P1.13 IDENTIFYING THE CAUSE OF WSR-88D GHOST ECHOES

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1. INTRODUCTION

During April 2004, staff at the Lubbock (KLBB) National Weather Service (NWS) Weather Forecast Office (WFO) were seeing bogus echoes in WSR-88D (Weather Surveillance Radar, 1988-Doppler) products. The Radar Operations Center (ROC) began an investigation to find the cause and to provide a solution. We called the false echoes "ghost echoes."

From fields of meteorology, engineering, and electronics, a ROC troubleshooting team was assembled. The team examined KLBB products containing these false returns. We found ghost echoes were only produced from WSR-88D batch waveform. WSR-88D scanning strategies often utilize batch waveform for elevation angles above 1.65º and below 6º.

Batch waveform consists of a short series of long radar pulse intervals (Surveillance) followed by a longer series of short radar pulse intervals (Doppler). The true range detected from the surveillance pulses is used to correct range folding in Doppler pulses (Doviak and Zrnic 1993). The team believed ghost echoes were second- or third-trip echoes in Doppler pulses displayed at first-trip range due to a range-unfolding failure. The reason for a failure of the range-unfolding process in the WSR-88D was less obvious.

2. TROUBLESHOOTING PROCESS

Although later proven wrong, the first prevailing theory was that ghost echoes were somehow related to a new operational scanning strategy called Volume Coverage Pattern (VCP) 12 (Scott et al. 2002). The Lubbock WSR-88D was one of the first sites to use VCP 12 operationally. ROC staff reviewed playback of KLBB Archive Level II data and found ghost echoes seemed to only occur with batch cuts of VCP 12. However, we found no direct link between ghost echoes and VCP 12. The team considered other possible reasons for ghost echoes; those considerations included the newly installed Build 5 software for the Radar Product Generator (RPG) and components of some site-specific hardware.

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A review of the WSR-88D Hotline database, culminating over a decade of records about WSR-88D field problems, yielded no similarities to the ghost echoes found at Lubbock. Since ghost echoes appeared to be a singular problem, team members were inclined to suspect a Lubbock hardware problem. Critical components at KLBB were soon found to be operable.

Troubleshooting efforts were vastly aided when we could study ghost echoes in a controlled environment. A detailed account of the troubleshooting process is not discussed in this paper.

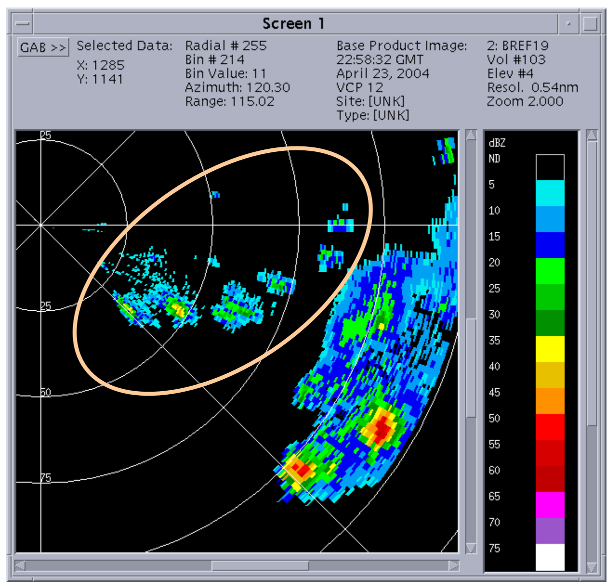

Figure 1 - Ghost echoes (circled) are visible between the WFO Lubbock WSR-88D and strong thunderstorms in the first batch cut of VCP 12 at an elevation angle of 1.8º.

3. BASIC INGREDIENTS OF GHOST ECHOES

After an elusive search for the cause of ghost echoes, the team had compiled considerable information about the problem. In order for ghost echoes to occur, several conditions must be met:

a. The real echo must be beyond the Doppler unambiguous range which depends on the specific Pulse Repetition Frequency (PRF). If present, the ghost echo will be located along the same radial with a range equal to the real echo minus the Doppler unambiguous range.

b. The real target, a thunderstorm, must be sufficient in height to be observed from one or more elevation scans of the batch waveform.

c. The real echo signal must be sufficient in strength so the weaker ghost echo is observable in the reflectivity field (i.e., above threshold).

d. The site operator must have applied high segment clutter suppression for all bins or constructed a user-defined area of suppression where the ghost echo appears.

Of the listed conditions, only one, item (d) above, does not illustrate a classic example of a range-unfolding failure and the misplacement of second-trip echoes. Clutter suppression settings are not normally thought to have any impact on the performance of the range-unfolding process.

The WSR-88D has several clutter suppression options available to operators. One of these options is the ability to tailor suppression in upper tilts and lower tilts, recognizing that clutter problems near the ground are very different from those at higher levels. Currently, radar returns from elevation angles above 1.65º are processed in the "high segment" clutter regime.

An operator can independently control many clutter suppression schemes for high and low segments. Suppression options include: 1) no suppression, 2) a site-specific clutter map (bypass map) which filters over locally identified terrain, 3) operator-defined "wedges" which filter clutter in specified locations, or 4) all bin suppression which uniformly applies clutter suppression to all bins. Options can be implemented with low, medium, or high notch widths to remove roughly 30, 40, or 50 dBZ of power, respectively, depending on PRF.

A new technique gave us a way to test factors causing the range-unfolding error without waiting for strong thunderstorms to form at a certain range. ROC engineers inventively developed a way to inject a signal into the radar that simulated strong target returns at a specified range as if transmitted by batch waveform. The team verified the problem was related to applied clutter suppression in the high segment. We found that whenever the bypass map was in control the problem did not occur; however, ***when suppression was applied to all bins the ghosts did occur***.

Artificial "storms" would display an inner ring of reflectivity if the range-unfolding algorithm failed (Figure 2). If only an outer ring of reflectivity displayed, the range-unfolding algorithm was working properly (Figure 3).

The team quickly converged to the cause of ghost echoes. A latent malfunction had been isolated to the receiver signal processor that consists of a Hardwired Signal Processor (HSP) and a Programmable Signal Processor (PSP). There had been no changes to the HSP firmware or PSP code since the WSR-88D had been deployed. The "ghost echo" problem had been with all WSR-88Ds since deployment.

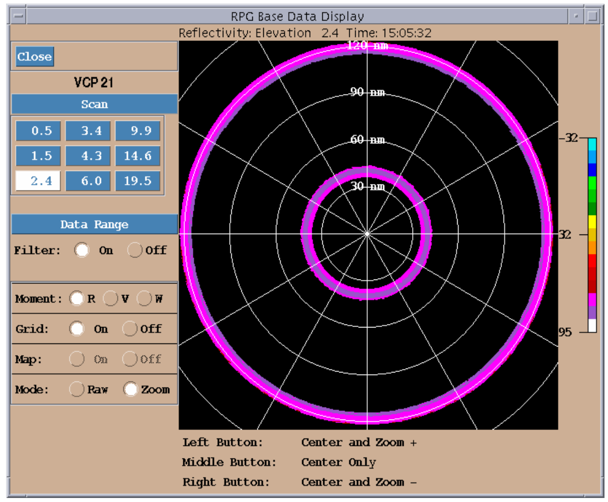

Figure 2 - Engineers used a signal generator to simulate strong echoes at a range of 100 nmi as detected in batch waveform. The presence of the inner ring indicates a failure of the WSR-88D range-unfolding process in the HSP/PSP.

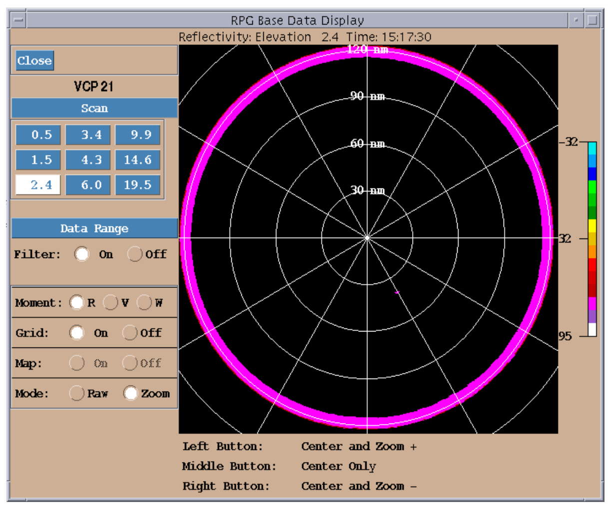

Figure 3 - After a technician rebooted the system and a meteorologist updated clutter suppression settings, ghost echoes were no longer present in the first batch cut given that the inner ring did not appear.

The VCP 12 scanning strategy has a batch waveform lower in elevation angle (1.8º) than other VCPs. This allowed the radar beam of batch waveform to intersect stronger regions of distant storms. During the investigation members of the team began discovering instances of ghost echoes in radar products from other WSR-88Ds. Tall, strong thunderstorms located well beyond first-trip range were common in each case. Most discoveries were while radars used VCP 12, but ghosts were found with VCPs 11 and 21, as well.

4. ROC RECOMMENDATIONS

Once the cause of ghost echoes was sufficiently understood, actions were taken to remove adverse operational impacts. An explanation of ghost echoes and a work-around were sent to WSR-88D Regional Focal Points who forwarded the details to field site personnel. Instructors at the Warning Decision Training Branch also prepared on-line training about ghost echoes.

Operationally, ghost echoes are most noticeable in the base reflectivity products with elevation scans at and slightly above 1.8º. Composite reflectivity products can contain ghost echoes. Ghost echoes can cause precipitation accumulations in all precipitation products. That is, if ghost echoes are present, they can have an impact on precipitation estimates if the hybrid scan includes the bogus reflectivity values from higher elevation scans. Operational impacts of ghost echoes appear to be minimal since the problem has been present for many years with no complaints from the field. Operational meteorologists and hydrologists using the WSR-88D should at least be aware of ghost echoes.

As always, each site should use the minimum amount of suppression necessary to remove clutter. In nearly all cases, this means using the bypass map with a filter setting of medium or low. If the use of high suppression is required in the high segment there may be other site-specific problems which need to be investigated.

Even before the discovery of ghost echoes, the ROC recommended use of the bypass map in the high segment. After many years of operation, the ROC Hotline continues to get questions about data dropouts in upper tilts. This is a result of over-suppression in the high segment.

5. PROCEDURES TO REMOVE GHOST ECHOES

Operationally, ghost echoes can be entirely eliminated from products in the WSR-88D. One proven way to eliminate ghost echoes is to only use the bypass map for high segment clutter suppression. Step-by-step procedures to remove ghost echoes from the WSR-88D can be found in a document linked to the Warning Decision Training Branch web site at the URL:

www.wdtb.noaa.gov/resources/fieldupdates/ghostechoes

5. SUMMARY

Ghost echoes had been a potential problem to WSR-88D field sites for over a decade. However, the likelihood of producing ghost echoes had recently increased since the elevation angle of the lowest batch waveform had been lowered from 2.4º in VCPs 11 and 21 to 1.8º in VCP 12. Labors of many talented people revealed the seemingly illogical connection between clutter suppression and the failure of the range-unfolding algorithm.

The Shanghai and Taiwan NEXRADS are affected by the incorrect processing we found since they use an identical receiver signal processor. ROC staff notified authorities working with these systems and others. The S-Band CINRADS, the Romanian WSR-98Ds, the FAA TDWR C-band radars, and the Enterprise system at Evansville, IN, use different signal processors, so no problem is anticipated with these systems.

Forecasters can easily spot ghost echoes by inspecting reflectivity fields produced from the first elevation angle above 1.65º. If a user-defined clutter suppression (or “all bins”) region is inadvertently used in the high segment, reflectivity products will contain ghost echoes when other basic ingredients exist.

The work-around to fix ghost echoes is temporary. Plans are underway to deploy an Open system RDA (ORDA) to field sites (Cate et al. 2003). Isolation of the ghost echo problem to the legacy signal processor was important since the ORDA will include a robust replacement to this equipment. A pre-deployment test of ORDA will utilize the techniques developed during our investigation to ensure no ghost echo-issues exist in the new signal processor.

6. ACKNOWLEDGMENT

Numerous ROC government and contract employees unselfishly contributed toward a solution to ghost echoes. Steven Cobb, the Science and Operations Officer at WFO Lubbock, first noticed the ghost echo problem and began communication with Warning Decision Training Branch instructors and, later, with ROC Hotline staff. Steven was the first to demonstrate that clutter suppression settings had noticeable effects on the performance of the range-unfolding algorithm. Other WFO Lubbock staff also contributed to finding the cause of ghost echoes.

7. REFERENCES

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