P1.29

Standard Benchmark Data for WSR-88D

Rajiv Khanna[1]*, R. Elvander[2], A. Zahrai[3], D. Zrnic[3], R. Saffle[2], B. Bumgarner[4], M. Istok[2]

[1] Mitretek Systems, Falls Church, Virginia
[2] National Weather Service/Office of Science and Technology, Silver Spring, Maryland
[3] National Severe Storms Laboratory, Norman, Oklahoma
[4] BAE Systems, Washington DC

1. INTRODUCTION

The authors propose a standard benchmark for WSR-88D. The benchmark will support research, development, analysis, and both qualitative and quantitative evaluation of new science and technology for WSR-88D. It will be a tool with broad applicability and appeal to researchers and engineers.

The benchmark will be comprised of raw time series data collected after analog-to-digital conversion and prior to signal processing, called *Archive Level I* (AL-I) data because of its similarity to a legacy capability of WSR-88D. The benchmark will include supporting parameters and metadata about the conditions under which the data is collected that may be useful in future processing and evaluation.

Researchers can use the benchmark data to identify features and weather events. They may develop new techniques for processing the data to help protect important features while reducing clutter and other noise characteristics. To avoid removal of critical information, no filter will be applied to the benchmark data.

The benchmark can be used to develop new algorithms for the Radar Data Acquisition (RDA), Radar Product Generator (RPG), and display systems. For RDA algorithm development, the time series data can be processed using new algorithms to create base data. For product generation at the RPG, the time series data can be processed using WSR-88D signal processing algorithms, resulting in standard base data that can be used to develop new product generation algorithms. The data and products can be used with new display methods, providing a complete digital processing thread. During development, interoperability testing can be conducted to ensure that the new algorithms work together.

Technology evaluation requires standardized test methods. The benchmark can be used to assess the improvement to be gained by using new technology. Systems engineers can use the benchmark data to measure effectiveness, performance and resource utilization, leading to system development and deployment. For technology evaluation, it is essential to use standard benchmark data inputs and use standard and consistent methods to compare outputs. The evaluation methods should be repeatable across different processes and processors.

This paper introduces the concept of standard benchmark data, discusses performance metrics, identifies types of data and key meteorological features that will be needed, and identifies parameters that should be collected. It concludes with future directions for weather radar that the benchmark development could support.

2. PERFORMANCE METRICS

2.1 NWS Performance Metrics

The NEXRAD system's fundamental mission requirement is to reduce loss of life, injuries, and property damage due to severe weather. Specifically, the radars were designed to improve over the legacy NWS weather radars by increasing accuracy and resolution, providing Doppler wind information, and improving data distribution to users.

As the NEXRAD capabilities continue to evolve through the NEXRAD Product Improvement (NPI) program, it is important to validate that system changes are providing improvements to this mission. While radar data are just one component, they are perhaps the most critical for a successful severe weather warning program. The NWS bases its NPI program planning and funding on the impact that NEXRAD improvements will have on accuracy and lead times for tornado, severe thunderstorm and flash flood warnings. Specific values for these NWS performance parameters are included in the Department of Commerce performance goals under the Government Performance and Results Act of 1993 (GPRA). The current NWS tornado warning GPRA goals are presented in Table 1.

* *Corresponding author address*: Rajiv Khanna, MS F530, Mitretek Systems, 3150 Fairview Park Drive South, Falls Church, Virginia, 22042-4519 (rkhanna@mitretek.org)

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

Table 1. NWS GPRA Goals

GPRA Measure	FY 2001 Skill	FY 2007 Goal
Lead Time (min)	10	14
Accuracy (POD)	68%	78%
False Alarms	72%	68%

2.2 FAA Performance Metrics

The use of weather data products from the WSR-88D is important to the FAA's daily operation of the National Airspace in maintaining safety of operations and maximum possible airspace capacity. WSR-88D products are used by the FAA in operational display systems such as the Integrated Terminal Weather System (ITWS), Weather and Radar Processor (WARP), Medium Intensity Airport Weather System (MIAWS), and most recently in the Corridor Integrated Weather System (CIWS) demonstration project. Placing timely high quality data and derived products in front of air traffic controllers and supervisors requires data that is void of non-meteorological noise such as artifacts or anomalies.

The FAA's requirement for future RDA enhancements is to improve the quality and resolution of the base data. Presently, data quality can be compromised through clutter and artifact contamination as well as range and velocity folding. Development and testing of advanced signal processing techniques to mitigate these problems requires numerous controlled sets of time series data which encompasses the meteorological situations causing those problems. The proposed benchmark data would help meet this need.

The performance of weather radar signal processing techniques can be measured through several steps— generation of the standard three moments, reflectivity, velocity, and spectral width from the time series data; the building of a standard format level II base data stream; and the analysis of that data using various specialized algorithms to check for range folded echoes, proper velocity unfolding, and performance of artifact and clutter removal algorithms. The results of the proposed processing schemes should be compared and scored originally against legacy system results. The metrics derived from those comparisons will determine which advanced techniques are ready for operational use and which will require more study and research. As new techniques are deployed, the baseline should be updated, and the process can be re-iterated to create a series of improvements.

With the new capabilities in signal processing there may be a tendency to rush to implement older research techniques that can now be done in real-time. However, in the FAA's opinion, for routine operational use there should a clear and demonstrated improvement to any new technique. In particular, advanced signal processing techniques using power spectral methods should be analyzed and scored in the same rigorous manner by comparing the standard three moments with the legacy system. As these techniques mature there may be additional derived outputs available that will require further downstream processing and analysis.

3. TYPES OF DATA

Most Doppler weather radars in use today produce spectral moments which are estimated from autocovariances of echo samples. Only profiling radars employ more sophisticated spectral processing techniques. Profiling radar signals are weak. Therefore the superposed spectral artifacts are deleterious and it is very beneficial to eliminate these artifacts via spectral processing.

Recently the computing power of commercial processors has increased to a point where real-time spectral processing and automated recognition of artifacts is feasible. There are two motivating factors for analysis of spectral data. One is to improve signal quality by filtering noise and non-meteorological artifacts. The other is to recognize spectral signatures of significant weather phenomena. Tornado spectral signatures have been observed in the early seventies and used to estimate the maximum wind speeds. It is reasonable to assume that other phenomena such as gustnadoes, water spouts and wing tip vortices produce distinctly different spectra than surrounding environment. Furthermore, Doppler spectra from microbursts and gust fronts could yield important information about the impending strength of these phenomena. These spectra may also reveal information concerning impending severe events sooner than is possible from the spectral moments.

Except in cases of tornado vortices and ground clutter, very little analysis of Doppler spectra in other circumstances has been made. Such analysis is in order before implementing any method to detect these events in real-time. Particularly timely and pertinent is spectral processing of polarimetric signals. Polarimetric variables, such as differential reflectivity and phase have stringent error requirements. Exploration of new efficient ways to obtain these variables is desirable so that the error requirements could be met through specialized Doppler spectrum processing. Moreover, evaluation of various schemes to mitigate effects of range and velocity ambiguities also requires further analysis.

The spectral properties of the time series data, for many of the weather events discussed in this paper, will become important tools in the basic understanding of these events and should lead to advances in radar meteorology in the near future. For example, can properties associated with clutter be more easily identified through spectral processing, compared to those techniques using the mean values? Can clutter effects be removed or reduced for meteorological interests? In other words, should clutter removal be done with some type of adaptive filtering dependent upon the spectral nature of the data? The benchmark data will support this type of algorithm development, test, and evaluation.

Presently, bird and insect identification can be done using polarimetric radar data. Advances in spectral signal processing may help identify birds and insects and help differentiate them from true weather data.

In order to effectively analyze various acquisition schemes and processing algorithms a comprehensive collection of raw data is highly desirable. Such a collection would allow meteorologists and scientists to process and analyze the data using the computer environment and tools of their choice. Such data could also serve as benchmarks allowing engineers to measure and analyze the performance of signal processing equipment.

Raw radar data are essentially the digitized samples of the returned echoes prior to any filtering or conditioning. These data are referred to as time series data. WSR-88D specifications refer to these data as Level-I data. Although these specifications contain an archive level 1 port, this capability was never implemented on operational radars. An archive device was developed by NCAR and has been successfully used to collect several data sets. The research WSR-88D at the National Severe Storms Laboratory has the capability to acquire and store time-series data. Time series data at every range bin can now be acquired and stored in real-time. Currently the storage equipment can accommodate several hours of continuous data depending on the volume coverage pattern selected.

4. KEY METEOROLOGICAL FEATURES

The weather events from which time-series data is highly desired are as follows:

a) Local events within widespread convective storms. These types of events may contain vortices, microbursts, and gust fronts. In addition, a variety of artifacts of interest may be present, such as anomalous propagation from previous storms or occurrence in areas of low reflectivity, where nearby strong reflectivity may strongly influence mean values. Often circulations develop within the lower atmosphere, without a well-defined mesocyclone aloft. To be able to better observe these using the complete spectrum is of utmost importance.

b) Isolated supercells. These events usually contain strong mesocyclones, violent tornadoes, strong winds, and heavy rain and hail.

c) Mesoscale convective systems. These events contain squall lines which in turn could harbor tornadoes, gust fronts, hail, etc. They are wide spread and often cause range obscuration and velocity aliasing. If SZ phase encoding, or other de-aliasing procedures have been used in the transmission of the base data, then similar results from signal processors should result.

d) Wide spread stratiform precipitation. These are wide spread rain and snow events. Range obscuration can occur at lower elevations.

e) Tropical storms and hurricanes. Sometime these events produce tornadoes, and almost always high winds and heavy rain. These systems are large and cause echoes to overlay in range.

f) Rain, especially moderate to heavy rain, from different types of weather systems; such as tropical storms, mid-latitude low pressure areas, mesoscale convective systems, and severe storms (including hail/rain mixtures). These include both maritime and continental events. Spectral processing may better differentiate these processes.

5. COLLECTED PARAMETERS

Time series data gathered at every range bin within the Pulse Repetition Time (PRT) should be at maximum possible resolution and without any filtering. These data must be grouped per transmitted pulse and must have identifying headers containing acquisition parameters of importance such as date and time, azimuth, elevation, pulse width and mode and other applicable information.

Since spectral processing and analysis is expected to be most beneficial, it is reasonable to suggest that most of the volume coverage patterns (VCPs) will have uniform, although not necessarily equal PRTs at various elevation angles. The highest elevation angle will be selected depending upon the type of event being observed.

Currently two complimentary methods for mitigation of range and velocity ambiguities are being considered for implementation on the WSR-

88D. One, applicable at the two lowest elevations, is a systematic phase coding (SZ code) and the other, applicable at higher elevations, is a staggered PRT.

The lower elevation cuts of a volume coverage pattern for the phase coding scheme may contain one scan with long PRT without phase coding followed by one scan at medium PRT and another scan with short PRT with phase coding. The long PRT allows determining the exact location of range overlaid echoes. The overlaid echoes in the two shorter PRTs occur at different locations and the unambiguous velocities differ. Thus, it will be possible to compare the performance and evolve a sound strategy for operational applications. To verify statistical errors it would be beneficial to obtain time series data from fixed azimuth locations with the same PRTs listed herein.

Time series data for staggered sequences will also be required for analysis. Although this scheme is proposed for higher elevations, staggered data at the lowest elevation angles should be acquired for analysis. Thus a potential VCP will contain a cut at 0.5 degree with one scan in the long PRT, followed with one in a staggered PRT (Ratio 3/2 and shorter unambiguous range of 150 km). The next elevation of 1.5 degrees will be the same. Above 1.5 degrees only the staggered PRT will be transmitted. Statistical properties of the errors will be verified from analysis of time series data that will be collected with a stationary antenna.

6. FUTURE WORK

Since inexpensive parallel signal processing systems have become readily available we may have reached a stage whereby diverse schemes could be implemented in parallel to suite a variety of users, similar to implementation of algorithms on the Open RPG. That is, the principal mission of the WSR-88D could be supported with its optimum signal processing and VCP strategy. Other potential users would be constrained only with the VCP but in all other aspects could tailor the signal processing to their particular needs. Entomologists and ornithologists who are interested in migration of insect and birds and identification of species may be looking for specific spectral characteristics in regions free of artifacts. Air traffic controllers might benefit by identifying point targets, the ones that are currently eliminated from weather radar data. Regardless whether the distributed signal processing becomes a norm in the future, many secondary users will benefit from experience gained by analyzing time series data. It may be much simpler and cost effective if these users maintain and manage their specific signal processing routines rather than be a lower priority part in a much larger system.

7. ACKNOWLEDGEMENTS

The authors wish to thank Dale Sirmans for his technical review of this paper.

8. REFERENCES

Albertelly, M., 1999: CW Substitution Reflectivity Error Check: *NEXRAD NOW*, Issue 9, WSR-88D Operational Support Facility.

Doviak R. J., and D. S. Zrnic, 1993: Doppler Radar and Weather Observations. Second Edition. Academic Press, San Diego, CA.

Elvander, R., S. Holt., B. Bumgarner, and R. Ice, 2001: Weather Surveillance Radar - 1988 Doppler (WSR-88D) Open Radar Data Acquisition (ORDA) Enhancements. Preprints, *30th Conf. on Radar Meteorology*, Munich, Germany, Amer. Meteor. Soc. 12B.2.

Istok, M., A. Zahrai, R. Saffle, R. Rivera, D. Martindale, and R. Khanna, 2002: Near Term Planned Mission Enhancements for the WSR-88D Open Radar Data Acquisition System. Preprints, *18th Conf. on Interactive Information and Processing Systems*, Orlando, Florida, Amer. Meteor. Soc. 5.12**.**

Saffle, R., M. Istok, and L. D. Johnson, 2002: NEXRAD Product Improvement - Progress and Plans. Preprints, *18th Conf. on Interactive Information and Processing Systems*, Orlando, Florida, Amer. Meteor. Soc. 5.1.

Sirmans, D., and B. Bumgarner, 1975: Numerical Comparison of Five Mean Frequency Estimators. *Journal of Applied Meteorology*, Vol. 14, No. 6, pp. 991-1003.

Wurman, J., S. Heckman, and D. Boccippio, 1993: *A* bistatic multiple-Doppler Network. *Journal of. Applied Meteorology*, 32, 1802-1814.

Zahrai, A., S. Torres, I. Ivic, and C. Curtis, 2001: The Open Radar Data Acquisition (ORDA) Design for the WSR-88D. Preprints, *18th Conf. on Interactive Information and Processing Systems*, Orlando, Florida, Amer. Meteor. Soc. 5.10.