6B.10

TERMINAL DOPPLER WEATHER RADAR FOR NWS OPERATIONS: PHASE 3 UPDATE

Michael J. Istok*
NOAA/National Weather Service, Office of Science and Technology, Silver Spring, MD

Andrew D. Stern and Robert E. Saffle
Noblis, Inc., Falls Church, VA

Bill Bumgarner
BAE Systems, Washington, D.C.

Brian R. Klein, Ning Shen, Yukuan Song, and Zihou Wang
RS Information Systems, Inc., Silver Spring, MD

Warren M. Blanchard
Short and Associates, Inc., Silver Spring, MD

1. INTRODUCTION

After several years of testing and evaluation, the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) will begin full scale deployment of the Supplemental Product Generator (SPG) during the spring of 2008. The SPG is based on the successful open-systems Radar Product Generator (RPG) but has been customized to accept and process radar data from non-NWS systems such as the Federal Aviation Administration's (FAA) Terminal Doppler Weather Radar (TDWR) (Istok, 2004). The 10 prototype deployment systems have generated products compatible with the NWS Advanced Weather Interactive Processing System (AWIPS) and have been credited with providing valuable supplemental data for the NWS forecast and warning programs (Istok, 2006). During the last year, these SPG's have been upgraded to the second build of the processing system, allowing for full resolution products and a subset of algorithm-based products to be supplied to forecasters.

During the fall of 2007, the NWS was busy developing plans to deploy SPG's to access TDWR weather radar data from the remaining 35 radars. This paper will provide details about the full deployment phase of the SPG. In addition, significant progress has been made toward the implementation of a full suite of advanced, algorithm-based products which will be included with the deployment of SPG Build 3. Storm analysis products, derived reflectivity products and precipitation-based products will be described.

While the SPG continues its evolutionary development, so does the TDWR. Information will be provided on the progress to modernize the TDWR Radar Data Acquisition (RDA) system as well as proposed changes to its scanning strategies. Finally, this paper will provide an outlook toward future SPG plans and enhancements involving data from the TDWR and other FAA and Department of Defense (DoD) radars.

2. BACKGROUND

Development and testing of the SPG took place over a number of years from 2003 through 2005. Finally, during the summer of 2005, the first operational SPG units were delivered to ten NWS WFOs. These systems contained Build 1 of the processing system which included a full compliment of reduced resolution base products and the ability for the SPG to send these data for integration and display within AWIPS. These systems were in use during the very busy 2005 hurricane season where they provided valuable supplemental radar information during the landfalls of Katrina, Rita and Wilma.

* *Corresponding author address*: Michael J. Istok, NOAA/National Weather Service, W/OST32
1325 East West Highway, Silver Spring, MD, 20910
Email: Michael.Istok@noaa.gov

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Build 2 of the SPG processing system was completed in 2006 and deployed to the original ten WFOs in early 2007. This version of the SPG upgraded base products by allowing the use of full resolution data for the creation of base products. In addition, as shown in Figure 1, the ability to process the TDWR velocity data through the WSR-88D Dealiasing algorithm was added along with several additional new products, and the ability to generate products immediately in response to one-time product requests.

During the spring of 2007, and prior to the beginning of the hurricane season, an eleventh SPG was deployed to the field. This system was delivered to the WFO in Tampa, Florida. Figure 2 shows the TDWR coastal network that has been deployed along the Atlantic and Gulf coasts. The outer circles represent the long range reflectivity coverage (416 km/225 nm). The smaller circles show the range of the Doppler velocity coverage (90 km/56 nm).

3. SPG DEPLOYMENT

Full deployment of SPG systems to NWS WFOs will begin during the spring of 2008. By the end of September 2008, all 45 operational TDWRs should be connected to SPGs in their associated WFOs via a T1 communications line. Figure 3 provides a national map illustrating the distribution of TDWR systems and their pairing with field offices. For each TDWR, there will be an independent SPG.

Evolution of SPG Capabilities

SPG System Capabilities	Web Server	SPG Build 1	SPG Build 2	SPG Build 3
Real-Time Ingest of TDWR Data Stream	✓	✓	✓	✓
GIF Images of Base Data (V & Z)	✓			
31 Day Archive/Playback of GIF Images (V & Z)	✓			
Translate TDWR to RPG Format		✓	✓	✓
Products Integrated into AWIPS		✓	✓	✓
One Time Request (OTR)		✓	✓	✓
Reduced Resolution Base Data Products (Z)		✓		
Full Resolution Base Data Products (Z)			✓	✓
User Selectable Layer Composite Reflectivity			✓	✓
Velocity Azimuth Display/ VAD Wind Profile			✓	✓
Immediate Product Generation from OTR			✓	✓
88D Velocity Dealiasing			✓	✓
Storm Analysis Products				✓
Derived Reflectivity Products				✓
Precipitation Products				✓

Figure 1. Listing of SPG system capabilities from risk reduction through the developmental builds.

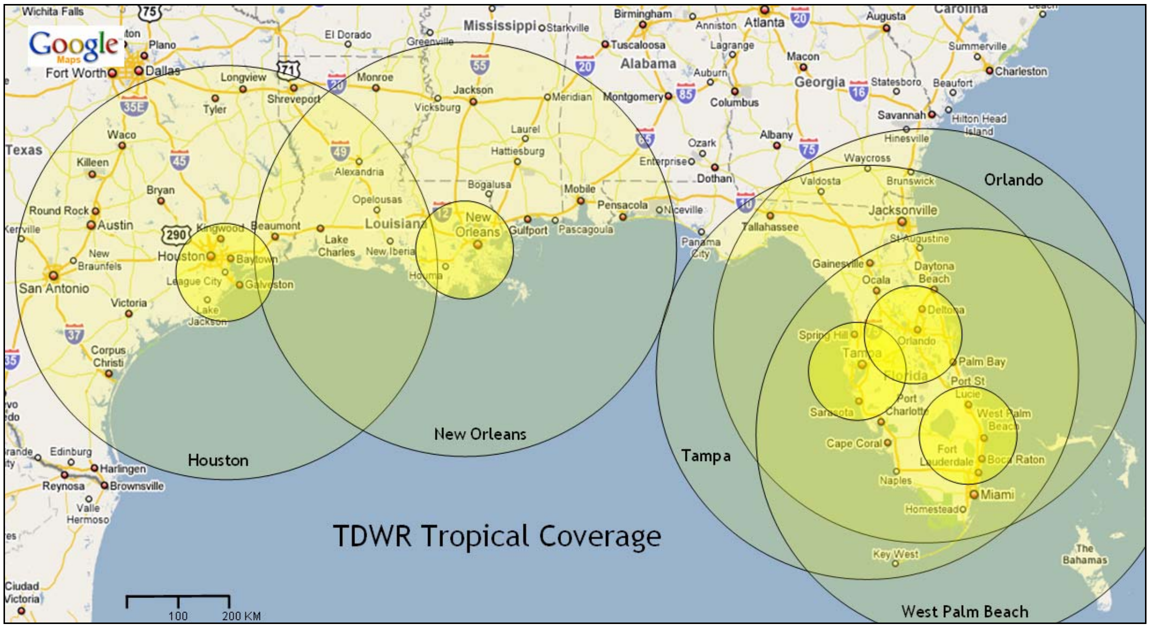

Figure 2. Deployment of SPG systems along the Atlantic and Gulf coasts prior to the 2007 hurricane season. Outer ring shows maximum reflectivity coverage (416 km/225 nm). Inner ring shows maximum Doppler coverage (90 km/56 nm).

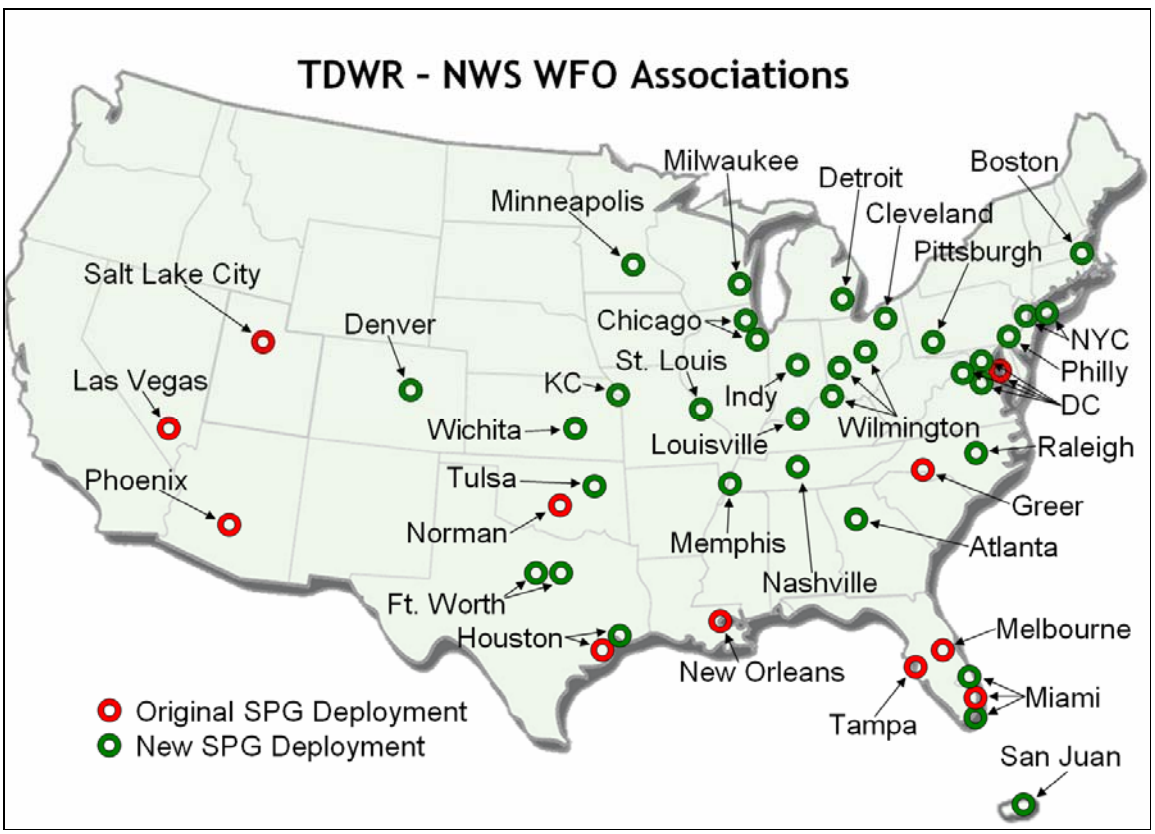

Figure 3. Initial deployment (red circles) and new deployment (green circles) of TDWR SPG systems. NWS WFO associations are shown as text. Each WFO will have one SPG for each TDWR connection. SPG deployment will be completed by the end of September 2008.

4. SPG BUILD 3 STATUS

Design and testing of the third build of the SPG has been completed. Figure 1 shows that the major emphasis of this build was to provide a full suite of storm analysis, derived reflectivity and precipitation products.

4.1 *Storm Analysis Algorithms and Products*

In SPG Build 3, several WSR-88D storm analysis algorithms were adapted to accept TDWR data as input and to run on the SPG. These included Storm Cell Identification and Tracking, the Hail Detection Algorithm, the Mesocyclone Detection Algorithm, and the Tornado Vortex Signature algorithm. The corresponding output products are Storm Tracking Information (STI), Hail Index (HI), Mesocyclone Detection (MD), Digital Mesocyclone Detection (DMD), and Tornadic Vortex Signature (TVS).

The TDWR "monitor mode" scanning strategy, called VCP 90, is similar to a WSR-88D VCP in that a single volume scan progresses from the lowest elevation angle to the highest, in a sequential order. Therefore, modifications to the WSR-88D algorithms for operation within VCP 90 were not required. However, the TDWR "hazardous mode" scanning strategy, called VCP 80, presented a challenge for algorithm redesign due to its non-continuous pattern of elevation scans and duplicate elevation angles that occur within a single volume scan. An example of the VCP 80 scanning strategy for the Baltimore Washington International (BWI) Airport TDWR is shown in Figure 4.

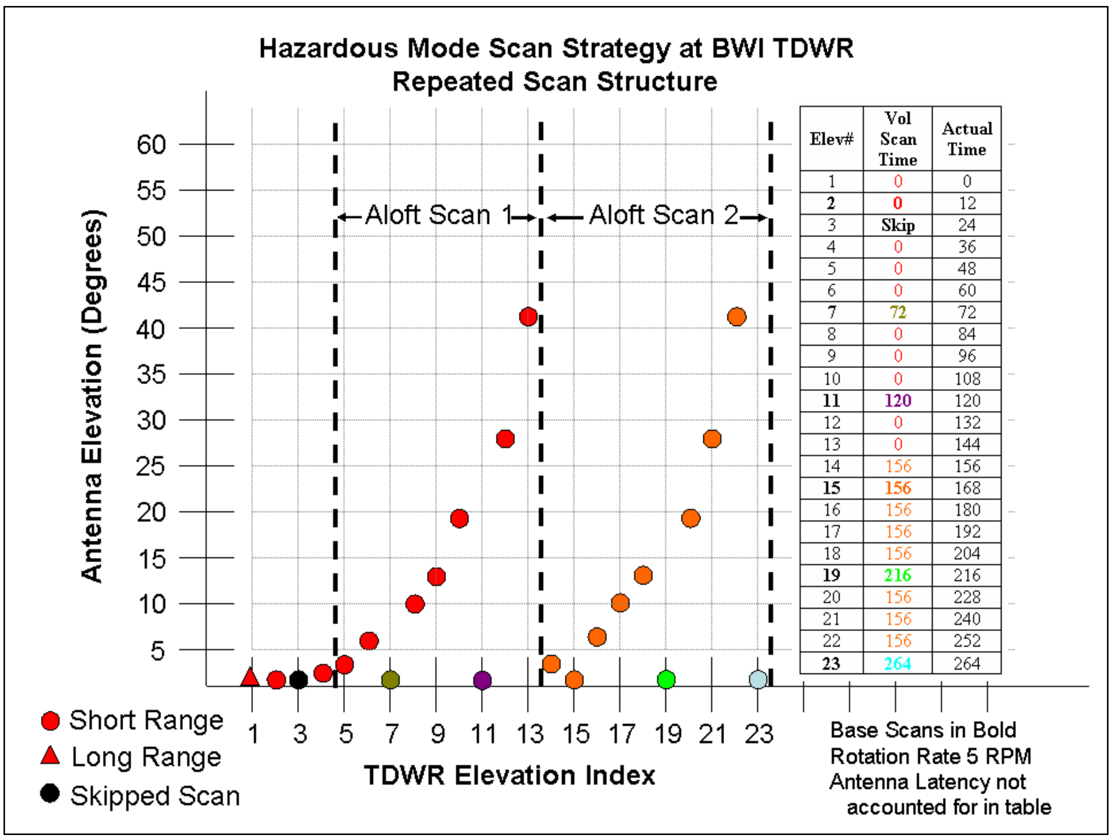

Figure 4. The repeated scan structure of the TDWR hazardous weather mode, VCP 80 (as customized for the Baltimore-Washington International Airport (BWI) TDWR)

The VCP 80 scanning strategy contains two nearly identical “mini-volumes” within a single volume scan. The WSR-88D storm analysis algorithms were modified to take advantage of these two mini-volumes by identifying meteorological features within each. This results in STI, HI, MD, DMD, and TVS products being produced at three-minute intervals, or twice during each six minute VCP 80 volume scan. The only factor keeping the two mini-volumes from being identical is that the 1.0-degree elevation is only scanned in the first mini-volume. To account for the missing 1.0-degree elevation data in the second mini-volume, the 1.0-degree data from the first mini-volume is reused by the algorithms in the second mini-volume. Features detected on the 1.0-degree elevation in the first mini-volume are not spatially advanced to account for the time difference between the mini-volumes. Testing has shown that this is generally not an issue with the storm analysis algorithms although there is a potential for misidentification of features in the second mini-volume when environmental conditions result in very fast moving storm cells.

At most TDWR sites, VCP 80 includes maximum elevation angles up to 42.5 degrees and VCP 90 contains maximum elevations as high as 60 degrees. However, the SPG storm analysis algorithms stop processing in both VCPs at a predefined elevation index, which is about 13.5 degrees but varies by TDWR site because each site's VCP definitions contain unique elevation angles. Stopping the storm analysis algorithms at a predefined elevation index was done because the algorithms were not designed to handle the large vertical spatial gaps that exist between the higher TDWR elevation angles and to improve timeliness of product delivery.

Figure 5 contains examples of storm analysis products generated from the Newark, NJ (TEWR) TDWR. The left image shows a tornadic vortex signature while the right image shows the associated mesocyclone. Both images are from 20UTC 11 October, 2007.

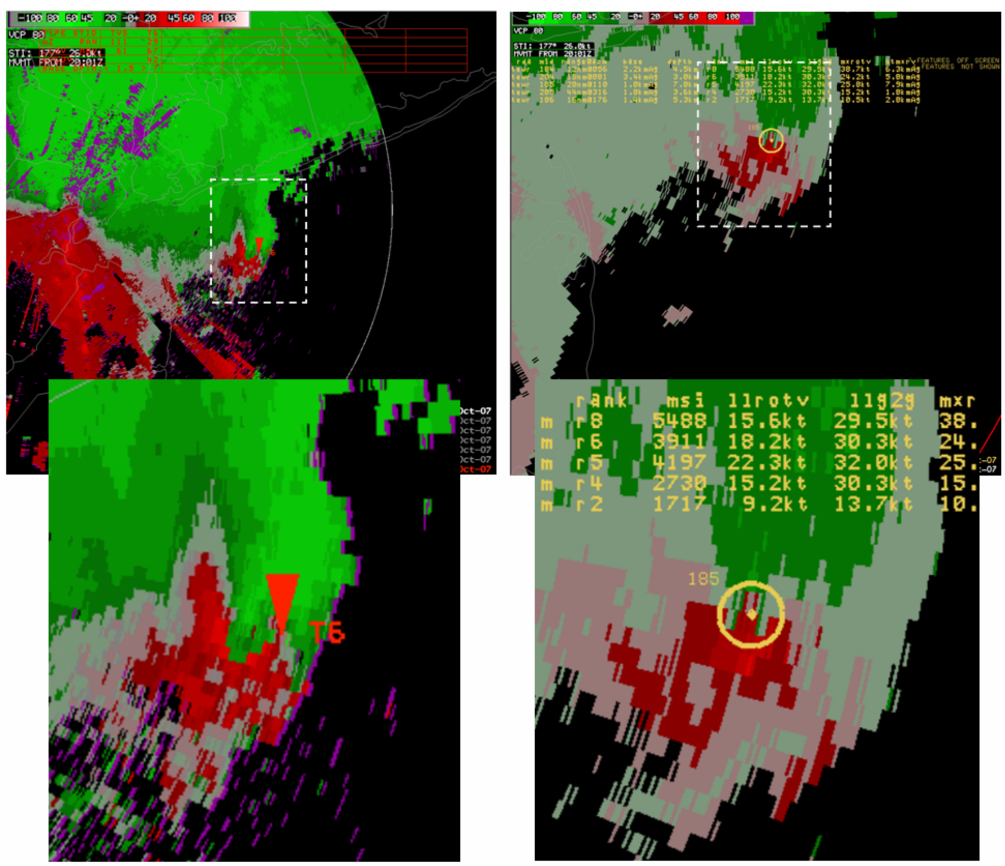

Figure 5. Storm analysis products from the Newark, NJ TDWR from 20UTC 11 October, 2007. The left image shows the identification of a tornadic vortex signature (TVS). An enlargement of the inset box is at the lower left. The tornado’s associated mesocyclonic signature can be seen in the right image with an enlargement of its inset box available at the lower right.

4.2 *Derived Reflectivity Algorithms and Products*

Algorithms for several products derived from base reflectivity data were converted to run on the SPG in Build 3. The converted algorithms included Vertically Integrated Liquid, Echo Tops and Composite Reflectivity. The corresponding output products were Vertically Integrated Liquid (VIL), Echo Tops (ET) and Composite Reflectivity (CR/CZ).

As described in Section 4.1, derived reflectivity algorithm logic was modified slightly to handle hazardous weather mode. The VIL, ET and CR/CZ products are generated for each VCP 80 "mini-volume", and thus are available every three minutes during VCP 80. Unlike the storm analysis products, the derived reflectivity algorithms process the entire range of TDWR elevation angles.

Examples of derived velocity products can be seen in Figure 6. The left image shows a composite reflectivity product with STI overlaid from the BWI TDWR (14:08UTC 15 Nov 2007). The right image shows VIL and STI for the next "mini-volume" at 14:11UTC.

4.3 *Precipitation Algorithms and Products*

SPG Build 3 includes the entire suite of RPG-based precipitation algorithms and products. This includes the following products:

- One-Hour Precipitation (OHP)
- Three-Hour Precipitation (THP)
- User-Selectable Precipitation (USP)
- Storm Total Precipitation (STP)
- Hourly Digital Precipitation Array (DPA)
- Digital Storm Total Precipitation (DSP)
- Supplemental Precipitation Data (SPD)
- Digital Hybrid Scan Reflectivity (DHR)
- Hybrid Scan Reflectivity (HSR)

The precipitation products are provided to AWIPS using the same range, resolution and formats that are produced by the WSR-88D RPG. This similarity among products was done to limit the changes needed to the Precipitation Processing System (PPS) and for downstream applications within AWIPS such as the Flash Flood Monitoring and Prediction (FFMP) system and the Multi-sensor Precipitation Estimator (MPE).

There are a few important differences between RPG and SPG-based precipitation processing. The SPG precipitation products utilize only data from the long range low elevation angle scan, which is the first scan of each full volume. This constraint was introduced because the TDWR scanning strategies are different for each radar, and there is only one elevation scan per volume with reflectivity data out to a long range (230 km/125 nm), and this scan uses a very low Pulse Repetition Frequency (PRF) and therefore will not contain data voids from range folded echoes. Also, within the SPG PPS, there is no accounting for terrain blockage.

There are additional differences in data processing. The resolution of the reflectivity data used in the SPG PPS is reduced from its 300 m sample length to the native WSR-88D (1000 m) sample length. In addition, the reflectivity data are not filtered by the RPG's Radar Echo Classifier (REC) algorithm because the TDWR uses an alternative clutter filtering scheme. Finally, compared to the WSR-88D, the TDWR SPG-based precipitation estimates are subject to more attenuation at greater ranges beyond areas of heavy precipitation because the TDWR uses a 5 cm wavelength (versus the 10 cm wavelength used in the WSR-88D).

4.4 *AWIPS Enhancement*

AWIPS Operational Build (OB) 8.2 has been enhanced to handle the TDWR SPG Build 3 products: STI, MD, DMD, TVS, HI, VIL, ET, CZ, USP, OHP, THP, STP, DPA, DSP, SPD, HSR and DHR. The SPG products are processed in AWIPS in the same way that RPG products are processed. Therefore, users will be familiar with how to request, decode, store and display the new products, and minimal infrastructure changes were required to add this capability. AWIPS OB 8.2 has finished its Beta test and will be deployed in 2008.

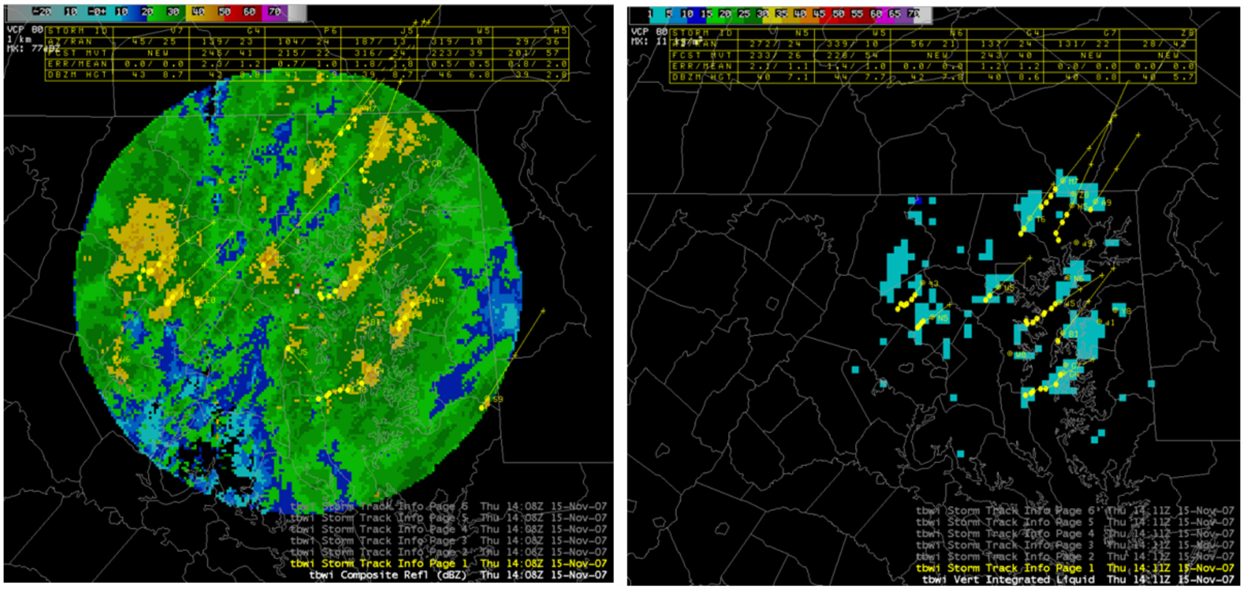

Figure 6. Derived reflectivity products from the BWI TDWR. Composite reflectivity with storm tracking information is from 14:08 UTC 15 Nov 2007 (left image). Vertically integrated liquid with storm tracking information is from 14:11 UTC 15 Nov 2007 (right image).

5. TDWR SYSTEM ENHANCEMENTS

5.1 *TDWR System Modernization Overview*

In 2002, the FAA determined that the TDWR Radar Data Acquisition (RDA) subsystem needed replacement to improve supportability. The signal processor in the system was proprietary, had no expansion capabilities, and was becoming unsupportable. The FAA funded MIT Lincoln Laboratory to develop an engineering prototype that consists of a COTS open systems hardware platform, easily expandable, and easy to support. Initially, the new system will provide the same functional capability as the current legacy system. Once the functional equivalence has been demonstrated, the new hardware along with changes in processing algorithms will eventually allow operational improvements to the quality of the base data (Cho, Elkin & Parker, 2005).

In accordance with FAA's policies, RDA system changes were tested on two non-operational TDWRs located at the Program Support Facility (PSF) and the training academy in Oklahoma City, OK. After considerable integration and testing, the system was accepted for key-site testing at an operational site. In the spring of 2007, the system was installed at Salt Lake City, UT (SLC), and subsequently at Las Vegas, NV (LAS) with a plan of collecting summertime gust front and microburst data needed for algorithm improvement validation. After considerable field testing, the prototype system was removed from both sites because of intermittent failures of its automatic calibration system. Through extensive troubleshooting, once the error is found and tested, the key-site testing will resume with a projected restart time in early 2008.

5.2 *TDWR Projected Changes*

The initial rehosting of the RDA is designed to mimic the present functionality of the TDWR with no base data format changes (designated as RDA Build 1). The system must pass the required key-site testing at SLC and LAS before any future changes can be made. The new signal processor will allow the use of more modern algorithms and more flexible transmitter control to improve the overall data quality. Less range folding and superior velocity dealiasing will be possible through adaptive selection algorithms developed by Lincoln Laboratory (Cho 2005, Cho & Chornoboy 2005, Cho 2006). These algorithms were developed using simulated data and real weather data recorded at the PSF. They are currently (winter 2008) being tested at the PSF in a non-operational mode (designated as RDA Build 2). Because the RDA Build 1 base data stream is used by an operational FAA weather processor and display system (the Integrated Terminal Weather System) there can be no changes in the base data format at this time.

In RDA Build 2, the transmitter waveform and antenna scanning strategy will be changed but the derived products will still adhere to the present base data format. Within the TDWR data stream, only one parameter in the header field will be changed. This field contains the Pulse Repetition Interval (PRI). Further investigation will be needed to determine the impact of this minor change on the ITWS operational software. A revised scanning strategy will allow the elimination of one duplicate low elevation 90 km scan used for velocity dealiasing and allow the addition of an extra low elevation scan.

Perhaps the most significant format change involves the velocity data fields. In RDA Build 2, the new velocity algorithm will only provide dealiased velocity output and not the unprocessed velocity fields as included in RDA Build 1. In order to maintain format consistency for ITWS, the new dealiased velocity field will be duplicated within the base data stream. The mixture of waveform algorithms and scanning strategy used are still under test evaluation and may change when more data become available.

At the time of this writing, the Pulse Repetition Interval algorithm sequence follows the scheme shown in the following table (Cho, 2007):

Elevation (EL)	**Mode**	**RV Ambiguity Requirement**
Surface (Lowest)	LP	RV
Surface (Lowest)	DP/MP*	RV
Lowest < EL < 11.9°	DP	RV
≥11.9°	SP	V

*Adaptive selection of either DP or MP

In this table:

- LP is the long-PRI scan used to select either the multi-PRI (MP) or dual-PRI (DP) modes on a radial-by-radial basis in the subsequent scan.
- MP is the multi-PRI mode using PRI pulses from different out-of-trip range gates where no range folding is present. Velocity dealiasing is performed within each radial using the “clean” estimates.
- DP is the dual-PRI phase-code mode where the PRI is switched between two values on every radial and velocity dealiasing is performed across adjacent radials. The DP mode is always performed on two radial pairs.
- SP is the staggered PRI mode (spectral processing is used to filter ground clutter when present; otherwise, pulse-pair processing is used on each PRI to provide two aliased velocities for generating the dealiased velocity).

Once the optimal waveform and algorithm methods are determined, a baseline version of RDA Build 2 could be fielded once ITWS has been tested and modified to accommodate the new scanning strategy and header change. However, there is presently an effort under way to test the new Sigmet RVP9 for use in the TDWR rehosting instead of the RVP8. A RDA Build 3, consisting of hardware and software changes, would be tested at the PSF, key-site tested, and then fielded. At that time, there would be the opportunity to change the base data format to better utilize communication bandwidth and storage requirements through the elimination of the redundant velocity field, the Signal-to-Noise Ratio field (which can be recreated at the user end), and the addition of housekeeping information such as site magnetic declination, version number, and the PRI pair that was used.

5.3 *Data Compression*

The legacy TDWR Product Generator transmits base data over a local Ethernet for both local and external use using the User Datagram Protocol (UDP). Lincoln Laboratory has added a data compression computer to a number of sites for the purpose of establishing a reliable connection over long distances back to Boston at a much lower telecommunication cost for support of several FAA programs. During 2008, the FAA will be formulating requirements meeting the needs of the FAA, NWS, and Lincoln Laboratory for data compression. To implement such a change to the baseline system, extensive analysis and modification will be needed for the FAA external systems. At this time, the FAA does not have any internal requirements for data compression but at the request of Lincoln Laboratory and NWS, they will examine and consider data compression as an option for external users.

6. FUTURE PLANS

With the deployment of SPG Build 3, the NWS will have a robust hardware/software architecture and set of scientific algorithms for utilizing TDWR data. As with any new sensing and product generation capability, however, it is expected that operational experience will indicate ways to improve the initial algorithms (and perhaps development of new ones) for better utilization of the fine scale temporal and spatial data. When funding is established, the TDWR base data (formatted to emulate WSR-88D Level II) will be centrally collected, distributed and archived. The data will then be available for development of innovative uses by the laboratory, numerical modeling and private sector communities.

In addition to its use with TDWR data, the SPG is anticipated to be the NWS foundation architecture for ingesting and processing data from other 'target-of-opportunity' radars such as FAA (e.g., ARSR-4, ASR-11, ASR-9), private sector (e.g., TV stations), and international (e.g., Canadian, Mexican and Caribbean). Some of these radars have limited weather data (perhaps reflectivity only) and vastly different sensing capabilities from the WSR-88D and TDWR, but would be useful to mitigate areas of poorer coverage from WSR-88Ds and TDWRs. While base data products from these radars should always be useful, there should also be value for precipitation estimation, storm cell identification/tracking and general backup for WSR-88D outages.

7. SUMMARY

NOAA's NWS has been developing and deploying a system to ingest data from the FAA's Terminal Doppler Weather Radar (TDWR) over the last several years. To date, communications connections and installation of 11 Supplemental Product Generators (SPG) have been delivered to NWS Weather Forecast Offices (WFO). These initial prototype systems have worked with 2 builds of the processing system and have shown that TDWR data can provide valuable information for forecasts and warnings as well as allow for integration and display within AWIPS.

Deployment of SPG systems to connect the remaining TDWRs to NWS WFOs will begin during the spring of 2008 and is expected to be completed by the end of September 2008. Simultaneously, Build 3 of the SPG processing system will be deployed which will provide a full suite of storm analysis, derived reflectivity and precipitation products to the WFOs.

While the SPG continues to evolve, the FAA has contracted with MIT Lincoln Laboratory to design and develop a modernized Radar Data Acquisition (RDA) processor. Details about potential changes to internal formats, data streams and dealiasing methodologies have been described or referenced. The changes and deployment of the modernized RDA will still take a couple of years.

Finally, with the success of the TDWR SPG program, the NWS is now looking at using this architecture to possibly ingest other types of radars from the government, private sector and from partner nations.

8. ACKNOWLEDGEMENTS

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