Assessment of Nexrad Coverage and Associated Weather Services

NEXRAD Panel, National Weather Service Modernization Committee, National Research Council

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Toward a New National Weather Service —

ASSESSMENT OF NEXRAD COVERAGE AND ASSOCIATED WEATHER SERVICES

Prepared by the
NEXRAD Panel
National Weather Service Modernization Committee
of the
Commission on Engineering and Technical Systems National Research Council

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Preface

This report responds to a request from the Secretary of Commerce who, in a letter dated August 18, 1994, asked the National Research Council's (NRC's) National Weather Service Modernization Committee (NWSMC) to conduct a study on the adequacy of coverage of the Next Generation Weather Radar (NEXRAD) with respect to a congressional requirement that the system result in “no degradation of service.” This request was further amended by an October 5, 1994, agreement between the National Oceanic and Atmospheric Administration (NOAA) and Congressman Bud Cramer of Alabama. Accordingly, the NRC established a panel of experts to (1) review the new radar's technical specifications and network spatial coverage, (2) evaluate and compare the detection capabilities and coverage of the pre-NEXRAD and NEXRAD radars, (3) assess the performance of both networks from the standpoint of significant weather events, and (4) establish general criteria for evaluating the adequacy of coverage of the NEXRAD network and identifying areas where service might be degraded when the old radars are decommissioned. A site-by-site evaluation using these criteria was excluded from the panel's task, but the data and procedures to conduct such evaluations are included in this report.

The NWSMC has been functioning for more than 5 years under contracts between the NOAA and the NRC. Five substantive reports have been issued about the ongoing modernization of the National Weather Service (NWS) and various aspects of its planning and implementation. The NEXRAD program has been evaluated and reported upon in four of the five reports (NRC, 1991, 1992, 1994a, and 1994b), and certification criteria for critical phases of the modernization were addressed in NRC, 1993.

The panel includes three NWSMC members and two additional engineers and scientists chosen for their special competencies and with regard for appropriate balance of viewpoints and expertise. Two special technical advisors, R. Jeffrey Keeler and James Wilson, participated fully in all panel activities and contributed substantially to the written report.

The panel conducted five formal meetings and several informal, opportune meetings to gather and analyze technical data and other information, to develop evaluation criteria, and to assess the adequacy of weather radar coverage for the nation. As part of this effort, the panel developed criteria for use by the NOAA to adjudicate possible degradation issues related to decommissioning of existing radars and services provided by associated weather offices.

The panel appreciates the cooperation and extensive assistance provided by members of NOAA: the NEXRAD Joint System Program Office (JSPO), the NEXRAD Operational Support Facility, and the NWS Headquarters staff. In particular, the panel recognizes the provision of technical materials and special briefings by David Smiley, Robert Elvander, Juris Petriceks (SRI International, contractor to the NEXRAD JSPO), Donald Burgess, Paul Polger, and Richard Lane. Special thanks also to the Publications Department, Massachusetts Institute of Technology, Lincoln Laboratory, for all of the illustrations of weather phenomena and to Steven Zubrick, Weather Service Forecast Office, Sterling, Virginia, for providing the NEXRAD display for the cover.

The panel is also indebted to Peter Ray, of Florida State University, for his briefing about related studies; and to the many NWS radar operators, university, and private-sector researchers who reviewed information about radar characteristics and the ability of various radars to detect significant weather phenomena across the United States.

The panel thanks the members of the NWSMC for their review of the report and for their support and guidance during its preparation. Finally, the panel acknowledges the excellent support of three NRC staff members—Floyd F. Hauth, Study Director; Mercedes Ilagan, Study Associate; and Susan Coppinger, Administrative Assistant—as well as that of consultant/writer, Courtland S. Lewis, in carrying out the panel's work. Their services in making logistical arrangements, conducting liaison with federal agencies, universities, and the private sector and in preparing the report were invaluable.

William E. Gordon
Chairman, NEXRAD Panel
National Weather Service Modernization Committee

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Executive Summary

Modernization and associated restructuring of the National Weather Service (NWS) will usher in a new era for severe weather and flood warning and forecast services in the United States. Important advances in the science of meteorology, coupled with major new technological capabilities for observing and analyzing the atmosphere, will provide unprecedented weather service improvements over the next decade. The existing systems for making weather observations and processing and communicating data and information about the weather are obsolete and costly to maintain. The modernized NWS will obtain substantially more weather data through the use of new technology that will include automated surface observations, Doppler radars, satellites, and data assimilation on supercomputers. Advanced information processing technology will be used to integrate the various data fields and to provide them to the forecaster in useful forms. This technology will also assist in the generation and issuance of improved forecasts, warnings, and other products and services.

The NWS' parent agency, the Department of Commerce, in response to a request from the Chairman of the Committee on Science, Space and Technology of the U.S. House of Representatives, asked the National Research Council's National Weather Service Modernization Committee (NWSMC) to “assess the adequacy of Next Generation Weather Radar (NEXRAD) coverage for the nation…” to ensure that there will be no degradation of weather services as a result of this aspect of the modernization.

Based on an intensive 6-month study, the NEXRAD Panel of the NWSMC arrived at a strong overall conclusion that weather services *on a national basis* will be improved substantially under the currently planned NEXRAD network. This improvement derives from factors described in the following paragraphs.

First, in comparison with the old network, the NEXRAD network will cover a much broader area of the contiguous United States. For the detection of specific weather phenomena—supercells, mini-supercells, macrobursts, lake-effect snow, and stratiform snow—the NEXRAD coverage is much greater than it was for the old system; for hurricanes, the NEXRAD coverage is complete over the entire area of risk.

Second, because the NEXRAD radars meet or exceed their technical design specifications relevant to the detection of weather phenomena and because they are substantially superior to the radars they replace (even in the non-Doppler mode), the panel concludes there is no degradation of service when a NEXRAD is located at or near the site of one of the old radars. In fact, service at those locations, which constitute the majority of sites, will be markedly improved. The panel is confident that the introduction of NEXRADs will significantly improve overall storm detection and warning performance.

Third, the NEXRAD's Doppler feature and other technical characteristics allow for greatly increased capability for short-term forecasting (“nowcasting”) of thunderstorm initiation; detection of damaging winds, such as macrobursts and wind shear; and mesocyclone detection, which is often associated with tornadoes and other severe storm hazards.

Fourth, digital signal and data processing will permit the production and display of a wide variety of automated weather products which, in turn, will improve the forecaster's ability to rapidly assimilate and use the available data, not only from their NEXRAD but also from neighboring NEXRAD sites.

Finally, the NEXRAD is only one element (although an important one) of a composite system that consists of several powerful new observational systems, including geostationary and polar satellites, automated surface observing equipment, lightning detection networks, wind profilers, and other atmospheric sounders. The composite system also includes cooperative networks of human observers and spotters, the skills of experienced forecasters, and improved numerical forecast models. These diverse data sets will be assimilated and integrated by an Advanced Weather Interactive Processing System at each Weather Forecast Office (WFO) that will connect the many parts of the system to permit effective use by specially trained staffs who prepare forecasts, warnings, and other products and services.

NWS storm warning statistics accumulated over 5 or more years at six NWS radar sites show a distinct improvement in performance associated with the installation of a NEXRAD. Data concerning warning performance as a function of range from a NEXRAD present a mixed and somewhat confusing picture. In the panel's judgment, definitive conclusions cannot be drawn from the data available at this time. Further testing in the Modernization and Associated Restructuring Demonstration and at diverse geographic locations, with particular attention to the verification data, will be necessary to draw specific conclusions with respect to the effect of distance from the radar on the quality of warning performance.

In areas where the pre-NEXRAD radar is not replaced, and service is to be provided by a NEXRAD located some distance away, the panel's analyses show that there is a potential for some degradation in radar-detection coverage capability.[1] Areas of concern are illustrated in this report by a series of maps. These areas include those now covered by pre-NEXRAD radars located in northern Alabama, northern Indiana, northwestern North Dakota, northwestern Pennsylvania, and southeastern Tennessee.[2] The northern Alabama area is a special case because the existing radar, which is to be decommissioned, is a functioning Doppler radar. As a result, the potential degradation in detection capability for this area is greater than for other sites in the pre-NEXRAD radar network. Also shown are a few areas where the switch from the pre-NEXRAD network to the new network results in a “degradation of service,” as defined in P.L. 102-567, Sec. 702(4), due to “a reduction in existing weather radar coverage at an elevation of 10,000 ft.”

Degradation of *radar-detection coverage* does not necessarily imply degradation of weather *service* in the forecasting and warning functions. Integration of all data sources and other elements of the composite system plays a significant role in the provision of services, permitting considerable compensation for lesser detection capabilities over specific areas. However, in general, the greater the distance the pre-NEXRAD radar site is from a NEXRAD, the more likely is the degradation in radar-detection coverage in portions of the area covered by the existing radar. Similarly, there is an increased potential for degradation of associated warning services that must be compensated for by other improvements in the system through the modernization.

[1] Radar-detection coverage is the area over which detectable signals are returned from various weather phenomena as the radar scans at and above the horizon. See Appendix A, page 68 for more details.

[2] A site-by-site evaluation was excluded from the panel's task, but the data, criteria, and procedures to conduct such evaluations are provided in this report.

The panel's conclusions regarding the adequacy of coverage and service with the NEXRAD network are based on the assumption that 15 of the NEXRAD radars (listed on p. 32) currently planned to be under the control of the Department of Defense (DoD) will be operated and maintained to the standards set for the national NEXRAD network. Removal of any of these radars from the network or operation of any of them with standards and availability that are less than those of NWS-operated units will degrade radar-detection coverage.

In the national NEXRAD network, there will be four NEXRADs without a nearby WFO (i.e., Yuma, Arizona; Key West, Florida; Caribou, Maine; and Cedar City, Utah). When a WFO is remote from a NEXRAD, the reliability of the NEXRAD, the dependability of services derived from it, supporting communications and back-up capability, forecast office staffing, and warning and forecast dissemination become even more-important factors in meeting the requirements of distant service areas.

Based on its analyses and on the conclusions derived from them, the panel recommends the following:

1. Where the panel has identified specific geographic areas where degradation of radar-detection coverage may occur, the National Weather Service should examine each potentially vulnerable area to determine whether such degradation would result in degradation of associated weather services.
2. The procedures and criteria for decommissioning old radars are specified in existing National Weather Service documentation; these should be rigorously applied, especially in vulnerable areas. Additional criteria/procedures proposed by the panel (described in Chapter 4, under "Assessment Criteria and Procedures") should be followed in assessing the degradation of service and determining corrective actions. These assessment processes should be incorporated into official National Weather Service guidelines and procedures and used in conjunction with the requirements in P.L. 102-567.
3. The National Oceanic and Atmospheric Administration should take immediate steps to ensure that the 15 NEXRADs under the control of the Department of Defense, which are needed to avoid degraded coverage, function as fully committed elements of the national weather radar network, operating with the same standards, quality, and availability as the National Weather Service-operated NEXRADs.
4. The National Weather Service should ensure that maintenance for, operation of, and communication with NEXRADs that are not located near a Weather Forecast Office are in full accordance with network standards. In addition, responsibilities for weather services to the area covered by these NEXRADs should be unambiguously assigned to a specific Weather Forecast Office to ensure high-quality weather services for that area. Staffing and communications capability should be commensurate with each Weather Forecast Office's service area's responsibilities.
5. The storm-detection and warning performance of the composite national weather system, as a function of range from a NEXRAD, should receive an in-depth independent technical assessment that considers region-specific issues. This assessment should evaluate the warnings and reported events on a per-unit-area basis, as well as the traditional National Weather Service verification statistics. The assessment should include further testing in the Modernization and Associated Restructuring Demonstration in addition to tests at diverse geographic locations.
6. The adequacy of NEXRAD coverage with respect to the "no degradation of service" requirement should be reexamined in an independent study after all National Weather Service NEXRADs are commissioned.

1

Introduction

Modernization and associated restructuring of the National Weather Service (NWS) will usher in a new era for severe weather and flood warning and forecast services in the United States. Important advances in the science of meteorology, coupled with major new technological capabilities for observing and analyzing the atmosphere, will provide unprecedented weather service improvements over the next decade. The existing systems for making weather observations and processing and communicating data and information about the weather are obsolete and costly to maintain. The modernized NWS will obtain substantially more weather data through the use of new technology, which will include automated surface observations, Doppler radars, satellites, and data assimilation on supercomputers. Advanced information processing technology will be used to integrate the various data fields and provide them to the forecaster in useful forms, as well as to assist in generating and issuing improved forecasts, warnings, and other products.

In the transition from the old system to the new, Congress and others have expressed concerns about the adequacy of the new radar network to detect significant weather events over vulnerable areas of the contiguous United States such that there will be no degradation of the service currently provided by the NWS.[1] It is important to note that degradation in any one component of the new system, including NEXRAD coverage, does not necessarily imply a net degradation in the overall system. Congress asked the National Research Council (NRC) and its National Weather Service Modernization Committee (NWSMC) to address these concerns. This report is the result of a 6-month study conducted by a panel of radar engineers and meteorologists qualified by training and experience.

The background leading to the study, the charge to the committee/panel, and the study process followed by the panel are described in the section entitled "Background: Modernization of the National Weather Service." To determine the technical adequacy of the new Doppler radar with respect to the "no degradation of service" requirement, the panel defined and mapped the radar-detection capabilities in Chapter 2. This analysis provided the basis for a comparison of the old and new systems, which is discussed in Chapter 3. The panel's comparison was made with respect to weather services, that is, warnings that involve a forecaster and his/her expertise, supported by all of the available information. This information includes both radar observations and a wide variety of other observational information that is provided by the new technology and by other elements of the composite national weather system.

[1] Use of "contiguous United States" in this report will denote the 48 contiguous states (i.e., not including Alaska or Hawaii). Degradation of services related to radar-detection services is not a factor in Alaska and Hawaii since NEXRADs will provide new coverage capabilities in both states. (There was no NWS radar coverage prior to NEXRAD.)

Guidelines for assessing potential degradation of service at specific sites are discussed in Chapter 4. The panel's conclusions and recommendations are listed in Chapter 5.

General criteria for evaluating a weather radar system and the technical aspects of radars—system configuration, spatial coverage, resolution, and sensitivity—are detailed in Appendix A. While a site-by-site evaluation was excluded from the panel's task, these criteria, guidelines, and data will allow others to conduct such evaluations.

References, a list of acronyms, and a glossary are provided at the end of the report.

BACKGROUND: MODERNIZATION OF THE NATIONAL WEATHER SERVICE

In the late 1980s, the NWS embarked on a modernization and restructuring of its operations and the associated field office structure. When completed, this modernization will provide a much-needed updating of the technologies used to observe weather features (especially often-destructive phenomena, such as severe thunderstorms, tornadoes, wind shear, flash floods, and hurricanes) and will include new information systems that will enable the NWS to provide more accurate and timely weather forecasts and warnings to the public.

The new observing systems include the Weather Surveillance Radar–1988 Doppler (WSR-88D) Next Generation Weather Radar (NEXRAD), the Automated Surface Observing System (ASOS), and the next generation of Geostationary Operational Environmental Satellites (GOES). In the new system, an Advanced Weather Interactive Processing System (AWIPS) will process the large volume of information, provide the forecaster with information in useful forms, and provide an interactive communications link among the offices.

The associated restructuring of the NWS is driven by these new technologies. The current field office structure includes 52 Weather Service Forecast Offices (WSFOs), whose responsibilities are organized on a geographical basis; about 200 smaller offices, including Weather Service Offices (WSOs) and Weather Service Meteorological Observatories, which manually take surface observations and, in some instances, weather radar observations (and, in the case of WSOs, issue local-area forecasts and warnings); and 13 River Forecast Centers (RFCs) (NWS, 1985, 7 and 21). The new, modernized structure of the NWS will include 118 Weather Forecast Offices (WFOs), 112 of which will be located in the contiguous United States, at sites determined primarily by the locations of the NEXRADs, and the 13 RFCs (NRC, 1993, 12). Even though there will be a substantial reduction in the total number of field offices, the new organizational structure is intended to provide equivalent or improved services.

The modernization process is now well underway with the ongoing deployment of the new NEXRAD and ASOS observational technologies and the successful launch of a GOES-8 satellite in April 1994. Development of AWIPS is in progress.

The NEXRAD

One cornerstone of the modernization program is the NEXRAD, more accurately described as the WSR-88D. In addition to conventional reflectivity observations, this advanced radar uses the

"Doppler effect"[1] to measure motion of clear air and atmospheric phenomena within storms, up to a maximum distance of 230 km from the radar. This allows much more accurate detection of circulations associated with tornadoes and other significant weather. NEXRADs will replace a network of 128 older radars that were concentrated east of the Rocky Mountains, primarily in the central and eastern United States. A comparison of radar characteristics is provided in Appendix A.

The 138 NEXRADs to be deployed in the contiguous United States will provide national coverage. The NWS will operate 116 of the NEXRADs; the Department of Defense (DoD) will operate 22. Through AWIPS, forecasters in the new field offices will work interactively with all of the available data. The deployment of these radars nationwide is spread across a 6-year period (1990-1996). As of April 1995, 116 NEXRADs had been installed.

CHARGE TO THE COMMITTEE

The charge transmitted by the Secretary of Commerce to the NRC (Appendix B) calls for the NWSMC to

> assess the adequacy of NEXRAD coverage from a scientific and technical standpoint, in terms of the no degradation of service requirement of the Weather Service Modernization Act, P.L. 102-567.

The Act, section 702 (4), states that

> degradation of service means any decrease in or failure to maintain the quality and type of weather services provided by the National Weather Service to the public in a service area, including but not limited to a reduction in existing weather radar coverage at an elevation of 10,000 feet.

This request from the Secretary of Commerce was amended by an October 5, 1994, agreement between National Oceanic and Atmospheric Administration (NOAA) and Congressman Cramer of Alabama. In accordance with this agreement (see sections 4 and 5 "Study Guidelines," in Appendix B) the panel agreed to receive public comments and "to conduct an independent scientific assessment of the proposed NEXRAD radar coverage and consolidation of field offices[2] in terms of 'no degradation of services' and to establish criteria for identifying service areas where the decommissioning of existing radars could degrade service." The panel did not explicitly address nontechnical issues, such as economic, safety, and population risk factors, that were beyond the scope of this study. The Statement of Task of the NRC's NEXRAD Panel of the NWSMC is in Appendix C.

[1] The Doppler effect is the change in frequency of electromagnetic radiation (light, radio waves, radar pulses, etc.) or sound waves as the point of emission or reflection approaches or recedes from an observer. An example is the change in pitch of an emergency vehicle siren as it approaches and passes an observer.

[2] "Consolidation of field offices" is, among other things, tied to the decommissioning of existing radars and associated transfer of service responsibilities. Thus, the only scientific assessment that is applicable pertains to the technical aspects of radar-detection coverage and the associated forecast and warning services for the service area of the radar.

STUDY PROCESS

Panel members interviewed many people who were familiar with NEXRAD and solicited opinions from meteorologists and others on NEXRAD's performance. The interviewees reflected a high level of satisfaction with the capabilities of the NEXRAD and an enthusiasm for the operation and outputs of the radar. This suggests that there is a high level of confidence in the performance of the system and the quality of its associated services.

Making a balanced comparison of weather radar systems to ascertain a possible “degradation of service” requires the use of objective criteria upon which to base the comparison. In a broad sense, the important criterion is the system's ability to recognize and respond to significant weather features of concern. These criteria and the technical aspects of a radar that relate to its detection capability are discussed in Appendix A.

The panel reviewed the history of the NEXRAD siting plans and was briefed by NOAA personnel and others on technical aspects of the program. At the panel's request, NOAA asked SRI International to provide spatial coverage, resolution, and sensitivity charts for elevations 4,000 ft, 6,000 ft, 10,000 ft, and 40,000 ft above site level for the entire contiguous United States. It soon became apparent to the panel that the detection of specific types of weather phenomena needed to be quantified and compared (see Chapter 2) in order to assess NEXRAD and pre-NEXRAD detection coverage realistically.

The panel derived detection ranges for several significant weather phenomena. Site-specific coverage characteristics for five weather phenomena were used to generate coverage charts for the pre-NEXRAD and NEXRAD networks. At the panel's request, NOAA asked SRI to prepare “difference charts,” which the panel analyzed to determine areas where the decommissioning of old radars could result in a degradation of radar-detection coverage (see Chapter 2).

Where sufficient data were available (see Chapter 3), the panel reviewed warning performance data and compared pre-NEXRAD and NEXRAD operations at weather offices in different areas of the country. The panel also reviewed these data in the context of the overall composite system considerations of the pre-NEXRAD and NEXRAD networks.

Finally, the panel developed criteria (see Chapter 4) to use as guidelines in assessing possible degradation of service in areas where the decommissioning of existing radars, and changes in related services provided by the associated weather offices, might be in question.

2

Radar Network Configuration and Detection Capabilities

NETWORK COVERAGE AT 10,000 FEET ABOVE SITE LEVEL

The pre-NEXRAD NWS radar network consisted of 128 WSR-57, WSR-74S, and WSR-74C radars concentrated primarily in the central and eastern United States. The WSR-57 and WSR-74S radars, both 10-cm wavelength systems, were configured as manually operated surveillance radars. The 68 WSR-74C radars functioned as “local warning” radars and often were operated only during periods of significant weather. In recent years, three of the pre-NEXRAD radars had some Doppler capability; two of these have been replaced by NEXRADs at nearby sites.

The pre-NEXRAD radars routinely scanned only at low elevation angles in the surveillance mode and were operated manually for other scans, such as vertical scans in the range-height indicator mode. Figure 2-1a indicates the composite coverage provided by the pre-NEXRAD network at 10,000 ft above site level over the contiguous United States and bordering areas.[1] Here “coverage” means that the lower edge of the radar beam, as determined from the radar horizon with standard atmospheric refraction and with due consideration of any blockage by intervening terrain, would intercept any weather phenomenon reaching at least that altitude (see Appendix A, pages 68–70). The altitude of 10,000 ft is used here only because the charge to the panel asked for an examination of any reduction in radar coverage at 10,000 ft. This request stems from the definition in P.L. 102-567, Sec. 702(4) that “‘degradation of service' means any decrease in or failure to maintain the quality and type of weather services provided by the National Weather Service to the public in a service area, including … a reduction in existing weather radar coverage at an elevation of 10,000 feet.” From a scientific point of view, there is no compelling reason to specify this or any other specific height, however, because the requisite altitude coverage for detecting various weather phenomena differs for each phenomenon. Thus, coverage at the 10,000-ft level gives no guarantee that every phenomenon of concern can be detected.

The NEXRAD network, when complete, will consist of 138 10-cm wavelength NEXRADs in the contiguous United States, including 22 operated by the DoD. All of these NEXRADs are computer-controlled radars that are designed to operate continuously in a three-dimensional, volume-scan mode. Figure 2-1b indicates the composite coverage at the 10,000-ft level that will be provided by the

[1] Above site level (ASL) altitudes are used since the siting documentation and data base are given in terms of ASL. Certain radars in the West (e.g., Tucson) are located on mountains high above the surrounding ground level (AGL). Therefore, ASL and AGL altitudes may differ by several hundred or even thousands of feet.

Figure 2-1a Composite pre-NEXRAD coverage at 10,000 ft above site level for the contiguous United States and the locations of the radars by type. Courtesy of SRI International.

Figure 2-1b Composite NEXRAD coverage at 10,000 ft above site level for the contiguous United States and the locations of NWS and DoD sites. This figure also shows those areas (striped blue) where there will be reduced coverage at 10,000 ft by the NEXRAD network compared with that which existed with the pre-NEXRAD network, as specified in P.L. 102-567, Sec. 702(4). Courtesy of SRI International.

NEXRAD network in the contiguous United States.[1] Coverage will be nearly complete over the central and eastern United States. In addition, the previous gaps in coverage over the western United States will be reduced substantially. Figure 2-1b also shows (striped blue) where the coverage by the NEXRADs at 10,000 feet is reduced from that provided by the pre-NEXRAD radars. The 10,000-foot requirement is defined in P.L. 102-567, Sec. 702(4).

Over land, the areas where coverage is reduced include small portions of North Dakota, Montana, and Wyoming. As noted in Chapter 1 in the section on study process, to make a meaningful assessment of adequacy of coverage, radar coverage also must be considered in terms of the resolution and sensitivity of the radars with respect to specific weather phenomena. These aspects of radar coverage are examined and discussed later in this chapter and in Appendix A.

The NEXRAD network will be capable of detecting tall storms anywhere in the contiguous United States and in most of the 230-km bordering area. Specifically, any storm reaching a height of at least 26,000 ft above site level will extend through at least the lower half of the beam of some NEXRAD in the network (scanning at the lowest elevation angle). However, for shallower phenomena, NEXRAD will not provide detection coverage at the desired altitudes over the entire contiguous United States; therefore, coverage for locations far from NEXRAD sites, but close to pre-NEXRAD radars, needs to be examined more closely. The section entitled “Comparisons of Detection Coverage by Pre-NEXRAD and NEXRAD Networks,” later in this chapter, discusses the panel's review of this coverage. It is important to note that the old network did not provide full coverage for shallow weather phenomena.

CALCULATED VERSUS OBSERVED DETECTION RANGES

Critical to assessing the possibility that any degradation of service may exist in a particular geographic area is the need to quantify the range to which significant weather phenomena can be detected by the old and new radars. In some situations the radar detects weather events directly, leading the forecaster to issue warnings or advisories. These events include hurricanes, strong surface winds, heavy rain, heavy snow, and wind-shift lines. In other situations, features detected by the radar are only indirectly related to the actual weather event. This is the case for tornadoes, hail, and precipitation amount. Large tornadoes at relatively close radar range are an exception because the tornado circulation can be seen by a radar in Doppler mode (appearing as a “tornadic vortex signature,” or TVS), even though the circulation may not be fully resolved.[2]

Research has shown (Burgess and Lemon, 1990) that rotating thunderstorms, which are associated with mesocyclones or misocyclones, often produce tornadoes or other severe weather like hail and strong surface winds. However, not all rotating thunderstorms produce severe weather, and not all severe weather is associated with rotating thunderstorms. Thus, more than radar information goes into the issuance of a tornado or severe-storm warning. The forecaster integrates atmospheric stability and melting level information, wind profiles, numerical model outputs, and other environmental characteristics to determine the potential for significant weather. Spotter reports, features

[1] For a NEXRAD operating with a 1-degree beamwidth and scanning at 0.5 degrees elevation, the lower edge of the detection cone crosses the 10,000-ft elevation dictated by P.L. 102-567 when the beam is 230 km from the radar. (Terrain or other obstructions to the beam will reduce the range of coverage. Technology considerations limit the usable NEXRAD Doppler range to 230 km.)

[2] Drawings and descriptions of weather phenomena are provided in Appendix D.

observed in satellite data, and other weather observations supplement the radar data as aids for the forecaster to make a decision to issue a warning.

The panel used two methods to determine the maximum range at which significant weather phenomena can be detected by the old and new radars. The first method was to describe the phenomenon in terms of its physical dimensions and radar reflectivity factor and use the radar characteristics to calculate the maximum range at which the phenomenon could be detected. The second method was to survey the observational experience of research and operational meteorologists. The results of these two methods are presented as Table 2-1 and Table 2-2. To ensure credibility of the results, the panel distributed the tables twice to a large cross-section of the weather research and operational communities for their comments. A total of 35 people (listed in Appendix E) provided comments. After the revisions this process produced, there was no significant disagreement among the panel members or the 35 respondents as to the data shown in the tables.

The pre-NEXRAD network contained three radars with various levels of Doppler capability. These radars were located in Huntsville and Montgomery, Alabama, and in Marseilles, Illinois. The radars in Montgomery and in Marseilles were replaced by nearby NEXRADs; the radar in Huntsville is still in use. The NWS currently plans to decommission the Huntsville radar and provide detection-coverage service for that area from NEXRADs at Birmingham, Alabama; Nashville, Tennessee; and other adjacent NEXRADs. The capabilities of the Huntsville WSR-74 Doppler radar are included in Table 2-1 to allow a comparison of the existing radar with the planned NEXRAD coverage.

Table 2-1 describes the characteristics (top, limiting horizontal extent, and reflectivity) that the panel used to calculate the maximum ranges at which various weather phenomena can be detected. The typical spread of the values for each characteristic is listed, along with an estimated median value. These values take into account regional and seasonal differences, but the limits do not include extreme cases. In the case of reflectivity, the values refer to average values within the phenomena. The spread of values is based on the scientific literature (see references) as well as on the panel's experience and that of those who responded to the mailings.

Calculations of the range for each radar and each phenomenon shown in the table were based on the panel's assumption that a phenomenon can be detected if (1) the center of the beam at a 0.5 degree elevation angle is at or below the top of the phenomenon; (2) the half-power beam width for supercells, mini-supercells, and misocyclones is less than one-half of the horizontal diameter of the rotation, while for all other phenomena the half- power beam width is less than the smallest azimuthal dimension; and (3) the minimum detectable signal at a particular range is less than the radar reflectivity factor of the phenomenon. (The minimum detectable signal for each radar is found in Appendix A, Table A-1.)

Table 2-2 provides a comparison of calculated and experienced maximum ranges for detection of various radar- observed phenomena by pre-NEXRAD radars and NEXRAD. The table is based on two sources of information: the theoretical calculations given in Table 2-1 and forecaster/researcher experience.

In Table 2-1 and Table 2-2, the WSR-57 and WSR-74S radars are grouped together because their beam widths and minimum detectable signals are very similar. The most range-limiting of the three characteristics of the phenomena is given in Table 2-2 as the calculated maximum range. The altitude of the top of the phenomenon is often the limiting characteristic. For the calculations of maximum range, the altitude of the top of the phenomenon is assumed to be radar-independent. In two cases, convergence lines and lake-effect snow, the minimum detectable signal is also a significant factor. The horizontal dimension is the limiting characteristic for mesocyclone and misocyclone; the vertical dimension is the limiting characteristic for the bright band.

As the tables indicate, the Doppler feature of the NEXRAD provides a new capability for directly measuring several weather phenomena and winds within the phenomena. These phenomena include tornadoes, mesocyclones, misocyclones, microbursts, macrobursts, convergence lines, and winds within hurricanes, precipitation, and the clear-air boundary layer. The confidence in detecting supercells, mini-supercells, and macrobursts using Doppler radar is much higher than with non-Doppler radars, since the detection is direct and reliable. Supercells are rotating thunderstorms whose circulation can be detected directly in the Doppler velocities, but which can only occasionally be inferred indirectly by a hook-shaped radar reflectivity feature with non-Doppler radars. Macrobursts are strong surface winds associated with some thunderstorms, which (using the old radars) occasionally can be inferred from a bow-shaped radar reflectivity signature. Fujita (1985) has shown that the most dangerous phase of downburst storms occurs when radar returns are developing a distinctive bow-echo appearance; at that time wind damage has already occurred in many cases. The NEXRAD can provide earlier precursor information, and the Doppler capability can detect the winds directly.

In addition to listing the calculated maximum range values, Table 2-2 also lists the observed maximum range for each phenomenon and each radar in the “Experience” column. These values reflect the actual experience of forecasters and researchers who use the radars to observe specific weather phenomena.[1] The spread of maximum range values shown within the brackets under the “Experience” colum represents differences caused by seasonal, geographic, and meteorological factors. The number in front of the bracket is a subjective estimate of a median maximum range value that would be applicable within the contiguous United States.

The calculated values admittedly contain many assumptions, but they are, nevertheless, very useful for providing an independent consistency check of the experience values. Comparison of the calculated and experience values in Table 2-2 shows general agreement. However, there are some apparent disagreements, including the following:

- The maximum-range values for detecting mesocyclones and misocyclones with the NEXRAD, as shown in the “Experience” column in Table 2-2, are lower than the calculated values. The panel believes that this difference is due to the assumed detection criteria; that is, only two samples are needed over the diameter of the weather phenomena circulation. While theoretically this low number of samples would allow the feature to be detected, its magnitude would be greatly underestimated in the actual observation (Carbone et al., 1985).
- The calculated maximum ranges for detecting stratiform snow and lake-effect snow, particularly for the wider-beamed pre-NEXRAD radars, are greater than experience indicates. The panel believes that the calculations do not fully account for partially filled beam effects, which are particularly prevalent for these features because of the relatively sharp decrease in reflectivity near the top of the phenomenon (see cloud/snow illustration in Appendix A, Figure A-3). As a result, in these situations, the measured reflectivity could even be below detectable thresholds. Also, when the contoured displays of the phenomena were viewed on the old radars, the display thresholding tended to remove much of the snow return.

[1] A list of forecasters and researchers who contributed to the experience values is provided in Appendix E. This list included responses from experts at 11 NWS operational sites, many with experience in operating NEXRAD and pre-NEXRAD radars. In many instances, the participants conferred with their colleagues at the site listed in developing their estimates. Their experience values were in good agreement with those from other operational sites and from technical experts from research and development locations. These values were in general agreement with the panel's calculated values and reflected relatively conservative interpretation of detection coverage for each significant weather phenomenon.

TABLE 2-1 Calculated Maximum Ranges for Detecting Various Radar-Observed Phenomena for the WSR-57, WSR-74S, WSR-74C, WSR-74 Doppler and NEXRAD. The calculated ranges are based on the observed characteristics of the phenomena. For the characteristics shown, the bracketed numbers represent the typical spread of observed values (extreme values are not included). The number in front of the bracket is the estimated median value. These values are used in determining the calculated maximum range. NSDL = No significant detection limitation. NC = No capability. Values >460 km are not indicated since this is the maximum display range of the NEXRAD.

Phenomena	Characteristics			Calculated Maximum Range (km)											
	Top[a] (km)	Limiting Horizontal Dimension (km)	Reflectivity[b] (dBZ)	WSR-57 / 74S			WSR-74C			WSR-74 Doppler			NEXRAD		
				Top (km)	Horz (km)	Refl (km)	Top (km)	Horz (km)	Refl (km)	Top (km)	Horz (km)	Refl (km)	Top (km)	Horz (km)	Refl (km)
Hurricane															
eye wall	12[8-16]	45[15-70]	45[40-55]	386	>460	>460	386	>460	>460	386	>460	>460	386	>460	>460
winds	12[8-16]	NSDL	35[25-45]	NC	NC	NC	NC	NC	NC	136[c]	136[c]	136[c]	230[d]	>230[d]	>230[d]
Supercell															
mesocyclone	7[4-10]	8[4-12]	45[25-60]	NC	NC	NC	NC	NC	NC	136[c]	136[c]	136[c]	230[d]	>230[d]	>230[d]
hook echo[e]	2[1-4]	8[4-12]	45[25-60]	126	120	>460	126	192	>460	126	192	>460	126	240	>460
Mini-Supercell															
miso- or mesocyclone	4[2-8]	4[1-8]	35[20-60]	NC	NC	NC	NC	NC	NC	136[c]	120	136[c]	199	120	>230[d]
hook echo[e]	1[0.5-2]	4[2-8]	35[20-60]	77	60	>460	77	96	>460	77	96	>460	77	120	>460
Misocyclone[f]	1[0.5-3]	2[0.5-4]	20[5-50]	NC	NC	NC	NC	NC	NC	77	60	136[c]	77	60	>230[d]
Tornadic Vortex[g] Signature	3[1-6]	0.2[.02-2]	40[25-55]	NC	NC	NC	NC	NC	NC	136	*[h]	136[c]	165	*[h]	>230[d]
Microburst	0.5[0.3-1.2]	3[2-4]	45[5-65][i]	NC	NC	NC	NC	NC	NC	45	136[c]	136[c]	45	180	>230[d]
Macroburst															
reflectivity signature[j]	3[1-5]	50[15-100]	40[30-50]	165	>460	>460	165	>460	>460	165	>460	>460	165	>460	>460
velocity signature	1.0[0.5-2]	15[4-30]	50[40-65]	NC	NC	NC	NC	NC	NC	77	136[c]	136[c]	77	>230[d]	>230[d]
Precipitation Detection															
convective rain	9[5-17]	NSDL	40[25-65]	327	NSDL	>460	327	NSDL	>460	327	NSDL	>460	327	NSDL	>460
stratiform rain	6[3-8]	NSDL	30[15-45]	255	NSDL	>460	255	NSDL	>460	255	NSDL	>460	255	NSDL	>460
stratiform snow	5[1-7]	NSDL	20[10-30]	226	NSDL	160[k]	226	NSDL	210[k]	226	NSDL	210[k]	226	NSDL	>460
lake-effect snow	2[1-3]	NSDL	20[10-30]	145	NSDL	130[k]	145	NSDL	130[k]	145	NSDL	130[k]	145	NSDL	150[k]
Winds															
boundary layer[m]	1.5[0.5-3]	NSDL	10[-5-20]	NC	NC	NC	NC	NC	NC	103	NSDL	136[c]	103	NSDL	>230[d]
high sfc winds with precipitation	1.5[0.5-3]	NSDL	30[15-45]	NC	NC	NC	NC	NC	NC	103	NSDL	136[c]	103	NSDL	>230[d]
profiles[n]				NC	NC	NC	NC	NC	NC						

Convergence Lines[p]	1[0.3-4]	3[1-5]	10[-5-45]	77	86	100[q]	77	138	120[q]	77	138	120[q]	77	180	>460
Melting level (bright band)	1.5[1-3][r]	0.3[0.2-0.5][s]	35[20-45]	103	9	>460	103	14	>460	103	14	>460	103	18	>460

NOTES

a. In general the feature extends from the ground to the indicated top. However, mesocyclone and tornadic vortex signatures may not extend to the ground.

b. The indicated reflectivity is the near-surface typical value; the reflectivity generally decreases rapidly near the top of the feature. This is generally not a limiting consideration except for snow and convergence lines; see appropriate footnotes for these features.

c. Limiting range in Doppler mode is 136 km.

d. Doppler velocity available only to 230 km and sometimes only to half of that range.

e. Reflectivity signatures resembling hooks are sometimes observed with meso- and misocyclones but often the feature is absent or misleading.

f. This refers to misocyclones observed in the boundary layer along convergence lines in either clear air or precipitation. Misocyclones observed aloft in precipitation are covered under mini-supercells.

g. Tornadoes occasionally will cause large beam-to-beam velocity differential values. This subject has been extensively discussed by Brown et al. (1978).

h. As discussed by Brown et al. (1978), a tornadic vortex signature can be detected in the radial velocity field even when the rotation is smaller than the half-power beam width of the radar. Their Figure 7 shows that regardless of tornado diameter or rotational velocity, extreme values could occur one beam width apart in the azimuthal direction. Based on their discussion, there is no convincing way to compute a theoretical value; thus, none is given here.

i. Microbursts may occur with a wide range of reflectivities. The low-reflectivity (dry) ones typically have reflectivities from 5 dBZ to 30 dBZ. Low- and high-reflectivity microbursts are not separated here since reflectivity is not a limiting criterion for detection of either one.

j. The observation of “bow-shaped” echoes in reflectivity is often indicative of storms that produce strong surface winds (Fujita, 1981).

k. When calculating the maximum detection range for snow, the vertical profile of reflectivity should be considered rather than the single low-level value indicated in the Characteristics colum. This is because the echo tops are relatively low, and the beam may be intercepting reflectivities considerably less than the low-level value. Typical lake-effect snow and stratiform snow reflectivity profiles from Wilson (1975) were used for this calculation.

m. These numbers refer to the warm season (temperature > 10° C). At that time winds can be obtained through the depth of the boundary layer primarily as a result of scattering from insects and secondarily from refractive index fluctuations principally in the vicinity of inversions. Nocturnal wind measurement, particularly in the Great Plains, may be contaminated by bird migrations. During the cool season, clear-air return is limited to scattering from refractive index fluctuations, which nominally can't be detected beyond about 20 km.

n. For this phenomenon the limitation is height, rather than range. The profile is representative of the area in the immediate vicinity of the radar for heights of detectable echo. For nonprecipitation situations in the warm season, the profiles are limited in height to the depth of the boundary layer (1 km to 3 km). In the cool season clear-air winds are very limited.

p. Included are all forms of convergence lines, such as sea breezes, gust fronts, dry lines, topography-induced convergence lines, coastal fronts, and synoptic fronts. These convergence lines may occur with or without precipitation. The majority are clear-air phenomena that are most easily observed at a greater height than the velocity convergence signature. In precipitation the convergence line is observed only as a Doppler velocity signature. The characteristics listed here are for the reflectivity thin line during the warm season. Cool-season reflectivity thin lines are seldom observed beyond 10 km to 30 km. During the cool season, fronts associated with precipitation can be detected from Doppler velocity convergence signatures.

q. The vertical profile of reflectivity within the line partially based on Wilson et al. (1994) was used instead of the single low-level value in the Reflectivity Characteristics column.

r. This height interval is chosen as being operationally significant for monitoring the melting level height to anticipate surface precipitation changes from rain to snow.

s. In this case the vertical dimension is considered, since it is the more-limiting dimension. The numbers refer to the vertical dimension of the bright band, which averages about 10 dB more than the values above and below.

References Consulted: Battan, 1973; Brown et al., 1978; Burgess and Lemon, 1990; Burgess et al., 1993; Burpee, 1986; Carbone et al., 1990; Fabry et al., 1992; Fujita, 1981; Hjelmfelt, 1988; Joss and Waldvogel, 1990; Klingle et al., 1987; Kingsmill and Wakimoto, 1991; Mahoney, 1988; Marks, 1990; Mueller and Carbone, 1987; Pettit, 1990; Wakimoto, 1982; Wakimoto and Wilson, 1989; Weckwerth and Wakimoto, 1992; Wilson, 1975; Wilson and Brandes, 1979; Wilson et al., 1984; Wilson et al., 1994.

TABLE 2-2 Comparison of Calculated and "Experienced" Maximum Range Values for Detecting Various Radar-Observed Phenomena for the WSR-57, WSR-74S, WSR-74C and NEXRAD. Calculated values are the most range-limiting value for each phenomenon in Table 2-1. The "Experience" columns reflect the actual experience of trained forecasters and researchers who have used the equipment. The typical spread of values is due to seasonal, geographic, and meteorological variations. The number in front of the brackets is the estimated median, defined here as the "experienced" median maximum range. NC = No Capability.

Phenomena	Calculated Median Maximum Range (km)			"Experience" Median Maximum Range (km) and [typical maximum range values]		
	WSR-57 -74S	-74C	NEXRAD	WSR-57 -74S	-74C	NEXRAD
Hurricane						
eye wall	386	386	386	350[250-450]	375[275-450]	400[300-460]
winds	NC	NC	230[a]	NC	NC	230[a]
Supercell						
mesocyclone	NC	NC	230[a]	NC	NC	180[150-230]
hook echo	120	126	126	75[20-120]	85[25-140]	100[40-160]
Mini-Supercell						
miso- or mesocyclone	NC	NC	120	NC	NC	100[70-150]
hook echo	60	77	77	45[15-55]	55[20-80]	70[30-110]
Misocyclone	NC	NC	60	NC	NC	35[10-70]
Tornadic Vortex Signature	NC	NC	*[b]	NC	NC	45[10-130][c]
Microburst	NC	NC	45	NC	NC	35[20-50]
Macroburst						
reflectivity signature	165	165	165	150[100-200]	150[100-225]	150[100-250]
velocity signature	NC	NC	77	NC	NC	70[50-100]
Precipitation Detection[d]						
convective rain	327	327	327	300[150-450]	325[175-450]	350[200-460]
stratiform rain	255	255	255	225[125-300]	235[140-325]	250[150-350]
stratiform snow	160	210	226	120[60-150]	140[70-160]	180[120-240]
lake-effect snow	130	130	145	60[30-90]	80[40-140]	120[80-160]

Winds						
boundary layer (warm season)	NC	NC	103	NC	NC	80[20-120]
high surface winds with precip.	NC	NC	103	NC	NC	70[20-120]
profiles within cloud and precip.	NC	NC	*[e]	NC	NC	*[e]
Convergence Lines (warm season)	77	77	77	limited[f]	limited[f]	80[40-120]
Melting level (bright band)	9	14	18	20[10-30]	35[20-40]	45[25-70]

NOTES

References Consulted: Battan, 1973; Brown et al., 1978; Burgess and Lemon, 1990; Burgess et al., 1993; Burpee, 1986; Carbone et al., 1990; Fabry et al., 1992; Fujita, 1981; Hjelmfelt, 1988; Joss and Waldvogel, 1990; Klingle et al., 1987; Kingsmill and Wakimoto, 1991; Mahoney, 1988; Marks, 1990; Mueller and Carbone, 1987; Pettit, 1990; Wakimoto, 1982; Wakimoto and Wilson, 1989; Weckwerth and Wakimoto, 1992; Wilson, 1975; Wilson and Brandes, 1979; Wilson et al., 1984; Wilson et al., 1994.

a. Doppler velocity is available only to 230 km and sometimes only to half of that range.

b. A theoretical value is not possible (see footnote letter g of Table 2-1).

c. The estimated median value is skewed to the low end of the maximum range distribution. This is because there are many more relatively weak tornadoes with small diameters. The likelihood of detecting a tornadic vortex signature increases as the diameter and rotational speed increases. Fortunately, the more-intense tornadoes (F3-F5) will typically have tornadic vortex signatures observable to greater ranges. The estimated median range for these cases is near 100 km.

d. Precipitation measurement is discussed separately at the end of the section entitled “Calculated Versus Observed Detection Ranges.”

e. Range is not an issue; this is a profile for the immediate vicinity of the radar.

f. The limited observation of thin lines with the WSR-57, WSR-74S, and WSR-74C is believed to be a combination of three factors: (1) display thresholding and large display quantizing intervals; (2) low reflectivity at the top of the thin line combining with partial beam filling; and (3) absence of clutter filters resulting in the loss of the thin line in clutter.

- Experience indicates that for all radars the maximum range for detecting the bright band (the horizontally stratified region of enhanced reflectivity) is considerably greater than the calculated value. This is due to the assumption that the bright band could be detected if the half-power beam width were less than the typical 300-m thickness of the bright band. But since the bright band has a peak reflectivity about 9 dB (Fabry and Zawadzky, 1995) or nearly 10 times greater than the echoes above and below the band, it would still be detected when the beam width is larger than 300 m, although it would appear to be of lesser intensity.[1]

While not specifically mentioned in Table 2-1 and Table 2-2, radar estimates of precipitation rate and amount are extremely important for flash-flood forecasting, heavy-snow advisories, heavy-rain advisories, and water management of reservoirs and streams. Precipitation rate is directly related to the intensity of the radar returned power; however, the relationship is not absolute and varies in time and space. In addition, the vertical profile of radar reflectivity is affected by precipitation growth, evaporation, and type; thus, the precipitation observed at radar beam height may not be representative of that reaching the ground (Wilson and Brandes, 1979). Consequently, the maximum ranges for estimating precipitation rate or amount will be less than those given for detection in Table 2-2.

Estimates of the maximum range that precipitation can be measured quantitatively are convective rain, 100 to 200 km; stratiform rain, 75 to 150 km; and lake-effect snow, 40-100 km. Provided that suitable precipitation-accumulation software was present on an old network radar, possible degradation in precipitation measurement could occur for locations more than 100 km to 150 km from a NEXRAD that replaced a radar at a nearby location. For snow and rain events with very low melting levels, this range could be less than 100 km. The NEXRAD has automated algorithms for routinely estimating precipitation accumulation. These algorithms represent a major improvement over the rudimentary techniques used with the WSR-57s and WSR-74s.

Hail detection is not specifically listed in Table 2-1 and Table 2-2. Although the NEXRAD algorithms show skill in hail detection, little is known about how this type of detection varies with range. Hail could be detected out to ranges of 250 to 300 km; however, it cannot be distinguished from heavy convective rainfall reliably.

COMPARISON OF DETECTION COVERAGE BY PRE-NEXRAD AND NEXRAD NETWORKS

The median values of the maximum detection range for each radar under the "Experience" column of Table 2-2 were used to prepare maps showing national detection coverage for both the pre-NEXRAD and NEXRAD networks for selected weather phenomena. Maps were also prepared indicating those areas where the pre-NEXRAD network afforded better coverage for each phenomenon. (The panel refers to the latter as "difference maps.") The phenomena shown in these coverage and difference maps are hurricanes (Figure 2-2a andFigure 2-2b), supercells (Figure 2-3a and Figure 2-3b), mini-supercells (Figure 2-4a and Figure 2-4b), macrobursts (Figure 2-5a and Figure 2-5b), lake-effect snow (Figure 2-6a and Figure 2-6b), and stratiform snow (Figure 2-7a and Figure 2-7b). Note that boundaries are added to hurricane, lake-effect snow, and stratiform-snow maps to mask-out areas with negligible risk of occurrence of these

[1] An extensive analysis of bright bands in the vicinity of Montreal by Fabry and Zawadzky (1995) showed an average value of about 9 dB. This value is similar to that shown by Battan (1973).

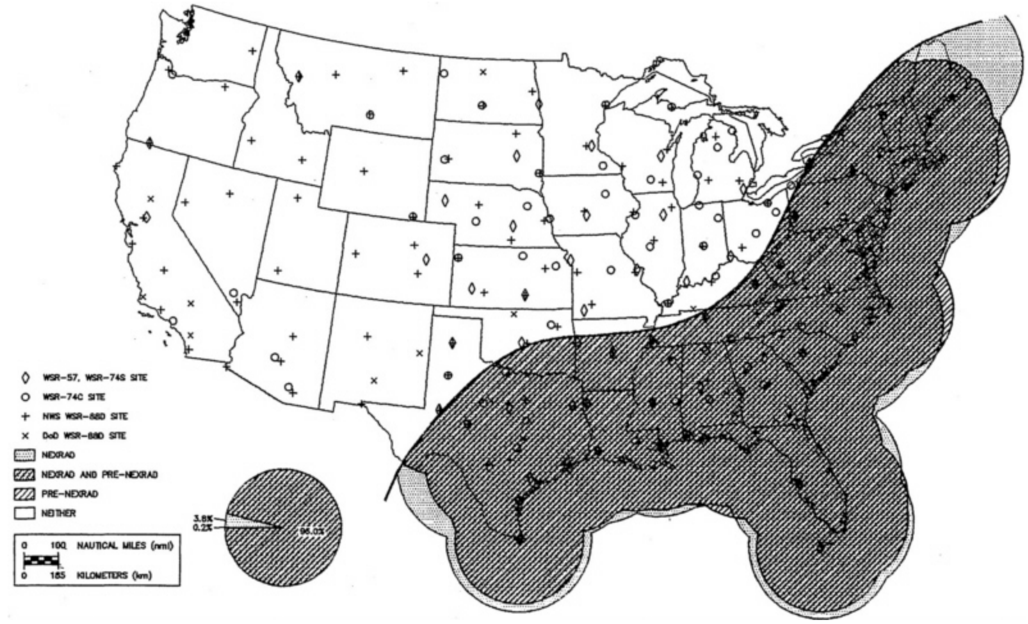


Figure 2-2a Areas of hurricane detection by the NEXRAD network and the pre-NEXRAD network. These areas are shown in dotted-red and striped-blue backgrounds, respectively. The coverage extent of each individual radar in the two networks is taken from the median values of the "experience" maximum range values from Table 2-2. The pie chart shows the percentage of vulnerable areas (contiguous United States + 230 km across borders or oceans within the marked boundary) where only the NEXRAD network provides this coverage (dotted red), where both networks provide coverage (combined red/blue), where only the pre-NEXRAD network provides coverage (striped blue), and where neither network provides coverage (white) for this weather phenomenon. Courtesy of SRI International.

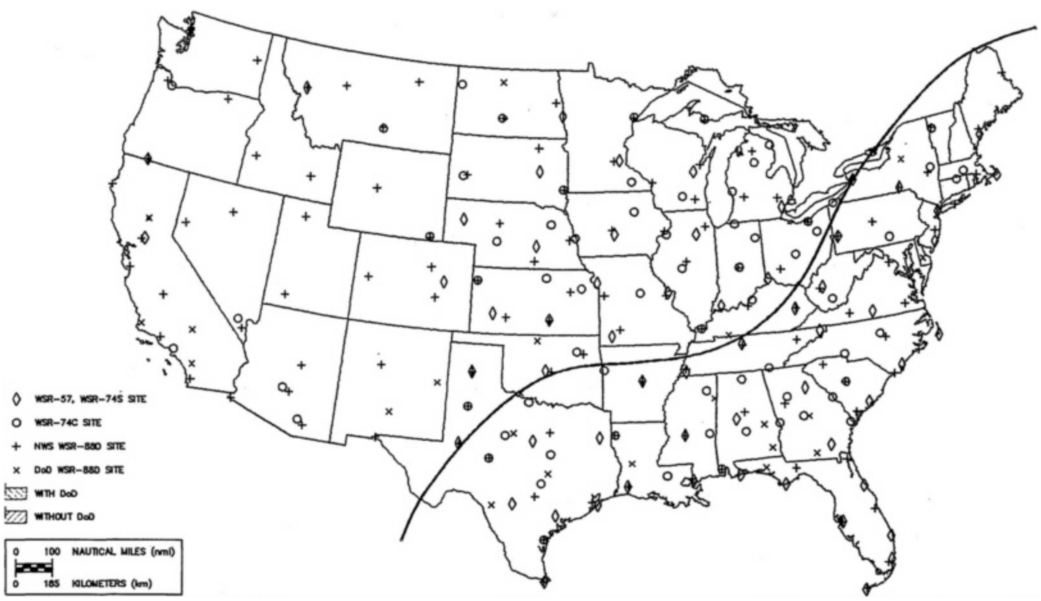


Figure 2-2b Hurricane detection coverage. There are no areas with potentially degraded detection coverage for hurricanes by NEXRAD. The solid black line on each map extending from western Texas to northern Maine marks the boundary of the area under risk from hurricanes from those areas with negligible or no risk. Courtesy of SRI International.

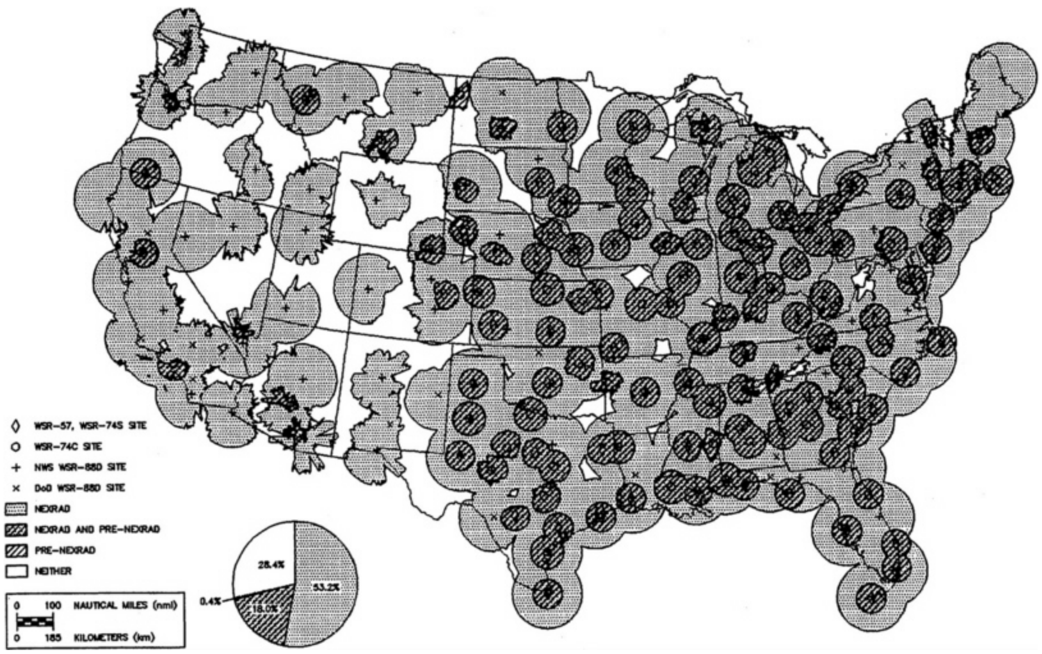


Figure 2-3a Areas of supercell detection by the NEXRAD network and the pre-NEXRAD network. These areas are shown in dotted-red and striped-blue backgrounds, respectively. The coverage extent of each individual radar in the two networks is taken from the median values of the "experience" maximum range values from Table 2-2. The pie chart shows the percentage of vulnerable areas (contiguous United States + 230 km across borders or oceans) where only the NEXRAD network provides this coverage (dotted red), where both networks provide coverage (combined red/blue), where only the pre-NEXRAD network provides coverage (striped blue), and where neither network provides coverage (white) for this weather phenomenon. Courtesy of SRI International.

Figure 2-3b Areas with potentially degraded detection coverage for supercells by NEXRAD with DoD (red) and without DoD (blue) NEXRADs compared with the pre-NEXRAD radars. The pre-NEXRAD radars relied on the "hook echo" for supercell detection, while the NEXRAD detects mesocyclone circulation. Courtesy of SRI International.

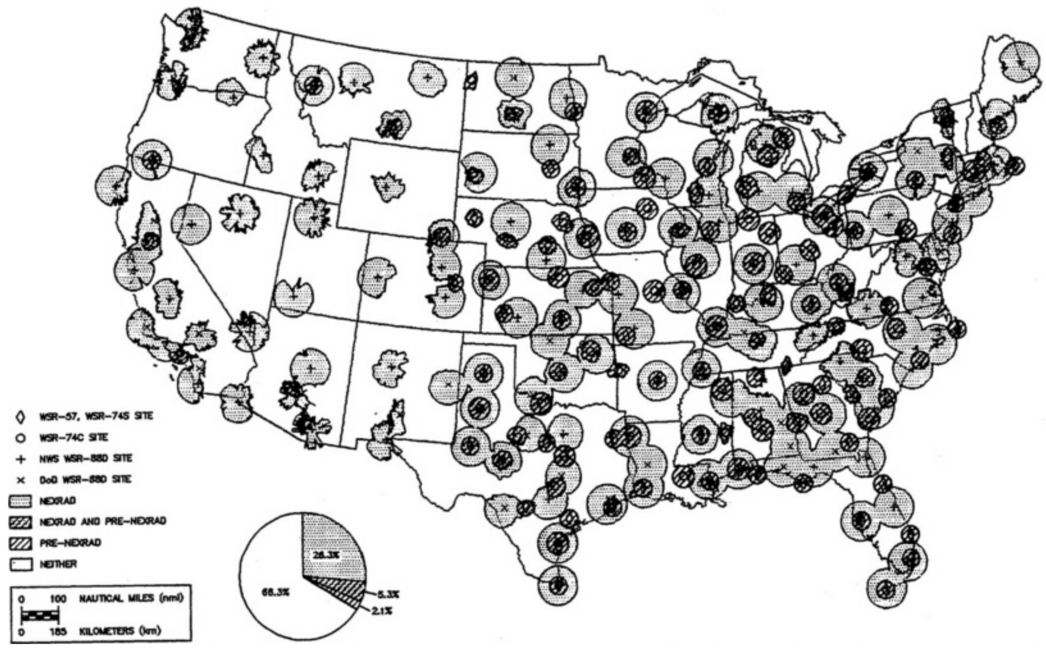


Figure 2-4a Areas of mini-supercell detection by the NEXRAD network and the pre-NEXRAD network. These areas are shown in dotted-red and striped-blue backgrounds, respectively. The coverage extent of each individual radar in the two networks is taken from the median values of the "experience" maximum range values from Table 2-2. The pie chart shows the percentage of vulnerable areas (contiguous United States + 230 km across borders or oceans) where only the NEXRAD network provides this coverage (dotted red), where both networks provide coverage (combined red/blue), where only the pre-NEXRAD network provides coverage (striped blue), and where neither network provides coverage (white) for this weather phenomenon. Courtesy of SRI International.

Figure 2-4b Areas with potentially degraded detection coverage for mini-supercells by NEXRAD with DoD (red) and without DoD (blue) NEXRADs compared with the pre-NEXRAD radars. The pre-NEXRAD radars relied on the "hook echo" for mini-supercell detection, while the NEXRAD detects misocyclone or mesocylone circulation. Courtesy of SRI International.

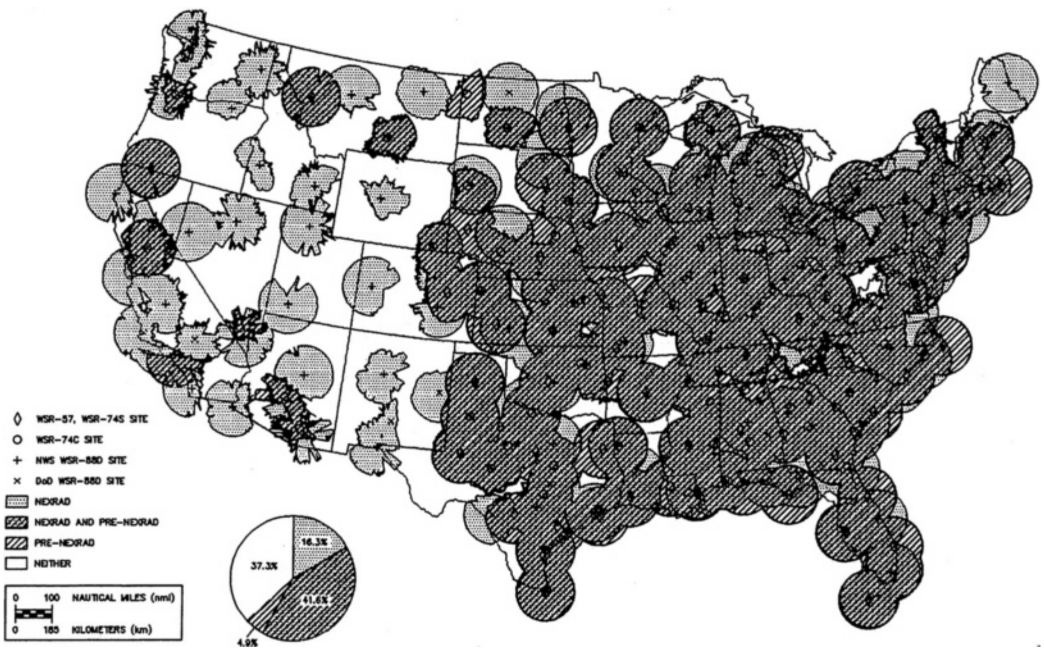


Figure 2-5a Areas of macroburst detection (reflectivity signature) by the NEXRAD network and the pre-NEXRAD network. These areas are shown in dotted-red and striped-blue backgrounds, respectively. The coverage extent of each individual radar in the two networks is taken from the median values of the "experience" maximum range values from Table 2-2. The pie chart shows the percentage of vulnerable areas (contiguous United States + 230 km across borders or oceans) where only the NEXRAD network provides this coverage (dotted red), where both networks provide coverage (combined red/blue), where only the pre-NEXRAD network provides coverage (striped blue), and where neither network provides coverage (white) for this weather phenomenon. Courtesy of SRI International.

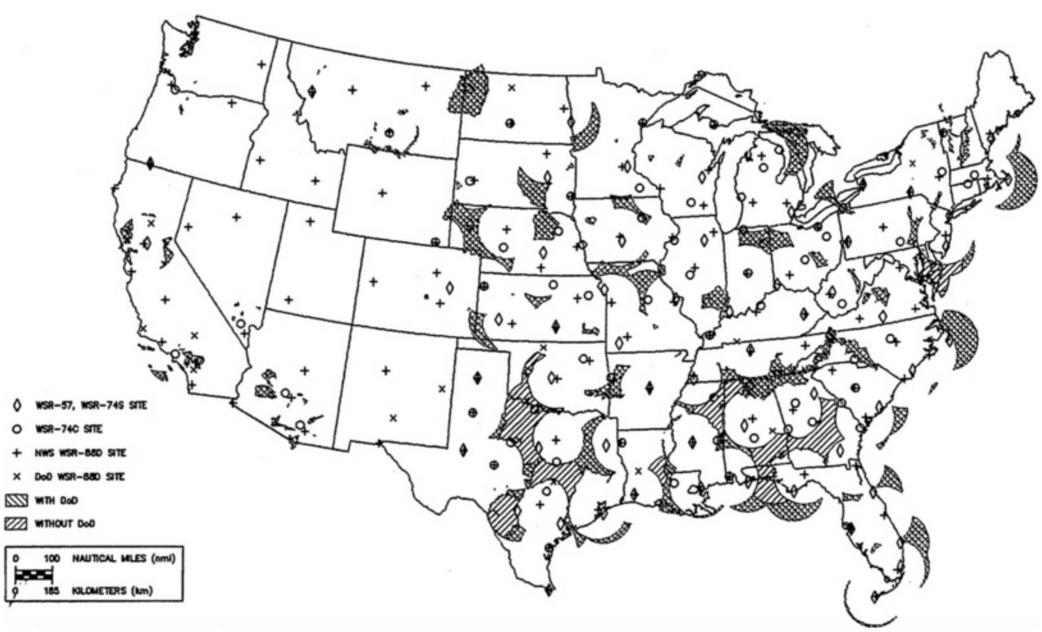


Figure 2-5b Areas with potentially degraded detection coverage for macrobursts (reflectivity signature) by NEXRAD with DoD (red) and without DoD (blue) NEXRADs compared with the pre-NEXRAD radars. Courtesy of SRI International.

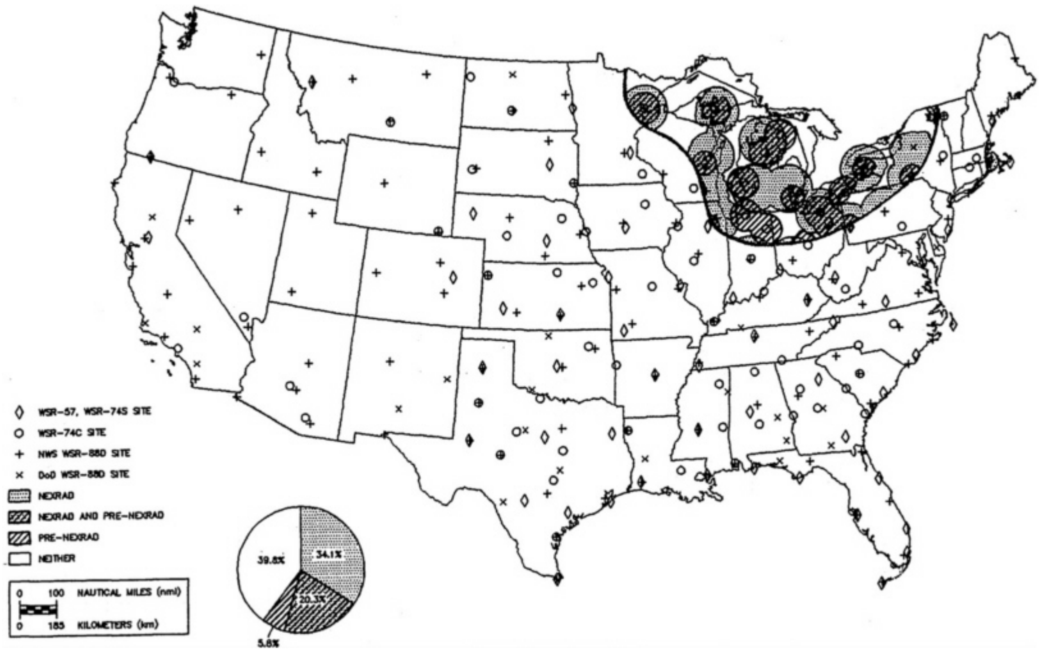


Figure 2-6a Areas of lake effect snow detection by the NEXRAD network and the pre-NEXRAD network. These areas are shown in dotted-red and stripe- blue backgrounds, respectively. The coverage extent of each individual radar in the two networks is taken from the median values of the "experience" maximum range values from Table 2-2. The pie chart shows the percentage of vulnerable areas (contiguous United States only, within marked boundary) where only the NEXRAD network provides this coverage (dotted red), where both networks provide coverage (combined red/blue), where only the pre-NEXRAD network provides coverage (striped blue), and where neither network provides coverage for this weather phenomenon. Courtesy of SRI International.

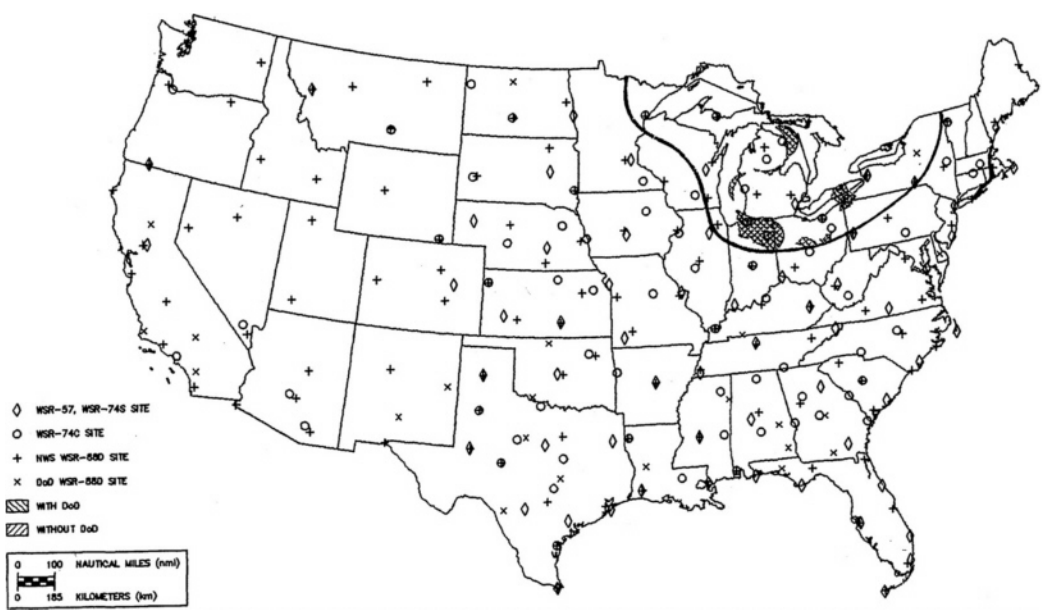


Figure 2-6b Areas with potentially degraded detection coverage for lake effect snow by NEXRAD with DoD (red) and without DoD (blue) NEXRADs compared with the pre-NEXRAD radars. The solid black line marks the boundaries on each map for the areas that have a significant risk of lake-effect snow. Courtesy of SRI International.

Figure 2-7a Areas of stratiform snow detection by the NEXRAD network and the pre-NEXRAD network. These areas are shown in dotted-red and striped-blue backgrounds, respectively. The coverage extent of each individual radar in the two networks is taken from the median values of the “experience” maximum range values from Table 2-2. The pie chart shows the percentage of vulnerable areas (contiguous United States + 230 km across borders or oceans within boundary lines shown) where only the NEXRAD network provides this coverage (dotted red), where both networks provide coverage (combined red/blue), where only the pre-NEXRAD network provides coverage (striped blue), and where neither network provides coverage (white) for this weather phenomenon. Courtesy of SRI International.

Figure 2-7b Areas with potentially degraded detection coverage for stratiform snow by NEXRAD with DoD (red) and without DoD (blue) NEXRADs compared with the pre-NEXRAD radars. The solid black line marks the boundaries on each map for the areas with a significant risk of stratiform snow occurring. Courtesy of SRI International.

phenomena. With the exception of convective rain, stratiform rain, and melting level,[1] the other phenomena in Table 2-2 either were not detectable by the old network or were only marginally detectable. In the case of stratiform and convective rain, the detection (not quantitative precipitation measurement) range for all the radars is so large that there are no locations over land where the old network had better detection capability.

It is quite apparent from a cursory visual scan of these 12 maps that the NEXRAD network greatly increases the total area over which these phenomena can be detected. The hurricane coverage maps show full coverage by NEXRAD for areas of risk. However, for the rest of the significant weather phenomena, there are some areas where the pre-NEXRAD network had better coverage. A few such areas appear in Figure 2-3b, which shows supercell detection. There are more areas where the old network could detect mini-supercells (Figure 2-4b) or macrobursts (Figure 2-5b) and the NEXRAD network will not. These are mostly locations that were near pre-NEXRAD radars but are more distant from the nearest NEXRAD or planned NEXRAD. For example, Table 2-2 indicates that a mini-supercell that is more than 100 km from a NEXRAD but within 45 km of a WSR-57 would be more likely to be detected by the WSR-57 (beam resolution and smoothing of Doppler velocity structures are key factors). It is this type of location that is evident in Figure 2-4b. Unfortunately, no definitive experiments have been carried out to indicate that this actually would be the case. Because of the limitations in using the bow-echo feature for macroburst detection, as discussed earlier, it is not clear whether detection by the pre-NEXRAD radar in these cases gave better service; the detection often was not timely enough to give adequate warning.

The coverage areas in the figures are based on estimated median maximum range values from Table 2-2. It should again be emphasized that there is considerable variability in these maximum range values, as indicated by the numbers within the brackets in Table 2-2. Small changes in the maximum range values used to prepare Figure 2-4 and the other maps could easily eliminate or add areas where the pre-NEXRAD network had better coverage. An example is provided by Figure 2-8a, which shows (in comparison with Figure 2-3a) how radar-detection coverage changes when maximum detection range (i.e., "experience") values are used for supercell detection. The corresponding difference chart in Figure 2-8b shows that the potentially degraded areas of supercell detection coverage by NEXRAD for the contiguous United States are reduced substantially when the maximum NEXRAD capability threshold is used. Rather than using any of these figures to label areas where the pre-NEXRAD network provided better coverage, the panel believes that it is preferable to use these figures in a relative sense. Thus, those areas identified in the figures as having detection coverage by the pre-NEXRAD network and not by NEXRAD are areas where radar-detection coverage is *more likely* to be degraded than in other areas.

Where there is a one-for-one replacement of an old radar by a NEXRAD, radar-detection capability will unquestionably be improved. Degradation of detection capability might occur where the pre-NEXRAD radar is decommissioned and coverage is provided by a NEXRAD located some distance away. Appendix F shows the distance of the nearest NEXRAD from each of the pre-NEXRAD radars.

Following are examples of areas shown in Figures 2-2 through 2-7 in which radar-detection capability for one or more phenomena is likely to be degraded with the NEXRAD network. The order of locations discussed below is alphabetic by state. The order does *not* imply priority.

Northern Alabama (e.g., Huntsville vicinity)

This area currently has a WSR-74C Doppler weather radar and is slated to be covered by a NEXRAD located 164 km away. As a consequence of the large increase in distance of this area from

[1] Altitude at which ice/snow melts.

the new NEXRAD radar, radar detection of smaller-scale, low-altitude weather phenomena (i.e., mini-supercells, tornado vortices, macrobursts, and microbursts) and of precipitation reaching the ground (important for flash-flood warnings) may be significantly degraded.

Northern Indiana (e.g., Fort Wayne, South Bend vicinity)

A DoD NEXRAD at Grissom Air Force Base was planned, but this NEXRAD was eliminated when the base closed. As a result, radar-detection capability for a number of weather phenomena that occur in this region (e.g., supercells, mini-supercells, lake-effect snow, macrobursts, and stratiform snow) may be degraded when existing radars are decommissioned.

Northwest North Dakota (e.g., Williston vicinity)

The existing radar site for this area is the most distant (207 km) from a NEXRAD installation of any of the pre-NEXRAD radars that will be decommissioned. The locally occurring weather phenomena whose radar-detection capability may be degraded include stratiform snow, supercells, and macrobursts. The state of North Dakota is currently sponsoring work in hail suppression in a portion of the potentially degraded radar-detection coverage area which is identified in Figure 2-3b (top center of map).

Northwest Pennsylvania (e.g., Erie vicinity)

This area has a region-specific, low-altitude weather phenomenon (lake-effect snow) that is difficult to detect with NEXRADs located at Cleveland, Ohio; Buffalo, New York; and Pittsburgh, Pennsylvania. The pre-NEXRAD radar in this region was able to detect lake-effect snow within approximately 110 km of the existing radar site. Other locally occurring low-altitude phenomena that may have degraded radar-detection coverage include mini-supercells and macrobursts.

Southeastern Tennessee (e.g., Chattanooga vicinity)

Radar-detection capability in this area for low-altitude phenomena (e.g., mini-supercells and macrobursts) and even supercells is difficult to achieve at even moderate ranges from a NEXRAD due to the complex terrain features. Figures 2-3 through 2-5 show that the area covered by the existing pre-NEXRAD radar in this location is, itself, significantly limited by the topography.

The difference maps also make it evident that there are 15 DoD NEXRAD sites (the striped blue areas in Figure 2-2b, Figure 2-3b, Figure 2-4b, Figure 2-5b, Figure 2-6b through Figure 2-7b) that cannot be considered "supplemental."[1] These sites provide the only detection coverage of certain phenomena in their area of coverage. Without these 15 radars, there would be more geographic regions in the contiguous United States where radar-detection capability may be degraded.

[1] These 15 NEXRAD sites are East Alabama, Alabama; Beale and March, California; Dover, Delaware; NW Florida, Florida; Moody and Robins, Georgia; Ft Polk, Louisiana; Columbus, Mississippi; Minot, North Dakota; Frederick and Vance, Oklahoma; Central Texas, Dyess, and Laughlin, Texas. There are five additional DoD NEXRAD sites that provide sole coverage for areas that were not covered by the pre-NEXRAD network. These are Edwards and Vandenberg, California; Cannon and Holloman, New Mexico; and Griffiss, New York.

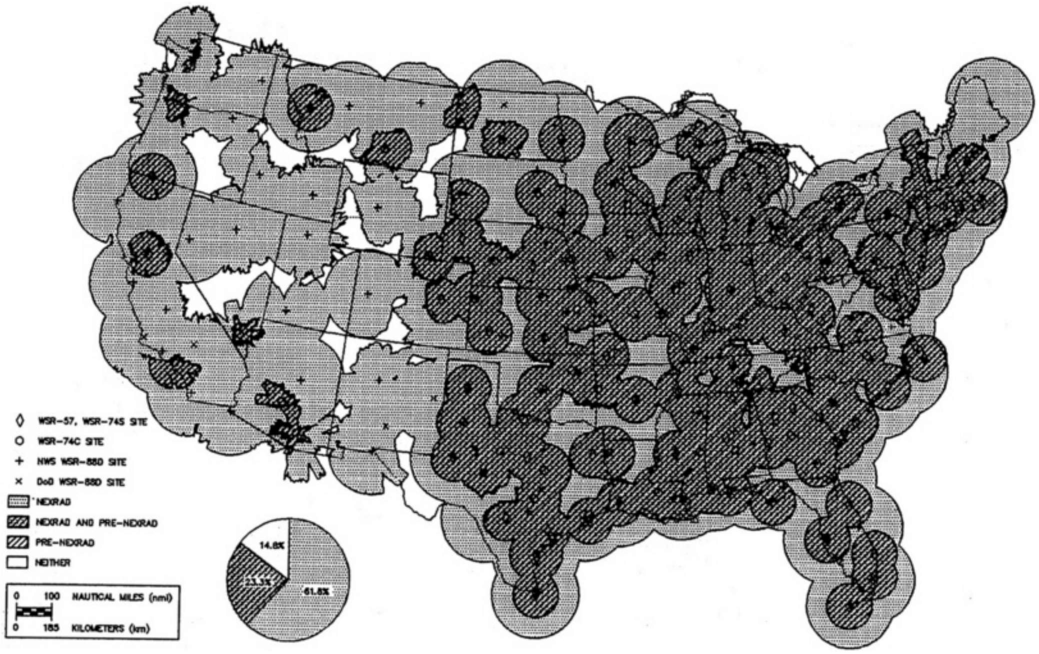


Figure 2-8a Maximum range detection coverage of supercells for the pre-NEXRAD (blue) and NEXRAD (red) networks. The coverage extent of each individual radar in the two networks is taken from the higher values of the "experience" median maximum range values from Table 2-2. The pie chart shows the percentage of vulnerable areas (contiguous United States + 230 km across borders or oceans) where only the NEXRAD network provides this coverage (dotted red), where both networks provide coverage (combined red/blue), where only the pre-NEXRAD network provides coverage (striped blue), and where neither network provides coverage (white) for this weather phenomenon. Courtesy of SRI International.

Figure 2-8b Areas with potentially degraded detection coverage for supercells by NEXRAD with (red) and without (blue) DoD NEXRADs compared with the pre-NEXRAD radars. Courtesy of SRI International.

IMPACT OF NEXRAD COMMUNICATIONS LINKS AND FORECAST OFFICE STAFFING

In generating NEXRAD radar-detection coverage information for Figures 2-2 through 2-7, the panel assumed that data from the closest NEXRAD radar to each location are available to the cognizant WFO. When the cognizant WFO is not located near the NEXRAD radar product generator (RPG), the products to be displayed on the WFO's principal user processor (PUP) must be provided over a telephone line. Full-capability access is provided by a 56-kbs communications line. Full-capability access is also needed for the four forecast offices that will provide service using two NWS NEXRADs to cover an extended service area.[1]

Coverage by the 15 DoD NEXRADs referred to previously is needed as part of the overall national detection coverage for significant weather. Currently, these NEXRADs are slated to have only a 9.6-kbs communications capability to the area WFO that provides warnings to the public. Additionally, there will be delays in providing certain products to a remote user. The consequence is that the effective radar-detection capability during significant weather, as perceived by the cognizant WFO, may be degraded due to inadequate communications and back-up capabilities. The panel has not quantified this potential effective degradation in radar-detection capability. However, this is an important issue that needs to be addressed immediately by the NWS through tests at a WSFO in conjunction with the supporting DoD radar (e.g. Norman, Oklahoma, operating in conjunction with the DoD NEXRAD at Frederick, Oklahoma).

The effective radar-detection capability of a NEXRAD depends on the skill and attentiveness of the forecaster using the PUP. Therefore, it is essential that WFOs using two NEXRADs to cover their extended service area have adequate staffing during significant weather to analyze the data from both radars, and from neighboring radars, and to issue timely forecasts and warnings for their entire extended area of responsibility. This issue needs to be addressed by the NWS (e.g., as a part of the Modernization and Associated Restructuring Demonstration (MARD) activity) through their use of assessment criteria to resolve degradation-of-service issues in areas of public concern.

[1] These offices are Phoenix for Yuma, Arizona, NEXRAD; Miami for Key West, Florida, NEXRAD; and Portland for Caribou, Maine, NEXRAD, which are a consolidation of two former service areas; and Salt Lake City for Cedar City, Utah, NEXRAD, whose service area does not change.

3

Comparison of Weather Services: Pre-NEXRAD and NEXRAD

In the preceding sections, and in Appendix A, the panel examined the technical aspects of the pre-NEXRAD and NEXRAD radars as well as their calculated and "experienced" detection capabilities. This section discusses the panel's comparison of the actual weather services provided by the old and new systems as a final approach to determining whether the implementation of the new system could result in a degradation of service to the nation.

It is important to consider the effect of other, nonradar elements of the nation's overall weather infrastructure on the NWS's ability to provide service. It is also important to consider the impact that nearby radars in the network will have on enhancing the service provided to each service area. Another key aspect of the comparison is the performance of both the old and new systems in detecting severe weather events and generating accurate, timely warnings. New technologies in Doppler signal processing, digital information systems, and color displays in the NEXRAD system contribute to the development of new products and services. These technologies are described and discussed in Appendix A.

COMPOSITE SYSTEM CONSIDERATIONS

The composite system is a combination of scientific, technical, and staff resources that are organized by the NWS to accomplish its mission of providing weather forecast and warning services, primarily for the protection of life and property. These resources include all of the weather data that are collected, processed, and analyzed; specialized equipment; dedicated communication networks and systems; centralized operation of supercomputers and numerical models; and highly trained staff. Detailed information about the composite system can be found in an earlier report by the NRC's NWSMC (NRC, 1994b).

Weather services provided to all users, including the public, are made available through a complex array of observations and models and through the interpretive skills of experienced forecasters. In the modernized NWS, there will be a host of new observational systems available to weather forecasters. These will include

- the NEXRAD network;
- the ASOS, which continuously provides surface observations of temperature, wind, humidity, pressure, and other atmospheric variables;
- the next generation of geostationary and polar-orbiting satellites; and
- a national lightning network.

In addition to these systems, there are a number of new observational systems that are currently being demonstrated or developed for future use. These systems include

- commercial aircraft measurements of wind and temperature, and possibly humidity, both at flight levels and during ascent and descent in the vicinity of larger airports;
- wind profilers that measure horizontal winds as a function of height above the ground; and
- the next generation radiosonde system.

Operational components of the composite system are shown in Figure 3-1. As shown in the figure, each WFO will have responsibility for what might be viewed as a cylindrical volume of coverage in the United States. These volumes are generally overlapping or contiguous, allowing the WFOs to benefit from one another due to the availability of network data from adjacent regions and nationally. The AWIPS is the critical component for the system because it brings together all of the information for use by the forecasters, as discussed in the following section.

The composite system of observation coverage will reside within a substantially restructured weather service that will include the following components:

- WFOs located near NEXRADs;
- RFCs collocated at WFOs;
- WFOs located on or near university campuses; thereby enhancing the interactions among forecast office staff, university faculty members, and students;
- a Science Operations Officer, on each WFO staff, who will be responsible for the development of new forecasting techniques; and
- WFO staff specially trained in modern forecasting techniques and newly emerging techniques.

As in the past, the composite system is also augmented substantially by such things as experienced local spotter and cooperative observer networks, hydrometeorological instrumentation that supports the work of the WFOs and the RFCs; and highly skilled forecasting staff who consider local geographical characteristics in their day-to-day forecasting responsibilities. These local characteristics might include terrain effects that produce elevated heat sources and are, therefore, preferred regions for thunderstorm development.

The NWS will use the MARD over the central United States to verify and test the composite system after all components are in place. The results of MARD should not be generalized to other geographical regions of the country due to differences in area weather and other factors.

Comparison of the full spectrum of services of the modernized NWS and of the past generation of weather services will be impossible to quantify convincingly until all components of the new system have been installed.

NETWORK CONSIDERATIONS

In a series of developments extending from the early 1970s into the early 1980s, the NWS provided some NWS offices with a computer-based system for processing radar-generated digital reflectivity data into products that forecasters could use directly (Wilson, 1970; McGrew, 1972; and Devore, 1983). This system, known as the radar data processor (RADAP II), ultimately was available at 12 locations. At six of these sites, an interactive color radar display (ICRAD) capability provided

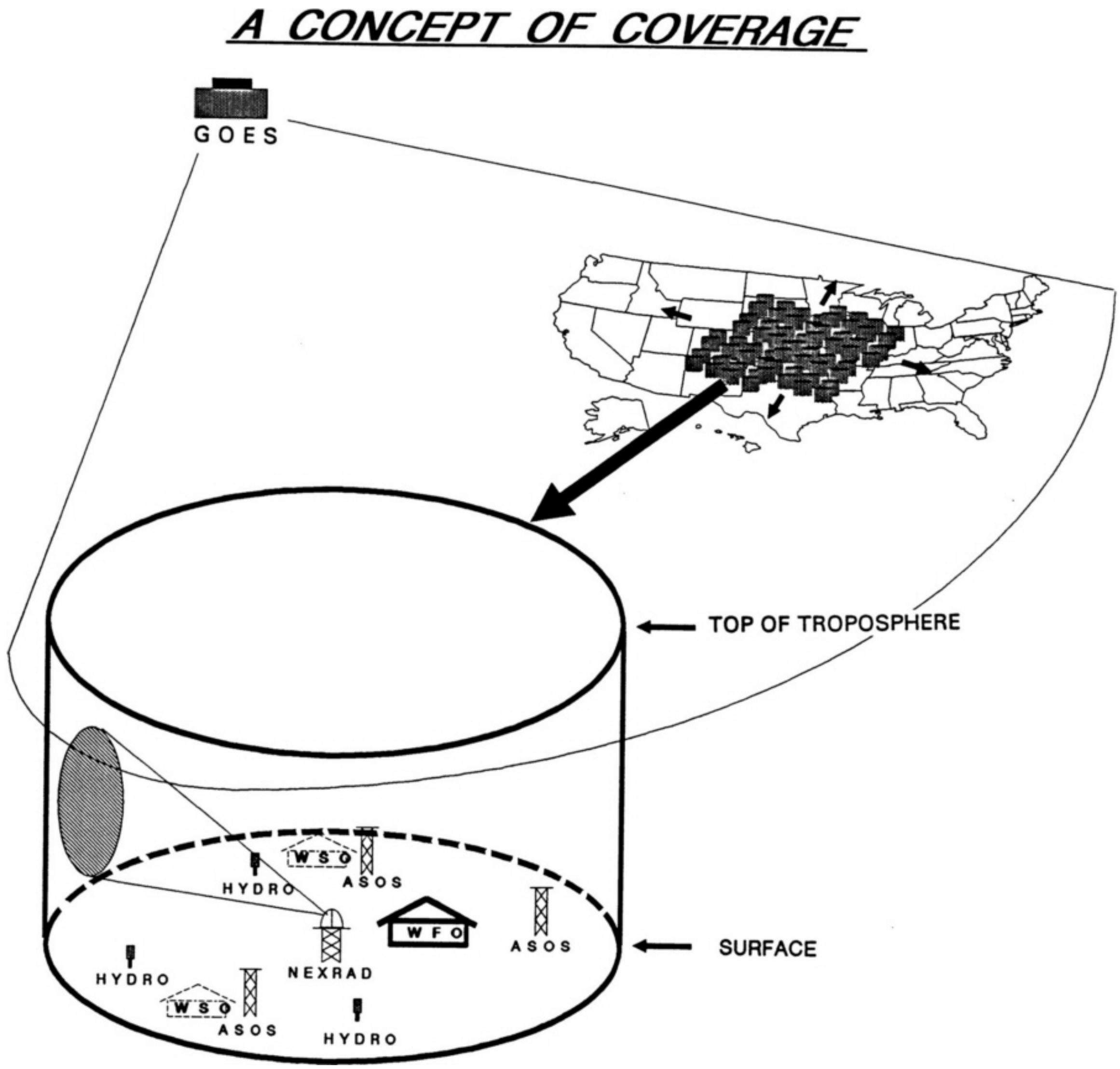


Figure 3-1 National Weather Service concept of observation coverage when the modernization is fully implemented. Courtesy of NOAA/NWS.

a color-map presentation of radar reflectivity data and derived products. ICRAD also made it possible to view the RADAP II products at a remote location.

Although NWS forecasters experienced occasional hardware and software problems, the RADAP II operations were considered a success. This capability gave both forecasters and researchers valuable pre-NEXRAD experience. Most of the radars at RADAP II sites were either directly replaced by NEXRADs, representing a clear improvement of both detection and algorithm capabilities, or were decommissioned following the installation of a NEXRAD nearby. The prior existence of RADAP II capability or an ICRAD display of products from a neighboring RADAP II radar is one of the factors NWS should consider when assessing possible degradation of service at a specific location.

While the NEXRAD network is being installed, an internal communications system is being used to distribute the “hourly digital precipitation array” of 2 km and 4 km data. In addition, the “radar coded message” from each NEXRAD site is being sent to the National Severe Storms Forecast Center in Kansas City, Kansas, to generate a national mosaic product. The NEXRAD information dissemination service providers (Baer, 1991) also offer a national mosaic radar reflectivity product that is widely used in the commercial sector and in government, including the National Meteorological Center and the National Severe Storms Forecast Center.

The NEXRAD system allows forecasters at each WFO to access some radar products from several neighboring radars. This information will be very important for observing and tracking significant weather as it approaches the WFO's primary geographic area of responsibility. This wider-area picture of the weather will provide information about the surrounding environment within which the WFO's primary responsibility lies. Some WFOs have multiple, associated principal user processors (PUPs), and others may obtain additional radar information for their area of coverage through the use of nonassociated PUPs. In the four locations with two associated PUPs, high-speed communications are provided to each radar product generator (RPG), and each PUP functions in an identical manner. The nonassociated PUPs have access to any NEXRAD, but this access is through a low-speed, dial-up communication line, and WFOs can receive products only on a by-request basis. WFOs that require data from DoD NEXRADs for part of their service area have access only through low-speed lines.

The NWS has instituted a continuing evaluation and upgrade program for the NEXRAD at the Operational Support Facility in Norman, Oklahoma. This facility is an essential element of the national network that will ensure that the associated services will improve over time.

In the modernized NWS, AWIPS will provide interactive analytical capability, of which NEXRAD will be a part. This capability will assimilate data from satellites, surface instruments and human observers, lightning detection networks, radiosondes, and commercial aircraft, along with data from radars and from numerical models run at national centers. Forecasters will use this data base to evaluate the state of the atmosphere and to produce short-term warnings, “nowcasts,” and forecasts of weather in support of public safety and other needs.

The panel emphasizes the need and importance for NWS to complete the modernization (including AWIPS) in a timely manner to avoid added risks of degraded coverage and service due to a prolonged transition to new technology.

WARNING PERFORMANCE

The overall performance of a system in producing forecasts, advisories, and warnings is an important criterion for evaluating the adequacy of radar coverage with respect to degradation of service. Most of the available data on the performance history of the pre-NEXRAD system concerns the warning function. Although radar is not the only source of data on which storm warnings are based, it tends to play a principal role.

Evaluation of warning performance requires data on warnings issued and on actual storm events, regardless of warnings issued. A warning is issued by the NWS for a particular county, or set of counties, for a specific period (generally 30-60 minutes). The warning is then logged systematically by the National Severe Storms Forecast Center. Data on storm events are accumulated and published periodically in *Storm Data.* When the NWS presented its analyses of verification data to this panel, the panel noted that the historical storm data, in particular, are not as comprehensive as would be desired for rigorous scientific analysis. The panel is encouraged by NWS efforts to collect more comprehensive storm reports as spotter networks and other networks in county warning areas are expanded and realigned to NEXRAD-equipped weather offices.

The NWS customarily uses two measures to evaluate performance: the probability of detection (POD), which in this context refers to the fraction of storm events for which warnings were issued; and the false alarm ratio (FAR), which refers to the fraction of warnings where a storm did not occur. A warning system that was functioning well would have a high POD and a low FAR.[1] Warning performance exhibits considerable variation from station to station and from year to year for reasons that involve factors other than the radar performance. In addition to ordinary random variations, these reasons include both human factors and the performance of other components of the composite system, the storm climatology of the area, and the time of day of storm occurrence. The POD and FAR statistics represent ratios, and, during the panel's consideration of those ratios, concerns were raised about the methodology used to determine whether storms occurred or were reported. Therefore, the panel found it necessary to examine the number of warnings and reported storm events in addition to the POD/FAR statistics.

The panel used information on weather fatalities as one gauge of storm severity for various phenomena. Data on natural-hazard deaths in the United States show that in 1992 and 1993 the primary causes of severe-weather fatalities include flash floods, lightning, and tornadoes, in that order. (NWS, 1993 and 1994). These fatality statistics were consistent with similar statistics gathered over 30 years.

Early Experience with NEXRAD

Several of the NEXRADs have been in service long enough to provide preliminary data on storm-warning performance (Polger et al., 1994; Maddox and Forsyth, 1994). Figure 3-2 shows severe storm warning statistics for six field offices. The POD and FAR statistics have been plotted versus time in years for each of these sites. The statistics shown for the early years represent the pre-NEXRAD era; those for later years indicate PODs and FARs after installation of a NEXRAD at each location. In all cases, POD and FAR performance has improved with the introduction of the new technology. Figure 3-2 also shows that, in general, the number of warnings issued since the advent of NEXRAD has increased. With more warnings being issued and a higher fraction of them being verified, as indicated by the lower FAR, it is clear that better service is being provided to the areas served by the NEXRAD-equipped NWS offices. At the same time, the overall increase in the number of reported storm events makes any attempt at quantitative comparisons difficult.

It is unlikely that the actual incidence of storms has shifted upward since the advent of the NEXRAD. The increase is probably due to a more vigorous verification program, involving greater

[1] The current verification system considers a storm to be covered by a warning, or a warning to be verified, if a reported storm occurs within an area and time period covered by the warning. Some warnings issued after a storm is already in progress are considered as verifications but only if the NWS received another report *after* the warning is issued.

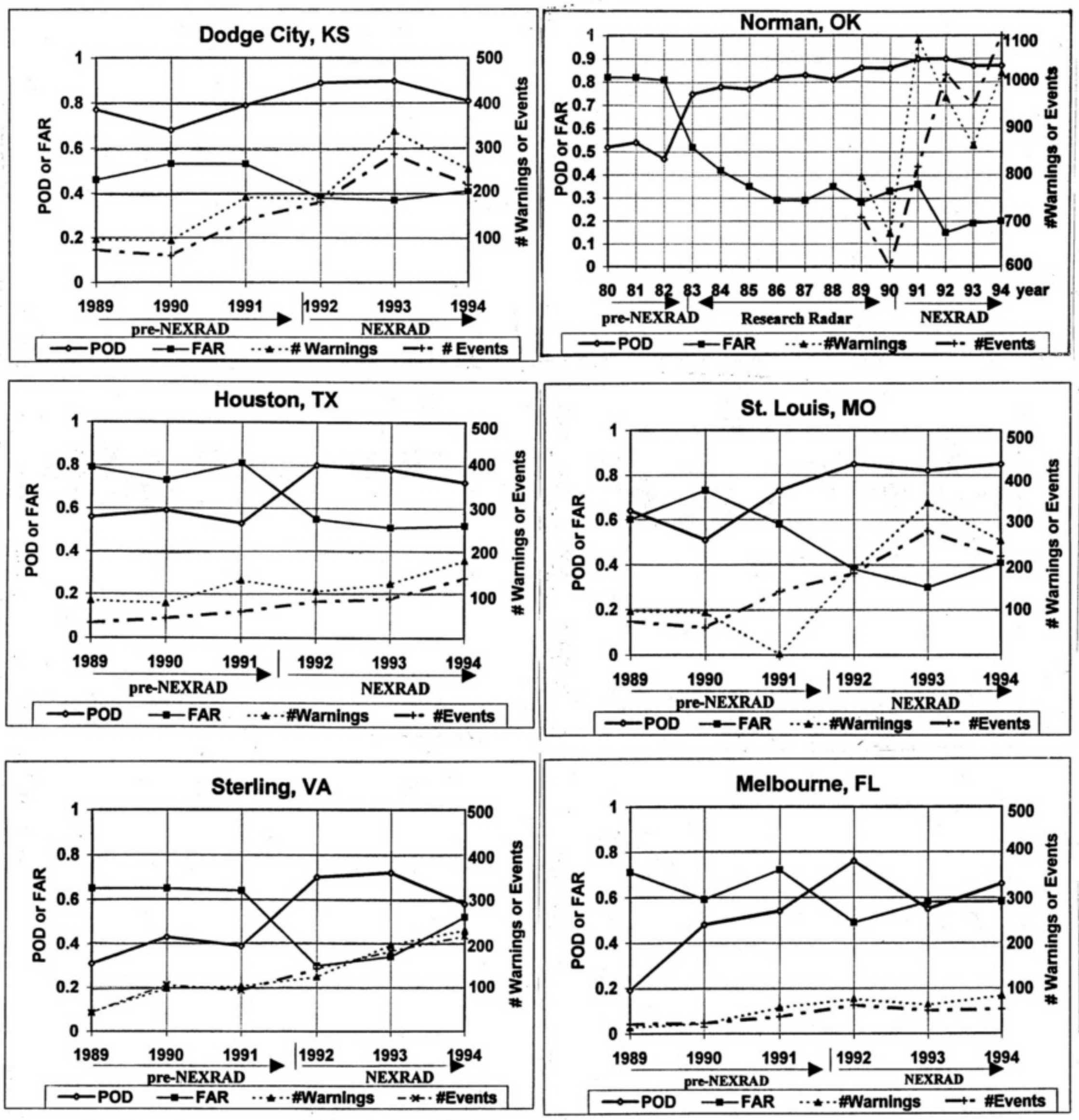


Figure 3-2 History of severe-storm probability of detection and false-alarm ratio at six field offices before and after installation of NEXRAD. Also shown are the annual number of warnings and reported storm events. The 1994 data are preliminary and still undergoing validation checks by NWS. In the case of Norman, Oklahoma, an experimental Doppler radar was used operationally beginning in 1983. Courtesy of NWS.

efforts to ascertain the presence of severe storms in the warning areas (e.g., by more phone calls to spotters). However, a more vigorous verification program, with no change in the radar or in the number of warnings, would produce similar changes in the POD/FAR statistics by converting some would-be false alarms into verified warnings. Thus, the trends in the POD/FAR statistics represent some indeterminate combination of improvements in the warning services and enhancements in the verification program.

Figure 3-3 shows POD and FAR statistics as a function of distance from NEXRADs to the centers of the served County Warning Areas for the same six sites shown in Figure 3-2. The corresponding numbers of warning and reported events per unit area for the 2 years are also shown in the figure. These data, which are intended to illustrate the warning performance as a function of distance from a NEXRAD, reflect some puzzling features. For most of the sites, the PODs and FARs are relatively constant with increasing range. Yet, in most cases, the number of warnings per unit area decreases with increasing range. Based on discussion of radar-detection capabilities in Chapter 2, one would expect fewer storm detections at longer ranges. Moreover, if radars were the major factor in the warning process, there should be fewer warnings at longer ranges, as is usually the case. But with fewer warnings, one would expect more missed detections and, consequently, a lower POD, in contrast to the pattern found in several cases. The reasons for these seemingly contradictory indications, and for the increase in warnings per unit area with distance from the Melbourne NEXRAD (see Figure 3-2), are not clear.

There is no apparent reason why the number of storm events should vary in any systematic way with distance from a radar. Yet, in most cases, the number of reported events decrease with increasing range. This reflects some kind of nonuniformity in the verification data, perhaps due to variations in population density or in the spotter networks. Such nonuniformity makes it difficult to evaluate the effect of range on warning performance with any confidence.

Furthermore, in each case, the number of warnings and reported events per unit area seem to be closely related. A similar correlation is evident in Figure 3-2. This correlation suggests some kind of coupling, either direct or indirect, between the issuance of warnings and the reporting of storm events. The panel has been unable to account for this relationship and is concerned that it clouds the picture with respect to the effect of distance from a radar on warning performance. The panel was unable to resolve these complicating factors, which need to be examined further in future studies. Degradation of service evaluations for specific sites will require NWS to demonstrate that a county that is distant from a NEXRAD and associated WFO will receive, as a minimum, the same quality of warning service that was provided by the existing, nearby office in the past. That is, the new office's performance must be compared against that of the existing office that is equipped with a radar with pre-NEXRAD capabilities and pre-modernization components.

Figure 3-4 shows the results of an independent study on tornado warning lead times (Bieringer and Ray, 1995). As indicated by the figure, there is a clear and substantial improvement after NEXRAD technology is made available to forecasters. Polger et al. (1994) also analyzed the comparative performance of the NEXRAD and pre-NEXRAD eras for flash-flood warnings. The relevant data for flash-flood PODs and FARs for five sites are shown in Figure 3-5a and Figure 3-5b. Substantial improvements are seen at all locations, with the exception of Norman, Oklahoma. There may be several reasons for this anomaly. First, it may be that even in the pre-NEXRAD era Norman and Oklahoma City forecasters had access to data from better experimental radar equipment with computer processing capabilities (Maddox and Forsyth, 1994). Second, special flash-flood forecast and warning procedures were in place in the pre-NEXRAD era. In addition, the pre-NEXRAD staff were thoroughly trained, and strong management-support practices were in effect.

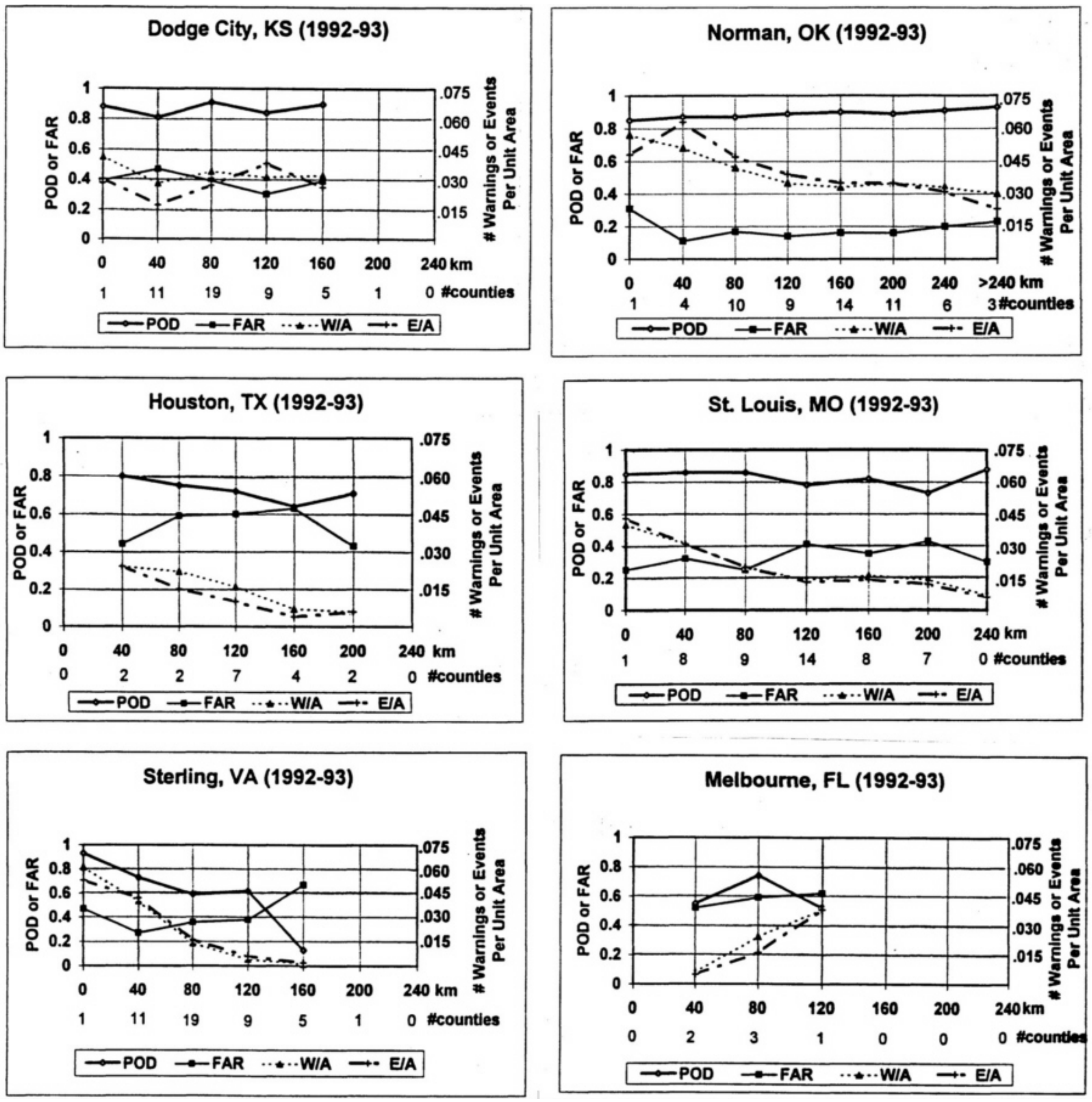


Figure 3-3 Probability of detection, false alarm ratios, and number of warnings and events per unit area for 1992 and 1993. These data are shown with distance from the NEXRAD for the same six field offices depicted in Figure 3-2. Courtesy of NWS.

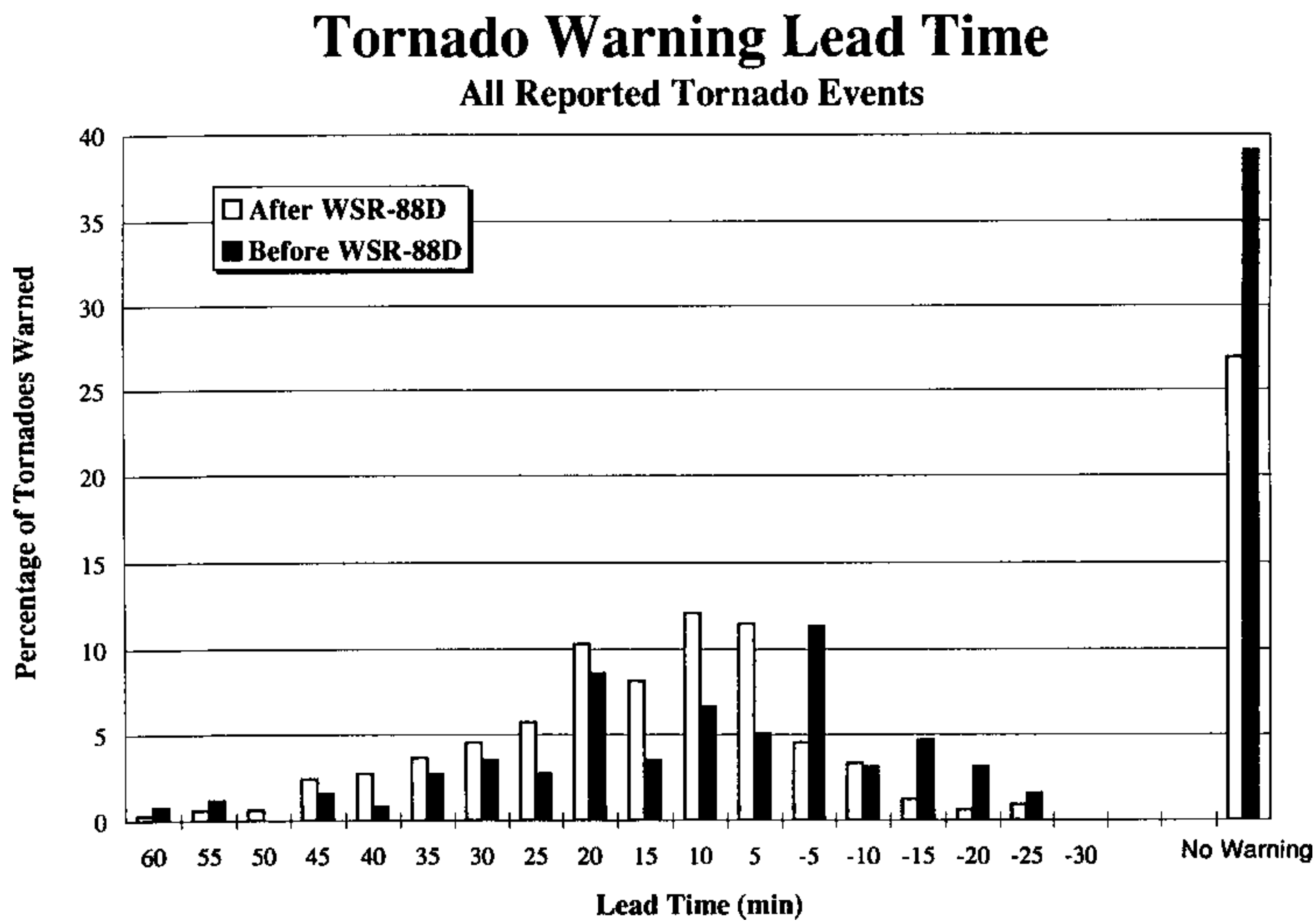


Figure 3-4 Comparison of lead times for tornado warnings obtained after (open) and before (shaded) NEXRAD data became available. The average lead time for all tornadoes increased from 8.0 minutes (before NEXRAD) to 13.0 minutes (after NEXRAD). The percent of tornadoes receiving a warning before touchdown increased from 61 percent (before NEXRAD) to 73 precent (after NEXRAD). Source: Bieringer and Ray, 1995. Reprinted with permission.

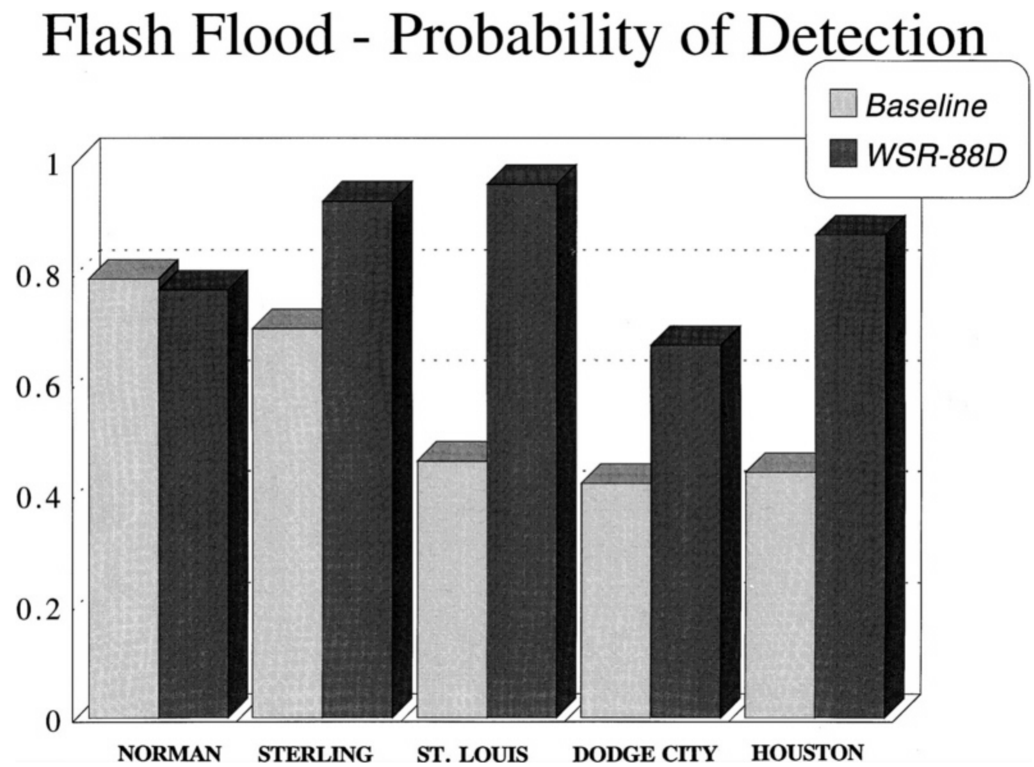


Figure 3-5a Comparison of flash-flood probability of detection prior to NEXRAD (baseline) and with NEXRAD for five field offices. Courtesy of NWS.

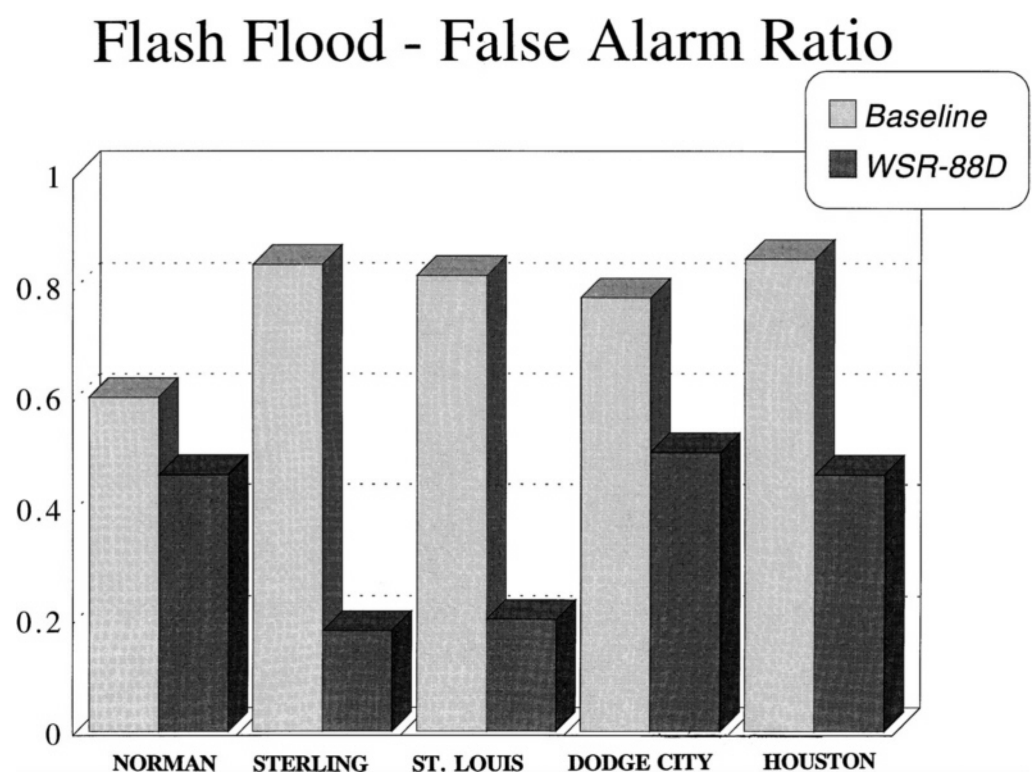


Figure 3-5b Comparison of flash-flood false-alarm ratios prior to NEXRAD (baseline) and with NEXRAD for the same five field offices. Courtesy of NWS.

Comments and Conclusions on Warning Performance

It is apparent that warning performance at all locations analyzed by the panel has improved substantially with the introduction of NEXRAD. PODs, FARs, and lead times for tornadoes and flash floods have also improved significantly. It is reasonable to expect that performance will improve further as forecasters gain additional experience with the system, forecasting methods are streamlined, and algorithms are refined. This general result is consistent with what would be expected from the information found in the tables and coverage maps in Chapter 2.

Even though many of the early NEXRAD sites had specially qualified staff, the panel is confident that overall increases in warning performance are likely at all sites. This improvement will stem from the use of the new technology, the extensive training provided to all the NEXRAD operators, the sharing of lessons learned within the NEXRAD community, the continuing development efforts of the Science Operations Officers and the Operational Support Facility, and similar efforts.

The data regarding warning performance as a function of distance from a NEXRAD site present a more mixed picture. In all likelihood, the warnings and storm reports for the more distant locations concern mostly larger and more intense storms. If further study shows that smaller and less intense storms are less likely to result in warnings and storm reports from a NEXRAD that is more distant from them than a nearby, older radar would be, then this effect of distance may result in a degradation of these particular services at some locations.

In the panel's judgment, insufficient data currently exist to permit definitive conclusions to be made. Although the early results are very promising, further testing in the MARD and at diverse geographic locations will be necessary to draw more general conclusions regarding the quality of weather warnings as a function of distance from the radar.

The panel concludes with confidence that the introduction of NEXRAD will significantly improve overall storm detection and warning performance.

4

Guidelines for Assessing Possible Degradation of Service in Specific Areas

The panel conducted an assessment of the adequacy of NEXRAD coverage *for the nation* in terms of the "no degradation of service" requirement imposed by the Weather Service Modernization Act. Accordingly, the panel examined the relative capabilities of the pre-NEXRAD and NEXRAD systems on a national level. In the course of this analysis the panel identified some geographic areas where there appears to be a potential for degraded radar-detection coverage with the new system. However, the panel deliberately *did not* attempt to make specific determinations as to the possible degradation of service at particular locations; nor did it conduct a site-by-site investigation of the possible need for additional radars.

As discussed in previous sections, *service* is a much more complex and subjective matter than radar-detection coverage. Many factors, apart from technical considerations, enter into decisions regarding the need for additional radars, including budgets, congressional interests, pressure from the public, and similar input. It is beyond the panel's purview to make such determinations; however, these factors, as well as economic vulnerability and impacts, are important and should be considered by the NWS. The panel recognizes that the NWS will be pressed to make such determinations with regard to specific sites as the modernization progresses. The public concerns discussed in the following section reflect these kinds of site-specific issues. A set of general criteria are provided in Chapter 4 under "Assessment Criteria and Procedures." These criteria can be used to assess possible degradation of service in particular locations and to determine whether additional radars are warranted.

CONSIDERATION OF PUBLIC CONCERNS

Concern about possible degradation of services in the course of the NWS modernization program has generated considerable public comment. In accordance with a *Federal Register* announcement of November 4, 1994, the NWS received comments from approximately 67,000 people in the form of letters, postcards, collections of information, and signatures on resolutions and petitions. About 65,000 of these people (largely from 3 areas) signed petitions or sent form postcards as part of organized efforts to obtain additional NEXRAD coverage for their communities. In contrast, of the approximately 1,800 individually formulated letters and postcards, most (90 percent) commented on the need for continued services from their local weather office. About 10 percent provided technical data or other information about deficiencies in radar coverage that might be encountered when an existing radar was decommissioned and the coverage for an area would be provided by a NEXRAD relatively distant (usually 80 or more miles) from their community. Figure 4-1 shows the 32 areas of the nation from which public comments were received. Comments from 15 areas (solid circles) were concerned primarily with the planned closure of a local weather office. The other 17 areas (the open circles and

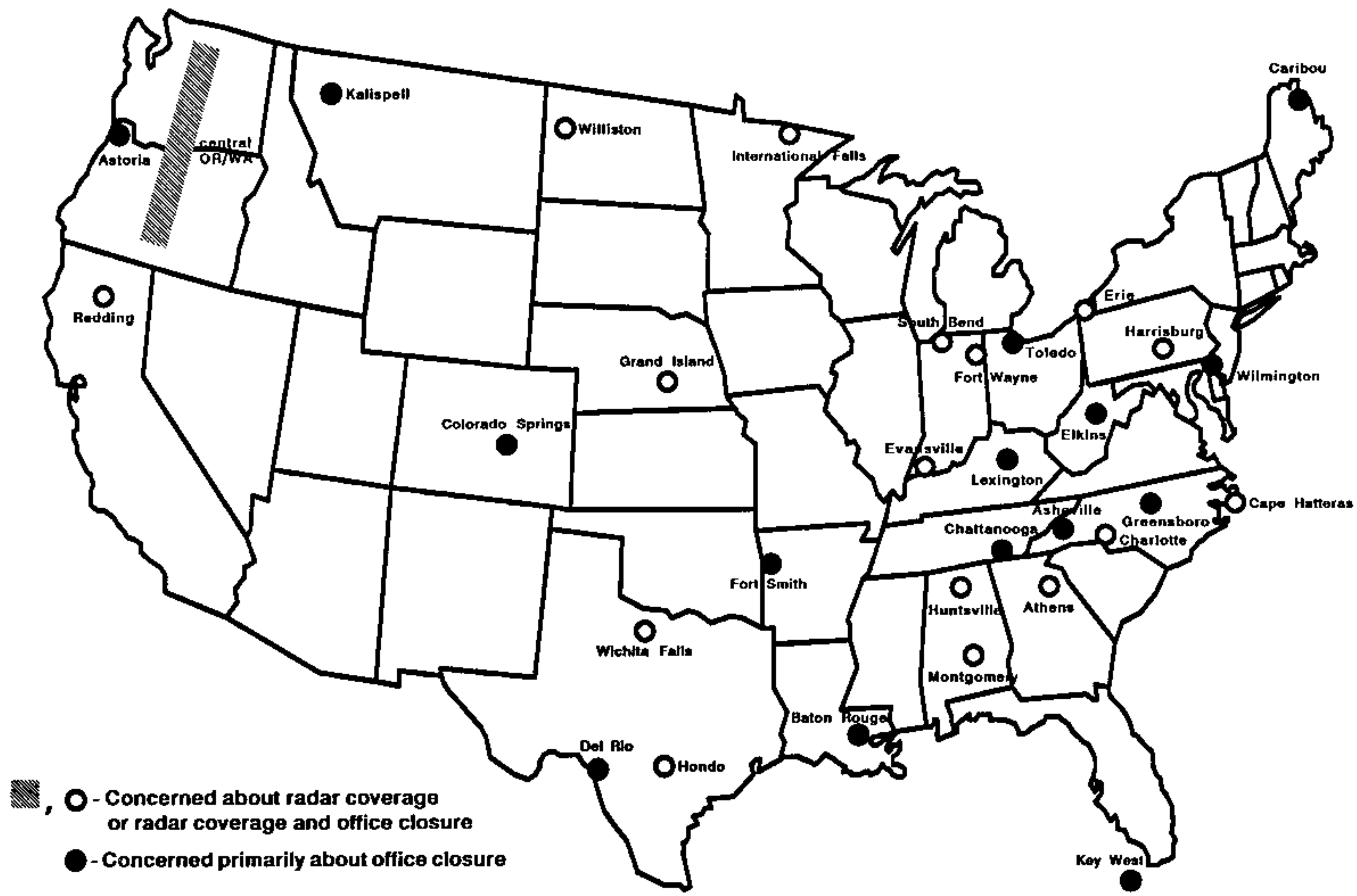


Figure 4-1 Thirty-two geographical areas identified by public comments as being concerned about degradation of service in connection with NEXRAD coverage, decommissioning of existing radars, and/or associatad weather office consolidations and closures. Courtesy of NWS.

the hatched area) were concerned about radar coverage or about both radar coverage and office closure. The NWS forwarded the comments to the NRC for use by the NEXRAD panel. Technical information included in the public comments was incorporated into the panel's analyses and was considered during the course of the study.

ASSESSMENT CRITERIA

The panel's charge included the task of "establish[ing] criteria for evaluating the adequacy of coverage of the pre-NEXRAD and the proposed NEXRAD network and areas for decommissioning of existing radars." In response to this task, the panel recommends the following criteria and procedures for use in evaluating the adequacy of NEXRAD coverage for specific areas.

The suggested evaluation criteria are as follows:

1. *Weather phenomena of concern to the area*—Are the weather phenomena of concern detectable by weather radar?
2. *Degradation of radar coverage relative to the weather phenomena of concern*—Do the radar-detection coverage maps for specific weather phenomenon show degraded coverage by NEXRAD?
3. *Performance of the composite system relative to the phenomena of concern*—Does the composite system evaluation indicate that the new system performs as well as the old system?

The suggested evaluation procedures are as follows:

1. Determine the weather phenomena of concern in the area of interest.
2. Examine the relevant weather phenomena radar coverage map(s) to identify regions where radar coverage of each phenomenon is reduced from what had existed with the pre-NEXRAD system.
3. Assess the composite system capability and its impact; especially on reducing the risk to life and property. The composite system elements include, but are not limited to, those listed below.

- characteristics of local weather phenomena;
- radar coverage and terrain features;
- data quality and availability;
- local spotter network and the user community;
- adequacy of communications within the composite system and with users;
- education and training for the forecasters and user community; and
- other composite system elements, such as ASOS, satellite data, soundings, prior RADAP II and/or ICRAD capability, AWIPS, centralized support products and services, and similar elements.

If an assessment of composite system performance and its consequences concludes that services related to radar coverage would be degraded, then there is inadequate radar coverage for the area. Wherever there is inadequate radar coverage, the NWS should take appropriate actions to reduce the risk of adverse weather consequences to human life and property to acceptable levels. One of the options would be to determine the cost and benefits of providing the needed detection coverage for the area of concern by adding or relocating a NEXRAD or by using some other radar alternative.

The detection coverage charts for specific weather phenomena that were developed by the panel, along with the suggested assessment criteria and procedures, provide a baseline for the NWS (or others) to make decisions on the adequacy of NEXRADs to meet the coverage and service requirements for specific areas. The panel's assessment criteria and procedures should be incorporated into official NWS guidelines and used in conjunction with the requirements in P.L. 102-567.[1]

[1] The certification criteria for decommissioning an existing radar and consolidating weather offices were published in the *Federal Register,* Vol. 59, No. 41, March 2, 1994, “Rules and Regulations.” These criteria included formal actions that certify and commission the supporting NEXRAD, provide adequate notification to users, provide user confirmation of associated services, and determine that the existing radar is no longer needed for service coverage of that area.

5

Conclusions and Recommendations

CONCLUSIONS

Based on an intensive 6-month study, the NEXRAD Panel of the NWSMC arrived at a strong overall conclusion that weather services *on a national basis* will be substantially improved under the currently planned NEXRAD network. The panel's conclusions were as follows:

- The NEXRAD radars generally meet or exceed their technical design specifications in all respects relevant to the detection of weather phenomena and are substantially superior to the radars they are replacing. Therefore, there is no degradation of radar-detection coverage, but always improvement, when a NEXRAD is located at or near the site of one of the old radars. Indeed, the introduction of NEXRAD radars will significantly improve overall storm detection and warning performance and will substantially improve weather services on a national basis.
- Compared to coverage by the old network, the NEXRAD network will provide greater coverage at the 10,000-ft level over the contiguous United States.
- For the detection of specific weather phenomena, that is, supercells, mini-supercells, macrobursts, lake-effect snow, and stratiform snow, the NEXRAD coverage is generally much greater than it was for the old system; for hurricanes, the NEXRAD coverage is complete over the area of risk.
- Digital signal and data processing will permit the production and display of a wide variety of automated weather products which, in turn, will improve the forecasters' ability to rapidly assimilate and use the available data, not only from their NEXRAD but also from neighboring NEXRAD sites.
- The NEXRAD's Doppler feature and other technical characteristics allow for greatly increased capability for short-term forecasting ("nowcasting") of thunderstorm initiation; detection of damaging winds, such as macrobursts and wind shear; and detection of the mesocyclones that are often associated with tornadoes and other severe storm hazards.
- Despite the fact that NEXRAD provides overall network superiority, in areas where the old radar site is relatively distant from the replacement NEXRAD, there may be some degradation in NEXRAD detection coverage. Examples of areas of concern include northern Alabama, northern Indiana, northwestern North Dakota, northwestern Pennsylvania, and southeastern Tennessee.
- The regions of degraded coverage will increase for most weather phenomena if 15 of the DoD NEXRADs that are currently operating in the network are not operated and maintained as part of the national network. Operation of any of these radars with stan

dards and availability less than those of NWS-operated units will effectively degrade coverage. Principal areas of concern include portions of DoD NEXRAD coverage areas in Alabama, Georgia, Mississippi, and Texas.

- In the national NEXRAD network, there will be four NEXRADs (i.e., Yuma, Arizona; Key West, Florida; Caribou, Maine; and Cedar City, Utah) without a nearby WFO. The reliability of the NEXRAD and the dependability of services derived from it, as well as communications, forecast office staffing, and warning and forecast dissemination, all become even more important when forecasters are remote from the radar site.
- Weather services are influenced by the full complement of observations and products available to the forecaster, as well as by cooperative spotter networks and the skills of experienced forecasters. The performance of this composite system is the critical element in assessing whether areas that have degraded radar-detection coverage will also have a degraded quality of weather services. Such assessments need to include a much more in-depth technical analysis for these areas and locations where there are radar coverage concerns than has been the case to date.

RECOMMENDATIONS

Based on its analyses and on the conclusions derived from them, the panel recommends the following:

1. Where the panel has identified specific geographic areas where degradation of radar-detection coverage may occur, the National Weather Service should examine each potentially vulnerable area to determine whether such degradation would result in degradation of associated weather services.
2. The procedures and criteria for decommissioning old radars are specified in existing National Weather Service documentation; these should be rigorously applied, especially in vulnerable areas. Additional criteria/procedures proposed by the panel (described in Chapter 4, under "Assessment Criteria and Procedures") should be followed in assessing the degradation of service and determining corrective actions. These assessment processes should be incorporated into official National Weather Service guidelines and procedures and used in conjunction with the requirements in P.L. 102-567.
3. The National Oceanic and Atmospheric Administration should take immediate steps to ensure that the 15 NEXRADs under the control of the Department of Defense, which are needed to avoid degraded coverage, function as fully committed elements of the national weather radar network, operating with the same standards, quality, and availability as the National Weather Service-operated NEXRADs.
4. The National Weather Service should ensure that maintenance for, operation of, and communication with NEXRADs that are not located near a Weather Forecast Office are in full accordance with network standards. In addition, responsibilities for weather services to the area covered by these NEXRADs should be unambiguously assigned to a specific Weather Forecast Office to ensure high-quality weather services for that area. Staffing and communications capability should be commensurate with each Weather Forecast Office's service area's responsibilities.
5. The storm-detection and warning performance of the composite national weather system, as a function of range from a NEXRAD, should receive an in-depth independent technical assessment that considers region-specific issues. This assessment should evalu

ate the warnings and reported events on a per-unit-area basis, as well as the traditional National Weather Service verification statistics. The assessment should include further testing in the Modernization and Associated Restructuring Demonstration in addition to tests at diverse geographic locations.

6. The adequacy of NEXRAD coverage with respect to the "no degradation of service" requirement should be reexamined in an independent study after all National Weather Service NEXRADs are commissioned.

References

Baer, V.E. 1991. The transition from the present radar dissemination system to the NEXRAD information dissemination service (NIDS). Bulletin of the American Meteorological Society 72: 29–33 .

Battan, L.J. 1973. Radar Observation of the Atmosphere. Chicago: University of Chicago Press.

Bieringer, P., and P.S. Ray. In Press. A comparison of tornado warning lead times with and without NEXRAD Doppler radar. Weather and Forecasting. Boston: American Meteorological Society.

Brown, R.A., L.R. Lemon, and D.W. Burgess. 1978. Tornado detection by pulsed Doppler radar. Monthly Weather Review 106: 29–38. Boston: American Meteorological Society.

Brown, R.A., and V.T. Wood. 1987. A Guide for Interpreting Doppler Velocity Patterns. Report No. R400-DV-101. NEXRAD Joint Systems Program Office. National Oceanic and Atmospheric Administration. Silver Spring, Maryland.

Burgess, D.W., R.J. Donaldson, Jr., and P.R. Desrochers. 1993. Tornado detection and warning by radar. Pp. 203–221 in The Tornado: Its Structure, Dynamics, Prediction and Hazards. Geophysical Monograph #79. Washington, D.C. : American Geophysical Union.

Burgess, D.W., and L.R. Lemon. 1990. Severe thunderstorm detection by radar. Pp. 619–647 in Radar in Meteorology, D. Atlas, ed. Boston: American Meteorological Society.

Burpee, R.W. 1986. Mesoscale structure of hurricanes. Pp. 311–330 in Mesoscale Meteorology and Forecasting, P.S. Ray, ed. Boston: American Meteorological Society.

Byers, H.R., and R.R. Braham, Jr. 1949. The Thunderstorm. U.S. Department of Commerce. Washington, D.C. : Government Printing Office.

Carbone, R.E., M.J. Carpenter, and C.D. Burghart. 1985. Doppler radar sampling limitations in convection storms. Journal of Atmospheric and Oceanic Technology 2: 357–361 . Boston: American Meteorological Society.

Carbone, R.E., J.W. Conway, N.A. Crook, and M.W. Moncrieff. 1990. The generation and propagation of a nocturnal squall line—Part I: Observations and implications for mesoscale predictability. Monthly Weather Review 118: 26–49 . Boston: American Meteorological Society.

Crum, T.D., and R.L. Alberty. 1993. The WSR-88D and WSR-88D Operational Support Facility. Bulletin of the American Meteorological Society 74: 1669–1687 .

Crum, T.D., R.L. Alberty, and D.W. Burgess. 1993. Recording, archiving, and using WSR-88D data. Bulletin of the American Meteorological Society 74: 645–653 .

Davies-Jones, R.P. 1985. Tornado dynamics. Pp 197–236 in Thunderstorm Morphology and Dynamics, E. Kessler, ed. Norman, Oklahoma: University of Oklahoma Press.

Devore, D.R. 1983. The operational use of digital radar. Pp. 21–24 in 13th Conference on Severe Local Storms held October 17-20, 1983, in Tulsa, Oklahoma. Boston: American Meteorological Society.

Department of Commerce. 1985. Operations of the National Weather Service. National Oceanic and Atmospheric Administration. Silver Spring, Maryland.

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

Fabry, F., G.L. Austin, and D. Tees. 1992. The accuracy of rainfall estimates by radar as a function of range. Quarterly Journal of the Royal Meteorological Society 118: 435–453 .

Fabry, F., and I. Zawadzki. 1995. The melting layer of precipitation: Radar observations and their interpretation. Journal of Atmospheric Sciences 52: 838–851 . Boston: American Meteorological Society.

Federal Register. March 2, 1994. Rules and Regulations. Vol. 59, No. 41. Pp. 9921-9925 . Weather Service Modernization Criteria. Department of Commerce, National Oceanic and Atmospheric Administration.

Federal Register. November 4, 1994. Notices. Vol. 59, No. 213. Pp. 55254-55255 . National Weather Service Modernization and Restructuring. Department of Commerce. National Oceanic and Atmospheric Administration.

Fujita, T.T. 1981. Tornadoes and downbursts in the context of generalized planetary scales. Journal of the Atmospheric Sciences 38: 1511–1534 . Boston: American Meteorological Society.

Fujita, T.T. 1985. The Downburst. Chicago: University of Chicago Press.

Heiss, W.H., D.L. McGrew, and D. Sirmans. 1990. NEXRAD: Next generation weather radar (WSR-88D). Microwave Journal 33: 79–98 .

Hjelmfelt, M.R. 1988. Structure and life cycle of microburst outflows observed in Colorado. Journal of Climate and Applications in Meteorology 27: 900–927 . Boston: American Meteorological Society.

Joss, J., and A. Waldvogel. 1990. Precipitation measurements and hydrology. Pp. 577–618 in Radar in Meteorology, D. Atlas, ed. Boston: American Meteorological Society.

Kingsmill, D.E., and R.M. Wakimoto. 1991. Kinematic, dynamic, and thermodynamic analysis of a weakly sheared severe thunderstorm over northern Alabama. Monthly Weather Review 119: 262–297 . Boston: American Meteorological Society.

Klazura, G.E., and D.A. Imy. 1993. A description of the initial set of analysis products available from the NEXRAD WSR-88D system. Bulletin of the American Meteorological Society 74: 1293–1311 .

Klingle, D.L., D.R. Smith, and M.M. Wolfson. 1987. Gust front characteristics as detected by Doppler radar. Monthly Weather Review 115: 905–918 . Boston: American Meteorological Society.

Maddox, R.A., and D.E. Forsyth. 1994. Comments on National Weather Service warning performance based on the WSR-88D. Bulletin of the American Meteorological Society 75(11): 2175 .

Mahoney, W.P., III. 1988. Gust front characteristics and the kinematics associated with interacting thunderstorm outflows. Monthly Weather Review 116: 474–1491 . Boston: American Meteorological Society.

Marks, F.D. 1990. Radar observations of tropical weather systems. Pp. 401–425 in Radar in Meteorology, D. Atlas, ed. Boston: American Meteorological Society.

McGrew, R.G. 1972. Project D/RADEX (Digitized Radar Experiments). Pp. 101–106 in 15th Conference on Radar Meteorology held October 10-12, 1992, in Champaign–Urbana, Illinois. Boston: American Meteorological Society.

Mueller, C.K., and R.E. Carbone. 1987. Dynamics of thunderstorm outflow. Journal of the Atmospheric Sciences 44: 1879–1898 . Boston: American Meteorological Society.

NRC. 1991. Toward a New National Weather Service—A First Report. National Weather Service Modernization Committee, National Research Council. Washington, D.C.: National Academy Press.

NRC. 1992. Toward a New National Weather Service—Second Report. National Weather Service Modernization Committee, National Research Council. Washington, D.C: National Academy Press.

NRC. 1993. Review of Modernization Criteria. National Weather Service Modernization Committee, Naitonal Research Council. Washington, D.C. : National Academy Press.

NRC. 1994a. National Weather Service Employee Feedback. National Weather Service Modernization Committee, National Research Council. Washington, D.C.: National Academy Press.

NRC. 1994b. Weather for Those Who Fly. National Weather Service Modernization Committee, National Research Council. Washington, D.C.: National Academy Press.

National Weather Service. 1993. A Summary of Natural Hazard Deaths for 1992 in the United States in Storm Data. Warning and Forecast Branch, Office of Meteorology, National Weather Service. Silver Spring, Maryland.

National Weather Service. 1994. A Summary of Natural Hazard Deaths for 1993 in the United States in Storm Data. Warning and Forecast Branch, Office of Meteorology, National Weather Service. Silver Spring, Maryland.

Office of the Federal Coordinator for Meteorological Services and Supporting Research. 1990. Federal Meteorological Handbook No. 11. Doppler Radar Meteorological Observations—Part B, Doppler Radar Theory and Meteorology. Report FCH-H11B-1990, Interim Version One. Rockville, Maryland. Department of Commerce, NOAA. Washington, D.C.

Pettit, P.E. 1990. Doppler radar detection capabilities at Montgomery, Alabama, 1982—1988. National Weather Digest 15: 23–27 . National Weather Association.

Polger, P.D., Goldsmith, B.S., Przywarty, R.C., and J.R. Bocchieri. 1994. National Weather Service warning performance based on the WSR-88D. Bulletin of the American Meteorological Society 75: 203–214 .

Simon, S. 1988. The Edmonton Tornado. Cover photo in 15th Conference on Severe Local Storms held February 22-26, 1988, in Baltimore, Maryland. Boston: American Meteorological Society.

Sirmans, D. 1993. WSR-88D Polarization Change. Operational Support Facility Technology Report, January 1993. Joint System Program Office, National Oceanic and Atmospheric Administration. Norman, Oklahoma.

Wakimoto, R.M., and J.W. Wilson. 1989. Non-supercell tornadoes. Monthly Weather Review 106: 29–38 .; 117; 1113–1140 . Boston: American Meteorological Society.

Wakimoto, R.M. 1982. The life cycle of thunderstorm gust fronts as viewed with Doppler radar and rawinsonde data. Monthly Weather Review 110: 1060–1082 . Boston: American Meteorological Society.

Weber, E.M., and S. Wildrotter. 1981. Satellite Interpretation. Technical Note No. 3WW/TN-81/001. Air Weather Service. Offutt, Air Force Base, Nebraska.

Weckwerth, T.M., and R.M. Wakimoto. 1992. The initiation and organization of convective cells atop a cold-air outflow boundary. Monthly Weather Review 120: 2169–2187 . Boston: American Meteorological Society.

Weisman, M.L., and J.B. Klemp. 1986. Characteristics of isolated convective storms. Pp. 331–358 in Mesoscale Meteorology and Forecasting, P. Ray, ed. Boston: American Meteorological Society.

Wilk, K.E., J.T. Dooley, and E. Kessler. 1965. Weather Detection by ARSD-1D, ASR-4, and WSR-57 Radars: A Comparative Study. National Severe Storms Laboratory Technical Memo, No. 1. Norman, Oklahoma. Department of Commerce. U.S. Weather Bureau. Washington, D.C.

Wilson, J.W. 1970. Operational measurement of rainfall with the WSR-57: Review and recommendations. Pp. 257–263 in 14th Conference on Radar Meteorology held November 17-20, 1970, in Tucson, Arizona. Boston: American Meteorological Society.

Wilson, J.W. 1975. Measurement of snowfall by radar during the IFYGL. Pp 508–513 in the 16th Radar Meteorology Conference held April 22-24, 1975, in Houston, Texas. Boston: American Meteorological Society.

Wilson, J.W., and E.A. Brandes. 1979. Radar measurement of rainfall—A summary. Bulletin of the American Meteorological Society 60: 1048–1058 .

Wilson, J.W., R.D. Roberts, C. Kessinger, and J. McCarthy. 1984. Microburst wind structure and evaluation of Doppler radar for airport wind shear detection. Journal of Climate and Applications in Meteorology 23: 898–915 . Boston: American Meteorological Society.

Wilson, J.W., T.M. Weckwerth, J. Vivekanandan, R.M. Wakimoto, and R.W. Russell. 1994. Boundary layer clear-air echoes: Origin of echoes and accuracy of derived winds. Journal of Atmospheric and Oceanic Technology 11: 1184–1206 . Boston: American Meteorological Society.

Acronyms

AGL	Above Ground Level
ASL	Above (Radar) Site Level
ASOS	Automated Surface Observing System
AWIPS	Advanced Weather Interactive Processing System
cm	centimeters
dB	decibels
dBZ	decibels (radar reflectivity ratio)
DoD	Department of Defense
DVIP	Digital Video Integrating Processor
FAR	False Alarm Ratio
GOES	Geostationary Operational Environmental Satellite
ICRAD	Interactive Color Radar Display
kbs	kilobits per second
km	kilometers
MARD	Modernization and Associated Restructuring Demonstration
mbs	megabits per second
NEXRAD	Next Generation Weather Radar
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NWS	National Weather Service
NWSMC	National Weather Service Modernization Committee
O&M	Operations and maintenance
POD	Probability of Detection
PUP	Principal User Processor
RADAP II	Radar Data Processor II
RDA	Radar Data Acquisition
RFC	River Forecast Center
RPG	Radar Product Generator
SNR	Signal to noise ratio
TVS	Tornadic Vortex Signature
WFO	Weather Forecast Office
WSFO	Weather Service Forecast Office
WSMA	Weather Service Modernization Act
WSO	Weather Service Office
WSR-57	Weather Surveillance Radar -- 1957 (S band)
WSR-74C	Weather Surveillance Radar -- 1974 (C band)
WSR-74S	Weather Surveillance Radar -- 1974 (S band)
WSR-88D	Weather Surveillance Radar -- 1988 Doppler (S band)

Glossary

Boundary Layer: The layer of a fluid adjacent to a physical boundary in which the fluid motion is affected by the boundary and has a mean velocity less than the free-stream value.

Bright Band: The enhanced radar echo of snow as it melts to rain. The bright band is observed primarily in stratiform cloud systems.

Clutter: Echoes that interfere with observation of desired signals on a radar display.

Convective Rain: Rain associated with convective clouds or cumuliform clouds characterized by vertical development in the form of rising mounds, domes, or towers.

Convergence Lines: A horizontal line along which horizontal convergence of the airflow is occurring. Common forms of convergence lines are sea-breeze fronts, cold-air outflows from thunderstorms and synoptic fronts.

Cumuliform: Descriptive of all clouds with vertical development in the form of rising mounds, domes, or towers.

Decibel (dB): A logarithmic expression for the ratio of two quantities. Mathematically: $dB = 10Log(P_1/P_2)$

Doppler shift: The change in frequency at a receiver due to the relative motion of the receiver and the energy source.

Downburst: A strong downdraft that induces an outburst of damaging winds on or near the ground (macrobursts and microbursts are versions of this).

Eye Wall: The area of tall cumulonimbus storms surrounding the eye of the storm. Heavy rain and very high winds occur in the eye wall. The "eye of the storm" (hurricane, typhoon) is the roughly circular area of comparatively light winds and fair weather found at the center of a severe tropical cyclone.

Freezing Level: The lowest altitude in the atmosphere, over a given location, at which the air temperature is 0 degrees Celsius.

Ground Clutter: The pattern of radar echoes due to fixed ground targets.

Hail: Precipitation in the form of balls or irregular lumps of ice produced by convective clouds, usually cumulonimbus. An individual unit of hail is called a hailstone. By convention, hail has a diameter of 5 mm or more, while smaller particles of similar origin may be classed as ice pellets or snow pellets.

Hook Echo: A pendant, curved-shaped region of reflectivity caused by precipitation being drawn into the cyclonic spiral of a mesocyclone (Davies-Jones, 1985). The hook echo is a fairly shallow feature, typically extending only up to 4 km in height.

Hurricane: Severe tropical cyclone, with winds of 74 mph or greater, occurring in the North Atlantic Ocean, Caribbean Sea, Gulf of Mexico, and in the eastern North Pacific off the west coast of Mexico. A tropical cyclone is a general term for a cyclone that originates over the tropical oceans. At maturity, the tropical cyclone is one of the most intense and feared storms of the world.

Kinematics: Study of the motion of bodies or fluids without reference to the forces producing the motion. In meteorology, the analysis of the motion of isobars and fronts when treated as geometric features.

Lake-effect Snow: Localized snow that occurs over and in the lee of lakes that is caused by relatively cold air flowing over warm water. In the United States this phenomenon is most noted along the south and east shores of the Great Lakes during arctic cold-air outbreaks.

Macroburst: Similar to a microburst (see below) except the damaging winds extend over an area greater than 4 km and may last for tens of minutes. The term “downburst” includes both microbursts and macrobursts without reference to scale (Fujita 1985).

A. Reflectivity signature—Several reflectivity patterns have been associated with macrobursts. One of the most common is the “bow echo,” or region in a line of thunderstorms that bulges ahead of the line and is associated with damaging surface winds and occasionally tornadoes.

B. Velocity signature—The velocity signature of a macroburst shows a broad pattern of approaching and receding velocities associated with the strong divergent storm outflow.

Macroscale: Large scale, characteristic of weather systems several hundred to several thousand kilometers in diameter.

Median: A measure of central tendency. The middle value in a set of numbers arranged in order from lowest to highest.

Melting Level: The altitude at which ice crystals and snowflakes melt as they descend through the atmosphere.

Mesocyclone: A horizontal atmospheric rotation on a scale between 4 and 400 km (Fujita, 1981). Its use here refers to a rotation within a thunderstorm typically surrounding a small area of low pressure. Typically within thunderstorms the rotation is 4-12 km across and 4-10 km in height.

Mesoscale: On a scale of 4 km to 400 km.

Microburst: A strong downdraft induces an outburst of damaging winds on or near the ground. Damaging winds, either straight or curved, are highly divergent. The damaging winds extend over an area of less than 4 km and typically last for only a few minutes. This scale of diverging winds has been found to be particularly hazardous to aircraft while landing or taking off (Fujita, 1985).

Mini-supercell: Contains similar severe weather characteristics to a supercell, but the storm is significantly smaller in height and width. The diameter of the radar detected rotation is 1 to 8 km. This is a relatively new storm type whose existence has been confirmed by data from the new Doppler radars in the eastern half of the United States. Differentiating on scale is useful here because of the greater difficulty in detecting these smaller rotations.

Misoscale: On a scale of 40 m to 4 km.

Misocyclone: A horizontal atmospheric rotation on a scale between 40 m and 4 km (Fujita, 1981). Its use here refers to (1) a rotation within a thunderstorm with a horizontal scale < 4 km; and (2) a near-surface rotation along a convergence line with a horizontal dimension < 4 km.

Nautical mile: An international unit equal to 6,076.115 feet (1,852 meters) used officially in the United States since July 1, 1959. 1 nautical mile = 1.15 statute miles = 1.85 kilometers.

Nowcast: Statement of currently occurring weather conditions; also used to mean short-term forecast, that is, minutes to a few hours.

Pre-NEXRAD Network: Network of radars established before the introduction of the WSR-88D.

Reflectivity: A measure of the efficiency of a radar target in intercepting and returning radio energy, including effects of reflection, scattering, and diffraction.

Resolution: The smallest increment of a measurement of a parameter.

Storm: A disturbed state of the atmosphere strongly implying destructive or unpleasant weather.

Stratiform: Descriptive of clouds of extensive horizontal development, as contrasted to the more narrow and vertically developed cumuliform types.

Stratiform Rain: Horizontally widespread rain, uniform in character, typically associated with macroscale fronts and pressure systems.

Stratiform Snow: Same as for stratiform rain except precipitation is in the form of snow.

Supercell: Potentially the most dangerous convective storm type. It may produce high winds, large hail and long-lived tornadoes over a wide path. In its purest form it consists of a single, quasi-steady, rotating updraft that may have a lifetime of several hours (Weisman and Klemp, 1986). The radar-identified rotation typically has a diameter of 4 km to 12 km.

Thin-line Echo: A narrow, elongated nonprecipitating echo, usually associated with thunderstorm outflow, fronts, or other density discontinuities. Also called a “fine line.”

Tornadic Vortex Signature (TVS): A Doppler velocity signature sometimes produced by a large, intense tornado at close range. The signature is a very strong azimuthal shear in a distance < 2 km.

Tornado: A violently rotating column of air, pendant from a cumulonimbus cloud, and nearly always observable as a “funnel cloud.” On a local scale, it is the most destructive of all atmospheric phenomena. Its vortex, commonly several hundreds of meters in diameter, whirls cyclonically with wind speeds estimated at 50 m/s to 150 m/s.

Wind Shear: The rate of change of the vector wind in a specified direction normal to the wind direction. Vertical shear is the variation of the horizontal wind in the vertical direction.

WSR-88D System: Combination of the hardware, software, facilities, communications, logistics, staff, operations, and procedures for the collection, processing, analysis, dissemination, and application of data from the WSR-88D unit.

WSR-88D Unit: Combination of one radar data acquisition, one radar product generator, all associated radar product generator operational positions and principal user processor, and interconnecting communications of the WSR-88D.

APPENDIXES

Appendix A

Criteria for Evaluation of a Weather Radar System

The criteria for comparison of the Next Generation Weather Radar (NEXRAD) and pre-NEXRAD systems fall into three broad areas:

1. technical aspects including detection capabilities;
2. warning performance; and
3. products and services offered.

RADAR TECHNICAL ASPECTS

This section provides a system description and radar performance specifications and discusses the key radar technical aspects that were considered in developing criteria for addressing the quality of radar coverage. Key radar technical aspects include coverage at specific altitudes, spatial and temporal resolution, sensitivity, Doppler coverage, and radar availability.

Other technical aspects of radar operation (e.g., clutter suppression, antenna beam patterns, algorithms, and data archiving) are also discussed in this section. However, these did not enter directly into the evaluation of the detectability of weather phenomena for the "quality of service" assessment. The discussion of radar technical aspects concludes with a description of NEXRAD technical improvements.

System Description

The pre-NEXRAD NWS radar network consisted of 128 WSR-57, WSR-74S, and WSR-74C radars. The WSR-57 and WSR-74S radars, both 10-cm-wavelength systems, were configured as manually operated surveillance radars; the 68 WSR-74C, 5-cm radars functioned as "local warning" radars. The NEXRAD network, when complete, will consist of 138 10-cm WSR-88Ds in the contiguous United States, including 22 Department of Defense (DoD) radars. Beyond the contiguous United States, seven NEXRADs are planned in Alaska, four in Hawaii, three in the Caribbean, and several other systems in locations around the world.

Radar Performance Specifications

Table A-1 gives the technical characteristics of the NEXRAD and comparable values for the pre-NEXRAD radars. NEXRAD is a Doppler radar system that routinely generates products involving both reflectivity and velocity information. The reflectivity estimates of the NEXRAD have significantly higher data quality than the pre-NEXRAD systems due to higher spatial resolution of the narrow antenna beam, increased sensitivity to weak echoes, new Doppler clutter-suppression processing, and new calibration procedures. Radar coverage with limited Doppler capability was available in the pre-NEXRAD NWS network only at Montgomery, Alabama; Marseilles, Illinois; and Huntsville, Alabama. Therefore, for weather phenomena that can only be detected using Doppler features (e.g., mesocyclones or microbursts), limitations in the NEXRAD network Doppler coverage are not a factor for most of the country under the “no degradation of service” criterion. Where a combination of Doppler and reflectivity features is used for phenomena detection (e.g., supercells), limitations in the NEXRAD Doppler coverage could be a factor in those geographic areas where NEXRAD coverage at long range must be compared to pre-NEXRAD coverage at short range.

TABLE A-1 Radar Characteristics—Pre-NEXRAD and NEXRAD

	NEXRAD	WSR-57	WSR-74S	WSR-74C[a]
P_t = Transmitter peak output power (MW)	0.750	0.500	0.500	0.250
G = Antenna gain (dB)	45.5	38.5	38.5	40
λ = Wave length (cm)	10.53	10.71	10.71	5.33
`^{2} = Propagation loss (dB) @ 0.5° @ 50km	0.7	0.7	0.7	0.8
@ 230 km	2.5	2.5	2.5	2.8
θ_1 = Beam width (deg)	0.95	2.0	2.0	1.5
T = Pulse width (μsec)	1.57	4.00	4.00	3.00
B_n = Noise band width (MHz)	0.79	0.75	1.50	0.80
T_{sys} = System noise temp (K)	600	1700	1000	2150
Z_{min} = Min detectable dBZ @ 50 km (single pulse)	−7.6	−0.2	0.3	−1.7
Doppler Feature	yes	no	no	no
Clutter Suppression	yes	no	no	no

[a] The Huntsville, Alabama, WSR-74C has enhanced capabilities—G = 43 dB, θ_1 = 1.0 degree, T = 2.0 μsec, $Z_{min} < -5$ dBZ, Doppler and clutter suppression.

The NEXRAD has three major components, as shown in Figure A-1. These components are the radar data acquisition (RDA) unit, the radar product generator (RPG), and the principal user processor (PUP) (Crum and Alberty, 1993). The RDA includes the transmitter, antenna, receiver, signal processor, and Level 2 base data (wide band) communications interface. The RPG includes the computing power that generates the image products and the narrow band communications interfaces. The PUP is the processor workstation with which the forecaster requests and receives NEXRAD products. “Associated” PUPs are permanently connected with the RPG and routinely receive specified sets of products. “Non-associated” PUPS are intermittently connected to any NEXRAD via a dial-up, low-speed communication line and receive only requested products.

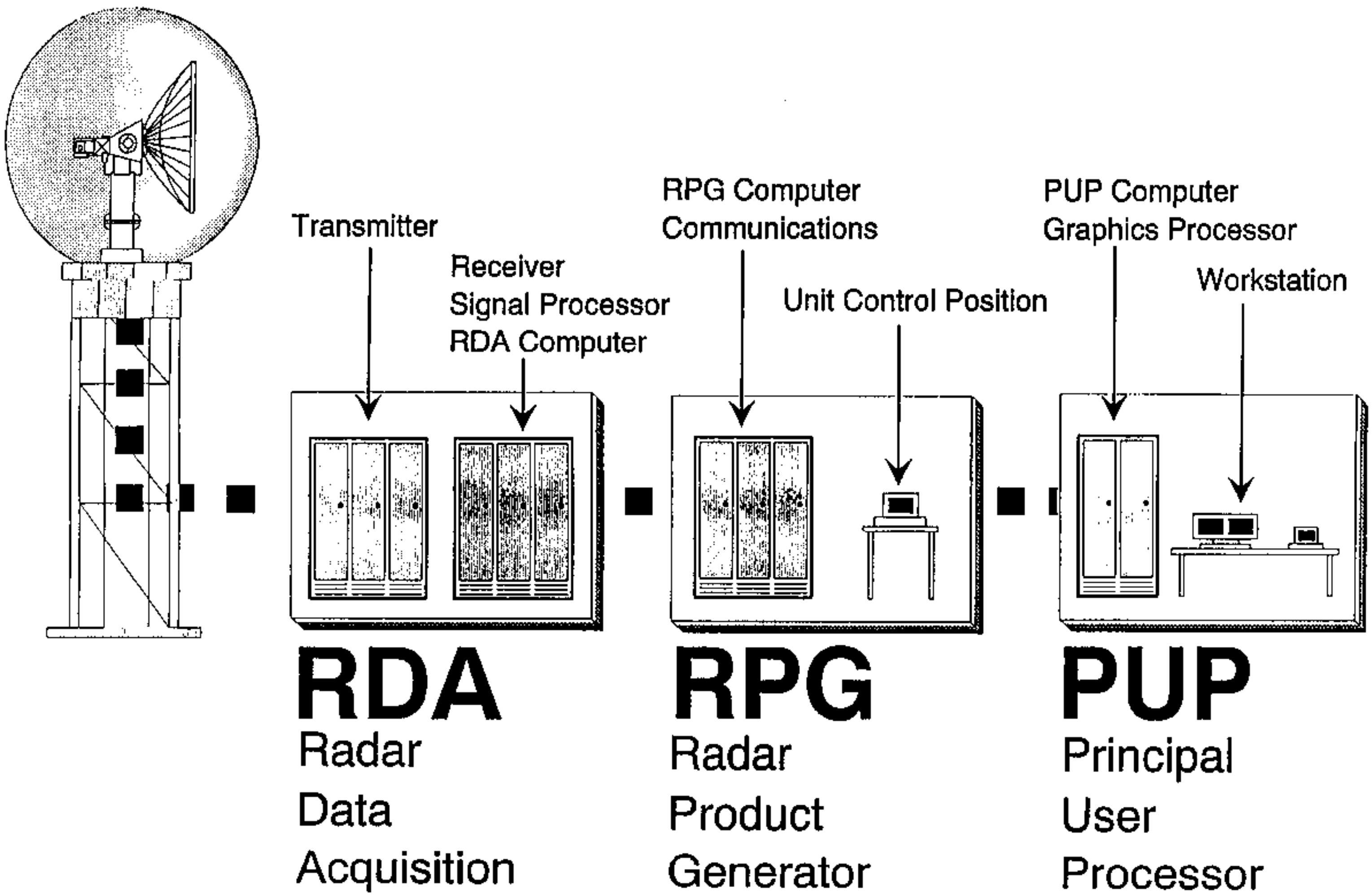


Figure A-1 The three major components of the NEXRAD system. Major subcomponents of each component are also depicted. A wideband (1.544 mbs) communication link transmits Radar Data Acquisition data to the RPG. The RPG units are connected to PUPS by narrowband links (56 kbs for NWS collocated PUPs, and 9.6 kbs for others). Courtesy of NOAA/NWS.

The Doppler capability of the WSR-88D allows measuring storm kinematics (i.e., velocity information) to generate more-accurate and timely weather advisories and warnings while suppressing interfering ground echoes; thereby improving short-range and low-altitude coverage. Another important design improvement is the availability of digital information in a variety of displays from the NEXRAD.

Spatial Coverage

In planning the layout of the NEXRAD network, consideration was given to the distribution of population within the contiguous United States. In meeting the needs of the sponsoring agencies, further siting criteria included proximity to existing or planned Weather Forecast Offices and to high-use commercial airports and designated high-value military facilities.

On a smooth spherical Earth, the coverage provided by a particular radar *would be* limited by the curvature of the Earth and the refraction of the microwaves in the atmosphere. Because of those factors, the maximum range of potential coverage for a given altitude is represented by a circle with the radar located at the center. Due to blockage of the radar beam by intervening terrain features, however, the area actually covered at a given altitude is not circular in some cases (particularly in the West). When the coverage zones of all operational radars are plotted and superimposed, the resulting "coverage map" provides one of the aids for evaluating the adequacy of radar coverage. Maps shown later in this appendix illustrate this coverage, or radar field of view. Radar resolution, sensitivity, and the forecaster's expertise must be added to the field-of-view in determining overall quality of service.

Generally the ability to detect weather phenomena decreases with increasing radar range because the low-altitude coverage, the radar resolution, and radar sensitivity all deteriorate with increasing range. In addition, there is a "cone of silence" above the radar, as illustrated in Figure A-2. This deficiency may be alleviated by observations from neighboring NEXRADs over most of the United States east of the Rocky Mountains.

At close ranges (up to, perhaps, 40 km) the interfering effects of ground clutter are at a maximum.[1] The NEXRAD clutter suppression feature mitigates this limitation to a considerable extent. At long ranges both the Earth's curvature and the increasing resolution cell size reduce the radar's ability to detect weather phenomena. These two features are illustrated in Figure A-3. For each weather phenomenon shown, no combination of resolution and sensitivity can compensate for the fact that the radar beam is simply too high above the ground for effective detection. Weather targets that protrude into the lower edge of the beam may be detected because of the NEXRAD's sensitivity. The restrictive effect of the Earth's curvature is a function of the height of the weather phenomenon and the degree to which signals received from high levels can be interpreted effectively in terms of weather at lower heights. At long ranges, the width of the beam may prohibit resolution of fine details of the echo structure needed to identify particular weather phenomena. Representative ranges for detecting various weather phenomena are discussed in Chapter 2.

The coverage at various altitudes for both the pre-NEXRAD and NEXRAD networks has been mapped. Figure A-4a shows the NEXRAD altitude coverage, that is, where the NEXRAD coverage

[1] All radars receive signals scattered from the ground. These signals are called "ground clutter" because the returns interfere with the signals from weather targets and often obscure the weather signal entirely. This problem is particularly severe at close range (approximately out to 40 km) but is also strongly influenced by terrain, especially in hilly or mountainous regions. Cities with tall buildings also produce strong clutter signals that can obscure weather above them.

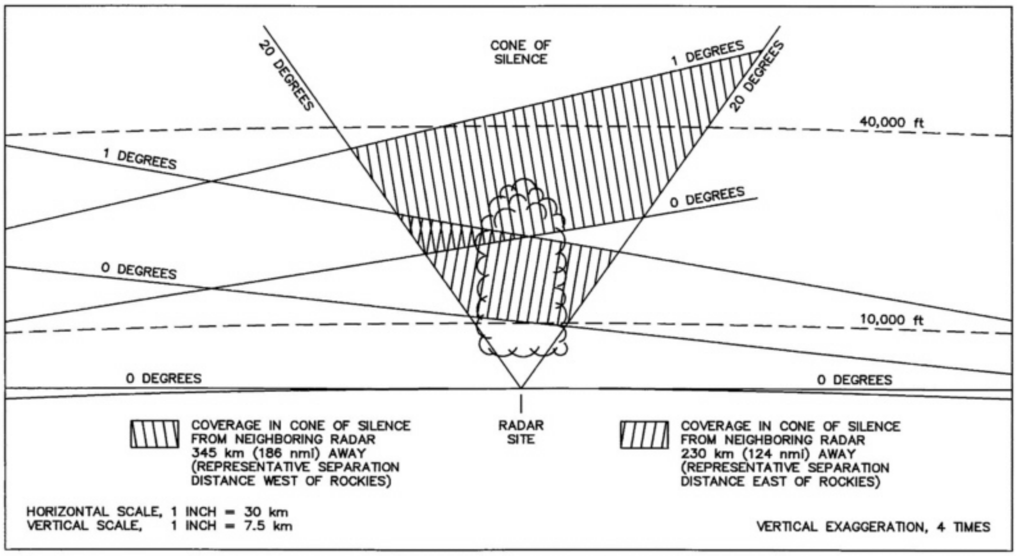


Figure A-2 Cone of silence for the NEXRAD. The cone of silence has a radius of 34 km at 40,000 ft and a radius of 8.5 km at 10,000 ft. Elevations higher than 19.5 degrees are not scanned using the existing volume coverage patterns; therefore, radar echoes are not received from within this cone directly above each radar. Overlapping coverage from adjacent radars is needed to cover this region and is shown for two radars operating with a 1-degree beam width centered at 0.5 degrees elevation. Courtesy of SRI International.

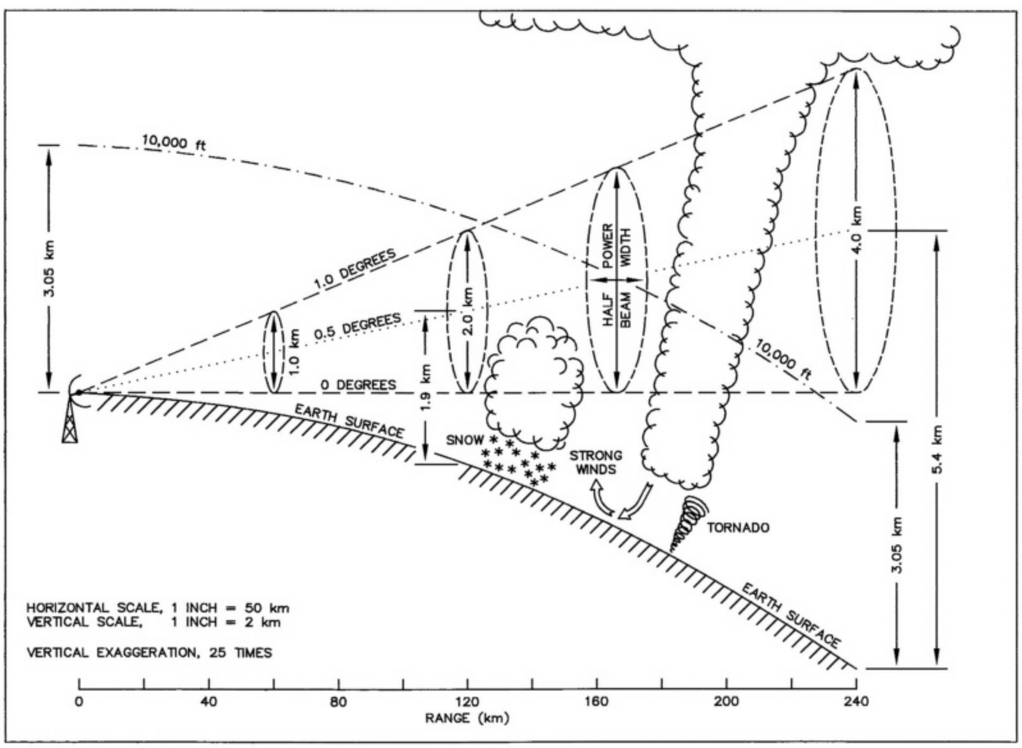


Figure A-3 Diagram illustrating the effect of range and earth curvature (with standard atmospheric refraction) on NEXRAD cross-beam resolution and coverage of low-level weather phenomena. Courtesy of SRI International.

at 0.0 degrees (lower half-power edge of a 1-degree beam that is centered at 0.5 degrees) extends down to or below 4,000 ft (red), between 4,000 ft and 6,000 ft (yellow), between 6,000 ft and 10,000 ft (green), and between 10,000 ft and 40,000 ft (blue) above site level (ASL). All altitudes in the figure are given ASL. Figure A-4b shows a map indicating differences between the two networks in minimum-altitude coverage over the contiguous United States and bordering areas—red indicating that the NEXRAD coverage reaches to lower altitudes than the pre-NEXRAD coverage, blue the converse, and green indicating regions of similar coverage. The blue areas indicate regions of potential degradation of service with the NEXRAD network. The pie chart in Figure A-4b shows that the NEXRAD coverage is similar to, or better than, the earlier network over most of the contiguous United States. However, over about 7 percent of the area, the earlier network coverage extends to lower altitudes. Altitude coverage, alone, is not equivalent to service, however, as discussed elsewhere in the report and in this appendix.

Resolution

Spatial resolution is important from a meteorological perspective since better radar resolution (i.e., a smaller radar-resolution cell) allows detection of smaller-scale features, such as tornado circulations, mesocyclone circulations, and hail or rain shafts, at greater ranges. Spatial resolution is defined as the maximum dimension of the volume "illuminated" by a pulse. At close ranges the resolution is governed by the pulse length, and at long ranges it is governed by the antenna beam width. The narrower beam of the NEXRAD antenna gives it an advantage over earlier National Weather Service (NWS) radars in resolution capability at long range. Figure A-3 depicts the NEXRAD beam-width dimension as a function of range.

Radar systems often average information over several adjacent resolution cells along the range direction to improve detectability and to measure the returned signal strength more precisely, but this is done at the expense of range resolution. In the NEXRAD reflectivity mode, four such cells of 250-m length are averaged together to yield an effective range resolution of 1 km. Comparable range resolution was obtained from the pre-NEXRAD radars using longer transmitted pulses. Table A-2 gives

TABLE A-2 Approximate Spatial Resolution Dimensions

Radar	Range Resolution	Cross-Beam Resolution At:		
		6 km	60 km	180 km
NEXRAD	1.0 km (reflectivity) 0.3 km (velocity)	100 m	1.0 km	3.0 km
WSR-74C	0.5 km	150 m	1.5 km	4.5 km
WSR-74S	0.6 km	200 m	2.0 km	6.0 km
WSR-57	0.6 km	200 m	2.0 km	6.0 km

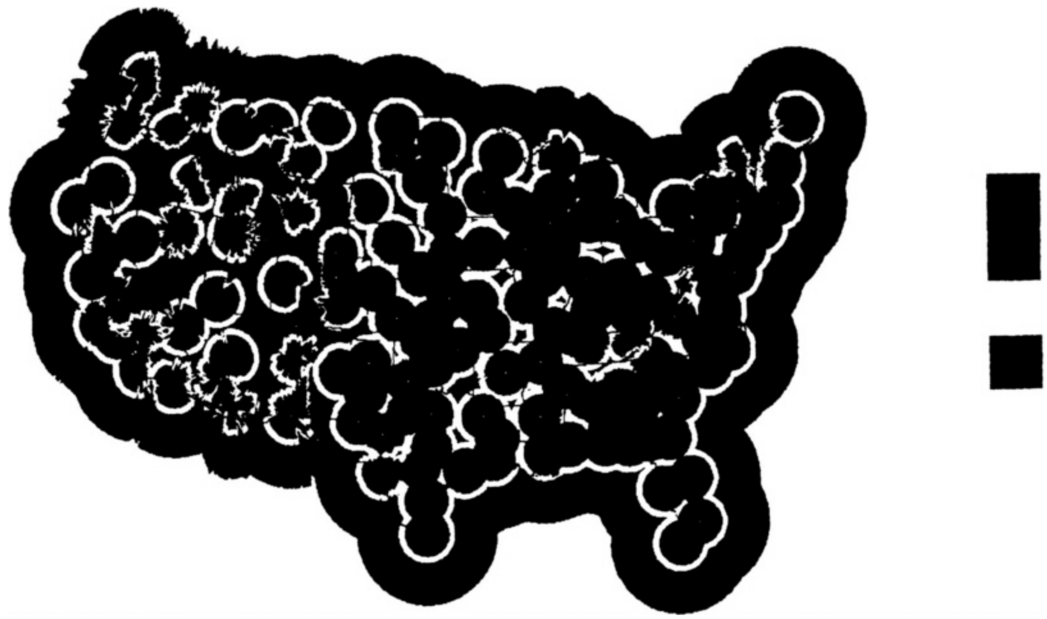


Figure A-4a NEXRAD altitude coverage. The figure indicates where the NEXRAD coverage at 0.0 degrees (lower half-power edge of a 1-degree beam that is centered at 0.5 degrees) extends down to or below 4,000 ft (red), between 4,000 ft and 6,000 ft (yellow), between 6,000 ft and 10,000 ft (green), and between 10,000 ft and 40,000 ft (blue) above site level. Courtesy of SRI International.

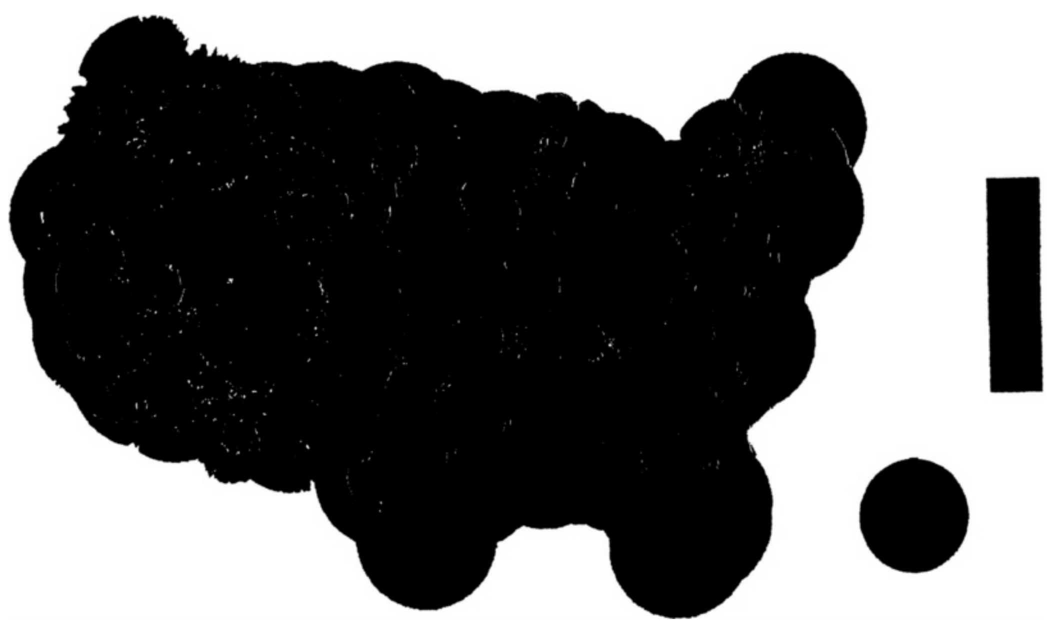


Figure A-4b Areas of contiguous United States and border regions having better radar coverage (i.e., coverage to lower altitudes above site level) with the NEXRAD network (red), with the pre-NEXRAD network (blue), and with the same coverage by both (green). The pie chart shows the fraction of the total area having lower-altitude coverage as indicated. Courtesy of SRI International.

the approximate spatial resolution of the base data for each of the radars at ranges of 6 km, 60 km, and, 180 km. Note that cross-beam resolution at 60 km is 1 km for the NEXRAD and about 2 km for the pre-NEXRAD radars.

Figure A-5a shows the resolution of the NEXRAD network for the 10,000-ft ASL coverage. The colors on the figure indicate resolution dimensions of less than 1 km, between 1 and 2 km, and between 2 and 4 km. Figure A-5b compares the resolution capabilities of the two networks for 10,000-ft coverage over the contiguous United States and bordering areas. The red areas indicate where the NEXRAD network provides better resolution; the blue areas indicate where the old network had better resolution capabilities; and green areas indicate where the resolutions were essentially the same. The blue areas do not imply a degradation of service but indicate regions that are candidates to examine for potential degradation of service. As indicated by the cumulative distributions in Figure A-6, the NEXRAD network will cover about 86 percent of the contiguous United States and bordering areas with resolution better than 4 km. (The percentage would be reduced slightly without the DoD radars.) The pre-NEXRAD network provided 4-km resolution over only 46 percent of the area.

Temporal resolution is also important in observing rapidly evolving weather features. The NEXRADs operate on predetermined scan patterns, and the temporal resolution of the volume data is 5 to 6 min (i.e., the scans are repeated every 5 to 6 min). Access to this continuously evolving volumetric data allows the forecaster to analyze time sequences that yield a better understanding of evolving weather. Furthermore, the PUP processing of volume-scan data allows analysis of vertical cross-sections of the radar echo to determine the vertical structure of the storms. The temporal resolution of the pre-NEXRAD network was considerably more variable and more difficult to assess because the radars were manually operated for any volume-scan functions. When used interactively, pre-NEXRAD radars could detect changes in severe storm phenomena in less than 1 min. However, on the basis of the evidence available to the panel from NEXRAD operators experienced with the old radars, the panel concludes that the type and amount of information from NEXRAD's set scan strategy, especially use of the four-panel storm and velocity structure display, is as effective as a vertical scan and has contributed to the improved probability of detection for severe storms.

Sensitivity

The NEXRAD is about 10 times more sensitive than any of the previous radars. The sensitivity of a radar as a function of range can be determined using conventional weather radar equations (Battan, 1973; Doviak and Zrnic, 1993). Figure A-7 shows the sensitivity versus range for all four radar types of concern.

The sensitivity curves of Figure A-7 show the single-pulse radar sensitivity, defined as the reflectivity factor that would yield unity signal-to-noise ratio (SNR = 1) of the received echo. The processing gain of the digital video integrating processor (DVIP) in the pre-NEXRAD systems and the signal processor of the NEXRAD reduce the variance of the reflectivity by averaging adjacent range gates. However, when data thresholds are used, this process frequently precludes realizing any gain in detectability. Since the pre-NEXRAD systems were not operated to observe low-reflectivity echoes, the DVIP typically suppressed any echoes below 18 dBZ, yielding acceptable operational performance. The NEXRAD more effectively processes the received signals and observes the low-reflectivity echoes in generating some products.

The network sensitivity at a given altitude for any contiguous United States location is the best sensitivity value of all network radars that provide coverage to that altitude at that location. Figure A-8a shows the sensitivity of the NEXRAD network on the 10,000-ft coverage map. Figure A-8b compares the sensitivities of the NEXRAD and pre-NEXRAD networks at the 10,000-ft level. In the figure, red denotes locations where the NEXRAD network has better sensitivity; blue denotes locations where the pre-NEXRAD network has better sensitivity; and green indicates equivalent sensitivity. White indicates no coverage at that altitude by either system. As before, the blue regions indicate a potential degradation in quality of service. However, one must also consider the sensitivity question in the context of the ability to observe specific weather phenomena as discussed in Chapter 2.

The cumulative radar sensitivity distributions in Figure A-9 indicate that the NEXRAD network will cover more than 80 percent of the contiguous United States and bordering areas at the 10,000-ft level with sensitivity sufficient to detect all precipitation echoes of consequence (5 dBZ or greater) as well as many echoes of nonprecipitation origin. The pre-NEXRAD network has this capability over only 30 percent of the area. For most purposes radar sensitivity does not limit the operational performance of the NEXRAD, but its greater sensitivity allows detection of a greater percentage of weak weather phenomena than the pre-NEXRAD radars could observe.

Doppler Coverage

The Doppler coverage (i.e., the region over which Doppler radial velocities are provided) is important in determining network capability to detect a number of weather phenomena, as discussed in Chapter 2. The Doppler coverage may differ from the coverage shown earlier due to two factors. These factors are as follows:

1. If minimum signal-to-noise ratio thresholds are imposed, a stronger echo may be required for Doppler velocity than for reflectivity measurement. This can reduce the effective range of Doppler coverage.
2. The Doppler velocities are measured with transmitted waveforms having ambiguities at multiples of approximately 115 km for the NEXRAD.[1] Thus, although the maximum stated Doppler range is approximately 230 km, the transmitted signals are such that Doppler data can sometimes be provided for only half of that range. Even then, if there are comparable weather echoes in the first two ambiguity intervals, for example, at x and (x + 115) km, no Doppler information may be available in either interval. Regions where Doppler velocity information is not available due to SNR or range-ambiguity considerations are portrayed on the PUP in a purple color, thus giving rise to the NEXRAD "purple-haze" display.

The impact of the above considerations is that NEXRAD Doppler coverage is not always available beyond the 115 km range and that it is sometimes impaired even at lesser ranges.

Availability Of Radars

For successful support of NWS operations, it is essential that the radars be available for use on a nearly full-time basis. System availability and reliability affect the accuracy and timeliness of forecasts and warnings of many weather phenomena. The NEXRAD radars have been designed for continuous, unattended operation with the expectation of an increased availability of the radars. Not

[1] The NEXRAD program office is modifying the radar wave forms and software to extend the unambiguous range to approximately 165 km.

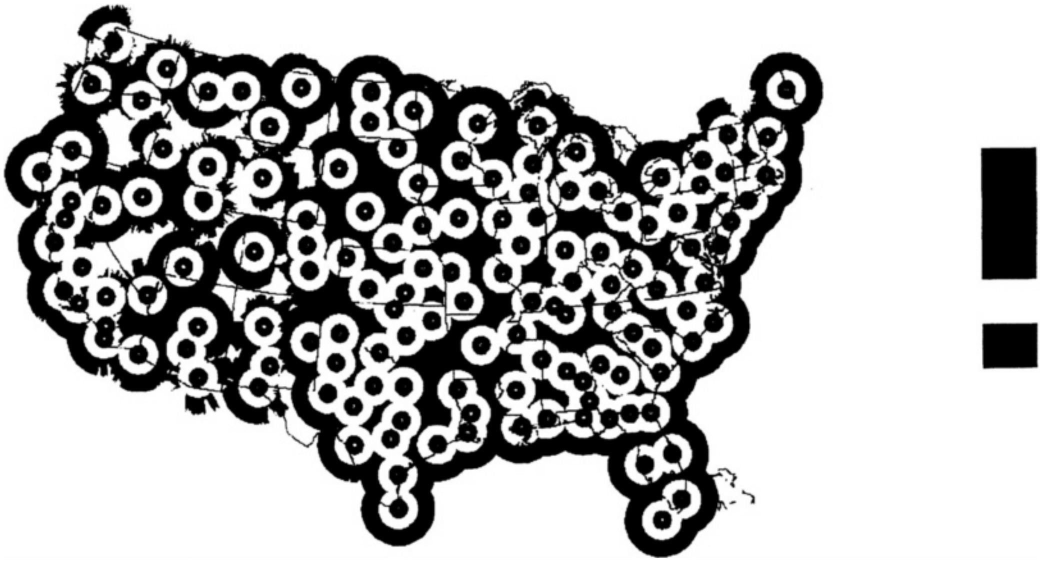


Figure A-5a NEXRAD resolution coverage at 10,000 ft above site level. Red depicts the area over which the beamresolution cell is less than 1 km; yellow, between 1 km and 2 km; and green, between 2 km and 4 km. Courtesy of SRI International.

Figure A-5b Areas of the contiguous United States and border regions having better resolution coverage at 10,000 ft above site level with NEXRAD (red), with equal resolution by pre-NEXRAD and NEXRAD networks (green), and with better resolution by the pre-NEXRAD network (blue). Courtesy of SRI International.

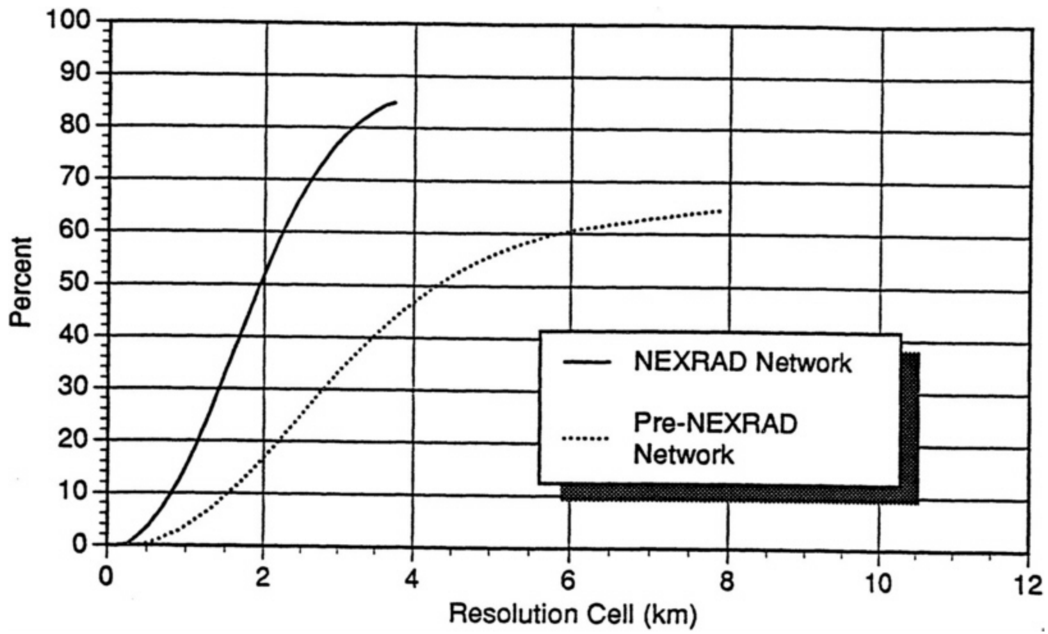


Figure A-6 Cumulative resolution distribution functions. The figure indicates the percentage of desired coverage area (contiguous United States plus bordering areas) at 10,000 ft above site level having resolution cell size smaller than that shown on the abscissa for pre-NEXRAD and NEXRAD networks. Courtesy of SRI International.

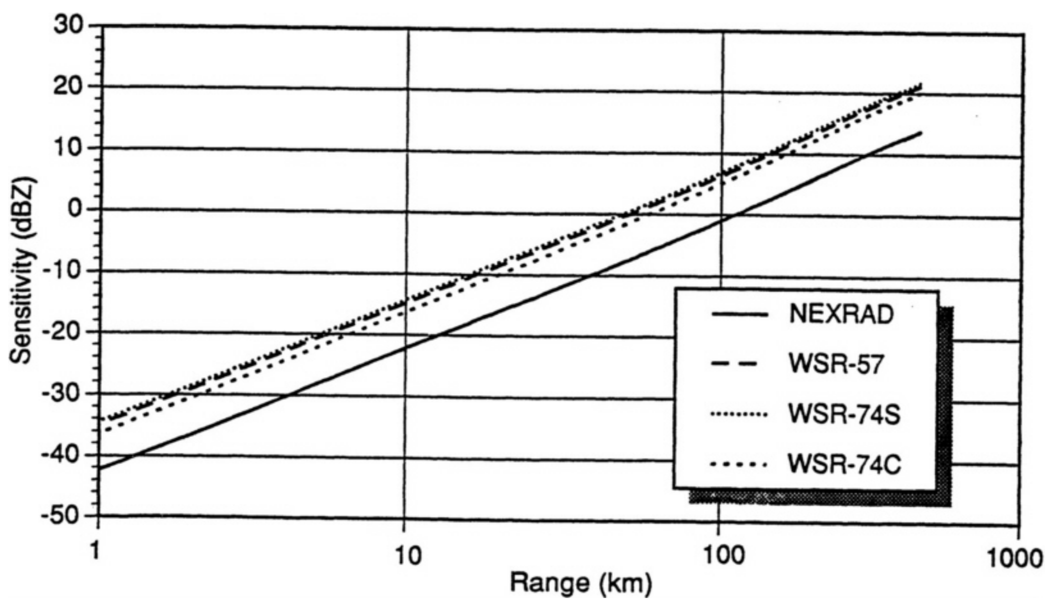


Figure A-7 Radar sensitivity curves showing reflectivity factor (dBZ) versus range for the single-pulse radar return power that yields equal signal and noise power, SNR = 1. (The sensitivity curves for the WSR-57 and the WSR-74S are nearly superimposed.) The processing gain to reduce the variance of base data reflectivity estimates is not shown in these curves. The NEXRAD value is based on the short-pulse mode; however, the NEXRAD long pulse increases sensitivity by 5 dB. Courtesy of SRI International.

only must the RDA, RPG, and PUP subsystems be available, but also the communication links among the three must be equally available for controlling the radar, requesting products, and receiving the base data and products. Important factors that impact system availability and reliability are

- availability of spare parts;
- responsiveness of parts distribution system;
- availability of qualified maintenance staff;
- maintenance education and training programs;
- availability of qualified radar meteorologists;
- radar operations education and training programs;
- reliable and effective communications to serve operations and maintenance activities; and
- adequate funding to support operations and maintenance activities.

Table A-3 gives availability statistics for the first 56 installed NEXRADs over a recent 27-month period, along with roughly comparable (and the best obtainable) statistics for the 3 pre-NEXRAD systems over the preceding 50 months. These initial availability data show that the NEXRAD systems are performing at the expected 96 percent availability level required for commissioning. The pre-NEXRAD systems indicate higher availability, but downtime for preventive maintenance, logistics delays, and system modifications was not included in the computation (such downtime data were never logged). This factor makes it difficult to provide a comparative assessment of network availability.

TABLE A-3 Weather Radar Availability Statistics

Radar	Availability (%)
NEXRAD	96.3 (does not include DoD radars)
WSR-57	98.5[a]
WSR-74S	98.2[a]
WSR-74C	99.1[a]

[a] Not considered reliable data or representative because outage times were not as rigorously defined nor adhered to in the pre-NEXRAD systems.

The availability of the DoD radars in the contiguous United States is important in considering NEXRAD network coverage and quality of services. Statistics on DoD radar availability were not available, but the panel received some reports of slow response in DoD maintenance of a DoD NEXRAD. The budgetary pressures on DoD, including possible base closings, raise additional concerns about availability of those NEXRADs. The possible impact of limited DoD NEXRAD availability has been addressed in this study by considering both the full NEXRAD network and a degraded network that includes only NWS NEXRADs when assessing the ability to detect certain weather phenomena.

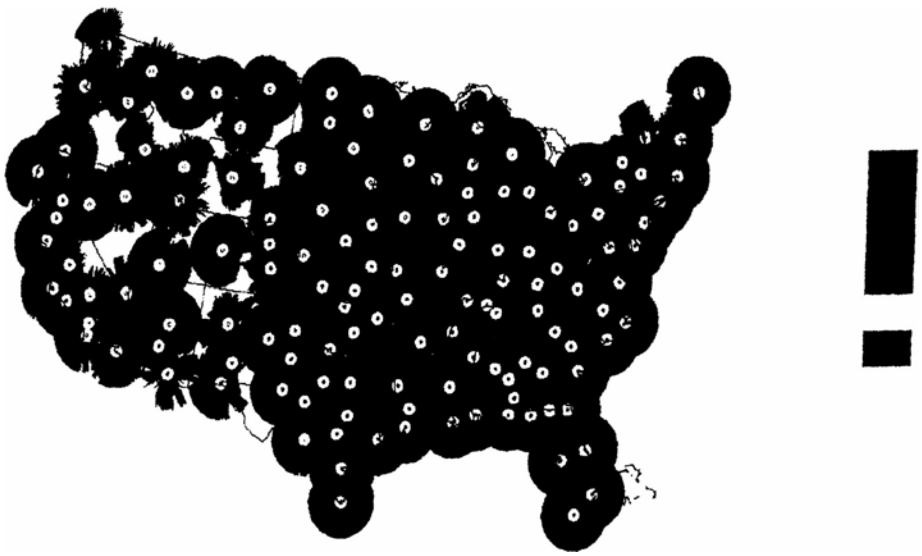


Figure A-8a NEXRAD sensitivity coverage at 10,000 ft above site level. The colors change in 10-dB increments, starting with the −30 dBZ to −20-dBZ increments as the initial sensitivity, which is shown as red (innermost concentric circle). Courtesy of SRI International.

Figure A-8b Comparative sensitivity of pre-NEXRAD versus NEXRAD network at 10,000 ft above site level. Red indicates that the NEXRAD network sensitivity is better; green indicates equal sensitivity; and blue indicates that the pre-NEXRAD network was more sensitive. Courtesy of SRI International.

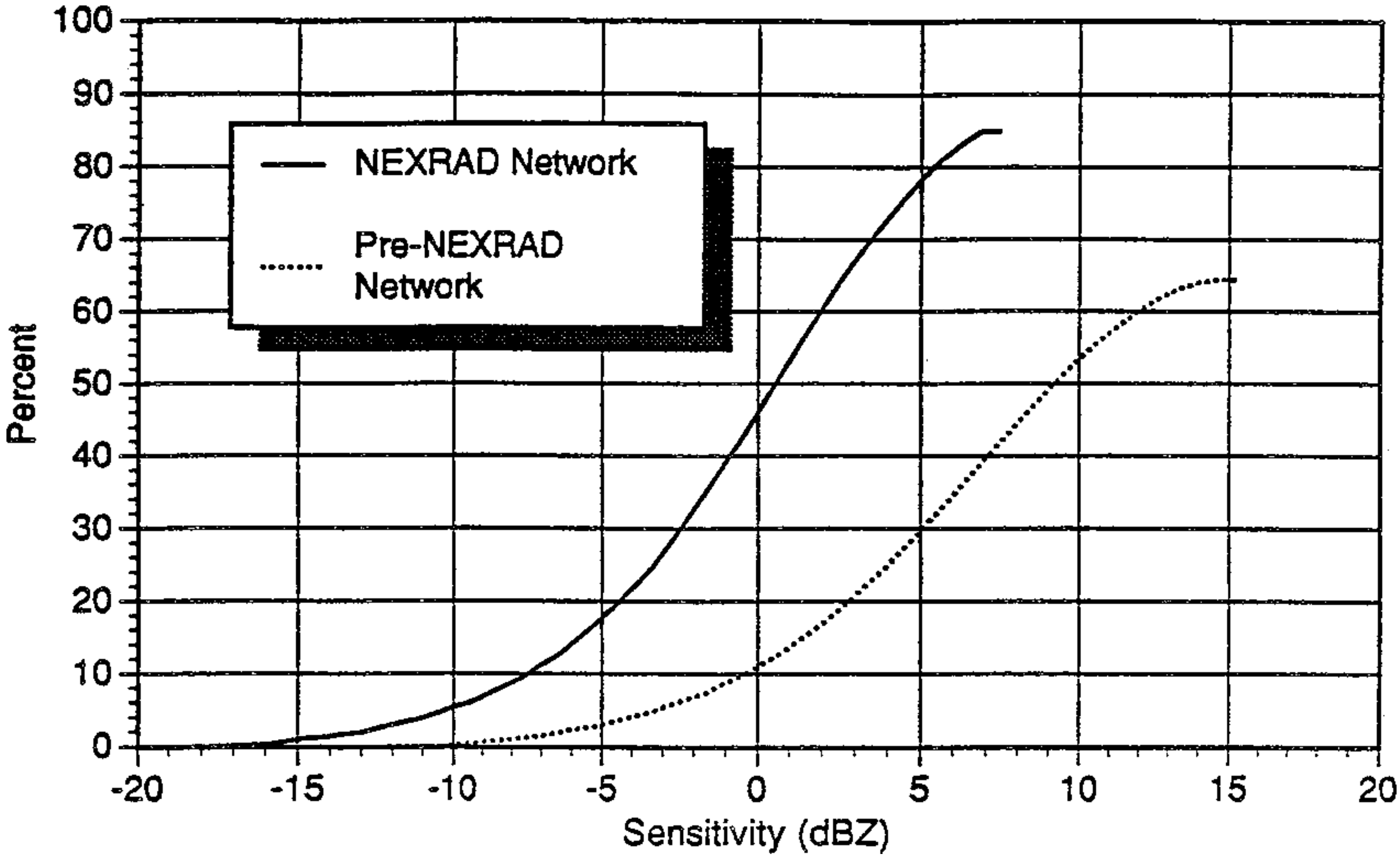


Figure A-9 Cumulative radar sensitivity distribution function. The figure shows the percentage of desired coverage area at 10,000 ft above site level having a minimum detectable reflectivity factor less than the sensitivity shown for both the pre-NEXRAD and NEXRAD networks. The median sensitivity is increased by about 10 dB with the NEXRAD network. Courtesy of SRI International.

NEXRAD Technical Improvements

There are a number of technical improvements in the NEXRAD system. Improvements have been made in terms of the transmitter and receiver, antenna, Doppler signal processing, and the digital information system. These technical improvements are discussed in the following sections.

Transmitter and Receiver

The NEXRAD transmitter is a phase-stable, high-power, klystron-based transmitter, in contrast to the lower-power magnetron systems of the pre-NEXRAD radars. The phase stability allows digital processing to improve the processing and display quality and to reject strong interfering clutter signals. The NEXRAD receiver uses modern low-noise amplification and wide-dynamic-range amplifiers to yield higher SNR signals from low-reflectivity weather targets even at distant ranges (Heiss et al., 1990).

Antenna

An important aspect of radar coverage is defined by the radar antenna beam pattern. The majority of the transmitted energy is radiated into a conical main beam about 1 degree wide. This beam width governs the resolution capability of the radar, except at very short ranges. However, a significant fraction of the energy is spread into the antenna "sidelobes" at angles outside the main beam. Typical azimuthal cuts of the antenna patterns for the NEXRAD and WSR-57 radars are shown in Figure A-10.

The early radars, particularly the WSR-57s, had antenna sidelobe levels so high that ground clutter often made short-range and low-altitude coverage virtually impossible unless the radar operator manually raised the antenna elevation enough to reduce the clutter. The WSR-57 antenna has sidelobes only about 18 dB down from the main lobe response (Wilk et al., 1965). Short-range and low-altitude coverage of the NEXRAD is improved by virtue of significantly better antenna sidelobe response and active clutter filtering in the radar processor. The NEXRAD has measured sidelobes down 29 dB from the main lobe response, using linear polarization with the radome in place (Sirmans, 1993). The much-improved sidelobe suppression provides an additional 20 dB (two way) of clutter suppression.

Doppler Signal Processing

Some weather radars, namely, the NEXRAD and three pre-NEXRAD systems with limited Doppler capability, measure the velocity of the weather target toward or away from the radar (i.e., the "radial velocity") in addition to measuring the reflectivity of the target. Knowledge of the radial-velocity characteristics of a weather target provides important assistance in recognizing and quantifying certain significant weather phenomena, such as tornadic storms, wind shear, or high surface winds with precipitation. This knowledge is also useful in general weather forecasting. Additionally, the Doppler feature provides vertical wind profiles and enables the radar to reject returns from stationary objects (i.e., "ground clutter") based on the radial-velocity information of the radar echo (*Federal Meteorological Handbook,* 1990).

The NEXRAD Doppler signal processor uses modern digital signal processing to compute accurate estimates of radar reflectivity and velocity while simultaneously suppressing interference and artifacts in the data, such as ground clutter. The WSR-57s and WSR-74s had no clutter-cancellation capability. The NEXRAD electronic clutter-cancellation feature reduces clutter by 30 dB in reflectivity mode. In Doppler mode, filters reduce clutter by 50 dB. Thus, including the 20 dB of additional clutter suppression through the reduction of antenna sidelobes, the NEXRAD gives about 50 to 70 dB of clutter suppression as compared with the WSR-57. This allows better coverage of the closest ranges, while suppressing isolated clutter, including much anomalously propagated ground clutter.

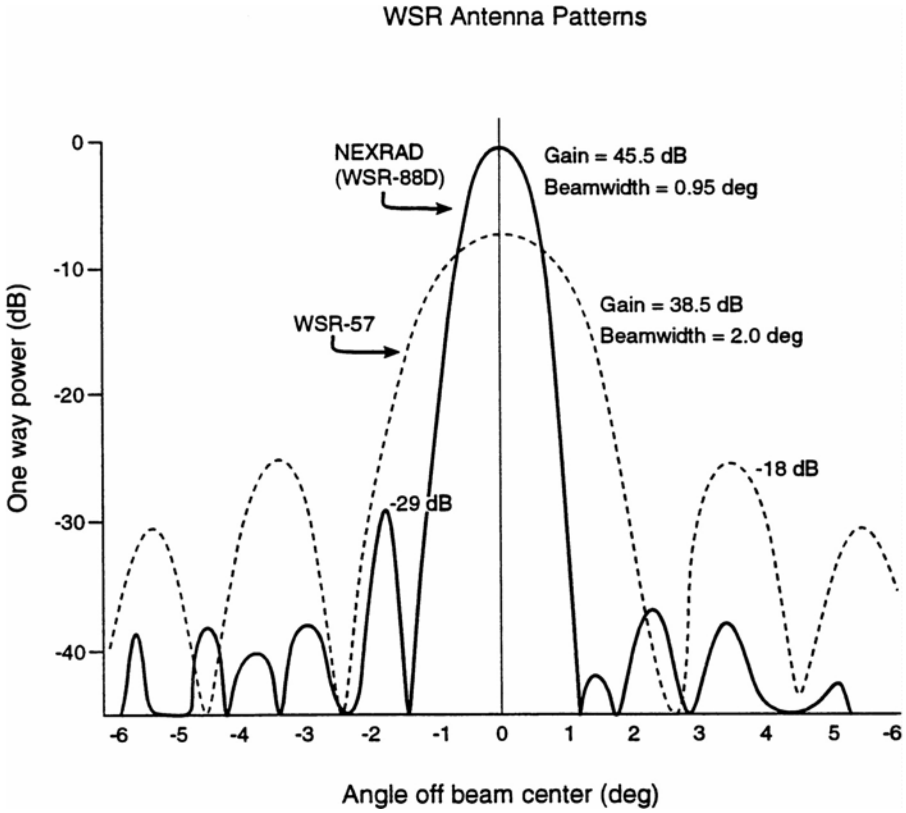


Figure A-10 Antenna radiation patterns (relative scale) showing main beam and first few sidelobes. The NEXRAD has a half-power beam width of 0.95 degrees while that of the WSR-57 is 2.0 degrees; the sidelobes of the NEXRAD are typically 10 dB lower than those of the WSR-57. The on-axis gain of the NEXRAD antenna is about 7 dB higher than that of the WSR-57. Based on data from Wilk et al., 1965 and Sirmans, 1993.

Digital Information System

The digital information system encompasses features that provide tools or capabilities for forecasters (Crum et al., 1993). They include the following:

- signal processing that provides digital or analog radar data from which weather products can be displayed or derived;
- algorithms that translate radar data into weather information—for example, radar reflectivity translated into rainfall rate and cumulative rainfall over some period of time, or reflectivity and velocity data combined in a hail detection and hail severity product;
- products that present this information in graphical image or alphanumeric format (Klazura and Imy, 1993);
- displays, which provide presentations of radar data and derived products; and
- data archiving (recording), which allows post-facto analysis to improve algorithms and products.

One technological advance incorporated into the NEXRAD systems is the provision of color displays. These displays enable the meteorologist to see informative images quantifying the weather conditions with the spatial and temporal resolution necessary to comprehend the mesoscale situation and the effects on local conditions. Moreover, the ability to make and view time-lapse imagery allows more accurate, targeted, and timely forecasts to be issued.

The NEXRAD automatically generates a specific list of products and distributes them to the associated PUPs without operator intervention. With these communications capabilities, the RPG can serve multiple users (multiple PUPs), meeting the specific needs of each. In addition, meteorologists can request additional products, which are produced by the RPG as processing time permits.

The Level 2 base data are the three quantities computed for each range bin of each radial of information: (1) the radar reflectivity factor (1-km resolution); (2) the velocity (at 250-m resolution); and (3) the spectrum width (at 250-m resolution). These base data are archived on 8 mm digital data tapes for later perusal and analysis by station meteorologists or the broader meteorological community in investigation of particularly interesting events. This can aid in developing new products, permit analysis of system performance, and serve as a climatological data base. New product development may require both full-range resolution reflectivity data (i.e., 250-meter spacing) and enhanced processing to improve the base data quality. The Level 3 product data are a subset of the various products. The data are routinely stored on disk for a relatively short period of time for later retrieval and analysis and are also archived for permanent record.

The NEXRAD network allows any given user to access data from radars in adjacent service areas. Furthermore, the four private NEXRAD information dissemination service data providers create national mosaics of NEXRAD products (Baer, 1991). These mosaics, because of their increased quantitative products, are superior to those provided through the pre-NEXRAD network.

WARNING PERFORMANCE

The issuance of weather advisories and warnings is supported by automated functions in the radar, however, it depends primarily on the expertise of well-trained forecasters. Evaluation of a system's warning performance is likewise partly objective and quantifiable and partly subjective and empirical. The panel has accounted for both the detection performance described above and the forecaster warning experience; taken together, they define the overall system performance. It is clear that the detection capability of the NEXRAD directly affects the warning performance. As such, both detection capabilities and warning performance represent the core of the most significant conclusions in this report and were used to develop assessment criteria for evaluating the potential degradation of service. The detection capability is discussed in detail in Chapter 2, “Radar Network Configuration and Detection Capabilities,” and in Chapter 3, “Comparison of Weather Services: Pre-NEXRAD and NEXRAD.”

PRODUCTS AND SERVICES OFFERED

Advisories and warnings of significant weather phenomena are relayed to the public and other users through a wide variety of specific products and services. These products and services are tailored to particular user communities (i.e., aviation, marine, agricultural, general public, etc.) and are disseminated through specific communications media (i.e., NOAA Weather Wire Service and Weather Radio, Federal Aviation Administration radio broadcasts, military meteorological offices, local radio and television stations, and private-service vendors). The warnings and advisories are also channeled to the "Family of Services" medium, which provides external user access to near real-time weather and hydrologic data and information through a dial-up service.

The NEXRAD network must be considered in the context of the modernized weather service, whereas the pre-NEXRAD radar network must be considered in the context of the former structure. The technical features of the NEXRAD allow the development and provision of new products and services that were, heretofore, unavailable. Many of the new NEXRAD products are available to users from the NEXRAD information dissemination service providers. The number and breadth of the automated products and forecasting aids have increased considerably, thereby adding to the complement of former products and services. Improvements in these radar products and services bring the overall NWS modernization another step closer to its goal of providing the nation with more timely and accurate warning of hazardous weather and flooding.

Appendix B

Documents Requesting NRC Study

Letter from Ronald H. Brown, Secretary of Commerce to Robert M. White, President, National Academy of Engineering

Letter from Ronald H. Brown, Secretary of Commerce to George E. Brown, Chairman, Committee on Science, Space and Technology

Letter from D. James Baker, Undersecretary for Oceans and Atmosphere to Robert E. Cramer, Congressman from Alabama

NOAA Study Guidelines. (Internal document to address congressional inquiries on NEXRAD Coverage.)

THE SECRETARY OF COMMERCE
Washington, D.C. 20230

AUG 18 1994

Dr. Robert M. White
President,
National Academy of Engineering 2101 Constitution Avenue, N.W. Washington, D.C. 20418

Dear Dr. White:

As we rapidly move to full modernization of the National Oceanic and Atmospheric Administration's National Weather Service, it is essential that we ensure that the deployment of the new technology (NEXRAD, GOES, etc.) continues to provide no degradation of service. As indicated in the enclosed letter to Chairman George Brown, a number of communities are concerned about their coverage.

The Chairman has asked that I commission an independent review to assess the adequacy of NEXRAD coverage from a scientific and technical standpoint, in terms of the “no degradation of service” requirement of the Weather Service Modernization Act, Public Law 102-567, and that the National academy of Science's National Weather Service Modernization Committee is the right group. I concur, and would like to use this letter to formally ask for the study. The contact point for the Department of Commerce on this topic will be D. James Baker, Under Secretary of Commerce for Oceans and Atmosphere.

We look forward to an expeditious review.

Sincerely,

Ronald H. Brown

THE SECRETARY OF COMMERCE
Washington, D.C. 20230

AUG 18 1994

The Honorable George E. Brown, Jr.
Chairman,
Committee on Science, Space, and Technology House of Representatives Washington, D.C. 20515-6301

Dear Mr. Chairman:

Thank you for your letter regarding adequacy of Next Generation Weather Radar (NEXRAD) coverage for the Nation. I share your confidence that the overall National Weather Service (NWS) modernization plan is sound. I, too, have heard from a number of communities concerned about the adequacy of NEXRAD coverage for their area. Many of these are from the areas listed in your letter.

I endorse your request that an independent review is needed to assess the adequacy of NEXRAD coverage from a scientific and technical standpoint, in terms of the "no degradation of service" requirement of the Weather Service Modernization Act, Public Law 102–567. I also agree that the National Academy of Sciences' National Weather Service Modernization Committee (NWSMC) is the appropriate body to conduct this assessment. D. James Baker, Under Secretary of Commerce for Oceans and Atmosphere, has already had preliminary discussions with the Academy and its NWSMC. He has informed me that the Academy is prepared to undertake the study and is ready to move expeditiously. Therefore, I will formally ask them to conduct the study.

Your interest in the NWS is appreciated.

Sincerely,

Ronald H. Brown

UNITED STATES DEPARTMENT OF COMMERCE
The Under Secretary for
Oceans and Atmosphere
Washington, D.C. 20230

October 5, 1994

The Honorable Robert E. Cramer
House of Representatives Washington, D.C. 20515

Dear Congressman Cramer:

As a result of our discussion in Vice President Gore's Office about HR 4998, the Weather Service Modernization Performance Review Act of 1994, I have reviewed the National Oceanic and Atmospheric Administration's (NOAA) actions as it moves ahead with the modernization of the National Weather Service. As I told you, I am confident that NOAA is proceeding in a manner that fully complies with the requirements of the Weather Service Modernization Act. I am also confident that, when the process is complete, the Nation will have the most efficient and effective Weather Service in the world.

However, you and representatives from some other areas are concerned that weather coverage in the future will not meet the requirements of the law. You have requested an independent assessment to ensure that this does not occur, particularly as we decommission outmoded radars and eventually consolidate some local offices into the fully modernized offices of the future.

I am pleased that we have been able to work with you to develop a mechanism to provide an independent scientific assessment of NEXRAD coverage in the modernized Weather Service. We have also agreed on a procedure to establish the criteria necessary to assure that weather services will not be degraded as we decommission obsolete radars, and to provide the public with an opportunity to participate in the process.

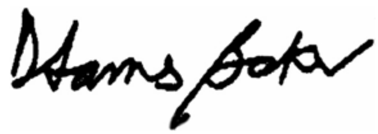
Sufficient time no longer remains in this Congress to enact legislation. However, I am convinced that application of the procedures we discussed will achieve our goals of assuring the public that no one will be put at risk of degraded weather services as modernization proceeds, while minimizing any resultant delay in the modernization process which is so

THE ADMINISTRATOR

essential to public safety. Therefore, we will put into place the procedures contained in the enclosed document. This will put into effect our discussions without the need for legislation.

Implementation of these procedures will instill public confidence in the modernization process and thereby contribute significantly to the national interest. Thank you for your participation in this effort.

Sincerely,



D. James Baker

Enclosure

STUDY GUIDELINES

(This is an internal NOAA document)

Section 1:

(a) Modernization of the NWS is essential to public safety and should proceed without unnecessary delay.
(b) The WSMA establishes procedures that assure that the modernization of the NWS will not result in the degradation of weather service currently provided to the public but these procedures do not provide for the independent review of decisions until shortly after the actual event; and
(c) It is appropriate to review the adequacy of the nation's overall NEXRAD coverage, to ensure a solid scientific and technical basis for the decision making process, and to assure meaningful participation by the public.

Section 2:

The purposes of this document are to provide the fullest opportunity for public participation in the modernization process without unduly delaying this process: and to ensure, through the application of independent scientific criteria that weather services provided in each service area will not be degraded as obsolete radars are decommissioned or as field offices are closed, consolidated, relocated or automated.

Section 3:

The definitions contained in Section 702 of the WSMA shall apply to the terms in this document. In addition, the term “area of concern” means a service area identified in a timely public comment in response to the Federal Register notice required by section 4 of this document.

Section 4:

Within 30 days the Secretary shall publish a notice in the Federal Register requesting comments on service areas where it is believed that current weather services may be degraded as existing radars are decommissioned or as field offices are closed, consolidated, automated or relocated. The notice shall allow 60 days for the submission of comments. Persons submitting comments shall state the basis for their belief as fully as possible, and shall include a description of local weather characteristics (including unique weather phenomena) and weather related concerns which involve a substantial threat to public safety which they believe affect the weather services provided in areas of concern. All comments received by the Secretary shall be provided promptly to the NRC.

Section 5:

(a) Within 30 days the Secretary shall contract with the NRC, or amend an existing contract as necessary, to conduct an independent scientific assessment of proposed NEXRAD radar coverage and consolidation of Field Offices in terms of “no degradation of services” and to establish criteria for identifying service areas where the decommissioning of existing radars could degrade service to affected users.
(b) Within 180 days, but not earlier than 60 days after the close of the comment period provided in the Federal Register notice of section 4, the NRC shall furnish to the Secretary the assessment and criteria required by subsection (a) together with recommendations regarding the need and timing for any future independent studies by the NRC.

Section 6:

(a) After receipt of the NRC report, the Secretary shall apply the NRC criteria and other applicable criteria previously approved by the NRC pursuant to the WSMA to areas of concern and, taking into account the comments received in response to the Federal Register notice of section 4, identify those where he/she believes that actions to decommission a radar or to close, consolidate, relocate, automate a field office noted in the current version of the NIP are not likely to satisfy the requirements of the WSMA. The Secretary shall report the results of his/her review to the Committee on Commerce Science and Transportation of the Senate and the Committee on Science, Space and Technology of the House of Representatives. If the Secretary believes that additional radars are needed to satisfy the requirements of the WSMA, he/she shall also identify the number and location of the radars needed.

(b) Submission of a report under this section shall not relieve the Secretary from the requirement of section 706(b) of the WSMA to certify no degradation of service when she/he restructures a field office. If the field office is located in an area of concern, the Secretary shall provide all comments relating to that area of concern received pursuant to section 4 to the MTC during the certification process.

Section 7:

(a) The Secretary shall not close, consolidate, relocate, or automate any field office or decommission any NWS radar until the public has had an opportunity to identify areas of concern.

(b) Regardless of the contents of the most recent NIP, the Secretary shall not decommission a radar or close, consolidate, automate or relocate a field office in an area of concern unless-

(1) The Secretary has reported to the Congress as provided in section 6 that he/she believes that the action contemplated would not result in a degradation of service: and

(2) 30 days have expired from the date the report was submitted to Congress.

Appendix C

National Research Council's Statement of Task for the Panel on the Adequacy of NEXRAD

Based on tasking from the Department of Commerce to the National Academy of Sciences/National Academy of Engineering, the National Weather Service Modernization Committee's Panel on the Next Generation Radar (NEXRAD) of the National Research Council will:

Examine and assess the adequacy of NEXRAD coverage for the nation from the scientific and technical standpoint, in terms of the “no degradation of service” requirement of the Weather Service Modernization Act, October 1992. As defined by section 702 (4) of Public Law 102-567, “degradation of service means any decrease in or failure to maintain the quality and type of weather services provided by the National Weather Service to the public in a service area, including but not limited to a reduction in existing weather radar coverage, at an elevation of 10,000 feet.”

Subtasks:

A. Review the specifications of the NEXRAD and NEXRAD network coverage.
B. Examine the performance of the operational NEXRADs in relation to their coverage and their ability to detect significant weather.
C. Establish criteria for evaluating the adequacy of coverage of the pre-NEXRAD and the proposed NEXRAD network and areas for decommissioning of existing radars.
D. Examine and evaluate the adequacy of coverage of the pre-NEXRAD network and the proposed NEXRAD network.

The findings and recommendations will be provided in a report targeted at the leadership of NWS, NOAA, and DOC, as well as at Congress and others.

Appendix D

Drawings and Descriptions of Weather Phenomena

The following drawings illustrate weather phenomenon features and, where applicable, show typical reflectivity patterns as displayed on weather radars. The drawings are listed in the order that weather phenomena are presented in Table 2-1 and Table 2-2.

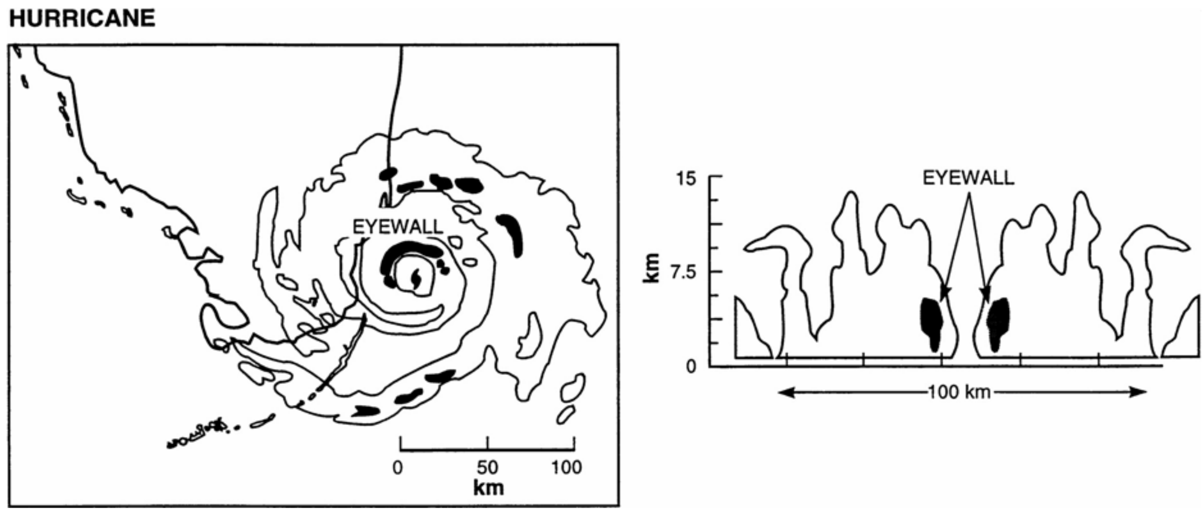


Figure D-1 The hurricane eye wall. This is the area of tall cumulonimbus storms surrounding the eye of the storm. Heavy rain and very high winds occur in the eye wall. The “eye of the storm” (hurricane, typhoon) is the roughly circular area of comparatively light winds and fair weather found at the center of a severe tropical cyclone. Based on data from Marks, 1990.

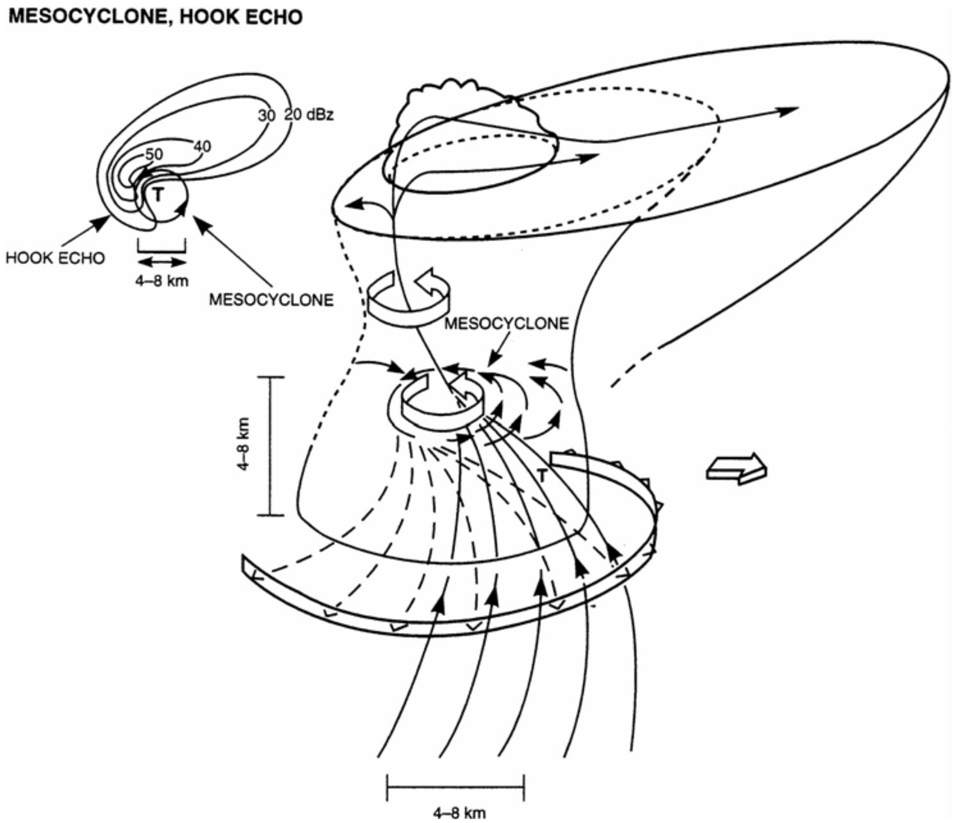


Figure D-2 Mesocyclone and hook echo. The mesocylone is a horizontal atmospheric rotation on a scale between 4 km and 400 km (Fujita, 1981). The hook echo is a pendant, curved-shaped region of reflectivity caused by precipitation being drawn into the cyclonic spiral of a mesocyclone (Davies-Jones, 1985). The hook echo is a fairly shallow feature, typically extending only up to 4 km in height.

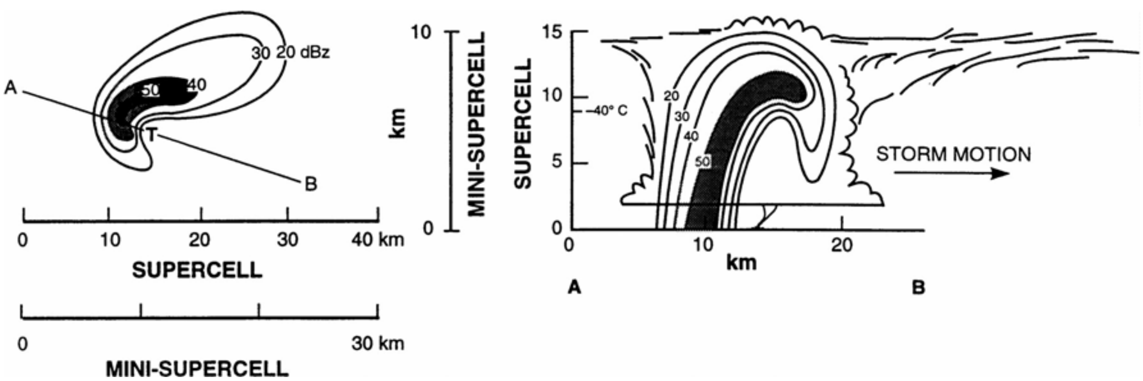


Figure D-3 Supercell and mini-supercell. The supercell is potentially the most dangerous convection storm type. The supercell may produce high winds, large hail, and long-lived tornadoes over a wide path. In its purest form the supercell consists of a single quasi-steady, rotating updraft that may have a lifetime of several hours (Weisman and Klemp, 1986). The radar-identified rotation typically has a diameter of 4 km to 12 km. The mini-supercell contains similar severe weather characteristics but the storm is significantly smaller in height and width. The diameter of the radar-detected rotation is 1 km to 8 km. This is a relatively new storm type whose existence has been confirmed by data from the new Doppler radars in the eastern half of the United States. Differentiating on a scale is useful here because of the greater difficulty in detecting these smaller rotations. Based on data from Burgess and Lemon, 1990; Davies-Jones, 1985.

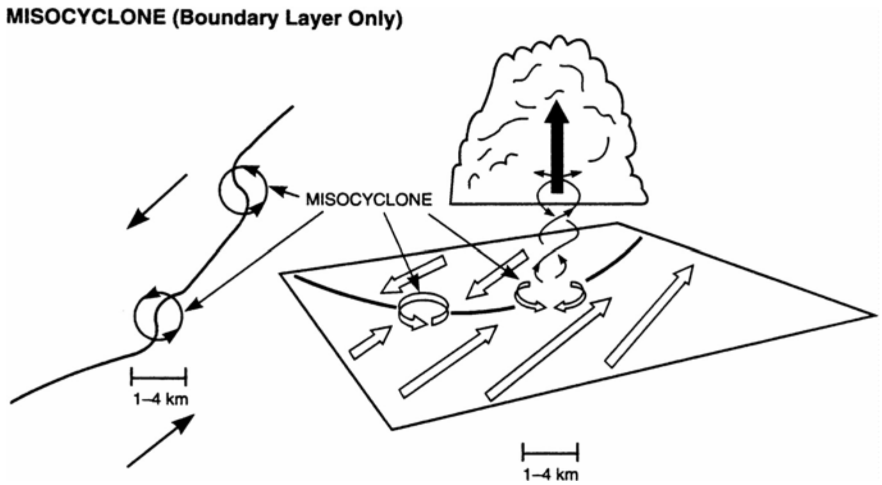


Figure D-4 Misocyclone. The misocyclone is a horizontal atmospheric rotation on a scale between 40 m and 4 km. Based on data from Wakimoto and Wilson, 1989; Fujita, 1981.

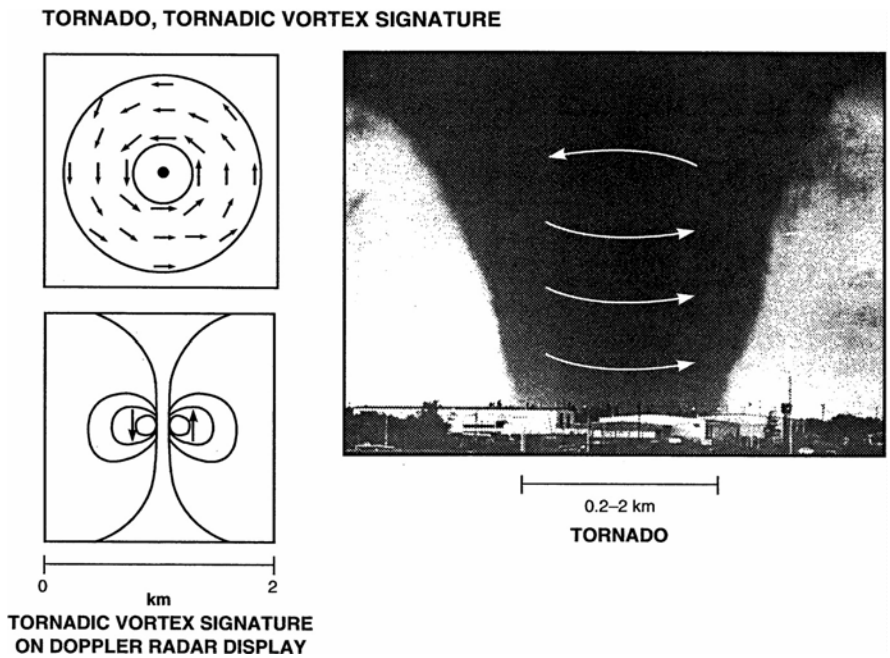


Figure D-5 Tornado vortex signature (TVS). The TVS is a Doppler velocity signature sometimes produced by a large, intense tornado at close range. The signature is a very strong azimuthal shear in a distance < 2 km. Based on data from Brown and Wood, 1987; Simon, 1988.

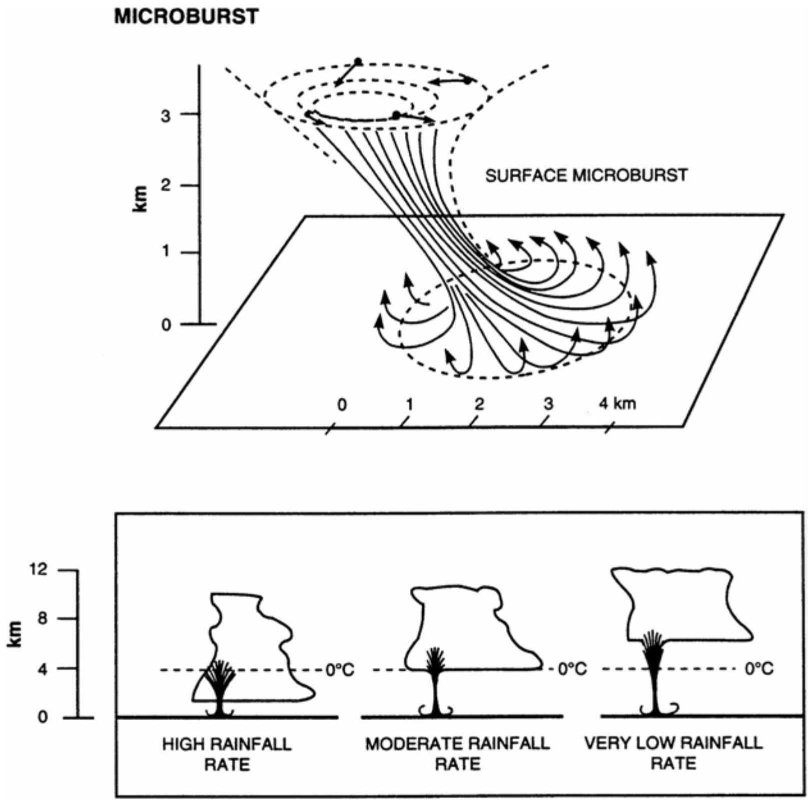


Figure D-6 Microburst. The microburst is a strong down draft that induces an outburst of damaging winds on or near the ground. Damaging winds, either straight or curved, are highly divergent. The damaging winds extend over an area of less than 4 km and typically last only a few minutes. This scale of diverging winds has been found to be particularly hazardous to aircraft landing or taking-off. Microbursts can be associated with widely varying surface rainfall rates. Based on data from Fujita, 1981, 1985.

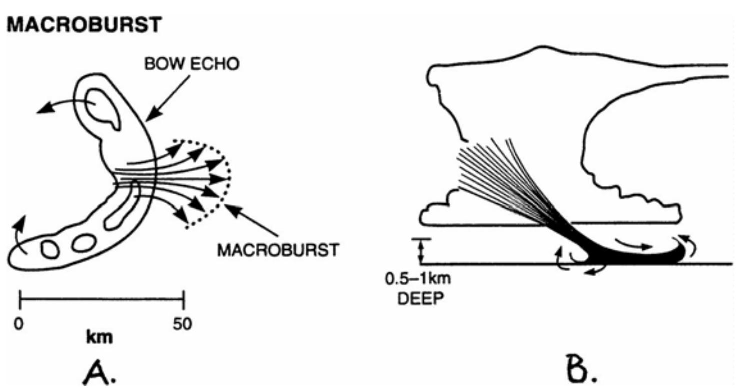


Figure D-7 Macroburst. The macroburst is similar to the microburst except the damaging winds extend over an area greater than 4 km and may last for tens of minutes. The term “downburst” includes both microbursts and macrobursts without reference to scale.

Side A. Reflectivity signature—Several reflectivity patterns have been associated with macrobursts. One of the most common is the “bow echo” (depicted on the left side of the figure), or region in a line of thunderstorms that bulges ahead of the line, and is associated with damaging surface winds, and occasionally tornadoes.

Side B. Velocity signature—The velocity signature of a macroburst shows a broad pattern of approaching and receding velocities associated with the strong divergent storm outflow, depicted on the right side of the figure. Based on data from Fujita, 1981, 1985.

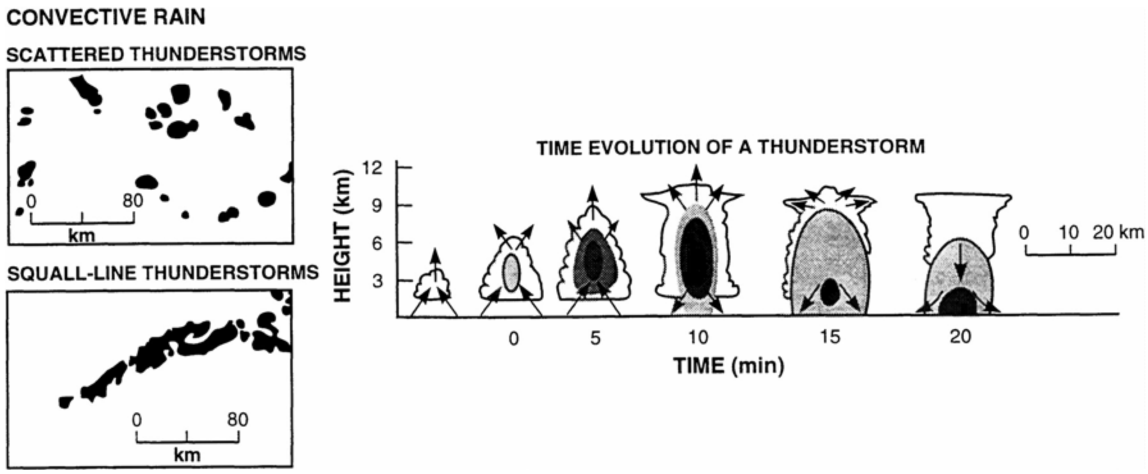


Figure D-8 Convective rain. Convective rain is associated with convective clouds or cumuliform clouds characterized by vertical development in the form of rising mounds, domes, or towers. Based on data from Byers and Braham, 1949; Burgess and Lemon, 1990.

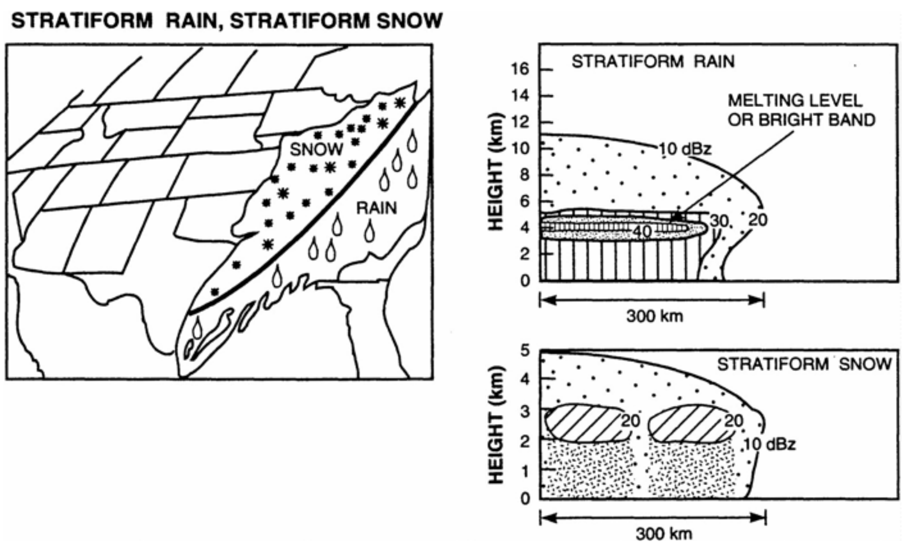


Figure D-9 Stratiform rain. Stratiform rain is horizontally widespread in character, typically associated with macroscale fronts and pressure systems. Stratiform snow has the same features as stratiform rain except precipitation is in the form of snow. Based on data from Weber and Wildrotter, 1981; Marks, 1990.

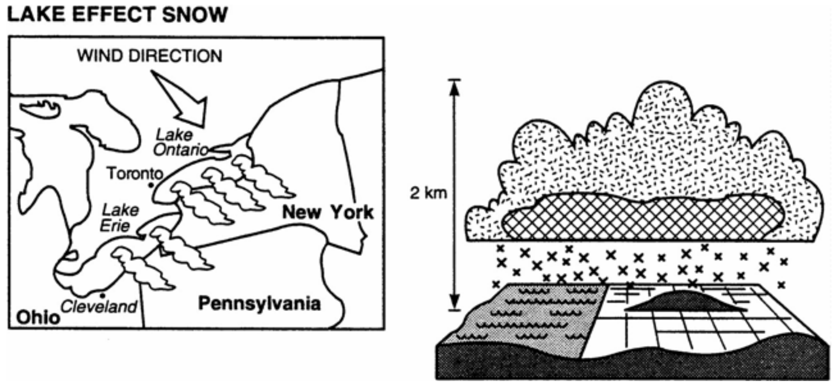


Figure D-10 Lake-effect snow. Lake-effect snow is localized snow that occurs over and in the lee of lakes. Lake-effect snow is caused by relatively cold air flowing over warm water. In the United States, this phenomenon is most noted along the south and east shores of the Great Lakes during arctic cold-air outbreaks.

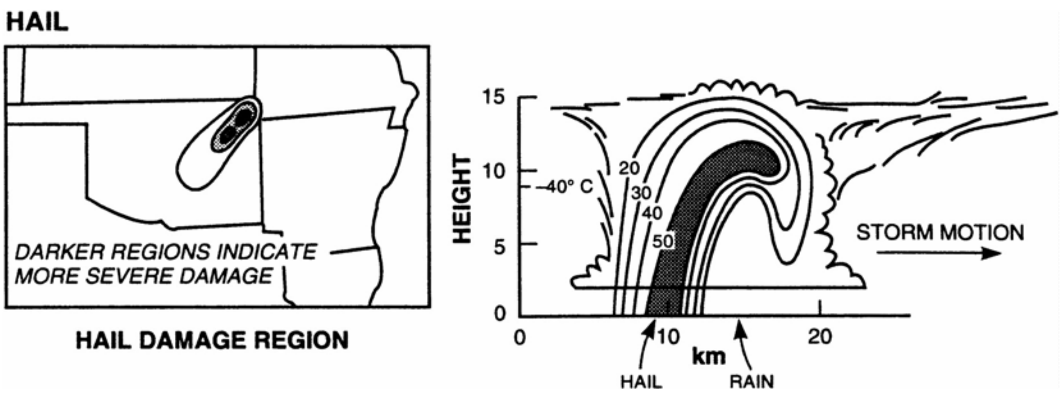


Figure D-11 Hail. Hail is precipitation in the form of balls or irregular lumps of ice that is always produced by convective clouds, nearly always cumulonimbus. An individual unit of hail is called a hailstone. By convention, hail has a diameter of 5 mm or more, while smaller particles of similar origin may be classed as ice pellets or snow pellets. The figure on the left shows a large hail damage region, and the figure on the right shows a vertical cross-section of the hail shaft in a supercell storm. Based on data from Burgess and Lemon, 1990.

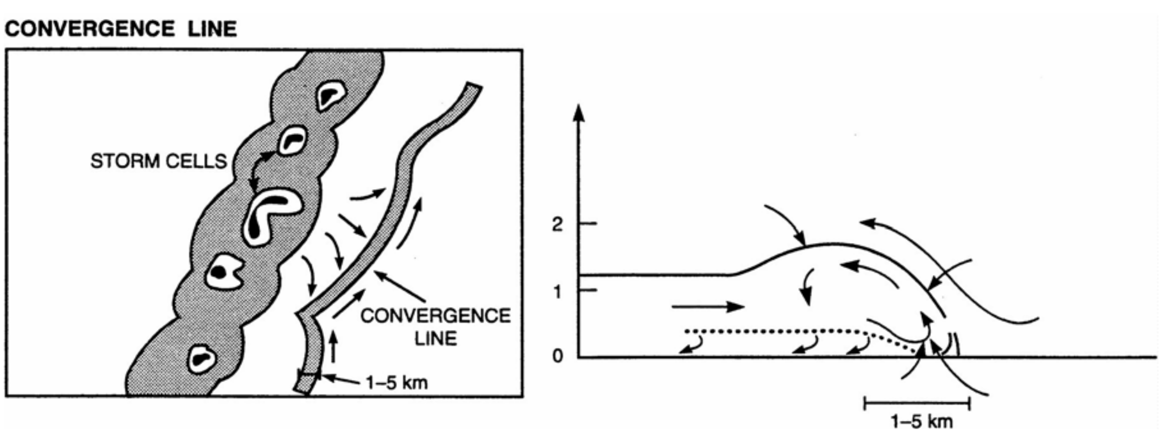


Figure D-12 Convergence line. The convergence line is a horizontal line along which horizontal convergence of the air flow is occurring. Common forms of convergence lines are sea-breeze fronts, cold-air outflows from thunderstorms, and macroscale fronts. The left side of the figure shows a convergence line ahead of a line storm caused by the pooled cold-air outflow from many storm cells in the line. The figure on the right shows a vertical cross-section of the leading edge of the convergence line. Based on data from Klingle et al., 1987.

Appendix E

Reviewers and Contributors to Detection Table 2-1 and Table 2-2

Ahnert, Peter	WSFO, Binghamton, NY
Allen, Steve	WSFO, Houston, TX
Atlas, Dave	NASA
Brady, Ray	WSFO, Binghamton, NY
Brandes, Edward	NCAR, Boulder, CO
Brown, Rodger	NSSL, Norman, OK
Burgess, Donald	OSF, Norman, OK
Carbone, Richard	NCAR, Boulder, CO
Eilts, Mike	NSSL, Norman, OK
Elvander, Bob	JSPO, Washington, DC
Elder, Dick	WSFO, Wichita, KS
Forbes, Greg	Pennsylvania State University, State College, PA
Forsyth, Doug	NSSL, Norman, OK
Goodman, Steve	NASA/Marshall, Huntsville, AL
Hagemeyer, Bart	WSFO, Melbourne, FL
Hedges, Jeff	WSFO, Wichita, KS
Imy, David	WSFO, Denver, CO
Johnston, Stephen	Baron Services Inc., Huntsville, AL
Lee, Alan	WSFO, Little Rock, AR
Lemon, Les	UNISYS
Mooney, Larry	WSFO, Denver, CO
Pettit, Paul	WSFO, Montgomery, AL (retired)
Pfost, Rusty	WSFO, Jackson, MS
Powell, David	NWS Employees Organization (President)
Przybylinski, Ronald	WSFO, St. Charles, MO
Rinehart, Ronald	University of North Dakota
Ruthi, Larry	WSFO, Norman, OK
Smith, Jim	Princeton University
Stewart, Mike	WSFO, Wichita, KS
Wakimoto, Roger	UCLA, Los Angeles, CA
Waldstreicher, Jeff	WSFO, Binghamton, NY
Walton, Mark	WSFO, White Lake, MI
Wagner, Tice	WSFO, Jackson, MS
Wilken, George	WSFO, Little Rock, AR
Zrnic, Dusan	NSSL, Norman, OK

Appendix F

Distance of Old Radar from Nearest NEXRAD in Descending Order by Distance

Location of Old Radar	Distance to Nearest NEXRAD (km)	Location of Old Radar	Distance to Nearest NEXRAD (km)
Williston, ND	207	Pensacola, FL	96
Alliance, NE	186	Waycross, GA	96
Chattanooga, TN	183	New York City, NY	95
Fort Wayne, IN	170	Alpena, MI	93
Huntsville, AL	164	North Platte, NE	92
Erie, PA	153	Stephenville, TX	92
South Bend, IN	147	Limon, CO	91
Fort Smith, AR	143	Cincinnati, OH	83
Waterloo, IA	142	Charleston, SC	80
Evansville, IN	140	Columbus, GA	79
Columbia, MO	134	Fargo, ND	79
Cape Hatteras, NC	133	Beckley, WV	79
Victoria, TX	133	Los Angeles, CA	78
Athens, GA	132	Longview, TX	77
West Palm Beach, FL	129	Grand Island, NE	73
Baton Rouge, LA	128	Worcester, MA	70
Apalachicola, FL	127	Kansas City, MO	69
Meridian, MS	126	Garden City, KS	68
Daytona Beach, FL	125	Madison, WI	68
Charlotte, NC	123	Akron, OH	66
Huron, SD	120	Muskegon, MI	64
Bristol, TN	119	Montgomery, AL	63
Norfolk, NE	115	Wichita Falls, TX	63
Harrisburg, PA	115	Savannah, GA	61
Volens, VA	114	Houghton Lake, MI	61
Concordia, KS	109	Monett, MO	59
Hondo, TX	109	Tupelo, MS	57
Hartford, CT	106	Wilmington, NC	57
Rochester, MN	105	Atlantic City, NJ	57
Patuxent River, MD	104	Marseilles, IL	56
Chatham, MA	103	Austin, TX	56
Columbus, OH	103	Centreville, AL	54
Augusta, GA	102	Detroit, MI	54
Waco, TX	100	Topeka, KS	53
		Las Vegas, NV	49

Neenah, WI	47
Springfield, IL	44
Abilene, TX	42
Tucson, AZ	39
Phoenix, AZ	37
Raleigh, NC	37
Atlanta, GA	36
Galveston, TX	34
Tulsa, OK	31
Portland, OR	31
Oklahoma City, OK	30
Louisville, KY	29
Omaha, NE	29
Macon, GA	28
Portland, ME	27
Minneapolis, MN	27
Albany, NY	27
Memphis, TN	25
Des Moines, IA	23
Rapid City, SD	21
Moline, IL	19
Sacramento, CA	18
Miami, FL	18
St. Louis, MO	14
Charleston, WV	13
Slidell, LA	10
Billings, MT	8
Key West, FL	7
Burlington, VT	5
Brownsville, TX	3
Paducah, KY	2
Lake Charles, LA	2
Shreveport, LA	2
Buffalo, NY	2
Lubbock, TX	2
San Angelo, TX	2
Indianapolis, IN	1
Goodland, KS	1
Duluth, MN	1
Columbia, SC	1
Corpus Christi, TX	1
Mobile, AL	0
Little Rock, AR	0
Tampa, FL	0
Wichita, KS	0
Jackson, KY	0
Marquette, MI	0
Jackson, MS	0
Missoula, MT	0
Bismarck, ND	0
Binghamton, NY	0
Cleveland, OH	0
Medford, OR	0
Pittsburgh, PA	0
Sioux Falls, SD	0
Nashville TN	0
Amarillo, TX	0
Midland, TX	0
Cheyenne, WY	0