Renovation of the Aberystwyth MST radar: Evaluation

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1 Introduction

During March 2011, the Natural Environment Research Council (NERC) MST Radar at Aberystwyth underwent its first major renovation in a 22 year lifetime. This principally consisted of a replacement of the Doppler Beam Swinging (DBS) phasing units. The design and installation of the new components was undertaken by the company ATRAD. As can be seen from the central panel of Figure 1, the renovation led to a remarkable 28% increase in the overall availability of horizontal wind data relative to pre-renovation levels. The quality of the data also appears to have improved. This extended abstract focuses on how geophysical considerations were used in order to evaluate the changes in radar performance.

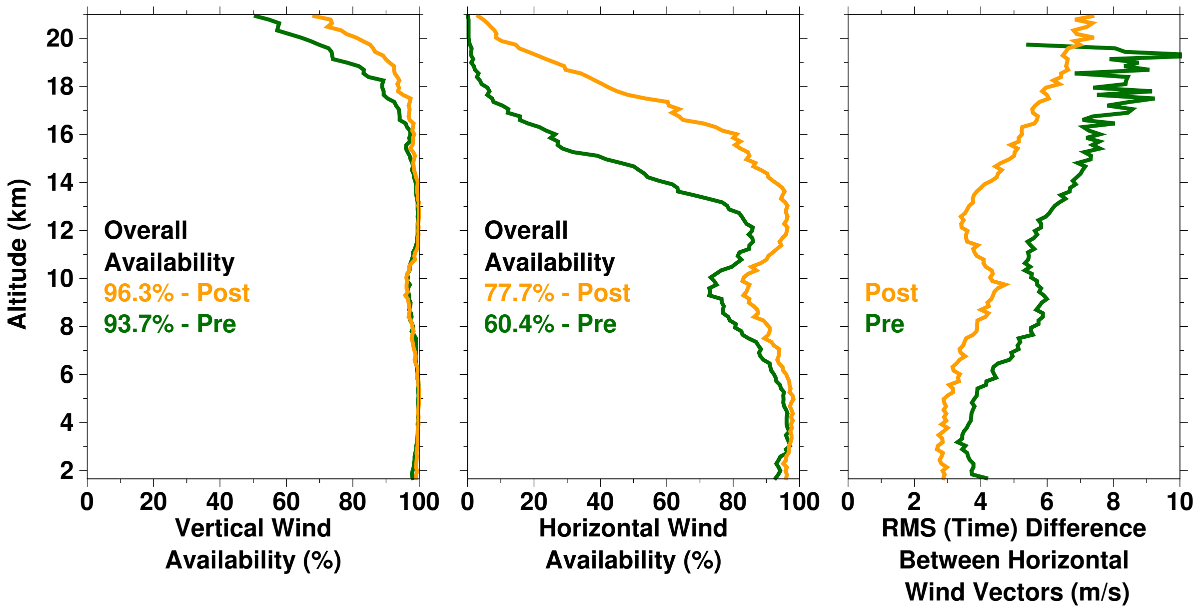

Figure 1: Statistical measures of radar performance for 18 days each of (green lines) pre-renovation observations (10th - 27th February 2011) and of (orange lines) post-renovation observations (18th March - 4th April 2011).

2 History of radar operations

For the first few years following its construction in 1989/1990, the radar was operated on a part-time basis. It would typically alternate between periods of use and non-use for up to a few days at a time. From 1992, special observations were made at six hourly intervals on behalf of the Met Office. If the radar was not already in use, it would be powered up specifically for this purpose. The frequency of special observations was increased to three hourly in late 1994.

The radar was operated continuously for the first two and a half months of 1997. Although it reverted to part-time operations for most of the rest of that year, it has been operated on a quasi-continuous basis ever since October 1997. By 2005, the useful altitude coverage for wind-profiling purposes was noticeably lower than it had been in the first years of operation. The situation became progressively worse until the time of the renovation in 2011. During these 22 years of operation, the radar's hardware had remained virtually unchanged.

A detailed inspection of the entire system was carried out during late 2008. This suggested that the poor state of the electro-mechanical relays, which are used in the DBS phasing units, was the primary reason for the reduced performance. The beam pointing direction is changed every 24 s, which results in approximately 1 million switching operations per year. The relays are therefore subject to continual but slow degradation, particularly through contact erosion. Examples of this can be seen in *Eastment et al.* [2010]. The original relays were repeatedly reconditioned rather than being replaced. Although this was initially effective, in some cases the erosion had become so bad that the relays had to be removed from active service.

Over the past decade the majority of observations have been made using a standard cycle of 12, principally st-mode, dwells. This takes approximately 5 minutes to complete and uses 6 of the 17 available beam pointing directions: NE6.0, Vertical, SW6.0, Vertical, SE6.0, Vertical, NW6.0, Vertical, W4.2, Vertical, m-mode Vertical, Vertical. The names represent the nominal azimuths and the zenith angles. The actual azimuth angle is 17.5° less than the nominal value, e.g. NE implies 27.5°.

In order to be able to validate the performance of the renovated radar, a special cycle of 24 dwells was used for just over 2 weeks prior to the renovation and for 6 weeks afterwards. This took approximately 10 minutes to complete and used all 17 available beam pointing directions: NE12.0, NE6.0, Vertical, SW6.0, SW12.0, Vertical, SE12.0, SE6.0, Vertical, NW6.0, NW12.0, Vertical, W8.5, W4.2, Vertical, E4.2, E8.5, Vertical, N8.5, N4.2, Vertical, S4.2, S8.5, m-mode Vertical.

3 Evaluating the performance of the renovated radar

It can be seen from the previous section that the validation cycle comprises of scans along each of the available azimuths at 5 consecutive zenith angles, including 0.0°. In this context, azimuth angles separated by 180° are considered to be equal and the difference is attributed to a change in the sign of the zenith angle. This sequence allowed an immediate check to be made of beam pointing direction self-consistency from an inspection of the Doppler shift profiles. As expected (but not shown here), consecutive profiles for each azimuth were qualitatively similar, albeit with the signs and magnitudes of the Doppler shifts changing as a function of the zenith angle. A quantitative measure of this self-consistency was also immediately available for the observations made at 6.0° off-vertical, i.e. the primary zenith angle used for wind-profiling purposes. The differences between the horizontal wind components derived from opposing beam pointing directions are used by the signal processing for quality control purposes [*Hooper et al.*, 2008]. The post-renovation values were similar to those for the pre-renovation period.

It was possible to demonstrate the consistency between pre- and post-renovation beam pointing directions using the spectral noise power. For each direction there is a distinct diurnal pattern, which follows the variations in lower-VHF cosmic emissions along a circle of constant declination [*Campistron et al.*, 2001]. This pattern is repeated once each sidereal day and so is seen approximately 4 minutes earlier on consecutive solar days. Figure 2 relates to observations made by the NE6.0 beam (declination +57.65°). These include an off-centre transit by Cassiopeia-A (declination +58.80°) at around 13:00 UT for the pre-renovation period and at around 11:30 UT for the post-renovation period. The radar beam has a one-way half-power half-width of 1.5°. It is noted that the amplitude of the transit feature is approximately 1 dB greater for the post-renovation period. There are also noticeable offsets between the two sets of lines at other times of the day. Although these differences are smaller than those between the patterns for different beam pointing directions, they suggest a slight change in the beam shape and/or pointing direction. It is likely that at least some of the original relays were no longer functioning. This would have caused the off-vertical beam pointing directions to be closer to the vertical than expected. This, in turn, would have led to horizontal wind speeds being slightly underestimated. However, as will be seen shortly, this appears to have been compensated, to some extent, by another effect. Surprisingly, the Met Office model-comparison statistics - see *“The usefulness of model-comparison statistics for wind-profiling radar operators* in these proceedings - suggest a negligible change in wind speed bias as a result of the renovation.

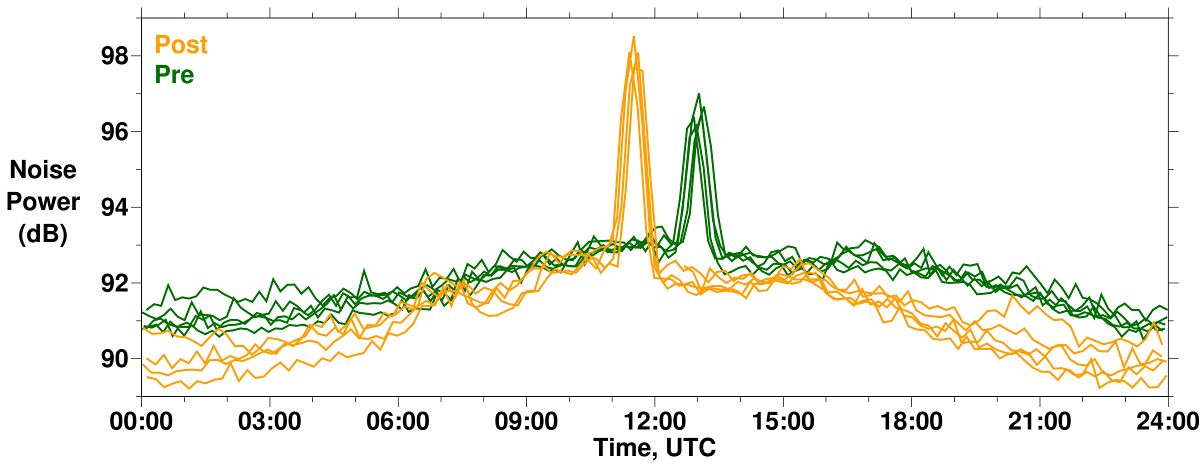

Figure 2: NE6.0 beam noise power, averaged over all range gates, for 5 consecutive days of (green lines) pre-renovation observations (23rd - 27th February 2011) and of (orange lines) post-renovation observations (17th - 21st March 2011).

None of the relays is activated in order to make observations in the Vertical direction. At least some of the relays must be activated for all other beam pointing directions. It can be seen from Figure 1 that the renovation led to a 28% increase in the overall availability of horizontal winds, relative to pre-renovation levels, but to only a 3% increase for vertical winds. This suggests that the original relays were attenuating signals, but primarily only when they were activated. There is further evidence for this in Figure 3, which shows two different measures of aspect sensitivity. The 6° off-vertical beam signal power decrease, relative to the Vertical beam, is expected [*Hooper and Thomas*, 1995] to be often (but not exclusively) close to 0 dB for tropospheric altitudes (lower left-hand panel). Although this is clearly the case for the post-renovation observations, it was rarely so during the pre-renovation period. The aspect sensitivity is expected to be generally larger for lower-stratospheric altitudes (top-left panel), but here too the pre-renovation distribution is significantly offset from the post-renovation one. These differences are consistent with the original relays causing 4 - 6 dB more attenuation for the 6° off-vertical beams than for the Vertical beam.

Aspect sensitivity causes the magnitude of the effective pointing zenith angle, θ_{eff}, for off-vertical beams to be slightly smaller than the nominal angle. This leads to the horizontal wind speed being slightly underestimated. However, a compensation factor can be applied through consideration of the θ_s parameter [*Hocking et al.*, 1986], which is determined from the ratio of signal powers observed at two zenith angles. This is routinely applied for observations made by the Aberystwyth MST radar using observations made at 4.2° and 6.0° off-vertical [*Hooper and Thomas*, 1995]. The right-hand panels of Figure 3 suggest that the wind speeds were being over-compensated by approximately 6% prior to the renovation. However, as mentioned previously, this effect appears to have been balanced by a slight reduction in off-vertical beam zenith angles.

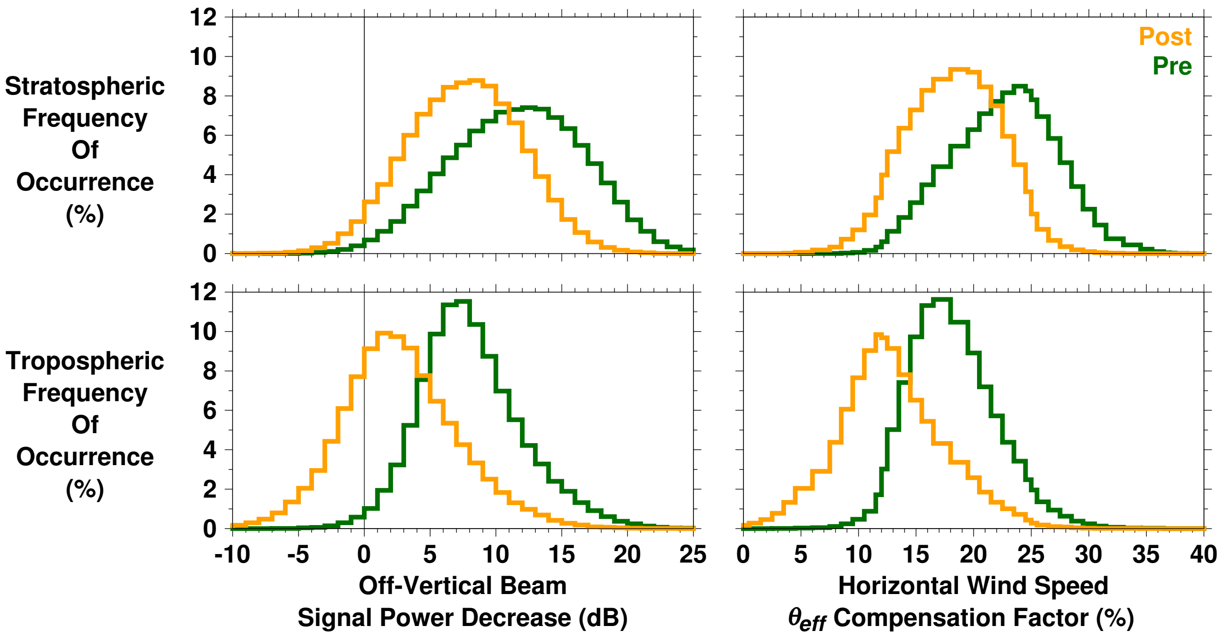

Figure 3: Two different measures of aspect sensitivity based on 18 days each of (green lines) pre-renovation observations (10th - 27th February 2011) and of (orange lines) post-renovation observations (18th March - 4th April 2011).

The root mean square (RMS) of the magnitude of the differences between adjacent horizontal wind vectors in time gives a combined measure of natural variability of the wind and of the random measurement errors [e.g. *Hooper et al.*, 2008]. The profiles shown in the right-hand panel of Figure 1 suggest that the random errors might indeed be smaller post-renovation.

4 Further work

It will be necessary to extend the RMS horizontal wind vector difference analysis over longer periods and pre- and post-renovation periods in order to encounter a wider range of atmospheric conditions. This will increase the confidence that the reduction in values does not represent a smaller range of natural variability during the post-renovation period. Moreover, the aspect sensitivity analysis needs to be extended over the entire observation archive in order to determine at what point the degradation of the original relays started to affect the quality of the data.

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