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RADAR INFORMATION ENHANCEMENTS FOR THE NWS OPERATIONAL USER

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1. INTRODUCTION

Through the NEXRAD Product Improvement Program, several radar capability enhancements have been deployed to National Weather Service Forecast Offices (WFO) (Istok, 2003) and more are currently in the development and implementation stages (Saffle, 2004).

The Federal Aviation Administration (FAA) operates 45 Terminal Doppler Weather Radars (TDWR) near many of the largest U.S. airports. These C-band Doppler weather radars provide data similar to the WSR-88D, but at higher spatial and temporal resolution and using different antenna scanning strategies. To demonstrate the utility of TDWR data at WFOs, the National Weather Service (NWS) Office of Science and Technology (OST) has provided TDWR products to a few WFOs for the past three years (Divecchio 2003). The expected benefits of using TDWR data to complement WSR-88D are described in Saffle (2001). Although the user interface has been through standalone systems, the data has been beneficial to WFO operations.

The NWS OST has developed a prototype system which ingests TDWR data and generates base products following WSR-88D Interface Control Documents (ICDs). The WSR-88D Open Radar Products Generator (ORPG) software was used to develop this prototype Supplemental Products Generator (SPG). The intent of the SPG is to generate and provide products to the Advanced Weather Interactive Processing System (AWIPS) for display and integration with other weather data. The NWS is at the proposal phase of a project to implement the SPG at WFOs which contain TDWRs within their County Warning Area (CWA). During the first phase of this project, a PC/Linux web server provides images of TDWR products that are viewable from the AWIPS Netscape browser (Stern, 2004). During the second phase, an SPG provides products to AWIPS in the same way and format as products are currently provided from the WSR-88D. Therefore, many capabilities currently available in AWIPS for WSR-88D products will be available for TDWR SPG products. Initially, the SPG will just provide TDWR base products. However, additional algorithms and products (e.g., multi-radar processing) will be incorporated in subsequent SPG software builds.

Using the Common Operations and Development Environment (CODE), WSR-88D ORPG software will be tailored to ingest TDWR data and generate products following the WSR-88D Class 1 Interface Control Document. The benefits of reusing the RPG software for the SPG include: providing common user capabilities for the TDWR data as is available for WSR-88D data; reducing the amount of new software development; increasing the return on investment from development of NEXRAD-centric capabilities; reducing technical risks, costs, and schedule. In addition, this same approach can be used for other types of weather radar data such as the FAA's ASR-9, ASR-11, ARSR-4, Canadian Radar data, or even commercial weather radars.

This paper will describe the SPG radar enhancement from the perspective of information content, processing architecture, and interactive user capabilities.

2. ARCHITECTURE

The SPG system will consist of ORPG software that is tailored to characteristics of the TDWR, a little-endian PC processor, the Linux operating system, and T1 ingest communications equipment. The SPG system will be on the AWIPS Local Area Network (LAN). The following sections will further describe the software and hardware architecture.

2.1 SPG Software Architecture

A Linux version of the Common Operations and Development Environment (CODE) will be used to tailor ORPG software to the characteristics of TDWR. Changes to the CODE baseline will be carefully controlled to simplify configuration management and also to support reintegrating TDWR changes into future ORPG software baselines.

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2.1.1 Built on Linux CODE

CODE is a WSR-88D algorithm development environment based upon an official source code release of the ORPG (Ganger, 2003). CODE is continuously updated to remain current with the operational ORPG. A Linux version of CODE is being developed in parallel with WSR-88D baseline operational support for Linux in the Build 8 time frame (which is scheduled for late 2005). Basing the SPG software on Linux CODE facilitates achievement of the stated design goals (minimum risk and effort through ORPG software reuse) and uses the PC Linux platform being embraced by AWIPS.

Basing the SPG on ORPG architecture not only leverages the data input and product generation capability of the ORPG, but takes advantage of the existing ORPG / AWIPS interface.

2.1.2 Overview of ORPG Architecture

The ORPG is a proven operational system with a full support organization. The ORPG software architecture is based upon a layered set of system services.

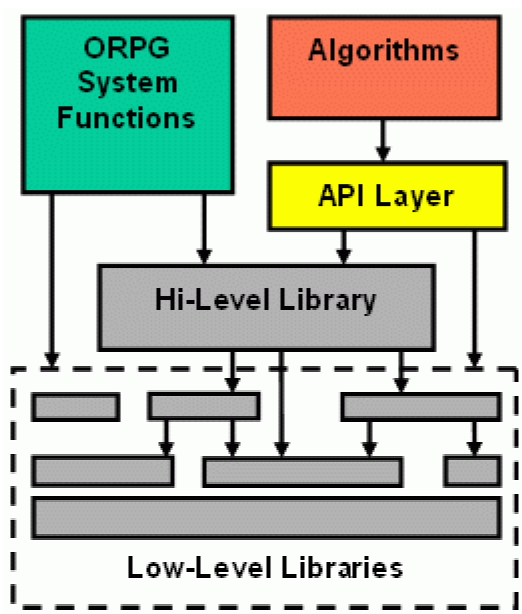

Figure 1 ORPG Software Architecture

The *ORPG System Functions* are constructed out of the ORPG layered libraries. The algorithms use an API layer to access the ORPG library services.

The strategy for tailoring the ORPG software for TDWR data is to

a. make maximum use of the existing ORPG system functions,

b. if any new functionality is written, the proper ORPG library services must be used, and

c. new algorithms should only use the API layer to access system services.

The challenge is to determine which ORPG functions to modify to minimize risk and long term maintenance effort. This is covered later in the paper.

The *ORPG System Functions* can be viewed as a collection of functional areas. One view could be as follows.

Data Ingest connects with the source of radar data and transforms these data into a form that the meteorological algorithms use. This function also maintains an internal table of data, called the *Scan Summary Table*, containing status of the current volume of data being ingested.

Product Generation consists of the meteorological algorithms and product formatting tasks. Collectively these read the base data provided by *Data Ingest* and place generated products into the product database. Individually a task reads one or more inputs (some read base data while others read intermediate products produced by other tasks), and produce an output (an intermediate product, a final product, or both).

Product Distribution connects with the user systems and distributes products stored in the product database.

Product Generation / Distribution Control. This functional area determines which products are generated and to which user products are distributed. Basically this is accomplished by keeping track of requests for products (these requests can be routine requests or one-time requests for a particular user or based upon an internal default generation table). When a final product is requested, a scheduler determines which intermediate products must be produced in order to generate the product and an internal request is created for those intermediate products.

The ***API Layer*** (used by the individual tasks) tracks requests for each task's output products and the availability of the needed inputs. The API layer relies upon the contents of the base data radial header (produced by *Data hgest*) if reading base data, and upon an internally generated header (produced by the *API Layer*, if reading intermediate products. In addition, the contents of the *Scan Summary Table* (produced by *Data Ingest*) are also used.

There are other major blocks of functionality such as the ***User Interface***, ***ORPG Control***, and ***RDA Control*** whose description is beyond the scope of this paper.

2.2 WFO Architecture

Figure 2 represents the primary communications architecture within a typical NWS field office.

Independent NEXRAD and AWIPS Local Area Networks (LAN) are connected through a NEXRAD router providing access to products from the local WSR-88D radar. The satellite receiver and AWIPS

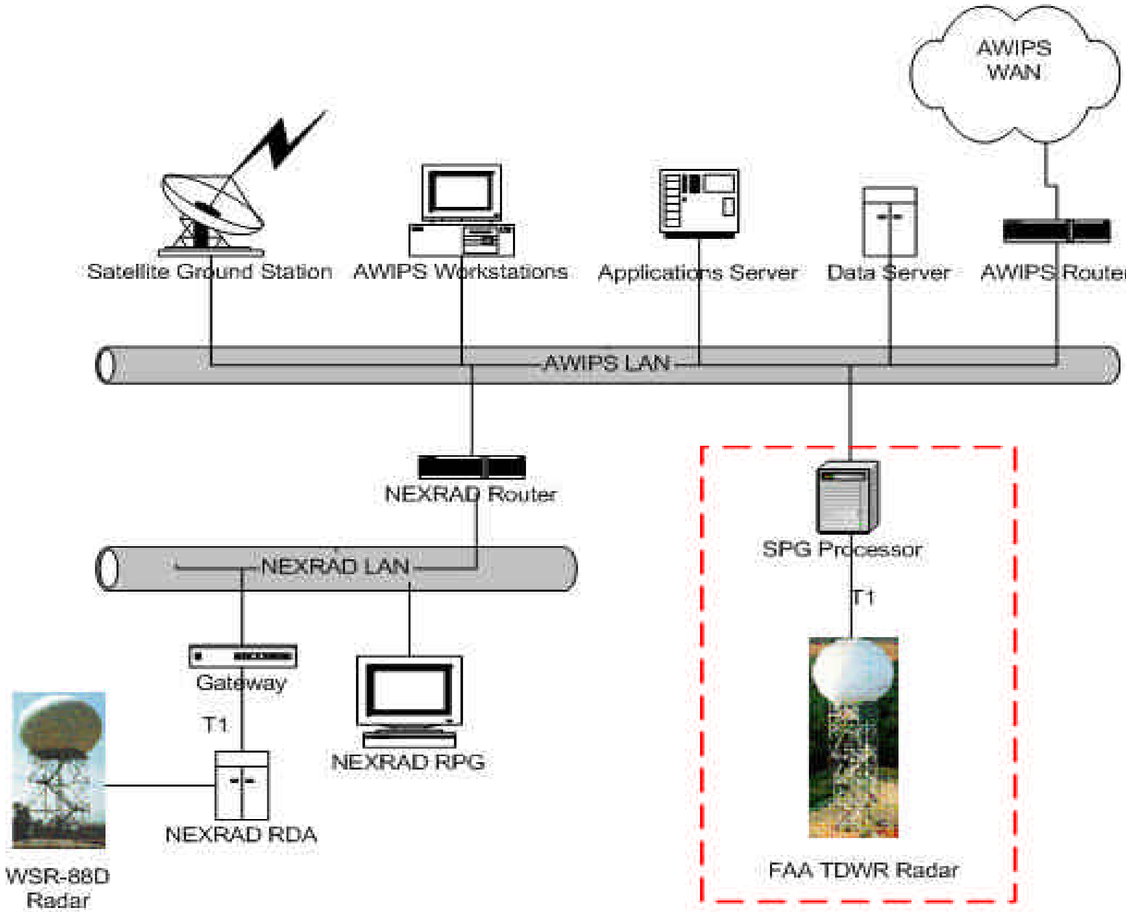

Figure 2 WFO Architecture

Wide Area Network (WAN) provide access to products from surrounding radars. The SPG processor will be connected directly to the AWIPS LAN and provide AWIPS access to TDWR radar products by duplicating the existing ORPG/AWIPS product interface. In this way, TDWR products may also be provided to external users in the same way as WSR-88D products.

2.3 SPG Hardware Architecture

Hosting SPG on the Linux version of CODE minimizes the unique SPG hardware requirements. A PC-based Linux architecture capable of supporting CODE and providing two network interfaces is sufficient. As seen in Figure 2, one network interface connects to the AWIPS LAN. The other is dedicated to receiving the TDWR raw data User Datagram Protocol (UDP) broadcast packets. WAN to LAN bridging hardware is needed to complete the TDWR radar interface.

2.4 SPG TDWR-Specific Software Design

In order to take advantage of the programming and infrastructure services offered by the ORPG, key components will be modified to make it appear as though the TDWR data stream is native to the system. As shown in Figure 3, the processes that will require modification include the communications ingest module, the base data processing module and internal data structures and processing support tables. The following subsections will provide an overview of these processes.

2.4.1 Communications Manager

The native ORPG communications manager, which has two-way communications with the radar data acquisition (RDA), will be replaced with a TDWR-specific module. Data from the TDWR are broadcast via a T1 line using the UDP.. Data packets from this one-way (inbound) broadcast must be captured and assembled into a complete TDWR (raw) data radial.

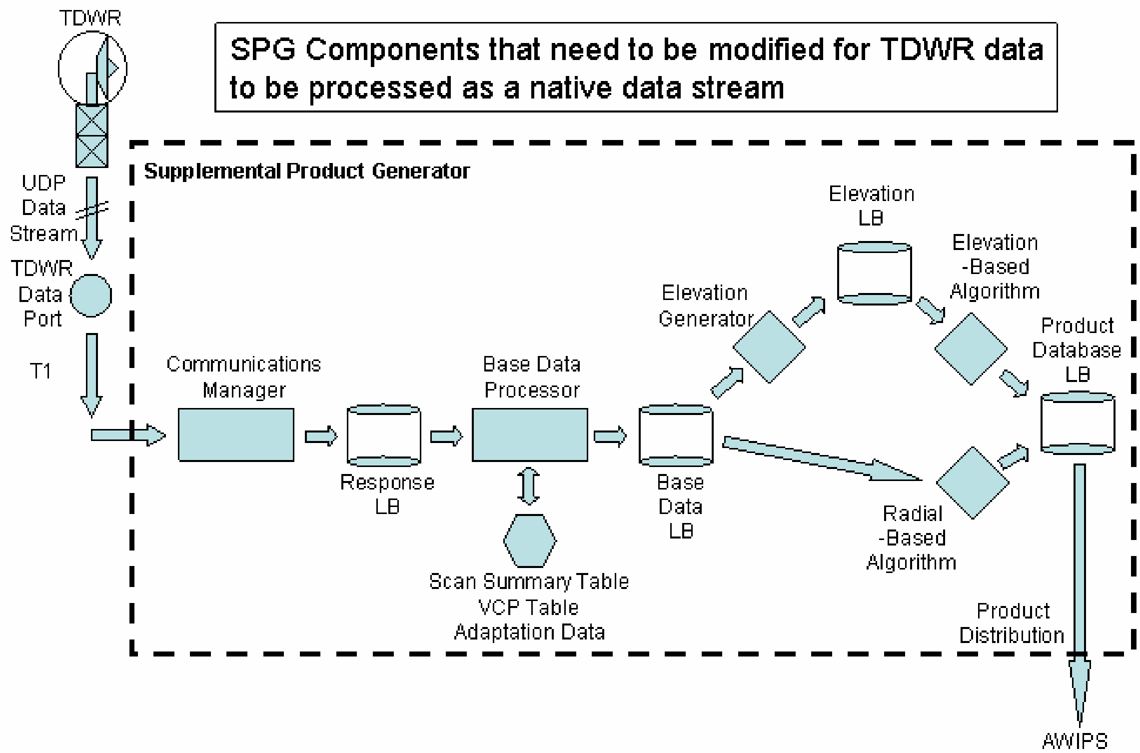

Figure 3 Flow diagram of ORPG components modified to handle TDWR data differences

Source code data structures for the incoming raw data radials will be changed to accommodate the higher resolution of the data and the larger number of data types transmitted from TDWR. The WSR-88D receives a base data radial with a size of 4704 bytes, which contains 1 km resolution reflectivity data and ¼ km (250 m) resolution base velocity and spectrum width data. The TDWR receives a base radial with a data size of 6144 bytes, which contains 3/20 km (150 m) resolution reflectivity, unconditioned base velocity, dealiased base velocity, spectrum width and signal-to-noise ratio data.

The communications manager will have to provide a cursory level of quality control and parse out incoming messages not directly associated with the meteorological scans. When complete, the assembled TDWR base data radial will be stored in the raw data linear buffer (LB) for use by the base data processor.

2.4.2 Base Data Processor

The base data processor (known as the PBD or "Process Base Data" module to the ORPG) is the heart of the SPG. This module is responsible for ingesting raw base data radials, performing quality control and consistency checks, updating the system heartbeat (based on volume sequencing) and posting assembled radial data structures into the base data LB.

A number of supplemental support files and tables will be modified to support SPG processing. Each of these files is accessed by the base data processor. For example, the VCP (Volume Coverage Pattern) table will be updated with the antenna-scanning pattern of the TDWR (see section 2.5.2 for more information on VCPs). Also, the Scan Summary Table will be modified to contain the different weather modes of the TDWR and sequencing information.

Each of the support files will be accessed by the base data processor as it assembles a base data radial. The base data radial differs from the raw data radial since it contains more system specific information that is passed on to potential post-processing algorithms. In addition, base data radials have undergone various consistency checks (making sure that elevation angles follow in VCP order and that all radials are present within an elevation).

Once a base data radial has been assembled, it is stored within the base data LB. At the end of an elevation or volume, the base data processor is responsible for issuing system level events and updating the volume sequence numbers. This last activity is used by the infrastructure for housekeeping.

2.4.3 Algorithm Processing

Algorithms within the ORPG can register for reading base data radials or can be queued to process at some system level event (e.g., an end of volume). Since the SPG is able to use the same infrastructure functionality, post-processing algorithms can execute in the same way.

The right half of Figure 3 shows two possible paths for algorithm queuing. The bottom path represents an algorithm that constantly reads base data radials and generates an output product. The output product is stored in the product database LB.

The top path is more complicated. It shows a separate process, called "Elevation Generator" that reads base data radials and creates a data structure with a complete (360 radial) elevation. This structure is stored in the intermediate LB called "Elevation LB". In this example, a second algorithm waits for the Elevation LB to indicate that a completed elevation is ready for processing. Once queued, the elevation-based algorithm executes and generates a product that is stored in the product database linear buffer.

The SPG will be able to have many different and more complex post-processing schemes since it is able to take advantage of the ORPG infrastructure.

Finally, products will be able to be generated according to the Class I Interface Control Document. This means that any TDWR product could be presented on systems that could display this format (e.g., AWIPS D2D, PUP, OPUP, etc). However, some software changes will need to be made on display system to address the higher resolution and the unique Volume Coverage Patterns of the TDWR.

2.4.4 Product Distribution

Product distribution is controlled by entries in infrastructure support files. Products can be kept local for display or used as input into other processes. Products can also be queued for distribution on the AWIPS wide area network. This will allow NWS offices not collocated with a TDWR to maintain an up-to-date database on products.

2.5 Unique TDWR Features

Similar to the WSR-88D, the TDWR has a concept of elevations, volumes and even volume coverage patterns. However, because the primary mission of the TDWR is to monitor its associated airport for the formation or occurrence of events hazardous to aviation (e.g., wind shear and downbursts), its scanning strategies and resolution are quite different. The following sections describe the TDWR resolutions and scanning strategies.

2.5.1 TDWR Data Resolution

Wind shear and downbursts can occur on a relatively small scale. In order to detect these phenomena, the TDWR was designed to operate with a very fine scale range resolution. At 150 m for both surveillance and Doppler moments, the TDWR has the highest range resolution of any of the most commonly used radars with weather surveillance channels (e.g., WSR-88D, ARSR-4, ASR 9/11).

The TDWR actually samples the atmosphere at 150 m resolution out to 460 km (248 nm). However, due to issues with data processing, storage and communications, the range resolution for reflectivity was reduced to 300 m beyond 135 km. As a comparison, the WSR-88D has a Doppler resolution of 250 m out to 230 km (124 nm) and a Surveillance resolution of 1km over its entire scanning range (460 km or 248 nm).

2.5.2 TDWR Volume Coverage Patterns

Similar to the WSR-88D, the TDWR employs different weather modes. The modes are automatically changed when continuously executing algorithms detect a potential hazard over and around its associated airport.

The TDWR utilizes two main weather modes: Monitor Mode and Hazardous Weather Mode. There are several other secondary modes used for diagnostics.

When the TDWR was first deployed, computer processing power and communications throughput was relatively limited. The original system (also called the legacy system) utilized a "sector scan" strategy during hazardous weather mode. This required the TDWR antenna to make rapid changes in both direction and elevation angle as its beam swept over the associated airport region. This strategy, while providing comprehensive coverage over the airport, put a tremendous strain on the gears in the radar dome that eventually began to lead to reliability and maintenance issues.

Beginning in 2003, the FAA began to use a new, less mechanically stressful scan strategy. With more powerful radar product generators deployed, a 360-degree hazardous weather mode was installed. This strategy used full 360-degree elevations, which provided for much better weather surveillance out to its operational range.

Both monitor mode and hazardous weather mode begin their strategies with one long-range (low pulse repetition frequency or PRF) base scan out to 460 km (248 nm). This scan is repeated every five to six minutes and is used by the system's algorithms to check for multiple trip echoes.

Beyond the first scan, both modes employ what is known on the WSR-88D as a "split cut". Two short range (90 km/48 nm) scans are per-formed at the same elevation angle but with different PRFs. Beyond these first three elevation scans, the scan strategies significantly differ.

The monitor mode provides for a consistently increasing elevation angle up to 60 degrees. With a constant rotation rate of 3.2 rpm, each monitor mode volume takes about 5.4 minutes. Figure 4 shows the monitor mode for the Baltimore-Washington International (BWI) Airport TDWR.

Hazardous weather mode is much different than the WSR-88D precipitation mode. In order to maintain a continuous weather watch over its associated airport, the TDWR makes a low elevation sweep (1.0 degrees or less) once per minute and repeats aloft scans every 2.5 minutes. This frequent lowering of the antenna every minute creates "sub-volumes" within the overall volume. Figure 5 shows the new 360-degree hazardous weather mode for the BWI TDWR.

This hazardous weather mode uses variable rotation rates for its 23 elevation scans (all of which are faster than in monitor mode). The faster rotation rate allows the entire volume to complete in 5.3 minutes.

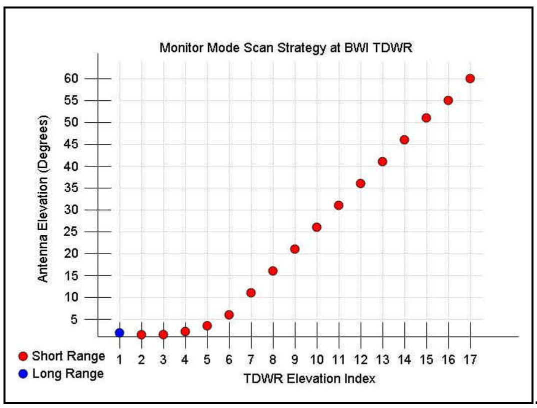

Figure 4 TDWR Monitor Mode VCP

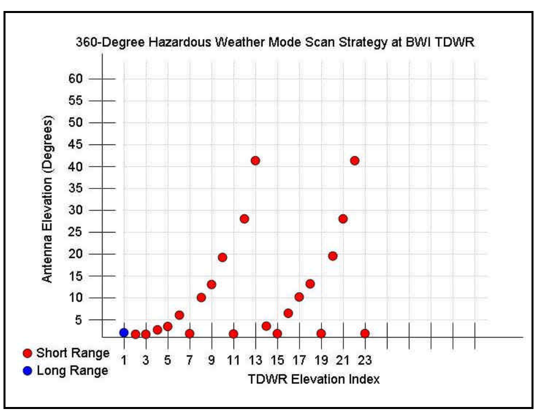

Figure 5 TDWR Hazardous Mode VCP

2.5.3 TDWR SPG Products

Initially, the SPG will generate 16-level and 256-level base reflectivity, radial velocity, and spectrum width products. Most products will be provided at a spatial resolution of 150 m by 1 degrees azimuth, extending to 90 km range. However, the long-range reflectivity product will have a resolution of 300 m out to a range of 460 km. Software requirements for these TDWR products are contained in Stern (2002) as redline changes to the WSR-88D Product Specification ICD and the ORPG to Class 1 User ICD.

Unique aspects of the TDWR data will be addressed in user training documentation. The shorter wavelength TDWR (5cm) vs. the WSR-88D (10cm) is a primary source of differences involving range folding, velocity aliasing, and signal attenuation. Furthermore, techniques employed by TDWR for range unfolding and velocity dealiasing are different than the WSR-88D and consequently data artifacts are different. Aspects of the TDWR VCPs that can affect data interpretation include higher angles at upper elevations and larger angular increment between elevations. In addition, the aggressive clutter filtering invoked by TDWR can affect the quality of the reflectivity data. Lastly, the TDWR beamwidth is smaller than WSR-88D (0.5 degrees vs. 1 degree). However, due to limitations in the signal-processing segment of TDWR, base data is provided at azimuth increments of 1 degree.

3.0 Summary

The NWS is developing the SPG system to provide TDWR data to the NWS operational user. Products will be formed following WSR-88D formats and product distribution methods so that TDWR data is available and fully integrated into AWIPS. TDWR products will be displayable in D2D along with WSR-88D data and also following single radar capabilities available with WSR-88D products.

The SPG system approach leverages key architecture elements of the NWS radar capabilities. Reuse of functionality developed for the WSR-88D radar reduces the effort to develop and maintain the SPG, increases the speed in which the system can be developed, and increases the return on investment of developing and supporting existing AWIPS and WSR-88D radar functionality.

The benefits to the NWS user are far reaching and include providing data during WSR-88D outages; providing a different viewing perspective in angle, distance, and height; and providing higher spatial and temporal data resolution. Although the TDWR radar covers a shorter range than the WSR-88D and contains limitations inherent to GBand radars, user feedback has been very positive.

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