Validation of a new signal processing scheme for the MST Radar at Aberystwyth

D. A. Hooper[1], J. Nash[2], T, Oakley[2], and M. Turp[2]

[1]Rutherford Appleton Laboratory, UK
[2]Met Office, UK

This extended abstract appears on **pages 311 - 315 of *Proceedings of the Eleventh International Workshop on Technical and Scientific Aspects of MST Radar*, edited by V. K. Anandan, published by Macmillan India Ltd., New Delhi, 2007.**

1. Introduction

The Aberystwyth MST radar operates according to the Doppler Beam Swinging principle. Horizontal winds are derived primarily from the observations made at 6° off-vertical (and in the vertical). Observations made at 4.2° and at 6° off-vertical are used to compensate for the effects of aspect sensitivity (e.g. *Thomas et al.*, 1997). The original signal processing scheme (v0) was gradually developed over the period 1990 - 2001. It is robust and produces wind-profile data of a sufficiently high quality for the UK Met Office to assimilate them for numerical weather prediction purposes. Two measures of the data quality (for the period February to June 2006) are shown by the green lines in Figure 1: the root mean square difference between the radar-derived and the Met Office's assimilation model wind components, and the average difference between the radar-derived and the model wind directions.

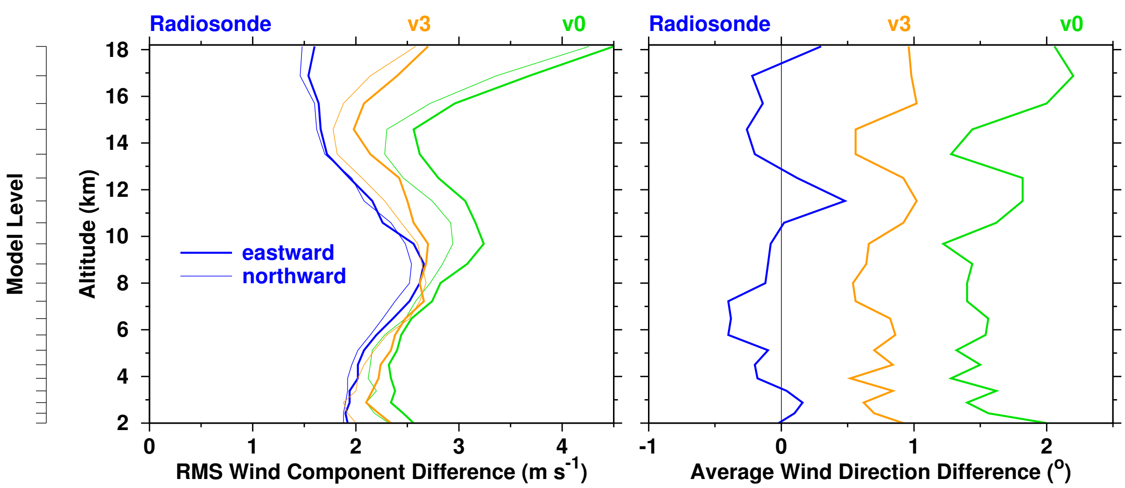

Figure 1: Profiles of (left panel) the root mean square differences between observed (from v0 and v3 MST Radar signal processing schemes, and from radiosondes) and Met Office model wind components and (right panel) the average differences between the observed and model wind directions.

These measures (which cover model levels 10 - 30, inclusively) should not be seen as indicating the errors in the radar data since the model is not a perfect frame of reference. Nevertheless it is the most important frame of reference so far as the Met Office is concerned and the one against which all observational data sets are checked. Those which do not have suitable quality characteristics are not assimilated. The blue lines in Figure 1 show the corresponding quality measures for radiosonde data relevant to the Aberystwyth area. Owing to the large distance between the radar site and the nearest radiosonde station, these quality measures relate to winds averaged from the nearest few radiosonde stations. This has been found to give a more representative comparison. The key feature of Figure 1 is that the quality measures are broadly comparable (up to an altitude of 14 km), suggesting that the v0 MST radar data and radiosonde data have roughly similar error characteristics. This is to be expected from the results of earlier validation campaigns; MST radar derived winds were compared directly with data from radiosondes launched 3 km from the radar site (e.g. *Thomas et al.*, 1997).

The v0 signal processing scheme is fundamentally restricted by a number of slightly inaccurate simplifying assumptions. Many of these are a legacy of the relatively limited computer processing power of the early 1990s when the scheme was first written. Consequently further improvements in data quality could only be achieved by rewriting the signal processing software from first principles. The Met Office took data from both schemes in parallel for a period of 12 months. Initially only data from the v0 scheme were being assimilated operationally. However, it soon became apparent that the new (v3) scheme was giving a measurable improvement in data quality at all altitudes, as indicated by the yellow profiles in Figure 1. Consequently the Met Office switched to v3 data for operational assimilation in August 2006. The improvements in data quality are largely a result of an improved understanding of the primary sources of unwanted signals: ground clutter, Rayleigh scatter from hydrometeors, and interference. The first two of these are specific to the radar's location: ground clutter is associated with strong low-level winds and both the low-level wind speed and the patterns of precipitation vary geographically.

2. Sources of unwanted signals

Ground clutter affects off-vertical beams and is characterised by signal components centred around zero Doppler velocity, as seen in the left panel of Figure 2. The desired clear-air radar return signal components are those with peak Power Spectral Densities (PSDs) in the Doppler velocity range +3 to +7 m s^{-1} (where a positive Doppler velocity implies motion away from the radar). This problem is confined to specific range gates, notably those just below 2 km, those around 3 km, those around 7 km, and sometimes those around 10 km. Occasionally the lower two range gate bands merge into a single broader band, as seen in this example. The ground clutter signal components are typically stronger (in terms of peak PSD) than the desired clear air signal components. Since the problem is associated with strong low-level winds, it can persist for anywhere between several hours and several days at a time.

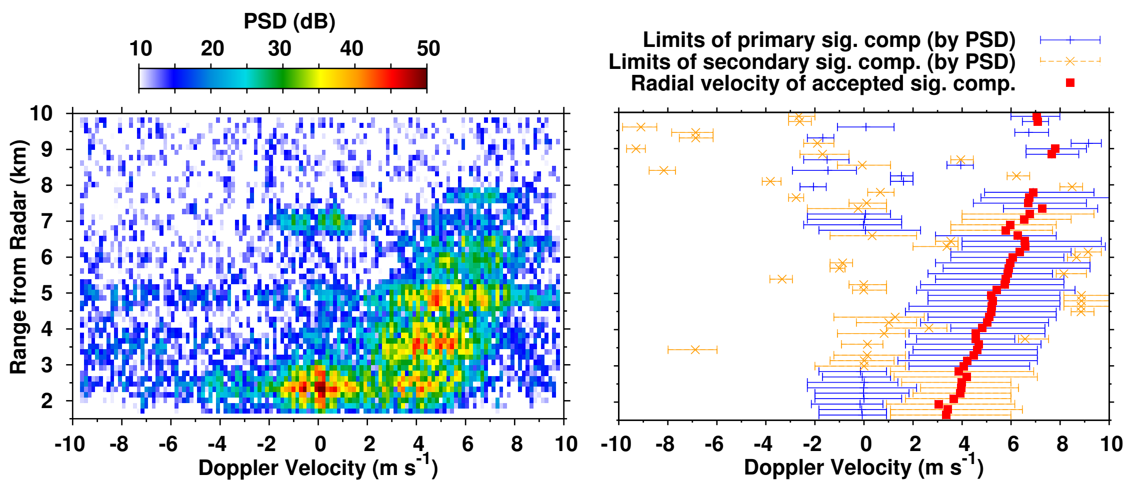

Figure 2: (left panel) Radar return spectra and (right) signal component limits for observations made by a SE6 beam at 07:06:56 UT on 18th January 2007 when ground clutter occurred.

Rayleigh scatter from hydrometeors, under stratiform precipitation conditions, affects all beams. As seen in the left panel of Figure 3, it is characterised by signal components with increasingly negative Doppler velocities with decreasing altitude below the °C isotherm (this can be located anywhere between the ground level and an altitude of 4 km at Aberystwyth). These signal components are sometimes, but not always, stronger than the desired clear air signal components. Stratiform precipitation is the most common type over Aberystwyth and it tends to persist for several hours at a time.

Interference can affect all beam directions. There appears to be more than one cause, though the primary one is thought to be related to an oscillation in there receive side of the radar system. It is characterised by signal components whose Doppler velocity limits and power change very little from one range gate to the next. These signal components tend to be stronger than the clear air signal components only at the higher range gates. The problem is sporadic and tends to persist for up to several hours at a time.

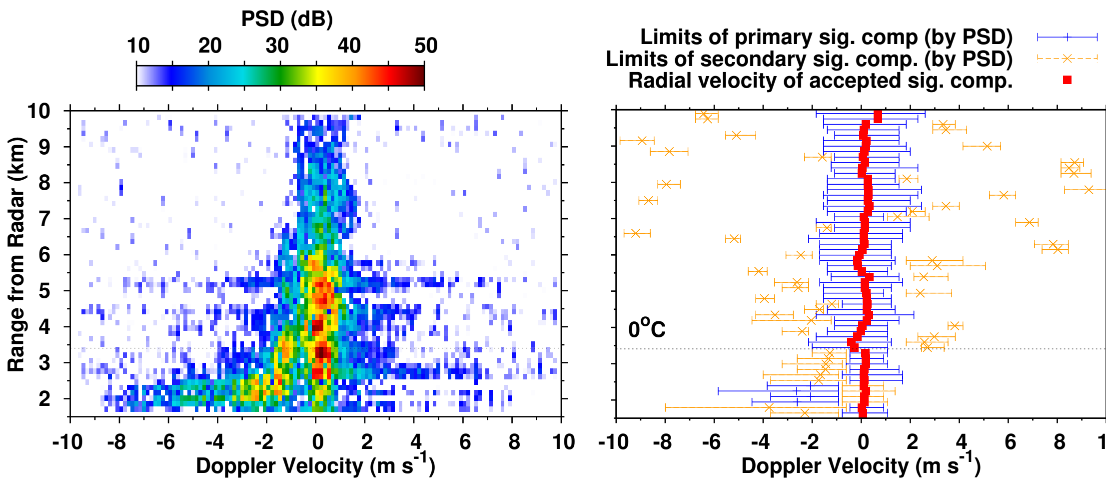

Figure 3: (left panel) Radar return spectra and (right) signal component limits for observations made by a vertical beam at 08:42:17 UT on 25th October 2006 when hydrometeor echoes occurred.

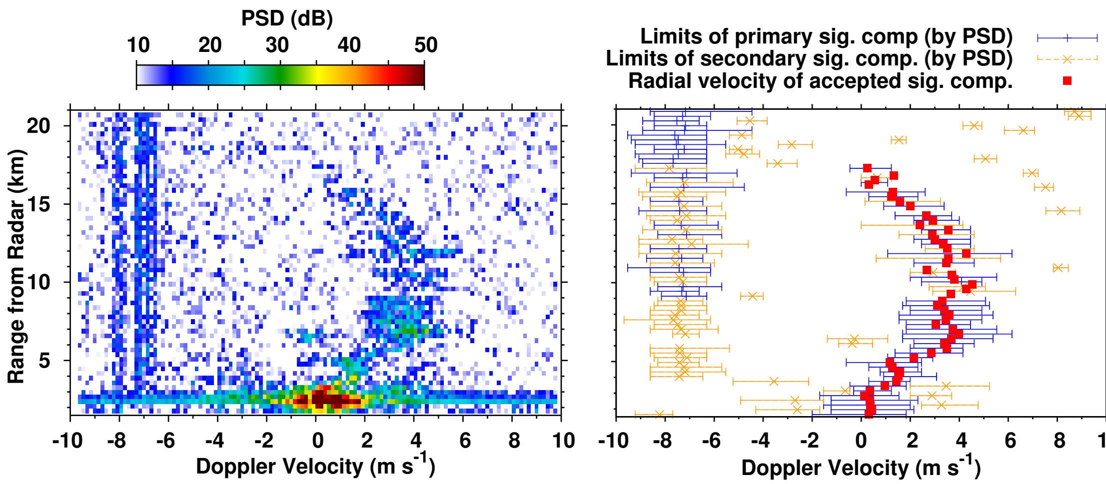

Figure 4: (left panel) Radar return spectra and (right) signal component limits for observations made by a vertical beam at 22:54:30 UT on 25th September 2006 when interference occurred.

3. How the different processing schemes deal with unwanted signal components

The v0 signal processing scheme identifies a single signal component within each radar return spectrum. Starting from the lowest range gate, it uses a radial-continuity algorithm in order to limit its search (in Doppler velocity space) for a signal component at the next range gate. Consequently the v0 scheme is effective at avoiding ground clutter signals, such as those seen at range gates around 7 km from the radar in Fig 2, and at avoiding interference contamination. A precursor to the v3 scheme (v2) also identified a single signal component within each radar return spectrum. However, it did not use a radial-continuity algorithm and simply selected the strongest signal component (by peak PSD). It relied on a time-continuity algorithm to subsequently reject those signal components which were deemed to be unreliable. However, since the characteristics of all three types of unwanted signal components tend to be quasi-constant over periods of several hours, the v2 wind-profile data were prone to contamination.

The v3 processing scheme is similar to the one described by *Griesser and Richner* (1998). It identifies two signal components within each radar return spectrum, the limits of which are shown in the right panels of Figures 2 - 4. The blue limits correspond to the signal components with the largest peak PSDs and the yellow limits correspond to the secondary signal components. A significant feature of the v3 scheme, which is not addressed by either the v0 or v2 schemes, is the ability to resolve partially overlapping signal components. At range gates below 3.0 km in Figure 2 and below 3.4 km in Figure 3, both the v0 and v2 schemes identified only a single, broad signal component at each range gate. Since these were acceptable to both radial and time continuity algorithms, the wind-profile data from both schemes suffered from contamination. After the v3 scheme has identified the two signal components within each radar return spectrum, a radial-continuity algorithm is applied in order to determine which of the two is most likely to belong to a clear air radar return profile. Since this algorithm does not assume that the desired profile begins at the lowest range gates (as in the case of v0 processing), it is necessary to check that the interference signal components have not been selected. Although they often shown greater radial continuity than clear air signals, they are distinguished by the constancy of their power. By contrast, clear air signal powers vary by many orders of magnitude over a profile.

The difference between v0 and v3 wind profile data quality is most marked at altitudes above 14 km. This has little to do with the ways in which the two schemes deal with interference (which is the only significant source of unwanted signal components at these altitudes). The tropopause above Aberystwyth occurs at altitudes of between 8 and 12 km and consequently the region above 14 km is characterised by a trend of decreasing signal power with increasing altitude. The signals are often close to the limit of detection. The v3 scheme makes use of a time-continuity algorithm for the individual wind components (the one used by the v0 scheme is very limited in its scope) and has a much more effective way of combining the radial wind components from the different beam pointing directions. Since observations are typically made at 6° off-vertical in 4 azimuths (each one separated from the next by 90°) a complementary beam comparison is made of the horizontal wind components. Those which differ by more than a set threshold are rejected. The v3 scheme leads to significantly greater altitude coverage. For the test period, wind-profile data were available for at least 80% of the time up to altitudes of 18 km. The v0 scheme could only provide this level of cover up to 17 km.

References

Griesser, T., and H. Richner, Multiple peak processing algorithm for identification of atmospheric signals in Doppler radar wind profiler spectra, *Meteorol. Zeitschrift*, *7*, 292–302, 1998.

Thomas, L., I. Astin, and R. M. Worthington, A statistical study of underestimates of wind speeds by VHF radar, *Ann. Geophys.*, *15*, 805–812, 1997.