8.5 PROGRESS IN IMPROVING UPPER AIR MOISTURE MEASUREMENTS OVER THE UK

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1. INTRODUCTION

The Met Office UK has been progressing towards an automated upper air network for several years. In 2002, the number of radiosonde stations reporting on a regular basis has been reduced from 8 to 6, but upper air observations are now augmented by the introduction of operational observations from 4 boundary layer wind profilers operating near 1 GHz and the MST radar, Aberystwyth, operating at 46 MHz. Work on the installation of a tropospheric profiler, operating at 64 MHz, in the Hebrides to the west of Scotland is in progress. The European AMDAR project is also contributing significant numbers of temperature and wind profiles near London and at some sites in Scotland and northern England. This paper will discuss the testing of new radiosonde relative humidity sensors, results associated with the European COST 716 GPS Total water vapour project and studies looking at the relationship between signal to noise measured by boundary layer wind profilers and relative humidity derived from microwave radiometer measurements.

2. NEXT GENERATION RADIOSONDES

Before 2001, the Met Office had been operating a radiosonde network with two systems, Vaisala PC-CORA with Vaisala RS80 Loran radiosondes and Sippican ground stations with MKII Loran radiosondes. With the reduction in the number of UK stations, operations have now reverted to a single supplier. However, two independent GPS radiosonde systems (Sippican and Dr. Graw) were purchased to provide reference winds and heights for test purposes at the Camborne test centre, replacing the obsolete Cossor tracking radar. In addition, the Met Office has purchased Meteolabor Snow white chilled mirror hygrometers flown using the Sippican ground system to provide a reliable method of measuring relative humidity independent of the Vaisala systems.

The new generation Vaisala Digicora-3 ground system was introduced into operation in 2001. Although this was extensively tested before introduction (no failures in 100 test flights), at a later stage serious problems occurred associated with introduction of various system peripherals and also with problems when the PC hard discs became relatively full. Rectification of these faults is still in progress. The Vaisala RS90 radiosonde was to be supplied with the new ground system. However, the absolute calibration of the RS90 relative humidity sensor and the protection from contamination for the relative humidity sensor when passing through supercooled water cloud were found to be outside of the procurement specification.

The Met Office was relatively happy with the relative humidity measurements of the RS80 H-Humicap radiosonde, as operational monitoring showed no systematic low bias in low cloud. This was probably because the radiosondes were not stored long enough before use for chemical contamination to be a problem. The operators returned batches that were clearly contaminated to the manufacturer. Thus, the Met Office chose to continue to use the RS80 radiosonde until the problems with the RS90 humidity sensor were resolved and a program of collaborative testing was agreed to resolve the problem.

As a result, the RS90 humidity sensor thickness was increased by Vaisala to improve calibration stability at high humidity. Vaisala using new laboratory test results also updated the temperature dependence of the RS90 calibration at temperatures below 0 ºC. Regeneration procedures to remove chemical contamination before launch were refined and sensors were also regenerated before calibration in the factory. The result of all these improvements were tested in the WMO GPS Radiosonde Comparison, hosted in Brazil in May/June 2001, where Snow White chilled mirror hygrometers were flown by Met Office staff in collaboration with Sippican operators.

The results from the 20 test flights in Brazil for the temperature range 15ºC to 0ºC are shown in Fig.1 and are compared with results from a similar test at Ascension Island in 1999 (also performed in collaboration with Vaisala). The results have been separated according to whether the measurements were made in the daytime or at night. The results from the two tests are quite consistent, with the standard deviations between the measurements from the two systems near 2 per cent R.H.. The

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Vaisala measurements were higher than those of the Snow Whites over most of the relative humidity range, indicating that sensor hysteresis may be limiting the accuracy of the Vaisala sensor at night.

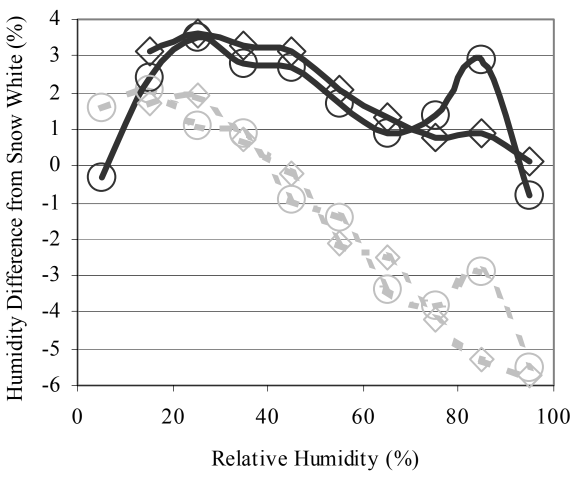

Fig.1 Relative humidity difference between Vaisala RS90 and Snow White chilled mirror hygrometer for the temperature range 15 to 0ºC, solid lines at night, dashed lines daytime, circles results from Ascension Island, 1999, diamonds results from Alcantara, Brazil, 2001.

In the daytime, the Vaisala measurements were much lower than those of the Snow White. The RS90 was clearly indicating correct relative humidity in daytime before launch in Brazil. Thus, it seems that the air passing over the two Vaisala relative humidity sensors in flight was being heated by passing over the bare copper surfaces on the upward facing side of the sensor boom before reaching the sensors. The Snow-white measurements in cloud appeared reliable in the daytime, whereas the Vaisala RS90 measurements were too low. Thus, it appears that even if the calibration of the humidity sensors is accurate to within a few per cent, it is necessary to correct daytime relative humidity measurements for diurnal heating if good accuracy is to be achieved in flight.

The tests in Brazil also demonstrated that it was possible for the RS90 relative humidity sensor to become heavily contaminated with ice at temperatures lower than -40ºC. Subsequent tests in the UK showed that contamination of the two RS90 sensors in supercooled clouds could be minimised if the pulse heating cycle of the two relative humidity sensors was speeded up to reduce the time for the build up of contamination. Thus, the Met Office has agreed that its next operational radiosonde will be a version of the Vaisala RS92, where the improved microprocessor electronics in the radiosonde will allow a pulse heating cycle that can be much faster at temperatures close to 0º C than the cycle in the current RS90. In addition, heating should continue at a lower rate down to temperatures of at least -60º C. The processing system should also incorporate some software correction for diurnal heating of the relative humidity sensors. It should also be able to identify whether the humidity sensor heaters are functioning correctly during flight. It is expected that the acceptance tests for the new radiosonde system should be completed during the latter part of 2003.

3. GPS TOTAL WATER VAPOUR

Progress with real time measurements of total water vapour using GPS has been rapid in Europe with the COST 716 demonstration network now processing data from more than 180 sites, see the web site at http: www.knmi.nl/samenw/cost716/. The UK does not have many sensors installed for geodetic purposes so that the Met Office has installed eight sites to bring the number of stations processed in real time in the UK up to a total of ten. The Ordnance (national) Survey currently has a network of about 30 sites with plans to expand to about 90 sites, but data are currently not available in real time. Near London the sensors are quite closely spaced and it is possible to post process total water vapour measurements at an effective spatial resolution of better than 20 km, utilising observations within 2 hours of nominal. Fig. 2 contains plots of total water vapour derived at 90-minute intervals from 09 August 2001. The stars indicate the positions of the GPS sensors around London. This was a relatively cold day, but one area of high total water vapour was generating at 1º W to the south-west of London in advance of a trough moving eastwards. Another area of high IWV was essentially stationary to the north east of London where thunderstorms had occurred earlier in the day. Thunderstorms were breaking out around the edge of the high IWV in the west and these eventually joined up by midday with the area to the northeast to give a line of thunderstorms stretching across north London. The precipitation from these storms led to flooding in the areas to the north of London. Case studies of total water vapour distribution associated with intense thunderstorm outbreaks convinced the Met Office users to authorise the initiation of a national real time GPS total water vapour observing network The work to start this network is now under progress in collaboration with IESSG, Nottingham University.

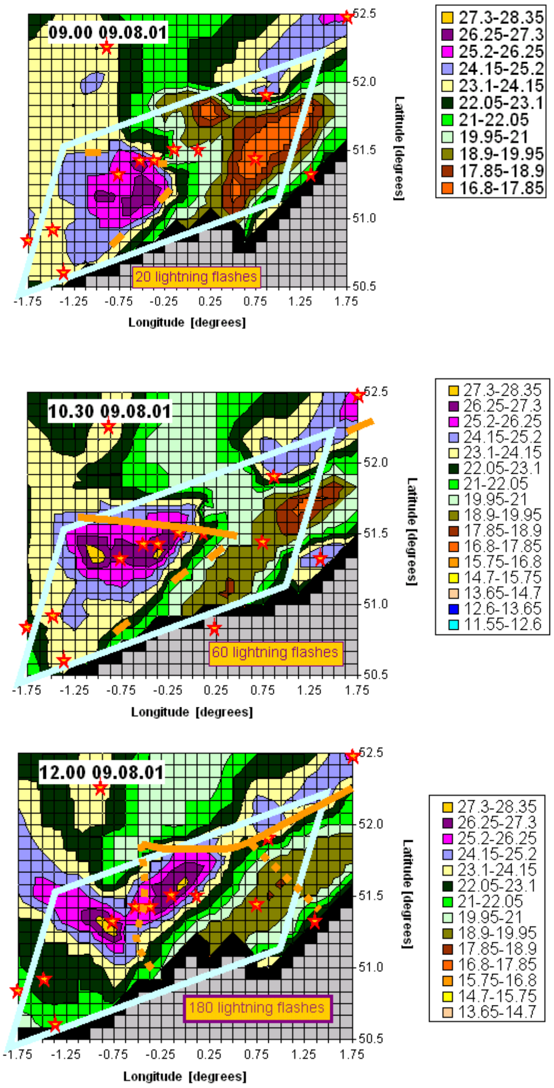

Fig.2 Post processed estimates of total water vapour distribution in southeast England on 09.09.01 between 09.00 and 12.00. The parallelogram encloses the area with best spatial resolution in measurement. The stars indicate the locations of the sensors. Note: 0.5º in longitude is about 35 km over the UK, so grid on diagrams is about 9 km and the scale of the structures in total water vapour is much less than 50 km.

4 RADIOMETER PLUS WIND PROFILER AND CLOUD RADAR

Whilst it is expected that the total water vapour measurements will improve the analysis of horizontal structure in moisture over the UK, more information on vertical structure in relative humidity is also required. In order to aid development in this field a Radiometrics multichannel radiometer was purchased and installed at Camborne in the far southwest of England in February 2002. This radiometer has worked reliably since installation, although it is clear that the marine environment is causing degradation to some components. It was soon recognised that the existing scan patterns were not well suited for an environment where clouds were moving rapidly through the fields of view. The Met Office is happy that the manufacturer has now taken steps to remedy this deficiency.

It was realised from the start that this radiometer could not produce detailed structure in the vertical moisture distribution without additional information. The first additional information available is the signal to noise measured by the 1 GHz wind profiler systems. This signal shows local maxima in the vertical when there is a temperature inversion/ pronounced hydrolapse. However, there are also strong signals when clouds with relatively large hydrometeors are present.

The presence of cloud can be detected using a laser ceilometer. However, there are often many layers of cloud over a site such as Camborne, exposed to the marine environment of the Atlantic. Thus, the Met Office is working with the Rutherford Appleton Laboratory on the development of a cheap FMCW cloud radar working near 78 GHz. Progress this year has been limited by the requirement to improve the data processing so that a resolution of 15 m from the surface to 8 km can be achieved. It is hoped that the improved version of the system will be ready for testing in January 2003. This system can measure fog top to an accuracy of about 15m and as such is expected to have many applications within the upper air observing networks in future.

Work on integrating the measurements from these different systems is being performed in association with a second European COST project, COST 720 – Integrated atmospheric profiling. Development of these techniques is planned in conjunction with the radiosonde testing at Camborne. Fig.3 shows vertical cross section of relative humidity derived from the microwave radiometer during a period when hourly radiosonde measurements were available. The signal to noise from the high mode of the 915 MHz wind profiler (vertical view) is also shown. The radiosondes show two drier layers between the surface and 4 km, with the first descending from 1.5 km to lower than 500m during the day, and the other rising from two to three km during the day. This structure is not resolved by the radiometer, but the local maxima in profiler signal to noise can be related to the gradients in relative humidity shown by the radiosondes. Thus, the challenge is to develop reliable techniques for mixing the profiler signal to noise with the microwave radiometer to provide both temperature and relative humidity with improved vertical resolution.

Above 4 km, the signals in the wind profiler measurements are related to scattering from larger hydrometeors associated with the mid-level cloud. Earlier tests with a cruder version of the cloud radar indicate that true cloud base may be higher than indicated by the lower limit of the wind profiler signals shown. This is because the profiler sees scattering from hydrometeors that are below the lower limits of the cloud. Understanding the origin of the profiler echoes will be pursued further once the cloud radar is operational.

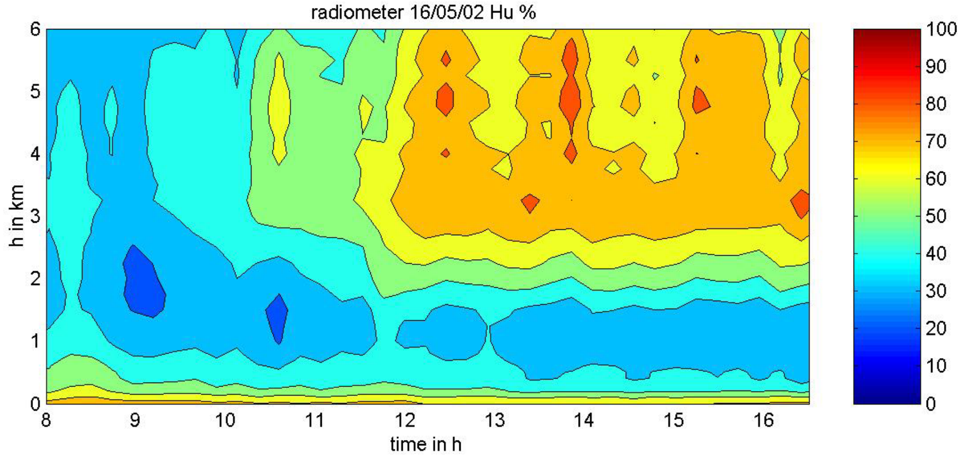

Fig3(a) Time series of relative humidity measured at Camborne by Radiometrics microwave radiometer

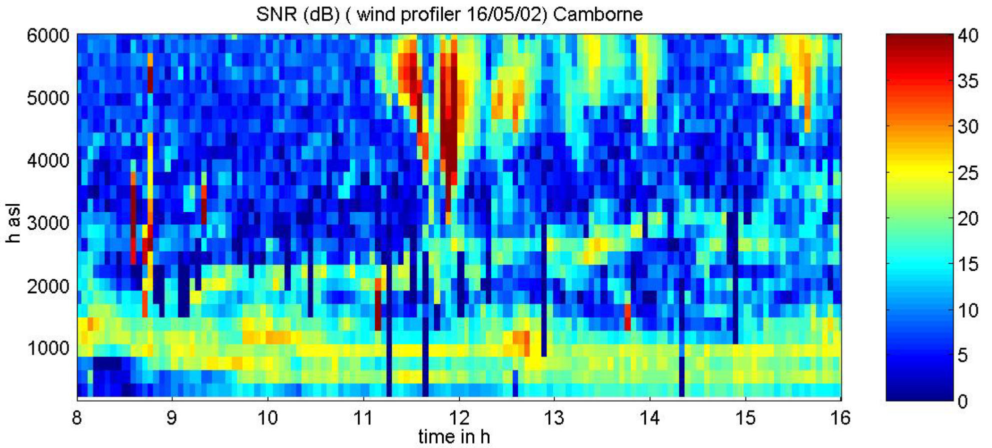

Fig. 3(b) Time series of signal to noise ratio measured at Camborne by 915 MHz wind profiler in high mode

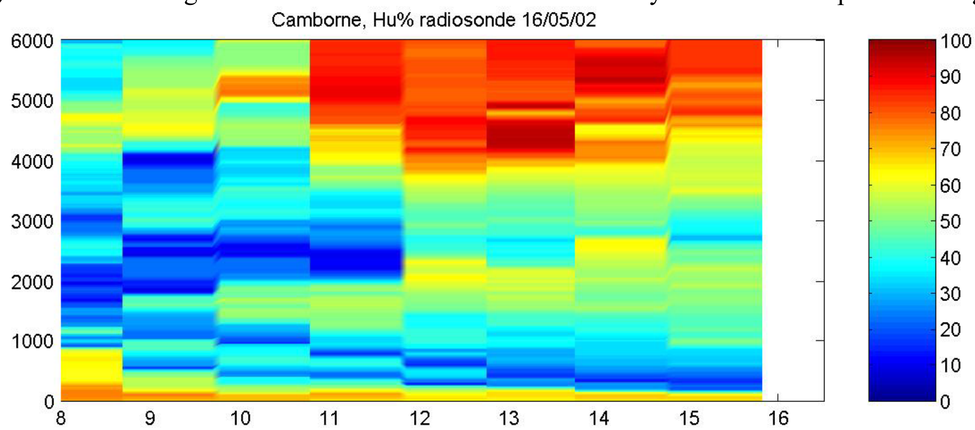

Fig. 3(c) Time series of radiosonde measurements of relative humidity at 1 hour spacing