A Quality Control Algorithm for the Osaka Phased Array Weather Radar

Juan J. Ruiz1,2,7, Takemasa Miyoshi2,3,4,7, Shinsuke Satoh5,7, and Tomoo Ushio6,7
1University of Buenos Aires, Buenos Aires, Argentina
2RIKEN Advanced Institute for Computational Science, Kobe, Japan
3University of Maryland, USA
4Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan
5National Institute of Information and Communications Technology, Koganei, Tokyo, Japan
6Osaka University, Suita, Osaka, Japan
7CREST, Japan Science and Technology Agency, Kawaguchi, Saitama, Japan

Abstract

This study develops and tests a quality control (QC) algorithm for reflectivity from the single polarization phased array weather radar (PAWR) in Osaka, with particular focus on clutter detection, in preparation for radar data assimilation into a high resolution numerical model. The QC algorithm employs a Bayesian classification that combines the information from different parameters based on reflectivity and radial velocity. To take advantage of PAWR’s unique high temporal and vertical resolutions, a new parameter based on the temporal variability of reflectivity is included. In addition, clutter probability estimations from previous volume scans are also included. The newly developed QC algorithm performs properly in two events characterized by heavy convective precipitation and stratiform precipitation.


1. Introduction

In recent years a large effort has been devoted to develop more effective prediction systems for convective-scale severe weather and to provide timely and precise warnings for local severe weather events. Weather radars provide valuable meteorological observations with a high temporal and spatial resolution. The phased array radar is the next generation of weather radars and is capable of providing particularly higher temporal and vertical resolutions. These high-resolution data are extremely valuable for monitoring severe weather more precisely, and may also be useful for very short range numerical weather prediction (NWP). Previous studies described quality control (QC) algorithms for radar reflectivity for different purposes such as rainfall estimation and data assimilation. These studies focused on the problems that affect the quality of the radar data: blocking by the terrain (Bech et al. 2003), non-meteorological echoes produced by non-weather related targets (Lackshamanan et al. 2007; Steiner and Smith 2002; Li et al. 2013; Hubbert et al. 2009 among others), second trip echoes, and attenuation (Delrieu et al. 1999a, 1999b). However, the previous studies usually assumed conventional parabolic-antenna radars.

Based on the previous studies, this study implements and tests a QC algorithm with particular focus on clutter detection for single polarization phased array radars. These radars have stronger side lobes and broader beams which can produce more ground clutter contamination than in conventional parabolic antenna radars. A measure of the temporal variability of reflectivity is used in the QC algorithm to take advantage of the high temporal frequency and high vertical resolution of the phased array radar data.

This QC algorithm aims mainly to generate radar reflectivity observations suitable to be assimilated into a high-resolution NWP model with an O(100)-m grid spacing, although in principle, the QC algorithm would be useful for other purposes like precipitation estimation. Section 2 describes the data and QC algorithm. Section 3 presents the results. Finally, Section 4 describes the conclusions and planned extensions of the QC algorithm.

2. Data and study method

2.1 Radar data

In this study data collected by the first Japanese phased array weather radar (PAWR), installed at the Osaka University, Suita Campus in 2012, is used (Ushio et al. 2014; Yoshikawa et al. 2013). The PAWR is an X-band (3.1 cm wavelength) one-dimensional phased array radar which can perform a full volume scan of reflectivity and Doppler velocity at a range resolution of 100 m in 30 seconds with a maximum range of 60 km and with about 100 vertical scan angles, providing a unique dataset with a high temporal and spatial resolution. PAWR radar uses a conventional Fourier digital beam forming technique to scan in the elevation range and a mechanically rotating antenna for the azimuthal scans (Ushio et al. 2014). De-aliased radial velocities in the range (+/-50 m s^-1) are obtained through a dual pulse repetition frequency approach.

For the development and evaluation of the QC algorithm data from two events are used: a convective heavy-rainfall event on 13 July 2013 that caused a disaster in Kyoto, and a stratiform precipitation event on 14 August 2012. The temporal scan frequency is 30 seconds for both cases while the number of vertical elevations are 98 (Fig. 1a) and 77 on the convective and stratiform cases, respectively.

2.2 Quality control algorithm

Before applying the ground clutter estimation filter, blocking by the topography is estimated using the approach of Bech et al. (2003). Here, all gates that are blocked by more than 60% are rejected and flagged as missing data. The radar beam height is...
estimated by assuming standard refracting conditions (Doviak and Zrnic 1993). The ASTER-GDEM (Advanced Space Thermal Emission and Reflection Radiometer global digital elevation model) terrain data available at http://gdem.ersdac.jspacesystems.or.jp is used to estimate the height of the beam over the terrain (Fig. 1b).

A speckle filter proposed by Zhang et al. (2004) is also applied as part of the QC algorithm. This evaluates the number of pixels exceeding 0 dBZ in a box with a size of $5 \times 11 \times 1$ pixels in the azimuth, radial and elevation dimensions. A pixel is detected as speckle if less than 30% of the pixels in the box are above 0 dBZ.

After applying the speckle filter a naive Bayesian classification approach (Rico-Ramirez and Cluckie 2008; Li et al. 2013) is used to detect the ground clutter based on 4 parameters. A brief description of the parameters used is given below:

- **Texture of the reflectivity (TEXT, Hubbert et al. 2009):** This parameter measures the spatial variability of the reflectivity field.
- **Texture of the reflectivity correlation with time (TRCT):** The correlation between reflectivity and time is computed over a 5 minute period (10 volume scans in case of the slowest 30-second azimuthal rotation of the Osaka PAWR), and its texture over the neighboring $5 \times 11 \times 1$ domain is obtained for each pixel. This parameter shows the spatial coherence of the temporal trend of reflectivity. Clutter exhibits a relatively large value of TRCT (low coherence), while meteorological echoes are characterized by small values of TRCT (high coherence).
- **Radial velocity average (RVA):** The temporal average of radial velocity over a 5-minute period (10 volume scans in case of 30-second azimuthal rotation scanning mode).
- **Vertical component of the reflectivity gradient (VGRADZ, Cho et al. 2006):** The vertical component of the reflectivity gradient computed over a height increment of 500 m. The local minimum of this quantity computed over a $5 \times 11 \times 1$ local neighborhood of each pixel is used.

To evaluate the skill of each individual parameter in distinguishing between clutter and meteorological echoes, a training sample containing both types of echoes is created as follows. A clutter mask obtained from a clear sky sample is applied to obtain a training sample for the QC algorithm from 0800 to 1300 JST 13 July 2013. Echoes with the echo tops lower (higher) than 3000 m a training sample for the QC algorithm from 0800 to 1300 JST 13 July 2013. Echoes with the echo tops lower (higher) than 3000 m are characterized by heavy convective precipitation, with a total number of 480 volumes. For the validation of the algorithm, the QC algorithm has been applied to radar data from 1400 to 1700 JST 13 July 2013 (characterized by heavy convective precipitation) and to radar data from 0711 to 0811 JST 14 August 2012 (characterized by stratiform precipitation), with a total number of 480 volumes.

First, an example of the performance of the algorithm for clutter-
ter detection on the heavy precipitation event is presented. Figures 3a, b show the distributions of the original and quality controlled reflectivity at the second elevation angle. Most of clutter has been eliminated by the QC algorithm, while precipitation echoes are preserved. Precipitation echoes can be recognized in this case with the 30 dBZ reflectivity contour at an elevation angle of 5.3 degrees displayed in Fig. 3b. Figures 3c, d show vertical cross sections at 81 degrees azimuth; this particular azimuth includes a mixture of precipitation echoes and clutter. The QC algorithm detects ground clutter between 0 and 20 km from the radar, but a part of the clutter associated with the mountains around 30 km is not well detected. Meteorological echoes are almost unaffected by the clutter detection algorithm.

Figures 4a, b, c, d show the distributions of the clutter probability computed using each individual parameter as the only classifier. We can see that the RVA, TEXT, TRCT and VGRADZ parameters show a high spatial coherence distinguishing between meteorological echoes and clutter. The TRCT parameter identifies clutter near the ground but it also detects areas with low spatial coherence in the reflectivity trend near the cloud edges, particularly away from the radar. The TEXT parameter produces high clutter probabilities not only associated with ground clutter but sometimes near strong reflectivity cores such as the ones near the cell located at 20 km from the radar. This is a known limitation of TEXT discussed by Zhang et al. (2004). The TRCT parameter produces better results in this area indicating low clutter probability.

Figure 5 shows the case dominated by stratiform precipitation, and here, ground clutter is mixed with precipitation. Most low level clutter is detected in this case although the algorithm fails, for example, to detect clutter contaminated pixels near 34.6°N, 135.4°E. Vertical cross sections (Figs. 5c, d) show a good performance of the algorithm to detect ground clutter mixed with precipitation echoes.

Figures 6a, b, c, d show clutter probability using each individual parameter as the only classifier for the same cross sections presented in Figs. 5c, d. The TRCT parameter shows a good performance in this case, too, detecting high clutter probabilities in an area close to the one detected by the RVA parameter and similar to the area frequently affected by clutter as indicated by the clutter mask (Fig. 6c). Clutter probabilities in the area dominated by weather echoes associated to the TRCT parameter are higher in this stratiform case than in the previous convective case. This might be because reflectivity trends of stratiform precipitation tends to be lower due to the spatial homogeneity of the precipita-

![Fig. 3. PPI display of the (a) original and (b) clutter removed reflectivity (dBz) corresponding to the second elevation angle. The black rings indicate the height of the radar beam with a 1000 m interval. In (a) the contours indicate probability of clutter greater than 10% as derived from the clear-air clutter mask. In (b), the contours indicate the 20 dBz reflectivity at the 7th elevation angle. RHI display of the (c) original and (d) clutter removed reflectivity for the 81° azimuth. The black line indicates the height of the topography. Dark grey shades indicate pixels blocked by the topography, and light grey shades indicate pixels identified as clutter by the QC algorithm. All panels correspond to 1520 JST, 13 July 2013.](image1)

![Fig. 4. RHI display for the 81° azimuth of clutter probability obtained from each individual parameter (a) RVA, (b) TRCT, (c) TEXT, (d) VGRADZ, (e) clutter probability obtained with the Bayesian classification algorithm, and (f) mean reflectivity in the clear-air clutter mask at 1520 JST, 13 July 2013. The 99% probability of having ground clutter is also indicated by black contours in (f). The black lines displayed in all panels indicate the height of the topography. Dark grey shades indicate pixels blocked by the topography.](image2)

![Fig. 5. Similar to Fig. 3, but for the first elevation angle (a and b), the 180° azimuth (c and d) and corresponding to 0721 JST, 14 August 2012.](image3)
tion field, so that the reflectivity trend may be more vulnerable to noise even in weather areas. TEXT performs worse than TRCT in this example, failing to detect low level clutter between 20 and 30 km from the radar.

A statistical verification of the QC algorithm has also been performed. A human expert classification of the echoes has been performed to construct a verification dataset. In both cases the verification dataset is consistent on the identification of two different regions: one dominated by ground clutter and the other dominated by meteorological echoes.

The objective verification has been performed using 5 versions of the QC algorithm:
• NOPRIOR: The Bayesian classification is performed by assuming a 0.5 a priori probability of clutter for each pixel. The four parameters (RVA, TEXT, TRCT and VGRADD2) are used. No echo top and echo depth filter is applied in this case.
• NOTRCT: Similar to NOPRIOR, but TRCT is not used. This aims to investigate the impact of the TRCT parameter.
• NOTEXT: Similar to NOPRIOR, but TEXT is not used.
• PRIOR: Similar to NOPRIOR, but the Bayesian classification is performed using the clutter probability computed in the previous classification as an a priori probability.
• ETOP: Similar to NOPRIOR, but the echo top and echo depth filters are used.

Table 1 shows the probability of detection (POD), false alarm ratio (FAR), critical success index (CSI) and equitable threat score (ETS) for the clutter detection obtained with the different experiments and for the two verification periods. The results show that the QC algorithm is performing generally well and that verification scores are comparable with the previous studies (Cho et al. 2006; Lakshamanan 2007; Li et al. 2013). Not surprisingly, the QC algorithm is worse when the clutter and precipitation are present simultaneously as in the case dominated by stratiform precipitation. In Table 1, pixels with clutter probability over 0.5 have been classified as clutter. All the scores are sensitive to this threshold. For instance, for NOPRIOR experiment, POD ranges from 0.89 to 0.97 when the threshold goes from 0.1 to 0.9, while CSI reaches a maximum value of 0.94 when the threshold is 0.7 and a minimum of 0.89 for a threshold of 0.1.

Comparing NOTRCT and NOPRIOR suggests that the TRCT parameter reduces FAR. Moreover, NOTEXT shows better results than NOTRCT in both POD and FAR, indicating that TRCT was superior to TEXT in these cases. This coincides with the behavior observed in the examples presented in Figs. 4, 6.

PRIOR uses the clutter probability obtained in the previous scan as an a priori probability for the classification of the next volume and shows the results with lower FAR and larger POD for the convective case, but produces no significant impact in the stratiform case. This approach works as an adaptive clutter mask that might help smooth out random noise in the classification.

The inclusion of the echo top and echo depth filters produces an increase in POD for both cases but a significant increase in FAR, too. The increase in FAR produces a degradation of CSI and ETS which are the lowest. This increase in FAR is produced by weather echoes corresponding to shallow elevated echo layers that are filtered by the echo depth filter.

The significance of the difference in the scores among the different experiments are tested using bootstrapping technique and 1000 realizations indicating that are all significant with a 95% confidence level.

4. Conclusion

A QC algorithm has been developed and applied to the Osaka PAWR data for convective and stratiform precipitation events. The proposed QC algorithm takes advantage of the frequent sampling capability of PAWR by relying on the TRCT parameter that is based on the temporal evolution of the signal. The QC algorithm was also capable to detect ground clutter combining TRCT with 3 additional parameters that describe the 3-dimensional structure and the temporally averaged radial velocity. The TRCT parameter presented in this study shows a promising performance in clutter detection. TRCT also shows low values in the areas of strong reflectivity, while texture might have problems in separating strong echoes from clutter (Zhang et al. 2004).

The use of a prior based on the result of the QC algorithm for the previous volume was also evaluated. This approach also aims to take advantage of the frequent scanning of PAWR. It has been shown that using a prior, reduces the number of false alarms and increases POD.

Although these results are promising, these are representative of the performance of the QC algorithm for the detection of ground clutter. It would be an important subject of future research to evaluate the performance of the algorithm under other meteorological situations (i.e. anomalous propagation, biological targets, sea clutter, etc.).

Many studies have shown that clutter detection can be improved by the use of parameters derived from the phase and power of the signal in the spectral domain (e.g. Li et al. 2013; Hubbert et al. 2009). The combination of TRCT with these parameters would be also an important subject of future research. A minimum mean square error (MMSE) beam forming technique which will help to mitigate clutter contamination is also under development (Yoshikawa et al. 2013) and will be implemented at Osaka PAWR in the near future.

Since the QC algorithm described in this paper is designed for a potential application in operational radar data assimilation, computational efficiency is an important issue. In its current
implementation, the algorithm takes approximately 40 seconds to process a single scan in a computer with four 8-core Intel Xeon E5-4620v2@2.6GHz CPUs (total 32 cores). This is slower than the 30-second volume scan, and we keep getting more data than processing. Further optimization to accelerate the computations is necessary for real-time application.

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**References**


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