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A METHOD FOR MONITORING THE CALIBRATION AND POINTING ACCURACY OF A RADAR NETWORK

Asko J. Huuskonen *
Finnish Meteorological Institute, Helsinki, Finland

1. INTRODUCTION

A uniform calibration and well known collection angles become increasingly valuable when radar network data are combined to form composite pictures. The calibration can be monitored in various ways; one of the most often used methods is to analyze the rainfall accumulation data. These checks, however, are often qualitative in nature, although data allows for a numerical analysis of the calibration and pointing accuracy.

In this paper we will describe a new method which gives the calibration difference of two radars, and also the difference in their collection angles. The method uses radar data measured within the common field-of-view of the radars. The vertical reflectivity profile need not be known in the method, but one has to assume that the cumulative rainfall is uniform over the area. We will describe the method is detail and present some first results on a selected radar pair. It is expected that in the future the method can be used as an operational tool to check the calibration and angular pointing accuracy of radar networks. The present work has been done within the framework of the NORDRAD Quality Assurance project. The NORDRAD network is operated within Finland, Sweden and Norway.

2. QUALITATIVE ANALYSIS

The analysis is based on Pseudo-CAPPI pictures for 500 m altitude, produced at every 15 minutes at every radar of the NORDRAD network. The data used in the analysis is a projection on a 2×2 km grid. As points below 1 km in altitude are not used, the analysis is in fact based on the PPI data from the lowest collection angle of the volume scan.

For the analysis a period of several rainy days is selected. A typical length varies from 5 to 20 days. Lengthy periods are needed because it is essential that the rain is uniform over the analysis region. The analysis region covers the common field-of-view of the radars.

*Corresponding author address: Asko Huuskonen, Finnish Meteorological Institute, Observational Services, Sahaajankatu 20 E, 00810 Helsinki, Finland. E-mail: Asko.Huuskonen@fmi.fi

The data processing preceding the analysis is done in two steps. Firstly, the data are averaged over the analysis period. In the averaging process the data are screened against a threshold value, which data from both radars must exceed for the data to be accepted. Both mean and median values are used to represent the average. Finally the data from the two radars are subtracted from each other. These difference data are the starting point for the analysis of elevation angle and calibration differences of the radars. An example of such data is shown in Fig. 1.

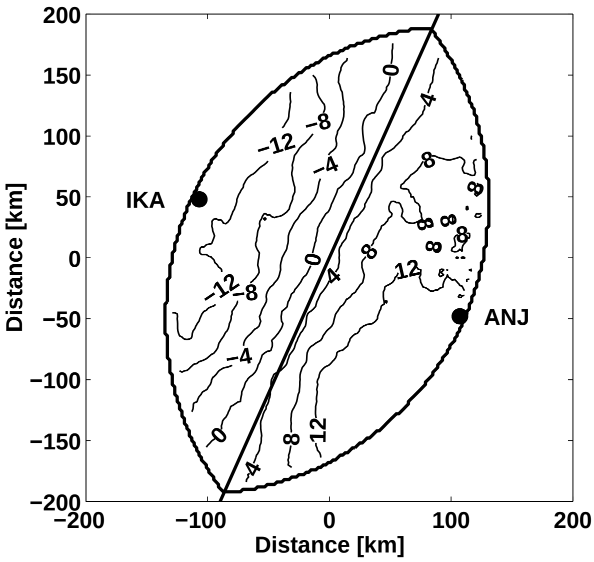

Figure 1: Difference of reflectivity between the Anjalankoski (ANJ, 60°54' N, 27°6' E) and Ikaalinen (IKA, 61°34' N, 23°4' E) radars. Contours of constant difference are given in steps of 4 dB. The radar locations are shown by black dots and the thick line connects points equally far from both radars.

Based on the appearance of the difference data, we may readily make some qualitative remarks about the collection angles and the calibration difference. Firstly, if both radars collect data at the same elevation angle, we can note immediately that

- the intersection of the two data collection surfaces will lie along a curve that when projected to the earth's surface is a line perpendicular to the join of the radars, and lying half way between them. This line is seen in Figs. 1 and 2.

- if the radars have the same calibration at all reflectivity values, then the zero difference line will lie on the above-mentioned projected line.
- if there is a constant calibration difference at all reflectivity values, then the difference value on the intersection line will indicate the calibration difference.
- if the calibrations are identical and the rainfall during the period is distributed uniformly over the area, then the difference image is symmetrical about the join line, and mirror-symmetrical about the perpendicular dividing line, with equal positive and negative values on either side. A difference in calibration will show up as unequal positive and negative values. The average of these gives the average calibration difference.

The above assumptions are not always valid. For instance, if the collection angles are different, the intersection curve when projected on the earth's surface will no longer be a straight line but a curve, concave towards the radar with the higher collection angle. An example is shown in Fig. 3. In this case, the whole image is no longer mirrored about the midpoint line, but will be unsymmetrical. Due to the non-uniformity of the cumulative rainfall over the image area, the image will in general be neither axisymmetric nor mirror-symmetric.

A look at the measured data in Fig. 1 shows that the figure is not fully symmetrical about the join line. In fact, symmetry is seen only on the Ikaalinen radar side. The Anjalankoski side in not symmetrical, as higher differences are seen on the Southern half than on the Northern half. This indicates that the rainfall has not been fully uniform. The unsymmetry may be explained by the shortness of the collection time, which was only 6 days in this case. The numerical values show that the zero line is shifted towards the Ikaalinen radar. Assuming that the collection angles are the same, the calibration difference can be estimated to be 2-3 dB positive for the Anjalankoski radar. This may not, however, be the true calibration difference, as the collection angles may not be the same. It is rather difficult to see the effect of the collection angle by naked eye.

3. QUANTATIVE ANALYSIS

The vertical reflectivity profiles determines to a large extent how the difference data shown in Fig. 1 will look like. The profile is not necessarily known. Below we will describe an analysis procedure which will give both the calibration difference and the difference of the collection angles and in which the reflectivity profile need not be known. We have to assume that the precipitation is uniform and the vertical profile is same for all locations.

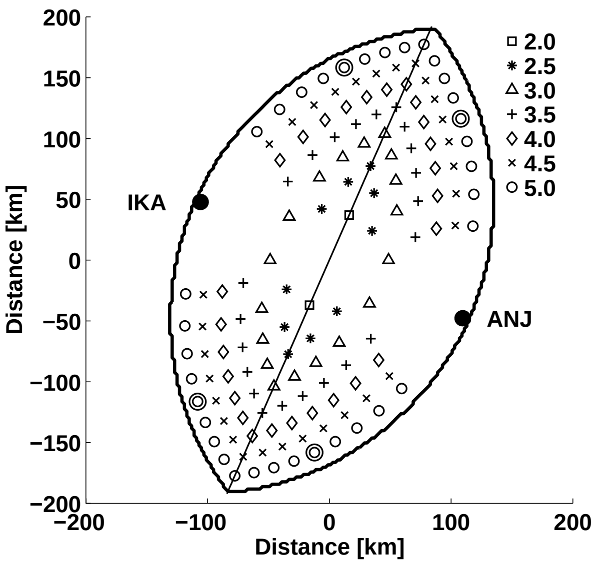

Figure 2: A selection of points for numerical analysis when both radars measure at an elevation angle of 0.5^{o}. The solid line connects points equally far from both radars. Other symbols are explained in text.

The starting point is Fig. 2, in which sets of points are given. Each set includes points for which the height of the beam from the far away radar is at a fixed altitude. This altitude ranges from 2.0 to 5.0 km in steps of 0.5 km. The symbols are explained in the figure. Midway between the radars, at a line shown in the figure, the height from either radar is the same. Going from there the height of beam from the closer radar decreases by 0.5 km for each successive point. The points at which the far away radar measured at 5.0 km and the closer radar at 3.0 km are denoted by doubled open circles. We note that there are four points altogether, one pair in either side of the join line between the radars.

For the data at these points, we get the following formulae:

$$m_l = \quad dBZ(5) - dBZ(3) + \Delta(\mathrm{ANJ}) - \Delta(\mathrm{IKA}) \quad (1)$$
$$m_r = \quad dBZ(3) - dBZ(5) + \Delta(\mathrm{ANJ}) - \Delta(\mathrm{IKA}), \quad (2)$$

where m_l and m_r refer to the measurement left and right of the dividing line, $dBZ(r)$ is the reflectivity at the altitude r, and Δ is the calibration error of the radar, which are assumed to be independent of the reflectivity. The ANJ signs are positive, because the IKA data have been subtracted from the ANJ data. Here we have made use of the fact that the precipitation is uniform and the vertical reflectivity profile the same at all locations. After

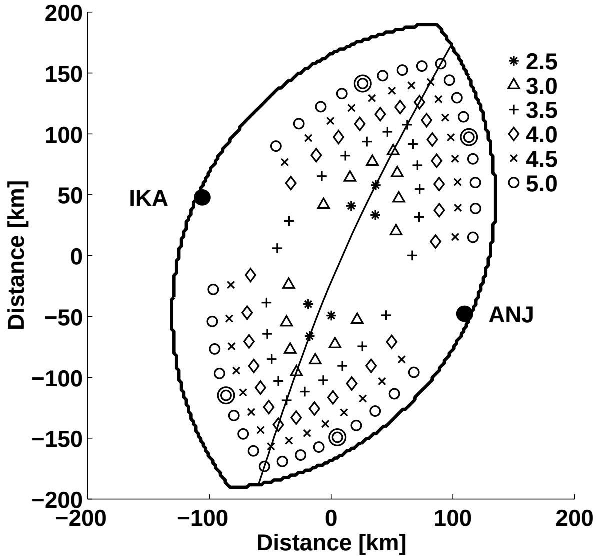

Figure 3: As Fig. 2, but for elevation angles of 0.5° and 0.7° for IKA and ANJ, respectively.

addition and division by 2 we get

$$\Delta(\mathrm{ANJ}) - \Delta(\mathrm{IKA}) = (\mathrm{m_l} + \mathrm{m_r})/2. \tag{3}$$

which tells that we will get the difference of the calibration errors of the radars, i.e. the relative calibration error between the radars.

In the above we have assumed that the collection angles are identical. This may not be the case. Fig. 3 shows the point locations when the collection angles are 0.5° and 0.7°, respectively. Comparison of figures shows that the points have moved considerably towards the Anjalankoski radar, the radar with the higher collection angle. Yet it is possible to find points which correspond to each other and to data from which the above formula can be used. It is easily seen that the location of the points is no more symmetric.

The determination of the collection angle is based on the study of the distribution of the calibration differences. If the assumption of the uniformity holds, each set of four points should give the same answer for the calibration difference, to within the error fluctuations. The collection angle, which produces the smallest variation of the calibration difference around its mean, is the most probable angle. It is possible to implement this as a standard least-squares search. Alternatively one can search through all elevation angle differences with a small step and find the minimum of the distribution. The latter can even be implemented manually by producing grids similar to those shown in Figs. 2 and 3 for a set of collection angle pairs. Both angles need not be stepped. Instead, one can fix one angle to e.g. 0.5° and step the other. Test have shown that fixing one angle even to a slightly incorrect value does not affect the angular difference hardly at all, if the other angle is correct to within 0.2°. This means that it is not possible to deduce the angles itself by the method, only the difference of the collection angles is obtained.

In a numerical implementation one can make the grids denser. Tests with data have shown that a grid having a step less than 100 m is optimal. Each range cell will then contain some 10 points only and one can calculate the mean and standard deviation. The goodness of fit is determined in a standard manner by looking at the fit residual or variance

$$\xi^2 = \frac{1}{N}\sum_i \frac{(m_i - \overline{m})^2}{\sigma_i^2} \tag{4}$$

where $\overline{m}$ is the mean of observations m_i weighted by the weights σ_i^{-2}. The expected value of the residual is 1 and the distribution has a width of $2/\sqrt{N}$.

For the data shown in Fig. 1, the analysis result is that the difference in the collection angles is -0.1° is and calibration difference is 1.3 dB, indicating that the Ikaalinen radar is collecting data at a slightly higher angle but that the Anjalankoski radar gives a slightly higher reflectivity. Initial error estimates tell that the angle is obtained to within ±0.1° and the calibration difference to within 0.4 dB.

4. CONCLUSIONS

The first tests with the method have shown that it is indeed possible to get the calibration difference and the collection angle difference by analyzing the reflectivity data from a radar pair. The next step is to extend the analysis to several radar pairs and to analyze data from different types of precipitation, including e.g. both summer and winter cases. For this, a set of radar pairs have already been selected from NORDRAD, the Nordic weather radar network.

Once the calibration and pointing angle differences have been obtained for the whole network, it will be possible to make additional checks on the accuracy of the results. Integration of the differences from a radar pair to the next and finally closing the loop should result in a zero difference both in calibration and pointing.

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