2.1 REPORT OF THE NRC COMMITTEE ON WEATHER RADAR TECHNOLOGY BEYOND NEXRAD

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Weather radar furnishes essential observations of the atmosphere used in providing weather forecasts and issuing weather warnings to the public. The primary weather surveillance radar system operated by U.S. agencies is the WSR-88D (NEXRAD) system, which consists of about 150 nearly identical radars deployed over the United States and some overseas locations in the 1990s. Data from this system support activities of the National Weather Service (NWS), Federal Aviation Administration (FAA), and Department of Defense (DoD). The data are also distributed to a wide variety of other users, including private sector organizations and the media.

Since the design of the NEXRAD system, important new radar technologies and methods for designing and operating radar systems have been developed. These advances provide the motivation for appraising the status of the current weather radar system and identifying the most promising approaches for the development of its eventual replacement. In order to address this issue, a National Research Council (NRC) committee was convened, charged with the following task:

> *To determine the state of knowledge regarding ground-based weather surveillance radar technology and identify the most promising approaches for the design of the replacement for the present Doppler Weather Radar. Specifically, the committee will:*
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> 1. *Examine the state of the present radar technologies;*
> 2. *Identify new processes for data analyses; and*
> 3. *Estimate the maturity of the various capabilities and identify the most promising approaches.*

The committee included experts in radar technologies, meteorological applications, computer-processing capabilities for data handling, and application to numerical models.

Each of the committee's recommendations appears below under the section of the report in which it is introduced. The recommendations in boldface italics deal with technologies that are deemed worthy of consideration in the development of the future replacement for the current NEXRAD system. They are categorized as "near-term," "far-term," or "visionary"[1]. The committee also felt that the processes by which the future system is developed and deployed could be as significant as the technologies. The recommendations in standard italics refer to such procedural issues, and have no assigned priority.

The feasibility of the "far-term" and "visionary" technologies depends upon a variety of factors such as the evolution of enabling technologies and advances in basic understanding. Moreover, further developments will depend upon the evolution of the political, social, and economic environment in the nation and the world. In-depth feasibility studies will be required to determine which approaches are most likely to provide the needed improvements. The committee encourages the agencies that commissioned this study to follow through with the investigations necessary to establish the technical feasibility of the "far-term" and "visionary" technologies and to conduct benefit-cost analyses of the feasible ones.

1. Radar in the Atmospheric Observing and Predicting Systems

Weather forecasting and warning applications are relying increasingly on integrated observations from a variety of systems that are asynchronous in time and are non-uniformly spaced geographically.

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[1] The committee designates as "near term" those technologies for which the capabilities exist currently and could be implemented even before the development of the replacement NEXRAD. "Far-term" technologies could be available within the time period covered by this report (25–30 years), though they will require continued scientific and technological development before they could be implemented. "Visionary" technologies are those that may or may not be ready for operational use within the 25- to 30-year time frame.

Weather radar is a key instrument that provides rapid update and full volumetric coverage. On regional scales, the combination of the primary radar with subsidiary radars (either fixed or mobile), satellite data, automated meteorological measurements from aircraft, and a network of ground-based meteorological instruments reporting in real time has been shown to provide enhanced nowcasting and short-term forecasting capabilities. Such capabilities improve severe local storm warnings (including forecasts of storm initiation, evolution, and decay), and they support activities such as construction, road travel, the needs of the aviation system (both civil and military), and recreation.

Recommendation

The next generation of radars should be designed as part of an integrated observing system aimed at improving forecasts and warnings on relevant time and space scales.

2. The Current System

The current NEXRAD system is a highly-capable weather surveillance radar that has proved to be of great value to many sectors of our society, with its value extending beyond the traditional goal of protecting life and property. The Radar Operation Center (ROC) and the NEXRAD Product Improvement (NPI) Program are continually improving the system.

Early field testing of NEXRAD concepts and systems in a limited range of geographic and climatological situations did not elucidate and evaluate the full range of operational demands on the system. Weather surveillance needs vary from region to region and from season to season, and they depend on factors such as the depth of precipitating cloud systems and local topography. As the NEXRADs were deployed in other regions, further needs developed and additional limitations surfaced. The desire for more rapid update cycles is widespread, as are concerns about data quality.

Recommendation—Near-term

The Radar Operation Center and the NEXRAD Product Improvement Program mechanisms should be extended to permit continual improvement to the NEXRAD system. Provisions should be made to carry features found to be beneficial, such as polarization diversity, over to the succeeding generation of systems.

Recommendation

Weather surveillance needs should be evaluated by geographic region to determine if a common radar system design is appropriate for all regions.

Recommendation

The development program for the next generation weather surveillance radar system should incorporate adequate provision for beta testing in the field in locations with diverse climatological and geographic situations.

3. Advanced Radar Technologies — Capabilities and Opportunities

The emergence of new radar technology provides an important foundation for updating the current NEXRAD system. A key technological issue related to future radar development and usage is that of spectrum allocation. Communications and other users of the electromagnetic spectrum are competing for the current weather radar spectrum allocation. There is particular concern that the use of S-band (10–cm wavelength) may be lost for weather radar applications. The loss of S-band would compromise the measurement of heavy rain and hail, the ability to provide warning of flash floods and tornadoes, and the monitoring of hurricanes near landfall. The cost of rectifying these impacts in the current NEXRAD system would be high, and the constraints on the design of a future replacement system would be serious.

Emerging hardware and software technologies offer promise for the design and deployment of a future radar system to provide the highest-quality data and most useful weather information. Adaptive waveform selection and volume scan patterns are important for optimizing radar performance in different weather situations. Radar systems with phased-array antennas and advanced waveforms can support a broad range of applications with observation times sufficiently short to deal with rapidly evolving weather events such as tornadoes or downburst winds. Polarimetric techniques offer means of dealing with many data-quality issues, provide a means for identifying hydrometeors over a storm, and offer the potential for the more accurate estimation of rainfall and the detection of hail. The ability of phased-array antennas to provide the requisite polarization purity has yet to be established.

Recommendation—Far-term

Adaptive waveform selection, which may even be applied to present systems, and agile beam scanning strategies, which require an electronically scanned phased array system, should be explored to optimize performance in diverse weather.

Recommendation—Far-term

The technical characteristics, design, and costs of phased array radar systems that would provide the needed rapid scanning, while preserving important capabilities such as polarization diversity, should be established.

Recommendation

The quality of real-time data should receive prominent consideration in the design and development of a next-generation weather surveillance radar system. Real-time data-quality assessment should be automated and used in deriving error statistics and in alerting users to system performance degradation.

Recommendation

Policy makers and members of the operational community should actively participate in the arena of frequency allocation negotiation. The impact, including the economic and societal costs, of restrictions on operating frequency, bandwidth, and power should be assessed for current and future weather radar systems.

4. Networks and Mobile Platforms

The new technologies also provide a foundation for the networking and placement of future radar systems. A closely spaced network of short-range radar systems would provide near-surface coverage over a much wider area than the current NEXRAD system. This would expand geographic coverage of low-level winds, precipitation near the surface, and weather phenomena in mountainous regions. Radars other than those in the primary network (e.g., weather radars operated by television stations or air traffic control radars operated by the FAA) could fulfill some of these roles.

Mobile radars can provide highly detailed views of weather events. Such observations not only have scientific interest, but also could be valuable in support of emergency services in cases such as fires, contaminant releases, and nuclear, chemical, or biological attacks upon this country.

Satellites and other aerospace vehicles represent alternatives to traditional ground-based systems. For example, the satellite-borne Tropical Rainfall Measurement Mission (TRMM) radar has demonstrated the ability to observe precipitation over regions not reached by land-based radars. Future satellite technology is likely to allow on-orbit operation of radar systems with larger antenna apertures and higher power outputs than are currently used in space. Satellite constellations, operating as distributed array antennas, could provide high-resolution global coverage. Both piloted and unmanned aerospace vehicles (UAV) are being developed for a variety of remote sensing and other applications. As the capabilities of these airborne platforms increase, it may become possible to place weather radar systems on station at a variety of altitudes, for an extended duration.

Recommendation—Near-term

The potential value and technology to incorporate data from complementary radar systems to provide a more comprehensive description of the atmosphere should be investigated.

Recommendation—Near-term

The potential of operational mobile radar systems to contribute to the nation's weather surveillance system for emergency response and for improved short-term forecasts should be evaluated.

Recommendation—Far-term

The potential for a network of short-range radar systems to provide enhanced near-surface coverage and supplement (or perhaps replace) a NEXRAD-like network of primary radar installations should be evaluated thoroughly.

Recommendation—Visionary

The capabilities of future space-based radar systems to supplement ground-based systems should be determined.

Recommendation—Visionary

The capabilities of Unmanned Aerospace Vehicles and piloted aircraft to carry weather radar payloads should be monitored for their potential to provide weather surveillance over the continental United States and over the oceans.

5. Automated and Integrated Products

Weather radar data are being increasingly used not only in forecasting and warning applications but also in climatological studies as well as in a wide variety of other research areas. Weather radar provides observations on the small space and time scales that are essential for monitoring precipitation and diagnosing certain weather events as well as for supporting nowcasting systems, hydrologic models, and numerical weather prediction models. Issues of data quality are central to most such applications, particularly to efforts to automate the applications. Effective assimilation of radar data in the models also requires detailed error statistics.

Broad dissemination of weather radar data in real time facilitates the application of these data to diagnostic and forecasting operations. Archiving of radar base data, as well as product data, facilitates research activities, retrospective studies, and climatological investigations. A long-term objective of the radar and other weather observation systems is the establishment of an integrated observational system, whereby most or all of these observations (e.g., ground-based, airborne, and space-borne radar, along with satellite, surface, and other data) would be assimilated onto a four-dimensional grid to provide the most complete diagnosis of weather impacts possible. Numerical weather prediction models and nowcasting techniques would then provide forecasts from a few minutes to many hours. A broad array of products will be used to support decisions that improve safety to humans, improve operational efficiency, and make homeland defense efforts more effective.

Recommendation

To support the use of radar data in the climate observing system and other research areas, standards for calibration and continuity of observations should be established and implemented.

Recommendation

The value of radar data, as part of an integrated observing system, in diagnostic applications, nowcasting systems, and hydrologic and numerical weather prediction models should be considered in the design of the next generation weather radar system. The characteristics of radar observations and associated error statistics must be quantified in ways that are compatible with user community needs.

Recommendation

Plans for next generation weather radar systems should include provisions for real-time dissemination of data to support forecast, nowcast, and warning operations and data assimilation for numerical weather prediction, and certain research applications. Routine reliable data archiving for all radars in the system for research, climatological studies, and retrospective system evaluation must be an integral part of the system. Convenient, affordable access to the data archives is essential.

Recommendation

Tactical Decision Aids and means for collaborative decision-making capabilities should be developed for both meteorological and non-meteorological users of the system, with attention to the demands on the integrated observing system.

6. Committee on Weather Radar Technology Beyond Nexrad

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