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FUTURE TERMINAL DOPPLER WEATHER RADAR (TDWR) PRODUCTS FOR NWS OPERATIONS

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1. INTRODUCTION

For several years, the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) has been evaluating the feasibility of utilizing weather data from radar systems that are owned and operated by other federal agencies. The Terminal Doppler Weather Radar (TDWR) of the Federal Aviation Administration (FAA) is a system that is optimized for hydro-meteorological surveillance and was selected as a candidate for inclusion into NWS operations. Several papers have been written on the engineering that was required to modify a Radar Product Generator (RPG) to handle non-NWS radar data streams (Istok, 2004, Stern, 2004, Istok, 2005 and Istok, 2006). The result was the creation of the Supplemental Product Generator (SPG) which has been successfully deployed to 10 NWS Weather Forecast Offices (WFO) (Stern, 2006). Data from the SPG is able to flow seamlessly into the NWS operational workstation, the Advanced Weather Interactive Processing System (AWIPS).

The initial deployment of the SPG (Phase 1) generated only a handful of base products. Work on a second phase of the SPG was completed in the fall of 2006. This 'Phase 2' system provides a richer suite of products including taking full advantage of the data resolution available in the TDWR. Software engineering has begun on the 'Phase 3' SPG system which is envisioned to include storm cell tracking and severe weather identification products as well as the full spectrum of precipitation products.

This paper will document and provide examples of the SPG products generated using TDWR data ranging from the initial Phase 1 deployment to what is expected to be included in SPG Phase 3.

2. SUMMARY OF PHASE 1 PRODUCTS

The Phase 1 deployment of the TDWR SPG occurred during the summer and fall of 2005. A total of 10 systems were installed at WFOs around the country with a particular emphasis on locating systems along the hurricane prone Gulf and southeast Atlantic coasts. Figure 1 shows the SPG Phase 1 deployment locations in green on the national map. Table 1 provides associations with TDWR locations and NWS WFOs. TDWR systems provided supplemental information to NWS forecasters during hurricanes Katrina, Rita and Wilma during the record breaking 2005 tropical cyclone season.

The inventory of products included in the SPG Phase 1 deployment was limited to the suite of products associated with the base moments; reflectivity, velocity and spectrum width (Table 2).

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The scanning strategy of the TDWR implements one long range, low elevation reflectivity scan for each volume (for range folding mitigation). The resulting long range reflectivity product has a range resolution of 600 meters (m) to a range of 150 nm (276 km). All remaining base products have a maximum range of 48 nm (90 km) (which is truncated when the elevation crosses 70,000 feet). Due to initial software limitations in the Phase 1 SPG, rather than displaying at its full resolution, the short range reflectivity product displayed a range resolution of 300 m. The Doppler moment-based products (base radial velocity and spectrum width), contained the native TDWR range resolution of 150 m.

Even though the Phase 1 SPG did not provide algorithms for advanced products, forecasters were still able to take advantage of the high resolution data and rapid (1-minute) update capability in their warning programs. Figure 2 shows a supercell as seen by the Greenville/Spartanburg, SC (KGSP) Weather Surveillance Radar, 1988 Doppler (WSR-88D). The 8-bit reflectivity image at 0.5 degree elevation was captured at 1840 UTC, 14 May, 2006, or 8 minutes before the reported tornado touchdown.

Figure 3 displays the same supercell as seen by the Charlotte, NC (TCLT) TDWR. This reflectivity product, at 1.0 elevation, shows a benefit of the 150 m resolution by clearly illustrating a well developed hook and weak echo region. This image, captured at 1842 UTC, shows the storm 6 minutes prior to tornado touchdown. The ability to view the storm from different vantage points and at a higher resolution allowed forecasters to issue a tornado warning with 37 minutes of lead time. The tornado eventually produced F1 damage in Cabarrus County, SC.

3. OVERVIEW OF PHASE 2 PRODUCTS

Development of SPG Phase 2 products began during the fall of 2005 and was completed during the summer of 2006. The emphasis during this developmental cycle was to improve the system infrastructure so that the SPG could take advantage of the TDWR's full data resolution. In addition, an evaluation ensued to determine if native TDWR data could be used as input to WSR-88D algorithms for product generation.

One big advantage to the Phase 2 SPG was that it was based upon the NWS Radar Product Generator (RPG) Build 8 which eased restrictions on the number of bins that could be processed in base data radials containing reflectivity data. This change allowed the short range reflectivity product to improve its range resolution from 300 m to 150 m. The long range reflectivity product was also able to double its range resolution from 600 m to 300 m and to extend its displayable range from 150 nm (276 km) to 225 nm (416 km) (Table 2).

In a first attempt to take legacy RPG algorithms and convert them to accept TDWR data, three new products were introduced in SPG Phase 2. These products were the:

- Velocity Azimuth Display (VAD) product
- VAD Wind Profile (VWP) product
- User Layer Reflectivity (ULR) product

It was found that only a minimal number of modifications were needed to have the products generate properly on the SPG. Figure 4 provides an example of both the VWP and long range reflectivity products for tropical depression Ernesto. These products, from the Baltimore (TBWI) TDWR at 2112 UTC on 1 September, 2006, show Ernesto's rain shield spreading north into Pennsylvania with increasing low level northeast winds. The dashed orange ring in the reflectivity image shows the maximum range (48 mi) of the velocity and short range reflectivity products.

In addition to products, the Phase 2 SPG provides new options for data processing. This version allows data to be processed using either the 0.5 meter/second (m/s, 0.97 knots) or the 1.0 m/s (1.94 knots) velocity mode interval. This capability could be important during tropical cyclone landfalls or strong convective events. Also, the Phase 2 SPG allows operators to select the velocity dealiasing methodology. Either the native TDWR dealiased velocity can be used or the legacy WSR-88D dealiasing algorithm can be selected for downstream algorithms and product generation. All of the SPG Phase 2 products are available in AWIPS with Operational Build 7.2 (OB7.2) via routine product set, dedicated and WAN-based class 2 one-time-request capabilities.

3.1 *Experimental Data Feed for SPG Phase 2*

The Massachusetts Institute of Technology (MIT) Lincoln Laboratory has been working with TDWR data on behalf of the FAA. To support their research, they have access to nearly a dozen TDWR systems extending from the upper Midwest to the Northeast. Figure 1 shows the locations of these sites in magenta. During the summer and fall of 2006, MIT made data from these radars available to the NWS for internal use. A subset of SPG Phase 2 products were made available to associated NWS WFOs for evaluation.

One example of the MIT data can be found in Figure 5. This case provides a first look at the same storm from four nearby TDWR systems simultaneously. The four panel image contains base velocity data from the lowest elevation scans and depicts different views of a microburst developing over northern Fairfax County, VA of the National Capital Area at 0030 UTC 4 August, 2006. The three closest TDWRs (TDCA, TIAD and TADW) displayed wind velocities of 45 knots between 1100 and 1600 feet.

4. PLANNED PHASE 3 PRODUCTS

The Phase 3 SPG will be based upon the RPG Build 9. This will allow for entire suites of legacy algorithms to be translated for use on the SPG. Deployment of Phase 3 software to SPG sites is expected to take place during the fall of 2007. Supporting changes are planned in AWIPS OB8.3 to enable the request and display of SPG Phase 3 products.

While there are numerous similarities between the WSR-88D and the TDWR, the structure of the TDWR scanning strategies will make translating some of the Phase 3 algorithms a challenge. The TDWR monitor mode generally contains increasing elevation angles with each scan in the volume. However the TDWR hazardous weather mode utilizes a much more complex strategy of generating a low elevation scan every minute and repeating most aloft scans twice per volume (every 3 minutes). While the faster low elevation update rate can be a benefit for such phenomena as downburst detection, there may be issues associated with scan timing and surveillance gaps between the elevations.

The SPG Phase 3 product suite is expected to include the full inventory of products generated in previous releases. In addition, there will be new products from three families of algorithms (see Table 3). The Storm Analysis Products family will include products such as Storm Cell Identification and Tracking, Mesocyclone Detection, Tornado Vortex Signature, and the Hail Index. More sophisticated reflectivity-based products will also be available. These products are envisioned to include Composite Reflectivity and Vertically Integrated Liquid along with their digital counterparts.

The entire suite of existing RPG precipitation products is planned for SPG Phase 3. These SPG precipitation products will be at the same range and resolution as their RPG counterparts. This was done primarily to limit the changes needed to a) the Precipitation Processing System (PPS) and to b) AWIPS and downstream applications such as Flash Flood Monitoring and Prediction (FFMP) and the Multi-sensor Precipitation Estimator (MPE).

In this initial implementation there are some features from the RPG precipitation processing that are not included in the SPG. Since the ranges of reflectivity data and scanning strategies are different, the precipitation products use only data from the long range low elevation angle scan. In addition, there is no accounting for terrain blockages. Finally, there is no data filtering by the Radar Echo Classifier (REC) algorithm because the TDWR uses an alternative clutter filtering scheme.

Figure 6 provides an example to compare precipitation products. The left image shows the One Hour Precipitation (OHP) accumulation product from the WSR-88D located in Sterling, VA (KLWX). The right image shows the same OHP product but generated using the SPG Phase 3 prototype using data from the Baltimore, MD TDWR (TBWI). Both images are for the same time, 0222 UTC, 7 June 2005. The red stars in the images represent the locations of respective radars. The SPG-generated OHP product shows less accumulated precipitation from several possible factors:

1. The inherent differences in attenuation characteristics between S-band and C-band radars (including signal attenuation by intervening precipitation),
2. Different viewing angles and the subsequent sampling of different vertical layers, and
3. Radar calibration differences.

5. SUMMARY

The TDWR has become a valuable asset in the NWS toolbox of weather surveillance capabilities. Its high resolution data and rapid low elevation refresh rate have provided forecasters with quality information that has already positively impacted severe weather warnings and short term forecasts. Several examples of severe weather as observed by TDWRs have been provided here.

The TDWR SPG is continuing to evolve with completion of Phase 2 software and new full resolution products during the fall of 2006. Phase 3 of the SPG is expected to be completed during the fall of 2007 and will have many new products from the storm analysis and precipitation processing algorithms.

6. REFERENCES

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Table 1 – TDWR/WFO associations for deployed SPG Phase 1 systems

TDWR Location	Associated NWS WFO
Salt Lake City (TSLC)	WFO Salt Lake City
Las Vegas (TLAS)	WFO Las Vegas
Phoenix (TPHX)	WFO Phoenix
Oklahoma City (TOKC)	WFO Norman & Radar Operations Center (ROC)
Houston (THOU)	WFO Houston/Galveston
New Orleans (TMSY)	WFO Slidell
Orlando (TMCO)	WFO Melbourne
West Palm Beach (TPBI)	WFO Miami
Baltimore (TBWI)	WFO Sterling
Charlotte (TCLT)	WFO Greenville/Spartanburg

Table 2 - SPG product specifications (Phase 1 & 2)

		SPG Phase 1		SPG Phase 2	
Product Type	**Data Res**	**Range**	**Range Res**	**Range**	**Range Res**
Long Range Reflectivity	4-bit	150 nm / 276 km	600 m	225 nm / 416 km	300 m
	8-bit	150 nm / 276 km	600 m	225 nm / 416 km	300 m
Short Range Reflectivity	4 bit	48 nm / 90 km	300 m	48 nm / 90 km	150 m
	8-bit	48 nm / 90 km	300 m	48 nm / 90 km	150 m
Base Radial Velocity	4-bit	48 nm / 90 km	150 m	48 nm / 90 km	150 m
	8-bit	48 nm / 90 km	150 m	48 nm / 90 km	150 m
Base Spectrum Width	4-bit	48 nm / 90 km	150 m	48 nm / 90 km	150 m
Velocity Azimuth Display (VAD)	--	--	--	--	--
VAD Wind Profile (VWP)	--	--	--	--	--
User Layer Reflectivity (ULR)	4-bit	--	--	48 nm / 90 km	150 m

Table 3 – Envisioned SPG Phase 3 Products

Algorithm Family	Product Name
Storm Analysis Products	Mesocyclone Detection (MD and DMD)
	Tornado Vortex Signature (TVS)
	Storm Tracking Information (STI)
	Hail Index (HI)
Derived Reflectivity Products	Composite Reflectivity (CR)
	Vertically Integrated Liquid (VIL)
	Digital High Resolution VIL (DVL)
Precipitation Products	Digital Hybrid Scan Reflectivity (DHR)
	Hybrid Scan Reflectivity (HSR)
	User-Selectable Rainfall Accumulation (USP)
	One-Hour Precipitation (OHP)
	Three-Hour Precipitation (THP)
	Storm Total Precipitation (STP)
	Hourly Digital Precipitation Array (DPA)
	Digital Storm Total Precipitation (DSP)
	Supplemental Precipitation Data (SPD)

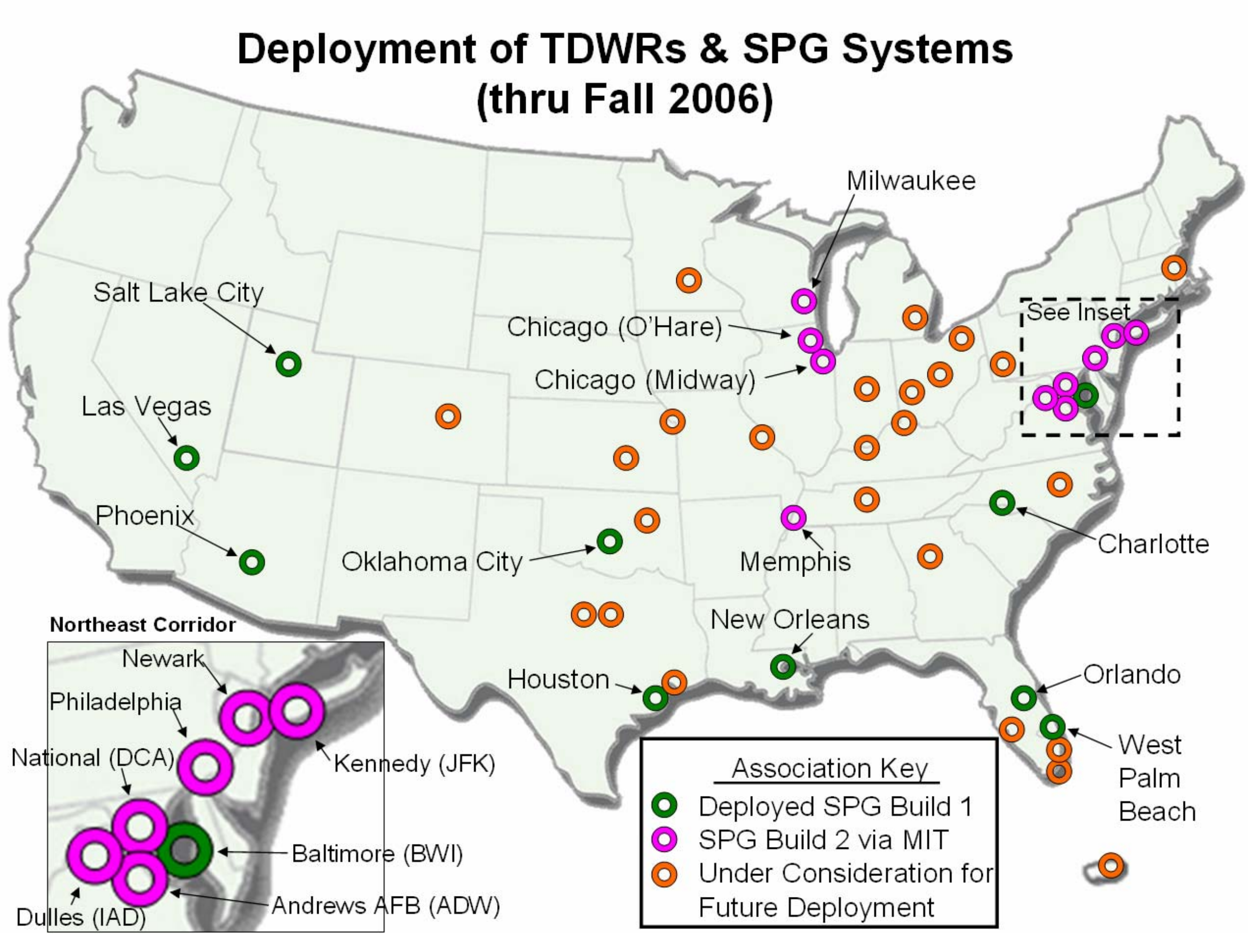

Figure 1 – TDWR locations across the contiguous U.S. and Puerto Rico. The green icons represent locations where SPG Phase 1 systems have been deployed. Table 1 provides a listing of those NWS WFOs that host the SPG Phase 1 systems. The magenta icons are TDWR systems that are accessed by MIT Lincoln Laboratory.

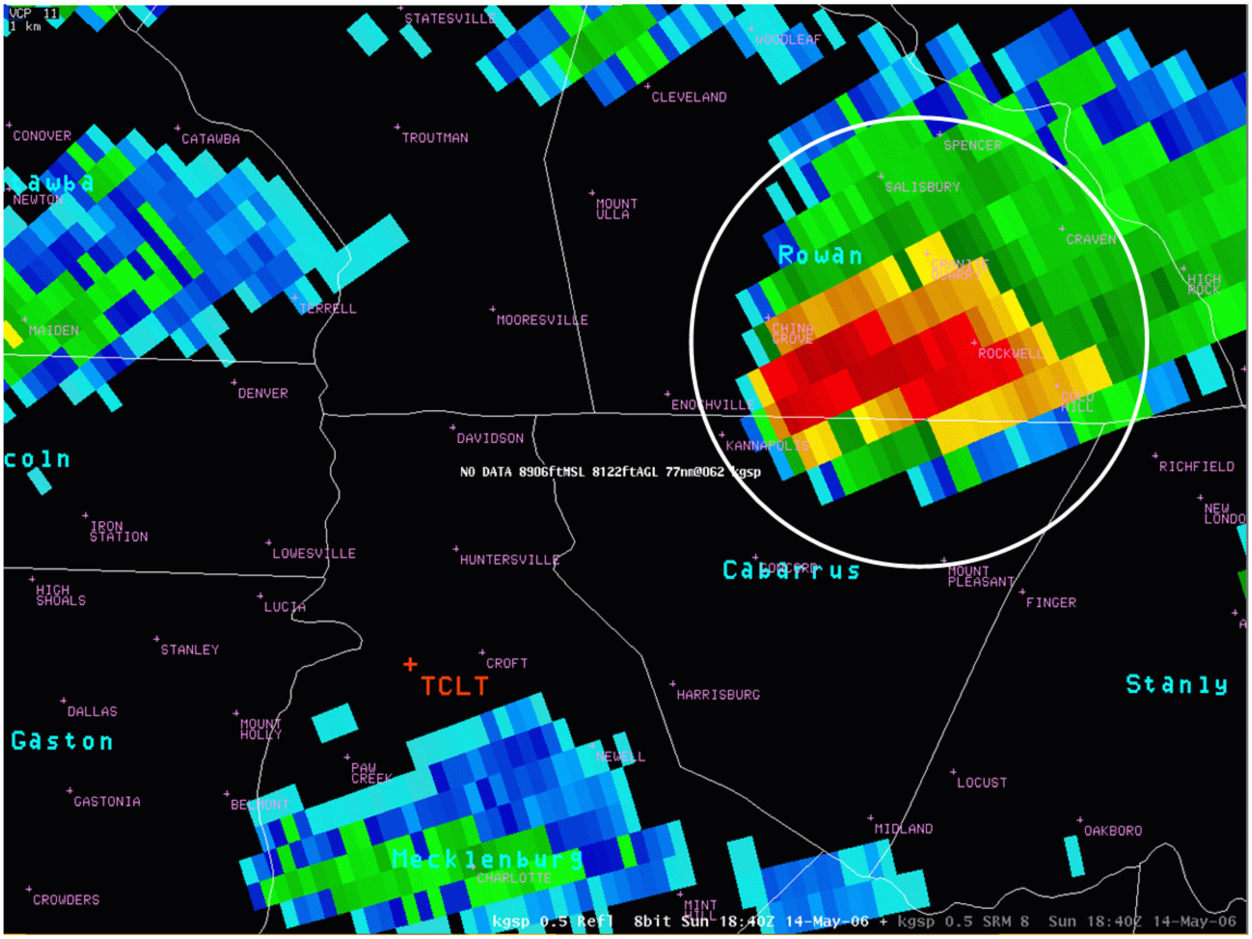

Figure 2 – WSR-88D reflectivity from KGSP (1 km resolution) at 1840 UTC, 14 May, 2006, 8 minutes before the tornado touchdown in Cabarrus County South Carolina. The radar is located off the image to the southwest. [Credit: Bryan McAvoy, WFO GSP]

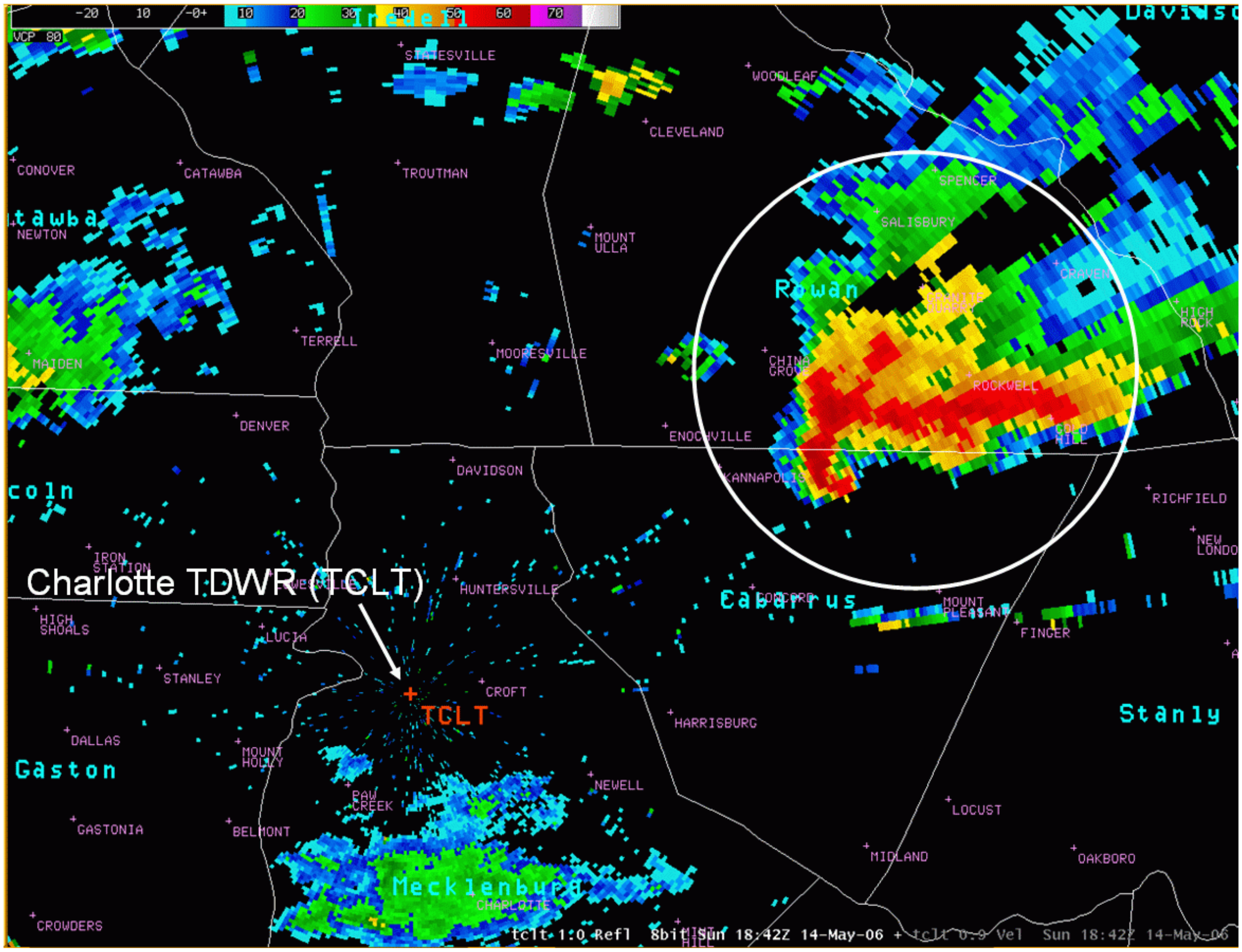

Figure 3 - TDWR reflectivity (300 m resolution) from Charlotte, NC (TCLT) at 1842 UTC, 14 May, 2006, 6 minutes before tornado touchdown in Cabarrus County, South Carolina [Credit: Bryan McAvoy, WFO GSP]

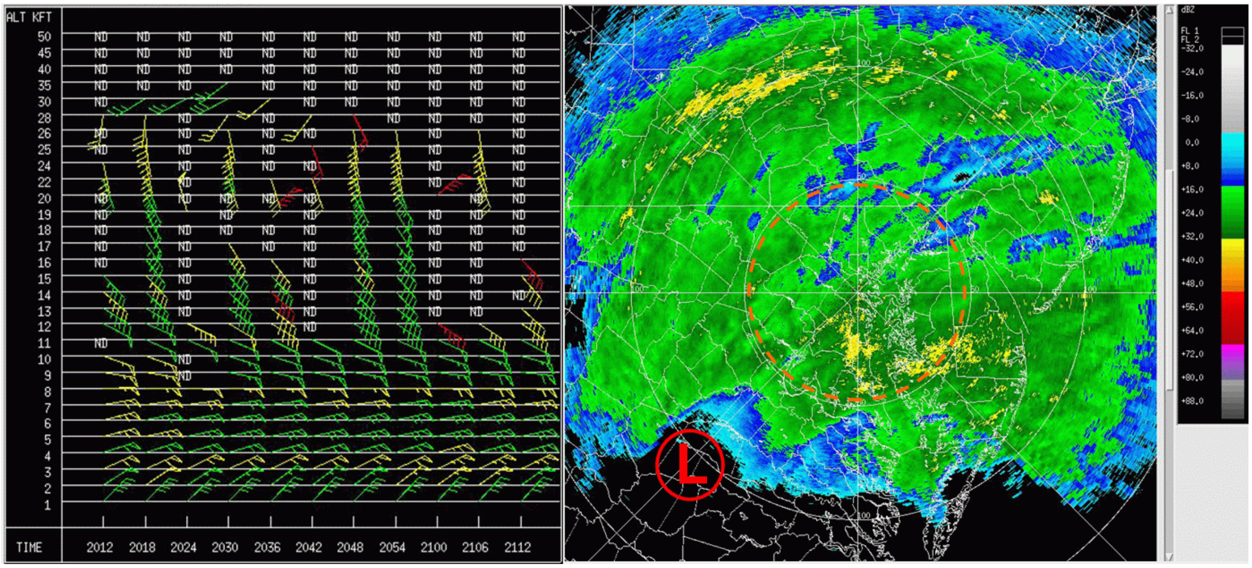

Figure 4 – VAD Wind Profile (left) and long range reflectivity product (right) from 2112 UTC, 1 September, 2006. The circled "L" in the right image represents the center of tropical depression Ernesto as it moved north over eastern Virginia. The dashed orange ring represents the extent of the short range reflectivity and Doppler products.

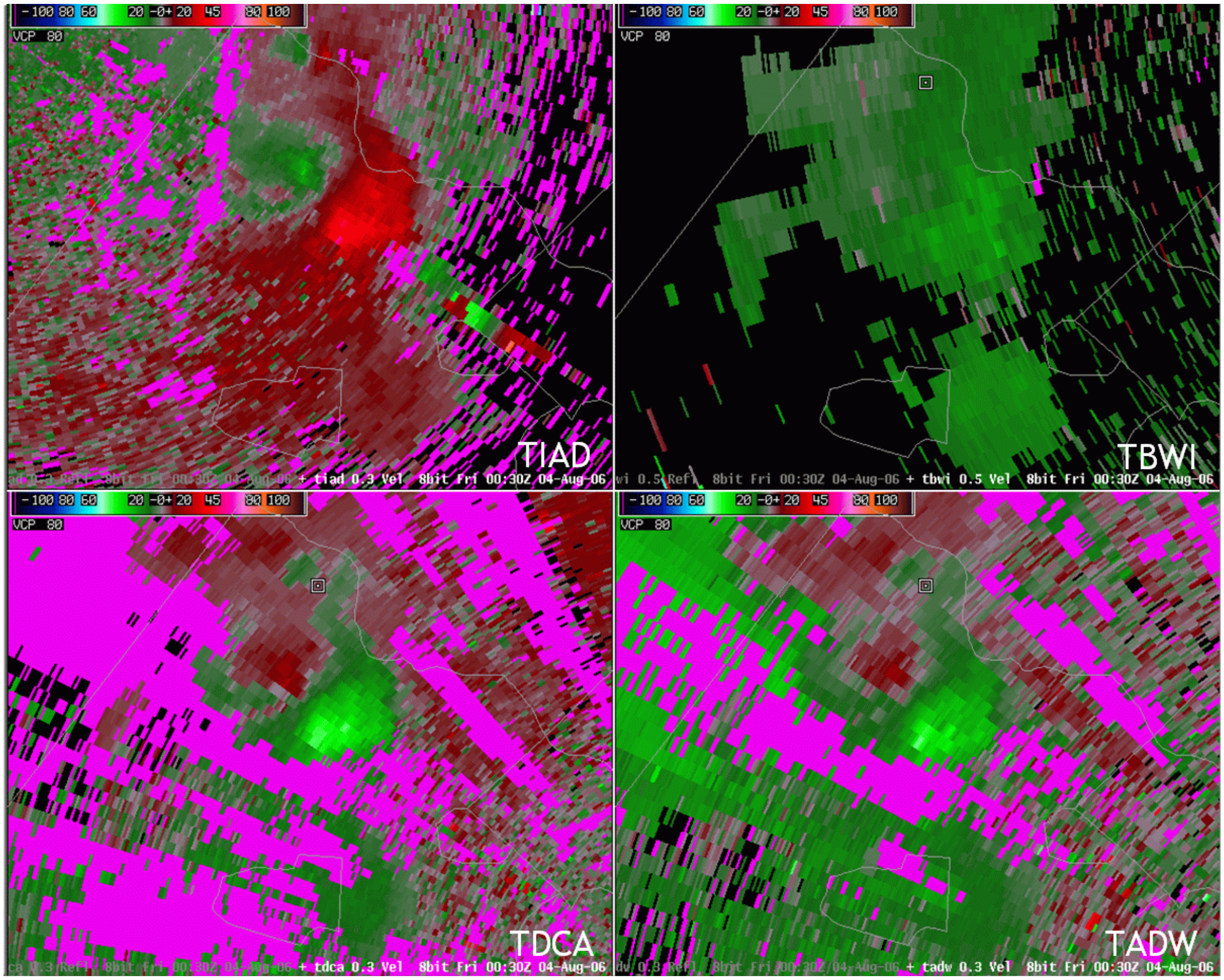

Figure 5- Base velocity data depicting a microburst viewed from four different TDWR systems simultaneously (0030 UTC, 4 August, 2006). The National Capital Area TDWRs are (clockwise, from upper left) TIAD (Washington Dulles, VA), TBWI (Baltimore, MD), TADW (Andrews Air Force Base, MD) and TDCA (Washington National, VA) [credit: Steve Rogowski, WFO LWX]

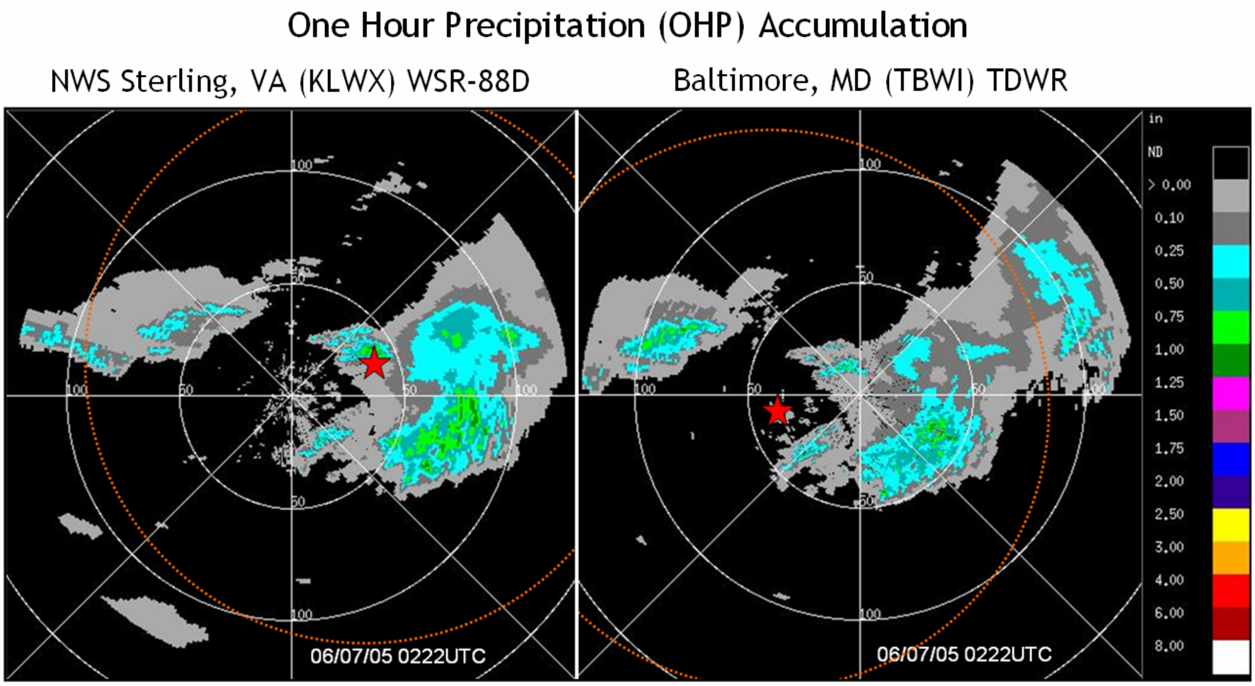

Figure 6 – Comparison of One Hour Precipitation (OHP) accumulation products for the Sterling, VA (KLWX) WSR-88D (left image) and the Baltimore, MD (TBWI) TDWR (right image). The red star in the left image represents the location of TBWI. Similarly, the red star in the right image represents the location of (KLWX). The dashed orange rings represent the 124 nm range of each neighboring radar centered on the red stars. The difference in the displayed accumulations is likely from a combination of signal attenuation, different radar viewing angles and differences in radar calibration.