values. Both lidars and cloud radar are able to measure the vertical velocityvariations seen in the daytime convective boundary layer, which seem to mostly stop at about 16.30 [note the vertical velocity scale in Figure 5 is quite different to that in Figure 6]. Between 12.00 and 16.00,the fluctuations in the vertical velocities extend up to the lower layer of clouds in Figure 6 but not higher, so the aerosol signals extending up to the second level of clouds indicate that similar air is exchanged up to the higher level by another mechanism. Between these times the reportable cloud radar signals [not cloud] extend slightly higher than the aerosol, and do not give an indication of the top of the boundary layer, although the local maxima in the standard deviation of the velocity measurements of the cloud radar between these times may give an indication of the top of the boundary layer.

Algorithms to estimate the top of the convective boundary layer from laser ceilometer measurements are under development by colleagues within the EG-CLIMET project. Users in the Met Office want to see what can be estimated from the basic ceilometers deployed at more than 100 sites in the surface observing network, and furthering this study will have to be one of the priorities for FUND as well as the development of the cloud products from the CLOUDNET algorithms. In the latter, it will be important to find whether the fmcw cloud radar needs to have a Doppler capability to give satisfactory CLOUDNET products.

4. FURTHER INTEGRATION DEVELOPMENT

As a wind profiler will be deployed at Chilbolton, under a formal agreement between the Met Office and Chilbolton, high temporal resolution wind and signal to noise measurements will be available to enhance the studies possible at Chilbolton in future. The signals need to have less spurious content than the current operational profilers. Improved exploitation of the signal to noise measurements from wind profiler radars should follow. This requires identification of target, i.e. clear air or precipitation, and also the stability of the atmosphere

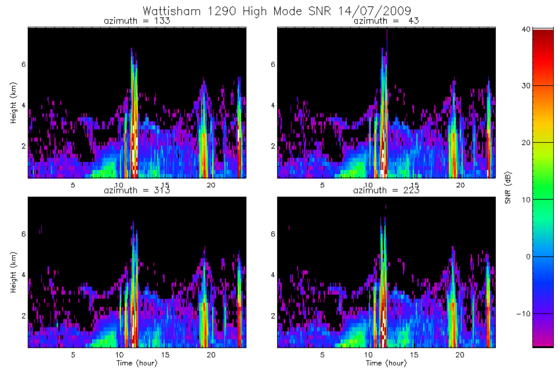

Figure 7 *Example of 24 Hour time series of signal to noise from the operational wind profiler at Wattisham*

The strong vertical bands in Figure 7 come from showers/thunderstorms, as could be identified from the vertical velocity measurements, but are any other signals associated with cloud? The greenish measurements at low levels are probably associated with the development and then collapse of the convective boundary layer either side of the thunderstorm around 12.00, but this needs to be verified from high temporal resolution vertical velocity measurements, not available operationally. The data from four beams are presented in Figure 7 to show whether a feature is seen in all beams. Automated integration of quality control exploiting data from different instruments is required in future.

REFERENCES

[1] Westwater, E.R , M. T. Decker, A. Zachs and K. S. Gage, "Ground-based Remote Sensing of Temperature Profiles by a Combination of Microwave Radiometry and Radar", J. Climate Appl. Meteorol., Vol. 22, pp. 126-133, 1983

[2] Bianco, L., and J. M. Wilczak, "Convective boundary layer mixing depth: Improved measurement by Doppler radar wind profiler using fuzzy logic." J. Atmos. Oceanic Technol.,19, 1745–1758, 2002:.

[3] Cloudnet website: http://www.cloud-net.org/index.html

[4] Gaffard, C. and Nash,J. "Future Upper-Air network (FUND) in the UK –Integration." WMO IOM Report No. 96 (TD 1462) Papers and Posters presented at WMO Technical Conference on Instruments and Methods of Observation, St Petersburg, Russian Federation, 1(5), 2008