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EXPERIENCES USING WSR-88D CODE AS A DEVELOPMENTAL TOOL FOR RADAR ALGORITHM DEVELOPMENT

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1. INTRODUCTION

The evolution of the Weather Surveillance Radar, 1988 Doppler (WSR-88D) has taken a major step forward with the deployment of the Open Radar Product Generator (ORPG) to the National Weather Service (NWS) forecast offices beginning during the fall of 2001. The Common Operations and Development Environment (CODE), of which the ORPG is a key component, will mark a new era in radar algorithm development. CODE allows atmospheric scientists and techniques developers to tap into the real-time radar data stream, to create and validate algorithms and thereby speed the integration of new science directly into the operational suite of products available to the forecaster.

In this paper, pathfinding activities by a number of national resources that have had early experience with the ORPG and CODE are described. The Massachusetts Institute of Technology's Lincoln Laboratory (MIT/LL), the NWS Hydrology Laboratory (HL), the NWS Tropical Prediction Center (TPC) and the NWS Office of Science and Technology (OS&T) have provided contributions. It is hoped that these experiences will highlight both the problems and the power of CODE and encourage others to push the envelope of the science of radar meteorology.

2. MIT/LINCOLN LABORATORY

The arrival of the ORPG and CODE has opened new opportunities for the Massachusetts Institute of Technology's Lincoln Laboratory to interact with WSR-88D algorithms. A number of Federal Aviation Administration (FAA) critical systems rely on products from WSR-88D algorithms. These projects include WARP (Weather and Radar Processing), ITWS (Integrated Terminal Weather System), MIAWS (Medium Intensity Airport Weather System), and CIWS (Corridor Integrated Weather System). The Anomalous Propagation Edit/Removal algorithm (APR) produces a layer composite, maximum reflectivity factor product with AP (anomalous propagation) removed and is one of the products utilized in some of these systems.

The APR was implemented into the WSR-88D suite of algorithms prior to the CODE/ORPG era from a parent algorithm originated at MIT/LL. A comparison of the two versions of the APR shows that the WSR-88D version is significantly less robust in its removal of AP. This has serious consequences during episodes of non-obvious AP. The problem is exacerbated during critical times such as after thunderstorm passages over radar sites. With the advent of the CODE/ORPG era, an opportunity to improve the performance of the APR is provided.

The APR partitions a radar volume into regions relating to tilt elevation angles, distances from the radar, and altitudes AGL (above ground level). Within these regions, data of the three radar moments are analyzed to determine the presence of AP. A simple set of rules relating to reflectivity factor, radial velocity, and spectrum width are applied. Order statistic filters are then used to expand the initial identification of AP to neighboring gates and radials. The settings for the partitioning, AP identification rules, and order statistic criteria are controlled by a set of adaptation parameters.

The focus of the study was to discover some combination of changes to the adaptation parameters that would bring improved performance to the APR. Ten combinations of adaptation parameters were developed. With UNIX scripts, over 250 radar volumes were processed through the ten combinations by cycling the ORPG in CODE. The auxiliary CVT and CVG utilities (Stern, 2002) were used to analyze the results. They were compared with results from the same volumes processed by the parent MIT/LL algorithm.

A combination of adaptation parameters was found that did improve the APR's performance. Figure 1 illustrates the improvement for a case of embedded AP observed by the Dallas/Fort Worth, TX, WSR-88D on October 1, 1997 at 1538 UTC. The results are typical for all AP cases studied. The lowest image represents the "truth" as determined by the MIT/LL product. The uppermost image represents the current ORPG APR product while the middle image shows the results for the improved APR product. It is obvious that the embedded AP between 30 and 60 nautical miles north of the radar has been removed in the improved product.

For this study, it was very beneficial to use UNIX shell scripts to cycle the ORPG through the data and the ten different sets of adaptation parameters tested. UNIX scripts were also developed to query the CVT utility to identify product record numbers associated with the APR algorithm. This made interaction with a beta version of the CVG graphics package better. CVG was the primary analysis tool used. It was labor intensive in that it did not automatically save images of the results. It is also designed for time sequencing of data, making it cumbersome to cycle through images within a given volume. CVG was beneficial to the study, though, since it has an image

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saving capability and we were able to modify color tables to match that of the MIT/LL APR product. An improved package was to be released in the fall of 2001.

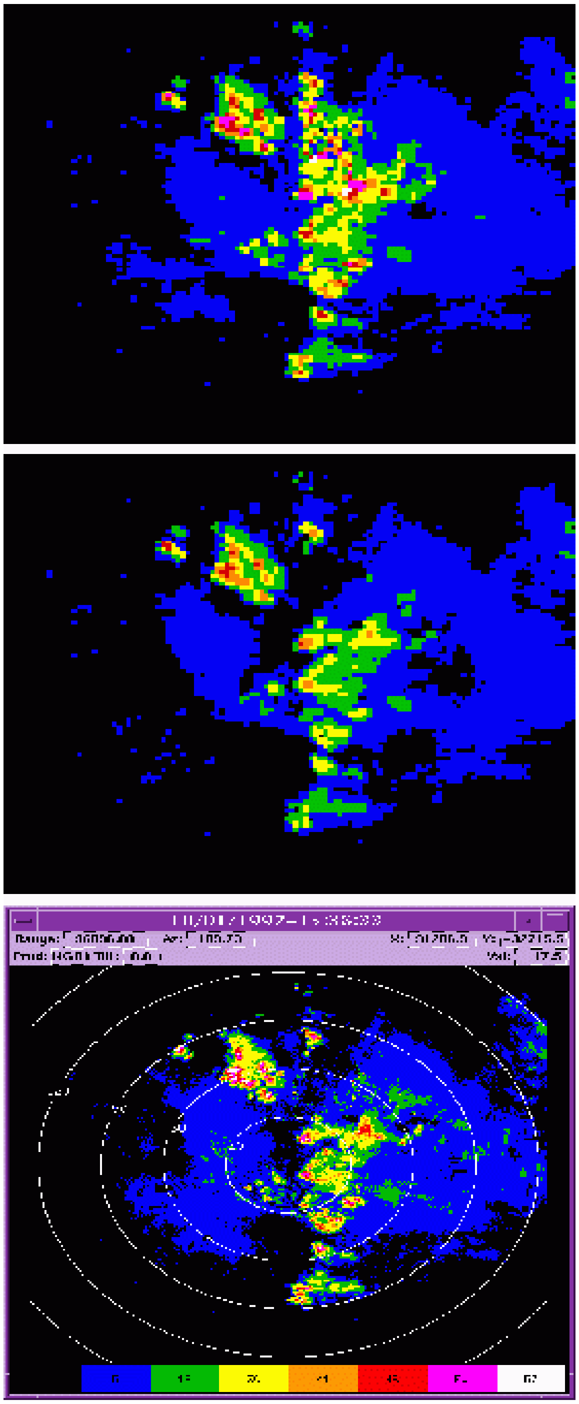

Figure 1. AP Edit Algorithm Removal Performance. Data from the Dallas/Ft. Worth WSR-88D on October 1, 1997, 1538 UTC. Upper image is the current algorithm. Middle image is the improved algorithm. Lowest image is the MIT/LL reference data set.

The CODE concept allowed MIT/LL to precisely identify the corrective changes to the APR algorithm for the WSR-88D Radar Operations Center (ROC) since radar and research sites will now share access to this common environment. Development of algorithms in this environment should facilitate smooth transitions and aid in interactions between developers and implementers of future algorithms. MIT/LL plans to develop additional algorithms using the CODE/ORPG system in the future.

3. NWS/HYDROLOGY LABORATORY

NWS/HL has been conducting research, development and software engineering of algorithmic improvements to the WSR-88D Precipitation Processing Subsystem (PPS) (Fulton, 1998) since the inception of the NEXRAD (Next Generation Weather Radar) Program. With the arrival of the ORPG, a number of major enhancements to the PPS, that were simply not possible on the legacy platform due to processing and memory limitations, are now being carried out. One such activity is the ORPG implementation of the WSR-88D vertical profile of reflectivity (VPR) correction algorithm (Seo, 2000).

The VPR effects, such as far-range degradation, bright band contamination, and discontinuities where tilt transitions occur, are one of the biggest sources of error in radar precipitation estimation. For example, in Figure 2, the top-left plot shows the reflectivity measurements in a single volume scan from the KRTX (Portland, OR) WSR-88D during the early February 1996 flooding event in the Pacific Northwest. The freezing level is marked by the intense bright band enhancement just below it. The VPR correction algorithm estimates what the mean VPR may be like if the radar beam were infinitely narrow. The solid line in the top-middle and top-right plots show the estimated 'true' mean VPR and the associated variance, respectively, corresponding to the top-left plot. Note that the estimated true mean VPR is more peaked than the 'apparent,' which is subject to beam smoothing.

The bottom plots in Figure 2 show the adjustment factors for the 1st, 2nd and 3rd tilts (from left to right), as a function of slant range, as derived from the estimated true mean VPR. These factors are multiplied to the raw rain rate estimates to correct for the VPR effects. Note that the amount of adjustment necessary is rather large; about a factor of two (downward) at ranges where the radar beams intercept the melting layer and a factor of ten (upward) at very far ranges.

Figure 3 shows the raw WSR-88D rainfall map from the KATX (Seattle, WA) WSR-88D over a 42-hr duration during the same event. The effects of complete beam blockage, partial beam blockage, tilt transitions to overcome beam blockage and bright band contamination are evident. For comparison, Figure 4 shows the VPR effect-adjusted rainfall map (with multi-scan maximization turned on: see Seo, 2000 for details). Note that many of the artifacts are significantly reduced. One of the by-products of the algorithm is the dynamic delineation of the maximum effective coverage of the radar (the solid line in Figure 4), as obtained from beam overshooting and blockage considerations. Note that, in places where upper tilts are used to overcome beam blockage, the effective range is reduced due to the beam overshooting the precipitation.

Thus far, the biggest benefit derived from using CODE is the relatively easy-to-use development environment. This has allowed HL to jump right into the actual software engineering of the algorithm, saving significant development time. The VPR algorithm is new and quite complex. It requires the development of multiple chained tasks, which are dependent on many other tasks. Hence, the VPR correction algorithm poses a number of software engineering hurdles.

HL's experience thus far is that the ORPG/CODE environment provides a number of very helpful 'templates' for the development of new tasks and interfaces with low-level routines. Further development and refinement of such templates will be extremely useful to external developers who may have little or no experience with WSR-88D software engineering. It is also HL's expectation that CODE will significantly facilitate integration testing by helping diagnose, in house, system-wide impacts of the algorithm under implementation. With the experience gained thus far, HL is migrating all WSR-88D software engineering activities to ORPG/CODE. Further experience will be shared with the community in the months to come.

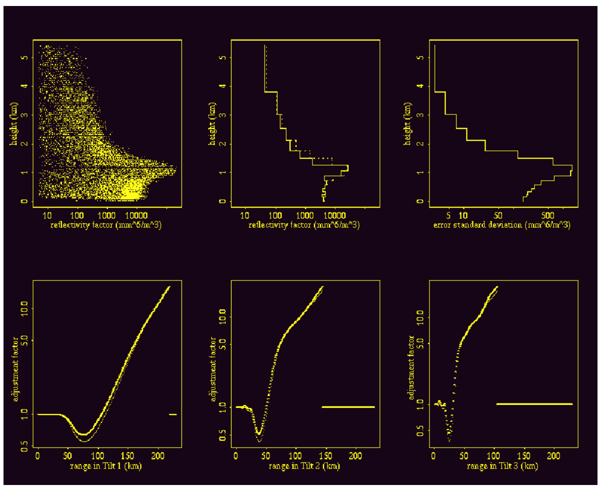

Figure 2. Measurements from a single volume scan from the KRTX (Portland, OR) WSR-88D during an early February 1996 flooding event in the Pacific Northwest. Top-left is reflectivity. Top center is the estimated true mean VPR and associated variance (top-right). The bottom plots show the adjustment factors for the 1st, 2nd and 3rd tilts (from left to right), as a function of slant range, as derived from the estimated true mean VPR.

4. NWS/TROPICAL PREDICTION CENTER

The primary motivation for obtaining CODE, the UNIX-based ORPG-clone at TPC, was to provide a development platform for tropical-cyclone specific radar data processing algorithms. Thus far, development efforts at TPC have focused on using the archive IV (image) files as a proxy for the full resolution digital data (McAdie, 2001). This is because as a remote center, TPC receives imagery only from the offices generating the base data, rather than the base data itself. It has been found that attempting to run developmental algorithms in real-time, even with the somewhat degraded resolution of the imagery files, is an extremely valuable component of the development process. We believe that the installation of the operational ORPG at the forecast offices should provide a mechanism for wider distribution of the base data (Saffle and Johnson, 2001). This should substantially alleviate the need for using the image files as a proxy.

One of the advantages of the ORPG-clone is that although it is capable of ingesting a real-time data stream from the WSR-88D, when used in conjunction with an 8 mm tape drive, the software is also able to ingest archived data sets. An algorithm developed using CODE on archived data will then be much more easily adapted to the real-time environment. The next step is to then consider incorporating these algorithms into the operational job suite. In this progression, algorithms ultimately become available for use at the local forecast offices, running on the operational ORPG platform.

Work at TPC has thus far centered upon the Ground-Based Velocity Track Display (GBVTD) algorithm (Lee, 1999), which gives an estimate of the total horizontal wind from the single-Doppler velocities, and the Tracking Reflectivity Echoes by Correlation (TREC) algorithm (Tuttle and Gall, 1999). Other techniques, such as the Hurricane-Customized Extension of the VAD method (HEVAD) (Harasti and List, 2001) may also be incorporated into a combined wind analysis.

5. NWS/OFFICE OF SCIENCE AND TECHNOLOGY

The NWS Office of Science and Technology (OS&T) is working with CODE on several different fronts. First, new algorithms are being developed to create a suite of digital base products. Second, efforts are underway to integrate non-WSR-88D radar data into the ORPG.

Digital products can display the full range, resolution and detail of the radar data up to 256 levels. For example, reflectivity data are collected at 1 kilometer (km) resolution. Legacy base reflectivity algorithms only display 1 km resolution data out to 230 km. To display the full 460 km range of the reflectivity data, the resolution had to be reduced to 2 km. The maximum number of data levels displayed was limited to 16.

With the ORPG, full resolution (1 km) data will be available out to 460 km and the data will be displayable in 256 levels. This added detail enhances a forecaster's ability to interpret storm structure. The same advantage will be seen in using digital Doppler velocity data. While velocity data do not extend out to 460 km, the full ¼ km resolution data will be able to be displayed.

OS&T is also working to bring non-NWS radar data into the ORPG (Stern, 2002, Saffle, 2001). During the summer of 2001, work progressed on ingesting and processing data from the ARSR-4 (Air Route Surveillance Radar, model 4) into the ORPG. An algorithm to create a hybrid scan reflectivity product was initiated using this data set.

Engineering to bring the FAA's TDWR (Terminal Doppler Weather Radar) into the ORPG began during the fall of 2001. Additional non-NWS radars will be considered for inclusion in the ORPG in the future.

6. CONCLUSION

The deployment of the ORPG and CODE has already made an impact on the science of radar meteorology as seen through the experiences of several national resources. The open systems platform of the ORPG provides more power and flexibility with which to work. CODE provides the interface for users to access data, system services and internal buffers. Having a non-operational ORPG-clone allows for development to proceed with no degradation to operational systems.

As ORPG-clones and CODE become more mature available to a wider audience, it is hoped that a broad range of scientists ranging from line forecasters to universities will be able to take advantage of the relative ease of use of the system and to significantly add to the science of radar meteorology of the future.

7. REFERENCES

Fulton, R. A., J. P. Breidenbach, D.-J. Seo, D. A. Miller, and T. O'Bannon, 1998: The WSR-88D rainfall algorithm. Weather and Forecasting, 13, 377-395.

Harasti, P.R., and R. List, 2001: The hurricane-customized extension of the VAD (HEVAD) method: wind field estimation in the planetary boundary layer of hurricanes. 30th Conf. on Radar Meteorology, Munich, Amer. Meteor. Soc.

Lee, W.-C., B. Jou, P. Chang, and S. Deng, 1999: Tropical cyclone structure retrieved from single Doppler radar observations. Part 1: interpretation of Doppler velocity patterns and the GBVTD technique on analytical tropical cyclones. *Mon. Wea. Rev.,* 127, 2419-2439.

McAdie, C.J., P.R. Harasti, P. Dodge, W-C Lee, S. Murillo, and F. Marks, 2001: Real-time implementation of tropical cyclone specific radar data processing algorithms. 30th Conf. on Radar Met., Munich, Amer. Meteor. Soc.

Saffle, R.E., W.M. Blanchard, M.J. Istok, P.K. Pickard, S. Shema, S.M. Holt, L.D. Johnson, 2001: Progress in the use of Weather Data from Federal Aviation Administration (FAA) Radars in Combination with the WSR-88D, 17th Conf. On Interactive Information Processing Systems, Albuquerque, NM, Amer. Meteor. Soc., Paper 3.3

Saffle, R.E., and L.D. Johnson, 2001: NEXRAD product improvement - progress and plans. 30th Conf. on Radar Met., Munich, Amer. Meteor. Soc.

Seo, D.-J., J. Breidenbach, R. Fulton, D. Miller, and T. O'Bannon, 2000: Real-time adjustment of range-dependent biases in WSR-88D rainfall estimates due to nonuniform vertical profile of reflectivity. Journal of Hydrometeorology, 1, 222-240.

Stern, A.D., T.J. Ganger, S.A. Dobbs, and M.J. Istok, 2002: Developmental Utilities for the WSR-88D Common Operations and Development Environment, 18th Conf. On Interactive Information Processing Systems, Orlando, FL, Amer. Meteor. Soc., Paper 5.8

Stern, A.D., P.K. Pickard, W.M. Blanchard, M.J. Istok, B. Bumgarner, D.L. Estes, S. Shema, 2002: Analysis and Plans for Using FAA Radar Weather Data in the WSR-88D, 18th Conf On Interactive Information Processing Systems, Orlando, FL, Amer. Meteor. Soc. Paper 5.6

Tuttle, J. and R. Gall, 1999: A single-radar technique for estimating the winds in tropical cyclones. *Bull. Amer. Meteor. Soc.,* 80, 653-668.

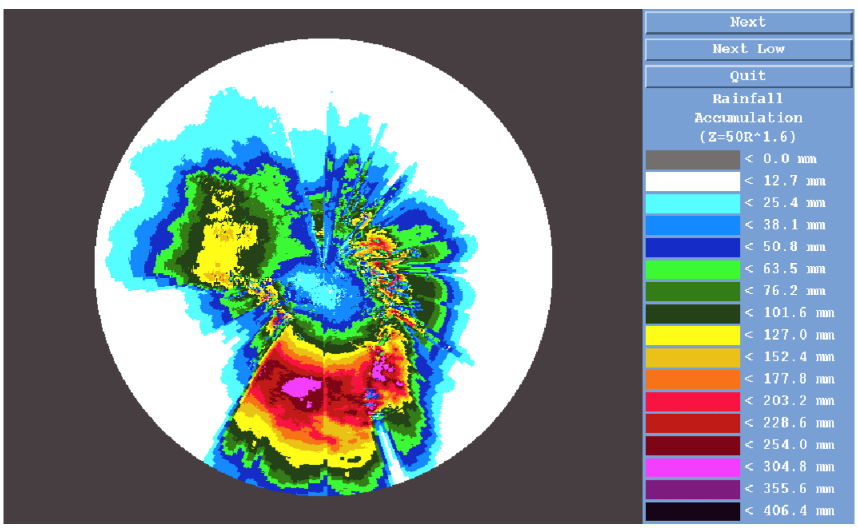

Figure 3 (left). Rainfall accumulation map from the KATX (Seattle, WA) WSR-88D over a 42-hr duration during the early February 1996 flooding event. The effects of complete beam blockage, partial beam blockage, tilt transitions to overcome beam blockage and bright band contamination are evident

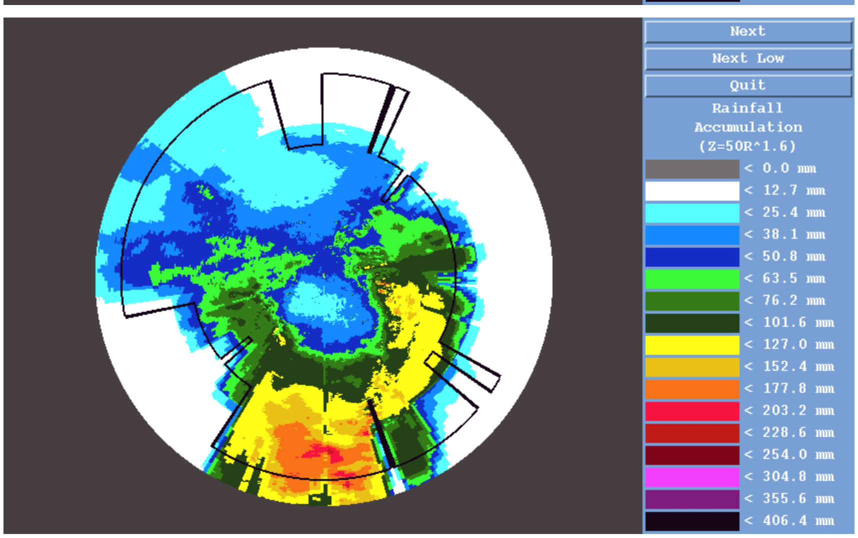

Figure 4 (left). The VPR effect adjusted rainfall accumulation map with multi-scan maximization turned on. Note that many of the artifacts are significantly reduced (as compared with Figure 3).