

CANADIAN RADAR QUALITY CONTROL IN THE MULTI-RADAR-MULTI-SENSOR SYSTEM

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1. INTRODUCTION OF THE BACKGROUND AND CANADIAN RADAR DATA

Radar data quality control (QC) is important for many meteorological, hydrological, and aviation applications that make use of the radar observations. One major objective of radar data QC is to mitigate effects of terrain, environmental conditions, biological presence (birds, bats, and insects), and radar maintenance practices that may result in false presentations of weather in radar observations. Since 2011, NSSL has had access to real-time data from thirty Canadian radars from the Environment Canada weather radar network through Integrated Robust Assured Data Services of the University of Oklahoma. The Canadian radars run on a 10-minute cycle consisting of a 24-elevation reflectivity only scan sequence and a 4-elevation Doppler scan that is split into two types of Doppler scans with different Nyquist velocities and reflectivity ranges. The full 3D volume scan ("CONVOL") base level data for Canadian radars are used in the Multi-Radar Multi-Sensor (MRMS, Zhang et al., 2015) system to create the 3D reflectivity grid and QPE. Due to the negative scanning elevation angles in Canadian radars and limited quality control before the base level data dissemination, the CONVOL data suffers from severe ground clutter in the low tilts. The CONVOL data does not contain velocity and spectrum width fields, nor is signal-to-noise data available. Further, the Canadian radar scan at lower elevation angles (as low as -0.49 degrees) than the US NEXRAD (lowest at 0.5 degrees). While the lower scanning strategy provides a better radar coverage near the ground and is beneficial to applications such as the quantitative precipitation estimation, it also makes the data more vulnerable to the ground clutter contamination. These factors make the Canadian radar QC a challenging task. An earlier effort used a neural network approach (QCNN) based on reflectivity texture and atmospheric environmental data, which was able to remove a large portion of non-precipitation echoes. However, it had a difficulty to distinguish widespread and intense AP

ground clutter from real weather.

The current work tries to develop a real-time scheme for the identification and removal of both normal and abnormal propagation (AP) ground clutter in the reflectivity field. The clutter mitigation scheme ("APQC") is physically based and consists of a set of heuristic rules based on 3D reflectivity structure and atmospheric environmental fields. It is fully automated and computationally efficient and has been implemented in the operational MRMS system.

The rest of the paper is organized as follows: section two describes the methodology of the Canadian radar QC; section three presents some case-study results and section four provides a summary and an outlook for future work.

2. METHODOLOGY

The APQC scheme consists of three main steps: 1) to remove the persistent ground clutter by applying the statistical ground clutter maps; 2) to mitigate the clutter due to AP; and 3) to correct the reflectivity voids due to the clutter removal when the non-precipitation contamination is embedded in the precipitation echoes. Each step is described in details below.

2.1 Mitigation of persistent ground clutter

This step tries to mitigate persistent ground clutter by applying static clutter reflectivity maps to the real-time reflectivity fields. The clutter maps were derived via a statistical analysis of various reflectivity intensities at each azimuth/range bin in radars' native coordinates (Lakshmanan et al. 2012). Two clutter maps are derived for each elevation angle of all radars – one for their summer and another for the winter scanning strategies. The ground clutter could appear near the radar (< 50 km) with weak intensities or impact a large area (~ 200 km) with strong intensities for different radars. Fig. 1 shows example clutter maps of different radars at their lowest tilts. By subtracting the clutter maps from the raw reflectivity fields, most of the persistent ground clutter are cleared or largely reduced especially under the clear-air condition.

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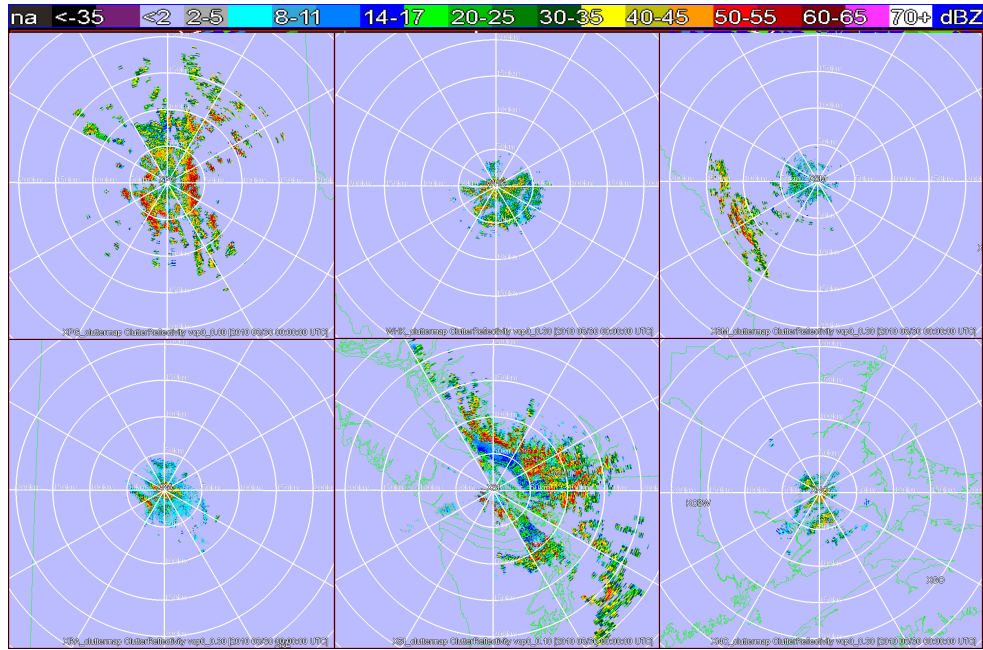


Fig. 1: Clutter maps for radars XPG, WHK, XSM, XRA, XSI and XNC at their lowest scanning angles using summer scanning strategies.

2.2 Mitigation of the AP clutter

Anomalous propagation (AP) of the electromagnetic (EM) waves often occurs when strong vertical temperature and moisture gradients (especially temperature inversions) are present in the lower atmosphere. Strong nocturnal radiation cooling at the surface could cause rapid decrease of temperature near the ground while the air aloft remains relatively warm. The EM wave propagation bends toward the ground instead of continuing straight upward, causing part of the radar beam hitting the ground and results in ground clutter contaminations in radar data. Severe AP clutter is a major issue with the Canadian radar network due to the negative scanning elevation angles, yet the removal of such clutter remains a significant challenge because of their similarity to strong and isolated convective storms in terms of reflectivity intensity and texture. Additional challenges for the Canadian radar CONVOL data were the lack of velocity, spectrum width and signal-to-noise ratio. Several previous efforts tried to mitigate the AP clutter (CHO et al., 2006; Pamment and Conway, 1998) with varying degrees of success through statistical approaches. This work tries to analyze the 3D reflectivity structure and the 3D atmospheric environment to identify and remove AP clutter for Canadian radars.

One spatial characteristic of AP is the rapid decrease of echo areas from lower to upper tilts. Radar reflectivity observations are obtained on conical planes (or “tilts”) with small positive elevation angles [Fig. 2]. Since the radar beam height increases with increasing range, amount of AP echoes decreases

with range and with elevation angles resulting in a significantly larger AP echo area on the first tilt (e.g., e1 in Fig.2) than on the second (e.g., e2 in Fig.2). In the operational NWS radar Precipitation Processing System (PPS, Fulton et al. 1998), this feature was the basis for a so-called “tilt test” procedure that reduced AP echoes in precipitation estimates. The same concept is extended for identification of AP in Canadian radars. Two polar-grid reflectivity maps are selected from the lowest tilts that are at least 1-degree (warm season) or 0.5-degree (cool season) apart in elevation angles. If the reduction in the size of area from the two tilts exceeds a threshold, then the echoes on the 1st tilt are considered as pure (or being dominated by) AP or other clutter and completely removed. This scheme is able to remove the biological clutter because birds/insects has limited vertical extent too.

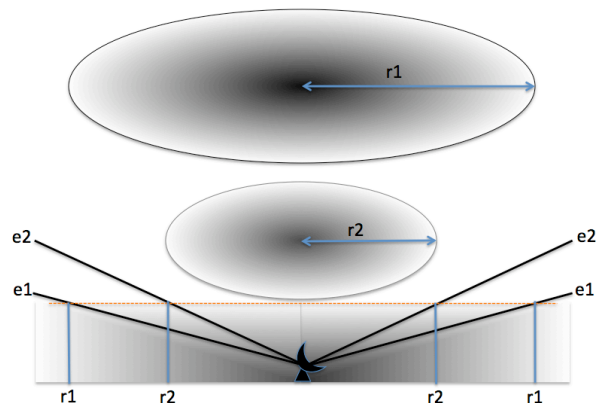


Fig 2: Illustration of AP echo distributions on the radar tilts.

Some of Canadian radars suffer from severe ground clutter due to their mountainous environment. The ground clutter could sometimes be observed at the radar gates higher than 3 kilometers above the sea level assuming a normal propagation condition of the radar beam. Anomalous propagation also causes reflectivity intensities in areas of persistent clutter to be much stronger than the intensities in the static clutter map, thus leaves residual clutter even after the clutter maps are applied. Fig. 3 is an example of the combination of persistent ground clutter and AP in clear-air weather condition observed by radar XWL at UTC 13:29:25 on July 21st, 2013. Panel (a) is the vertical cross section of the reflectivity field along the line in (b), the reflectivity PPI at the elevation angle of 0.3 degrees. It is observed that the strong power returns from the ground are only found at the lowest tilt and do not have the continuity in vertical direction. After identifying the AP clutter, the algorithm removes all the returns of the whole volume as shown in panels (c) and (d).

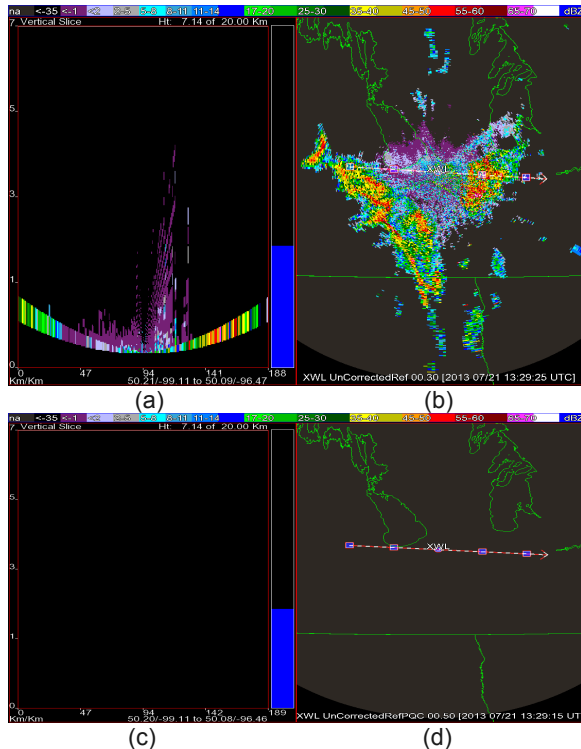


Fig. 3: A ground clutter and AP case observed by radar XWL at 13:29:25 UTC on July 21st, 2013. Panel (a) is the vertical slice of the reflectivity field along the line in (b), the reflectivity PPI at the elevation angle of 0.3 degrees. After the AP mitigation algorithm, panels (c) and (d) are the corresponding vertical slice and PPI, respectively.

The AP echoes from the ground and ground objects have different texture feature from

precipitation targets in most cases. The features of spatial reflectivity texture are used to identify AP echoes. Following the calculations used in Park et al. 2009, the estimate of the Z texture is obtained by averaging Z data along the radial using a 3-km running-average window and subtracting the smoothed estimates of Z from the original values. The root mean square value of the residuals is calculated as the local Z texture. The texture characterizes the magnitude of the small-scale fluctuations of Z along the radial. The echo is censored as clutter when its Z texture is larger than a threshold of 5.0. Some of the severe AP clutters are associated with strong power returns as high as 40 dBZ or higher. During precipitation storms, strong weather echoes are normally associated with high echo top while the AP clutters are generally confined in a few low elevation tilts. The height of echo top is recorded for each of power returns that meet $Z \geq 40$ dBZ. These strong echoes are identified as non-precipitation contamination if the corresponding echo top is not high enough. The SPIN feature field (Steiner and Smith, 2002) measures the frequency of the reflectivity gradient changes sign along a radial. The SPIN parameter indicated the number of reflectivity fluctuations larger than 2dBZ within a window of 5 (azimuth) by 9 (radial) pixels. Radar returns from non-precipitation objects potentially cause large changes of the reflectivity gradient on the horizontal plane where the texture method would assist the clutter identification.

The algorithm applies spike filter to search for continuous Z values within stripe shapes, i.e. at least a length of five-bin in radial and one/two-bin width in azimuth, with cleared-echo neighborhoods. The spike filter identifies the possible electrical interference and sun strobes as non-precipitation clutter. In the last step of the QC process, a median filter is applied to remove the speckles, considered as residual from the clutter map or random noise, and to fill in small voids due to the removed echoes, where random sparse weather echoes are found with high standard deviation in their textures.

2.3 QC of clutter embedded in precipitation

It is most challenging for a radar QC when AP ground clutter is embedded in precipitation, since there must be a trade-off between leaving the contaminated reflectivity data or removing the data and losing storm information (e.g., Fig. 4b). APQC elected to remove the contaminated data and then fill the void with uncontaminated data either from the nearby regions or from the DOPVOL data.

Several techniques have been tested to fill in the voids. The first attempt is to interpolate onto the removed pixels using neighboring reflectivity values that were not contaminated. It works well for small sized holes but causes over-smoothing for the large ones. The second option is to fill the voids on the lower tilt with data from a higher elevation angle where the Z field is free of clutter contamination. The

challenge is how to account for the vertical profile of reflectivity (VPR) before the hole filling. Without an adjustment for the vertical variations of reflectivity, potential bright band contamination may be introduced from a high altitude. A third option is to take reflectivity data from the Doppler volume scans. An examination of reflectivity data from the corrected Doppler volume scans showed much less clutter contamination due to QC processes in the signal processing of the level-I data, which suppresses non-meteorological signals in the spectral domain. However, DOPVOL data has a

smaller coverage area (maximum range of 113km vs. 256km in CONVOL) and only contains 3-4 low elevation tilts. Therefore, an ongoing work in the APQC is to merge reflectivity fields from DOPVOL and CONVOL and generate a full volume scan (24 tilts up to 24.6 degrees) of reflectivity field that contains minimal ground clutter. Fig. 4 shows some preliminary results from different hole-filling techniques.

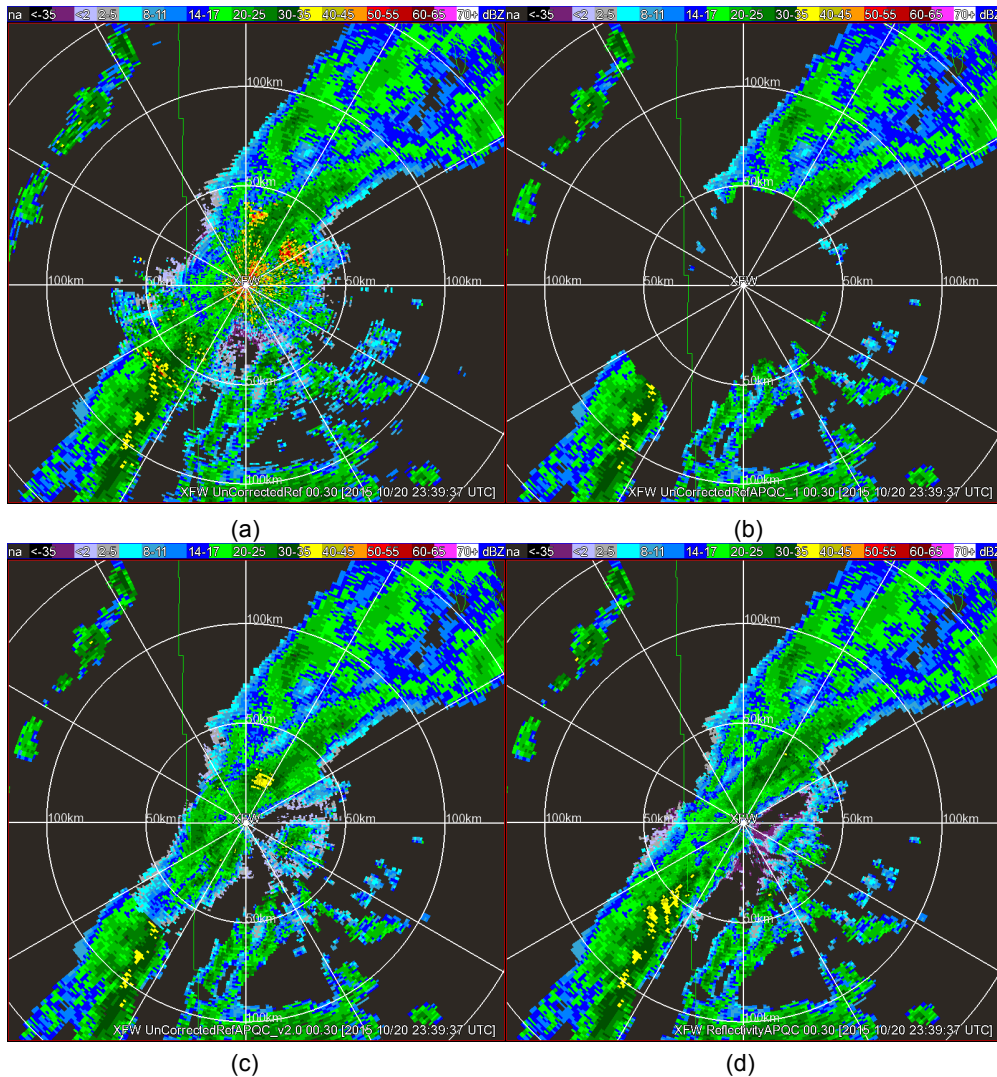


Fig. 4: A case when AP and regular ground clutter mixed with precipitation echoes observed by radar XFW at 23:39:37 UTC on Oct 20st, 2015. Panel (a) is the raw reflectivity Z field at the elevation angle of 0.5-deg; (b) is the processed field without any correction; (c) shows result corrected with CONVOL data from a higher tilt; (d) is the result corrected with the data from Doppler scans.

3. CASE STUDIES AND REAL-TIME TESTS

The APQC algorithm has been tested extensively using about 3000 volume-scans of base level data

from 26 Canadian radars. The cases included ground clutter under normal and abnormal propagation conditions, ground clutter under clear air as well as mixed with precipitation. The cases encompassed

scans from both warm and cold seasons. The results show that the APQC algorithm is able to effectively remove AP clutter during clear-air conditions, and to mitigate severe AP echoes close to the radar site. However, the APQC has limited effect on AP echoes at far ranges. The new APQC was implemented into the real-time MSMS system and was compared with the early QCNN algorithm since Oct. 6, 2015. Fig. 5 shows the mosaicked seamless hybrid reflectivity (Zhang et al. 2015) fields from the two QC algorithms, Fig. 5(a-b), and the 24-hr QPE accumulation based on the reflectivity, Fig. 5(c-d). Fig 5(a) and 5(c) are the fields applying QCNN algorithm, and (b)(d) uses the new APQC algorithm. These cases show that the APQC algorithm has an improved performance in mitigating AP clutter.

4. Summary and Future Work

This paper presented a quality control scheme ("APQC") for Canadian radar CONVOL data. The QC is relatively challenging because of a lack of Doppler information in the CONVOL data and low (negative)

scanning elevation angles. APQC consists of 3 main steps, which are 1) mitigation of persistent ground clutter, 2) mitigation of the AP clutter, and 3) correction of the reflectivity voids among the precipitation echoes due to the clutter removal. Case studies and real time testing showed that APQC is able to identify majority of the ground clutter under both normal and anomalous propagation conditions. One remaining issue is the AP clutter at far ranges, which is difficult to be separated from the shallow stratiform precipitation echoes, especially when the associated reflectivity field shows a relatively smooth texture due to the degradation of data resolution. Additional data sources such as satellite may help further mitigate such AP clutter. Also, the issue could be alleviated in the mosaic of a radar network because far range data may not be used when near range data from neighbor radar is available.

The APQC scheme is fully automated and highly efficient in computations; thus suited for operational applications. It would also be very useful for any other single-polarization radar networks.

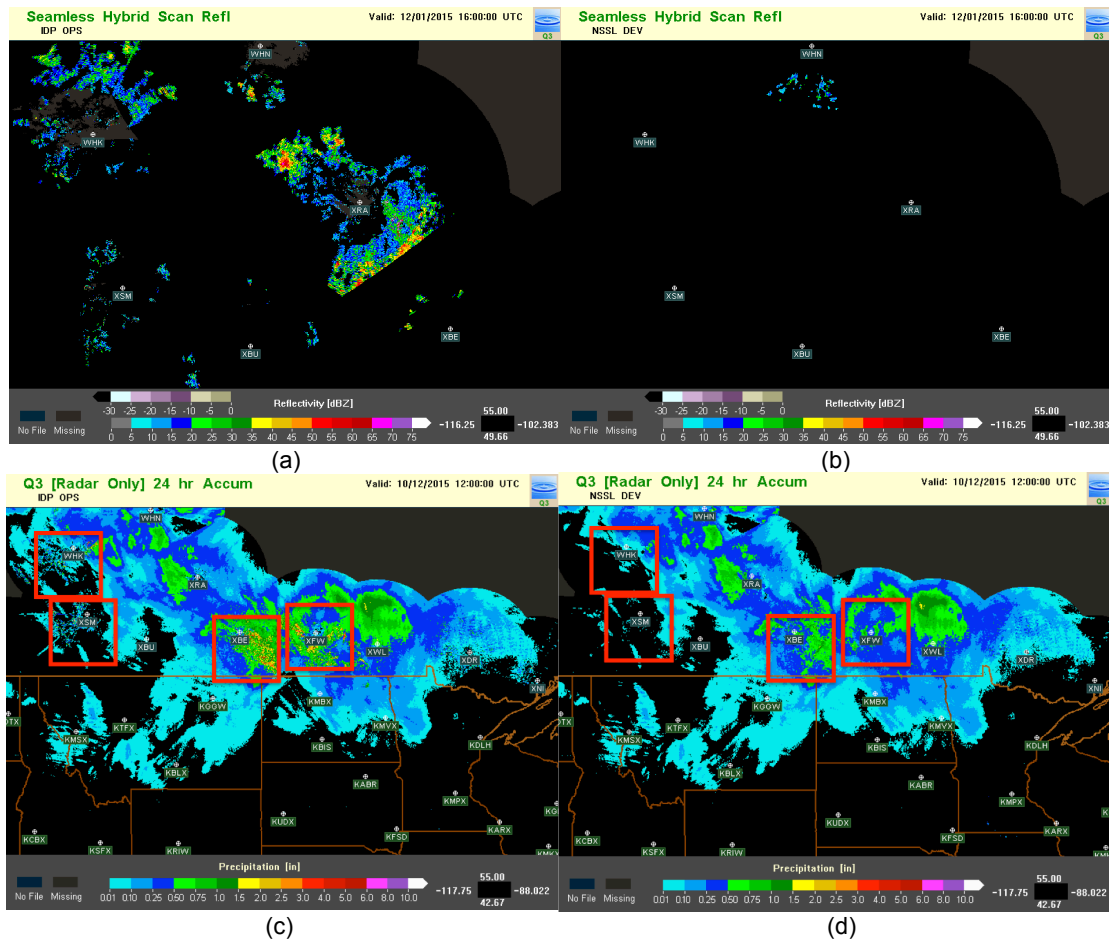


Fig. 5: The testing results using QCNN (a, c) and APQC (b, d) algorithms in MRMS system. Panels (a) and (c) show the seamless hybrid reflectivity fields and (b) and (d) the 24-hour QPE accumulations with the QCNN and APQC processing, respectively. The red squares highlighted the regions where the two schemes showed difference results with the severe AP clutter.

5. ACKNOWLEDGEMENT

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