12B.4 STRATEGIC DIRECTIONS FOR WSR-88D DOPPLER WEATHER SURVEILLANCE RADAR IN THE PERIOD 2007-2025

John T. Snow*
Chair, NEXRAD Technical Advisory Committee, Norman, Oklahoma

Rhonda B. Scott
Executive Secretary, NEXRAD Technical Advisory Committee, Norman, Oklahoma

1. Background

In Spring 2002, the NEXRAD stakeholder agencies requested that the NEXRAD Technical Advisory Committee (TAC) develop a "strategic directions" document for the long-term evolution of the total NEXRAD system. This document would address both the WSR-88D system and the national radar network, and describe possible enhancements for the 2007-2020 time frame. The intent is to guide the evolution of the radar through the final 15 to 20 years of its design life cycle, taking advantage of new technologies as they become available.

A select group of 15 weather radar experts provided short discussions of the emphases they believe the NEXRAD Program should have for the period 2007-2020. In providing their comments, these experts were asked to consider both enhancements and upgrades to the WSR-88D system, and broader strategies for the national network as a whole.

The responses were analyzed by members of the TAC and synthesized into a series of points. TAC members also incorporated their own perspectives in preparing this paper. This is a continually evolving document that provides possible "strategic directions" for the radar and the national network. The presentation and paper will present the most significant points from the "strategic directions" document and suggest areas where additional research and new technology development is needed to realize the potential inherent in the NEXRAD system.

2. TAC Recommendations

The fifteen responses of radar experts were analyzed by the TAC and formulated into the eight recommendations provided within this section. NEXRAD managers and engineers can use these points in preparing future upgrades to radar hardware/software and developing new operational strategies. Scientists can also use these points in planning basic studies in weather radar research. However, each point should be evaluated in terms of agency mission and projected future needs.

1. Coordinate enhancements to the WSR-88D with parallel developments of the follow-on system to NEXRAD.

As a first general principle, enhancements to the WSR-88D through the remainder of its service life should be closely coordinated with the parallel development of the follow-on system. While each is a distinct program, the two efforts offer many opportunities for synergy. The follow-on system may be a completely new radar, or it could be a major retrofit and upgrade to the current radar, replacement of the current mechanically scanned dish antenna with a phased array antenna would be a good example.

Coordination will ensure that promising technologies developed in one program (e.g., phased-array antenna, pulse compression, oversampling, etc…) are considered in the other and that the transition to the follow-on system will be smooth from the point of view of the users of the radar data. While the development of the follow-on system is only in its earliest stages at the National Weather Radar Testbed, now is the time to develop the management structure to ensure this coordination.

2. Increase the density of radars in the national network.

As articulated in the National Academy study "Weather Radar Technology Beyond NEXRAD", a significant shortcoming of the present NEXRAD network is the limited coverage at low levels. This heavily impacts useful ranges for precipitation estimation (snowfall as well as rainfall), severe storm detection, convergence line detection, and boundary layer wind estimation. Several respondents also note problems in detecting low-level phenomenon (initiation of convection, lake effect snow) and phenomena passing over the radar (cone of silence). Part of this limitation is due to the inherent geometry of the radar beam passing over the curved Earth, coupled with having a rather widely spaced network of fixed station radars. However, the problem is exacerbated by programmatic decisions that no radar is to be operated with the center of the

*Corresponding authors address: John T. Snow
Chair, NEXRAD Technical Advisory Committee
1200 Westheimer Drive, Norman OK 73069
E-mail: JSnow@OU.edu

beam below 0.5^o elevation and that RHI scans were not to be made.

The only way to remedy this problem is to have more radars closer together. In some instances, scanning at lower elevation angles would also help. In regard to the former, the situation could be improved at relatively modest cost by assimilating data streams from other radars, especially the FAA's Terminal Doppler Weather Radars (TDWR) and Aviation Surveillance Radars (ASR). Commercial weather radars used by the media and mobile X-band radars also offer possibilities. Along the U.S-Canadian border, joint sharing of Doppler weather radar data by the two nations would contribute to improved coverage. These multiple data streams could be used to prepare national, regional, and local radar mosaics.

The above discussion assumes that over the next decade forecasters and other users will shift from working with data from single radars to utilizing products that are digital mosaics of multiple radar data streams (perhaps incorporating data streams from other sources as well), a National 4-D Radar Database. It is anticipated that such mosaics could provide a more reliable, detailed, accurate view of the atmosphere on the mesoscale than could be obtained from the output from any single radar.

3. Produce the best quality data possible from the WSR-88D throughout the remainder of its service life.

Users are demanding not only high quality data – accurate, reliable, timely -- from the radar network but also measures of the quality of the data to be included as part of the data stream. This demand for data quality measures is a direct consequence of the increasingly more diverse and more sophisticated uses being made of the data. In particular, applications being developed by the FAA are based on processing the NEXRAD data using fully automated algorithms with the end product going directly to end users such as controllers, supervisors, and traffic flow managers. Similarly, the NOAA National Weather Service (NWS) and several university based research groups are now assimilating reflectivity and velocity data directly into numerical forecast models. Private vendors are generating automatically value-added radar products and transmitting them directly to non-meteorologist users, such as the media; consumer oriented products (briefly noted in Recommendation 7) are in the near horizon. All of these applications require that quality control/assurance be applied automatically, thus measures of data quality provided by the radar greatly simply the process of flagging bad data, adjusting analysis schemes, etc.....

As a minimum, real-time meta-data regarding calibration, timing, beam position/pointing, and other system settings could be provided to users. More extensive meta-data could include self-diagnostic information on the radar, information on samples that are being eliminated during signaling process (extremes and unusual returns are often of special interest), and a "confidence index" that estimates the reliability of the resulting products from the radar system.

Signal processing could be improved to almost completely mitigate ground clutter, and range and velocity folding. As part of the deployment of the polarimetric retrofit, signal processing could be enhanced to use this additional data for enhanced identification of non-meteorological targets (ground clutter, sea clutter, birds, insects, chaff, etc) so that they can be removed from appropriate products.

It would be highly desirable to occasionally operate some radars at elevations below 0.5^o. For example, this would enhance use of Fabry's moisture mapping technique, providing forecasters detailed information on low-level moisture. Such information would also have value in the initialization of small-scale numerical models.

Bi-static technology (additional remote receivers associated with one NEXRAD emitter) could be explored to increase the amount of data generated from one radar.

The scanning rate of the WSR-88D could be increased. Using the fast signal processing techniques now available and over sampling, the WSR-88D should be able to scan at its rated maximum of 6 rpms, which translates to approximately 3 minutes for a full Volume Coverage Pattern (VCP). Efforts could be accelerated to determine the usability and limitations of the over sampling method with operational testing performed on a test bed as described in Recommendation 8. Further, in partnership with the effort to develop the follow-on system, efforts could be made to develop technology that would reduce to less than 1 minute the time required for a full-coverage VCP.

4. Increase significantly the computing power and the telecommunications bandwidth

All data streams – from in-situ measurements, satellites, and the radar network – will be continuously expanding for the foreseeable future. As an example, the installation of polarimetric capabilities on the WSR-88D will result in a 2- to 4-fold increase in the data stream. Several of the appended suggestions from the radar experts would also increase significantly the amount of data that will need to be handled. It is apparent that future successful operation of the radar system – either individually or as part of a national network -- will require substantial increases in both the computational power associated with the radar and the telecommunication bandwidth that is the backbone of the network. While every effort should be made to optimize the use of existing bandwidth through compression schemes, current trends indicate that a wider telecommunication bandwidth will become essential by 2010.

The TAC recommends that if at all possible, the development of the technology to provide the recommended growth in both computing power and bandwidth be done as a multi-agency effort, perhaps even covering several types of radar. There appears to be numerous opportunities for synergy – and cost savings -- in developing a common system to meet multiple agencies needs.

5. Develop, test, and implement advanced radar waveforms and signal processing techniques

Phase coding, staggered pulse repetition time, pulse compression, and over sampling are possible engineering advances that need to be vigorously pursued since they are likely to lead to improved data quality, sensitivity, and increased scan rates.

Spectral processing of the radar data stream could be investigated since it is well suited for adaptive removal of artifacts and interference from external radiation sources. Further a gain of about 10 dB in effective signal to noise ratio can be achieved, which would extend coverage in clear air and enable better cloud detection. Spectral processing schemes for identifying tornadic circulations could be explored.

6. Support a coordinated effort to integrate radar data and other data into enhanced decision support systems

Enhancements to the radar must not be considered in isolation. Data fusion systems, locally run storm-scale numerical models, decision support systems, and fully automated processing systems generating products for non-meteorologists are but a few examples of the technologies either currently being deployed or under development in several institutions within the United States and other countries. Many such systems are being deployed or developed by one or another of the tri-agencies to support mission accomplishment. All this suggests that there needs to be a well-articulated vision for the desired functionality of tri-agency systems using radar data in the 2010 to 2020 period, a vision that will in turn drive radar enhancements and network development.

For example, it seems clear that the NWS forecaster workstation should provide a seamless interface between 4-D assimilated observations and model results, providing a picture of the immediate past, the present, and the near future on micro-, meso-, and synoptic scales. Articulating what functionality such a workstation – for example, the ability to select particular enhancements of imagery -- must provide determines the requirements for products from the radar and for mosaic or composited products, as well as the necessary assimilation and display tools. The mosaics can be created from the National Radar 4-D Database, which could include data from not only the WSR-88D network but also all other appropriate radars as discussed above. The goal here is to achieve nearly uniform, high-resolution data all across the nation, including in the boundary layer. As noted previously, this approach where user-forecasters interact with 4-D assimilated fields in addition to the data streams directly has implications for operational strategies and organization of the forecast office.

7. Establish a coordinated program to develop products and display tools for the various user communities

There is a growing community of users who rely on the radar data. These users range from professional and technical staff employed by the tri-agencies to private sector weather forecasters, to the media (including the national media such as The Weather Channel), to emergency managers, and transportation system managers. Each of these communities needs to be considered as changes are made to the way the radar network is operated and as new products are developed. Indeed, as a general principle, the TAC strongly recommends involving the user community, be it the tri-agency users or users outside the tri-agencies, as early in the change or development process as possible.

There is increasing demand for radar products that flow seamlessly into Geographic Information Systems. In the future, radar data products could be formatted to be compatible with standard Geographic Information System (GIS) software. Indeed, the architecture of the future forecaster/user workstation discussed in Recommendation 6 could be based on standard GIS software.

Similarly, there are strong indications from the commercial market that users will increasingly demand high resolution radar data and products be made available in a wide range of formats, including in vehicles and on Personal Data Assistants (PDAs). There appear to be many opportunities for partnership with the private sector in this area.

Radar retrieval techniques could be developed to obtain high-resolution wind fields. The retrieval of high-resolution near-surface water vapor fields from radar refractivity could be implemented on all radars in the national network. The development of enhanced warning and nowcasting techniques that utilize the high resolution multiple data sets could be accelerated.

Voice-activated intelligent agents can be developed to speed manipulation of data fields, speeding analysis and so improving warnings and other time-sensitive applications. While 3-D visualization tools have not yet found significant applications in meteorology, recent advances in such technology plus the anticipated future increases in 4-D environmental data streams suggest that it would likely be profitable to explore 3-D visualization tools for the operational forecaster. 4-D mosaics from multiple radars offer opportunities for such explorations.

Under the direction of the World Weather Research Program, efforts are being formulated to coordinate these and similar activities to improve efficiencies and speed the transfer of technology to operations. The TAC could monitor these activities and provide advice to the PMC/NEXRAD tri-agencies on the implications and possibilities for the U.S. national radar network in the areas of technology (for both the radar and the network) and applications of the data.

8. Establish national test beds and prototyping sites for testing new radar technologies and nowcasting/forecasting capabilities in operational environments

To properly develop many of the promising technologies now on the horizon, a number of test beds and prototyping sites should be established. These could be located around the nation to explore systematically various approaches to dealing with important meteorological phenomena and the needs of important user communities, e.g., an eastern Great Lakes facility to explore both lake effect snows, highly sheared thunderstorms with low ceilings and visibility, and critical aviation products, such as winds aloft, for the highly congested air space over that region. There are many other issues concerning wavelengths, calibration, resolution and communications that must be investigated. Further, it is desirable that the activities under recommendations 6 and 7 be implemented first at the test beds.

In addition to a Northeast U.S./eastern Great Lakes facility, prototype sites could be considered for the Gulf Coast (hurricanes), central Great Plains (severe thunderstorms, winter storms), the mountainous Western states (winter storms, fire), and in the northwest or central California coast (heavy rainfall, winter season storms). In many cases, this can be accomplished by deploying two Radar Data Acquisition (RDA) units to an existing WSR-88D site. One RDA would provide normal signal processing for current operational use, while the second would provide experimental signal processing, perhaps supporting an experimental forecasting effort.

It is important that prototyping efforts be structured to ensure that the resulting products are provided in real time to external users so that the user community can provide feedback early in the development process on the value and utility of the products for their specific agency applications.

To develop means for increasing the density of radars in the national network, field experiments could also be conducted with the aim of developing techniques for supplementing and extending the national WSR-88D network using other deployed radars (TDWR, ASR, mobile X-band radars, and commercial radars such as those used by the media).

3. Summary

The intent of the eight points used in this paper is to guide the evolution of the radar through the final 15-20 years of its service life. It was anticipated that research and development work currently getting underway at the National Weather Radar Testbed to investigate phased-array technology would be accomplished in parallel with many of the enhancements discussed here and that there would be a continuous exchange of information between the two parallel efforts.

4. Acknowledgements

Special thanks to the following individuals for providing your thoughts on the future of the WSR-88D for use in this paper: Stephen Brueske, Bill Bumgarner, Don Burgess, Paul Desrochers, Larry Dunn, Jim Evans, Doug Forsyth, Jeff Keeler, Vernon Preston, Paul Smith, William Spaulding, Dan Strawbridge, Mark Walton, Roger Whiton, Jim Wilson, Dusan Zrnic.

5. References

Fabry, F., C. Frush, I. Zawadzki and A. Kilambi, 1997: On the extraction of near-surface index of refraction using radar phase measurements from ground targets. *J. Atmos. and Ocean. Technol.*, 978-987.

National Research Council, 2002: *Weather Radar Technology Beyond Nexrad*. National Academy Press, Washington, D.C.81 pp.