Proceedings of ERAD (2004): 330–334 © Copernicus GmbH 2004

ERAD 2004

The influence of vertical effects on the intercomparison of weather radars

N. R. Donaldson[1] **and A. Huuskonen**[2]

[1]Cloud Physics Research and Severe Weather Research Div, Meteorological Service of Canada, Downsview, Ontario, Canada
[2]Finnish Meteorological Institute, Helsinki, Finland

Abstract. This paper discusses the impact of vertical variation of reflectivity on radar intercomparisons. Such intercomparisons are useful for monitoring the calibration of radars in a network, but can be biased by elevation pointing errors and smoothing of the reflectivity profile over the antenna beamwidth. The paper presents some simulations of these factors, focussing on their impact on the technique of Huuskonen (2001, 2002).

1 Introduction

In weather radar networks, monitoring the calibration of the radars is important for their proper scientific application. Many methods have been developed to establish the proper calibration of the individual radars, including such methods as solar calibration, and using known targets suspended from balloons or kites. Less directly, radar estimates of surface rainrates can be compared to estimates from rain gauges. Techniques for establishing calibration are fairly difficult to do properly, so it is also desirable to find techniques to monitor whether the calibration is likely to be changing. Under suitable conditions monitoring of individual radars can be done by examining time series of measurements from fixed ground targets. Finally, measurements from neighbouring radars can be intercompared to monitor relative calibration. The reader is referred to Manz (2001) and the American Meteorological Soc. (2001) Radar Calibration Workshop for more extensive presentations on radar calibration.

Radar users typically expect two radars pointing at the same location to report the same thing, in the absence of effects like attenuation, but differences can occur for both legitimate and erroneous geometric reasons. The schematic in Fig. 1 shows some potential sources of difference. The most obvious source of difference is miscalibration of the radars. Another source of differences is incorrect pointing in elevation. In Fig. 1, one radar is pointing lower than its antenna is reporting, into the bright band, and it would report much higher values than the value at the nominal height. A legitimate source of differences is due to differing antenna beam sizes, arising from either different radar ranges or different antenna sizes. In Fig. 1 the large beam is shown to include a portion of the bright band and it would report values significantly above the point value at the nominal height. A narrow beam should report a value reasonably close to the point value at the nominal height.

It is important to try to separate differences due to electronic calibration and pointing errors. If two radars are brought to relative calibration by applying an adjustment to the electronic calibration, while ignoring elevation pointing bias, then the elevation errors will can still add a considerable variance to the intercomparison. Furthermore, unidentified pointing errors can play havoc with products like echo-top-height and algorithms correcting for the vertical reflectivity profile (VRP). Such problems can be quite pronounced at middle and high lattitudes.

This paper will address the influence of vertical variations of reflectivity on the intercomparison of weather radars, focussing most closely on the technique of Huuskonen (2001, 2002) and others at FMI. For compactness that technique will be referred to as the “Finnish technique”.

2 An Illustration from Canada

Before turning to the Finnish technique for isolating the calibration and elevation pointing, an illustration of the issues will be given with some data from two radars in Ontario, in southern Canada. These two volume-scanning radars are located only 158 km apart and both have 0.65° beamwidths, so intercomparing them should be relatively easy. This particular pair of radars is expected to have a known difference in reported reflectivities. King City Radar (WKR) is a research radar that has been compared to rain gauges over many years. The gauge comparisons resulted in a 5 dB adjustment over

Correspondence to: N. R. Donaldson
(norman.donaldson@ec.gc.ca)

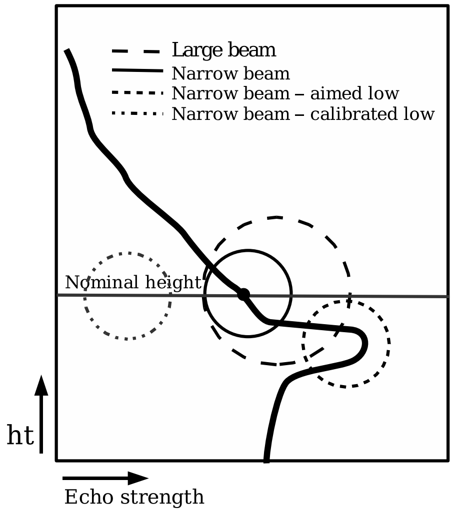

Fig. 1. Differing radar measurements for the same nominal height from the same profile of reflectivity. Reported values would be the reflectivity at the circle centres. The vertical extent of each circle indicates the height averaged.

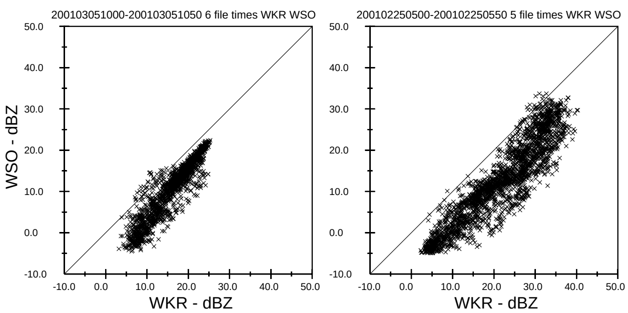

Fig. 2. Scatterplot of observations reported by WKR and WSO radars for common points along their midline on 2001-03-05 (left) and 2002-05-10 (right).

the WKR electronic calibration. No gauge adjustment has been made to the electronic calibration at Exeter (WSO).

Figure 2 shows scatter diagrams of collocated reflectivity measurements made along the mid-line between these two radars on two different dates. The two radars have synchronous volume scanning using the same nominal elevations and the antenna heights only differ by 60 m, so they should be very close to looking at the same heights at the same times. The data extraction technique uses the readback elevations rather than the requested angles, since these are known to differ on occasion. The reported beam heights must be within 100 m to be accepted. In addition, the extraction routine attempts to estimate attenuation due to precipitation between the radars and the mid-line and rejects data where attenuation exceeds 3 dB.

Scatterplots of data from WKR and WSO would be expected to lie on a straight line offset from the diagnonal by 5 dB. Figure 2a approximates this expectation, with a fairly narrow scatter along a line. Figure 2b is less close to meeting the expectation, with a lot more scatter.

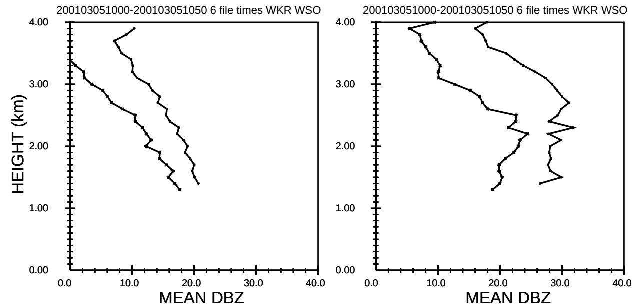

Fig. 3. Profile built at common points along midline between WKR ans WSO radars. 2002-05-10 (right) and 2001-03-05 (left).

Figure 3 shows the same data as Fig. 2, but the data have been used to build averaged profiles over the data collection periods. The profile in Fig. 3a is for snow, with no distinct profile features. Differences between those profiles could be resolved with offsets in either height or calibration. The data in Fig. 3b contains a bright band and offsets in both height and calibration are required to minimize differences. Furthermore its clear that mismatches of heights results in some of the large variance seen in Fig. 2b.

Profiles like the ones shown have been used in the past to examine pointing and calibration problems with Canadian radars. Unfortunately this techniques has the conflicting requirements that the averaging period be long enough that noise is reduced and that the profile be collected from an unchanging profile. The Finnish technique has the advantage of estimating errors first and averaging second.

3 Finnish Technique

3.1 Overview

The Finnish technique attempts to separate effects of pointing and calibration error from VRP effects at each comparison time. The resulting estimates of pointing and calibration differences can be combined into larger samples that give better estimates than the single time estimates.

3.2 Without beam smoothing

The idea behind the technique is to find pairs of locations that are similarly sampled. Under the assumption that the VRP's have the same shape at each location a calibation difference can be calculated that is independent of the VRP. Consider Fig. 4. In this figure two radars are sampling over two locations at the same heights, h_1 and h_2, in an opposing sense. The reflectivity measurements (in logarithmic units) are a and b from the first radar and A and B from the second. Assume that the true reflectivites at the lower height are x and y, and that the change in the VRP between the two heights is $\Delta(h_1, h_2)$. Finally, assume that radar 2 has a multiplicative calibration error, giving a logarithmic offset of E. With these assumptions the following equations for the reflectivities seen at the beam centres may be written:

$$a = x \quad (1)$$

$$A = x + \Delta + E \quad (2)$$

$$b = y + \Delta \quad (3)$$

$$B = y + E \quad (4)$$

If we define the factor D to be

$$D \equiv (A - a + B - b)/2 \quad (5)$$

it can be seen that $D = E$ under the assumptions above. Many estimates of D can be made from a PPI, or a volume scan of PPI's, by using different locations pairs. If there are errors in the assumptions, including the implicit one that the antennas are in fact pointed at heights h_1 and h_2, then bias and variance can be introduced into the population of estimates of D.

The contribution to the variance D due to elevation pointing differences should be eliminated if the appropriate elevation offset correction were applied to one of the radars. Applying such an offset should not systematically change the variance due to other factors, so the correct elevation offset should minimize the variance of the estimates D. The Finnish technique is to calculate factor D and its variance from the data for a range of elevation offsets applied to the first radar. If a trial offset results in a distinct minimum of the variance of D, the corresponding mean value of D is assumed to be actual calibration difference between the two radars, E. As an aside, in this process the pairs of points to be cross-compared will change as the elevation offsets change, so the contribution to variance from other factors in the real world may not be held constant for a particular set of measurements.

The Finnish technique recovers the relative difference between any elevation errors for the two radars. If both radars had the same error, no relative offset would be reported. A labour intensive approach to determining absolute elevation errors is to find days in which a bright band is expected to be at a constant height over a wide area. Adjustments to elevation angles may be added to ensure the bright band appears approximately level in RHI-type displays. This has been done on some suitable occasions and it is reassuring that the difference between absolute elevation offsets for neighbour radars does match the value retrieved from the Finnish technique.

3.3 Antenna beam smoothing

Equations 1-4 are useful for illustrating the underlying idea, but the effect of vertical smoothing must be also considered. Most particularly, as suggested by Fig. 1, differing radar beam widths produce a source of difference between radar measurements and may confuse the intercomparison process. With different beamwidths, the vertical reflectivity profile *as measured* by the two radars is in fact different. Rather than a single profile factor Δ in the equations above, the effective

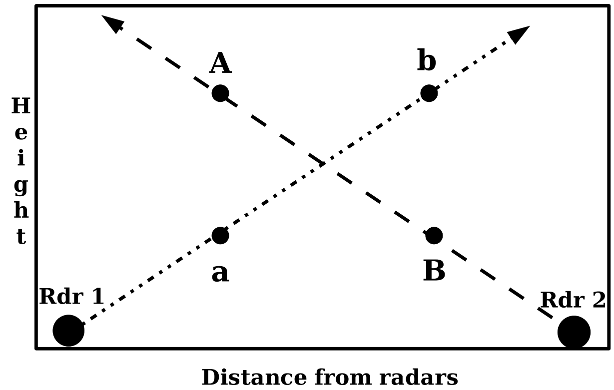

Fig. 4. Geometry of Finnish technique. Two measurements are made on a PPI for each radar. (a,b) are values measured by Radar 1 and (A,B) are values measured by Radar 2.

values of Δ will differ for A and b. D and E will now differ somewhat.

The degree to which beam smoothing affects the Finnish technique depends on the details of the antenna patterns, the range of the radars from each other and the specific VRP. The simplest way to assess these factors is to apply the Finnish technique to simulations of radar observations for different situations.

4 Simulations of the Finnish Technique

If one assumes a VRP, $f_A(h)$, then the reflectivity values are given by equations like this one for a:

$$a = \log \int_{-\delta e}^{+\delta e} f_A(h(\theta_1 + \delta\theta + e, r_{1a}, h_1)) B_1(e) de$$

where e is elevation difference from the antenna axis elevation angle, θ_1, $B_1(e)$ is the horizontally averaged antenna gain, r_{1a} is the range from radar 1. A potential elevation $\delta\theta$, is included. Radar data is assumed to be collected on a single PPI. In the simulations date from one radar has imposed elevation and calibration errors, which the technique should recover as opposite offsets to the other radar. These equations for the reflectivities can be substituted into Eq. (5) to get a very complex formula for D for finite beamwidths. That expression includes E plus a number of partially compensating integral expressions.

For the simulations presented here a single profile type is assumed, with constant reflectivity at the bottom (rain) a rectangular peak (bright band) and an exponential decrease at the top. The height of the bright band can be raised or lowered so the simulated radar data could be collected near the bright band or restricted to only the snow or rain regimes. Simulations were done with antenna beamwidths of 0.6° and 1.1°, as used in the Canadian weather network.

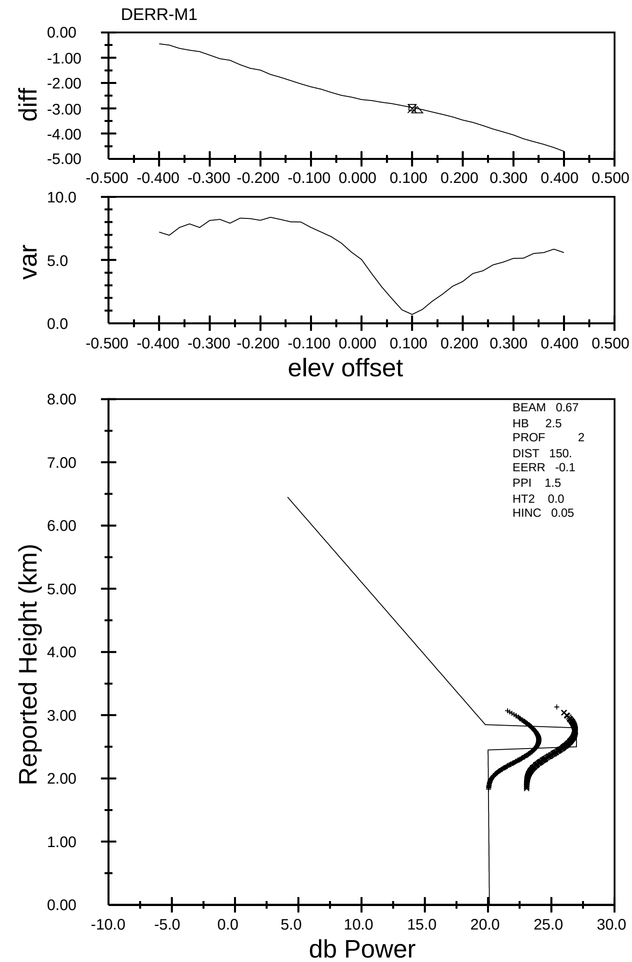

Fig. 5. Sample simulation results. Bottom, input VRP and the radar measured VRP's. Middle, variance in D as function of assumed elevation offset. Top, D as function of assumed elevation offset. Nearly overplotted, an "X" indicates "true" value of the imposed values of D and offset elevation and a rectangle indicates the retrieval. (A triangle marks result of a linearized version of the method that is not discussed.)

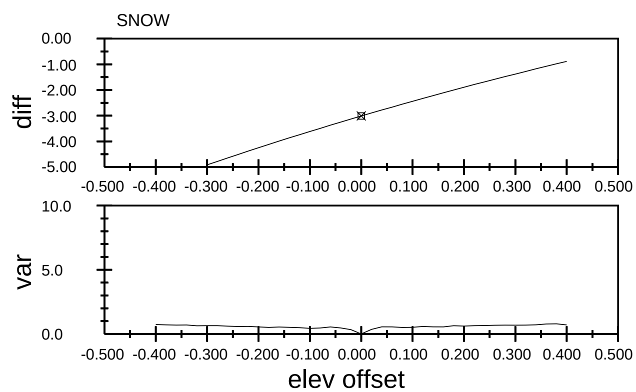

Fig. 6. Simulation results in snow. Bottom, variance in D as function of assumed elevation offset. Top, D as function of assumed elevation offset.

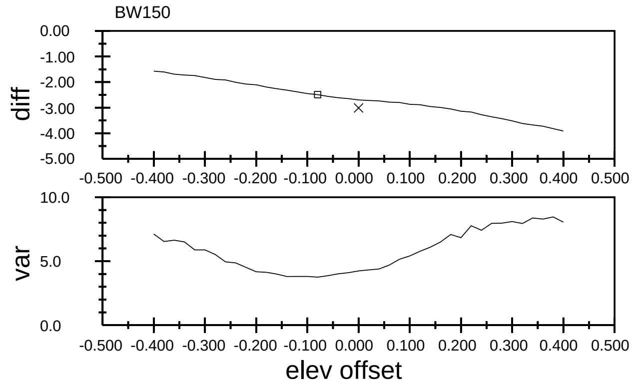

Fig. 7. Simulation results for beams of different sizes . Bottom, variance in D as function of assumed elevation offset. Top, D as function of assumed elevation offset. "X" indicates "true" value and rectangle indicates the retrieval.

5 Results

Figure 5 shows the output of a simulation for two radars sampling near a bright band. The imposed elevation and calibration errors were $-0.1°$ and 3 dB. The variance of the trial offset can be seen to have a distinct minimum at $0.1°$, and the corresponding calibration offset is -3 dB. This is how the Finnish technique hoped to work.

Experiments with increasing the range between the radars showed two important things. The minimum in the variance of D becomes less distinct, because the bright band becomes smoother and less strong. As a result, other real-world sources of variance would increasingly disguise the desired minimum. The other point seen in the simulations is that the bright band needs to be increasingly high to be in the common volume of the radars. At high latitudes, radars with large separations may only rarely have adequate data to analyze. The implemented versions of the Finnish technique attempt to verify that any detected minimum is distinct, so it is hoped that it will not return results when the situation becomes too bad.

Experiments with constant rain profiles show that the variance in D changes exceedingly little with the trial elevation offsets. In reality, no variance is expected, but slight variations in the sampling geometry produce residual changes. On the other hand, because the rain profile has very little vertical variation, the retrieved value of D is more or less the same for all offsets. In rain the Finnish technique should retrieve the proper value of D, but the value of elevation offset is probably suspect. In this situation the Finnish technique behaves essentially the same as simple radar intercomparison with no consideration of vertical effects. (Some trials were also done with weak variation of the VRP in the rain regimes, and the results were essentially the same.) Where radar intercomparisons are done entirely in rain, elaborate intercomparison techniques are less necessary. These are also situations where knowing a vertical profile correction for surface precipitation is of lesser importance.

Experiments with snow profiles show that the variance in D is only weakly dependent on the applied pointing offsets, as shown in Fig. 6. Despite the lack of change in the variance, changing the assumed elevation offset does change the retrieved calibration difference. This indicates that the Finnish technique performance will be prone to errors when data is collected in snow. In reality, snow profiles are not as smooth as the idealized profile and in some situations enough structure exists to guide the Finnish technique.

Simulations with radars with differing antenna sizes produced biased results. Figure 7 shows the results for radars lying 150 km apart, with beamwidths of 0.67° and 1.1°. There is no imposed elevation error but the retrieval indicates an optimal offset of almost 0.1°. This offset is the one that makes the least RMS difference between the smoothed VRP's from the two different radars. The minimum in this case is less distinct than for similar beams, but could still be reported by the technique.

Simulations with large angle differences show that the technique returns a slightly biased value of D and the elevation error. For example with an imposed difference of 0.2°, the simulation returned 0.18°. The reason for this is somewhat unclear, but seems to arise from nonlinearities in the equations for height.

In general, the simulation results are consistent with the output of the Finnish technique for radars in NORDRAD and the Canadian meteorological radar network. In practice the technique is been seen to work well in some situations and but not in others, and the simulations have provided a useful framework for understanding the technique's behaviour. The caution about radars of different beam sizes is significant in Canada, where there is almost an alternation across the network between radars with new large antennas and radars with older small antennas.

Acknowledgements. The first author is funded by the MSC Meteorological Research Branch, as a contribution to the National Radar Program, and the Canadian Weather Research Program.

References

American Meteorological Society: Radar Calibration and Validation Workshop, Albuquerque, N.M., Available on CDROM or the AMS web site, American Meteor. Soc., Boston, 2001.

Huuskonen, A.: A method for monitoring the calibration and pointing accuracy of radar network, in Proc. 30th International Conference of Radar Meteorology, Munich, Germany 19–24 July 2001, AMS pp 29–31, 2001.

Huuskonen, A.: Monitoring the calibration level of a radar network by using reflectivity data, in Proceedings 2nd European Conference on Radar Meteorology (ERAD), 18–22 November 2002, Delft, Netherlands, Copernicus GmbH, 2002.

Manz A., Smith, A. H., and Hardaker, P. J.: Comparison of different methods of end to end calibration of the UK Weather Radar Network, in Proc 30th International Conference of Radar Meteorology, Munich, Germany 19–24 July 2001, AMS, Boston, 2001.