The challenges for an operational wind profiler – remote and unattended.

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The Met Office has recently installed a Tropospheric 64MHz wind profiler on South Uist, an island off the west coast of Scotland. After many years in developing the use of wind profiler observations as a component of the UK upper-air network, this was the first system procured directly for operations and was linked to the closure of a radiosonde sounding station. This presentation will describe the challenges encountered, from the original specification, the installation/testing process and ultimately the hand over to operations, in delivering an unattended, remote managed observing system.

The Requirement/Specification for a Wind Profiler Radar.

At the beginning of 2000 the Met Office Upper-Air observing network consisted of 8 Radiosonde stations providing 4 ascents per day and a number of supplementary stations providing irregular ascents based on local forecasting requirements. Figure 1 shows the location of these sites.

A strategic review of the network in 2000 provided plans to reduce the number of manned upper-air stations in the network with the use of Autosondes and some site closures. In addition it recommended a greater integration of other upper-air measurements (i.e. Amdar, profilers) within the operational network.

With the closure of the radiosonde station at Stornoway (NE Scotland) the upper-air development team were tasked with the procurement and installation of a wind profiler (WPR). The decision to install a WPR as a direct replacement for the operational wind measurements was based on extensive experience of operating boundary layer WPR's in Southern UK. However this procurement would be unique, in providing a system suitable for operations, with a maintenance and spares policy for a 10 year life time.

Figure 1 – UK Upper Air Network (Jan 2000)

A summary of the specification of the wind profiler radar is as follows:

- An operating frequency either in the band 440-450MHz or 50 - 65 MHz.
- Winds reported in the range 1 - 12km, at a minimum of 90% availability.
- Height Resolution 150m – 500m
- Temporal Res. 30min → 10min
- Random Error ≤ 2ms-1 (Absolute error tested against Radiosondes)
- Lifetime 10 years, harsh environment. 1 visit per 6 months.
- System to run unattended, with complete remote access capability.

As a result of a competitive tendering exercise the contract to supply the WPR system was awarded to Vaisala (Finland), who was using ATRAD (Australia) as a sub-contractor to provide the antenna and amplifiers. The agreed specification for the system was as follows:

- An operating frequency in band 50 - 65 MHz. The final frequency of 64MHz was agreed at a later stage.
- 90% availability of winds reported in the range 1.5 - 12km, however on occasions it is expected that winds up to 16km would be reported.
- Height Resolution 150m (1.5-6km) and 450m (3-16km)
- A recommended temporal resolution of either 1 hour or 30minutes. However 10 minute resolution is possible to configure for research use.
- Random Error will meet those detailed in the tender document.
- A detailed maintenance document and level of spares for a 10 year operational lifetime. Once operational a maintenance visit is only required every 6 months.
- System will run unattended and has remote access capability.

Site Selection.

A site needed to be identified which was still in the western Isles of Scotland but had the necessary land and services for the wind profiler. Careful consideration was needed to ensure that a licence to operate at the chosen frequency would be granted and that the likelihood of external interference was small. Criteria used to assess the suitability of the site were as follows:

- Possible to transmit in the band 50-65 MHz and have adequate protection from other non-licensed users.
- A flat area of land suitable for the installation of an antenna array of $160m^2$.
- A nearby shelter with power and communications.
- A secure site, as for most of the time the system will be unattended.
- Local contact with technicians/caretaker able to provide on-site support.
- Located near other Met Office equipment (sharing of resources).

The site selected was on a military range on the Hebridean island of South Uist. The range already hosted surface observing equipment and had an onsite forecast office capability for trials work. On-site technical, work services & security support was available and a communication link between the Met Office HQ at Exeter and the range already existed. Figure 2 shows a picture of the selected site.

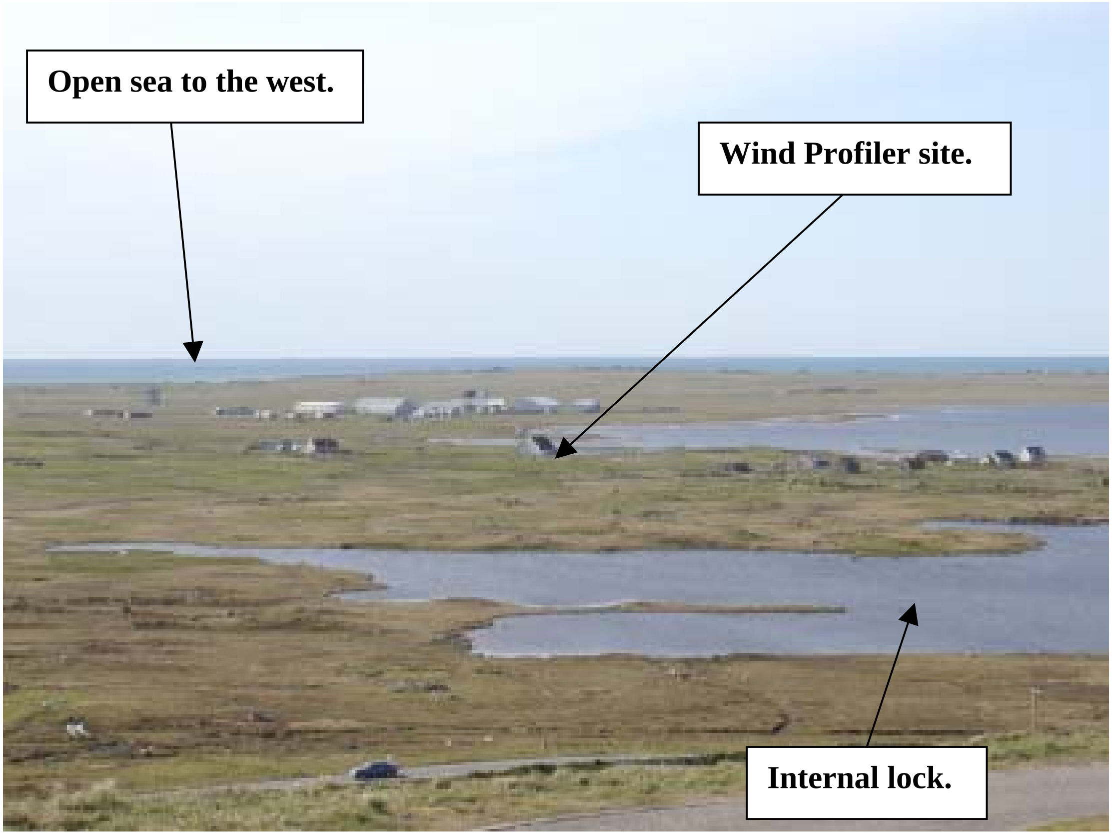

Figure 2 - The wind profiler site on South Uist

System Installation.

Work services for the antenna and internal electronics began in November 2002. Not only did the installation need to be fully compliant with the regulations for the Met Office but also needed to be accepted by the range authorities to ensure that the profiler didn't interfere with other equipment on the range. Extensive work was necessary to prepare the site and install a concrete base for the antenna. A solid concrete base was chosen for the antenna, as this would make the YAGI antenna installation, earthing and tuning a simpler process. The antenna would be easier to maintain over the lifetime of the system. Figures 3-6 show the progress of the antenna installation, which was completed at the end of March 2003. Approximately ⅓ of the total cost of the project was for work services.

Figure 3 – Start of site preparation.

Levelling of site and concrete capping of existing communication duct.

Figure 4 – Concrete base.

Concrete base being constructed in strips, to allow the concrete to fully harden and for access to create a polished surface. Requirements stipulated a level of ± 10cm over the whole base.

Figure 5 – YAGI Mountings.

Installation of mounting plates. Positioning required an accuracy of ± 2cm between each plate. Security fence being installed.

Figure 6 – Completed antenna.

Completed installation of YAGI antennas, cables and earthing straps.

Work was also required to prepare the shelter for the wind profiler electronics. A 3 phase-supply was necessary to power the 6 transmitter modules and air-conditioning was needed to maintain the room at a constant temperature. Security constraints meant that a communication link to the Met Office forecast office had to be a fibre-optic link over a distance of 4km. Figure 7 shows the internal electronics for the wind profiler system. Installation was completed in early May 2003, with the first transmission on 9th May 2003.

Figure 7 – Internal Electronics. (1) Communications cabinet. (2) Transmitters and power supply. (3) Beam Steering unit and digital processing.

System Acceptance.

Once the wind profiler started working at the beginning of May 2003, a number of issues needed to be resolved before the system could be regarded as ready for the 4 week acceptance test by the Met Office. This acceptance test would require the system to run unattended for a period of 4 weeks, with the wind measurements meeting the specification documented in the tender documents. The major initial problems with the system were as follows:

1. 'Bleed through' of the transmit signal on the receive (Problem in T-R Switch).
   This was a serious problem causing an interfering signal around zero Doppler frequency which dominated the atmospheric signal above 5km. Attempts on-site and later in Australia were unable to modify the T-R Switch to remove the problem. A software fix was necessary by Vaisala to eliminate all the signals around zero and thus allow the atmospheric signal to be selected by the software.
2. Polar Mesosphere Summer Echo's (PMSE).
   Signals from 80-90km were being aliased into the Doppler spectrum and causing significant problems with the wind measurements from 10 – 14km (See Figure 8). A change in the configuration was necessary to ensure that these signals were ignored.
3. Internal & External interference.
   Significant problems were encountered with interfering signals from either an internal or external source. Attempts were made internally to limit the effects of the likely culprits (i.e. 32MHz oscillators) but these problems persisted on an ad hoc basis for a period well after installation. Figure 9 provides wind measurements from the system for 24/12/03, with an example spectrum plot in Figure 10. Clearly the winds are unusable above 9km. At a later stage it was possible to demonstrate that much of the interference originated internally within the system, notably after switching off and working on the system. This highlighted that particular care was required in replacing components and earthing links after working on the system.
4. Ground clutter and Precipitation.
   On occasions both ground clutter and precipitation signal returns caused errors with the measured winds, especially when the signals were in one beam but not the other. When validating the system against the specification (random error) for these periods the measurements were clearly outside the limits.
5. Remote monitoring and diagnostics.
   Once the system was delivered and left running unattended, it was clearly evident that the remote monitoring capability, especially fault diagnostics, was not suitable for operations. Unfortunately this was a weakness in the procurement specification with a lack of detail in defining the monitoring capability required for a remote, stand alone operational system.

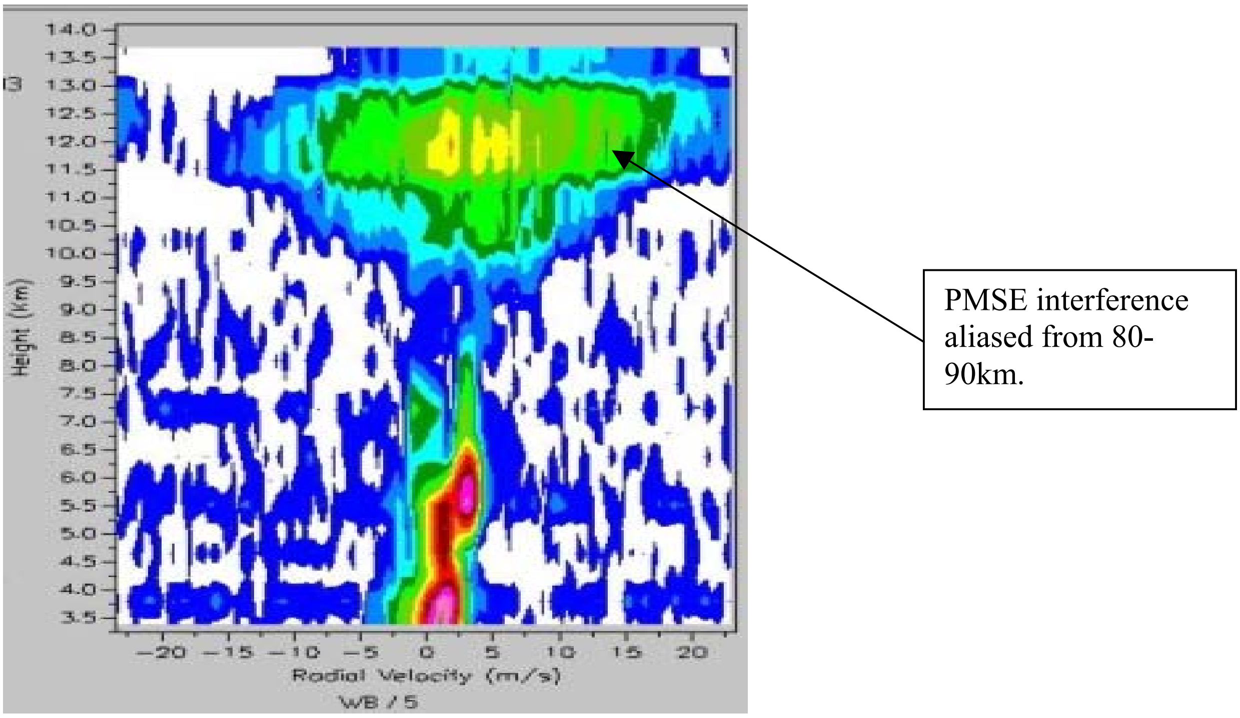

Figure 8 – Non normalised log contour plot of the Doppler spectrum (PMSE interference).

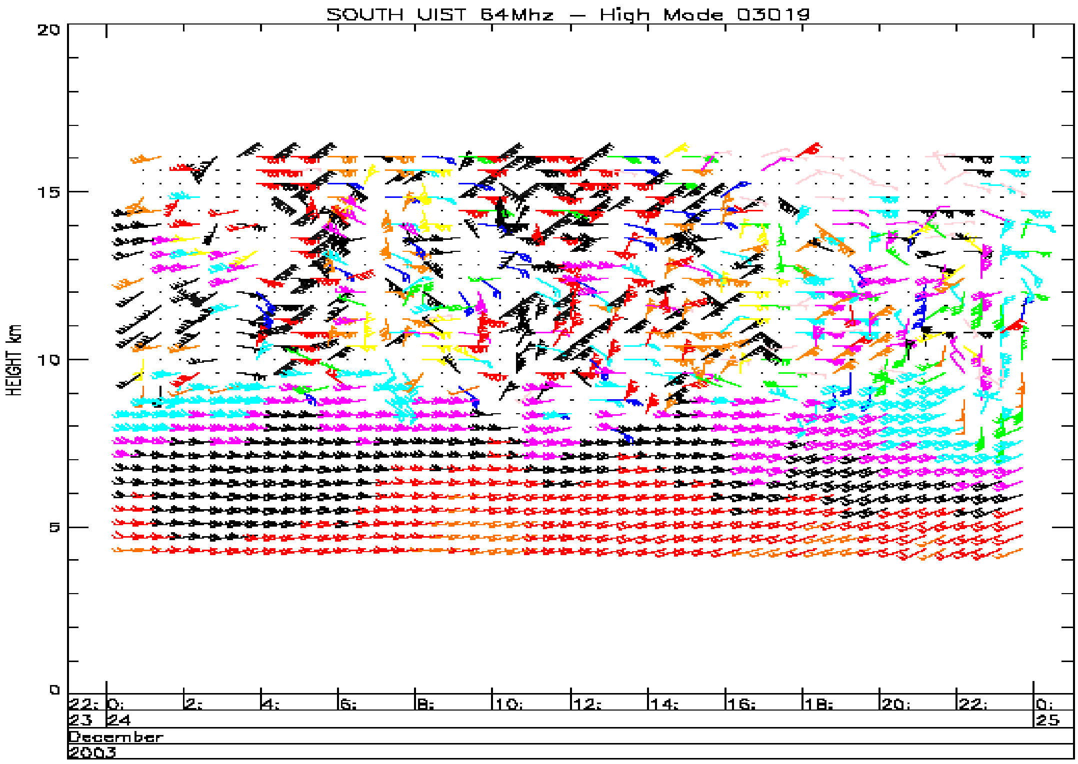

Figure 9 – 24 hour wind barb plot, showing measurement problems above 9km

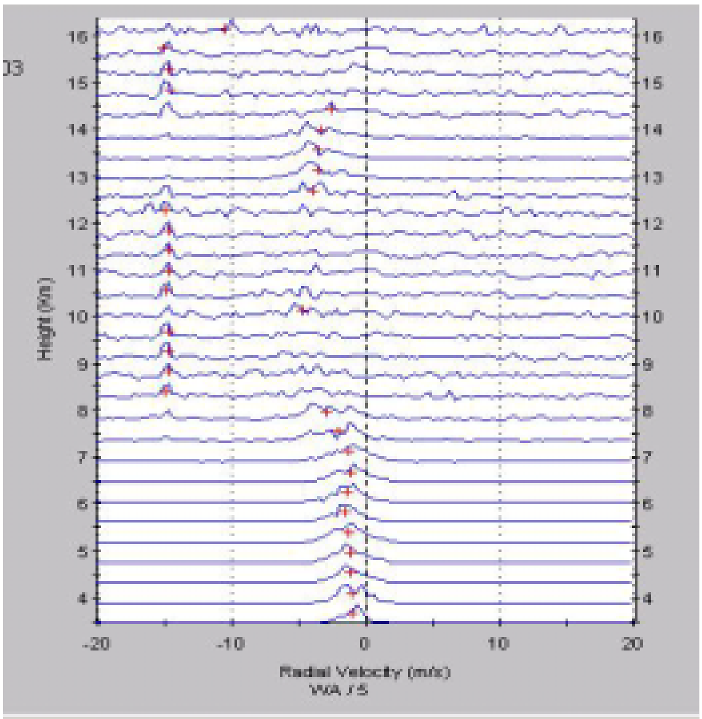

Figure 10 – Stacked Doppler power spectra plot showing interfering signal.

At this stage it was evident that additional signal processing was required to fully optimise the system for operations. The low mode data (1 – 5km) had been accepted for operational use by the Met Office (NWP assimilation from Nov 03) but during precipitation there were some errors in the reported winds. The high mode was still clearly outside the acceptance limits detailed in the tender documents and thus was not accepted for data assimilation. It should be stressed that this is a unique system which required a significant learning commitment for all parties involved in the installation and acceptance process.

At the beginning of 2004 it was decided to use a 'Multi-Peak' solution in processing the spectral data. Work on the archived spectral data by Vaisala and further testing by the Met Office demonstrated a significant improvement in the high mode wind data. Figure 11 provides an example of the improvement on 24th Dec using the same spectral data as shown in Figure 10.

These new algorithms were introduced operationally on the system from February 2004. With additional Quality Control on the reported winds the high mode data was accepted for NWP data assimilation by the end of March 2004. A 2nd Radiosonde acceptance test was conducted in July 2004 to document the comparison statistics between the radiosonde wind measurements, a 915MHz boundary layer profiler and the 64MHz profiler. Figure 13 shows an example of the wind measurements from the 3 systems. Figure 14 summarises the standard deviation of the differences of the wind profiler measurements with the radiosonde (26 comparison flights).

The wind profiler system was fully handed over to operations in October 2004. This process not only required the acceptance of the system against the tender documents but required detailed documentation and training so that the daily support and the long-term maintenance of the wind profiler could be maintained by the network managers.

Figure 12 shows a 24-hour wind barb plot for the South Uist wind profiler as reported in real-time. The overall measurement quality and vertical coverage can easily be assessed from this plot, which is produced on a daily basis.

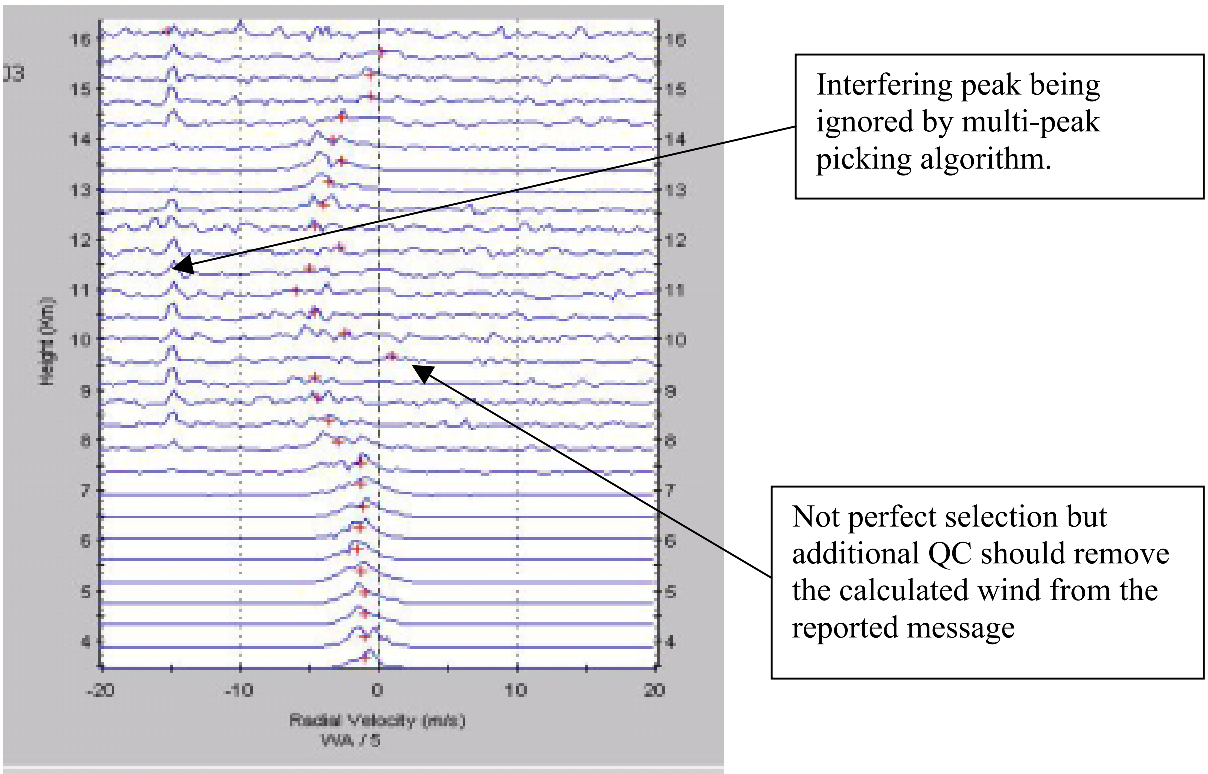

Figure 11 – Stacked power spectra and peak identification using the multi-peak algorithm

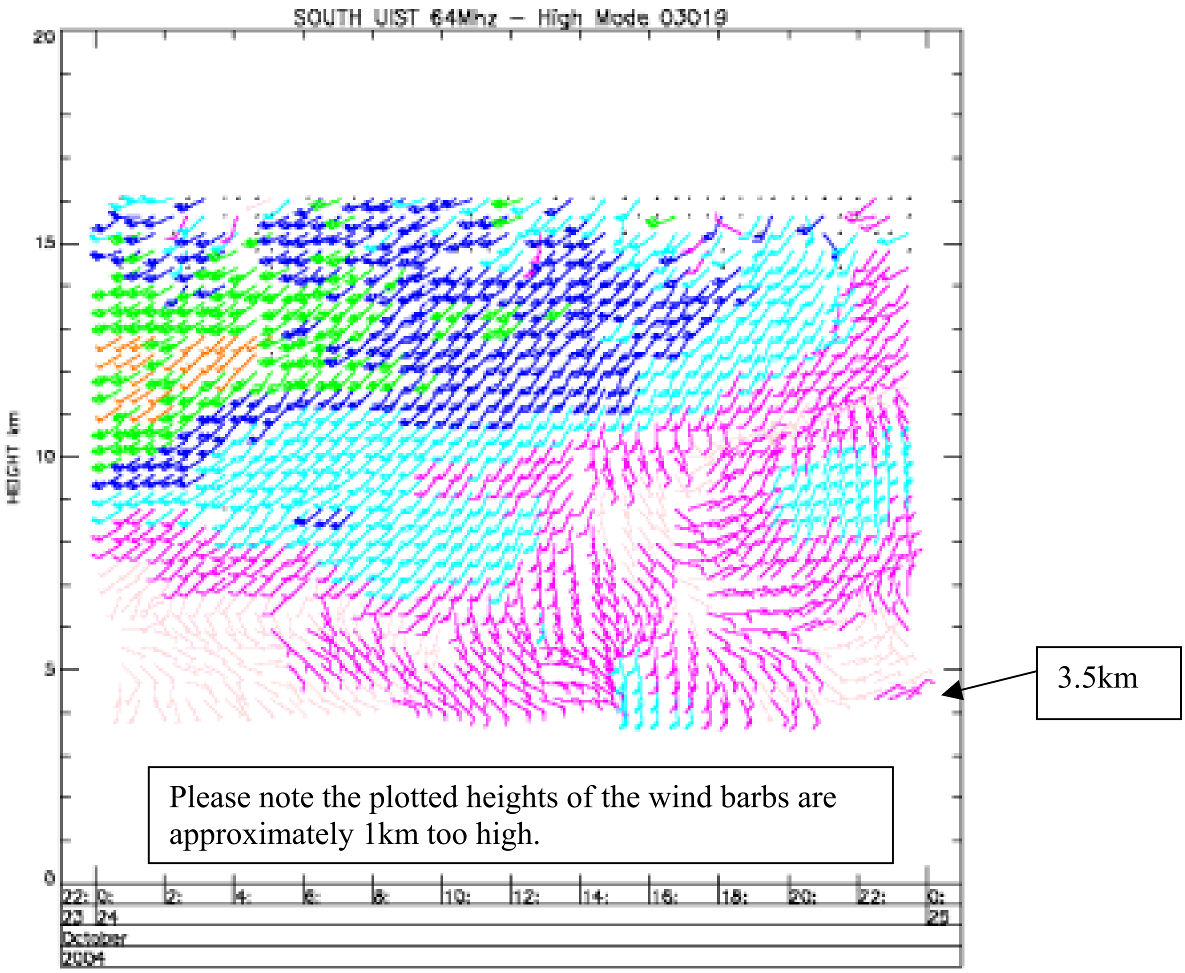

Figure 12 – Example of 24-hour wind barb plot (South Uist 64MHz wind profiler)

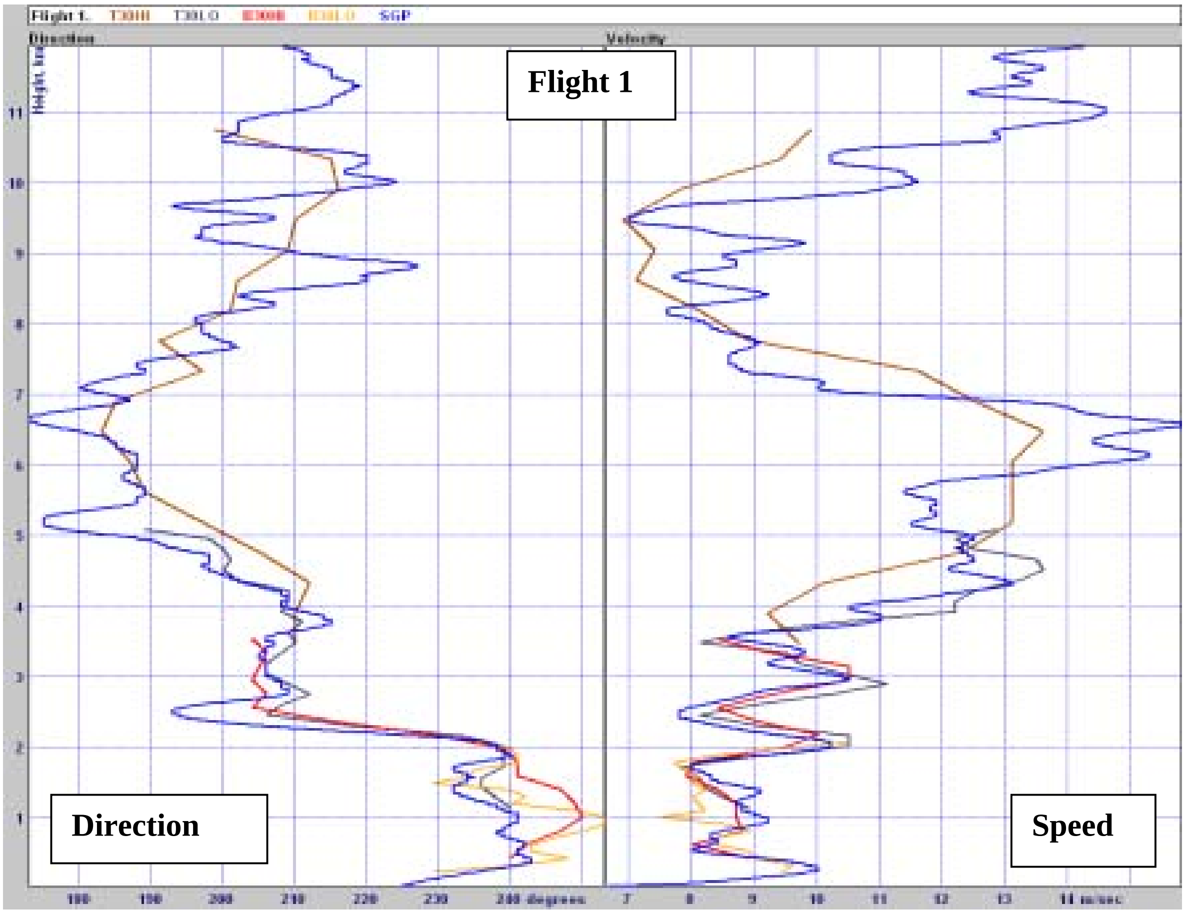

Figure 13 – Radiosonde & Wind Profiler (64MHz and 915MHz) comparison.
[Blue– Radiosonde, Brown– 64MHz(high), Red– 64MHz(low), Grey– 915MHz(high), Yellow– 915MHz(low)]

Height Band	64MHz (High) u,v components Standard Deviation	64MHz (Low) u,v components Standard Deviation	915MHz (High) u,v components Standard Deviation	915MHz (Low) u,v components Standard Deviation
0-1km			0.7 , 0.8	0.7 , 0.8
1-2km		0.7 , 0.6	0.8 , 0.7	0.8 , 0.7
2-3km		0.8 , 0.9	1.0 , 1.0	1.0 , 1.0
3-4km	1.3 , 1.1	0.9 , 1.0	1.0 , 1.0	
4-5km	1.1 , 1.2	0.8 , 1.0		
5-6km	1.5 , 1.2	1.2 , 1.1		
6-7km	1.4 , 1.1			
7-8km	1.7 , 1.3			
8-9km	1.9 , 1.5			
9-10km	1.9 , 1.8			
10-11km	1.2 , 1.4			
11-12km	1.5 , 1.5			
12-13km	2.1 , 1.7			

Figure 14 – Acceptance test (26 Flights). Standard Deviation of the differences (m/s)

Conclusion and future work.

- The wind profiler system has now been running unattended for a period of greater than 6 months.
- The remote access has proven capable of allowing updates of the software & system configuration and maintaining the IT security of the processor whilst operating on the Met Office network.
- Data from both modes are being operationally assimilated in the NMP models and real time displays are used by forecasters.
- The manufacturers have been requested to address the hardware issues for the system, notably on the T-R switch problem and with remote monitoring/diagnostics.
- Additional analysis was done to assess the quality of the lowest wind measurement (1.5km) and to compare the reported winds where the 2 modes overlap. Comparison statistics for the lowest range gate showed a good agreement between the profile winds and that of the GPS radiosonde & the 915MHz wind profiler. In general the low and high modes show a good agreement but on occasions where there are marked variations in the signal power in the vertical there are inconsistencies in the measurements. Further information on these studies can be provided by contacting the author.
- With the introduction of the multi-peak picking (MPP) algorithm there was a significant improvement in the reported winds. On most occasions the algorithm is able to ignore any ground clutter or interference peaks. Also when precipitation is present below the melting layer the winds are normally resolved correctly. However above the melting layer the ice-crystals present more of a problem as their fall speeds are closer to the atmospheric signal. Figure 15 shows a plot of vertical velocity from the wind profiler low mode, with clear examples of the processing locking onto the ice-crystal signals. The wind measurements are satisfactory as long as all beams lock onto the ice-crystal signal but this is not always the case.

Vertical velocity, 64 MHz, SouthUist low mode , 21.11.04

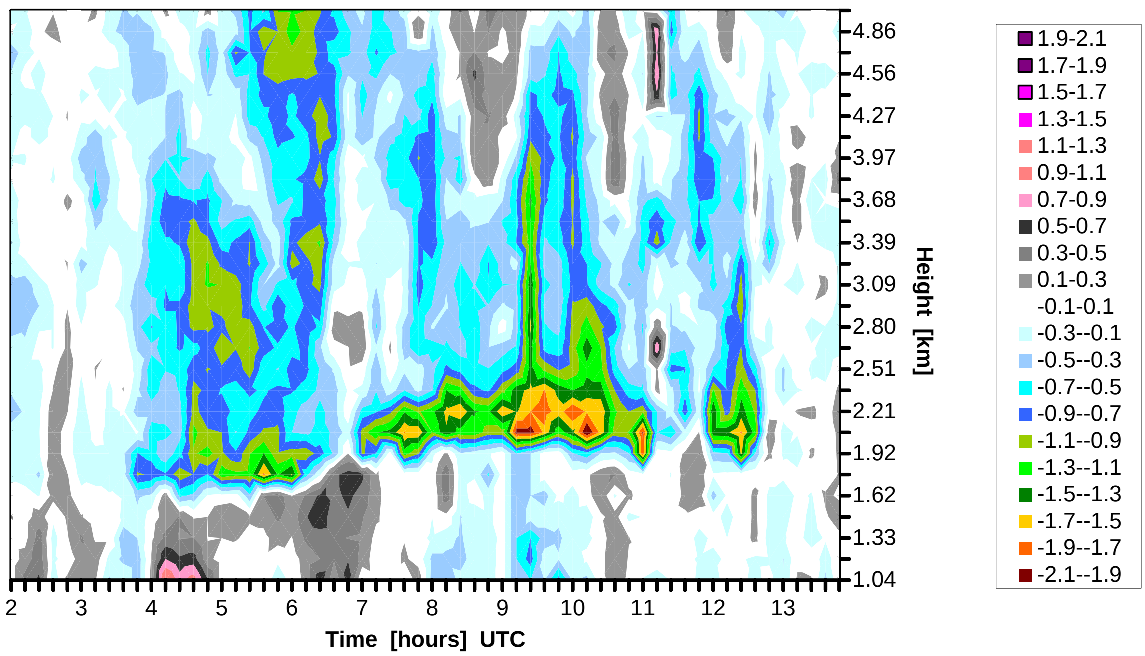

Figure 15 – High resolution vertical velocity measurements from the 64MHz profiler.

- Operational monitoring of the reported winds shows that on 1 or 2 days a month, notably in winter conditions, the current MPP algorithm is not identifying the peaks correctly in one beam. Thus further work is necessary in an attempt to 'fine-tune' or even update the algorithm to improve the wind data on these occasions. The Met Office has an ongoing collaboration with Vaisala to investigate these cases.

Case Study

This winter (04/05) has proven a good test of the resilience of the wind profiler system. One of the key requirements was for the system to maintain full operations during severe weather. Thus the system included a back-up generator which would automatically provide power in the event of a cut in the main supply. On 11th January 2005 a severe storm battered the west coast of Scotland, causing some loss of life, significant structural damage and periods in excess of 24 hours without power on South Uist. Figure 16 shows the 18utc analysis chart for 11th January. Throughout the storm the wind profiler continued to provide measurements, for long period in excess of 100 knots (110 mph). Figure 17 shows the wind speeds measured by the system from 09 -21utc.

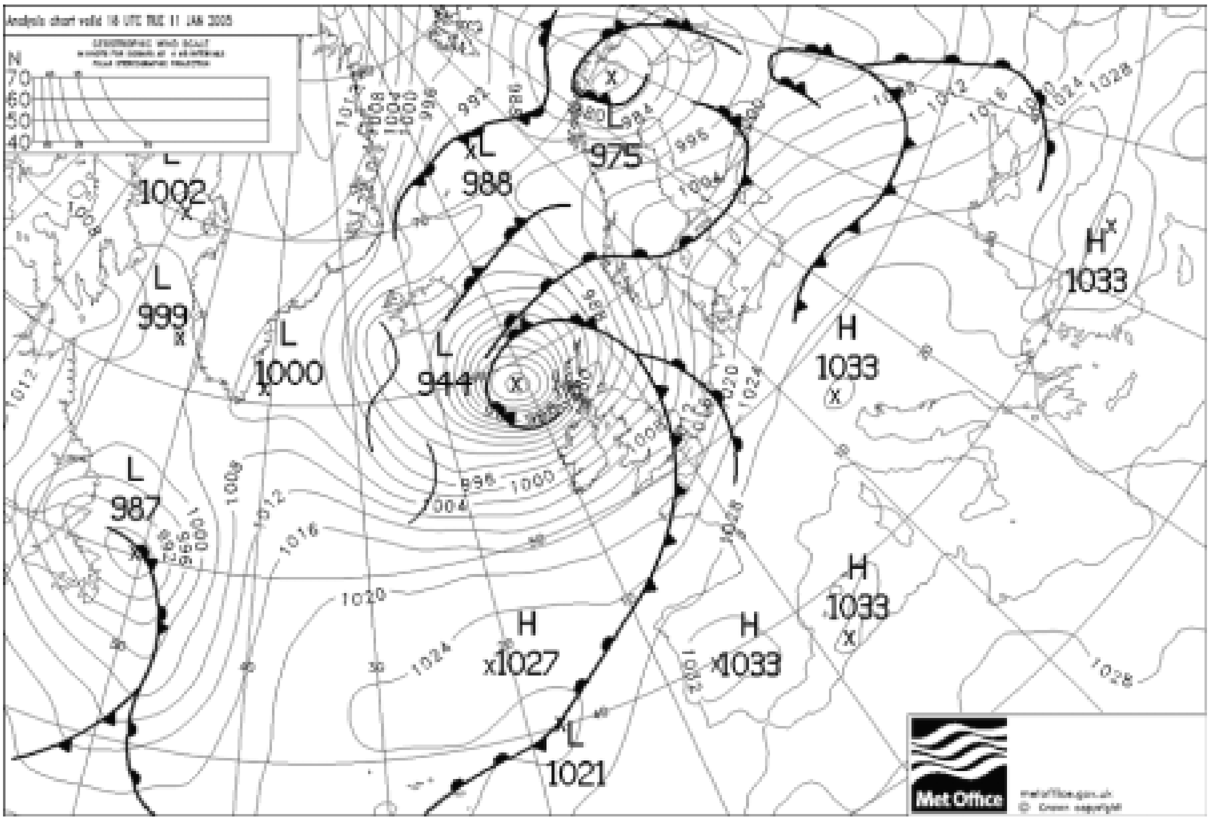

Figure 16 – Met Office analysis chart for 18utc on 11th January 2005.

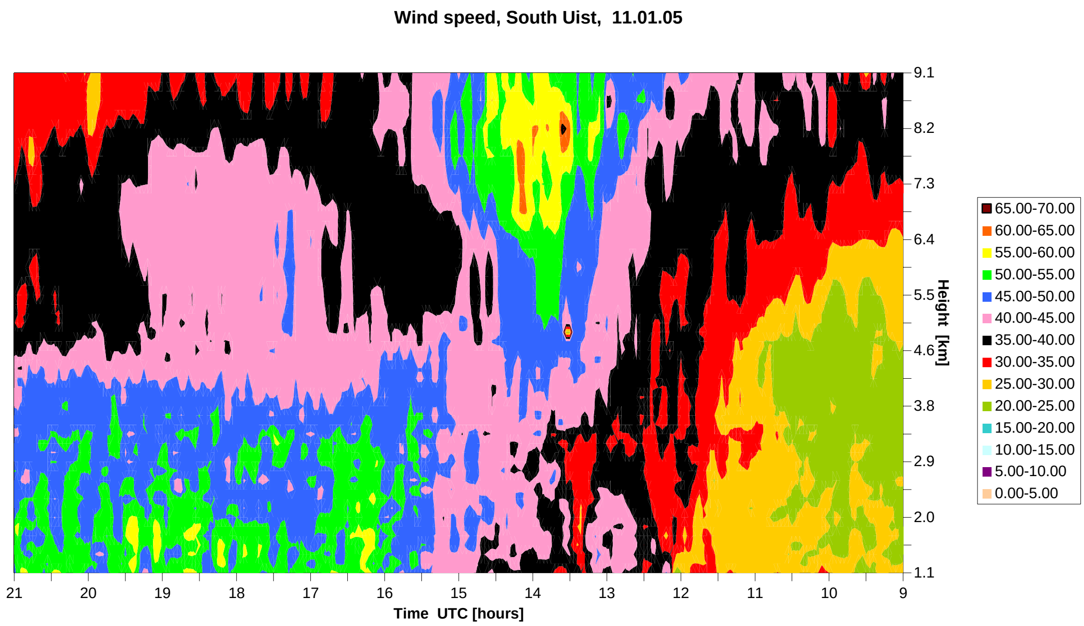

Figure 17 – South Uist Wind Speed (m/s) 11th January 2005 [contoured at 5m/s] Integrated from both high and low mode measurements.