14.2 WSR-88D Radar Data Processing at NCEP

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1. Introduction

Weather Doppler radar has the capability to scan large volume of the atmosphere at high spatial and temporal resolutions. The weather Doppler network of Weather Surveillance Radar-1988 (WSR-88D) Next-Generation Weather Radars (NEXRAD) provides invaluable observations for capturing the atmospheric conditions. The images from radar observations are successfully used to detect severe weather and warn of thunderstorms (Burgess, 2004, Mitchell et al. 1998; Vasiloff 2001 and Liu et al. 2007). The use of high-resolution radar data to improve numerical weather prediction (NWP) is also active in the academic and research communities. A number of algorithms have been developed over the years to initialize numerical prediction models by assimilating the radar reflectivity and/or radial wind observations. These bodies of research indicate that the utilization of radar data has great potential to improve the NWP forecasts (Xue et al. 2000).

However, progress in the use of high-resolution Level-II data in operational NWP models has been much slower than that used by the research community over the years (Weygandt and Stan 2007; Albert and Kumar 2007). Some of the key outstanding problems for the lack of progress may be attributable to: (1) the relatively large volume of radar data restricting the data to be transmitted to the operational center in real time; (2) the radar data decoding software and storage taking excessive computational resources; (3) the various of radar data quality problems further limiting the applications of radar data for operational uses. Recently, with the success of the Collaborative Radar Acquisition Field Test (CRAFT) project (Droegemeier et al, 2000) NCEP has been accessing the level II data in real time from a net work of 136 National Weather Service (NWS) WSR-88D radars since May 2005. National Centers of Environmental Prediction (NCEP) Central Operations (NCO) assigned a dedicated node with 32 processors at the NCEP's operational supercomputing environment to process level-II radar data in real time. With the addition of CPU and disk storage resources, the first two obstacles were circumvented, an efficient system to process the raw level-II radar data must be then developed. This system should be reliable and efficient enough to remove radar data quality problems and provide level-II radar data product to support the NCEP operational applications using the radar data.

In this paper, the radar data processing system at NCEP is reported in detail. A flowchart of radar data processing is introduced in Section 2. The implementation of QC package is described in section 3 and the performance of QC package is examined in section 4. A summary is provided in section 5.

2. Radar data processing at NCEP

The WSR-88D radar data processing system at NCEP comprises of the following components outlined in the flowchart shown in Fig. 1. (1) Local Data Management (LDM) system is used to receive compressed raw level-II radar data at NCEP/NCO. Uncompressing and decoding software developed by NCO are used to obtain radial wind, reflectivity and spectrum width. (2) The uncompressed and decoded reflectivity data at elevations 3.5° and 4.5° are used to estimate mixing layer height based on "ring" features shown in reflectivity (Pam et al. 2009). (3) Then comprehensive QC packages are implemented to radial wind and reflectivity data to deal with various QC problems. (4) For each volume scan, the quality controlled radial wind and spectrum width data are stored into BUFR data tanks. The radial wind data are dumped every 3 hour and used by NCEP's regional data assimilation system to improve the WRF-NMM

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model forecast. The quality

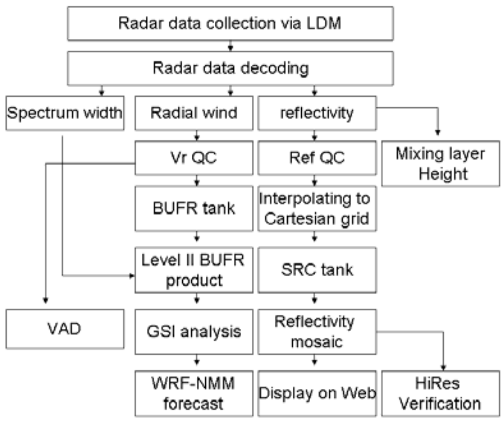

Fig. 1. Flowchart of radar data processing at NCEP

controlled radial wind are further used to calculate Velocity Azimuth Display (VAD) winds for each station. (5) Quality controlled reflectivity fields are further interpolated from radar polar grid to Cartesian grid via a Single Radar Cartesian (SRC) (Zhang et al. 2005) package. Gridded reflectivities from each volume scan are put into a buffer area first and 3D reflectivity mosaic package developed by NSSL is used to dump 3D reflectivity product and derived products in an unified Cartesian coordinate. The derived products currently include composite reflectivity and echo top. 3D reflectivity products are assimilated into Rapid Update Cycle's (RUC) operational model. The derived products are also used for high resolution composite reflectivity verification at NCEP. The whole WSR-88D radar data processing system is found to be robust in operation since its implementation in May 2005. Among the above steps, radar data QC algorithms have evolved over time and found to bear a beneficial impact on the ease of applying radar data. We will discuss the NCEP QC algorithms in detail in Section 3.

3. Radar data quality control

A prototype real-time radar data QC algorithm developed by Liu et al. (2003) were improved and implemented in operation at NCEP since May 2005. A flowchart of NCEP radar data QC is shown in Fig. 2. The key functionalities of the NCEP radar data QC involve seven steps to remove and correct unqualified radar observations in operation. (1) The super resolution (0.5^o x 250 m) raw level-II data are recombined to the legacy resolution (1^o x 250 m for radial winds and spectrum width and 1^o x 1000 m for reflectivity) and all three observation variables radial wind, reflectivity and spectrum width, are used as input to the QC package. (2) A fussy-logic based ground or sea clutter detection algorithm (Liu et al. 2008; Kessinger et al. 1998) is applied first to remove clutters in radial wind and reflectivity. (3) After clutter removal, an improved version of radial velocity dealiasing algorithm based on Gong et al. (2003) is then used to correct or remove aliased radial velocity. (4) Sunbeam filter is applied to remove unqualified returns when the antenna of radar aims at the sun. (5) After the above steps, the QC statistical parameters on each tilt are calculated. QC parameters contain the standard deviation of radial wind (STD), percentage of radial wind sign change along radial direction (SC), Mean Reflectivity on a tilt (MRF), Percentage of along-beam perturbation velocity Sign Changes (PSC), radial velocity data coverage (VDC) and the maximum number of velocity-jump between adjacent beams (NJV). (6) The above QC parameters are subsequently used to identify migrating bird first with the Bayesian method developed by Zhang et al. (2007) and Liu et al. (2007). (7) Finally the statistical QC parameters are further used to eliminate noisy and other bad-quality data based on the probability distribution of QC parameters. If the calculated values of QC parameters fall into the area of small probability, data on the tilt are rejected. The data that pass through successfully all the steps in QC are stored into BUFR data tanks for further use by the NCEP's North American Mesoscale (NAM) Data Assimilation System (NDAS).

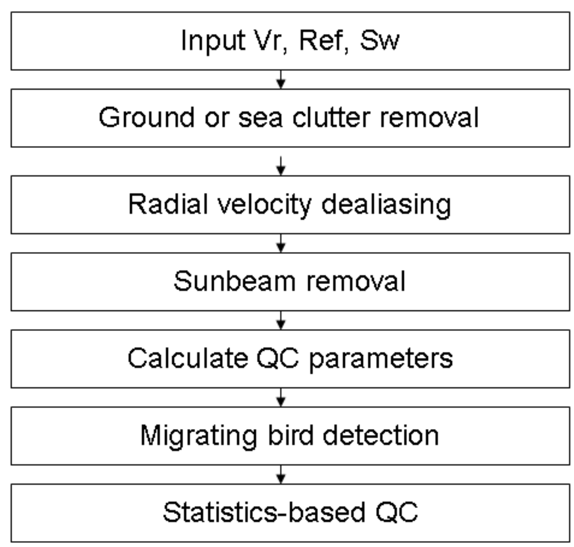

Fig. 2. Flowchart of radar data QC at NCEP.

4. Performance of radar data QC

a. Radial wind QC

Since there are a lot of conventional wind observations available at NCEP in operation from other instruments, such as rawinsonde, profiler, aircraft etc., and the radial wind forward model in data assimilation is simple and linear, it is relatively easy to examine the performance of radial wind objectively by using other independent observations. NAM analysis is performed first. All observational data used in operation except the radar radial wind are analyzed with regional data assimilation system. The analyzed winds are used as reference winds to examine the performance of radial wind QC. Reference winds are projected to radial direction at radial wind observation locations. Scatter plots of radial wind with and without QC are shown in Fig. 3a and Fig. 3b. The x and y-axes are magnitude of observed radial wind and reference radial wind, respectively. If observations agree with the reference data, data points will fall on diagonal line in the figure in an idealized situation. If data points deviate farther from the line of best fit, large bias exists between observed and reference radial wind. It is clear that data points have a large scatter prior to QC (Fig. 3a) than with QC (Fig. 3b). In particular, dramatic large differences between the observed and reference radial wind are found in left-upper corner and right-lower corner. These differences are larger than 20 m/s. The large difference may be attributable to issues pertaining to data aliasing. Clearly, assimilating raw data without any QC directly into NWP model has high potential to degrade the forecast skill. Large differences are also found when observed radial winds are near zero, which may be caused by ground or sea clutters in the returned echoes. After applying QC, most of the data points with large bias in Fig. 3a are eliminated in Fig. 3b. It is shown that the bias between the observed and reference radial wind has reduced considerably with the application of QC. Overall, various diagnostics from the current radial wind QC package indicate reasonably good performance in rejecting unqualified data.

After the above radar data QC package was implemented at NCEP in May 2005, the radial-velocity QC technique has been further improved and tested through detailed case studies (Xu *et al*. 2009). The improved technique has been incorporated into the recently upgraded QC package at NCEP. This upgraded QC package is expected to yield further improved statistics than those presented in Fig. 2,

b. Reflectivity QC

Deriving radar reflectivity data directly from other sources of observations in operation are currently not feasible which constrains seriously a direct and quantifiable measure to examine the performance of radar reflectivity QC within the framework of current operational data sets. Currently, the performance evaluation of reflectivity QC mainly relies on human expertise. The pictures of composite reflectivity from 3D reflectivity mosaic in real-time are displayed at NCEP's webpage on http://www.emc.ncep.noaa.gov/mmb/wx22hl/REF. The performances of reflectivity QC are then monitored by NCEP's and NOAA's Global Systems Division's users. Based on the feedback from users, reflectivity QC package to date is able to reject most of the contaminated or unqualified data by tilt.

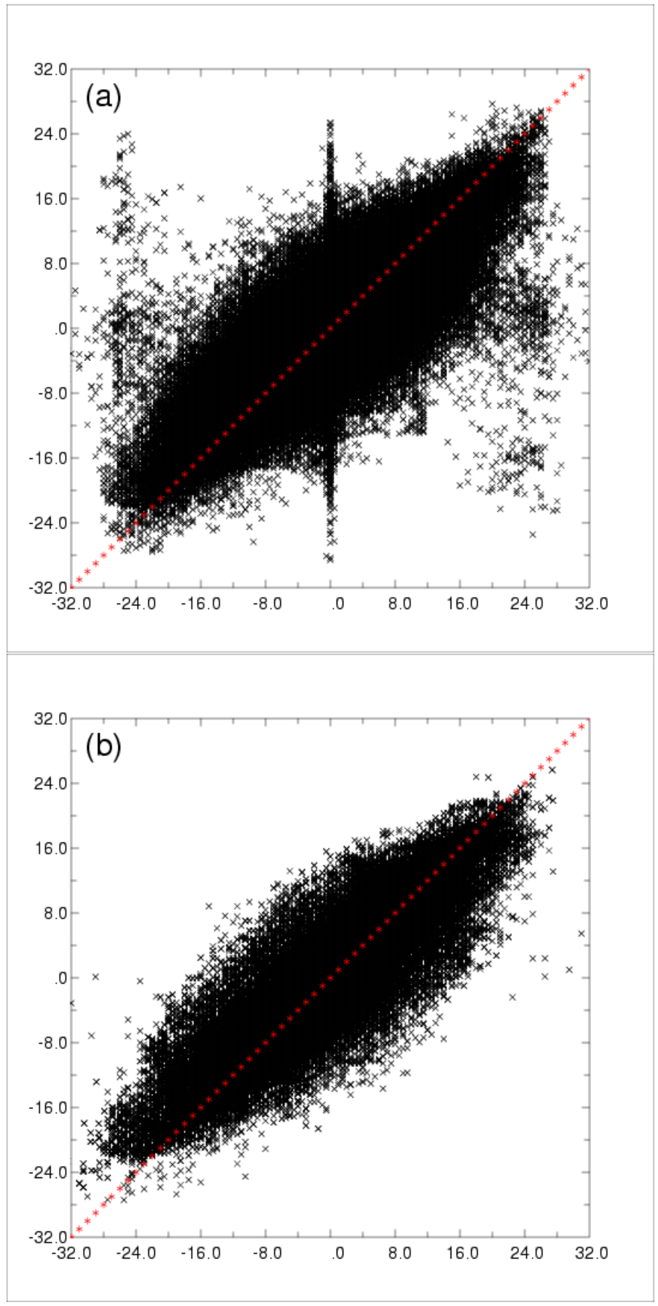

Fig. 3. Scatter plots of radial wind before (a) and after QC (b)

An example of composite reflectivity with and without reflectivity QC is shown in Fig. 4a and 4b. Without reflectivity QC, blue-disk like echoes emerge throughout the CONUS as shown in Fig. 4a. This may be caused by clear-air echoes or unphysical (non-meteorological) echoes. Application of QC package instantly eliminates most of the contaminated or unqualified data retaining most of the physical or meteorological echoes as displayed in Fig. 4b. However, some unqualified data are still observed which are not completely discarded by the QC algorithms as seen in Fig. 4b. For example, echoes from KILX in the central Illinois are shown in Fig. 4b. The blue-disk like features are observed from this station. The reflectivity is around 15-20 dBZ near the center of radar station. These observations may not be meteorological echoes. On the north of the station, there are some convective cells with reflectivity larger than 30 dBZ. Due to mixing between meteorological and non-meteorological echoes, current reflectivity QC fails to reject this tilt. To properly identify unqualified data from the same radar scan, more complex methods are needed to further check the quality of reflectivity by pixels instead of by tilts.

5. Summary

Several key characteristics of WSR-88D radar data processing and radial wind and reflectivity QC algorithms at NCEP are reported in detail. Most of components in the data processing system have been implemented in operation for more than two years. A few improved components are currently under parallel testing for planned operation in the near future. The whole data processing is proven to be efficient and effective. However, radar data QC in the system is not perfect. There is still room for further improvement in the radial wind and reflectivity QC by using other sources of observations, for example satellite images. Elaborate QC method may be considered for operational implementation for identifying QC problem pixel-by-pixel instead of tilt-by-tilt in current operation when adequate computational resources become available at NCEP. In addition, TDWR radar data from 46 stations will be delivered to NCEP in the near future. New observation variable from the NWS's upgraded dual-pole WSR-88D radar network is scheduled to deliver data to NCEP in the beginning of 2010 and this new data certainly require several enhancements with regard to computing power, disk storage, data flow network and development of totally new QC algorithms thereby posing several new challenges to the NCEP's radar data processing system and product line. Efforts on further improving current radar data processing at NCEP are constantly needed.

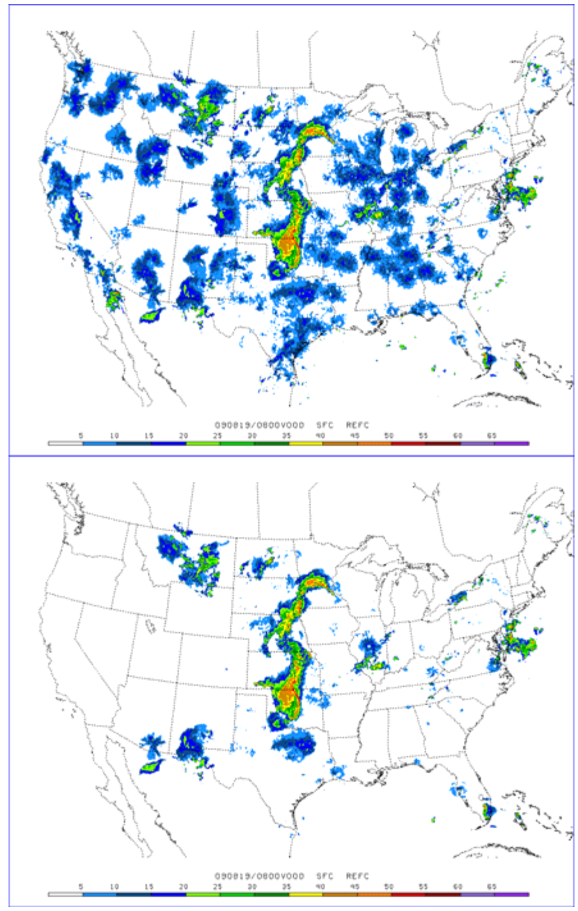

Fig. 4. An example of composite reflectivity before (a) and after QC (b) at 0000 Z on Aug 18, 2009

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