14.6 NEXRAD PRODUCT IMPROVEMENT—IMPLEMENTING NEW SCIENCE

Michael J. Istok[1]*, R. Elvander[1], R. Saffle[1], J. Roe[2]

[1] National Weather Service/Office of Science and Technology, Silver Spring, Maryland
[2] National Weather Service/Office of Hydrologic Development, Silver Spring, Maryland

1. INTRODUCTION

This is an exciting new era for NEXRAD radar applications. Network deployment of the WSR-88D Open Systems Radar Product Generator was completed in August 2002. The expansion capacity of this system upgrade is enabling the operational implementation of new scientific applications to improve the forecast and warning missions of the NEXRAD agencies.

The Common Operations and Development Environment (CODE), developed to streamline the transfer of technology into the WSR-88D operational baseline is being used by research and development organizations to implement and demonstrate enhancements to the WSR-88D (Saffle et al., 1998).

The National Weather Service (NWS) and the Federal Aviation Administration (FAA) have identified and prioritized future NEXRAD system functionality (Saffle et al., 2003) and have created software engineering groups to implement agency-specific scientific enhancements.

The WSR-88D software development and maintenance paradigm was refined to incorporate the concept of NEXRAD applications being developed and evaluated by several organizations using CODE on RPG clones, and the decoupling of techniques development from the software release cycle.

With this paradigm shift along with the ORPG design and CODE, agency-sponsored mature applications are being smoothly integrated into the WSR-88D baseline following an efficient defined process, schedule milestones are being met, WSR-88D software containing greater functional improvements are being released every six-months, and the quality of the deployed system remains high.

Through the NEXRAD Product Improvement Program, software engineering of agency-specific scientific enhancements is being conducted at the NWS Office of Science and Technology (OST) Systems Engineering Center (SEC), NWS Office of Hydrologic Development (OHD), and MIT/Lincoln Laboratory. The SEC and OHD implement NWS specific-applications, Lincoln Lab implements FAA specific-applications, and there is collaboration on applications of joint interest. Although the Air Force Weather Agency (AFWA) has not yet sponsored development of new applications, request and display of the NWS and FAA-sponsored enhancements are available to the AFWA Open Principle User Position (OPUP) system.

This paper describes the functionality of the enhancements deployed in 2002 and the first half of 2003 and the process by which they are developed, tested and deployed.

* *Corresponding author address*: Michael Istok, NWS, W/OST32, 1325 East West Highway, Silver Spring, MD, 20910 (Michael.Istok@noaa.gov)

The views expressed are those of the author(s) and do not necessarily represent those of the National Weather Service.

2. FUNCTIONALITY

Functional enhancements have been deployed in Open RPG Builds 1, 1.2, 2 and development is progressing for future builds scheduled for release every six months. Enhancements developed by the NWS for RPG Builds 1.2, 2, and 3 are described below. Enhancements developed by Lincoln Laboratory for the FAA are described in Smalley and Bennett. (2003).

Deployment of the RPG Build 1.2 began in March 2002, Build 2 began in September 2002, and Build 3 deployment is scheduled for March 2003. Deployment of the AWIPS Build 5.2.1 began in May 2002, Build 5.2.2 in October 2002, and Operational Build 1 (OB1) is scheduled for February 2003. Deployment of each software build can take up to three months to complete.

2.1 Full Resolution Base Products

Full resolution base reflectivity and velocity products were provided with RPG Build 1.2 and are displayable with AWIPS Build 5.2.1. These products are at the same resolution and coverage area as the RDA base data. Consequently, they are very large (160-330 Kbytes) and so the high speed RPG-AWIPS TCP/IP product distribution interface is needed to acquire them in a timely manner. In RPG Build 2 these products became replayable, meaning that a product will be generated and distributed immediately upon one-time request. In AWIPS OB1, the capability to remove a specified storm motion from the full resolution base velocity product will be available. Full resolution base products will improve the visual identification of mesocyclone and tornado vortex signatures. An example of this improvement is shown by comparing Figures 1a and 2b. Notice as compared to the standard Storm Relative Velocity product, how the mesocyclone signature is much more apparent in the full resolution product with its fourfold increase in range resolution and the 16-fold increase in the radial velocity data resolution.

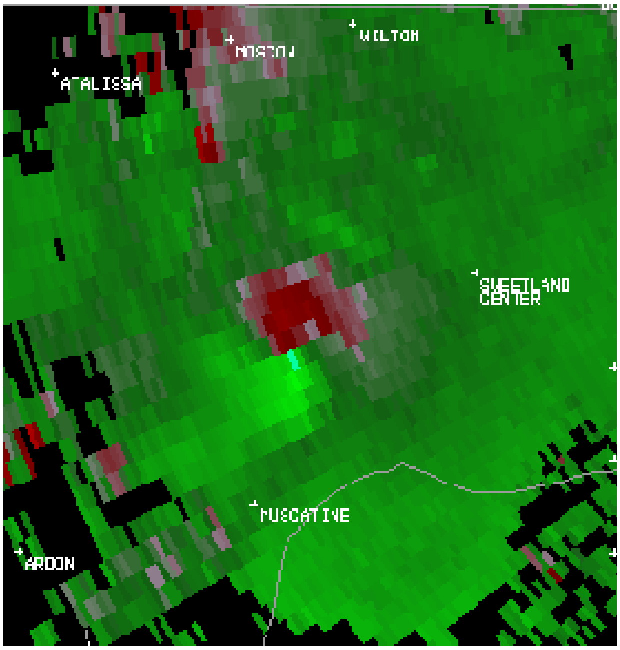

Figure 1a. Full Resolution Base Velocity Product

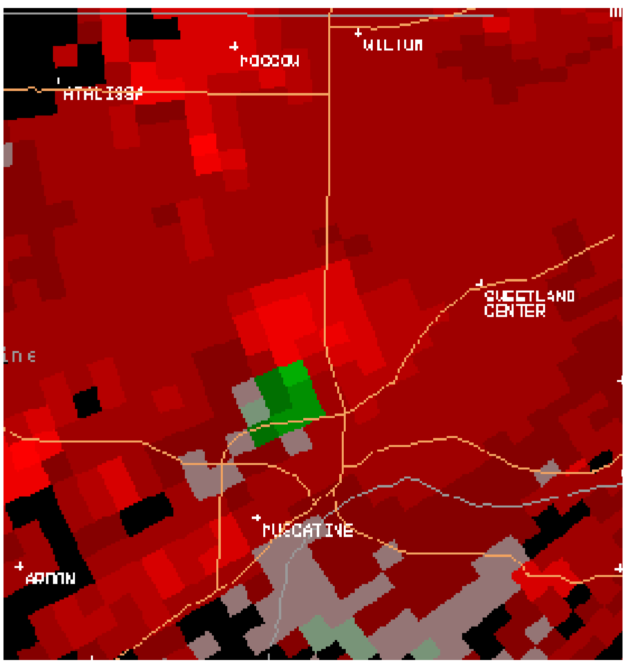

Figure 1b. Standard Storm Relative Velocity Product

2.2 Super-ob Product

The Super-ob (SO) product is derived by averaging Doppler velocities in small sectors (cells 5 km by 6 degree azimuth) on each elevation angle over a period of one hour. The SO product is generated at 30 minutes past the hour and extends out to 100 km radius from the radar. Individual Super-ob cells are registered in space and time by averaging the position of each base data velocity bin contributing to the each Super-ob cell. The following attributes are derived for each Super-ob cell: latitude, longitude, altitude, time deviation, azimuth, elevation, average Doppler velocity, and standard deviation of velocity. The data compression efficiency of the Super-ob is greater than 1500 to 1. For example, in a widespread severe weather event, the SO product is around 112 kilobytes, while one-hour of base data can exceed 165 Megabytes.

Super-ob products from each WSR-88D began flowing to the National Centers for Environmental Prediction (NCEP) in October 2002 (RPG Build 2 and AWIPS Build 5.2.2). As described by Alpert et al. (2003), along with other remotely sensed and conventional observations, Super-obs will provide a high resolution wind component in the analysis cycling system.

2.3 Radar-Rainfall Bias

The NWS has been computing the difference between radar and rain gage measurements of rainfall in order to remedy the bias that is sometimes present in radar derived rainfall products. With RPG Build 2 and AWIPS Build 5.2.2, this radar-rain gage bias factor will be automatically sent from each WFO AWIPS to the corresponding NEXRAD RPG. A software switch provides the RPG user an option to apply the radar-gage bias to the precipitation accumulation products. When applied, the accumulation data in the NEXRAD precipitation products (all but the Digital Precipitation Array (DPA) product) will be modified based on the bias value. The actual bias value is contained in the header and/or alphanumeric portions of the precipitation products. This adjustment is intended to remove systematic biases in the NEXRAD precipitation products caused by radar calibration problems and variations in rainfall characteristics.

2.4 REC and Clutter Likelihood Products

The RPG Build 2 Radar Echo Classifier (REC) implements the Anomalous Propagation (AP) detection algorithm described by Kessinger and VanAndel (2001). The REC outputs AP/clutter likelihood arrays which are then used to generate Clutter Likelihood Reflectivity (CLR) and Doppler (CLD) Products. The CLR and CLD products are formatted just like standard base products (i.e., elevation based, radial, 4-bit, run-length-encoded bins). The data in the CLR and CLD products may closely resemble each other. However, subtle differences due to differences in data resolution and azimuth angles are expected. These new radar products will be displayable on AWIPS OB1 and depict the likelihood the corresponding base data is contaminated by ground clutter due to AP. When displayed in combination with a base product, the user will see which data is suspect. A Clutter Likelihood Reflectivity product is shown in figure 2a and the corresponding Hybrid Scan Reflectivity Product is in Figure 2b for a case containing a mixture of rain and AP/clutter. Notice the areas of AP/clutter in the middle of the screen between lines of rainfall. It is expected these products will help users determine in which regions to invoke clutter suppression, which data to not trust, and to develop experience and confidence with the algorithm. In build RPG 4, the AP/clutter likelihood array will be used by the precipitation pre-processing algorithm to edit data suspected to be AP/clutter. This is expected to improve the data quality in the Hybrid Scan products, Radar Coded Message product, and the precipitation products.

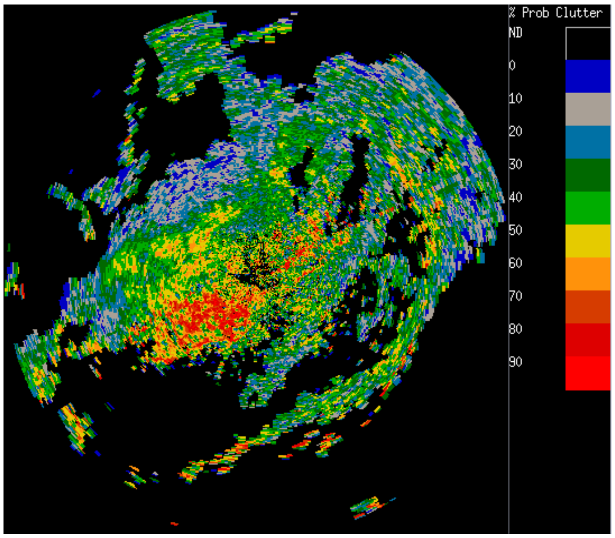

Figure 2a. Clutter Likelihood Reflectivity Product

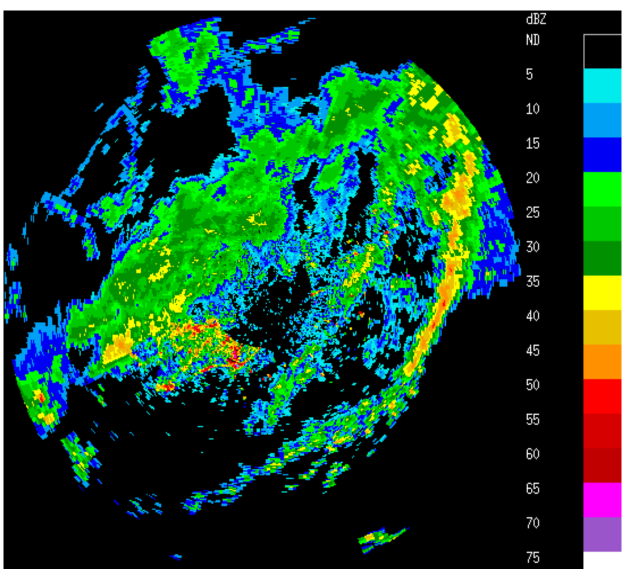

Figure 2b. Hybrid Scan Reflectivity Product

2.5 User Selectable Layer Reflectivity Product

The User Selectable Layer Reflectivity (ULR) product in RPG Build 3 addresses several limitations of the standard Layer Composite Reflectivity product. A user specifies the boundaries of the layer (1000 ft minimum thickness) through the product request and the RPG will simultaneously generate up to 10 products with different combinations of boundaries. This product is replayable, meaning that a product will be generated immediately upon one-time request. The ULR product extends to 230km range, has a spatial resolution of 1 km by 1 degree, and is formatted similar to standard base products (i.e., radial, 4-bit, run-length-encoded). Similar to other 16-level reflectivity products the width of data levels are 5 dBZ, but only between 5 and 55 dBZ. There are two extra 5 dBZ data levels between 5 and -5 dBZ. On the low end there is a data level for below -5 dBZ, and on the upper end, a data level for above 55 dBZ. In addition, there is a data level for below Signal-Noise ratio threshold. Finally, there is a data level for where the layer is unsampled due to large angular intervals between elevation scans or where all of the scans are above or below the layer. A thin layer is presented in figure 3 which clearly shows where each elevation scan intersects the 40-45kft layer. The light blue circle in the center shows “no data” in the cone of silence. If a high altitude layer is thin enough, light blue rings of “no data” will appear due to large increments between elevation angles at the top of the Volume Coverage Pattern. In figure 4a and 4b, a standard LRM product is shown next to the corresponding ULR product. The ULR product will have many uses since it can be generated at whatever layer is relevant to the meteorological situation. For example, requesting a layer just above the 0-degree isotherm can show icing potential, at the convective initiation level to detect the onset of convection, or above certain altitudes to highlight the tallest storms.

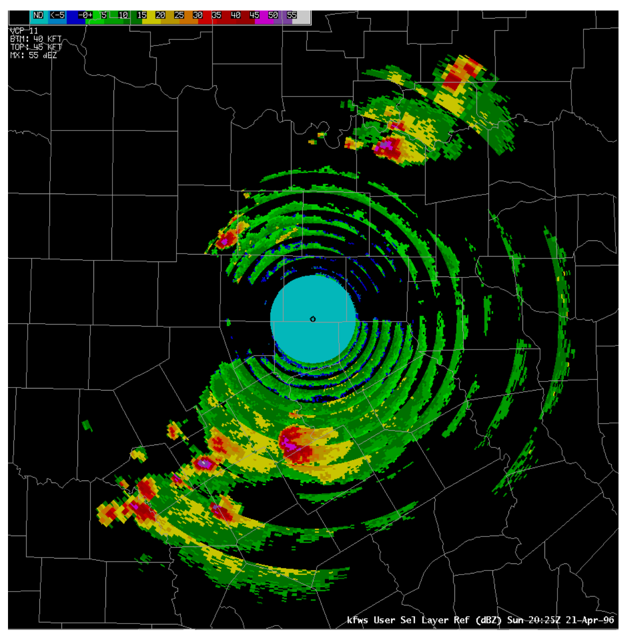

Figure 3. User Selectable Layer Reflectivity Product. 40-45k ft above sea level.

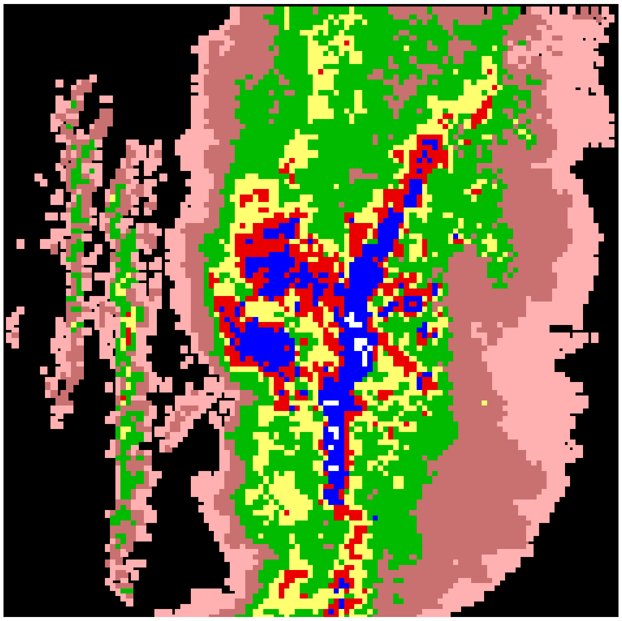

Figure 4a. Standard Low Layer Reflectivity Product

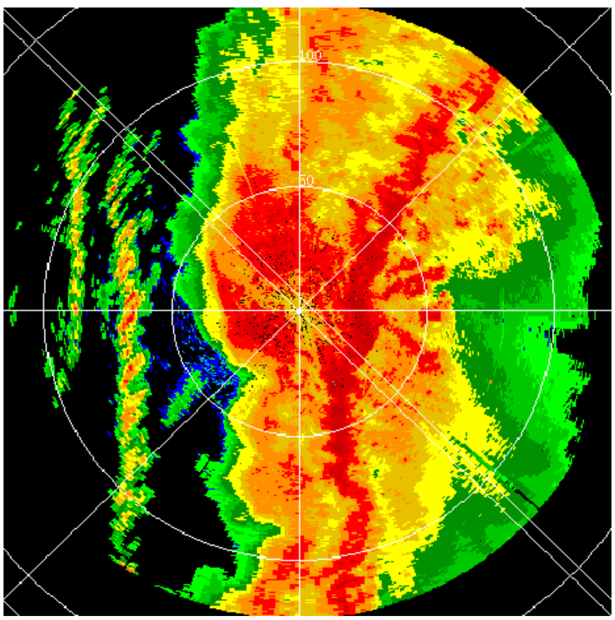

Figure 4b. User Layer Reflectivity Product for 0-24 kft.

2.6 VWP Product and Hodograph Display

The alphanumeric part of the Velocity-Azimuth-Display (VAD) Wind Profile (VWP) product is modified in RPG Build 3 to report the complete set of wind data derived by the VAD algorithm during the volume scan. The VWP graphic product contains wind data at 30 specific altitudes. These altitudes are used to derive specific slant ranges and elevation angles for the VAD algorithm analysis. The algorithm also derives a wind estimate at a constant range (at the optimum range) for each elevation angle and a wind estimate at one-third the optimum range on the two lowest elevation cuts. The low-elevation short-range estimates are done to improve the performance of velocity dealiasing at low altitudes. The constant range wind estimates are done to compute divergence and vertical velocity on a scale twice the optimum range (Rabin and Zrnic, 1980). The alphanumeric part of the VWP product will contain the complete wind data in a tabular format, as shown in figure 5. Where winds are available and parameters applicable, the table contains the altitude, wind speed and direction, vertical velocity, divergence, RMS value, analysis slant range and elevation angle. In AWIPS OB1, this wind data will be used to provide a hodograph display to the user, as shown in figure 6. This wind data can also be used for many other purposes.

VAD Algorithm Output 06/19/97 23:57

ALT	U	V	W	DIR	SPD	RMS	DIV	SRNG	ELEV
100ft	m/s	m/s	cm/s	deg	kts	kts	E-3/s	nm	deg
009	-2.2	5.3	NA	158	011	4.2	NA	5.67	0.5
010	-1.0	6.9	NA	172	014	4.2	NA	6.78	0.5
015	-1.9	12.0	NA	171	024	1.4	NA	5.67	1.5
016	-1.5	11.2	-0.1	172	022	1.6	0.0020	16.20	0.5
020	-1.3	11.9	NA	174	023	1.3	NA	20.49	0.5
030	0.1	13.2	NA	180	026	1.1	NA	14.13	1.5
034	1.1	13.2	-1.5	185	026	1.1	0.0263	16.20	1.5
040	2.6	12.7	NA	192	025	1.1	NA	19.58	1.5
050	5.3	10.6	NA	206	023	1.2	NA	15.88	2.5
051	5.2	10.3	-3.9	207	022	1.2	0.0450	16.20	2.5
060	4.7	7.6	NA	212	017	1.6	NA	14.15	3.5
069	5.7	5.5	-1.0	226	015	2.2	-0.0590	16.20	3.5
070	6.2	5.3	NA	229	016	2.2	NA	16.69	3.5
080	7.5	4.3	NA	240	017	2.4	NA	15.16	4.5

Figure 5. VWP wind data in the alphanumeric product

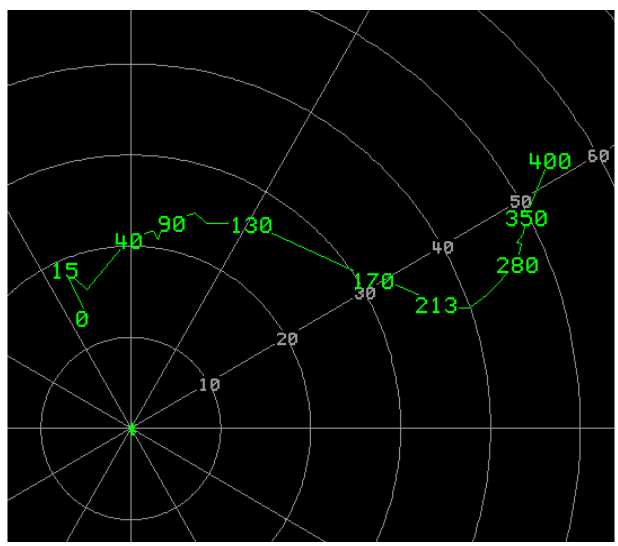

Figure 6. Hodograph display created from VWP (Note: different data case than shown in figure 5)

2.7 Digital Storm Total Precipitation Product

The Digital Storm Total Precipitation (DSP) product in RPG Build 3 has the same spatial and temporal resolution as the standard Storm Total Precipitation product, except 8-bits are used to encode rainfall accumulation quantities. The resolution of the DSP rainfall data is a function of the maximum rainfall accumulation. That is, when the maximum accumulation is less than 2.55 inches the resolution is 0.01 inches, when the maximum is between 2.56 and 5.10 inches the resolution is 0.02 inches, and so forth for larger accumulations. The DSP product is tentatively planned to be incorporated into AWIPS OB3. Likely uses include Multi-Sensor Precipitation Estimator (MPE), Flash Flood Monitoring and Prediction (FFMP), or as a graphic display.

3. SOFTWARE DEVELOPMENT ENVIRONMENT

The development environment available to today's researchers and software implementers has never been better. The baseline RPG software runs on affordable hardware platforms and plentiful WSR-88D base data is available from the archives at the National Climatic Data Center (NCDC) (Del Greco, 2003), live via the Craft demonstration project (Droegemeier, 2002), and directly from sites through the Base Data Distribution Server (BDDS)(Johnson et al., 1999). The Common Operations and Development Environment (CODE) (Ganger, 2002) combines the RPG baseline software, with tools to aid development, and a web-based suite of documentation. The NWS/OST has also developed scripts to configure the RPG to any of the network WSR-88D's, and software to interface between an LDM node in the Craft demonstration network and an RPG. RPG clones are being proliferated by several organizations to support applications software development, demonstrations of future capabilities, and to support testing of other systems. An RPG clone is a workstation running RPG software on WSR-88D base data from one of the available sources.

At the NWS headquarters, base data is being received via the Sterling, VA WSR-88D BDDS and also through the LDM/Craft network. There are eight AWIPS systems, one baseline RPG system, and 10 RPG clones which support development and testing for both AWIPS and the NEXRAD RPG. The Sterling BDDS feed is driving the baseline RPG system 24/7 which is running the fielded version of RPG software, and providing products to eight AWIPS systems via the LAN product distribution interface. The baseline BDDS also provides base data to several RPG clones. Base data received via the LDM/Craft network, drives two RPG clones 24/7, each clone running two instances of RPG software, and provides Wakefield, VA, Birmingham, AL, Tulsa, OK and Sterling VA, products to six of these same AWIPS. The other RPG clones ingest base data via tape, CD, disk file, or from any of the 58 radars available from the LDM/Craft network.

The FAA has installed six RPG clones at four ITWS prototype sites which get base data via LDM/Craft or directly from a BDDS. MIT/Lincoln Laboratory also has four RPG clones for software development which ingest base data via archive playback or via LDM/Craft. The MIT/Lincoln Laboratory network is further described in Smally and Bennett (2003).

4. CAPABILITY ENHANCEMENT PROCESS

The approach to adding capabilities to the NEXRAD baseline has been undergoing process improvement (Istok et al, 1999). The steps for inserting enhancements into the WSR-88D baseline follow a three-phase process: technique development, software implementation, and integration.

Technique development is where ideas are prototyped and validated. If researchers use the CODE they can focus more on the science of an application, rather than development environment details such as data access, base data preprocessing, velocity dealiasing. Ideas which are shown to meet an operational need are evaluated and prioritized by the requirements arm of each NEXRAD agency and target deployment schedules are established.

Based on target schedules, implementation is performed by software engineers following a systematic development process. Prototype software is reused if possible, but often software is developed following the typical steps of requirements, design, code, and unit test. After implementation, the operational utility of the applications are demonstrated and validated prior to being delivered to the Radar Operations Center (ROC) for integration.

At six-month intervals, implementing organizations deliver completed scientific packages to the Radar Operations Center (ROC). The delivered package includes requirements, design, source code, test artifacts, interface control documents, and software documentation. Because the implementing organization's software was developed and tested on the CODE, the application has already been functioning in an RPG compliant environment. The ROC integrates each delivered software package and infrastructure changes, into the RPG operational baseline, and then tests the new software build to verify that both the existing functionality and the new functionality operate as desired with no adverse effects. The ROC then deploys a new software load nine-months after beginning integration.

5. SUMMARY

Recent accomplishments of the NEXRAD Product Improvement program have been reviewed in this paper. Functional enhancements have been identified and prioritized by the NEXRAD agencies and implementation time-lines have been established. The process to transfer developed techniques to the operational WSR-88D baseline has been refined. The Open RPG is deployed and CODE is providing an environment for efficient development and implementation of functional enhancements. Software engineering groups, formed to implement agency-specific applications, have delivered several functional enhancements which are being deployed at six-month intervals. These enhancements are improving the forecast and warning missions of the NEXRAD agencies.

The NEXRAD enhancements deployed in 2002 and early 2003 provide increased resolution over several standard NEXRAD products; improve the accuracy of rainfall accumulation products; provide information to control clutter filters during AP conditions; distill Doppler velocity data to a size and frequency which can be ingested by NCEP operational models; and edit data contaminated by artifacts and AP/clutter. These recent accomplishments are just the beginning of a series of improvements scheduled to be deployed over the next several years.

6. REFERENCES

Alpert, J., P. Pickard, Y. Song, M. Taylor, W. Facey, M. Istok, and D. Parrish, 2003: A Super-ob for the WSR-88D radar radial winds for use in the NCEP operational assimilation system. Preprints, 19th *Conf. on Interactive Information and Processing Systems*, Long Beach, Amer. Meteor. Soc., **P1.51**.

DelGreco, S., and A. Hall, 2003: NCDC "The one stop shop" for all WSR-88D Level II data. Preprints, 19th *Conf. on Interactive Information and Processing Systems*, Long Beach, Amer. Meteor. Soc., **P14.3**.

Droegemeier, K., K. Kelleher, T. Crum, J. Levit, S. DelGreco, L. Miller, C. Sinclair, M. Benner, D. Fulkner, and H. Edmon, 2002: Project CRAFT: A test bed for demonstrating the real time acquisition and archival of WSR-88D level II data. Preprints, 18th *Conf. on Interactive Information and Processing Systems*, Orlando, Amer. Meteor. Soc., **P5.20**.

Ganger, T, M. Istok, S. Shema, and B. Bumgarner 2002: The WSR-88D Common Operations and Development Environment - Status and Future Plans. Preprints, 18th *Conf. on Interactive Information and Processing Systems*, Orlando, Amer. Meteor. Soc., **P5.7**.

Istok, M. J., W. Armstrong, D. Burgess, M. Eilts, R. Saffle, and A. White, 1999: Next Generation WSR-88D Applications Development - A Change in Paradigm. Preprints, *29th Conf. on Radar Meteor.*, Montreal, Canada, Amer. Meteor. Soc., **58-60.**

Johnson, L. D., J Abernathy, S. Ahlert, W. Blanchard, A. Cheek, P. Pickard, and R. Saffle, 1999: Communications Subsystems for the WSR-88D - Providing Data Where and When Needed. Preprints, 15th *Conf. on Interactive Information and Processing Systems*, Dallas, Amer. Meteor. Soc., **123-126**.

Kessinger, C., and J. VanAndel, 2001: The Radar Echo Classifier for the WSR-88D, 17th *Conf. on Interactive Information and Processing Systems*, Albuquerque, Amer. Meteor. Soc., **137-141**.

Rabin, R., and D. Zrnic, 1980: Subsynoptic-Scale Vertical Wind Revealed by Dual Doppler-Radar and VAD Analysis. Journal of the Atmospheric Sciences: Vol. 37, No. 3, pp. 644–654.

Saffle, R., J. Cappelletti, W. Carrigg, T. Ganger, M. Jain, D. Miller, and S. B. Smith., 1998: Accelerating the Integration of New Meteorological Algorithms into the WSR-88D-The Common Operations and Development Environment. Preprints, 14th *Conf. on Interactive Information and Processing Systems*, Long Beach, Amer. Meteor. Soc., **254-258**.

Saffle, R., R. Elvander, and M. Istok, 2003: NEXRAD Product Improvement - Expanding Science Horizons. Preprints, 19th *Conf. on Interactive Information and Processing Systems*, Long Beach, Amer. Meteor. Soc., **P14.5**.

Smalley, D. and B. Bennett, 2003: New products for the NEXRAD ORPG to support FAA critical systems. Preprints, 19th *Conf. on Interactive Information and Processing Systems*, Long Beach, Amer. Meteor. Soc., **P14.12**.