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AUTOMATED REAL-TIME MONITORING OF RADAR SENSITIVITY AND ANTENNA POINTING ACCURACY

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1. INTRODUCTION

Weather radar systems comprise complex hardware and software, which requires careful setting up and routine maintenance. Despite this attention, a number of faults can occur which have a detrimental effect on the accuracy of the reflectivity measurements. Some can be detected through routine maintenance, but others are difficult or impossible to identify such as loss of power in the waveguide, in the antenna or caused by the radome; sometimes errors are produced by the misalignment of the antenna. If undetected, these can result in intermittent or persistent degradation in the quality of radar data and radar-based products. It is therefore desirable that monitoring processes are established which cover all possible sources of error in the reflectivity measurement.

The weather radar network in the UK consists of 15 operational radars and the resources necessary to apply the established calibration methods regularly have never been available. Moreover, there is continued pressure to reduce radar network running costs whilst at the same time increasing data accuracy and availability. Other radar operating authorities are likely to be working under similar resource constraints. Established methods of checking weather radar sensitivity and pointing accuracy have been adapted so that they can run automatically at a central location and utilise the normal operational radar data output. These methods are now practical because the capacity of modern communications networks can support the transfer of raw polar-format data to a central analysis centre. The advantages of this approach are that many problems with the radar hardware can be detected quickly and cheaply, without the need for site visits or deployment of specialist radar engineers.

Establishing an accurate absolute end-to-end calibration of the radar system is extremely difficult and time consuming. Historically, the tracking of spheres carried by balloons has been used, but more recently, the use of mast-mounted transponders has also been proposed (Manz *et al.*, 2001), as well as a more operationally practical approach making use of ground fix clutter returns (e.g. Sempere-Torres *et al*, 2001). The basing of the latter is to remotely check automatically the radar sensitivity through monitoring of ground clutter targets within the operational data. It has the advantage to allow early indication of faults and initiation of remedial actions.

Several possible methods are available to check pointing accuracy. The Gematronik review of radar calibration methods (Manz *et al.*, 2001) suggested that most weather radars were aligned using of the sun. Typically, to check azimuth angle, the radar is taken offline and then set to execute partial PPI scans around the solar azimuth. The signal is recorded and the azimuth of either the position of the maximum or the –3dB points recorded. For elevation, the method is similar except the radar is made to execute RHI scans. Gematronik report that the accuracy that can be achieved by this method is 0.1 degrees, this being the typical resolution on the angle encoding. This idea of using the sun is very attractive, with the possibility to develop an on-line system to make the checks routinely. Also, the pointing can be checked at different azimuth and elevation angles, although obviously not across the full range of azimuth used in operational radar scans. This is in contrast to the use of a fixed mast-mounted target (e.g. a radar transponder) where the check is only possible in a single direction.

In section 2, the method of checking radar sensitivity is described in more detail. Some preliminary results from a feasibility study are described with some operational results. Section 3 is similar in content to section 2, but refers to the antenna pointing check. Finally, section 4 summarises the work and draws some conclusions.

2. SENSITIVITY MONITORING

2.1 Description of the technique

Almost all the clutter that is evident in weather radar operational scans can be ascribed to the radar beam being incident on facing ground slopes (Archibald, 2000). Ground and vegetation are likely to show variability in the radar return because of seasonal changes in vegetation or soil moisture. Fixed structures, such as masts and buildings, are therefore more likely to provide a steady signal where they are available. Clutter targets at short range are preferred because a long atmospheric path is likely to increase variability due to refractive index structure changes.

However, the radars in the UK network also have a minimum effective range of about 2km imposed by the waveguide switch (the T/R cell), which acts to stop the receiver being exposed to the transmitter pulse. Ideally, the target should produce a return in the upper half of the receiver range; because weaker signals are more likely to contain relatively larger contributions from other ground clutter within the same area, and will be subject to greater variation in rain. The target should extend well above the radar horizon in adjacent azimuth sectors and preferably into the main lobe of the radar beam in one or more scan elevations. This should provide a strong signal and make the target easily and unambiguously identifiable in the operational data.

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2.2 Return signal overall stability trial: - Chenies radar

Chenies radar is located at an altitude of 150m on the south-eastern edge of the Chiltern Hills. To the north and west of the radar, there are a number of nearby hills, which are of a similar altitude to that of the radar. A number of fixed structures are evident in the radar horizon diagram in this sector. A list of potential calibration targets was identified (Table 1) from a theodolite survey of these structures (Pilditch, 2000). The Venus Hill mast is a microwave communications tower of girder construction with four 'legs' tapering to a lattice structure (similar to an electricity pylon). The other three masts are similar girder constructions of uniform cross-section.

Table 1: Fix clutter target at Chenies use for radar sensitivity monitoring

Targets	Height (m)	Range (Km)	Azimuth (Degree)	Elevation (Degree)
Venus Hill Mast	65	2.29	339.5	1.6
Mast A	47	4.84	357.0	0.7
Mast B	43	4.67	356.1	0.6
Mast C	38	4.63	356.5	0.6
Chimney	24	3.88	346.6	0.4

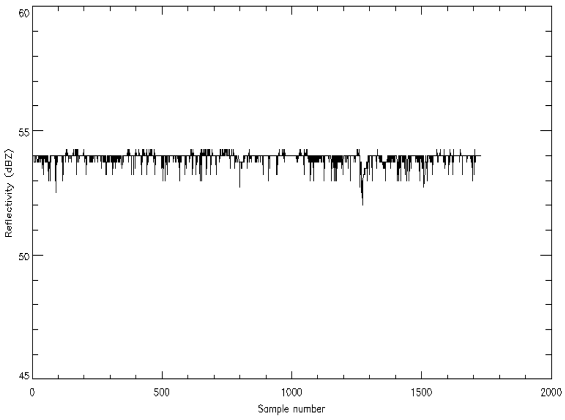
An example of data from the initial feasibility test is shown in Figure 1. For most of the time, the signal showed only small random fluctuations around 54 dBZ, but there were periods of a few hours when the signal was 1-10 dBZ below its normal level (not shown). These periods were coincident with prolonged periods of rainfall (light rain in this case). Some effect could be anticipated from attenuation by a wet radome, but another possibility is that when the target metal becomes wet, its backscatter cross-section is reduced. Time series for the other data collection periods are very similar and show remarkably stability in the signal. The mean and standard deviation of fitted Gaussian distributions are tabulated in Table 2 for the Venus Hill Mast.

Table 2: Venus Hill Mast - azimuth 340.0 - 340.9°, range 1.5-2.25 km.

Data collection period	1.5° elevation	
	Mean (dBZ)	Stdev (dB)
3	53.96	0.26
4	53.97	0.12
5	53.75	0.18

Both random variations within the data collection periods, and systematic differences between periods separated by a few months, were confined to a level, which is similar to the resolution of the data (0.25 dBZ). If this accurately reflects the overall stability of the radar hardware (and there is no reason to suppose it does not), then this may be interpreted as an uncertainty in the rainfall rate arising from imperfections in the end-to-end calibration of no more than 6%. This level of variation is far smaller than some other sources of error in the process of estimating rainfall rates from radar data (e.g. Z-R relationship variability).

Figure 1: Time series of reflectivity measurements – Venus Hill Mast (Period 4). 288 samples represent a 24 hours period.



2.3 Operational implementation of sensitivity monitoring

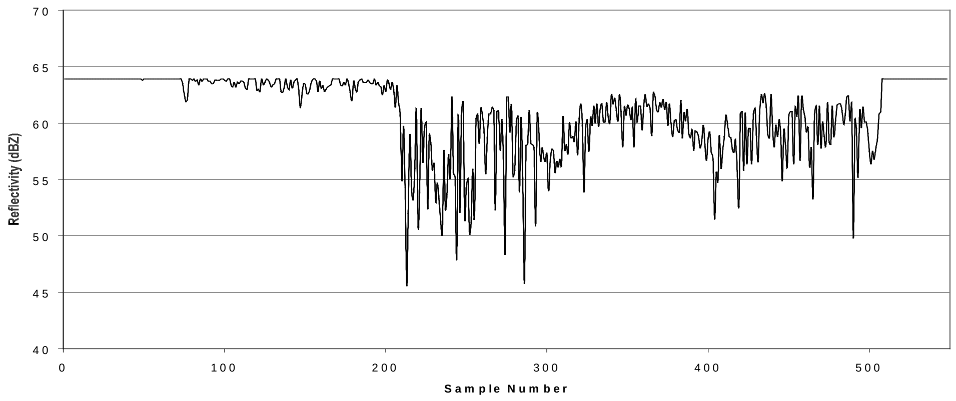
For each polar data file likely to contain suitable clutter targets (i.e. elevation below 2.0°), 24-hour accumulations of reflectivity and square reflectivity are performed for each range gate. These values are then used to derive average reflectivity and standard deviation at a polar resolution of 750m x 1°. Range gates with high reflectivity and low standard deviation have their unique "address", based on site number, beam number, ray number, and bin number, stored in a database, along with a count of the suitable events detected for that address. This database is used as a longer-term check of the stability of the automatically detected target. Based on the addresses and detection counts in the database, incoming files have the reflectivities of bins with a high percentage of detection counts extracted, stored and monitored. These stable values are then used to automatically trigger warnings and can be monitored visually as a time series of reflectivity values.

2.4 Warning of signal loosing sensitivity: - Castor Bay radar

Castor bay is located in Northern Ireland, on the edge of Lough Neagh, 50km south west of Belfast. At this site, clutter returns are mostly produced by the surrounding trees and by the power lines in the far distance. Around 30 fixed clutter targets are detected at Castor Bay, and are use to monitor the return power stability.

From time to time, radar sites have been known to suffer from malfunction of the waveguide dryer. If this occurs in winter (i.e. cold weather), water vapour may condense in the waveguide resulting in loss of return signal sensitive and stability, as was observed at Castor Bay on 19th December 2002 (Figure 2**)**. This loss of sensitivity was detected by all monitored clutter targets, and enabled immediate remedial actions to be taken.

Figure 2: Time series of reflectivity values from Castor bay showing the loss in sensitivity due to water in the waveguide. 288 samples represent a 24 hours period.



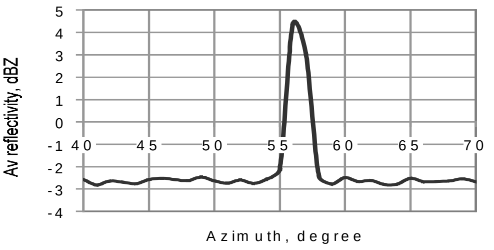
3. ANTENNA POINTING MONITORING

3. 1 Description of the technique

The sun subtends an angle of about 0.5 degrees at the earth’s surface, and the half-power width of the radar beam is about 1.0 degrees. Therefore, the sun appears as a target of finite angular width and careful analysis is required to obtain optimum accuracy. The effect of atmospheric refraction is a serious problem, requiring corrections to be applied. At very low solar elevations (<1.0 degrees), the correction can be up to about 0.6 degrees in elevation and varies significantly with the profiles of pressure, temperature and humidity. The magnitude and the uncertainty in the correction for refraction decreases rapidly with elevation angle. Thus, most accurate measurements of the radar elevation angle may be made at high elevation i.e. greater than 15° (Duffet-Smith, 1988). On the UK network, the highest elevation scanned operationally is at 4.0° is not significantly high to apply with confidence textbook correction for refraction. Thus for the purpose of this experiments, the alignment of the antenna in height will not be studying, and only the alignment along the azimuth will be investigated using the sun.

The data employed in this study are unprocessed polar data at 750m x 1° resolution, and only the basic $^{1}/_{R^{2}}$ correction has been applied. The data are available in real-time from operational radar scans. The method was developed on-line, and did not interfere with the operational use of the radar. To avoid contamination from ground clutter or precipitation, only data beyond 225km range and at elevation greater than 2° were processed. The average reflectivity (in dBZ) along each ray was computed and the plotted against azimuth within a 30 degree sector around the expected solar azimuth at sunrise and sunset. An example of one of these plots is shown in Figure 3.

Figure 3: An example of the average reflectivity at ranges between 225 and 255 km as a function of azimuth. The data were recorded at 4.0° elevation by the Wardon Hill radar at 0427UTC, 30th May 2003.



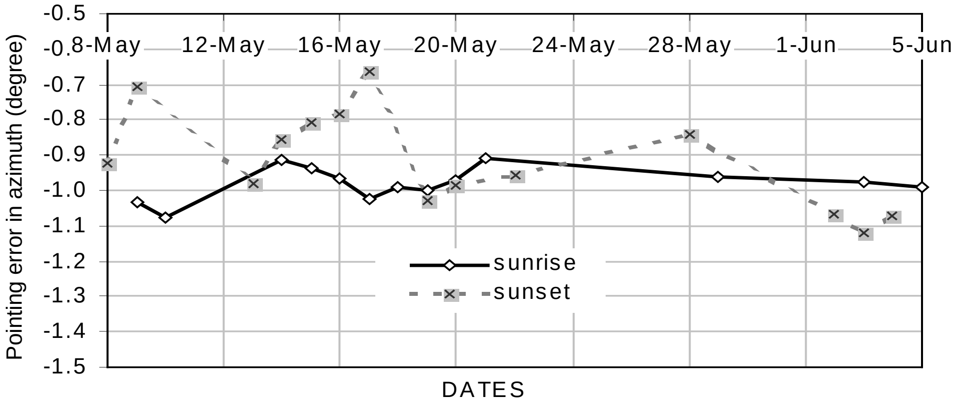
For those scans in which a signal from the sun can be discerned and are not contaminated with rainfall, a polynomial curve was fitted to the data. The curve fitting provided an estimate of the peak amplitude (in dBZ) and the azimuth of the peak signal to 0.1° precision. The scan start time and initial azimuth are recorded in data headers and all the PC’s controlling the radars have their time synchronised to a central accurate time server. It is therefore possible to assign a time to the radar antenna position to ± 1 second.

A program was written to compute the sun position, based upon equations by Schlyter. The accuracy of the routine stated by the author is 0.03 degrees. To ensure that the equations had been coded correctly, the results from the program were checked against sample calculations given by Schlyter and the results from another, simpler, solar position routine obtained from the Met. Research Flight, Farnborough. Results from the comparison with the MRF routine are shown in Table 3. The differences between the two schemes were found to be always less than 0.1° and in most cases less than 0.03°. It was therefore assumed that the Schlyter routine was working as designed.

Table 3: Comparison of solar position calculations

Date	Time (UTC)	Azimuth (degrees)			Elevation (degrees)		
		Schlyter	MRF	Difference	Schlyter	MRF	Difference
21/6/00	0400	50.738	50.725	0.013	1.108	1.099	0.009
21/6/00	2000	305.426	305.441	-0.015	2.084	2.076	0.006
21/9/00	0600	89.446	89.520	-0.074	1.196	1.128	0.012
21/9/00	1800	270.065	270.102	-0.037	-0.483	-0.391	-0.092
21/12/00	0800	126.144	126.124	0.020	-1.626	-1.638	0.012
21/12/00	1600	231.397	231.409	-0.012	-1.525	-1.532	0.007

Figure 4: Sun based azimuth error. The average pointing error is –1.0° with a standard deviation of 0.1° over one month.



3.2 Operation implementation of antenna pointing

For times at which it is known that a sunrise or sunset event could be observed, the raw polar data files are scanned, as part of the central processing chain, for events matching the criteria mentioned above. When an event is detected, the time at which the azimuth with maximum solar intensity was sampled is determined and the position of the sun at that time calculated. Following a conversion from true to grid north the difference can be measured. When enough events have been recorded to give an accurate estimate of any pointing error, the data is corrected by adjusting the azimuth values recorded in the data headers for each ray.

3.3 Case study: - Preliminary results from Chenies radar

Preliminary results from the sun based azimuth calibration code are very encouraging. Results from 8th May to 5th June for Chenies radar are shown in Figure 4. The variations seen at the start of the sunset data are thought to be due to interference from another radar operating in the sector where the sunset is seen. Towards the end of the month the month this interference was no longer seen and more stable results were obtained.

4. CONCLUSIONS

Automatic detection of candidates to act as stable clutter targets has been shown to be possible using accumulations of reflectivities, those reflectivities squared and a detection count. With this and using longer-term statistics, selected targets can be observed and the long and short-term stability of radar hardware monitored. Although this method does show some promise it has failed to detect stable clutter targets at one site, with one other site showing very few stable targets. Whether this is due to a lack of suitable clutter, a problem with the technique or due to some other problem, is currently under investigation. It is hoped that with more time and experience of the behaviour of these targets it will prove possible to give more information about the type of problem causing the signal variation.

We have shown that it is possible to develop a means of pointing calibration that can be run operationally, without interrupting the normal scanning cycle of the radars, using the sun as a known target. It should be noted that further verification of this technique is required, and it is hoped that in the near future it will be possible to visit a site with a pointing error and a direct measurement be made. Furthermore, we now recognise the need to have stricter criteria for determining that it is indeed that sun that has been seen and it is hoped that with additional checks in place the accuracy of this method can be improved.

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