P6R.11 Using Medium Term Reflectivity Statistics in Radar QPE

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1. INTRODUCTION*

The increasing availability of radar data on-line and from archive has made it much easier to collect and analyze medium to long term statistics of data from the radars in networks. Statistics of reported reflectivity as a function of range and azimuth are showing value in several areas of radar QPE. The statistics help show and quantify the effect of partial and complete blocking by terrain and features on the terrain. The statistics often show subtle obscuration problems that were not predicted in calculations based on digital terrain maps and will allow the development of better blockage maps. The distributions of reflectivity as a function of range have also shown hardware problems with individual radars in the Canadian weather network. For example, developing problems with TR cells show a distinctive pattern. Finally, the distributions of reflectivity can show the interaction between the vertical profiles of precipitation and the minimum detectable signal (MDS) level of each radar. Kitchen and Jackson (1993), indicated that a complete failure to detect precipitation was a significant source of rainfall underestimation at long range, but the problem varies by radar and meteorological situation. Using statistics of observed reflectivity for a particular situation it may be possible to identify a maximum range beyond which the probability of detection is so low that radar QPE is essentially non-recoverable.

2. DATA

The availability of large quantities of radar data has moved forward immensely over the last 15 years. Fifteen years ago full radar data in polar coordinates was typically only available at radar sites and historical data was only available on slow media such as tape. Today communications and disk storage have improved to the point where national centres such as the National Meteorological Centrer (NMC) and the Canadian Meteorological Centre (CMC) have the polar coordinate data on-line in real time. Historical data is becoming available on line as well. With on-line storage in the gigabyte and terabyte range, exploratory examination of months of data is becoming practical.

Again, looking back 15 years the only common operational use of medium term radar statistics was to develop clutter maps and determine areas that were completely obscured by terrain. These products were most commonly based on final products rather than the original polar data.

The data used in this paper was obtained by a combination of real-time downloads from a parallel (hot back-up) server at CMC, downloads from a prototype archive system in Canada's National Digital Archive, and backups on CD-ROM at the King City research radar. It includes original polar-coordinate "volume scan" data from the radars and intermediate "meta" products in polar coordinates at the radars' native resolution.

Data selection depends on the particular application. For some applications the presence of non-meteorological signals adds noise, whereas in others assessment of non-meteorological signal is the objective. In this paper a crude selection against non-precipitation echoes was done on the basis of file size, since our largest files occur with widespread precipitation.

3. RANGE DEPENDENT STATISTICS OF REFLECTIVITY

The first experimental statistical product to show value is the distribution of observed reflectivity as a function of range. The data is collected on sloping conical PPI surfaces, with increasing range corresponding to increasing height. The initial interest was to examine the consistency of our "PRECIP" product, which uses a combination of Doppler data and non-Doppler data (Appendix A). In the past weaknesses in calibration procedures had resulted in observable discontinuities on the product.

Figure 1 shows the type of image that is hoped for. The reflectivity's evolve smoothly with range until 126km where more low values appear due to the change in sensitivity at that range. The left side of the area with observation indicates the minimum detected

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signal (MDS) at each range. In passing, it may be mentioned that the change in sensitivity at 126km range means that averages of all values above the MDS drop to lower values at longer range and can give a misleading impression of a change in calibration.

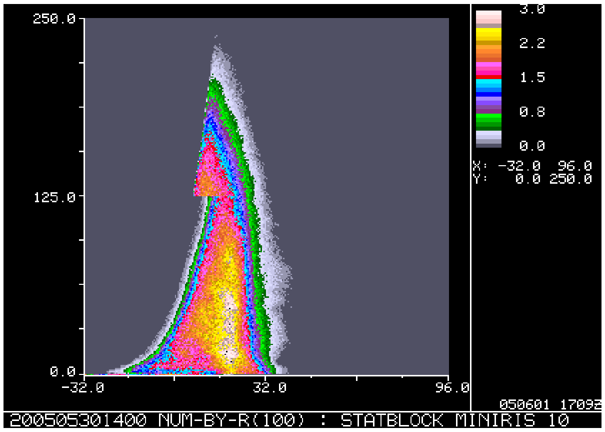

Figure 1: Normalized counts of each reflectivity value (horizontal) in dBZ at each range (vertical) in km for the WGJ radar.

One unexpected benefit of this set of statistics from all radars in the Canadian network was a clearer indication of the source of some problems being reported at a few radars across the county. Figure 2 shows data from the XFW radar, with a peculiar behaviour in the nearest 50km. The echo pattern is shifted to progressively lower values near the radar. This pattern is a strong indication of the failure of a transmit-receive (TR) cell. The TR cell attenuates radio power to protect the receiver during radar transmission and is then supposed to recover quickly (within a few microseconds) to allow the returning echoes to be received. At XFW the TR cell attenuation was remaining significant for over 200 microseconds after transmission. Examination of the same plots for other radars showed some radars with lesser TR cell problems, and these problems seem to have been traced to a particular set of TR cells.

4. PPI RATIOS AND PARTIAL BLOCKAGE

There are two widely used techniques for estimating blockage (occultation) by terrain. The first is to model blockage using a Digital Elevation Map (DEM) with information about the radar height. The second is to calculate long term statistics of the observed data. The first technique is very useful for initial siting and configuration of the radar but can be problematical if there are trees, towers, or small terrain features near the radar, since these are not in the DEM. Donaldson et al. (2003) and Langston and Zhang (2004) provide two recent examples of this approach. The second technique is “real” rather than modelled, but it is not as straight forward as it might seem. The observations do not directly give the fraction of the beam blocked, but rather the reduction of the returned echo, which includes variations in the vertical reflectivity profile (VRP). The usual method of looking at the data is to examine long term averages of reflectivity and this note introduces a new variation on that.

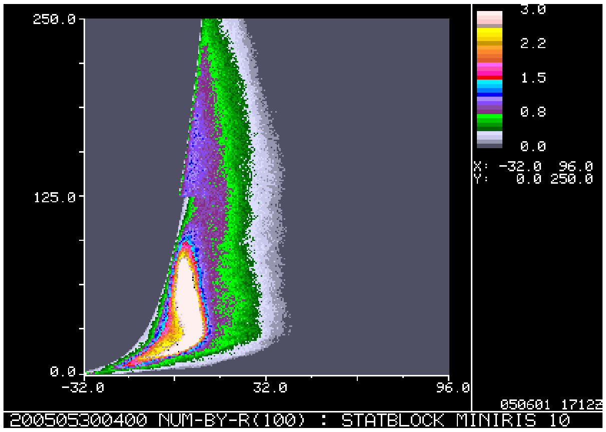

Figure 2. As Figure 1, for XFW radar, showing TR cell problems.

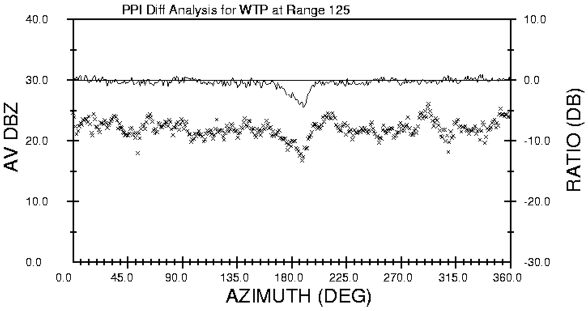

Figure 3. Average ratio between lowest two scans at WTP (solid line) in dB, and the average reflectivity in dBZ on the lowest scan (crosses) as a function of azimuth.

Unless averages of reflectivity are very long, only strong blockage can be detected due to spatial variations in the underlying precipitation pattern. Something more constant is desirable and can be found by exploiting the fact that the shape of the VRP is more constant than reflectivity itself. Techniques such as that of Andrieu and Creutin (1995) are based on the idea that the VRP is reasonably constant over large areas. Again with the assumptions of Andrieu and Creutin (1995) the ratio of reflectivity's at two PPI elevations at a constant range should be quite constant at any given time. So, if ratios from many times are averaged the result should also be almost constant in azimuth. Figure 3 shows the average ratio as a function of azimuth (expressed in db) at 125km from the WTP radar, made using data from several days. Also shown is the average reflectivity. Both patterns show a loss in echo of up to 5 dBZ due to blockage by a hill to the south of the radar, but the pattern in the reflectivity is less obvious due to spatial variations in the precipitation. Subtler blockage in the 1-2 db range would not be evident in this reflectivity plot.

One identifying property of blockage is that blockage should be roughly constant with range beyond the blocking terrain. Figures 4 and 5 show the average ratio and average reflectivity as a function of range and azimuth for the same times as in Figure 3. In these figures the area of blockage is a distinct vertical feature on the figures, but the background pattern is far less variable for the ratiofield.

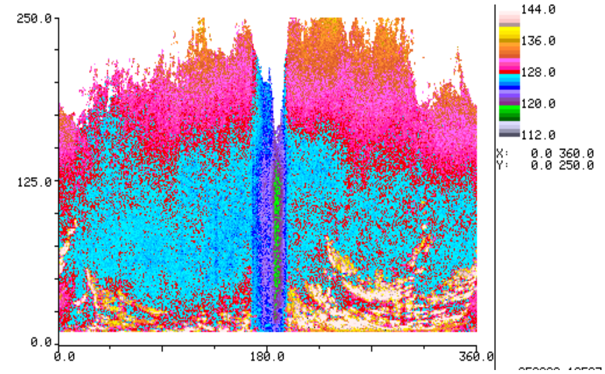

Figure 4 Average ratio between bottom two scans as a function of range (y) and azimuth (x) at WTP for same days as Figure 3. In ½ dBZ engineering units, where 128 = 0 dB. Areas of light colours near the radar are due to large vertical gradients of reflectivity due to ground clutter.

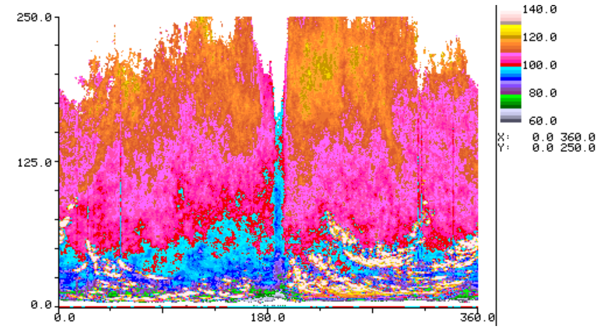

Figure 5 Average reflectivity scans as a function of range (y) and azimuth (x) in ½ dB engineering units on lowest scan from WTP for same data as Figures 3 and 4. Note colour scale is expanded relative to Figure 4 in order to accommodate a larger range of values.

Figures 6 and 7 show a different, more subtle pattern of occultation, at the XMB radar. The ratio plot shows a loss of a couple of dB in the northwest. On the reflectivity plot this same area shows no obvious problem in that direction.

There are limitations of the ratio technique. If the attenuation is estimated solely from the lowest two scans, as shown here, one might miss that the second scan could also be blocked, and the estimate would be a lower limit. Towers near the radar can easily give rise to this situation. Ratios from higher scans also need to be examined. As mentioned previously, the results give the differences in the echoes measured, not the fraction of the beam obscured, so the estimates are only a "zero-order" estimate of blockage. In summer. rain, the vertical gradients of reflectivity tend to be weak, but if data is collected in snow or especially in the bright band, vertical reflectivity gradients must be considered in the interpretation.

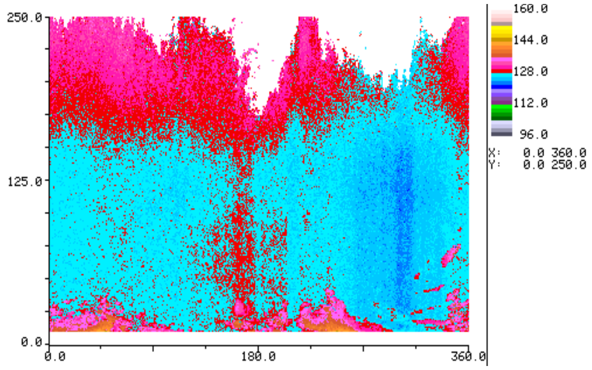

Figure 6 As Figure 4, but for XBM radar. (The red stripe in the south is not as significant as the colour change suggests. The change is from slightly below a ratio of 1 to slightly above.)

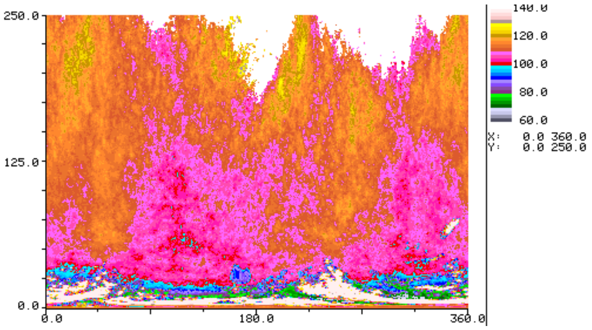

Figure 7. As Figure 5, but for XMB radar.

As an aside, it may be remarked that modifications of ratios between PPI's by blockage and ground clutter can pose problems in the method of Andrieu and Creutin

(1995), so they should be addressed before using the technique in QPE applications.

5. SPECULATION ON DETECTABILITY

The proper handling of a null measurement by a weather radar is an open question in radar QPE. Strictly speaking it only means that there are no echoes above the minimal detectable signal (MDS) at the measurement location. In practice there are two obvious actions: either assume that there is no precipitation at the surface (P=0), or assume one knows nothing at all based on this radar data at this location and obtain precipitation estimates from some other source. At close ranges where MDS is very low, the assumption that P=0 is reasonable. At long ranges however a number of uncertainties arise. First the MDS may have risen to the point that small, but non-negligible, precipitation rates are undetectable. Secondly, the lowest measurement height increases with range and at long range the radar overshoots measurable targets. At long ranges a null measurement might more reasonably be interpreted to mean that nothing is known about surface precipitation.

The question arises how to determine the range at which one should switch between the two interpretations. The answer will depend on the meteorological regime (such as winter vs summer). This is where medium term statistics of radar data could be useful. Data such as shown in Figure 1 shows variations by month in the distribution of echoes. Specific statistical products are being developed to answer the question “if nothing is measured aloft then what is probability there is no precipitation at the surface”. (See Appendix B.) It is too early to say whether such statistics can be turned into objective criteria or merely used as rules-of-thumb.

6. CONCLUSIONS

The ability to gather and analyze large quantities of radar data on the radars' native coordinate system is becoming practical. This allows the construction of new, more sophisticated statistics than those based on “products”. These statistics will allow better assessment of quality issues underlying quantitative precipitation estimation (QPE), and can help build statistics to guide the application/interpretation of radar measurements for QPE.

7. APPENDIX A – “PRECIP” PRODUCT

The radars in the Canadian weather radar network operate a compound scan strategy that is composed of some slow Doppler scans, with excellent ground clutter removal, and fast non-Doppler scans to longer ranges using longer pulses, which give greater sensitivity. The PRECIP product uses the lowest Doppler scan close to the radar and then switches to a more more sensitive non-Doppler data at the same elevation to provide data at longer range. This gives a good combination of clutter rejection and sensitivity.

8. APPENDIX B – PRELIMINARY DETECTIBITY RESULTS

Figure B.1 shows some preliminary statistics on the relation between measurements at 1km and 2.5 km AGL, based on volume scan data at King City radar for January and June 2004. It can be seen that the statistics for the two months are quite different. In June 2004, 91% of null observations aloft corresponded to null measurements at the lower level, whereas in January 2004 only 75% of null measurements aloft had no measurable signal at the lower level. These data were collected near to the radar, and need to be adjusted to correspond to changes in MDS at longer ranges. The data shown is actually a subset of statistics of all combinations of measurements at the two levels from which statistics at other ranges can be constructed using the range dependent MDS. More years and months need to be analysed and more thought given to interpretation in the context of specific applications.

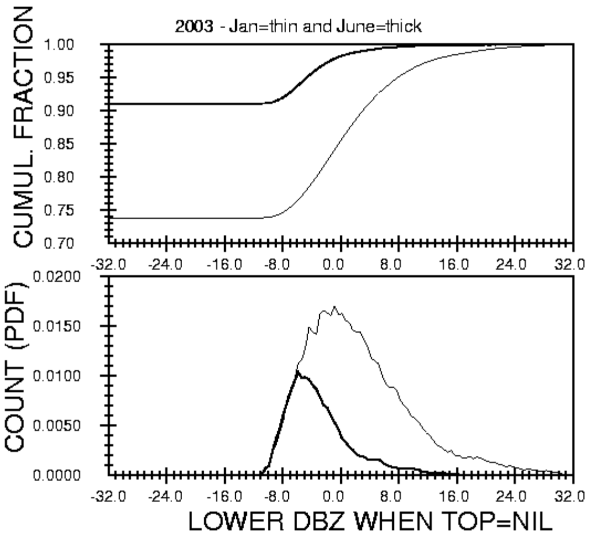

Figure B.1 Distribution of observations of reflectivity at 1km when there is no measurable echo at 2.5km over the same location, for January (thin) and June (thick) 2004. Bottom: probability distribution (with large number of “nil” observations not plotted) as function of reflectivity at 1km. Top: cumulative fraction of “nil” observations at 2.5km as function of reflectivity at 1km. (Note that the lower side of the peak in the PDF plot is *due to MDS varying over the ranges considered and is not a property of precipitation itself.)*

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