8.1 **WSR-88D RADAR PROJECTS: 2013 UPDATE**

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1. INTRODUCTION

As of February 2013, the average age of the Nation's network of Weather Surveillance Radar-1988, Doppler (WSR-88D) systems was over 17 years. Since the radars were first deployed (1991-1997), the Next Generation Weather Radar (NEXRAD) Program has executed a nearly continuous program of hardware modifications, technology refreshments, pre-planned product improvement upgrades, and major radar science upgrades. The aim of this continual modification has been to avoid obsolescence, integrate new radar science into operations to meet new mission requirements, improve system maintainability and reliability, and control operations and maintenance costs. As a result, today's WSR-88D is "state of the art" and arguably the best operational S-band weather radar network in the world – and getting better.

This paper summarizes the Dual Polarization upgrade/modification program and major WSR-88D software projects underway in 2013. In addition, we will outline WSR-88D Level 2 and Terminal Doppler Weather Radar-Supplemental Product Generator (TDWR-SPG) plans, plus long-term planning for a WSR-88D service life extension program (SLEP).

2. DUAL POLARIZATION MODIFICATION STATUS

All of the NEXRAD triagency-owned (DOC, DoD, and DOT) WSR-88Ds are being modified to add Dual Polarization capability. As of the end of January 2013, 131 of 160 operational systems have been modified (Fig. 1). The final operational WSR-88D is scheduled for completion in June 2013. Deployment status, schedules, and other Dual Polarization information can be found at:
http://www.roc.noaa.gov/WSR88D/DualPol/Default.aspx.

The initial operational capabilities of Dual Polarization are described in Istok et al. (2009). Many NWS weather forecast offices have reported operational success stories enabled by the Dual Polarization upgrade. Examples include more precise forecasts and warnings of hail location and size, discrimination of winter storm precipitation types, and detection of tornado "debris" signatures confirming the presence of a tornado on the ground. Dual Polarization data has also increased forecaster confidence in many of the warnings they issue resulting in more storm-situational forecasts and warnings. The Dual Polarization upgrade has proven to be operationally reliable, as anticipated.

As with the initial deployment of the WSR-88D, or with any other major system upgrade, forecasters are building on their training as they gain experience with the new Dual Polarization capability. This on-going learning process will lead to new and further improved use of the Dual Polarization capability. In turn, this should lead to more specific and accurate forecasts and severe weather warnings. In addition, the initial meteorological algorithms and techniques developed within the central Oklahoma environment will be "tuned"/"regionalized" to the various climatic regimes in which WSR-88D systems operate in to further improve their performance – similar to what occurred with the fielding of the original WSR-88D.

3. SOON-TO-BE DEPLOYED SOFTWARE BUILDs

The ROC develops and distributes triagency-approved "major" software releases on an annual cycle, and "minor" releases, primarily for software security updates, occur more frequently. Configuration Change Requests that define the contents of each software build are available at:
http://www.roc.noaa.gov/WSR88D/BuildInfo/SWBuildsList.aspx

3.1 Software Build 13

Build 13 was installed on all dual polarized WSR-88Ds, except redundant-channel sites during the summer of 2012. This software upgrade provided forecasters new tools to improve their forecast and severe warning operations.

Build 13 re-introduced the Clutter Mitigation Decision (CMD) (Ice et al. 2009) and Automated Volume Scan Evaluation and Termination (AVSET) (Chrisman, 2009) algorithms. The major radar science upgrade in this build was the deployment of the Enhanced Velocity Azimuth Display (VAD) Wind Profile (EVWP) function (Chrisman and Smith, 2009). The EVWP function consistently provides ~50% more wind estimates than the legacy VWP algorithm. These

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additional wind estimates improve the overall operational usability of the VWP product. A comparison of the legacy and Enhanced VWP products based on the same data set is in Fig. 2**.**

3.2 Software Build 13.1

Build 13.1 is the latest software release. Deployment began in mid-January 2013. It re-introduces CMD and AVSET to sites modified to Dual Polarization status, including redundant-channel NWS and FAA WSR-88Ds. The major science upgrades in this build are the implementation of an improved spectrum width estimator and a new, improved velocity dealiasing algorithm. The dealiasing algorithm, called the 2-Dimensional Velocity Dealiasing Algorithm (2-D VDEAL) (Zittel and Zhongqi, 2012) is the first change to the WSR-88D velocity dealiasing algorithm. The 2-D VDEAL will be available for all volume coverage patterns (VCPs) except VCP121, or when the velocity increment is 1 m/s. Note, this algorithm is only applied to Doppler products and not the Level 2 Doppler estimates. Examples of the improved velocity dealiasing capability are shown in Figs. 3 - 5. Examples of 2-D VDEAL dealiasing performance in VCP31 are available in (Witt et al. 2009)

3.3 Software Build 14

The next major software release, Build 14, is scheduled for Beta Testing at five sites starting in October 2013 and deployment to the network beginning in January 2014. In addition to three major operational changes, there are important changes to the data format of the Level 2 and Level 3 data streams. Data users should read the NWS Technical Implementation Notice (TIN) that will be issued in February 2013. The TIN will address the Build 14 changes in greater detail.

Summaries of the three major operational changes in Build 14 follow:

3.3.1 Supplemental Adaptive Intra-Volume Low-Level Scan (SAILS)

One of the most field-requested capabilities has been for more frequent low-elevation angle scans. In an effort to meet this need, a new dynamic scanning method, the Supplemental Adaptive Intra-Volume Low-Level Scan (SAILS), will be introduced in Build 14. SAILS inserts one supplemental “Split Cut” scan, normally 0.5°, into existing severe weather VCPs 12 and 212. This additional Split Cut scan is inserted into the “middle” of the volume scan to evenly space the time intervals between low-elevation angle scan updates. The “middle” of the volume scan is adaptive and is determined on a volume scan-to-volume scan basis based on the current termination angle. Execution of SAILS, like the recently-reintroduced AVSET function, will be operator controlled. Although SAILS was designed to work with AVSET, they are independent functions and may be active at the same time or executed separately. A drawing of how the antenna will operate with SAILS invoked is in Fig. 6.

3.3.2 Storm-Based Auto PRF and SZ-2 PRF Selection

The legacy Auto Pulse Repetition Frequency (PRF) algorithm selects the Doppler PRF that results in the least amount of range-folded (purple) data for the area within 230 km of the radar.

The new Storm-Based Auto PRF Function selects the PRF that provides the smallest area of obscured data over the storm or storms of interest. (Note: Depending on the selected option, the storm of interest is either designated manually or selected automatically based on the storm attributes.) The result of this function is a dynamic PRF selection that tracks up to three storms of interest and continuously assigns the “Best” Doppler PRF.

Build 14 also implements an automated PRF selection capability for the three (Sachi Dananda – Zrnic) SZ-2 VCPs (212, 211 and 221). This new SZ-2 Auto PRF Function determines the optimum PRF (Storm-Based or Legacy, as selected by the operator) and modifies the antenna rotation rate to maintain the 64 pulses per radial requirement. See Fig. 7 for an example of the improvement of the new storm-based PRF method versus the legacy method.

Additional information on the EVWP, SAILS, 2-D VDEAL, Storm-Based Auto PRF and SZ-2 PRF Selection algorithms are at:
http://www.roc.noaa.gov/WSR88D/NewRadarTechnology/NewTechDefault.aspx**.**

3.3.1 Radial-by-Radial Noise Estimation

Currently, the WSR-88D uses “blue sky” noise, adjusted to lower elevations, to produce the system noise power. However, noise changes with time and site-specific ground clutter and interference environments cause the noise to vary within an elevation scan, across elevations, and also as beam propagation is affected by the thermodynamic profile. Investigations have shown that, in many cases, the "legacy" noise value is higher than the actual value, which leads to invalid data or biased data at low to moderate Signal-to-Noise Ratio. A decrease in coverage for all moments and Dual Polarization variables is a likely side effect. Radial-by-radial noise-power estimation will accurately estimate noise on a radial-by-radial basis, which will provide more accurate base data in regions of weaker signals.

4. WSR-88D LEVEL 2 AND TDWR-SPG DATA

The NWS plans to add the remaining 8 Air Force WSR-88Ds in the “lower 48 states” to the network in 2013. The recently completed redesign of the NWS Level 2 Data Collection and Distribution Network has improved its data delivery reliability.

The data rates for Level 2 and 3 have increased greatly due to the addition of Dual Polarization data, AVSET, and soon SAILS (Crum et al. 2013). Adding the one-minute, low-angle Level 3 products from 11 TDWR-SPGs during a test in 2012 was very-well received. The NWS is evaluating the impacts of the added low-angle scan on communications and product distribution before adding more sites with this capability. Hopefully, some/all remaining sites can be added to the test before the spring 2013 convective season. An NWS TIN will be issued in advance of sites being added.

5. WSR-88D SERVICE LIFE EXTENSION PROGRAM

The WSR-88D was designed to meet a 20-year life of continuous operation. The 160 operational WSR-88Ds have been in operation for an average of 17 years. The NEXRAD Program employed a strategy of continuous modification and technology refreshment activities during the radars’ life to improve its data and performance and keep it maintainable. As a result, the WSR-88D continues to be upgradable, reliable, and maintainable through at least 2020, significantly exceeding the original design life of the system.

While no replacement for the WSR-88D has been determined, research underway to explore the benefits and capabilities of Phased Array Radar Technology and other alternatives. However, the FAA NextGen Surveillance and Weather Radar Capability (NSWRC), an option for the WSR-88D replacement, is not scheduled to implement the first operational radar until 2023 and the last installation scheduled for ~2040.

To meet the likely scenario that the WSR-88D fleet will be needed well beyond 2020, the NEXRAD agencies are planning a major WSR-88D Service Life Extension Program (SLEP). The SLEP will ensure the WSR-88D continues to meet its mission requirements through 2030, or until replacement technology is operational. The SLEP will focus on the following major components:

- A technology refresh of the receiver/signal processor and the computers in the Radar Data Acquisition unit. This must be completed by 2018 because current processor components are either obsolete or projected to be obsolete from an Original Equipment Manufacturer support perspective.
- Refurbish the transmitters,
- Refurbish the pedestals; and,
- Refurbish the three equipment shelters at each operational site.

6. SUMMARY

The WSR-88D is arguably the world’s best operational weather surveillance radar. The NEXRAD Program has increased its capabilities while controlling operations and maintenance costs through new science infusion, sustained engineering, NEXRAD Product Improvement efforts, and technology refresh investments. Continued new science infusion is particularly important to leverage the large investment and potential of the soon-to-be completed Dual Polarization modification. Critical components of the WSR-88Ds are aging and, if not replaced by ~2020, will need a Service Life Extension Program investment for the radar to remain viable through 2030 or until replacement technology is operational. The NEXRAD Program believes it is important to sustain the current WSR-88D capabilities, but also to continue to enhance them.

7. ACKNOWLEDGEMENTS

The authors thank the many people and organizations who have worked together through the decades to make, improve, and sustain the WSR-88D capabilities. The authors appreciate Zack Jing’s and ROC Engineering Branch’s hard work and dedication over the past three years designing, developing, and refining the 2-D VDEAL algorithm, and otherwise readying the algorithm for operational deployment. Thanks to Dave Zittel, ROC Applications Branch, for his leadership and work on the 2-D VDEAL testing, and providing the dealiasing comparison imagery. Appreciation is also given to Ed Ciardi for his support in finalizing the text and figures.

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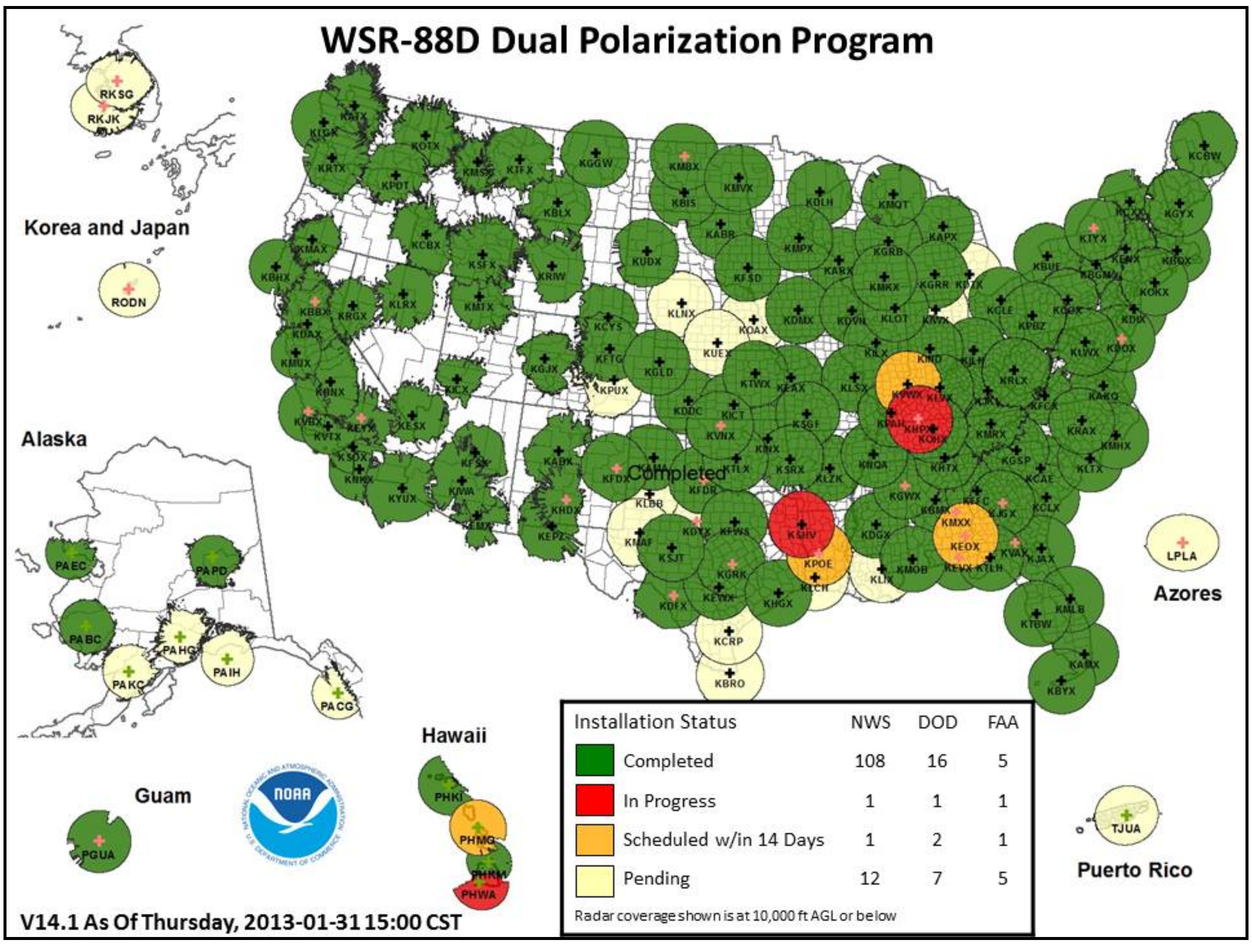

Fig. 1. A map of the status of the WSR-88D Dual Polarization modification deployment as of January 31, 2013. More information about the modification is at: http://www.roc.noaa.gov/WSR88D/DualPol/Default.aspx. The range "rings" around the radar sites depict where the radar coverage (center of beam) is below 10,000 ft above radar level.

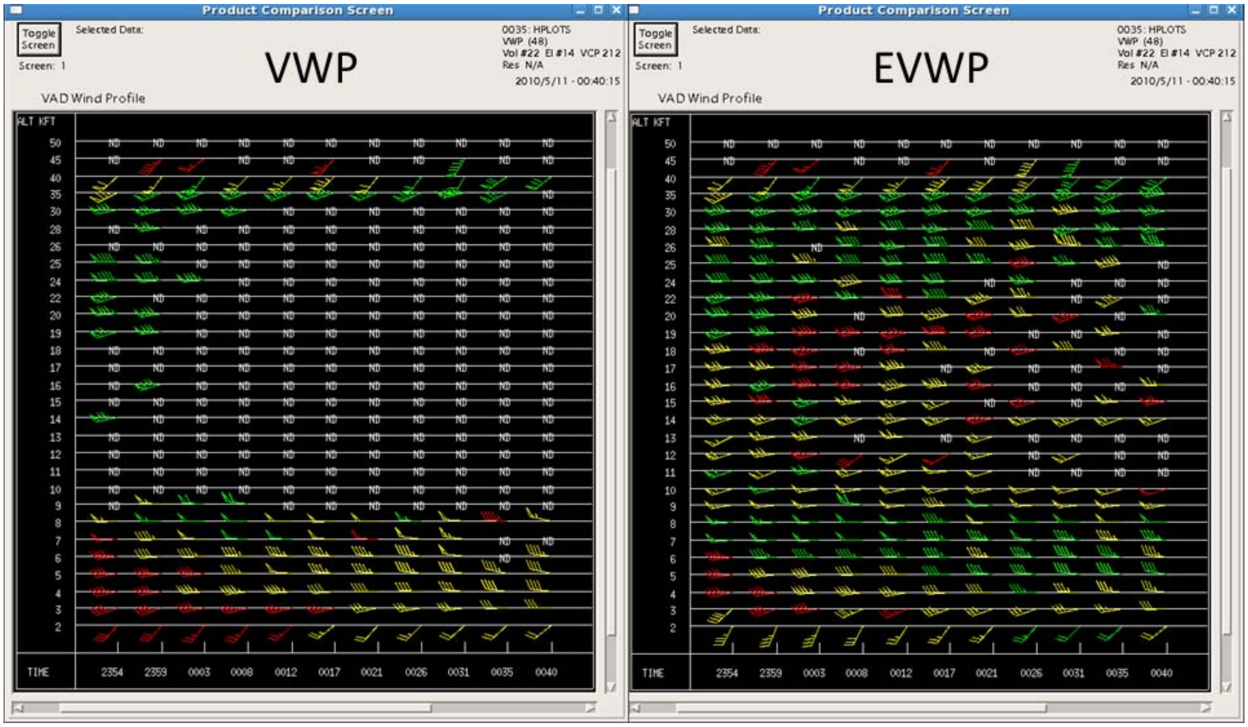

Fig. 2. A comparison of legacy VWP (left) and Enhanced Velocity Wind Profile (EVWP) (right) products using the same Level 2 data set from the Oklahoma City, OK WSR-88D (KTLX) at 00:40 UTC on May 11, 2010. The EVWP provides an average of approximately 50% more wind observations and more accurate observations. This improves the operational usability of the WSR-88D environmental wind product.

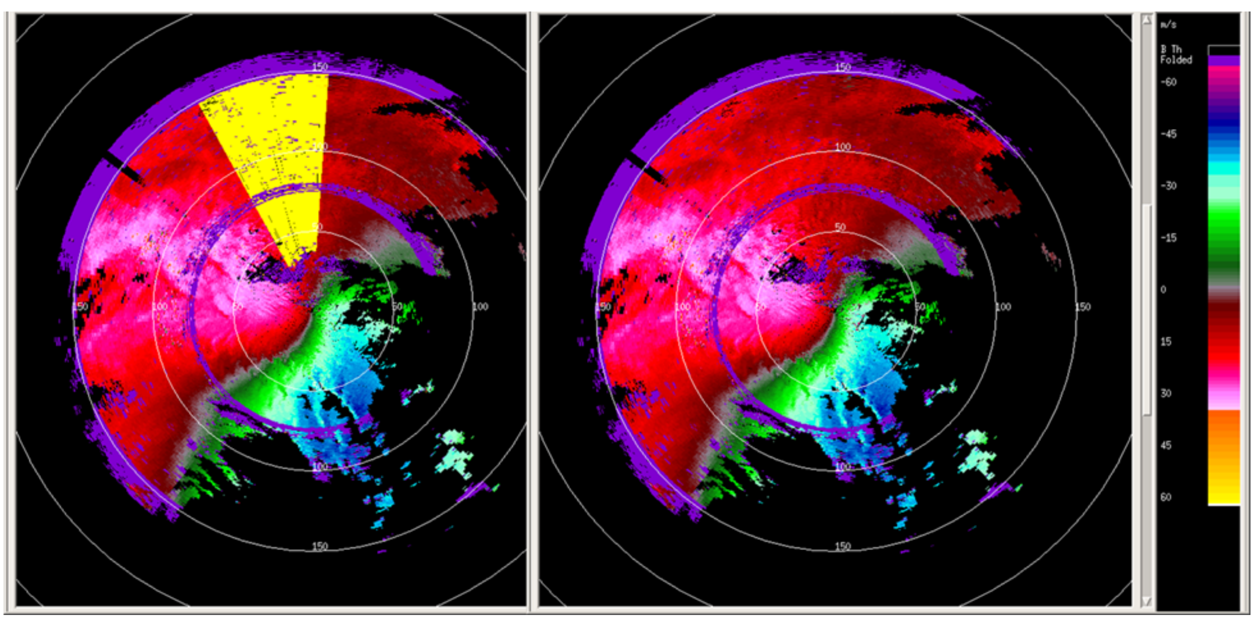

Fig. 3. Using the same Level 2 data set of Hurricane Irene on August 28, 2012 from the Upton, NY WSR-88D (KOKX) at 07:21 UTC and 0.5° elevation, a comparison of the Legacy VDA dealiased ½ deg azimuthal resolution velocity product is on the left, the 2-D VDEAL dealiased product is on the right. Irene's circulation center is 150 nm south-southwest of radar. Range rings are every 50 nm. Note the large yellow wedge of incorrectly dealiased velocities to the north-northwest for the legacy VDA, but the absence of improperly dealiased velocities the 2-D VDEAL produces. (Zittel and Zhongqi, 2012)

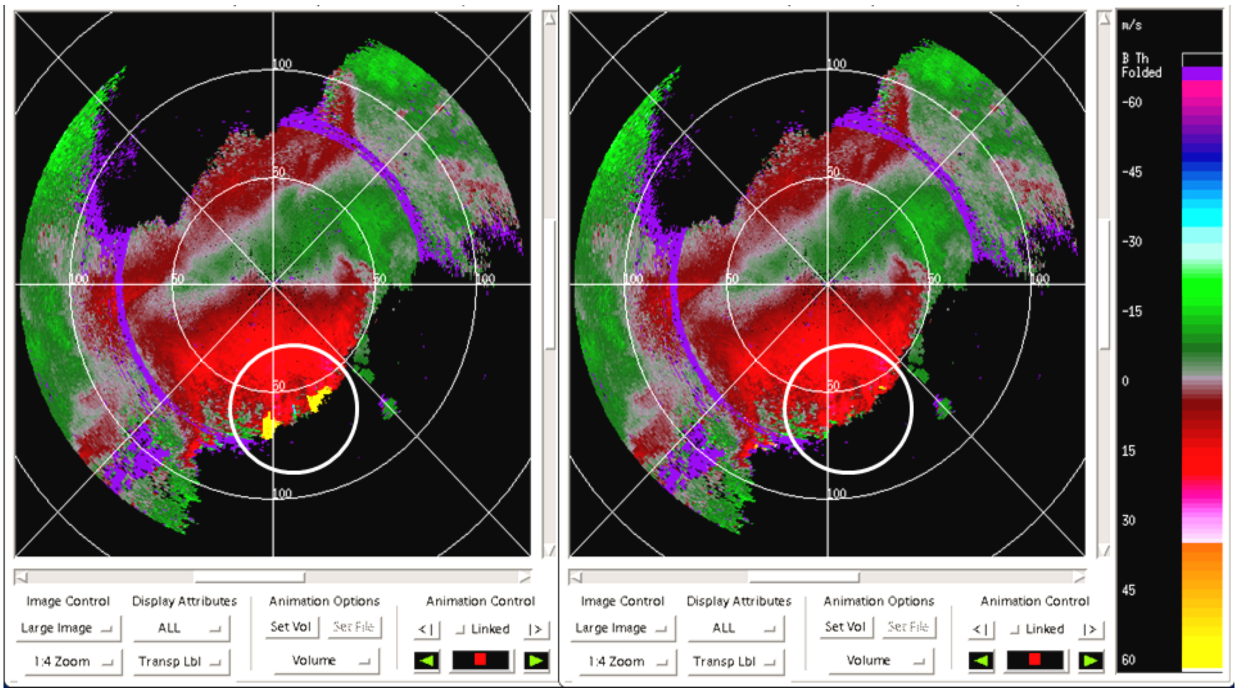

Fig. 4. Similar to Fig. 3, a comparison of the velocity dealiasing algorithms along a thunderstorm outflow boundary from the Oklahoma City, OK WSR-88D (KTLX) on June 20, 2007 at 07:54 UTC. The legacy VDA (left) and 2-D VDEAL (right) products are displayed. Notice the two areas of Legacy VDA improperly dealiased velocities south of the radar along the leading edge of the gust front in the circled area (left image). The 2-D VDEAL product has only a very small error. (Langlieb and Tribout, 2010)

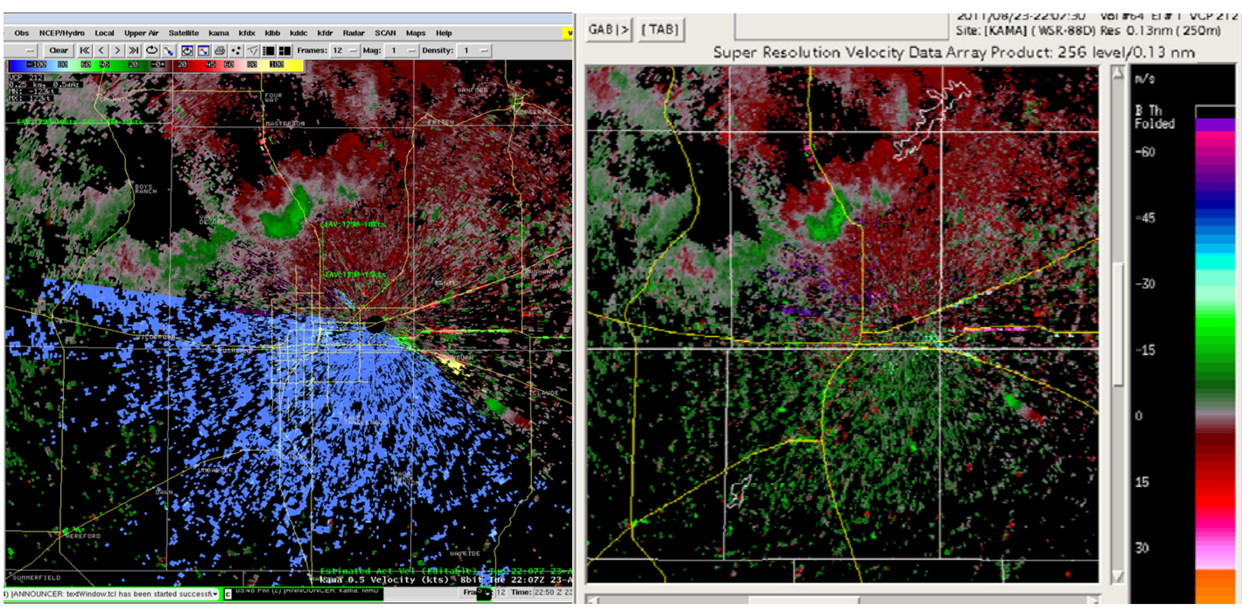

Fig. 5. Similar to Fig. 3 and 4, but this time with an example of how 2-D VDEAL corrects a large area of improperly dealiased data in a storm-free environment. The data are from the Amarillo, TX WSR-88D (KAMA) on August 23, 2011 at 22:07 UTC and 0.5° elevation in VCP212. In the left image, the Legacy VDA has improperly dealiased the velocity data for ~150 deg from the east, through south, to west. The 2-D VDEAL corrected the problem (right) image. Notice the two dealiasing algorithms handled the motion of the traffic on the two major roadways east and east north east of Amarillo in about the same manner.

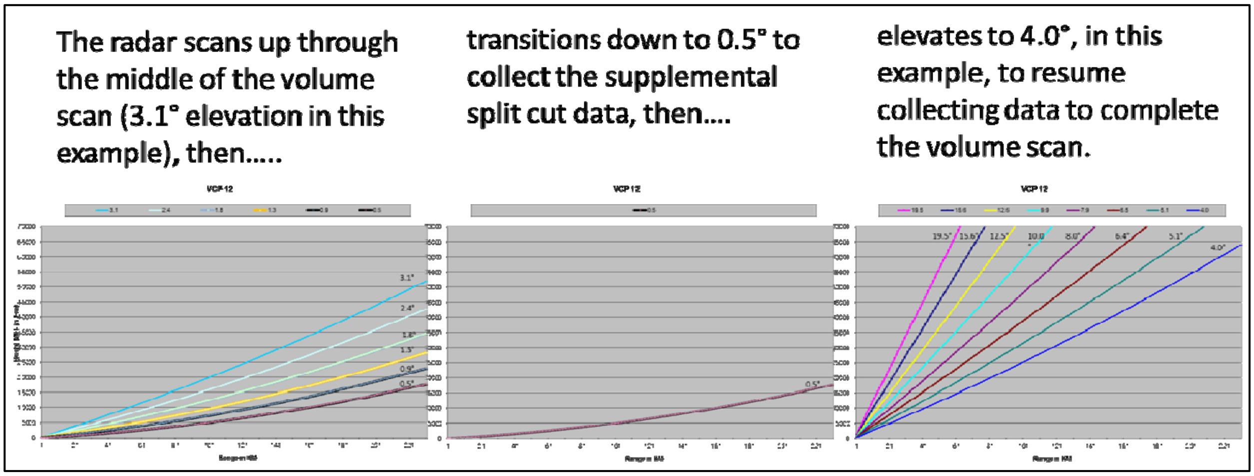

Fig. 6. A depiction of a sample SAILS scanning sequence. In the three figures above, the radar was operating in VCP 12 with a termination angle of 19.5° (AVSET was not active or AVSET was active and there were storms near the RDA). In this scenario, the "middle" of the volume scan was ~140 seconds which resulted in collecting the Supplemental Low-Level scan after completion of the 3.1° elevation cut.

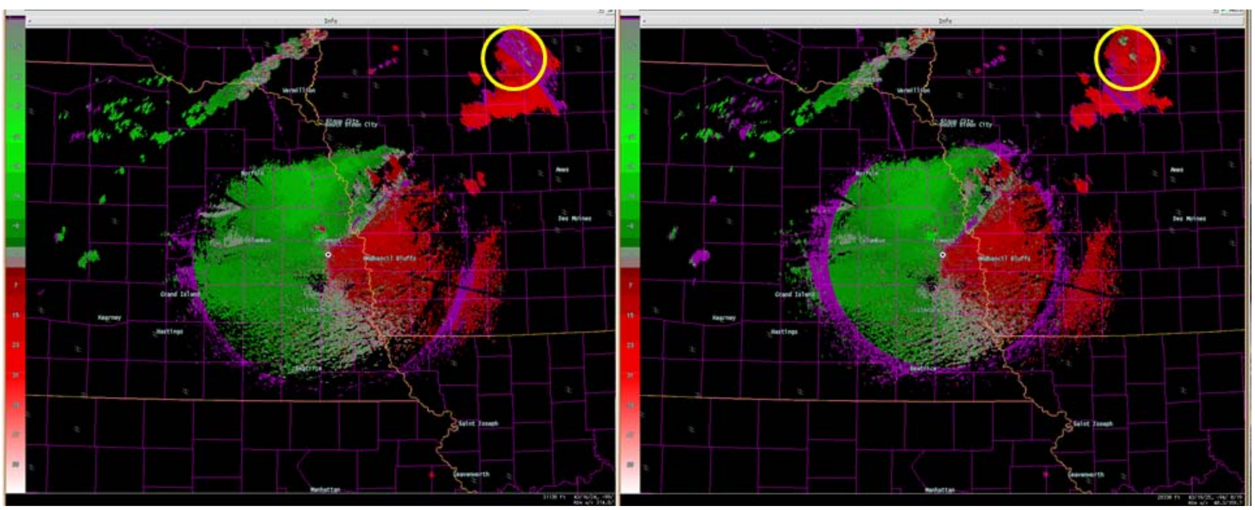

Fig. 7. An example of the improvement of the new storm-based PRF method (right image) versus the legacy PRF method PRF (left image). Note the absence of ambiguous radial velocity data northeast of the radar in the yellow-circled area of the right image that enables forecaster interrogation/analysis of the velocity data that was not possible with the baseline/legacy PRF selection algorithm. These data were collected on from the Omaha, NE WSR-88D (KOAX) on September 7, /2012 using a test VCP that alternated between the default legacy PRF (left image) captured at 20:31 UTC and Storm-Based Auto PRF selection (right image) captured at 20:26 UTC.