4B.3 RELATIVE IMPORTANCE OF FACTORS DEGRADING QUANTITATIVE PRECIPITATION ESTIMATES FOR HEAVY RAINFALL EVENTS IN COASTAL AND CONTINENTAL LOCATIONS

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1. INTRODUCTION

Weather radars are the most promising means determining the finer scales of quantitative precipitation estimates (QPE) over large areas. Radar data have detailed spatial resolution and are collected at frequent intervals. The process of converting radar reflectivity data into an accurate representation of precipitation accumulation for local areas has inherent problems, including such factors as variability in reflectivity-rain rate (Z-R) relations and drop size distributions (DSDs), radome wetting, and reduction of reflectivities about the wind zero isodop by clutter filters. This study assesses the relative importance of factors that affect QPE accuracy, for both a coastal and continental location. The scope of the study is constrained to significant rain events (generally at least 10 mm accumulation) in the absence of bright band contamination in the radar data.

2. METHODOLOGY

2.1 Data Sources

Radar data were obtained from C-band units within the Meteorological Service of Canada's network (Joe and Lapczak, 2002). Doppler scans are taken during a 10-minute cycle, at elevation angles of 0.5°, 1.5°, and 3.5°, a maximum range of 112 km, a range resolution of 0.5 km, and an angular resolution of 0.5°. For each scan, uncorrected and corrected reflectivities were recorded as well as radial velocities. For the rest of the cycle a series of 24 scans with elevation angles between 0.3° and 24° is obtained with maximum range of 256 km but only uncorrected reflectivity is recorded.

A Joss-Waldvogel disdrometer (Sheppard and Joe, 1994) was used as ground truth. This unit has a sampling area of 50 cm^2 and measures rain drops with diameters up to 5 mm following the calibration of McFarquhar and List (1993). Drop size data are recorded with a time resolution of 1 s. A Precipitation Occurrence Sensor System (POSS, see Sheppard and Joe, 1994) was also used as ground truth at the continental location

For the continental location the Centre for Atmospheric Research Experiments (CARE) site near Egbert (44°14'N., 79°47'W), about 70 km northwest of Toronto, Ontario, Canada, was chosen. The disdrometer, POSS, and several rain gauges were co-located here in gently rolling terrain 34 km from the King City Radar, which is located on top of the Oak Ridges Moraine and has an effective beam width of 0.6°. At this range the 0.5° elevation angle radar beam passed about 400 m above the site.

For the coastal location a site was chosen in the northwest part of Surrey, BC, Canada, about 20 km southeast of Vancouver with relatively flat terrain. The disdrometer was located on the roof of a fire hall at 49°09'N, 122°51'W, 31 km from the Aldergrove Radar, which is located further up the Fraser Valley, and has an effective beam width of 1.1°. At this range the 0.5° elevation angle radar beam passed about 400 m above the disdrometer. Rain accumulations were compared with those from the North Delta (DT34; 3 km to the west) and Newton Reservoir (SU42; 5 km to the south) tipping bucket rain gauges.

The coastal location also had a stream gauge station close by. Hydrological runoff was measured for a basin of about 25 km^2 area and an elevation range of about 100 m.

2.2 Analysis Procedures

Synoptic and mesoscale atmospheric patterns were assessed using a number of sources. Archived copies of charts, satellite pictures, and forecast discussion statements were studied to group the events into a few synoptic categories. Radar echo top patterns and rain intensity variations assisted in determining the character of the rain (convective/stratiform). Mesoscale factors were assessed with the help of low-level Velocity Azimuth Display (VAD) analyses and consideration of the local topography.

For radar QPE, reflectivities for 7X7 volume elements centered over the disdrometer were averaged. A standard Z-R relation was used as a benchmark for all cases to obtain radar-derived rain rate estimates, which were then integrated in time to obtain event accumulations. The mean radar reflectivity was plotted against the corresponding 10-minute average disdrometer rain rate, and a fit to the equation $Z = aR^b$ was determined for each rain event. This new equation was also applied to the radar reflectivities to obtain improved event accumulations. Both the coastal and continental locations have little or no ground clutter.

Variability in Z-R relations was assessed considering both instrumental and meteorological factors. The ***a*** term in the equation $Z = aR^b$ acts as a scaling factor and corresponds more closely with any changes in the radar calibration. Some comparisons of reflectivities with

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adjacent radars were also performed to determine the contribution of the radar calibration component to Z-R variability. The ***b*** term in the equation $Z = aR^b$ corresponds more closely with changes in the drop size distribution (DSD).

Clutter filters that are intended to remove stationary artifacts caused by terrain-induced echoes will also reduce reflectivities in precipitation when the wind flows perpendicular to the radar beam. An example of the resultant zero isodop gap may be seen in Figure 1. Rain accumulation estimates based on reflectivities 'corrected' and 'uncorrected' for clutter were compared, and related to the wind speed and direction calculated at low levels using the VAD algorithm.

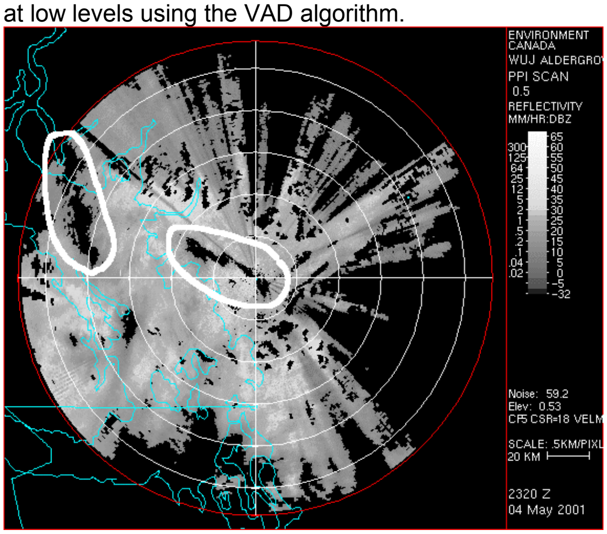

Figure 1: Zero isodop gap in reflectivities enclosed in circled areas.

Radar beam path attenuation becomes more significant at longer ranges than the 30-35 km where the disdrometer and rain gauges were located, whereas radome wetting affects all ranges. For this study reflectivity values at a close range (3 km) were averaged and the temporal variations compared with averaged reflectivities at longer ranges. When an intense convective cell passes over the radar, radome wetting will result in a rapid decrease in reflectivities at all ranges. In Ontario where path attenuation is more common it was also assessed.

To further validate accumulations for the coastal site hydrological data were obtained for the study period. Stream runoff flows and rain rates were plotted together and revealed a basin runoff period of about 2-4 hours. Integrating the total runoff with time and dividing by the basin area gave an upper constraint to the input rain accumulation, as sub-surface flows were negligible.

3. RESULTS

Rain accumulations showed a high degree of consistency among non-radar sources. Monthly rain accumulations recorded by the disdrometer agreed well with those of the nearby rain gauges. For the continental site the disdrometer and POSS-derived accumulations were close to those of the optical rain gauge as well as manual readings. For the coastal site the disdrometer accumulations were in reasonable agreement with the nearby North Delta and Newton Reservoir rain gauges. Stream discharge data showed that for longer time scales the runoff ratio (runoff volume to precipitation input) approached 100% for the wettest winter months. This is to be expected as the ground is saturated and evaporation losses are minimal due to frequent cloud cover and moist atmospheric conditions. Lower runoff ratios (down to less than 50%) occurred for the drier summer months when evaporation was stronger and the ground water table lower.

For the continental location 38 rain events were considered in depth. A summary containing event surface rain accumulation, maximum rain rate, the ***a*** and ***b*** coefficients in the Z-R relation, and the ratio of accumulations based on clutter corrected and uncorrected reflectivities is given in Table 1. There were 19 rain events considered in detail for the coastal location, and these are summarized in the same manner in Table 2.

Case #	total rain mm	max R mm/h	coefficient A	coefficient B	WKR Cor/Unc total R
1	25.0	8.7	283	1.22	0.98
2	19.4	16.0	254	1.37	0.57
3	28.3	14.1	481	1.15	0.88
4	32.3	19.8	242	1.76	0.91
5	10.6	6.1	335	0.87	0.73
6	12.8	5.3	298	1.44	0.97
7	32.6	12.9	284	1.29	0.97
8	33.2	29.4	1240	0.62	0.78
9	16.7	24.1	152	0.16	0.88
10	21.9	27.7	134	0.97	0.86
11	11.8	5.8	246	1.39	0.67
12	12.8	7.4	474	1.37	0.98
13	22.0	5.1	320	1.61	0.92
14	22.7	4.9	158	1.68	0.86
15	17.6	6.9	239	1.31	0.85
16	33.3	20.6	290	1.39	0.81
17	19.6	15.5	NA	NA	0.94
18	27.6	NA	NA	NA	0.87
19	27.4	NA	216	1.40	0.89
20	28.3	25.8	151	1.36	0.89
21	17.8	4.7	217	1.46	0.71
22	27.5	11.0	349	1.13	0.58
23	15.1	2.0	273	1.31	0.99
24	19.8	15.4	NA	NA	0.96
25	17.2	3.2	155	1.59	0.88
26	18.7	3.8	218	1.16	0.98
27	22.0	8.8	411	1.15	0.94
28	46.1	7.4	124	1.81	0.69
29	18.7	21.1	NA	NA	0.97
30	46.0	17.7	466	1.00	0.93
31	39.3	7.4	262	1.47	1.00
32	71.8	38.2	231	1.33	0.83
33	10.6	1.5	292	1.40	0.73
34	42.5	7.3	NA	NA	0.78
35	9.1	4.3	443	1.68	0.74
36	22.3	32.6	321	1.73	0.75
37	7.3	4.6	135	1.52	0.78
38	10.6	0.8	NA	NA	0.98

Table 1: Summary of continental events.

Case #	total rain mm	max R mm/h	coefficient A	coefficient B	WUJ Cor/Unc total R
1	25.9	3.3	131	1.67	0.99
2	20.9	11.0	76	0.73	0.87
3	23.6	5.2	78	1.42	0.94
4	32.5	4.4	65	1.37	0.95
5	32.3	9.2	80	1.13	0.70
6	21.6	3.6	18	1.14	0.80
7	43.8	7.4	20	1.21	0.84
8	19.0	6.6	18	1.16	0.58
9	37.8	4.6	21	1.17	0.99
10	33.9	9.8	28	1.25	0.99
11	18.5	5.0	35	1.23	0.93
12	7.5	3.8	75	1.20	0.98
13	18.8	4.0	58	1.27	0.99
14	46.9	7.8	83	1.27	0.96
15	18.3	3.0	110	1.11	0.81
16	12.6	7.4	152	1.21	0.88
17	13.5	3.5	113	1.07	0.74
18	10.1	3.7	179	1.19	0.78
19	30.9	6.2	154	1.09	1.00

Table 2: Summary of coastal events.

The linear ***a*** coefficients listed in Table 2 strongly indicate that the Aldergrove Radar calibration yielded significantly low reflectivity values. The reasonably high correlation of Z-R values for individual events indicates that the calibration varies at most very slightly for event time scales. Thus, the radar calibration error is one that may be systematically corrected. Following the study period the calibration for this radar has subsequently been improved. The ***a*** coefficients in Table 1 show that the King Radar calibration was stable and yielded reasonable reflectivity values. The exponential ***b*** coefficients did not show any strong consistency among different convective or stratiform cases. No vertical profile corrections were performed, as the low height of the radar beam above the rain gauges help mitigate spatial/temporal errors.

In the absence of ground clutter the ratios of corrected/uncorrected reflectivity-based rain accumulations show that clutter filters may have a significant effect even at longer time scales. For the 38 continental cases as a whole the average reduction in derived accumulations is 14%, though there is suspicion that anomalous propagation may have introduced some ground clutter contamination for a few cases. For the 19 coastal cases as a whole the average reduction is about 10%. Individual events have accumulations reduced as much as 40%. When events of similar wind speeds are compared there is a somewhat greater reduction at the coastal location. This is due to the operational requirement of stronger clutter filters for the more rugged terrain. In Figure 2 a radial velocity histogram is presented for different clutter filters applied during a clear air echo event. The top of the legend (time 22:32) corresponds to the no-filter scan, and a sharp peak at zero radial velocity occurs, as expected. Increasingly stronger filters (1 to 7) were applied sequentially from 21:22 to 22:22. For the Aldergrove Radar filter 5 is used operationally, and few volume elements with absolute radial velocities less than 2 m s^{-1} are retained. The weaker clutter filter 4 is used for King Radar. The degree to which QPE estimates are affected by the zero isodop error will also depend on the aspect of a location relative to the radar as well as the wind speed and direction climatology during precipitation events. For example, an outer coastal location with stronger winds may be expected to have smaller errors near the zero isodop, whereas a deep valley location with frequently light and channeled winds may have sizable errors. Thus, for areas devoid of ground clutter the 'uncorrected' reflectivities will be more suitable for QPE applications. For cluttered areas it may be possible to correct for zero isodop errors if the wind speed and direction is accurately determined.

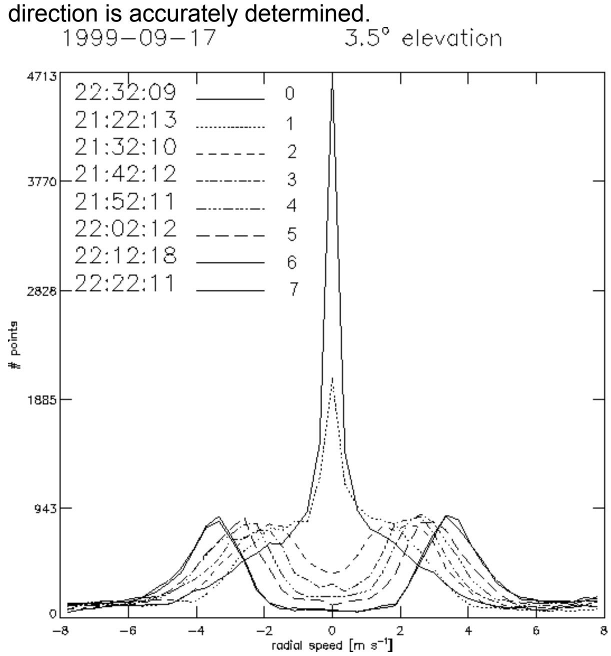

Figure 2: Radial velocity histogram for different clutter filters during a clear air echo case.

In Figure 3 azimuthally averaged reflectivity values for different ranges and times are plotted at the coastal radar for an event where rain rates up to 10 mm h^{-1} were recorded near the radar. Even though the rain rates were among the highest recorded at this location, reflectivity values at longer ranges do not show any significant reductions from radome wetting. Figure 4 shows reflectivity variations with time and range for a convective event at the continental radar. A sharp decrease in reflectivity values for all ranges is noticeable at 2.5 hours on the time scale, the third last scan of the sequence. At that time a heavy rain cell moved over the radar yielding significant radome wetting. A rain intensity histogram covering all events is given in Figure 5. Given this distribution as well as the lack of a decrease in reflectivities for the 10 mm h^{-1} event in Figure 3 it is evident that radome wetting was an insignificant factor for radar-derived QPE at the coastal (BC) location. For the continental (Ontario) location radome wetting appeared to be most significant for short time scales during rain events.

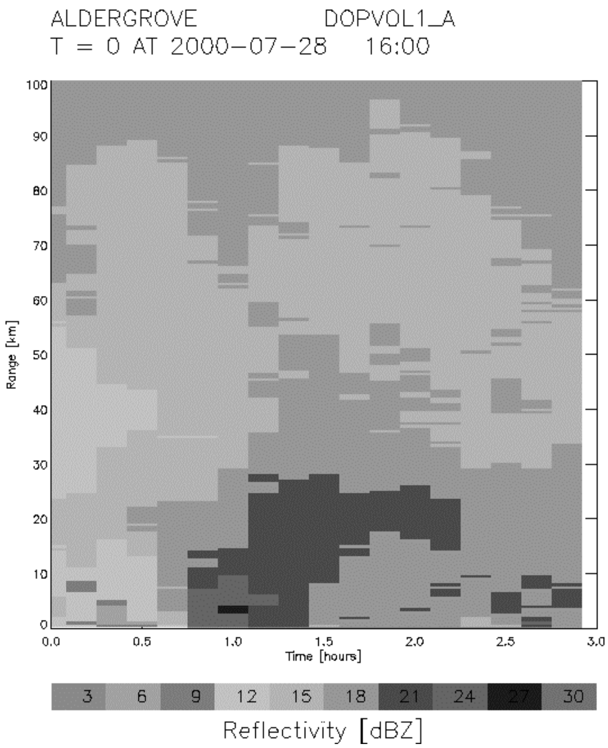

Figure 3: Time-range plot of average reflectivities at the coastal radar when rain rates near the radar were up to 10 mm h^{-1}.

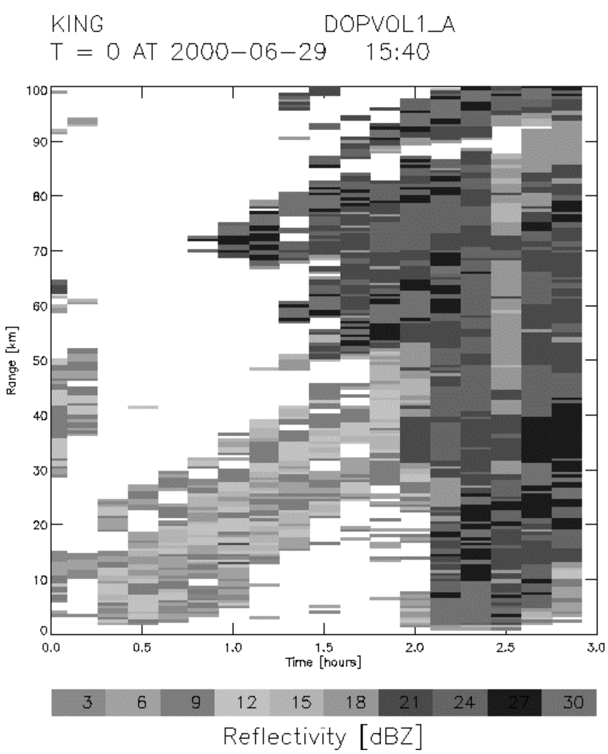

Figure 4: Time-range plot of average reflectivities at the continental radar illustrating radome wetting at time = 2.5 hours.

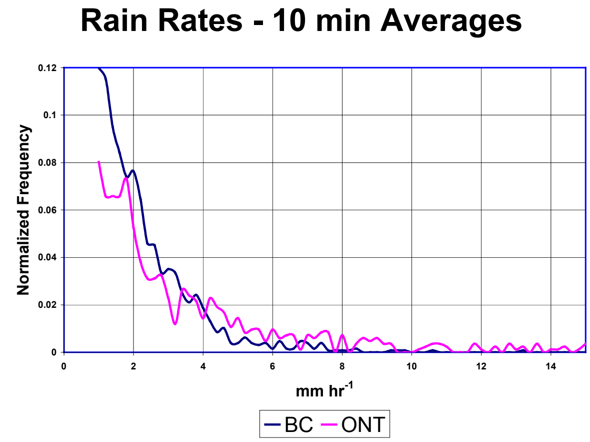

Figure 5: Normalized frequencies of rain rates for all events at the coastal (BC) and continental (Ontario) locations.

Future work will include further consideration of factors that have greater significance at longer ranges. These include radar beam path attenuation and space-time ("advection") corrections. The separation of ground clutter and zero isodop errors will also be more closely examined.

4. REFERENCES

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