Providing Selectable Elevation Layer Mosaic Generation Capability and Improving the Quality of WARP Mosaic Products

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1. INTRODUCTION

The FAA WARP (Weather and Radar Processor) Maintenance and Sustainment Services (WMSS) program is developing a user-selectable elevation layer radar mosaic product generation capability. The approach for generating selectable layer mosaics will not only provide a true user-selectable layer mosaic generation capability in real time, it will result in a significant improvement of the overall quality of the WARP mosaic products, something that users have requested. This paper describes how this approach will address those issues by enabling specific improvements in the overall quality of the WARP mosaic products, and will support selectable layer mosaic generation.

2. OVERVIEW OF CURRENT WARP MOSAIC GENERATION

The WARP system generates layer composite mosaic products for display on the Air Traffic controller display systems (DSR, ERAM, MEARTS and ATOP). WARP currently generates mosaics in the NAS plane projection for four fixed-elevation layers: 0–24 Kft, 24–33 Kft, 24–60 Kft and 0–60 Kft layers. WARP generates each of these layered mosaic products from a specific volume-based layer composite reflectivity radar product generated by the WSR-88D Radar Product Generator (RPG) at the end of each radar volume scan interval.

The current WARP mosaic products (ex: echo top, VIL, tilt 1 base reflectivity mosaic products in addition to layer composite reflectivity mosaics) have a number of limitations that are partially inherent in the volume-based radar products used for generating the WARP mosaics. The specific limitations are:

- Layer composite mosaics built from WSR-88D layer composite products represent fixed-elevation layers that do not generally correspond with the vertical extent of sectors being managed by controllers.
- Increased latency of the mosaic product data (the time lag from when a WSR-88D contributing to a WARP mosaic detects weather and when the corresponding radar returns are available for viewing on the controller display screens) due to the time lag between data collection and generation of the volume-based products at the WSR-88D radars.
- Coverage gaps in the mosaic products due to limited coverage area of the WSR-88D layer composite radar products.
- Decreased spatial resolution of the mosaic product data (effective resolution of the WARP mosaic products is determined by the spatial resolution of the WSR-88D layer composite products).
- Inconsistent data level resolution of the layer composite mosaic products due to in-consistent data level resolutions of the WSR-88D layer composite products.
- Ability to identify and remove non-meteorological radar returns from the mosaic products is limited by the reduced resolution of the WSR-88D volume-based products and the absence of any vertical structure information for these products.

The limitations detailed above, combined with the fact that on-board weather radars depict precipitation returns differently than do land-based radars and are real time, means that pilots and controllers are not seeing the same representations of the same weather phenomenon.

3. OVERVIEW OF THE PROPOSED SELECTABLE ELEVATION LAYER MOSAIC GENERATION

To help address the limitations noted above, the approach for generating selectable elevation layer mosaic products will utilize multiple tilts of high resolution base reflectivity product data (product type 94) for generating the selectable elevation layer mosaic products. This approach will permit the generation of reflectivity mosaic products for any user-specified elevation layer without any requirement for layer-specific processing and product generation by the WSR-88D RPG. Generating mosaic products directly from high resolution base product data instead of lower resolution volume-based radar products will also significantly improve the overall quality of the WARP mosaic products as described in the following sections.

4. SELECTABLE ELEVATION LAYER MOSAIC GENERATION CAPABILITIES

As was noted in Section 2, the current WARP layer mosaic products are generated from volume-based layer composite radar products generated by the WSR-88D RPG. Since the layer specifications for these products are fixed and have not changed since the WSR-88D radars were originally installed, changing them would likely require a WSR-88D software build and installation cycle, and would not really provide a user-selectable layer capability.

The WSR-88D RPG does provide some capability for generating user-specified elevation layer products on demand (product type 137). However, the RPG can only generate a limited number of these products at any time (across the entire radar data subscriber base). The algorithm used to generate these on-demand layer products is a less-refined form of the algorithm used to generate the fixed layer products which results in layer products with significant tilt-related ring artifacts. Therefore, these products are not suitable for generating selectable elevation layer mosaic products for the WARP system.

In contrast, generating mosaic products directly from base product data can provide a real-time, on-demand capability for generating selectable layer products with no layer-related interaction with the WSR-88D RPGs. These products can provide the user with complete flexibility in real time for specifying elevation layer boundaries.

There is a further benefit of this approach. In the current WARP mosaic generation strategy each mosaic product is generated from a specific WSR-88D radar product. Adding a new mosaic product requires acquiring and processing a new radar product type. In this approach all mosaic products are generated from a single radar product type using the high resolution digital base reflectivity product, NEXRAD Product 94. Furthermore, generating products directly from base product data provides real-time, on demand flexibility that is not possible when mosaics are generated from volume-based products generated by the WSR-88D RPG.

5. IMPROVED MOSAIC DATA LATENCY

The latency of the layer mosaic product displayed on the air traffic controller's display is a known issue. Controllers need to know where weather impacting their sector is at the current time, not where it was several minutes in the past. The overall latency of the data in the WARP mosaic products is attributable to several causes:

- WSR-88D volume scanning strategy (3–10 minutes)
- WSR-88D product generation strategy (< 10 seconds for base products, 3–10 minutes for volume products)
- WSR-88D to WARP product transmission delay (< 10 seconds)
- WARP mosaic product generation time (<5 seconds)
- WARP to DSR data dissemination protocol (data sent every 25 seconds)

As a result, the latency of the data in the WARP mosaic products can vary from less than 1 minute to 20 minutes with the bulk of the latency attributable to the WSR-88D volume scanning and radar product generation strategies.

To understand how using WSR-88D volume-based products for generating WARP mosaic products increases the latency of the mosaic product data see Figure 1. WSR-88D volume scanning strategies consist of a series of constant tilt elevation angle scans, starting with the first elevation scan angle of typically 0.5°, with the scanning elevation angle increasing for each subsequent scan until the highest scanning elevation angle is reached. When the highest elevation scan is completed the volume scan interval is complete and the radar begins the lowest elevation scan for the next volume scanning interval. The specific scanning elevation angles and azimuth scanning rates used depends on the volume scanning strategy being executed by the radar. Current volume scan strategies can have from 5 to 14 elevation scans, with individual elevation scan elapsed times varying from 15 to

90 seconds. As each elevation scan is completed the WSR-88D RPG generates and disseminates the associated base data radar products for the elevation scan. In contrast, the volume-based products are not generated until all of the elevation scans for the volume scan interval have been completed. On average most of the radar returns that appear in the WARP mosaic products derive from the lower elevation scans. Waiting until all elevation scans have been completed before the corresponding volume products are generated introduces significant additional delay.

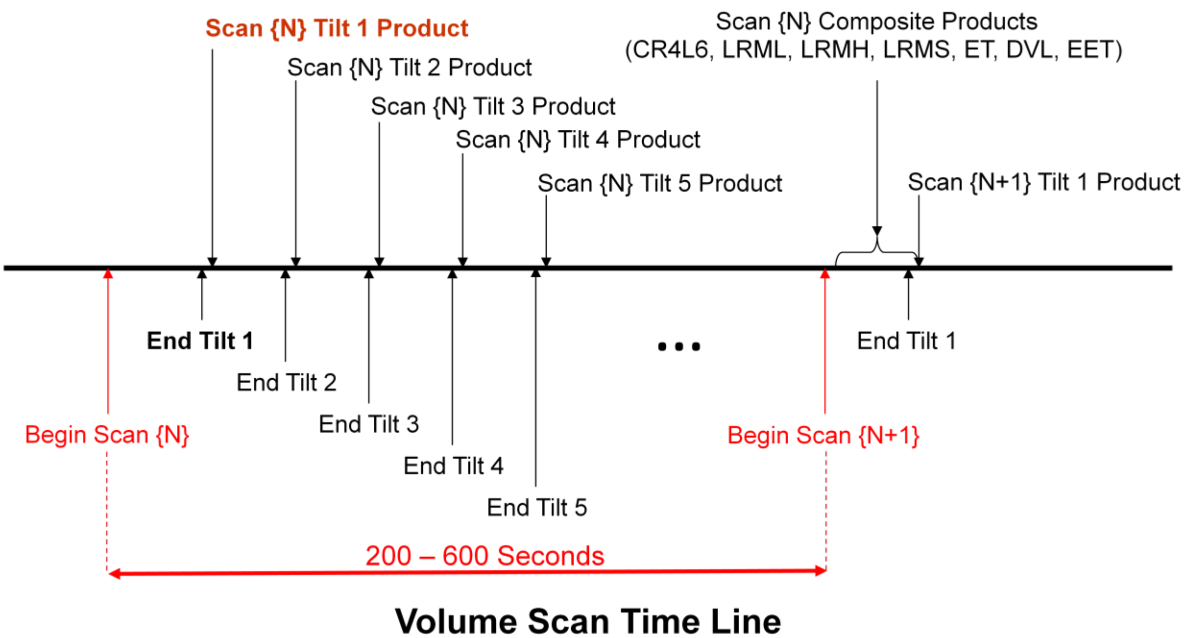


Figure 1: WSR-88D Data Collection and Radar Product Generation Model

Characterizing the latency of the data in a WARP mosaic product is a complex problem. There are different ways to characterize latency, and the latency of mosaic product data varies from product bin to product bin, and for a given product bin from second to second. A study conducted generated data latency products for the baseline WARP 0–60 Kft layer DSR mosaic product generated from WSR-88D 0–60 Kft layer composite radar products (product type 38) and a 0–60 Kft layer mosaic product generated directly from high resolution base reflectivity radar products (product type 94). The specific latency that we measured was the age of the maximum value contributor data that was selected for each mosaic bin by the mosaic generation algorithms. Age of the data is the difference, in minutes, between the current time (time of the mosaic product generation) and the time the maximum valued contributor data was collected by the radar (determined from radar product time stamp information).

An example of the latency products is shown in Figure 2. The frame on the left side of Figure 2 is a snapshot of a region of the DSR 0–60 Kft layer product which shows the convection along a frontal system moving in a roughly southeast direction at 25 mph. Individual convective cells along the front were moving to the northeast along the front at approximately 45 mph. The frame in the center of the figure depicts the latency of the maximum valued contributor data that was used to generate the corresponding 0–60 Kft mosaic product bin for the baseline WARP product from product type 38 data. The frame on the right depicts the latency of the radar data that was used to generate the corresponding mosaic product bin for a 0–60 Kft mosaic product generated from product type 94 base data. The minimum latency of the data in the baseline WARP mosaic product in this example is approximately 4 minutes, with an average latency around 7 minutes, and maximum latencies in excess of 10 minutes. For the corresponding mosaic product generated from base product data the minimum latency of the data in this example is less than one minute, with an average latency of less than 3 minutes, and maximum latencies of 6 minutes.

There is a correlation between data latency and data placement error. For the weather scenario shown in Figure 2, the average data placement error for the mosaic product generated from volume-based radar product data is in the range of 3–5 nm. The average data placement error for the mosaic product generated from base radar product data is in the range of 1–2 nm.

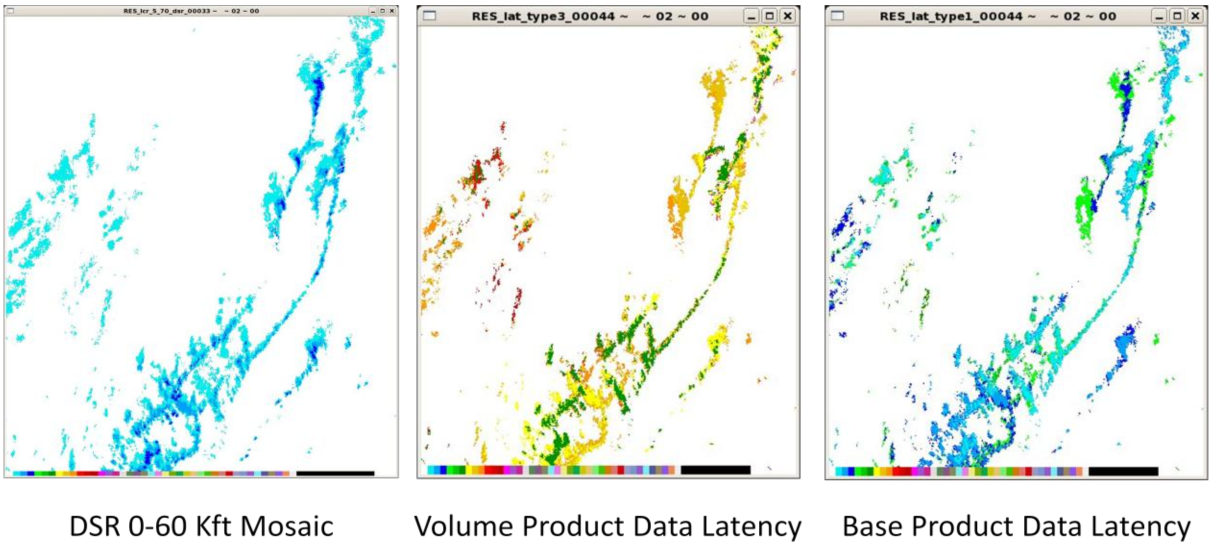
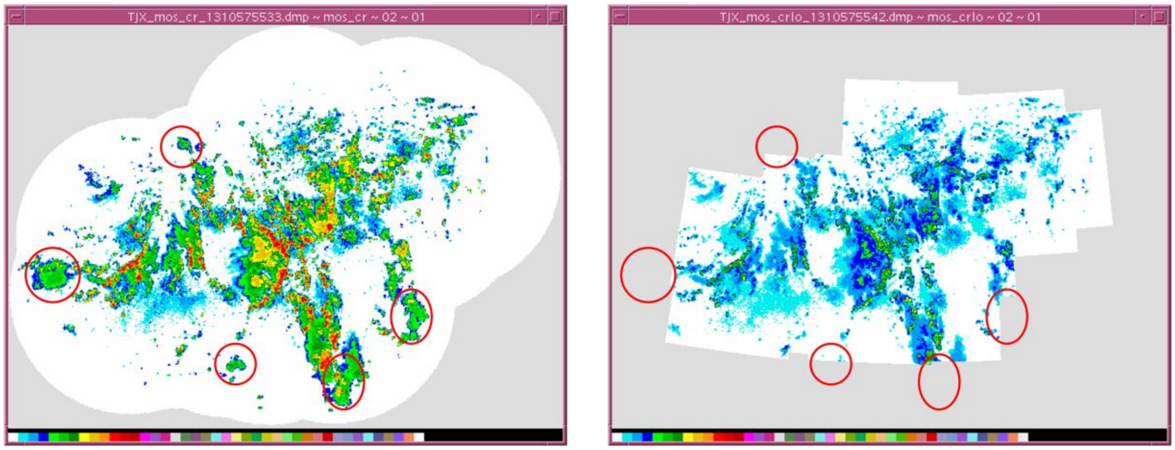


Figure 2: Comparison of Mosaic Product Data Latencies

6. INCREASED RADAR COVERAGE AREA

The effective coverage areas of the baseline WARP layer mosaic products are limited by the coverage areas of the respective layer composite radar products. The coverage area of the 0–60 Kft layer product extends to the maximum radar coverage range of the WSR-88D radar (248 nm). The coverage areas of the 0–24 Kft, 24–33 Kft and 33–60 Kft layer products only extends out to a range of 124 nm which effectively limits the radar coverage area of the corresponding mosaic products. Figure 3 illustrates the relative radar coverage areas of the 0–60 Kft and 0–24 Kft layer composite mosaic products. This figure shows snapshots of the 0–60 Kft and 0–24 Kft layer mosaic products at a time when there was widespread air-mass convective weather throughout the mosaic product coverage area. The grey areas surrounding the two mosaic products indicate areas where no radar coverage is provided by the input radar product data. Note that the extent of the “no radar coverage” area in the 0–24 Kft product is significantly larger than the “no radar coverage” area in the 0–60 Kft product. Note also that the areas of weather identified by the red circles in the 0–60 Kft mosaic are missing in the 0–24 Kft product because these areas are beyond the coverage areas of the input radar product data.

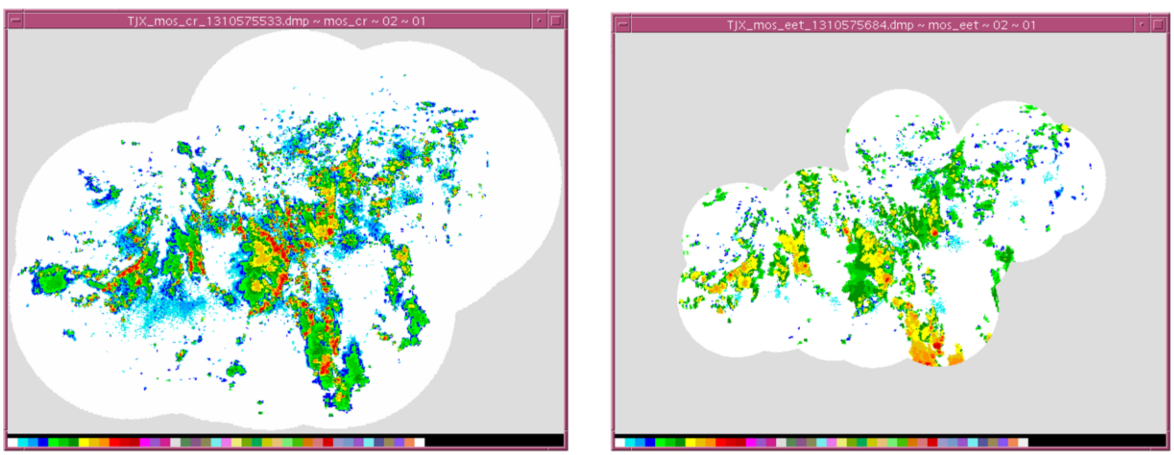


0-60 Kft Layer Composite

0-24 Kft Layer Composite

Figure 3: Comparison of WARP Layer Mosaic Product Coverage Areas

For the WARP enhanced echo top mosaic product the reduction in the coverage area of the mosaic product is even more pronounced due to inaccuracy of the enhanced echo top radar product data (see below). Figure 4 illustrates the relative radar coverage areas of the 0–60 Kft layer composite mosaic product and the enhanced echo top mosaic product for the same case shown in Figure 3. The grey areas of the two mosaic products again indicate areas where no radar coverage is provided by the input radar product data.



0-60 Kft Layer Composite

Enhanced Echo Top

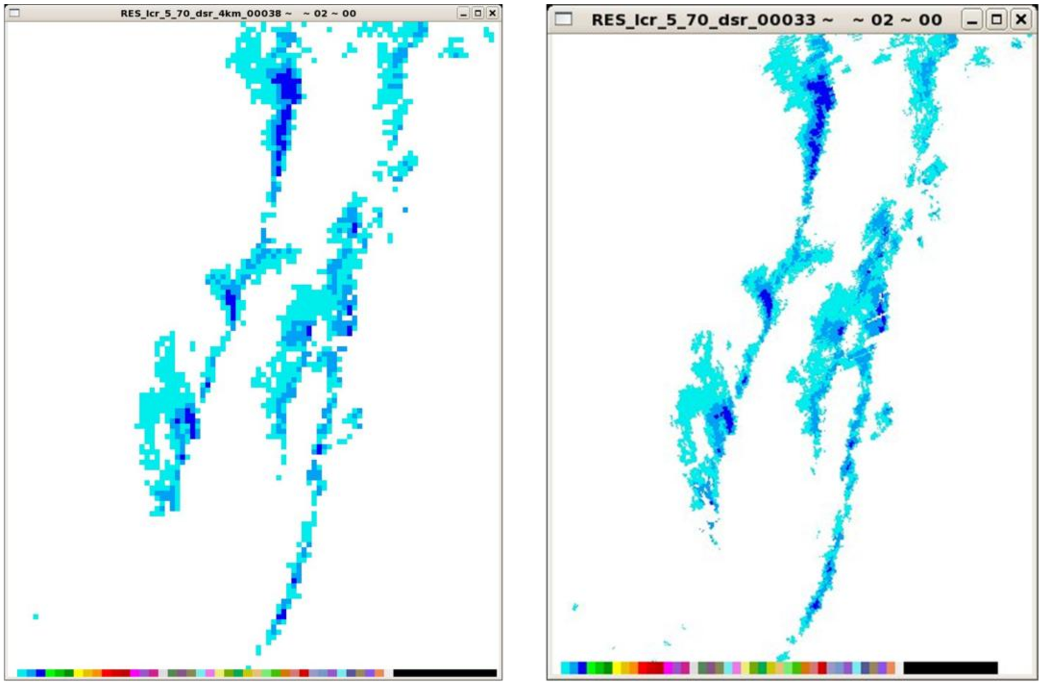
Figure 4: WARP Echo Top Mosaic Product Coverage Area

Generating mosaic products from base radar product data will mitigate the NEXRAD coverage restrictions imposed by the volume-based radar products. There will still be some reduction in the effective coverage areas of some mosaic products due to the effects of earth curvature, but the coverage restrictions will be significantly less than the coverage restrictions of the current WARP mosaic products.

7. INCREASED SPATIAL RESOLUTION

The effective spatial resolution of the baseline WARP mosaic products is determined by the spatial resolution of the radar product data used to generate the mosaic product. For example the nominal spatial resolution of the DSR mosaic products is 1 nm (1.852 km). The layer composite radar products used for generating the DSR mosaics are raster formatted products with 4x4 km bin size (16 km²). The effective spatial resolution of the current DSR mosaic products is therefore 4 km.

The high resolution base reflectivity products are radial formatted products with a spatial resolution of 1 km x 1°. The spatial resolution of the near-range product 94 data is higher than the resolution of the DSR mosaic products which will enable the system to generate mosaics with true 1 nm resolution. Figure 5 demonstrates the improvement of mosaic product spatial resolution that is possible when mosaics are generated directly from base product data. The frame on the left of the figure is a snapshot of a DSR mosaic generated from 0–60 Kft layer composite product data. The frame on the right is the corresponding mosaic product generated directly from high resolution base reflectivity product data.



DSR 0-60 Kft Layer
(Generated from Composite Reflectivity Data)

DSR 0-60 Kft Layer
(Generated from Base Reflectivity Data)

Figure 5: Comparison of Mosaic Product Spatial Resolution

8. IMPROVED DATA LEVEL RESOLUTION

The data level resolution of the WARP ARTCC mosaic products is limited by the data level resolution of the radar product data used for generating the mosaic product. The volume-based layer reflectivity products used to generate the current WARP mosaic products have different data level resolutions:

- The 0–60 Kft layer mosaics are generated from 16 level (0–15) radar product data where each data level corresponds to a detected reflectivity value (dBZ). The mapping of product data levels to dBZ values depends on a weather mode flag (clear air or precipitation mode) in the radar product header.
- The 0–24 Kft, 24–60 Kft and 33–60 Kft layer mosaics are generated from 8 level (0–7) radar product data where each data level corresponds to a dBZ value. For these products the mapping of product data levels to dBZ values does not depend on the weather mode of the radar. The mapping of data levels to dBZ values for these products is different than the data level mapping used for the 0–60 Kft layer products.

The difference in the data level mapping strategies used for the different layer mosaic products does not significantly affect the DSR mosaic products because all of the input radar products have data level mappings that are close to the 3-level mapping used for the DSR mosaic products (30, 41 and 50 dBZ data levels). However, when radars are operating in the clear air weather mode the differences in the data level mappings of the input radar product data can sometimes result in the DSR 0–60 Kft layer product having lower data levels than the corresponding areas of the other DSR layer products. This is a result of the weather mode dependency of the 0–60 Kft layer radar product data level mapping strategy used for these products.

The consequences of the differences in the data level mappings of the input radar product data are more apparent when comparing the ARTCC mosaic products. The different ARTCC layer products have different data level schemes (0–60 Kft layer is a 16 level product; the other layer products are 8 level products), and different data level to color mappings are used to represent product data levels. Figure 3 illustrates the differences in data level mappings used for the 16 level and 8 level mosaic products.

The high resolution base reflectivity products are 256 level products that span the full range of possible dBZ values from –32 dBZ to 94.5 dBZ in 0.5 dBZ increments. The data level mapping of the products does not depend on the weather mode of the radar. Generating layer mosaic products directly from high resolution base reflectivity data will allow all layer mosaic products to utilize the same data level mapping scheme and eliminate the data level inconsistencies between products introduced by the volume-based radar products.

9. IMPROVED DATA LEVEL ACCURACY

The algorithms used by the WSR-88D RPGs for generating the volume-based radar products currently used by the WARP mosaic generators have deficiencies that impact the data level accuracy of the volume-based radar product data, and therefore the data level accuracy of the current WARP mosaic products generated from volume-based radar products.

The base product data generated by the WSR-88D radars is radial formatted data where each product bin spans an area defined by fixed range and azimuth increments. The areal extent covered by a given data radial bin depends on the range of the bin from the radar. Radial product bins in the near range of the radar span a relatively small area. The area spanned by radial data bins increases linearly with range with bin coverage areas of 0.01 km² at a range of 1 km and increasing linearly with range to 8 km² at a range of 248 nm. The layer composite reflectivity radar products are 4 km raster products. Each layer radar product bin therefore spans an area of 16 km². The layer composite radar product generation algorithms used by the WSR-88D RPG assign each raster product bin the value of the highest of all of the radial data bins that fall within the 16 km² coverage area of the raster product bin. In the near range of the radar multiple radial product data bins map to each raster product bin. In the very near range of the radar (< 31 nm) the number of radial product bins that map to each composite product bin is >> 10 bins. This data level selection strategy has a tendency to significantly overestimate raster product data levels in the near range of the radar.

Figure 6 illustrates this phenomenon. The frame on the left of Figure 6 shows tilt 1 base reflectivity data in the near range of the radar (out to approximately 38 nm from the radar location). The frame on the right is the corresponding 0–60 Kft layer composite radar product generated by the RPG from the radial data. Within 10 nm of the radar (the area inside the red circle) the tilt 1 radial data shows largely low-level (≤ 15 dBZ) erratic returns. Within this area there are isolated bins of higher level returns that are likely of non-meteorological origin (birds, bugs, dust, ground clutter, etc.). In contrast, in the layer composite product most of the bins in this area have data levels > 15 dBZ, with a significant number of bins with data levels ≥ 30 dBZ (the DSR mosaic level 1 threshold). In the area between the red and yellow circles (range from the radar > 10 nm and ≤ 31 nm) the base data product shows approximately 20% of the area containing weather returns with 80% of the returns having data levels ≤ 15 dBZ and virtually no returns ≥ 30 dBZ (except for the small cell 16 nm east/northeast of the radar). In the corresponding area of the layer composite product over 50% of the raster product bins contain returns with over 50% of the returns having data levels > 15 dBZ and numerous small patches of returns ≥ 30 dBZ.

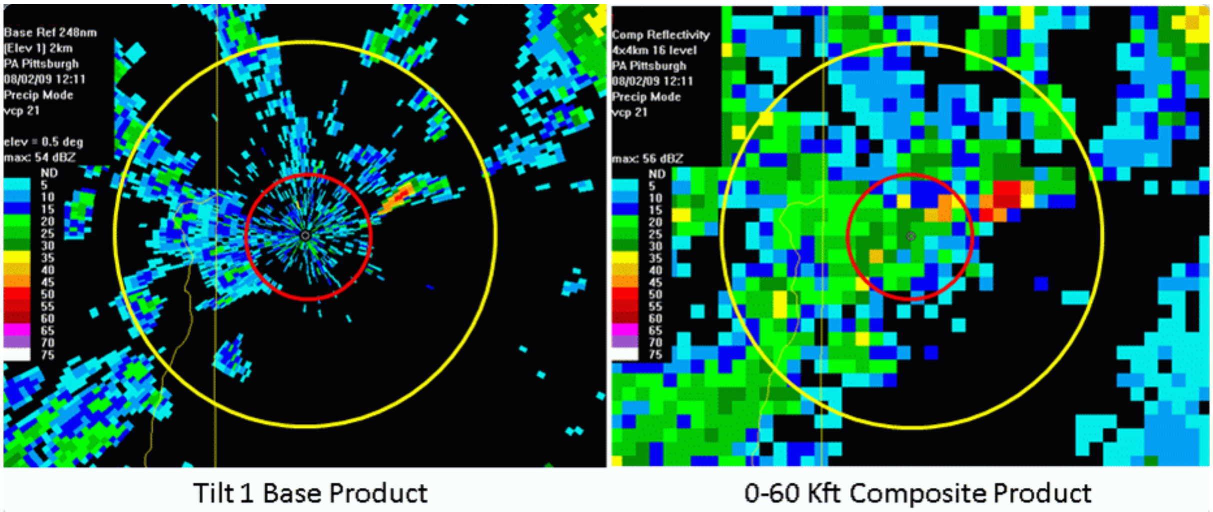


Figure 6: Comparison of Radar Product Data Levels

WARP also generates echo top and VIL ARTCC mosaic products which have data level accuracy problems due to data accuracy deficiencies in the volume-based radar products used to generate these mosaics. While the layer composite products tend to overestimate data levels in the near range of the layer composite radar products, the enhanced echo top and digital VIL radar products tend to overestimate product bin data levels in the far range (beyond 124 nm from the radar) which severely limits the effective coverage area of the products. See Figure 7 for an example of overestimated far-range echo top values in the enhanced echo top radar product. The figure shows enhanced echo top products for two adjacent radars (JGX and CLX). The red circles overlaid on these products are 124 nm from the corresponding radar locations. The area inside the ellipse in the far range of the CLX product in the right frame of the figure have echo top values that are 10–15 Kft higher than the echo top values for the corresponding area in the near range of the adjacent JGX radar shown in the left frame of the figure.

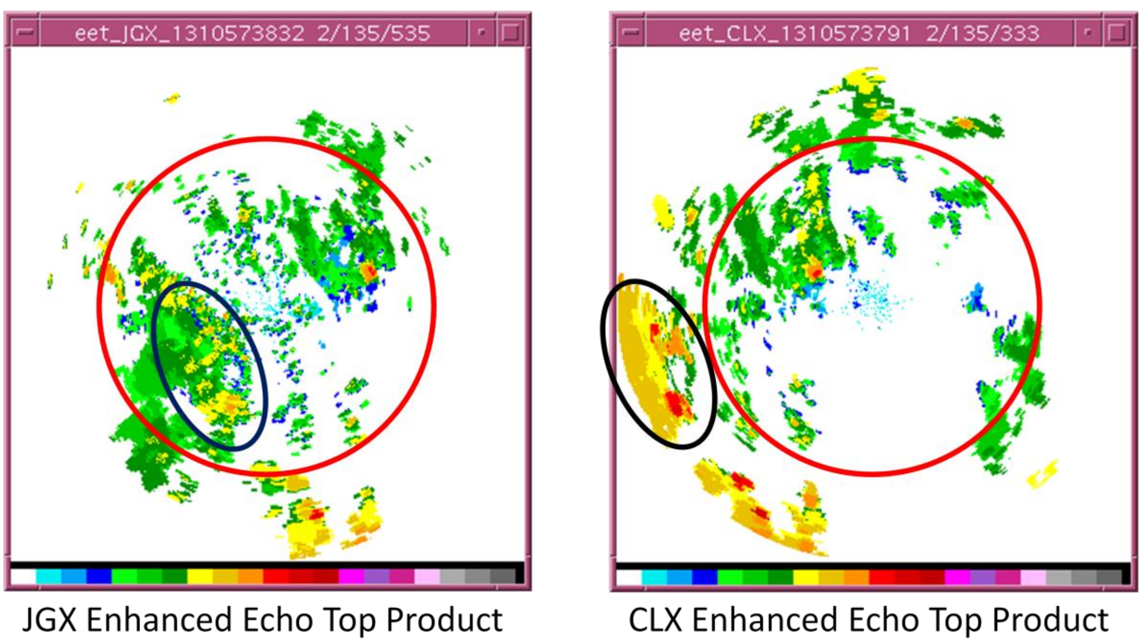


Figure 7: Example of Overestimated Echo Top Elevations

The WARP program has implemented a 230 km range restriction for the enhanced echo top radar product data used for generating the enhanced echo top mosaic product pending resolution by the NWS of the enhanced echo top radar products far range data accuracy problem.

Generating WARP mosaic products directly from high resolution base reflectivity data will avoid the mosaic product data levels accuracy problems that result from using volume-based radar products.

10. IMPROVED CAPABILITY FOR REMOVING NON-WEATHER RADAR RETURNS

The baseline WARP mosaic generators utilize several data quality enhancement functions whose primary role is to identify radar returns that are the result of non-meteorological phenomena (RF interference, ground clutter, AP, birds, bats, insects, etc.) and to remove this data from the WARP mosaic products. The resolution of the input radar product data used for generating mosaic products directly impacts the ability to identify and remove radar returns of non-meteorological origin. The volume-based products used to generate the current WARP mosaic products have significantly reduced resolution when compared to the high resolution base product data as shown in Table 1.

Table 1: Comparison of Reflectivity Radar Product Data Resolution

Parameter	Volume-based Products	High Resolution Base Data Products
Bin Coverage Area	• 4 km spatial resolution • bin coverage area is 16 km²	• 1 km range resolution • 1° azimuth resolution • coverage area is range dependent (0.01–8 km²)
Bin Elevation Coverage	• Unknown	• Known with high degree of accuracy
Bin Data Level Resolution	• ≥ 5 dBZ • Radar operational mode dependent	• 0.5 dBZ
Mosaic Product Data Latency	• Varies bin by bin • Latency range: 0–20 minutes • Average: 7–8 minutes	• Varies bin by bin • Latency range: 0–10 minutes • Average: 2–3 minutes

The increased resolution of the base product data enables a significant improvement in the overall accuracy of the data quality enhancement functions. An example of the performance improvement possible when generating mosaic products directly from high resolution base product data versus volume-based product data is shown in Figures 8 through 10 which illustrate the performance of RF interference editing functions. The interference editing functions operate directly on the input radar product data prior to incorporation into the mosaic products.

Figure 8 illustrates the performance of the baseline RF interference editing function applied to the 0–60 Kft layer composite radar product. The unedited product data in the left frame is contaminated by different types of RF interference returns that appeared in the tilt 1 and tilt 2 base data. The baseline interference editing function is able to identify and remove only one class of RF interference returns (constant radial power). Only a small fraction of the interference returns in the layer composite product fit the constant radial power model and consequently only a small fraction of the interference returns have been removed from the edited 0–60 Kft layer product in the right frame (the pink areas indicate where interference returns have been removed from the product data).

Figures 9 and 10 illustrate the performance of a prototype RF interference editing algorithm developed for processing high resolution base reflectivity product data (product type 94) for tilts 1 and 2. Most of the interference returns have been removed from the tilt 1 and 2 base product data. RF interference detection and editing applied directly to high resolution base data is significantly more effective than interference editing applied to layer composite product data.

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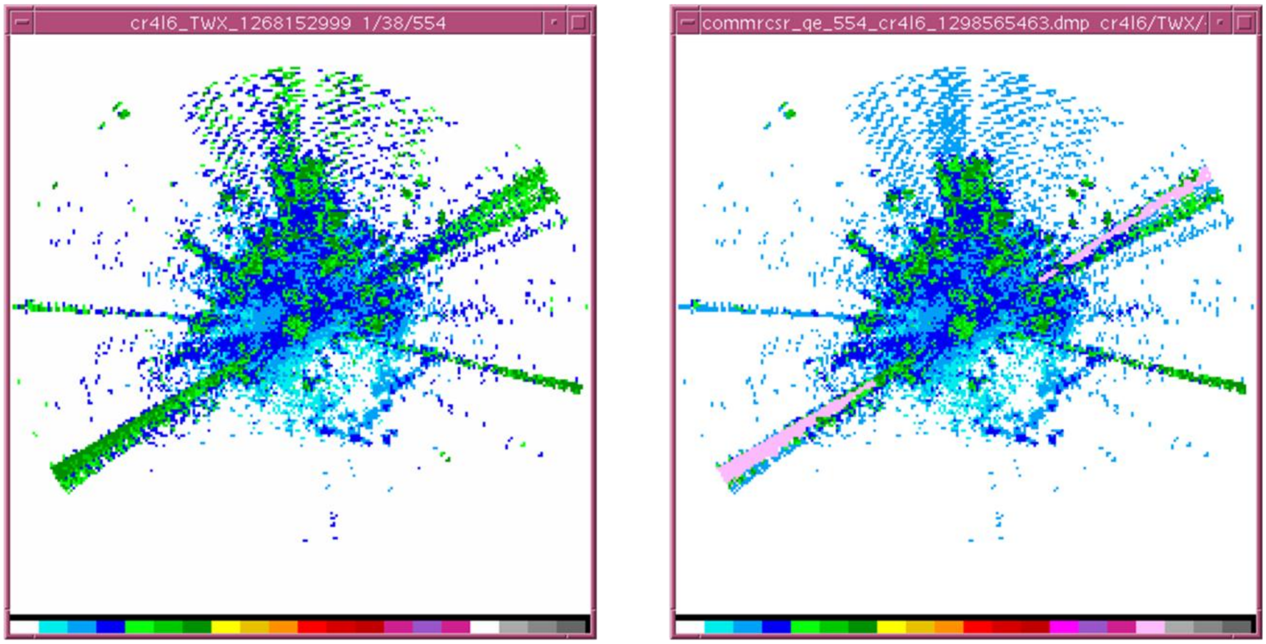
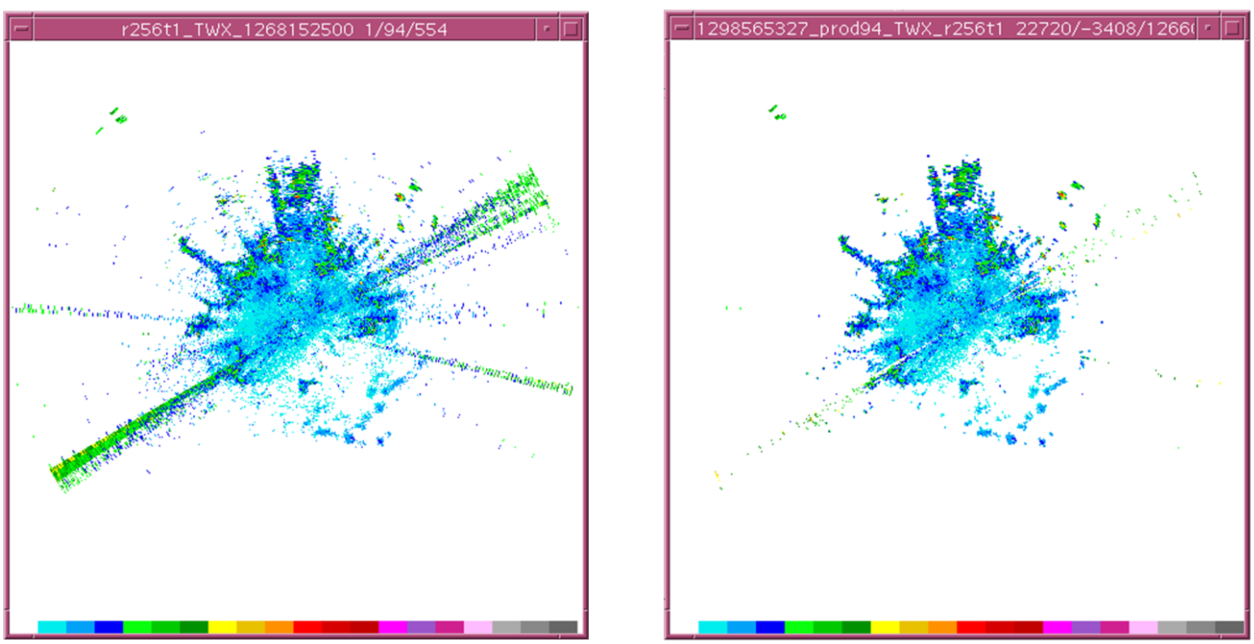


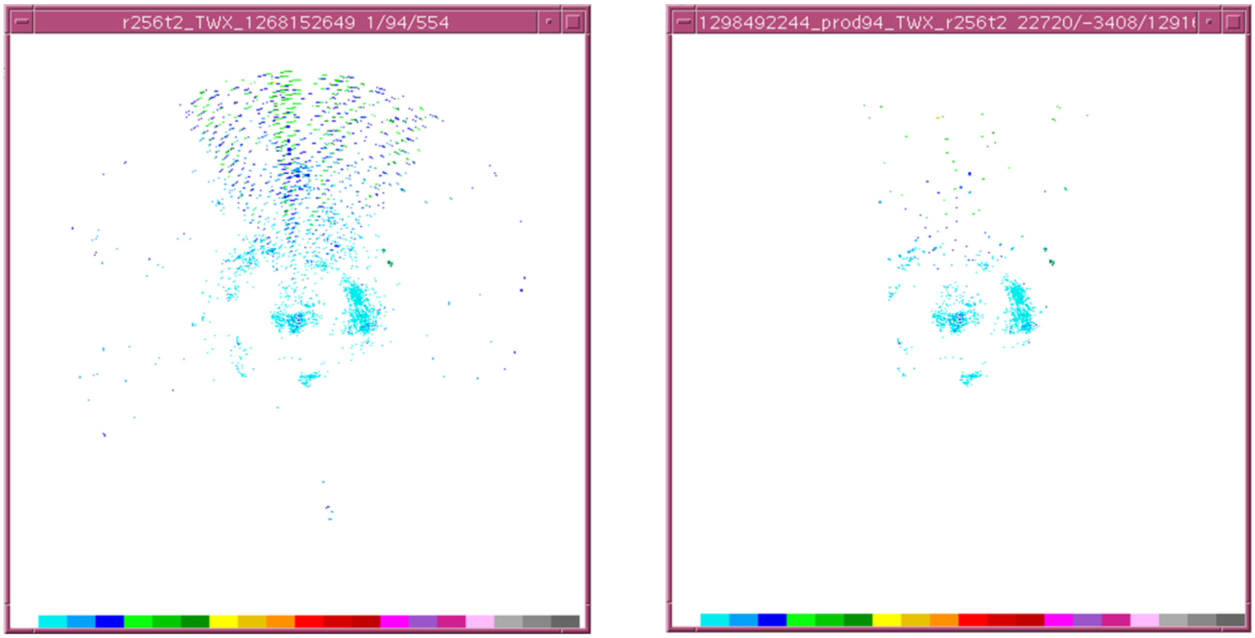
Unedited 0-60 Kft Layer Product Interference Edited 0-60 Kft Layer Product

Figure 8: 0–60 Kft Layer Composite Product Interference Editing



Unedited Tilt 1 Product Interference Edited Tilt 1 Product

Figure 9: Product 94 Tilt 1 Interference Editing



Unedited Tilt 2 Product   Interference Edited Tilt 2 Product

Figure 10: Product 94 Tilt 2 Interference Editing

11. CONCLUSIONS

This paper described how the WARP program is developing a true user-selectable elevation layer radar mosaic product generation capability. The approach being implemented will enable specific improvements in the overall quality of the WARP mosaic products. These enhancements will provide controllers with radar imagery which is closer to real time, resulting in enhanced shared situational awareness with pilots.

The paper showed how the generation of radar mosaic products directly from high resolution base radar product data has significant advantages to approaches using Kft radar products generated by the WSR-88D RPG:

- Unlimited user-selectable elevation layer mosaic generation capability on demand in real time
- No layer-specific processing or product generation by the WSR-88D radars is required
- Significant reduction of mosaic product data latency
- Increased effective mosaic product data coverage area
- Increased spatial resolution
- Ability to map radar product data in elevation
- Improved data level resolution for elevation layer mosaic products
- Consistent data level mapping across all elevation layer mosaic products
- Improved mosaic product data level accuracy
- Increased capability for identifying and removing non-weather radar returns