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CONTINUING ENHANCEMENT OF THE WSR-88D PRECIPITATION PROCESSING SYSTEM

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1 Introduction

The Precipitation Processing System (PPS) was delivered to the field with the first operational Weather Surveillance Radar, 1988 - Doppler (WSR-88D). Over the years, a number of enhancements have been made to the PPS and to the WSR-88D that improve the quality of radar rainfall estimates. However, in the past few years new programmatic involvement by the National Weather Service (NWS), the application of modern computer technology, and the culmination of WSR-88D algorithm development have combined to accelerate the continuing enhancement of the WSR-88D quantitative precipitation estimates (QPEs).

1.1 WSR-88D Technology Transfer - Focusing Resources

Most of the difficulties estimating rainfall from radar data have been known for years and are well described by Wilson and Brandes (1979). The Radar Operations Center (ROC) continues to work with the NWS Office of Hydrologic Development (OHD), Office of Science and Technology (OS&T), the National Center for Atmospheric Research (NCAR), and the National Severe Storms Laboratory (NSSL) to overcome or mitigate those difficulties by improving the accuracy and reliability of WSR-88D reflectivity data and developing new scientific techniques. Most of the enhancements discussed in this paper are the direct result of this cooperation.

2 Current Status/Recent Enhancements

2.1 ORPG

The originally mainframe-based Radar Product Generator (RPG) was recently rehosted to a Unix-based Open platform (ORPG). The ORPG offers substantially greater processing capability, allowing the development of more comprehensive meteorological and hydro-meteorological algorithms. In addition, the ROC has adopted a fixed 6-month cycle for ORPG software builds (Table 1) to facilitate the development and implementation of new radar analysis techniques.

Build#	2	3	4	5	6	...
Delivery	Sep	Mar	Sep	Mar	Sep	...

Table 1. ORPG software build schedule.

2.2 REC AP/Clutter Identification

The Radar Echo Classifier (REC) algorithm was developed by NCAR (Kessinger et al., 2003). It applies fuzzy logic techniques to identify the likelihood, on a bin by bin basis, that the radar target belongs to a certain category. The REC anomalous propagation (AP) clutter identifier (APID) was implemented in ORPG build 2 to guide operator clutter filtering decisions. The APID will also be used to help automatically remove AP/clutter contamination from the PPS (see section 3.2). NCAR has developed an additional REC functionality that identifies precipitation echoes to help remove clutter filtering biases from PPS products (see section 3.3).

2.3 PPS Error Corrections

Several minor errors have been discovered and corrected in the PPS code during the years since it was deployed. The most significant was a recent discovery that the truncation logic used in the PPS to internally store rainfall rates and accumulations into the two byte data format required by the old RPG hardware was causing an underestimation bias in the PPS products (Fulton et al., 2003). This bias were related to the length of time that rain occurred at a radar grid point, so the effects were most evident in long term rain events with extensive coverage. The recent software corrections have removed biases that were as much as 40% in the hourly WSR-88D products.

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2.4 AWIPS Mean Field Bias Adjustment

The Advanced Weather Information Processing System (AWIPS) uses radar rainfall estimates and rain gage data to compute a mean field bias (MFB) correction (Seo et al., 1999). The MFB correction information is sent to the WSR-88D ORPG where operators can apply it to remove systematic radar biases from PPS accumulation products in real time.

3 Near Future

The next few ORPG software builds will contain major enhancements that improve operational WSR-88D scan strategies, alter the functional structure of the PPS, and mitigate significant radar biases.

3.1 Optimized Scan Strategies

The WSR-88D has operated with the same four scan strategies (volume coverage patterns [VCPs]) since the radars were deployed. These VCPs are based on a vertical spacing of at least one degree between tilts. NSSL has developed new VCPs (Brown et al., 2000 and Scott et al., 2003) which optimize the vertical spacing of the tilts, increasing the sampling density at lower elevation angles. The improved vertical sampling resolution will allow the radars to define weather hazards at greater distances and will decrease the discontinuities in precipitation products caused when the lowest elevation data is blocked or contaminated.

Several new scan strategies are planned for implementation in the next few builds. The first, VCP 12 (planned for build 5), is designed for deep convection. It contains the same number of unique tilts (14) as the legacy VCP 11 but completes a volume of data in 4.1 minutes, nearly a minute faster than VCP 11. Future builds will include a still faster VCP designed for rapidly evolving storms and VCPs that better define clear air and shallow convection.

3.2 EPRE

The PPS Preprocessing algorithm builds Hybrid Scans of reflectivity containing the data from the lowest elevation angle that is not contaminated or blocked. The Hybrid Scans are used to compute precipitation estimates and are the basis of the Radar Coded Message (RCM). The legacy Preprocessing algorithm required fixed elevation angles and was not easily modifiable to work with new VCPs. The ROC and OHD used this opportunity and the increased capability of the ORPG to design and develop an enhanced Preprocessing (EPRE) algorithm. The EPRE refines the PPS preprocessing logic and makes use of new and improved information to mitigate clutter contamination and beam blockage.

The enhanced Preprocessing (EPRE) algorithm is scheduled to be implemented in ORPG build 5. It uses finer resolution and higher precision blockage information, replaces the “Tilt Test” with a bin by bin AP/clutter removal technique based on the APID likelihood, and removes the linkage to a WSR-88D software function that has inadvertently caused degraded precipitation estimates in the legacy PPS.

3.3 Compensating for Clutter Filter Bias

It is well known that applying a clutter filter to precipitation targets can remove substantial amounts of the weather signal where Doppler velocity and spectrum width values are near zero. This results in a persistent reflectivity bias that can reach several dBZ. The effect on PPS products is most noticeable in regions where the wind field is fairly homogenous over long periods of time, for instance during slow moving coastal rain events. The following two algorithms were developed by NCAR to automatically remove clutter filter bias from precipitation estimates in real time. They are planned for implemen-tation in ORPG build 6.

3.3.1 ZCOMP

The Reflectivity Compensation (ZCOMP) algorithm (Ellis, 2001) computes the expected reflectivity loss caused by clutter filtering. The loss is primarily a factor of the clutter filter characteristics and the radar base reflectivity, velocity, and spectrum width data values. ZCOMP presents the expected loss information as a lookup table of corrections that can be applied to remove the bias from each radar bin.

3.3.2 REC Precipitation Identification

It is important to limit the reflectivity compensation to regions of precipitation to ensure that reflectivity data from AP and ground clutter targets are not artificially enhanced. Kessinger et al. (2003) developed a REC Precipitation Identification (PID) module to define the radar bins that should be compensated. The PID uses base radar data and data patterns in the small regions surrounding each bin to identify the likelihood that the radar bin is precipitation.

3.4 RCA

The PPS tries to use reflectivity data that is closest to the ground, assuming that data best represents the precipitation falling at the surface. Because the vertical profile of reflectivity (VPR) is nonuniform, the radar beam height increases and the beam widens with range, and the beam can overshoot precipitation targets, reflectivity data from longer ranges or from higher elevation angles are generally less representative, particularly in stratiform or orographic rain events. It can be argued that these range/height biases are the single greatest factor degrading and restricting the usable range of radar precipitation estimates.

Seo et al. (2000) developed a Range Correction Algorithm (RCA) based on the real time monitoring of the VPR. The RCA computes a mean VPR from the base reflectivity data, then derives range/elevation angle correction factors considering the radar beam height and width. In addition, the RCA estimates the maximum height for radar precipitation detection and uses that height to define the maximum range for reasonable QPE for each elevation angle.

The RCA has shown significant skill in defining VPRs and correcting reflectivity values during stratiform rain and winter snow events, including the identification and removal of 'bright band' contamination. Work continues on ensuring that convective storms (see section 3.5) and clutter contamination are removed from the VPR processing. The RCA is planned for implementation in ORPG build 6 or 7.

3.5 CSSA

Vertical reflectivity gradients are more spatially inhomogeneous in convective rain than in stratiform rain and, on average, convective reflectivity values change less drastically with height. In addition, the misapplication of range corrections in convective storms could degrade flash flood monitoring and warnings. The OHD is developing a Convective Stratiform Separation Algorithm (CSSA) that will define radar bins to be excluded from VPR computation and range correction. The CSSA is planned for implemention in ORPG build 7.

4 ORDA

The WSR-88D signal processing functionality is being modernized to an open environment using Red Hat Linux. (Cate et al., 2003 and Elvander et al., 2001). The system, called Open Radar Data Acquisition (ORDA), is based on a Sigmet RVP8 processor. The new processing capability will allow the development and implementation of new and improved techniques to retrieve radar weather information and to resolve radar data quality issues. The ORDA deployment is planned for the autumn of 2004.

4.1 Migrating REC and ZCOMP

The performance of the REC and ZCOMP algorithms may be improved by moving that processing logic to the ORDA where the base data can be obtained with higher resolution and unfiltered data will available for all radar bins. In addition, locating these algorithms in the ORDA allows the implementation of automated clutter filtering decisions (see section 4.2).

4.2 Automated Clutter Mitigation

NCAR has developed a process to automatically control clutter filtering (Ellis et al. 2003) by using the APID to identify regions of clutter and then compensating when areas of precipitation are filtered. The process was originally planned for implementation in the ORPG but that implementation was complicated by the unavailability of unfiltered radar data. The pending deployment of the ORDA has redirected the investigation of automated clutter filtering decisions. Additionally, the spectral processing capability in the ORDA (section 4.3) may remove the need to use REC and ZCOMP logic in an automated clutter mitigation process.

4.3 Frequency Domain Processing

The legacy RDA uses pulse pair processing to derive radar base data from the returned radar signal. The increased processing ability of the ORDA provides the capability to spectrally process WSR-88D radar data in the frequency domain in real time. Spectral processing should drastically improve radar data quality by mitigating Doppler range/velocity ambiguities (Sachidananda and Zrnic, 1999), simplifying the removal of clutter and point targets, and allowing more precise retrieval of the reflectivity and Doppler data from weather targets (Keeler and Passarelli, 1990).

4.4 Dual Polarization

The NSSL and NCAR have shown that the additional weather radar information obtained using dual polarization can greatly improve radar QPE, particularly in heavy rain and flash floods (Vivekanandan et al. 1999), removing the biases caused by partial beam blockage, radar miscalibration, and hail contamination. It is expected that polarimetry will be implemented in the WSR-88D within the next few years.

5 Summary

The WSR-88D QPE has undergone systematic and continuing enhancement over the last several years as the ROC and OHD have worked with research partners to mitigate problems associated with radar rainfall estimation. Efforts have been aimed at increasing the accuracy and reliability of the PPS, improving radar data quality, and extending the range of useful precipitation estimates. The culmination of development efforts along with recent technological advances promise to accelerate these enhancements over the next few years.

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