

DEVELOPMENT OF THE TERMINAL DOPPLER WEATHER RADAR SUPPLEMENTAL PRODUCT GENERATOR FOR NWS OPERATIONS

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1. INTRODUCTION

For several years, the National Weather Service (NWS) Systems Engineering Center (SEC) has reported on exploratory activities associated with leveraging the resources of other federal agencies to enhance their warning and forecast operations. It was found that the Federal Aviation Administration (FAA) operated several aircraft tracking radars that contained weather channels as secondary capabilities. Istok (2005) provided a high-level synopsis of the characteristics of several of these weather radars and NWS proof-of-concept activities that are under way.

FAA's Terminal Doppler Weather Radar (TDWR) immediately stood out as a candidate that could complement the NWS Weather Surveillance Radar – 1988 Doppler (WSR-88D). The TDWR is a dedicated, high-quality meteorological surveillance radar with many attributes similar to the NWS network radars. Saffle (2001) listed the many advantages to being able to utilize this data set. Prototyping and proof-of-concept activities associated with the TDWR have been well documented by Stern (2002), DiVecchio (2003), Stern (2004) and Istok (2004).

To allow the NWS to easily incorporate and integrate new weather radar data sets, the SEC has been working on creating an easily customizable Supplemental Products Generator (SPG). The SPG, based on the WSR-88D open systems Radar Product Generator (ORPG), will be capable of receiving and processing non-NWS radar data streams. This paper will describe the engineering approach taken to implement an SPG customized for the TDWR and provide examples of successful interfacing with the NWS Weather Forecast Office (WFO) data integration and display device, the Advanced Weather Interactive Processing System (AWIPS).

2. SPG OVERVIEW

The design of the SPG is based on the proven technology of the NWS ORPG which was created to ingest, process and run algorithms on data from the WSR-88D. One of the major strengths of the ORPG is its well designed interface for incorporating new algorithms. This interface has greatly eased the integration of TDWR-specific modules in a Linux-base PC environment as well as providing several helpful development tools (Ganger, 2005).

Using the ORPG infrastructure has many advantages:

- Reuse of many services including applications level TCP/IP communications, product scheduling and algorithm generation
 - Reducing the amount of new software to develop

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- Reducing the developmental risk, cost, schedule and maintenance
 - Increasing return on investment
- ORPG is a proven operational system with a full support organization (the NWS Radar Operations Center (ROC) in Norman, OK)
- Products will be generated using the same WSR-88D output format
 - Reducing changes needed for display on end user systems such as AWIPS
 - TDWR-specific radar products on AWIPS can be added as just new radar products
- Unused ORPG components are easily disabled through changes in configuration table entries

Transforming a WSR-88D specific ORPG into a SPG customized for the TDWR involves the replacement, modification or addition of four components:

- The replacement of the ORPG communications manager
- The addition of a TDWR-specific data pre-processor
- The modification of how product algorithms handle TDWR scan strategies
- The modification of the human-computer interface (HCI)

The following subsections provide detail into these components.

2.1 SPG System Design

Because of the modular design of the ORPG, making changes to create a customized TDWR SPG requires relatively few steps. Figure 1 shows a simplified diagram of the SPG. The modules with white backgrounds represent unchanged ORPG modules. The modules with blue backgrounds are those modules that either need replacement, modifications or new development.

One main difference between the ORPG and the SPG is the ability to control a radar data acquisition (RDA) system. A RDA consists of a radar tower, antenna, transceiver, data processors, communications equipment and other supporting devices. The RDA associated with a WSR-88D system has two-way communications with its ORPG. This communications link allows the ORPG to send controlling instructions to the RDA as well as to receive status messages and radar moment data.

NWS access to a TDWR RDA has only a one-way connection, outbound from the RDA to the SPG. Because of this, the ORPG cannot send controlling instructions (e.g. scanning strategy changes) nor receive certain status messages that are important for the proper functioning of an ORPG. Hence, many of the functions provided by an RDA will have to be artificially created through a combination of data received from the FAA transmitter and a new SPG module called the pre-processor module (PPM). Output from the PPM is fed directly into the process base data (PBD) algorithm as if it were received from a local RDA. In the ORPG, the PBD algorithm handles quality control, internal sequencing and translates the incoming data into base data radials.

The ORPG uses a unique, flexible message passing, data passing, data buffering and storage utility library referred to as Linear Buffer (LB) for its task communications and data management. The SPG uses linear buffers in defining its unique resources and task communications.

With ORPG-formatted radial messages provided to waiting algorithms via the base data linear buffer, new products can be generated, stored and transmitted all using the supporting base infrastructure of the ORPG. A modified HCI provides a subset of functionality of a full ORPG graphical user interface (GUI). Those capabilities within the HCI that are not needed have been disabled or removed.

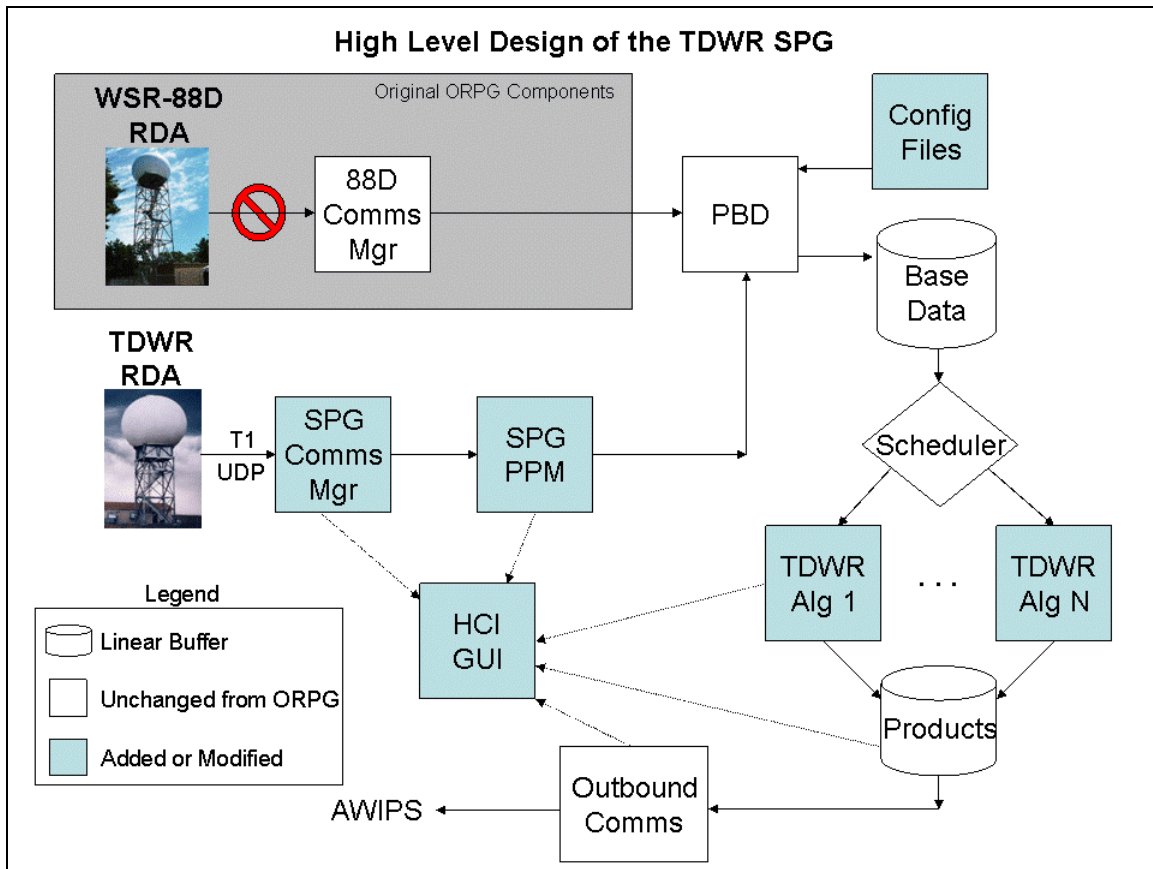


Figure 1 – High level design of a TDWR SPG. Boxes with white backgrounds represent unchanged ORPG components. Boxes with blue backgrounds depict modules that have either been added or modified to support TDWR processing. The darker box at the top left represents the biggest difference between an ORPG and SPG; a lack of two-way communication with a RDA.

2.1.1 Communications Manager

TDWR systems broadcast a one-way (outbound) data stream using the UDP (User Datagram Protocol). UDP is a connectionless broadcast that runs on top of IP networks. Because UDP has very few error recovery services, the communications manager must be ready to receive packets and efficiently collect them until a full radial message has been constructed. For the TDWR, it takes four UDP packets to construct one complete radial message.

In addition to collecting and concatenating radial data packets, the

communications manager keeps track of the communications link state between the TDWR and the SPG. If an error condition is detected, data fields within the 'message response structure' are modified to send status information to down stream processes such as the PPM (Figure 2).

Each complete radial message also contains a local time stamp and a message length field. These fields are added by the communications manager in the `cm_tdwr` message header. In Figure 2, data added by the local communications manager are indicated above the dotted line. Native TDWR data are found below the dotted line.

The TDWR radial message header contains all of the pertinent details about the upcoming radial data section. System status flags, azimuth and elevation fields can all be found in the radial header. The data section can contain different information depending on whether the TDWR is performing a long range (low Pulse Repetition Frequency) scan or a short range Doppler scan. The long range scan is performed once per volume (as the first elevation) and only

contains reflectivity and signal-to-noise ratio data. Short range radials contain reflectivity, velocity and spectrum width data in addition to signal-to-noise information and data quality flags.

Output from the SPG communications manager is deposited into a raw data linear buffer. This buffer is new to the ORPG infrastructure and serves as a data passage container for the PPM (Figure 3).

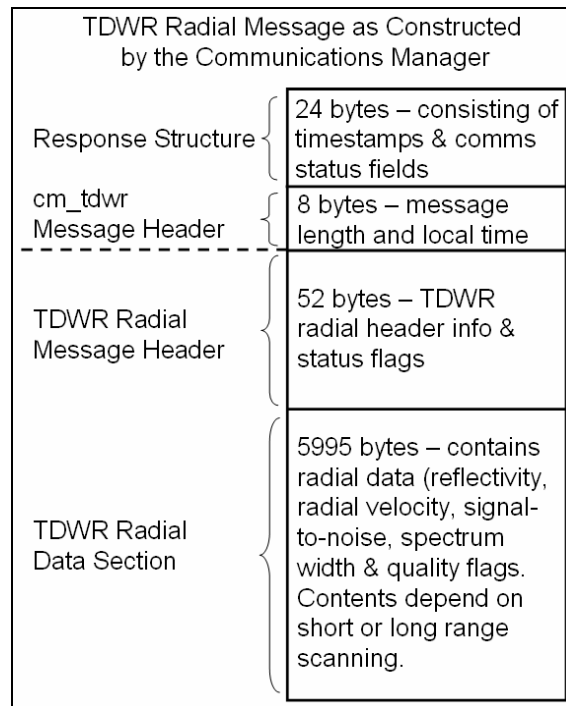


Figure 2 – Components of a TDWR Radial Message as passed from the SPG communications manager to the PPM

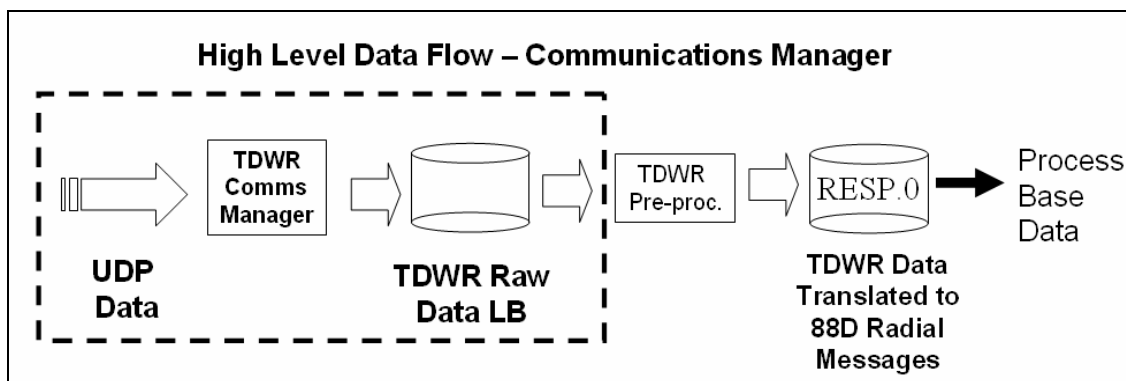


Figure 3 – The TDWR SPG Communications Manager subsystem (shown in the dotted box).

2.1.2 Data Pre-Processor

The PPM performs two important functions for the SPG. First, the PPM contains format translation logic to convert TDWR radial data into WSR-88D base data radial messages. It also provides some functionality that would have been provided by an interfaced RDA. In this capacity, the PPM maintains internal sequence numbers, provides an initial level of quality control and issues RDA status messages for both internal housekeeping and error detection. It also adds corrections to azimuth values to convert the TDWR's magnetic directions to values based on true north. Figure 4 shows that the PPM is located between the communications manager and the PBD algorithm.

Figure 5 provides a high-level view of the PPM logic flow. After program initialization, the PPM flow enters into an endless loop. At the beginning of each loop iteration, one complete TDWR radial message is read from the input linear buffer. Each message is checked both for changes in communications status and for proper formatting.

Once a radial message has cleared the quality control (QC) functions, the system provides housekeeping details by maintaining the ORPG volume sequence number, keeping track of the number of radials ingested in the current elevation and looking for start and end of elevation and volume flags. Data translation occurs first with a conversion of the TDWR radial header into a WSR-88D base data radial header. The process then branches

depending on whether the data are from long range (surveillance-only) or short range (containing all three moments). A complete data message in the WSR-88D base data radial format is then forwarded to the base data linear buffer where the PBD algorithm handles the message as if it were part of the native WSR-88D data set.

There are two differences in the reformatted base data radials when compared with WSR-88D radials.

- TDWR products will be generated at their full resolution
 - Long range reflectivity products: 300 meter resolution, maximum range of 276 km / 150 nm. This product will be truncated from its full 460 km range. This amount of data will surpass the maximum limit of the ORPG for reflectivity data (set at 460 bins) and use 920 bins.
 - Short range reflectivity products: 150 meter resolution, maximum range of 90 km / 48 nm. This amount of data will require use of 600 bins for storing reflectivity data.
 - Short range Doppler products: 150 meter resolution, maximum range of 90 km / 48 nm
- Base velocity resolution will be encoded as 1 meter/second to be able to take advantage of the +/- 80 meter/second range of the velocity data.

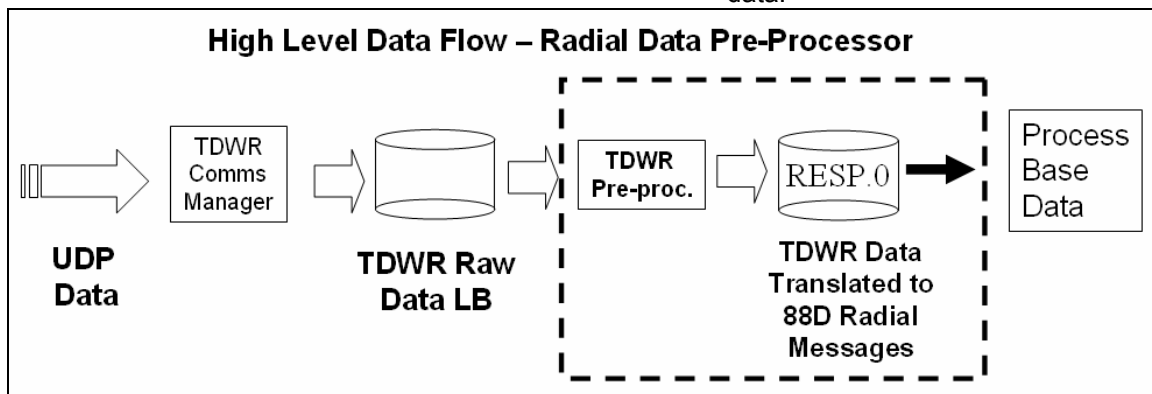


Figure 4 – The SPG Pre-Processor Module subsystem

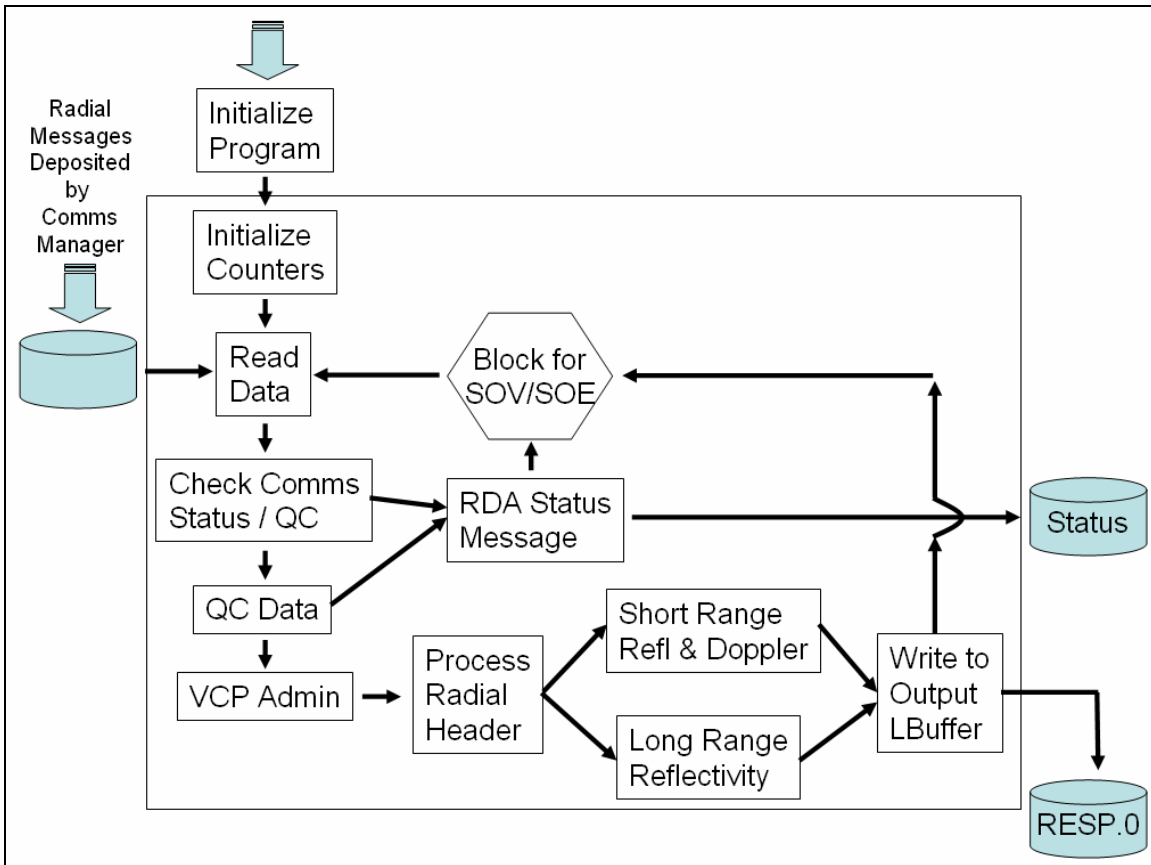


Figure 5 – TDWR SPG Pre-Processor Module flow diagram

2.1.3 Algorithm Generation

Adding new algorithms to the SPG has been made less complex due to the modular construction of the ORPG and its application programming interface. SPG algorithms take full advantage of the ORPG infrastructure (e.g. scheduling, requests, dissemination, etc) and receive data as a native component from the base data linear buffer. Figure 6 shows a high-level flow diagram of the algorithm generation subsystem.

While output from SPG algorithms complies with ORPG standards, some of the logic required within the algorithm is unique because of the TDWR scan strategies. Similar to the WSR-88D, the TDWR operates with two scan strategies: monitor mode (similar to clear air mode) and hazardous weather mode (similar to severe weather mode).

A monitor mode volume consists of 17 elevation scans (Figure 7). The first elevation is always a long range surveillance scan. The second and third scans use the same elevation angle but different pulse repetition intervals. These scans are always below one degree in elevation and may have a lower elevation angle than the long range scan. Beyond scan 3, the monitor mode scan strategy contains elevations of sequentially increasing elevation angles to a maximum of 60 degrees.

Conversely, a hazardous weather mode consists of 23 elevation scans (Figure 8). The first three scans are similar to monitor mode (surveillance-only followed by a split cut, two scans at the same elevation angle but different pulse repetition intervals). Thereafter, the hazardous scan strategy is quite different from the WSR-88D's severe weather mode.

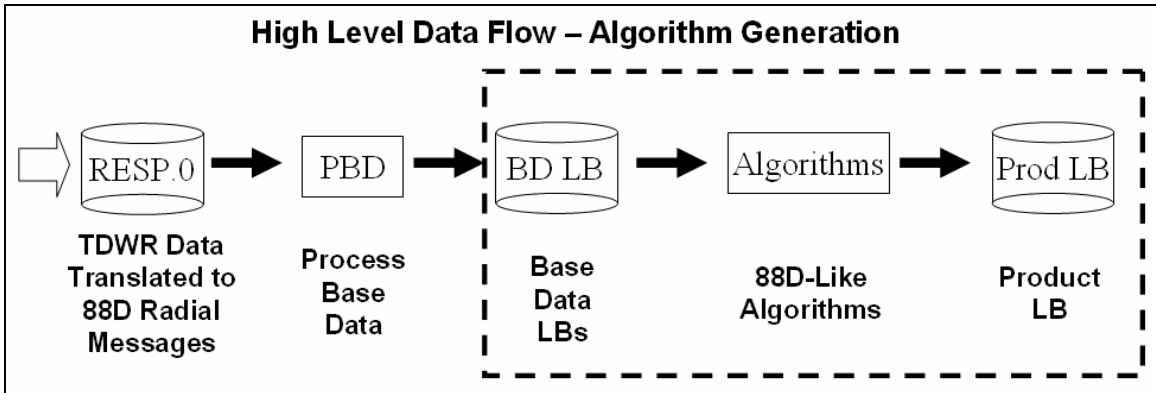


Figure 6 – The SPG Algorithm Generation subsystem

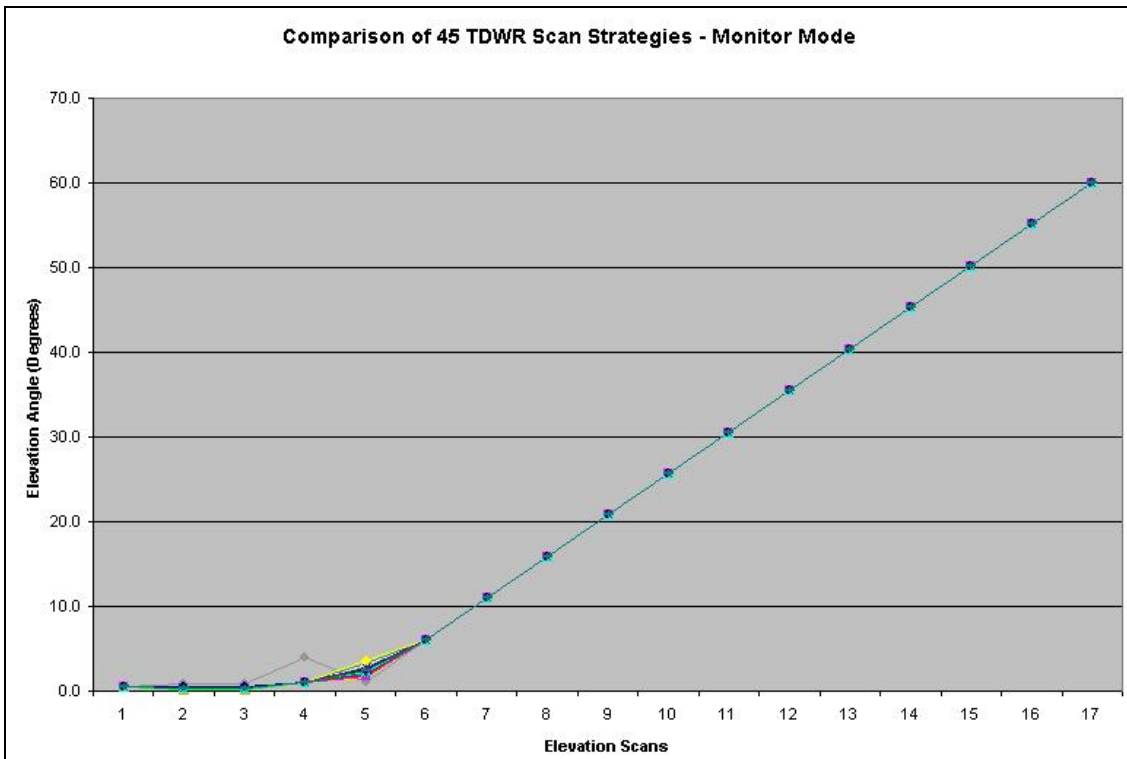


Figure 7 – Comparison of TDWR Monitor Mode Scan Strategies for 45 TDWR systems

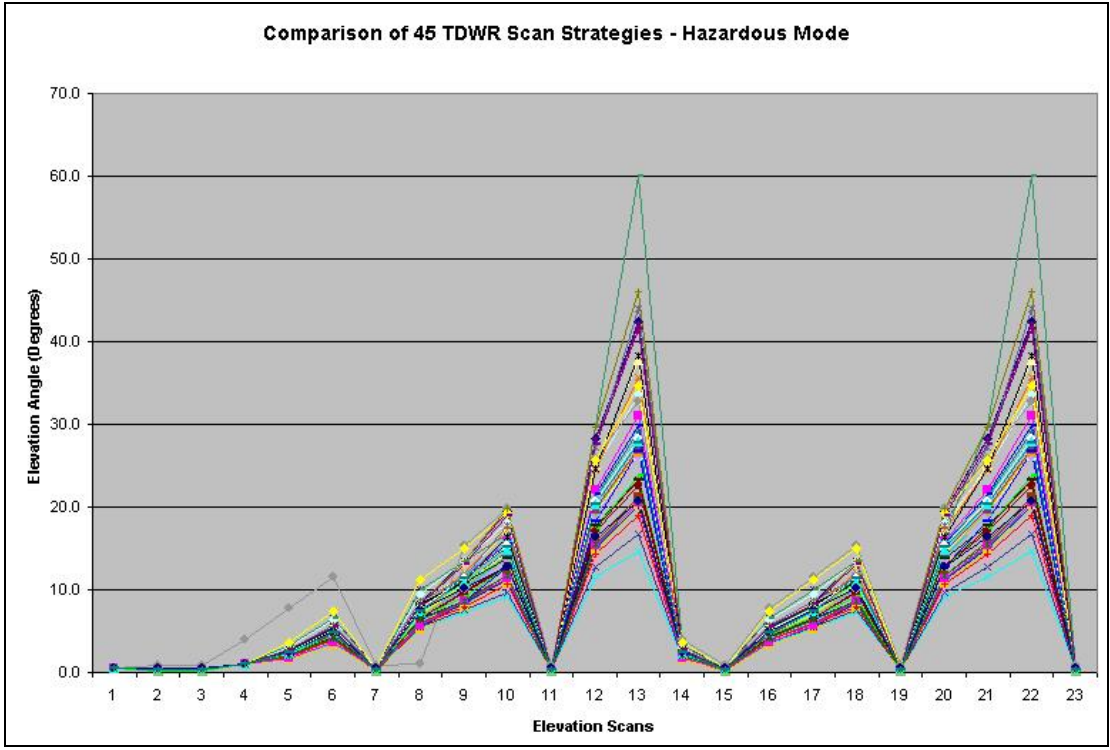


Figure 8 – Comparison of TDWR Hazardous Weather Mode Scan Strategies for 45 TDWR systems

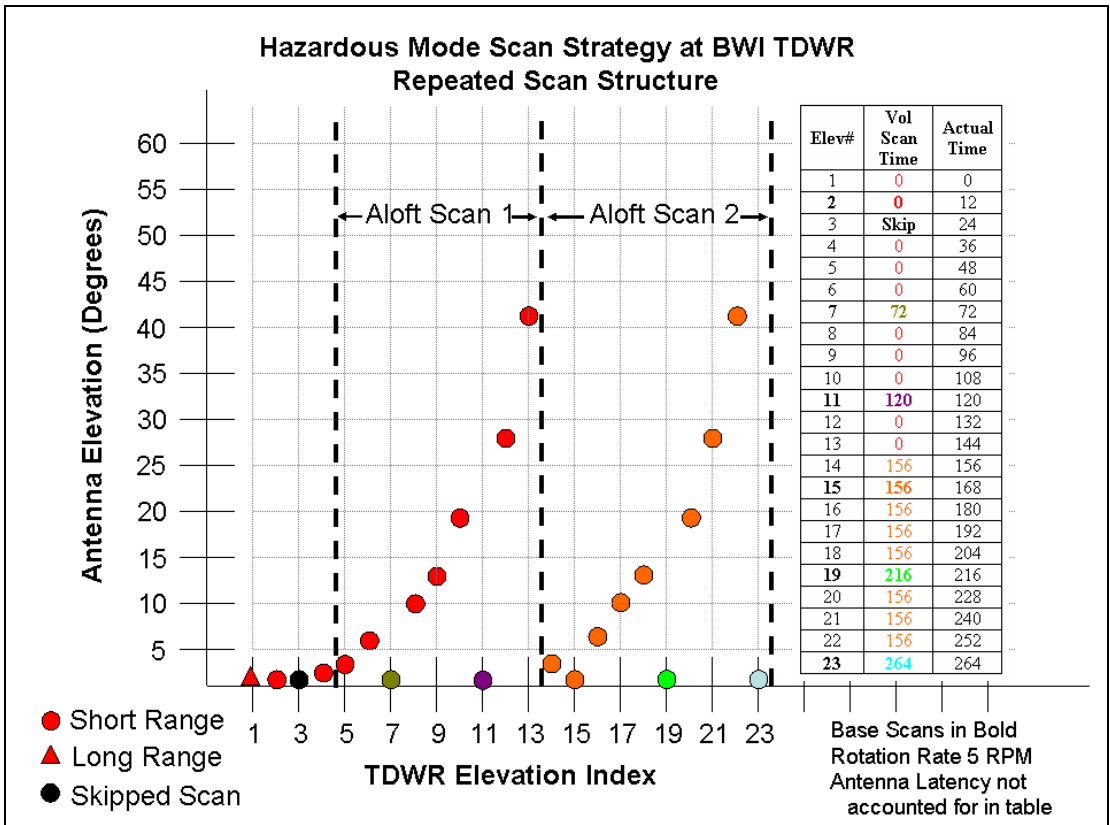


Figure 9 – The repeated scan structure of the TDWR hazardous weather mode (as customized for the BWI (Baltimore-Washington International Airport) TDWR)

Major differences between the WSR-88D and TDWR precipitation modes include:

- Each complete volume consists of three distinct sub parts (Figure 9):
 - Four low level scans, used both for surveillance and multiple trip echo mitigation
 - Followed by two repeating aloft scans
- Approximately every minute (or every fourth scan), the TDWR antenna returns to its lowest elevation for a base scan, and
- There are no two TDWRs that share the same set of elevation angles. Figure 8 shows the varied elevation angles that comprise hazardous weather mode for the 45 commissioned TDWRs. The differences in angles are directly related to the distance of the TDWR its associated airport plus consideration for local terrain.

Figure 9 provides additional insight to the structure of the TDWR hazardous weather mode and how the SPG algorithms handle product timing. In order to be able to correctly store and loop displayed products within AWIPS, the timestamps of repeated scans had to be different. The table in Figure 9 shows the logic behind the timing scheme for the strategy. These include:

- The base volume scan time of the first sub volume is based on the time at the beginning of the volume.
- The volume scan time for the second sub volume is based on the start of elevation time on scan 14.
- Each repeated base elevation scan uses its elevation start time as its volume start time.

The colors in the Figure 9 table match the colors in the circles of related elevation scans.

2.2 Human Computer Interface

Because of the absence of a local RDA and lack of control of the TDWR, the SPG HCI requires only a subset of the functionality of the full ORPG HCI. Rather than making significant modifications to the

interface code, simple “button insensitive” entries were added to the X-Window calls. This technique was used to disable buttons from the following screens:

- RDA Control Selection
- Clutter Regions Editor
- Bypass Map Editor
- PRF Selection
- RDA Performance Data Display
- Environmental Data Editor

Figure 10 shows the results of the X-Window modifications. The dark buttons along the right column have been rendered insensitive, thus disabling the functionality.

Figure 10 also shows other modifications that were made for the ORPG. Many of the controls found in the box at the lower center of the main HCI page have been disabled. This includes the Precipitation Category, VAD Update, Auto PRF, Calibration, Load Shed and RDA Message switches.

The new Volume Coverage Patterns (VCP) for the SPG have been made available on the HCI. VCP 90 represents monitor mode. VCP 80 is hazardous weather mode. Defining the new TDWR products in configuration files automatically includes them in the HCI products display screens. Finally, a new dialog box will be added to control the functions of the communications manager.

3. IMPLEMENTATION ISSUES

3.1 Initial Products

Upon initial deployment of the SPG, there will be seven base products available for distribution. These include:

- 16-level and digital long range reflectivity (at 300 meter resolution)
- 16-level and digital short range reflectivity (at 150 meter resolution)
- 16-level and digital short range velocity (at 150 meter resolution)
- 8-level spectrum width (at 150 meter resolution)

Figure 11 shows an example of a high resolution reflectivity image from the Baltimore, MD TDWR.

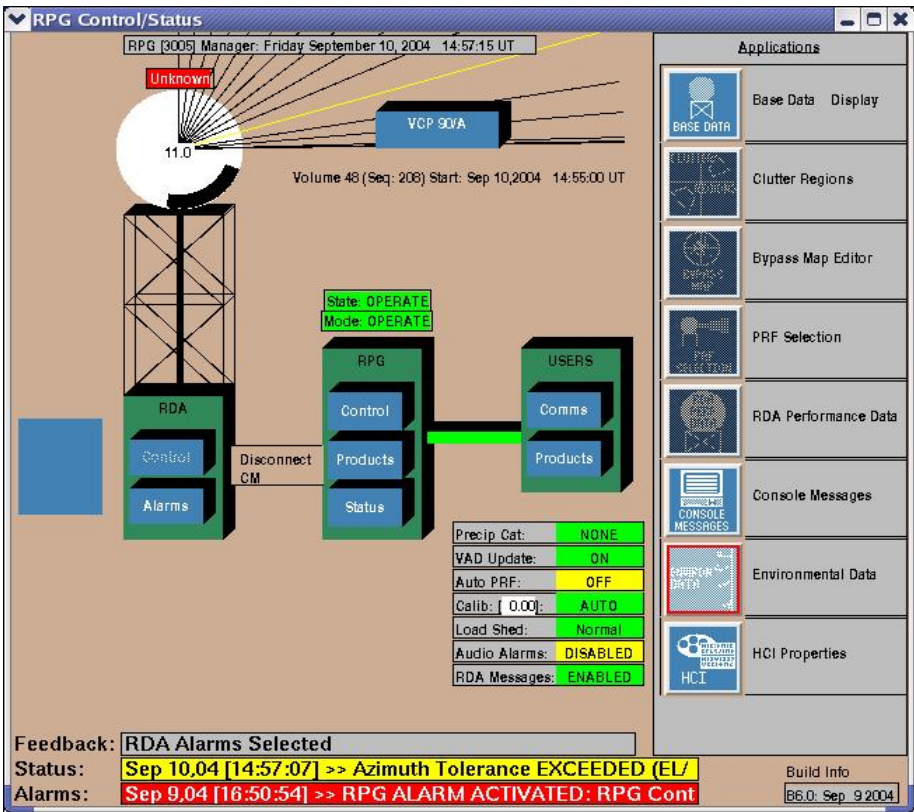


Figure 10 – Example of the SPG HCI with unused buttons disabled (dark).

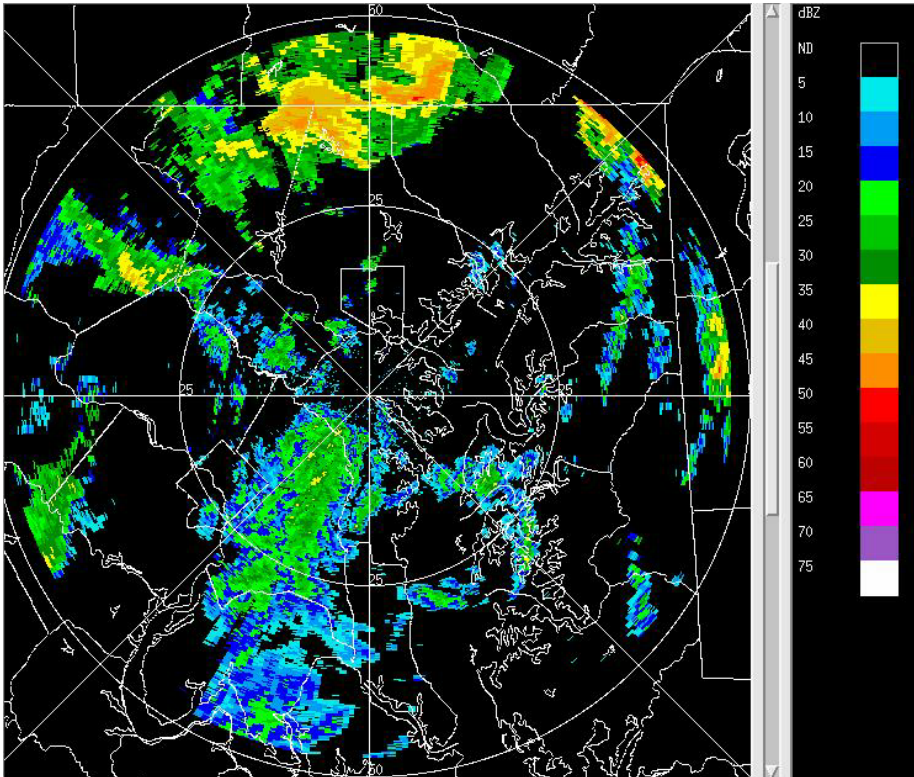


Figure 11 – Example of a 16-level, 150 meter resolution, 48 nm reflectivity image from the Baltimore, MD SPG using the ORPG CodeView Graphics (CVG) display tool.

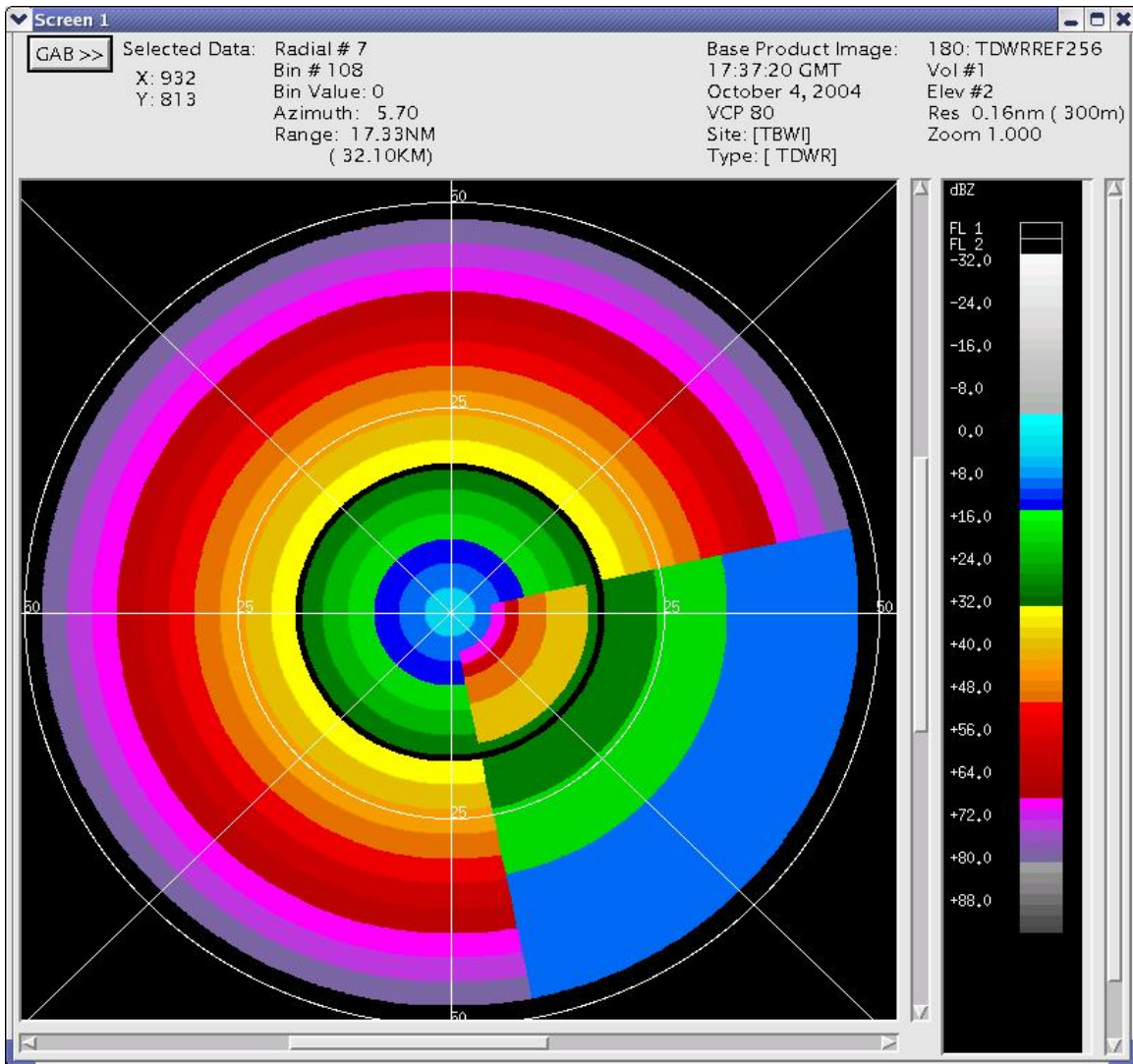


Figure 12 – The SPG Test Pattern Simulator (TPS) displaying 16-level reflectivity data (without magnetic to true direction correction).

3.2 Tools and Testing

A number of tools have been created to support the testing and validation of the SPG. A data metrics analyzer has been created to monitor product sizes. A data logger provides for the local archiving of base data for three days. This data can be played back into the SPG via a tool called a linear buffer data pump.

Finally, for diagnostic testing of both the internal processing and the output graphics, a Test Pattern Simulator (TPS) has been created. The TPS can generate different patterns for both reflectivity and velocity moments. An example of the TPS

interpreting a reflectivity signal is displayed in Figure 12.

3.3 Integration of TDWR data into AWIPS

Proof-of-concept demonstrations have already shown that TDWR data can successfully be ingested into AWIPS. More importantly, TDWR data can be combined with WSR-88D data to produce a multiplatform mosaic. Figure 13 shows an AWIPS D2D display with integrated data from the Baltimore, MD (BWI) TDWR and the Sterling, VA (LWX) WSR-88D. The light gray and blue circle surrounding the BWI TDWR shows the domain where the TDWR data contributed to the composite.

The SPG system will be physically located within NWS offices and logically inside the AWIPS network domain. Network security will include firewall protection on the TDWR network and AWIPS network firewalls at each WFO. Product requests and distribution of products to WFOs will be contained within the NWS network.

3.3 Multiple SPG Systems per WFO

The FAA operates 45 TDWR systems across the continental United States and Puerto Rico. In a few locations where there are multiple large airports, more than one TDWR may exist within a relatively small distance. The NWS has analyzed the locations of each TDWR and made associations with WFOs. In some cases, there are more than one TDWR within a WFO County Warning Area (CWA). In this situation, more than one TDWR may be connected to a WFO requiring multiple SPG units for processing.

Figure 14 graphically depicts the TDWR-WFO associations across the country. The color of the dot at the TDWR site represents how many potential SPG units will be required at the associated WFO. WFO Sterling, VA has four TDWRs within their CWA. WFOs Miami, FL and Wilmington, OH each have three TDWRs within their CWA. WFOs Chicago, IL, Houston, TX, Fort Worth, TX and New York City, NY all have two TDWRs within their CWA. All remaining WFOs depicted in the graphic have single TDWRs in their area.

3.4 Deployment Schedule

Deployment of the SPG at any WFO will follow their AWIPS software upgrade to open build 5. At the time of this writing, SPG system testing is scheduled for the winter and spring of 2005 with initial deployment beginning in May. Depending on funding levels, full deployment and installation of SPG systems may take up to two years.

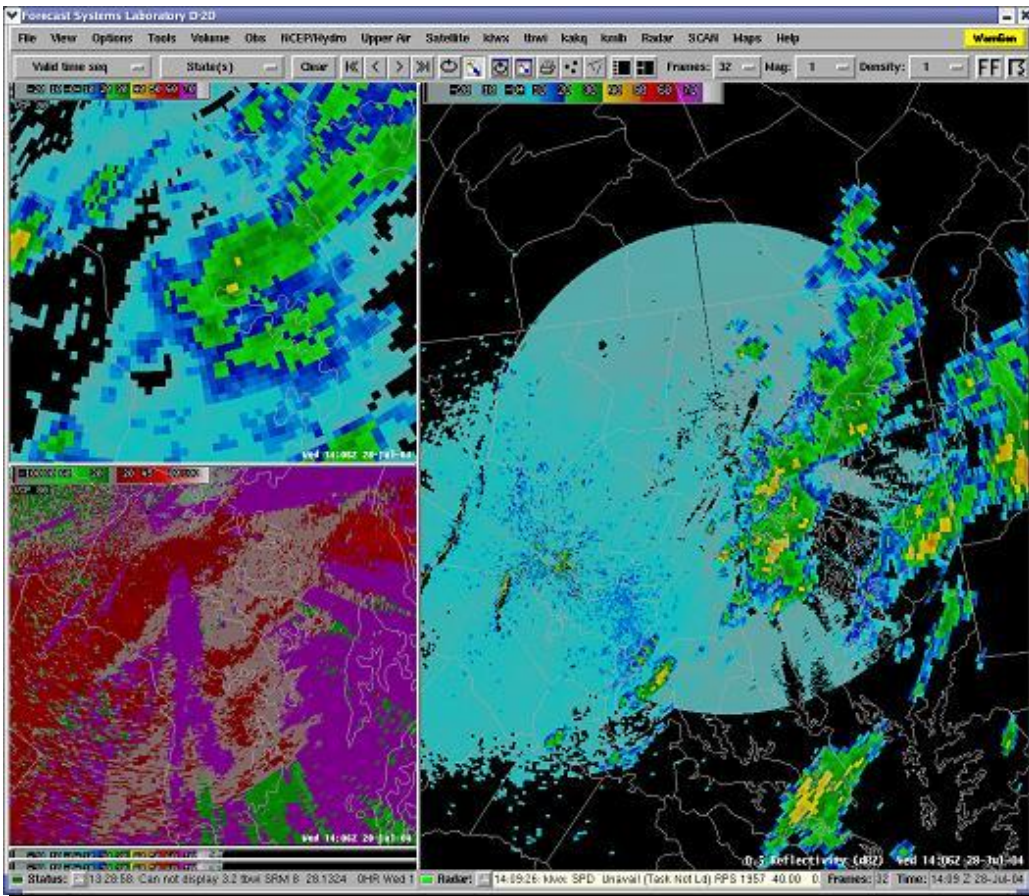


Figure 13 – AWIPS D2D display with integrated TDWR (from Baltimore, MD) and WSR-88D data (from Sterling, VA) in a composite

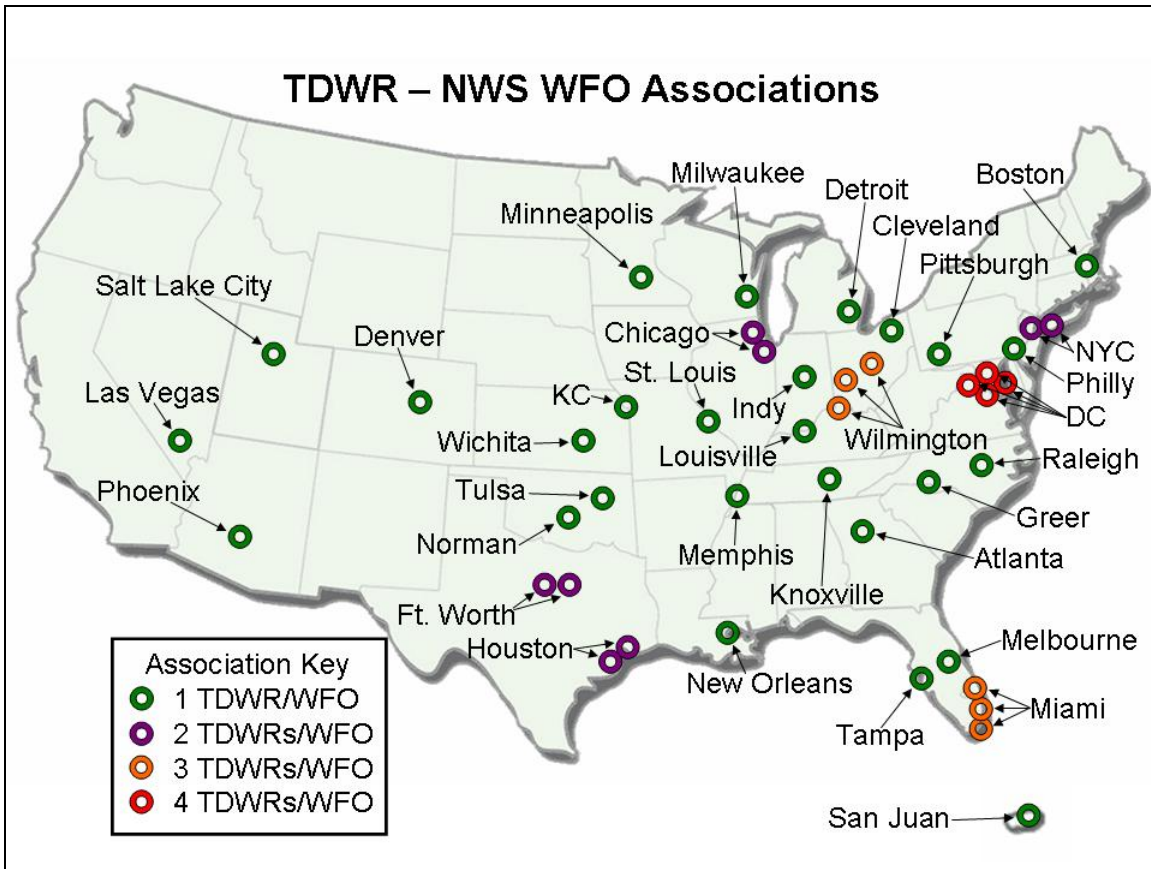


Figure 14 – TDWR – NWS WFO Associations. The association number indicates the highest potential number of SPGs that would be required to process all TDWRs at a WFO.

4. SUMMARY

The FAA owns and operates 45 dedicated, high-quality Doppler weather radars called the TDWR. The NWS SEC has been working on proof-of-concept prototypes of data ingest and processing systems to facilitate the acquisition of TDWR data into its field operations. The architecture for a SPG system has been engineered and implemented and test systems have shown the ability to create radar products that can be stored, displayed and integrated on AWIPS D2D systems.

Details have been provided showing the logic of the SPG communications manager, pre-processor and algorithm generation. Several diagnostics tools have been created to test and validate SPG systems prior to deployment. Deployment, which may take up to two years, is scheduled to begin in May 2005.

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