Millersville University

NEXRAD Radar Gaps and Impact on Meteorology and Emergency Management Response

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By

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ABSTRACT

The NEXRAD radar network is the backbone of the National Weather Service's (NWS) weather surveillance methods in the United States. Everyone in the United States relies on this information on a daily basis for predictions and decision making. Certain areas of the of the United States, such as La Plata County, Colorado, Charlotte, North Carolina, Schuylkill County, Pennsylvania do not have satisfactory radar coverage from the NWS radar network, and currently some of these gaps, in addition to others across the country, are only being addressed by private companies installing other types of radars. The gaps in these locations have an impact on the severe weather operations for both meteorologists and emergency managers, especially during the forecast and decision support stages. This includes identifying and examining these areas helps determine the significance of these radar gaps, then surveying the opinions and experiences of professionals in these areas when it comes to adequate performance using other tools. Using sample case studies and brief surveys of meteorologists and emergency managers in three specific regions with radar gaps will provide valuable insight into the importance of radar operations and viable alternative methods. Using this information, suggestions for future radar networks can be explored while examining the current technology and NWS plans.

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1. INTRODUCTION

The NEXRAD (Next Generation Weather Radar) Network is the backbone of the National Weather Service's (NWS) efforts to inform and warn the public about severe weather conditions. People across the United States rely on NWS data including but not limited to climatology and severe weather reports, current weather conditions, and radar imagery. The reliance on these radar systems goes one step further when factoring in the large number of private sector companies that rely on NWS radar data to inform and deliver customized information to their clients. Thus, it is critical that the NWS should remain as the foremost authority, leading the way with innovative technology and extensive coverage for any who rely on their data, but this is easier said than done.

The National Weather Service is challenged to remain up to date with the impacts of changing weather extremes and advancements in technology. Certain areas of the of the United States, like southwest Colorado, southwest North Carolina, and southeast Pennsylvania do not have satisfactory radar coverage through the NWS radar network. Instead of being at the forefront of innovation pushing forward to alleviate these radar gaps, the NWS has to go through approval processes that take time. In the meantime, the NWS is focused on extending the life of their aging fleet of radars while communities look into other options such as private sector companies to provide them with X-band radars that might bring some benefit but certainly are not perfect replacements for S-band radars from the NWS.

However, the question is whether the perceived impact these radar gaps have on severe weather operations translate to a noticeable impact in reality. Professional meteorologists and emergency managers in areas with radar gaps have additional challenges with limited radar data and shorter lead times, but the benefit of professional experience or additional products in the absence of this data likely limits the negative impacts. Because radar gaps only impact specific areas of the county, focusing uniquely on these specific areas will bring attention to key issues affecting these communities. By studying these areas through focused case studies of events and gathering information from professionals who work in these regions, a better understanding of the impacts can be found, leading to improved well-informed predictions and decisions.

This study intends to determine the impact of radar gaps on the services that both meteorologists and emergency managers provide to their communities inside these selected regions. This research will focus on La Plata County, Colorado, Charlotte, North Carolina, and Schuylkill County, Pennsylvania. Three severe weather events; blizzards, tornadoes, and snow squalls, will be analyzed using GR2 Analyst 3 to view archived radar products from the nearest NWS radar to determine how professionals manage the lack of data in these radar gaps. Survey results will be gathered from meteorologists, both at the nearest NWS office and local broadcast stations, and emergency managers, to gain a valuable cross section in the responsibilities and experiences faced by public and private sectors. The study will conclude with recommendations on future implementation of radar technology based on the current future plans of the NWS.

2. BACKGROUND

To best understand the current NWS radar network, and the history of weather radars, it helps to explain the developments leading to today's radar technology. The history of radar technology originated during World War II as it became increasingly important in military applications. Great Britain was the first nation to experiment with radars, and they likely saw their first weather signature by late 1940. However, this was seen as an inconvenience to the detection of military aircraft (Whiton et al., 1998a). As early as 1943, many terminal and defense radars were used for weather experimentation whenever doing so did not conflict with their main objective. In the same year, scientists from MIT's Rad Lab, the hotspot of American radar technology, often visited these early sites to determine impacts of the atmosphere on radar and their applications (Whiton et al. 1998a).

By 1947, the United States Army enforced the research mission: "if in the conduct of operations, it was found necessary to advance the state of meteorological knowledge or engineering practice or develop new techniques to apply that knowledge to customers' weather support problems, the on-site personnel often had the education, training, and ability to do so locally" (Whiton et al., 1998a). This method of utilizing radar technology is still in effect today as seen in the staffing at each NWS office where the ability to maintain, repair, and interpret radars and their products happens at the local level with additional assistance and standards passed down from the national level when required or requested.

After World War II, design began on a new radar system specifically built for weather observation, but until its completion, military radars were all that existed, and the APQ-13, a bombing and navigation system for United States bombers (Whiton et al., 1998a), was found to perform the best for weather applications. At the height of their use, over 60 were in operation by the Army Weather Service until the last one was removed from service in October 1977. Meanwhile, the Weather Bureau acquired 25 AN/APS-2F radars from the navy, rebranded them WSR -1, -1a, -3, -4 series systems, and began putting them into service with the first introduced in Washington, D.C. in March 1947 (Whiton et al., 1998a). These early radar networks not only showed the vast resources that would be needed to build a viable radar network but also the possible benefits that such a network would provide.

By early 1954, the intent of weather radar from a civilian standpoint began to drastically change compared to military needs. Therefore, it was important to choose a radar specifically for meteorological use. After several years of designing and testing, the AN/CPS-9, an X-band radar with a one-degree beamwidth and a 5-microsecond pulse duration (Whiton et al., 1998a), was determined to be most suitable. These specifications were ideal for identifying hydrometers and after several years of upgrades would provide critical information on synoptic-scale systems, cloud systems, and early short-range forecasting (Whiton et al., 1998a).

The impacts of Hurricanes Carol and Edna in 1954 helped pave the way for congressional funding for a new radar system in the early 1950s named the WSR-57. Learning from previous shortcomings, this radar would be an S-band radar which would limit the early problem of rainfall attenuation. A large antenna helped provide a two-degree beamwidth, a fiberglass radome for continuous operation, and an adjustable step attenuator which allowed for changes to signal strength that greatly improved the capabilities of this system (Whiton et al., 1998a). These advancements helped view features behind intervening rainfall including tornado signatures such as hook echoes and hurricanes at far distances, which was considered a priority for funding. Between the radome and backup power supplies, the NWS finally had radars that could be operated not just before but during severe weather events. At this time, the radar still provided no velocity data, moving parts experienced

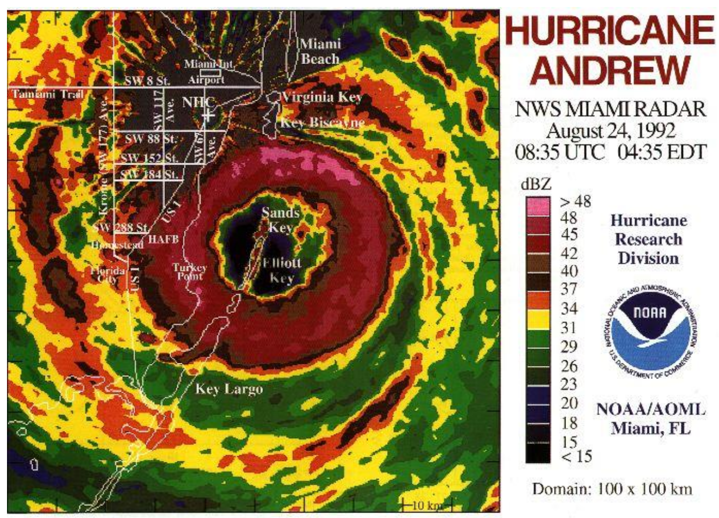


Figure 1: Last radar scan by the WSR-57 radar atop the NHC in Miami during Hurricane Andrew in 1992 (Rappaport, 1993)

increased wear, and excessive heat in the radome led to decreased lifespan of electrical components (Whiton et al., 1998a).

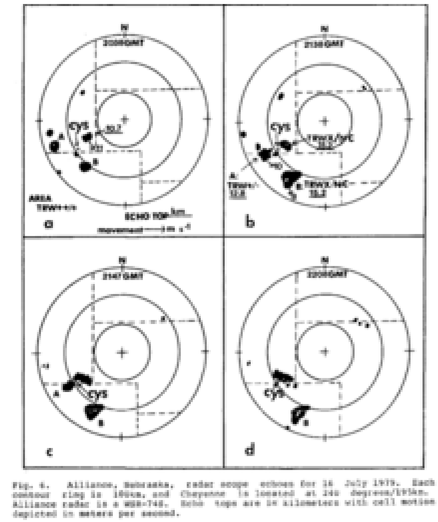


Figure 2: Radar scope echoes from the WSR-74S near Cheyenne, Wyoming during the July 16th, 1979, F3 tornado (Hickey & Parker, 1980)

By the late 1960s, large gaps in the network needed to be filled, but the WSR-57 was now outdated and no longer being produced. Therefore, a private company, Enterprise Electronics Corporation, designed, tested, and built a series of C- and S-band radars to cover these gaps in the network. The WSR-74C and WSR-74S were deployed to television stations for localized warnings and supplemented aging WSR-57 radars in areas that frequently handled tropical storms (Whiton et al., 1998a). By the early 1980s, the network was a mix of aging radars, newer C-band radars, aviation radars, and a plethora of military radars each of which required unique methods to operate and had increasing maintenance demands. While many had signal processing and data processors, the lack of Doppler radar data was beginning to impact research and severe weather information proving that Doppler radar would be key for future advancements.

With the significant aging of the preexisting radars, upgrades were going to be required soon, but Doppler radar was mainly seen as a research tool before the 1980s. The improvements were considered too minor and the price too high for operational applications (Whiton et al., 1998b). However, during the process of designing the radar, the benefits were clearly seen during the Joint Doppler Operational Project between the National Severe Storms Laboratory (NSSL) and the Air Force Geophysics Labrador (AFGL). Lead time improved from 2 minutes to 20 minutes, reduced false alarms, and updated severe storm identification (Whiton et al., 1998b). The experience gained from these early tests clearly impacted the components of the Next-Generation Radar (NEXRAD) Weather Surveillance Radar, 1988, Doppler (WSR-88D) radars. Its one-degree beamwidth increased sensitivity, and signal processing allowed for products like echo tops and vertically integrated liquid and algorithms to detect storm features like mesocyclones. Not only was the radar able to gather and process more data, but additional display modifications made it easier to use (Whiton et al., 1998b).

Perhaps the most important change compared with WSR-57 radars was the constant observations by the radar. No longer would it need to be manually run or physically adjusted when a storm approached because the WSR-88D was continuously scanning in all directions. The system was designed to be easily edited for new or mandatory requirements and needed less annual maintenance (Whiton et al., 1998b). In the 30 plus years since the WSR-88D was put into operation, additional requirements like dual-pol and AWIPs have kept the radars updated. Now the production lines for WSR-88D components are offline and research into possible operational replacements have progressed beyond Doppler.

3. DIFFICULTIES

As discussed in earlier sections, it is challenging for the NWS to build additional NEXRAD radars. As a result, the problems discussed in this study will benefit a future generation of radars. It is impossible to scan every square mile of the United States through 100 percent of the atmosphere. Processes like ducting and super refraction will impact the location of the radar beam along its path of travel, geographic features like trees and mountains will block the beam at lower levels, and distance makes it impossible to see low-level features far away from the radar. Building a radar every five miles would successfully remove this issue, but it will remain an extremely implausible hypothetical.

Therefore, difficult decisions are made to determine the locations where radars best benefit and can support each region. Factors such as population density, economics, and terrain variability play major roles in determining the correct locations, but the only variable that could significantly impact this gap would be the distance from the radar. It would not be ideal if a radar was built in a narrow valley where only a few people would benefit, and as a result, some areas are left without proper radar coverage.

While examples like the valley are simply unavoidable, other areas lack radar coverage as a result of the selective expansion of radar sites when the WSR-88D was introduced over 30 years ago. The Department of Defense, Department of Commerce, and Federal Aviation Administration met to determine what areas would be best for the detection of tornadoes, increased lead times, and improved rain-fall estimates (NWS, 2020), but many of the aforementioned factors have changed since the 1980s.

With a limited number of radars and budget, some areas were considered acceptable. Over the Continuous United States that equaled, “about 73 percent of the land mass and 94 percent of the population at the 6,000 ft. AGL range” (NWS, 2020). The complex terrain of the Western United States and the satisfactory coverage across the East were acceptable for the agreed upon requirements set in the 1980s. With the only possible remedy being the distance from a radar, some areas in the NEXRAD network of radars have difficulty capturing low-level weather features such as tornado signatures and snow squalls. In this regard, while focus can be placed on more localized radars, other methods including ground observations and satellite will also have to be analyzed to determine their impact on operations.

4. METHODOLOGY

The methodology for this study was twofold. First, events were identified in the areas of interest to verify an initial assertion that radar gaps do impact the communities within them. A variety of weather events were selected to show the widespread impact on the communities and the professionals involved in providing services. Two of the selected events, tornadic debris signatures and snow squalls, were small, low-level features. However, a third synoptic-scale event – a blizzard, was chosen to show that radar gaps impact weather events of all sizes. The analysis of radar data for these events was accomplished using GR2 Analyst 3 with data only from the nearest NEXRAD radar location.

Figure 3: NEXRAD Radar Coverage in the Continuous United States (Weber et al., 2021)

The locations were selected based on a few criteria that impacted each one when analyzing the current NEXRAD coverage as seen in Figure 3. The first criterion, as expected, was distance from a radar due to the rising height of the beam. Both southwest North Carolina and southeast Pennsylvania are locations where the radar beam can be as high as 10,000 feet above the surface at each area of interest. These regions, along with southwest Colorado where no low-level radar coverage is available, best exemplify the type of problem this research aims to address.

Another important reason for selecting each location was the amount of interest in the topic on both a professional and public level. This was gauged through the analysis of news articles in each area. For example, in La Plata, Colorado, their attempts to build an X-band radar were an ongoing struggle with funding limitations. This was well reported and documented since 2015 (Mimiaga, 2016). In Charlotte, North Carolina, severe weather caused local politicians to push bills about future radar networks and placement to the federal level in early 2025 (Lee, 2025).

Once the areas of interest were determined, a survey was distributed to gather information from experienced professionals who worked in these regions. By surveying local meteorologists and emergency managers, their personal experiences can be factored in when analyzing the impacts of radar gaps and better understanding of the needs of the community. A local broadcast meteorologist or emergency manager would be able to provide valuable information on a case-by-case basis, while NWS employees would be best for gathering information on a regional scale.

Two surveys were designed and distributed using the Qualtrics survey tool. Amongst those surveyed were broadcast meteorologists, NWS employees, and local emergency management coordinators near La Plata County Colorado, Charlotte, North Carolina, and Schuylkill County, Pennsylvania. There were a few differences between the two surveys to better suit the job responsibilities of each profession. Selecting locations with the aforementioned vested interest hopefully increased survey response rate. The list was curated to include only those with previous experience working with the NWS NEXRAD Network as the focus should be on said networks' performance and ability, and those who rely solely on a private company should be omitted. The survey was made up of a combination of Yes/No and short response questions and distributed via email.

5. STORM ANALYSIS FROM RADAR

When identifying radar gaps, it is important to identify previous significant events as a basis of comparison. Three different types of weather events were selected, one each in La Plata County Colorado, Charlotte, North Carolina, and Schuylkill County, Pennsylvania, so that the widest possible range of results could be obtained. The radar imagery used in this section are from the closest WSR-88D radar location. While NWS offices utilize private and airport terminal radar information in addition to the WSR-88D network, the main goal of this study is to show the gaps in NWS radars.

A. LA PLATA COUNTY, COLORADO

Colorado suffers from both persistent snowstorms and poor radar coverage, but La Plata County is a particular area of interest because of their local efforts to improve radar coverage. The town had been persistently pursuing their own local X-band radar since as early as 2016 through government funding. Many years of discussion about funding and location delayed the project, but in August 2025, the X-band radar in La Plata County, funded by the Colorado Department of Local Affairs and Department of Transportation, finally came online (Schafir, 2024). Before this, the county relied on the NEXRAD radar at Grand Junction, Colorado. The information from this radar is impacted by both the distance from the radar and terrain blocking. The San Juan Mountain Range directly north of La Plata

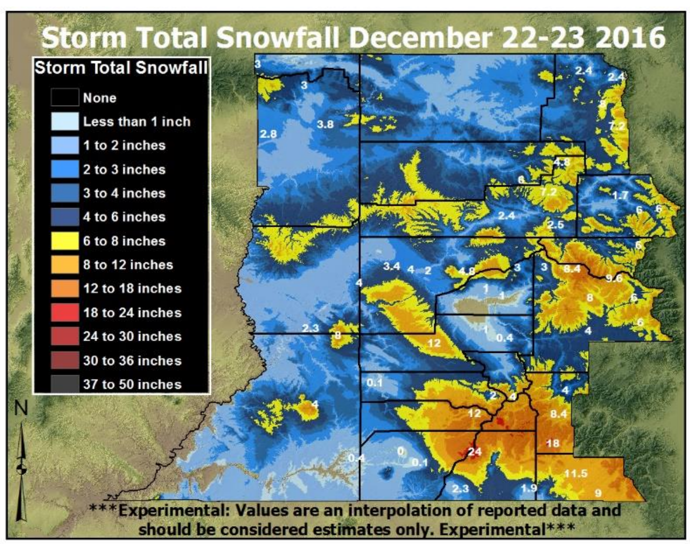
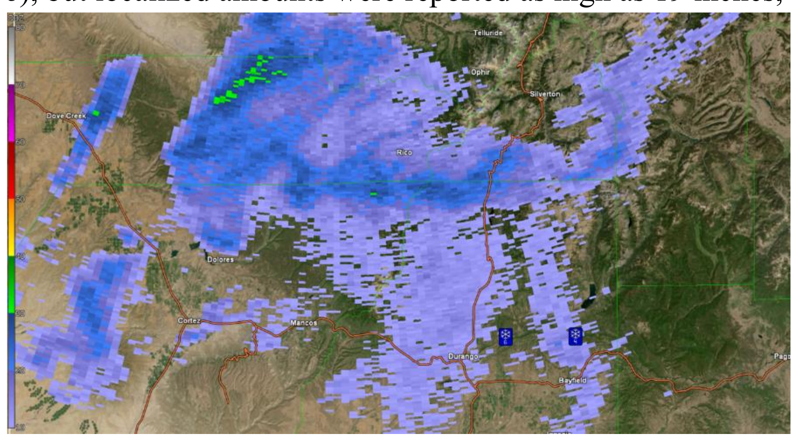


Figure 4: Snowfall Totals during the December 22-23, 2016, blizzard in southwest Colorado (NWS Grand Junction, 2017)

County is 6,000 feet higher than the valley, and this is more than enough to block low-level radar returns during snow events.

Using the December 22-23, 2016, blizzard event as an example, the problem with these radar issues can be identified. This blizzard arrived before noon on the 22nd and lasted until midday on the 23rd with most of the heavy snow in the late afternoon and early-evening hours on the 22nd. This storm was caused by an upper-level Pacific low bringing moist conditions that dropped pockets of extremely heavy snow in higher elevations while some areas in valleys received very little snow. Area forecast discussions did anticipate amounts of near 8-12 inches in the San Juan Mountains (NWS, 2016), but localized amounts were reported as high as 19 inches, and the localized impacts of this winter storm were reliant on community reports.

The radar images in figures 5a and 5b show the relatively low values of reflectivity over the area in Durango. Just outside of La Plata County in San Juan County, Coal Bank Pass, received 18.5 inches of snow while regions near Grand Junction received 2 inches or less. From the radar returns at 4:49 PM EST and 6:47 PM EST, this



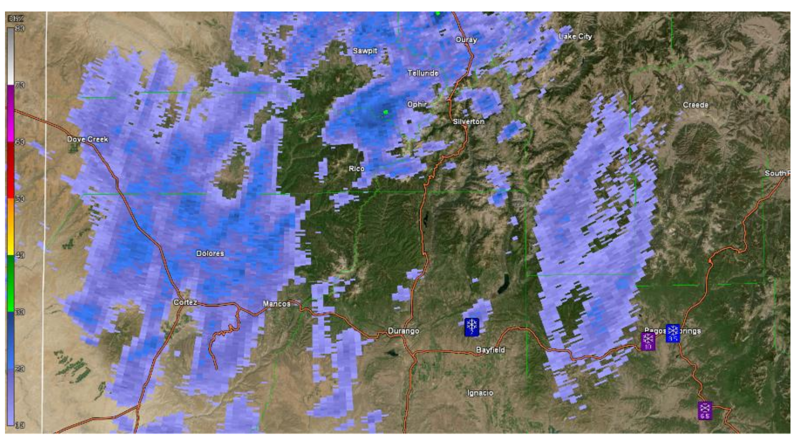


Figure 5a: Reflectivity returns from Grand Junction NEXRAD at the lowest tilt during the December 22-23, 2016, blizzard at 4:49 PM MST on December 22nd

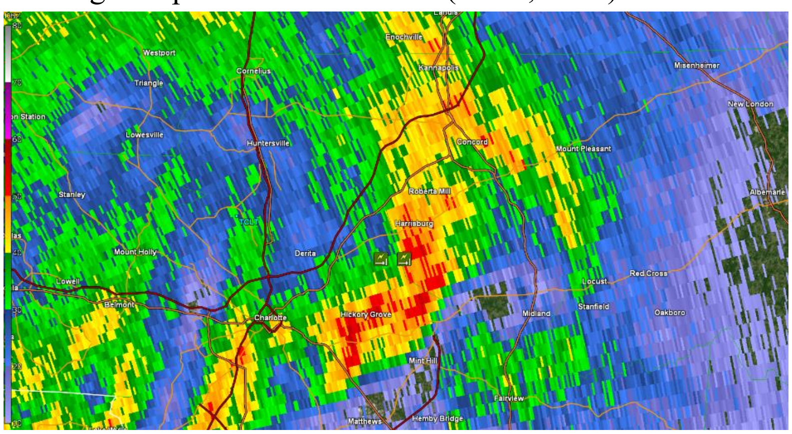
Figure 5b: Same as Figure 5a, but at 6:47 PM MST difference is not detected by radar coverage. The reflectivity returns are low and scattered and do not align with the amount of snow later reported by law enforcement and the public. For example, the report closest to Durango at 5:49 PM reported that heavy, wet snow was still falling with a strong intensity.

While these ground measurements are invaluable, they cannot always be relied upon to be accurate and timely. Although the storm was well forecasted from timing to snowfall totals via NWS Grand Junction, the reliance on voluntary reports from individuals cannot guarantee an accurate ground truth. Furthermore, in isolated areas where observations are less consistent, the best method for determining snow-fall totals is through radar reflectivity since synoptic-scale snowstorms are not independently low-level events. The impact on emergency managers is devastating because attempting to communicate between the National Weather Service and state and local authorities during time sensitive events should be easy. Instead of being able to locate information themselves, they are forced to contact NWS Offices for important information.

B. CHARLOTTE, NORTH CAROLINA

The city of Charlotte, North Carolina, deals with many types of severe weather events from hurricanes to tornadoes and flash flooding. The city is serviced by the Greenville-Spartanburg office in South Carolina, but that radar is 80 miles away from Charlotte in Mecklenburg County. By the time the radar beam reaches the city, it is nearly 10,000 feet above the surface and not able to detect low-level features. A series of tornadoes including an F3 in 1994 and an EF2 in 2008 and multiple EF1 and EF0 tornadoes have also increased focus on the gap. Recently, members of the community and local politicians have pushed to solve the problem with this radar gap. As Jeff Jackson, Charlotte's representative to Congress, said, "The meteorologists in my district say that when it comes to predicting and warning people about tornadoes and flash floods, that they consider themselves severely hampered by existing within this radar coverage gap.” (Malbrough, 2023; Lee, 2025).

While more recent examples exist, the EF2 tornado that touched down just east of Charlotte on March 3rd, 2012, was selected for this study. A quasi-linear convective system (QLCS) moving eastward began bowing outward with increasing reflectivity as it crossed the Charlotte metro area. A warm front oriented southwest to northeast had stalled near the regions over the Appalachian Mountains. When this QLCS crossed the metro area, it experienced a rapid increase in shear and CAPE by this stalled front before increases in rotational shear and convergence preluded the tornado (NWS, 2015).



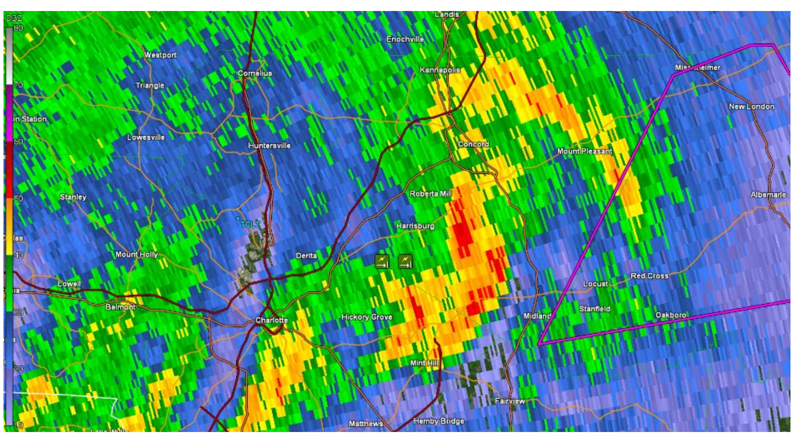


Figure 6a: Reflectivity returns from Greer NEXRAD at the lowest tilt during the May 3rd, 2012, EF2 tornado outside Charlotte at 2:37 AM EST

Figure 6b: Same variables at 2:41 AM EST

While this was before the Greenville – Spartanburg (Greer) radar had been updated with Dual-Pol capabilities, it still proves that the distance from the location had an impact on the analysis. In fact, NWS forecasters used the nearby Terminal Radar (TCLT) to make decisions during the event (NWS, 2015). While this worked on March 3rd, 2012, the lack of ability for the NWS to guarantee this radar will be optional is concerning.

Furthermore, members of the public and emergency managers might not know where to, or if they can, get access to this radar leaving them heavily reliant on NWS alerts and updates that might not alleviate specific concerns during a period where the office is conducting severe operations. While the community should trust the NWS as the voice of authority during storms, any preparedness to limit discussion during severe events would be beneficial.

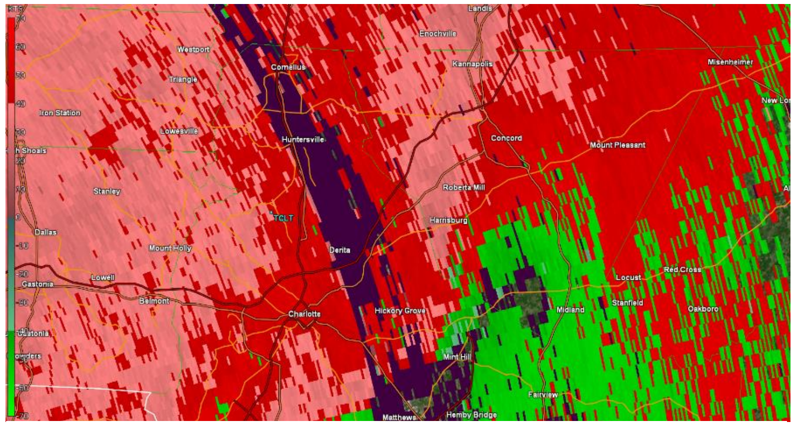


Figure 7: Storm Relative Velocity returns from Greer NEXRAD at the lowest tilt during the May 3rd, 2012, EF2 tornado outside Charlotte at 2:37 AM EST

C. SCHUYLKILL COUNTY, PENNSYLVANIA

On March 28th, 2022, at approximately 10:30 AM EDT, a snow squall in Schuylkill County caused a destructive and deadly mass pileup on Interstate 81. Around 80 vehicles were damaged, over 20 individuals were sent to the hospital, and 6 died during the event. Southeast Pennsylvania is one of the most populous radar gaps east of the Mississippi River. While everything is covered under 10,000 feet, that is not enough to identify snow squalls which are one of the region's most dangerous weather phenomena.

This low-level feature is often difficult to detect on radar in this region not only because of beam height, but also because of blocking caused by the terrain of the Allegany Mountains. Unlike blizzards, the most feature of snow squalls is rapid and drastic reduction in visibility rather than snowfall accumulation. Combining this quick heavy snowfall rate with rapid temperature drops can often lead to icy roadways within minutes making them even more critical to detect with radars as the best method to collect current weather information in rural areas without ground observations.

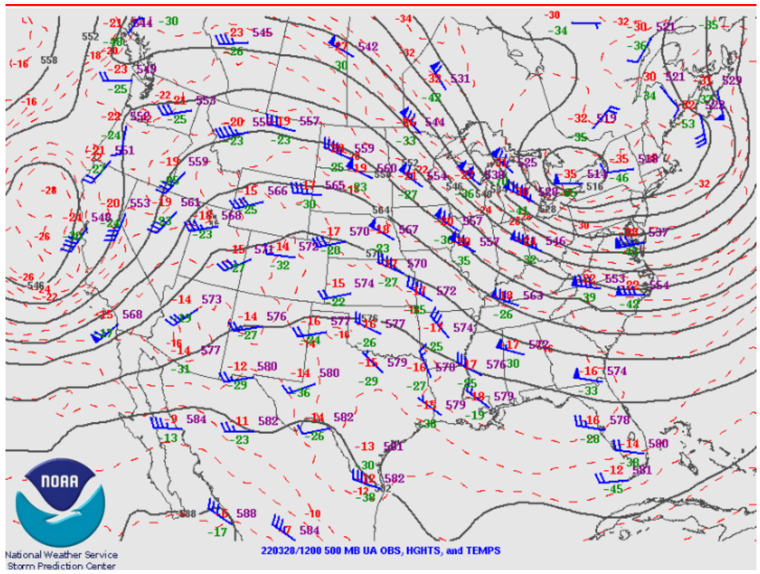


Figure 8: 500 millibar upper air map showing upper air observations, heights, and temperatures at 7:00 AM EDT on March 28th, 2022 (Storm Prediction Center, 2022)

The March 28th, 2022, event was initiated by a closed upper-level shortwave over southern Canada and through New York State which sent strong vorticities southeast across Pennsylvania in the early morning hours. Temperatures were near 32 degrees Fahrenheit, but a relatively dry atmosphere, down sloping, and westerly flow kept clouds to a minimum. However, the combination of morning sunshine, PVA, and steep lapse rates, was enough to initiate scattered snow showers and squalls (NWS, 2022). Due to strong, northwesterly flow, cold air continued to pump into the region while strong wind gusts and locally heavy snowfall rates increased the chance of low visibility in correlation with snow showers.

Radar reflectivity showed the persistent snow showers across central Pennsylvania closer to the radar, but they began to disappear as the beam height increased towards Southeastern Pennsylvania. The synoptic setup continued to favor snow squalls across the region, and this was recognized by the State College NWS Office in their Area Forecast Discussions and the flurry and snow squall warnings issued throughout the day, including one in the same location 1 hour and 45 minutes after the accident occurred (NWS, 2022). However, at the point of the accident, marked with the red cross in Figure 9, no radar returns were detected by the State College NEXRAD radar.

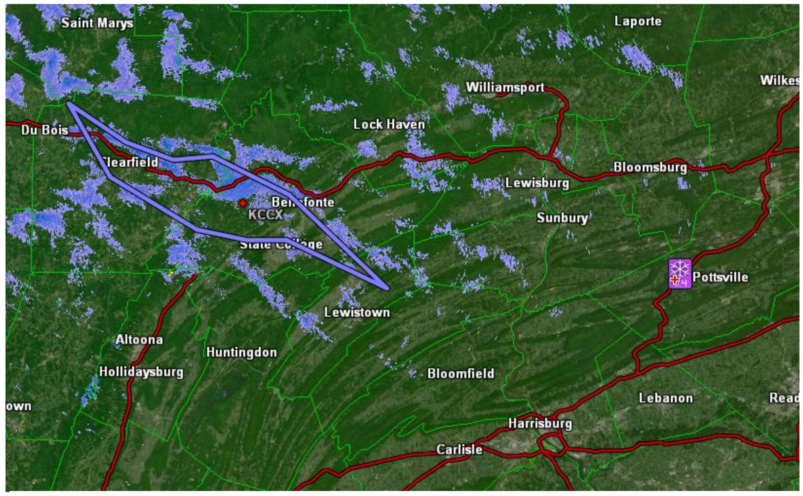


Figure 9: Reflectivity returns from the Stage College NEXRAD at the lowest tilt during the March 28th, 2022, snow squall event at 10:40 AM EDT

Despite snow squalls being quick-hitting events information about their location and timing are crucial to the response of emergency managers and services. Without the backing of radar imagery, emergency responders lack the needed information about possible hazard locations. Highway authorities cannot update road signs, and local commuters can be blindsided by low-visibility or rapid reductions in said visibility. While it is impossible to address these concerns entirely, more accuracy in identifying and tracking the exact locations of ongoing snow squalls would give additional lead time in time sensitive situations.

6. SURVEY AND SURVEY DATA AND RESULTS

Eighteen responses were recorded, six from emergency managers and 12 from meteorologists, and only fully completed surveys were included in the data. Tables 1 and 2 show the questions and responses for each survey sent to meteorologists and emergency managers.

Question	YES	NO	TOTAL
Do you live in an area you would consider to have limited coverage by the NWS NEXRAD radar network?	11	1	12
Do you think that lack of or limited radar coverage already has or will make your job more challenging?	11	1	12
Do you have experience with conducting severe weather operations during hazardous weather in these radar gaps?	9	2	11
Has an external partner, including Climavision, EWR Radar Systems, or local government filled in these NEXRAD radar gaps?	6	4	10

Table 1a: Yes/No Questions – Meteorologist

Question	TOTAL
Can you provide a brief account of how the lack of radar coverage negatively affected the emergency response time or actions?	8
Do you have access to this data? Do you think their data has been beneficial to your job?	3

Table 1b: Short Response Questions – Meteorologist

Question	YES	NO	TOTAL
Do you live in an area you would consider to have limited coverage by the NWS NEXRAD radar network?	3	3	6
Do you think that lack of or limited radar coverage already has or will make your job more challenging?	4	2	6
Do you have experience(s) with conducting emergency operations during hazardous weather in a location with limited radar coverage?	5	1	6
Has an external partner, including Climavision, EWR Radar Systems, helped to address these NEXRAD radar gaps?	2	4	6

Table 2a: Yes/No Questions – Emergency Manager

Question	TOTAL
Can you provide a brief account of how the lack of radar coverage negatively affected the emergency response time or actions?	7
Do you have access to this data? Do you think their data has been beneficial to your job?	1

Table 2b: Short Response Questions – Emergency Manager

DISCUSSION

A. METEOROLOGISTS

The data shows a unique difference between the interpretations of radar gap severity between emergency managers and meteorologists. Eleven of the 12 meteorologist responders agreed with the assessment that they live in an area with limited NEXRAD radar coverage. This is promising because it confirms the initial assessment that the impact of radar gaps exist. Because the meteorologists are more familiar with the NEXRAD radars both as a concept and in practice, they are more likely to interact with the data directly.

Eleven of the 12 meteorologist responders also acknowledged that the lack of radar coverage makes their job more difficult during severe weather operations. A noticeable relationship exists between a lack of radar data and delays in issuing severe weather alerts during time sensitive events. Although no specific number was given by the responders, individual survey responders noted that additional resources were used routinely to make up for these radar gaps included sourcing additional radars, using surface observations and lightning networks, or even waiting for ground confirmation or viewing live traffic cameras and videos. Some of these methods are much slower and may be less reliable than radar data.

Some of the previously noted hazards were identified by survey respondents, and this includes tornadic debris signatures (TDS) and snow squalls, and the distance from the radar was also mentioned as concerns for radar gaps. As one meteorologist responded, “Storm strength is often under- or overestimated based on the distance from the radar and composition of the cells. There is a need to utilize additional data resources (i.e. Lightning networks, satellite, surface obs) to have a better handle on storm strength. Utilizing multiple resources could delay response, but local expertise overcomes those negatives most of the time”. This confirms theories about slower response times in these gaps but highlights the importance of the local experience of meteorologists in these regions. Those with a wealth of experience in their region can overcome these barriers using analog, observational, and other operational forecasting techniques, but this may be an issue where the experience base may not be present.

Six of the survey respondents have benefited from external companies to address the radar gaps, but opinions on these additions have been mixed. While some praised their addition for detecting low-level features, others admitted the situation could be improved. As one meteorologist best put it, “Any additional radar coverage can be helpful. Unfortunately, private companies can do what they choose with that radar data. They don't always choose to share it with everyone who disseminates warning information and tracks dangerous storms.”

B. EMERGENCY MANAGERS

The range of responses varied more when surveying the emergency managers. Of the six emergency managers that completely filled out the form, four felt that lack of radar coverage has made their current or past job difficult, and five had experience with conducting emergency operations in the areas impacted by radar gaps. This information is noteworthy since it indicates that emergency managers have experience in and perceive the danger of the radar gaps, at the very least through their own viewpoint, but only half of those that responded feel that their current area suffers from lack of data due to radar gaps.

It is important to note a new set of issues arise when determining the impact of radar gaps on emergency response. One emergency manager acknowledged that terrain and beam curvature impacted their response time. One weather phenomenon that has not been discussed in this study is fire weather, but radar gaps impact this threat too. As the same emergency manager pointed out, “Towards the end of a major wildfire, a predicted system of afternoon thundershowers impacted the burn area. Several thunderheads formed; however, debris was flowing over highways and homes before they showed any significance on the radar". Others noted the delay in warnings and response actions in these areas not just focusing on tornadoes, but also wildfires and the possible dangerous impact to both the public and emergency responders.

The initial assumption was that the disparity in responses existed because of the addition of X-band radars in many of these areas with radar gaps. Moreover, emergency managers did not perceive these gaps in the same way the meteorologists had. One responder, who is likely from Southwest Colorado, mentioned a new local radar being put into place, but expressed uncertainty about its benefits from a sole forecasting lens. However, four survey respondents stated that they had not worked with external partners, although they would be willing to if given the opportunity, which was a drastic change compared to the meteorologists' responses. This could indicate a large gap in information getting to decision makers that might enhance the observations and response times in the absence of NEXRAD radar data.

Another explanation for these responses is the unique role of emergency managers in severe weather situations. Emergency managers do most of their work pre- and post- disaster in severe weather situations because of the inability to prevent weather events from occurring and the relatively short time spans. Regardless of the reasons for the disparity, it is still a promising sign that 50 percent of emergency managers realized their vulnerability in the areas affected by the current radar gaps. While none of the emergency managers mentioned benefits to warning times, any additional time for extra preparedness, especially during the event, is critical. One emergency manager even suggested doing so beforehand through community events like CERT (Community Emergency Response Team).

C. SHORT RESPONSE RESULTS

Several suggestions were provided by both groups of those surveyed about any other method that might benefit operations and emergency response in these regions with radar gaps. Meteorologists were divided in their suggestions for improvements to current methods including better use of high-resolution models and more reliance on lightning networks and satellite products. Other suggestions included the use of additional sensing methods and even a new National Weather Service office in Charlotte.

Some of the suggested improvements by emergency managers highlighted the importance of combining and integrating the experience of multiple sectors when resolving public safety issues. The limited or at times absence of communication between weather professionals and emergency managers was mentioned as a major component contributing to the limited lead time of warnings and watches, not just at the national level but especially between levels and local entities.

Unique to the emergency management field is the application of other field-dependent methods to address the problem. Some of the methods suggested included using "drones for damage assessment, GIS mapping and predictive analytics, additional community preparedness programs, and storm impact simulations." These methods help emergency managers interact with the community through outreach, preparedness, and mitigation, which meteorologists may not be involved with directly. They might also be more aware of additional concerns that plague each region in a unique way. For example, they are best prepared to understand which areas are most likely to have flash flooding due to poor drainage, where wind damage is usually severe, and the location of vulnerable communities.

It is important to note that there was a lack of suggestions involving the placement of radars from both the meteorologists and the emergency managers who completed the survey. This might indicate that those surveyed understand that the addition of more radars is a less likely possibility, whether through private sector or the NWS, and therefore excludes them from suggested beneficial methods, or the addition of extra radars can effectively be replaced by other data sources.

D. LIMITATIONS OF THIS STUDY

The sample size for this data is extremely small partially because of the unique properties needed for the survey. Because the focus is on areas with gaps, with a deeper concentration on three individual gaps with prior events, it was decided to limit the survey's distribution to these three areas. In addition, those surveyed in these gaps need the necessary experience and understanding to sufficiently respond to the survey, limiting it to meteorologists and emergency managers experienced with the NEXRAD network.

Because radar gaps often exist in more rural settings, a lack of meteorologists and emergency managers is just an unfortunate byproduct and a possible reason to expand the regions focused on or redefine the intent of the survey in the future. The fields of meteorology and emergency management benefit from connections and communication between professionals in each discipline, and additional staff with a wider range of connections might benefit from the distribution and response rate of a future survey. Future attempts to survey this information would benefit from a revised list of questions with a more binary response format. While all responses fully completed had no misinterpretation, some of the blank and unfinished responses might be in part to the abundance of fill in questions or confusion over the wording.

Additional research could be done by including more locations experiencing these radar gaps through focused case studies. Several suggestions can be implemented based on this experience. Although those who responded were the intended targets, a better curated list would increase the rate of response, and a more widespread survey encompassing entire regions might make this study more effective. Similarly, post survey analysis was limited by the ability to apply certain responses to specific areas, where environmental situations varied drastically.

7. FUTURE

The future path of NWS radars is yet to be charted. Recently, the NWS completed the Service Life Extension Program (SLEP) to revamp the hardware of the WSR-88D radars which are multiple decades past their life expectancy (NOAA, 2024). This included basic upgrades such as refurbishing the pedestal, repairing damaged supports, replacing the radome and support buildings, and replacing backup generators to comply with new requirements, and fixing issues with transmitter reliability and maintainability to computer equipment that control the radar (NOAA, 2024). Therefore, the issue of the next generation of weather radars has been postponed until 2035, but concerns about funding, location, and future radar technology remain prevalent.

The future of NWS Radar is dependent on the future needs of the NWS and their goals in the coming years. The NWS' mission, under NWS director Ken Graham, is to make the NWS better at decision support services which would make them more prepared to help the community and local officials with decision making. The choice to take greater interest in community outreach and public safety has resulted in important improvements like a public low resolution website radar, NWSChat to communicate with local officials, and implementation of changes inside the NWS such as increased teleworking to mitigate the impacts of shift work. (NOAA, 2025b).

Furthermore, other methods are still ongoing and promote these goals. A new NWS weather site to improve user experiences and updated flood inundation maps is just one of the features yet to come (NOAA, 2025b). To accomplish these goals, additional internal updates are needed including day 4-7 gridded forecasts at national centers to allow better allocation of local resources and expertise, AWIPS in the cloud, and Radar Next (NOAA, 2025b). Radar Next is the National Weather Service's plan for the future of weather radar in the United States. The program is in its infancy as professionals attempt to assess the needs of the public, capacity gaps, and requirements of the next generation (NOAA, 2025a). This aligns with the requirements suggested by meteorologists and emergency managers in the survey showing that not all improvements are going to be solely addressed by radar.

The irony of the situation is on full display with the concern of the NWS about reduced availability and prolonged gaps in radar coverage with goals to "improve public safety, reduce economic impact, and enhance infrastructure resilience" (NOAA, 2025a). Some of these goals are not accomplished due to the current radar network. With SLEP prolonging the current generation, the problems caused by radar location and the subsequent gaps have more time to make their case and better methods to be discussed.

A different type of radar, such as the phased array, may provide an alternative solution. Phased array radars (PAR) use thousands of small antennas to create a radar beam without mechanical motion of the antenna (Bodine & Griffin, 2024). PARs have fewer moving parts and therefore less fail points to maintain. They can also scan entire sections of the atmosphere in less than a minute compared to the multiple minutes with the WSR-88D, but at a much higher cost. Therefore, the benefits would have to be definitive and notable; however, more applicable methods including weather forecasting are inconclusive thus far. A radar test bed was conducted from 2010 to 2015, but it was limited in range and poor radar beamwidth and sensitivity with no dual polarization. The experiment was to test the warning performance and decision-making of forecasters getting 1 minute PAR data compared to 5 minute data, the same as the WSR-88D radars (Bodine & Griffin, 2024).

Figure 10: NOAA National Severe Storms Laboratory (NSSL) Phased array radar (NOAA NSSL, 2015)

The conclusion from these tests showed that PARs helped drastically increase lead time by 3-13 minutes, improve detection, and reduce false alarm ratio (Bodine & Griffin, 2024). Some improvements have already been made with the introduction of SAILS (Supplemental Adaptive Intra-Volume Low-Level Scan) mode on current radars, but this increased observation of low-level features diminishes observations of mid-level mesoscale features (Bodine & Griffin, 2024). However, there appears to be a limit to the amount of data a forecaster can possibly absorb (Bodine & Griffin, 2024), and the price of PARs might not justify these upgrades, especially when compared to automated algorithms.

NOAA meteorologists and scientists certainly see the benefit of PAR. In 2024, there was an interest in the possible use of PAR to replace the aging fleet. There are still some areas that need to be addressed. For example, the current tests can only detect in 90-degree sections, so an ability to rotate could be needed for operational use, but the information is promising (NSSL, 2024). PARs' benefits address a good portion of what the NWS is attempting to achieve, including better lead times and deceased false alarms which helps to build trust with the community and local partners. "Given the escalating frequency and intensity of severe weather events, the need for faster, more accurate weather forecasting tools has never been greater. Investing in Phased Array Radar would represent a bold leap forward in the United States' ability to predict and respond to life-threatening weather conditions" (NSSL, 2024).

8. CONCLUSIONS

The history of NWS Radar is complex and detailed, but a strong relationship with the military, engineering, and scientific discovery paved the way for the current network. Without the extensive history, unique features, and triumphs of early radars, it is entirely possible that the comprehension and understanding to make the largest and most detailed radar network in the world would not have happened. The NEXRAD radars still perform at a high level with top tier upgrades and maintenance despite being well past their life expectancy. Despite the existing issues with the current system, it is important to note that the NEXRAD Network is still one of the best networks in the world. No other nation covers as much area, with as much backup, and with the resolution of the NEXRAD network. However, there is no doubt that these radar gaps have led to some rather difficult situations for forecasters and emergency managers.

Based on the conclusions from the data gathered from the survey and the analysis of several radar gaps and events discussed in this study, it is clear that a choice has to be made with this next generation of radars. It would be logistically impossible to cover every square mile of the United States to ground level given changing elevation and the range of radars. The ability to even do this seems unlikely with future technologies, and some more plausible methods like PAR would not make up for these gaps. Additionally, concerns about the price of a PAR network might suggest no additional radar sites or NWS sites would be replaced, which would eliminate one method to limit the gaps on the national level.

Therefore, a program could be implemented to work with private companies to limit and address these radar gaps, and a more localized method might cover some of the areas left behind by modernization. However, the current relationship between these private sector companies and both meteorologists and emergency managers is not a simple one. As all users are required to pay for the data to use for their own purposes, that process may need to be streamlined and simplified with government contracts. Emergency managers and meteorologists who did not have access to the critical data expressed concerns, but many felt that these radars would not make a significant difference compared with the increasing accuracy and number of secondary sources.

Outside of new radar technology or replacement of current systems, emphasis was placed on other products to complete these objectives, and those may be the best means by which to mitigate the challenge of radar gaps from a community standpoint. Better use of regional observation networks like METARs, MESONETS, or trained spotter reports might help fill the gaps. While it will not prevent missed events or false alarms, having multiple, reliable methods to check would undoubtedly limit the importance and impact of the radar when it cannot always be relied upon.

As the NWS pushes forward with Radar Next, they need to identify how their mission and communities they serve have changed since the 1990s. The population density of the country has changed rapidly as increasing numbers of Americans moved farther west into areas with radar gaps. The future of radar in the United States is uncertain, and any new network has decades of history to compare it to, but notable shortcomings must be fixed to push forward the future of the NWS radar. By identifying the radar gaps in the current system, local meteorologists and emergency managers can help pave the way to best fix these issues whether that comes from a new national network, local private support, or better forecasts, models, and observations.

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