P1.12 A MULTIDISCIPLINARY APPROACH TO WSR-88D DATA QUALITY ASSURANCE

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1. INTRODUCTION

With the expanding availability of WSR-88D radar data on the Internet, the number of users of these data has increased greatly over the last few years. Many of these users have no formal training in weather radar interpretation; therefore, they are not able to assess the quality of the data.

Through experience and several field investigations, the Radar Operations Center (ROC) learned that efforts to optimize radars must be undertaken by a multidisciplinary team composed of both technicians and meteorologists, with weather radar-related experience in their respective fields. At the ROC, located in Norman, OK, a Data Quality (DQ) team peruses the WSR-88D network daily, proactively contacting sites, which appear to have data quality issues. The team also responds to requests from the field, via the NEXRAD Hotline, and from other ROC branches, concerning a number of issues that may arise, such as calibration, clutter filtering, and precipitation estimation. Additionally, when requested or required, ROC teams travel to radar sites to assist with persistent data quality problems.

To investigate possible causes of data quality problems occurring at sites operating nominally (also referred to as alarm free) the ROC solicited the assistance of several National Weather Service Regional Headquarters and associated weather forecast offices. Three of those investigations are summarized here.

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2. COMMON DATA QUALITY PROBLEMS

There are numerous reasons a radar system may be generating poor data. These can be caused/impacted by both hardware problems as well as operator selectable parameters. Some of the most common data quality problems are described.

2.1 *"Hot" Radar*

The phrasing "hot" or "bright" radar refers to higher than expected reflectivity values. It implies some type of calibration error, and although many DQ problems are a result of improper or drifting calibrations, these aren't the only reasons for "hot" radars. A site that is not utilizing adequate (operator-controlled) clutter suppression for current conditions will appear to be "hot" as compared to a site that is properly implementing suppression. A site, incapable of applying enough suppression, due to a hardware problem, will also appear to be "hot". Additionally, antenna pointing errors (pointing too low) have been found to be the problem at some "hot" radar sites. Each of these examples is separate and distinct from the "calibration" issue.

2.2 *"Cold" Radar*

A "cold" radar subjectively appears opposite from the "hot" or "bright" radar discussed above. These problems are usually related to power output or measurements, calibration, or an antenna pointing error (pointing too high). Over suppression is seldom an issue, since weather generally has enough velocity to remain outside the notch width of the selected clutter filters. This may not hold true if the problem is observed in the upper tilts, since clutter filtering, in "batch mode", is significantly more effective (larger notch width) than in the lower (split) cuts.

2.3 *High/Low Precipitation Estimates*

Probably the largest class of issues, voiced by field meteorologists, is related to WSR-88D precipitation estimates. These are also among the most difficult to troubleshoot. The WSR-88D precipitation algorithms are quite complex, with numerous adaptable parameters, any of which can significantly affect precipitation estimates. While operator-invoked settings such as Z-R relationship and clutter suppression choices can skew the precipitation estimates, a calibration error of 1 dBZ can impact accumulation estimates by approximately 17% per hour (using the default Z-R relationship R=300exp1.4) (Chrisman & Chrisman, 1999). A calibration error of 4 dBZ will approximately double (or decrease by half) the precipitation estimates each hour (O'Bannon, 1998). These induced errors, over the entire precipitation event, can be significant enough to impact warning operations. Since clutter suppression and calibration affects all base data and downstream algorithms, it is prudent to first ensure that the base data is of good quality. Only when the base data are good, should time be spent looking at the algorithms and adaptable parameters.

3. TOOLS

The ROC uses several tools which facilitate both subjective and objective assessments of the data being disseminated by the national radar fleet. Some of these include: (1) System Status Monitor (SSM) which obtains a general status message (GSM) from each radar approximately once per hour; (2) unedited composite reflectivity mosaics which allow side-by-side comparisons; (3) precipitation product mosaics; (4) Radar Height Program which allows the placement of a radar beam over local radar terrain; and (5) the Radar Reflectivity Comparison Tool (RRCT).

The RRCT is a relatively new tool developed by the National Severe Storms Laboratory (Gourley et al, 2003). It provides an objective assessment of adjacent radars. The details of the software design are beyond the scope of this paper, but can be found in the cited reference. A study of the operational utility of the RRCT is still underway; however, current results are encouraging. The Oklahoma City field investigation in paragraph 5.3 will discuss its usage in detail.

4. AN ELECTRONIC TECHNICIAN'S PERSPECTIVE ON DATA QUALITY

A question often asked of ROC technicians is, "How can a radar operating with no alarms have data quality problems?" It's a simple question, but the answer is quite complex. The radar is designed to operate within a given set of parameters (adaptation data). If it operates within these variable limits, it will remain alarm free. So, it would seem that in order to have a truly optimized radar, the key is to maintain the integrity of the adaptation data.

Sometimes this is still not enough. For example, all of the following can occur, without an alarm: transmit power can drop to 400 KW (from 700); clutter rejection can drop to 40 dB (from 57); and the calibration number can change +/- 4 dB. Most technicians and meteorologists would agree that an alarm-free system with a 3.99 dB calibration number, 400 KW transmitter peak power, and excessive clutter has data quality issues. Therefore, it is important not only to maintain the integrity of the adaptation data, but to also be conscious of the nominal operating condition of the system and to respond when it deviates, whether this is observed as a degraded product or a change in a critical number in the Radar Data Acquisition (RDA) calibration.

In an effort to learn more about this class of problems, the ROC performed investigative studies on three alarm free NEXRAD sites with known, long standing clutter/data quality issues. The procedures used in the study incorporated three phases. First, the DQ team collected data with all clutter filtering turned off, to establish a baseline of terrain "hotspots", against which future clutter suppression efforts could be compared. Data were collected, and specific terrain "hot spots" identified. Second, the team invoked maximum suppression and collected data to (1) determine the maximum amount of suppression the system would apply to these identified "hot spots", and (2) subjectively assess the overall quality of the products with the radar clutter filters doing all they were capable of doing. In the third phase, the team performed a variety of alignments (transmitter, receiver, Pulse Charge Regulator (PCR), etc.) while taking product sets between each change. The goal during this phase was to learn what changes tended to have the most impact on the quality of the data.

5. FIELD INVESTIGATIONS

Although the "hot versus cold" radar problem has existed since the WSR-88D deployment, it became much more apparent as different radar mosaics were made available to end-users. Such tools simplify *subjective* comparisons of adjacent radars. As discussed, both hardware issues and operator-influenced parameter selections can make a radar *appear* to be hot or cold, but a subjective assessment usually cannot differentiate between the two types of problems.

Further complicating the situation, a radar can be hot or cold, yet be completely alarm free. The site visits discussed, address exactly that situation. All sites were running alarm-free; all technical modification and software notes had been implemented; and site technicians had aligned their systems according to maintenance manuals. Site meteorologists were using adaptable parameters appropriate for the ambient conditions, and were filtering clutter in such a way as to reduce terrain echoes to the maximum extent possible. The notion that data quality problems could exist under these circumstances was, and remains, counterintuitive.

5.1 *Albuquerque (KABX), NM*

The Albuquerque Weather Forecast Office (WFO) had long experienced problems with strong residual clutter from the Sandia Mountains, which are approximately 16 miles east of the radar. When requested, the ROC sent a meteorologist and a technician to the site to troubleshoot the problem in an effort to determine if realigning the system would help in their clutter suppression efforts. Figure 1 shows how the system appeared before the ROC visit, in clear air mode, with maximum clutter suppression using the radar-generated clutter bypass map. There is no precipitation in the area.

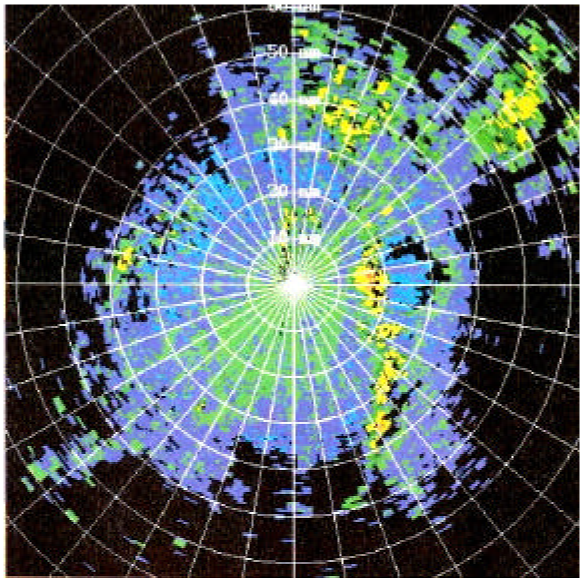

Figure 1. KABX residual clutter (after max suppression) before team arrived

To the east of the radar, the Sandia Mountains rise well above the 0.5 degree radar beam, as can be seen in Figure 2, which is an extract from the "Radar Height Program" used by the ROC.

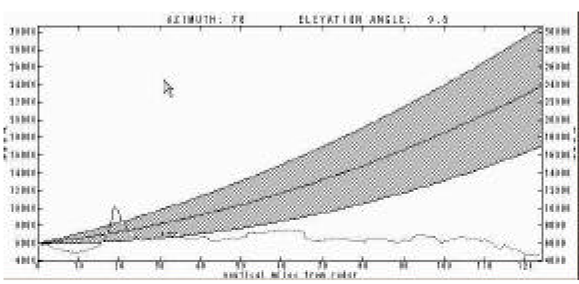

Figure 2. KABX beam blockage by Sandia Mountains

The terrain is clearly visible in the product (Figure 1) running North and South, just to the east of the radar. Also, there are several hills immediately north of the radar (between 10 and 20 miles).

Following the previously discussed procedures, after the radar was turned over to maintenance personnel, the ROC meteorologist turned all clutter suppression off. Then, using the Advance Weather Interactive Processing System (AWIPS) cursor annotation, looping function, and the high resolution map, several "hot" peaks were identified, with radar returns averaging 78 dBZ. Invoking maximum suppression decreased the reflectivity return to around 48-50 dBZ in those areas, placing the overall suppression capability at around 30 dBZ. Literature (Chrisman et al., 1994) indicates that operators should expect approximately 30, 40, and 50 dBZ of suppression for low, medium, and high notch widths, respectively. With a maximum suppression capability of around 30 dBZ vice 50 dBZ, it was evident some type of problem with the system existed.

At the radar site, technicians use the "8-Hour Check filtered and unfiltered numbers" to determine whether clutter suppression is adequate. In a well-calibrated system, the difference in these two numbers is on the order of 53 dB or higher. In this case, the two numbers were unstable, fluctuating from 30 to 40 dB.

The stability and value of the filtered and unfiltered numbers provide some indication of how well the Pulse Charge Regulator (PCR) is performing. Therefore, site technicians ordered a PCR, and the ROC technician began going through normal calibration procedures. As changes were made, the ROC meteorologist gathered products and compared the base line products with the new ones, looking for changes in clutter suppression capability. Technical procedures accomplished were: Suncheck; test path calibrations; and transmitter and receiver alignments. The latter actually made some improvement to the quality of the data, resulting in less "noise" in the base products; however, none of the procedures increased the system's clutter suppression performance.

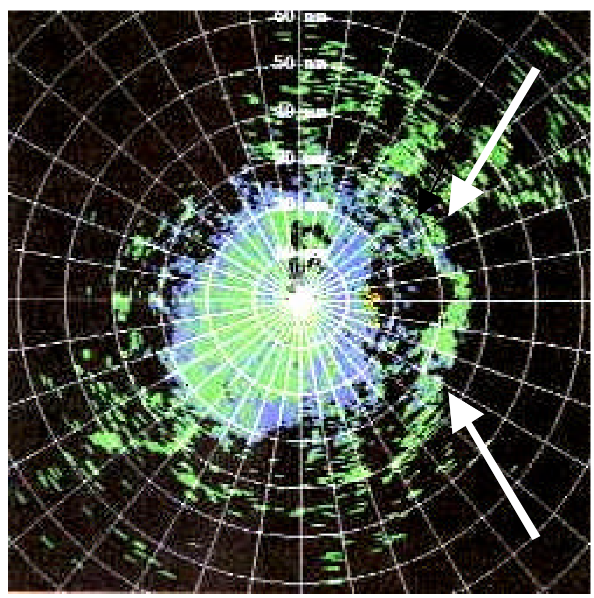

Figure 3. KABX terrain suppressed

When the new PCR arrived, the technicians installed it, tuned the klystron, and completed another transmitter alignment. The filtered and unfiltered numbers were steady at 50 dB. On the products, the effect of changing the PCR was a dramatic improvement in clutter filter performance. With the terrain removed, two interesting features became visible. The first, shown in Figure 3 between the white arrows, is what was determined to be returns due to radar side lobes. No radar energy gets through the mountain range in this direction, so there could be no legitimate return beyond the mountains. The data showed the echoes had a spectrum width of zero, a velocity of zero, and very weak power. It was a simple task to remove them by generating a clutter censor zone for that region. Figure 4 shows how the products appeared after suppressing those returns, and highlights yet another interesting feature.

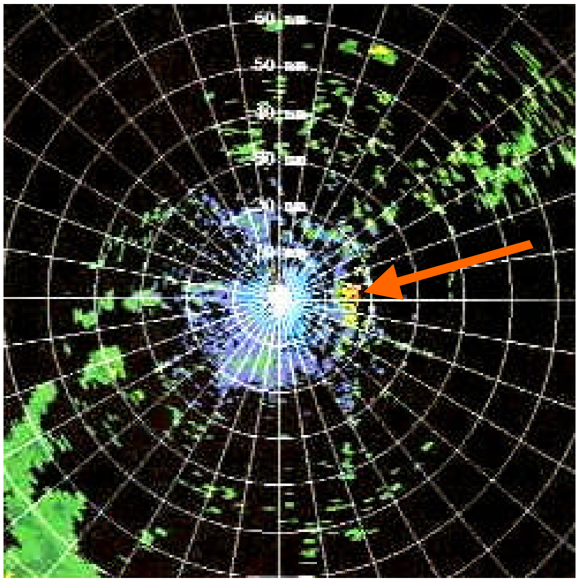

Figure 4. KABX after removing side lobe returns

Figure 4 showed one small area of "residual clutter" remained at the foothills of the Sandia Mountains (orange arrow). After some study, it was determined that these returns were coming from traffic along the streets and highways of Albuquerque. The city lies at the base of the mountains, and as one drives eastward, the terrain steadily rises, to the point that the roads of the eastern portion of the city actually rise into the lowest tilt of the radar beam. Figure 5 is a base velocity product showing the city of Albuquerque, with streets overlaid. The detail is such that one can even pick out what appear to be one-way streets. With non-zero velocities and high spectrum widths, current suppression techniques will not fully suppress these returns. It is interesting to note that these returns were completely masked by the inadequate clutter suppression, as seen in Figure 1.

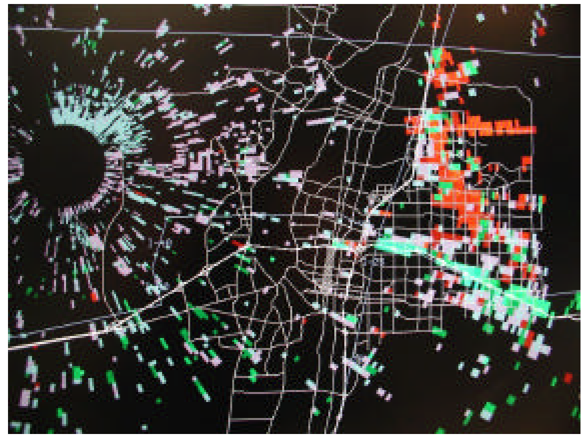

Figure 5. Base velocity returns from city of Albuquerque

In summary, the ROC meteorologist found that peaks, which had previously yielded 78 dBZ of residual clutter, completely disappeared on the base products, after the technicians completed their work. As a test, three points on terrain were selected, and then the system was operated with zero, low, medium, and high suppression, and the residual clutter returns were noted. The results are contained in Table 1.

Suppression	Point 1 (dBZ)	Point 2 (dBZ)	Point 3 (dBZ)
Zero	78	78	73
Low	43	55	38
Medium	0	15	8
High	0	0	0

Table 1. Notchwidth suppression levels compared; KABX

Obviously, the clutter suppression problem had been resolved. In fact, the team discovered that the system was quite capable of completely suppressing 78 dBZ of terrain return, well in excess of the 50 dBZ generally cited in the WSR-88D Operations Training manuals. Further, the bulk of the suppression capability appeared to occur with medium suppression. The team also learned that the numbers field technicians tended to rely on (PCR filtered and unfiltered values) were not a reliable indicator of exactly how well the system was filtering clutter.

5.2 *Burlington (KCXX), VT*

Similar to the problem experienced at KABX, the Burlington, VT WFO had significant clutter issues, and was running without alarms. Figure 6 is an 8-bit AWIPS image, which shows how the products appeared with the ROC DQ team arrived.

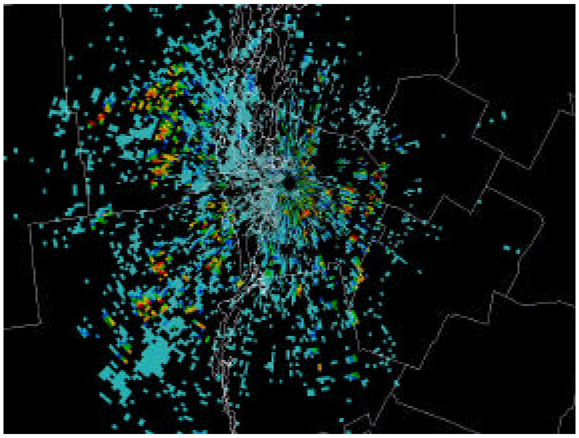

Figure 6. 8-bit AWIPS image of KCXX prior to ROC visit

Residual clutter, after applying maximum suppression, was over 65 dBZ. Using the team's established procedures, once the radar was turned over to maintenance, the ROC meteorologist downloaded zero clutter suppression to determine the extent of the problem. Figure 7 vividly shows the challenges posed by the terrain at the site. In this figure, and all subsequent AWIPS 8-bit products, the light blue colors are in the clear air regime.

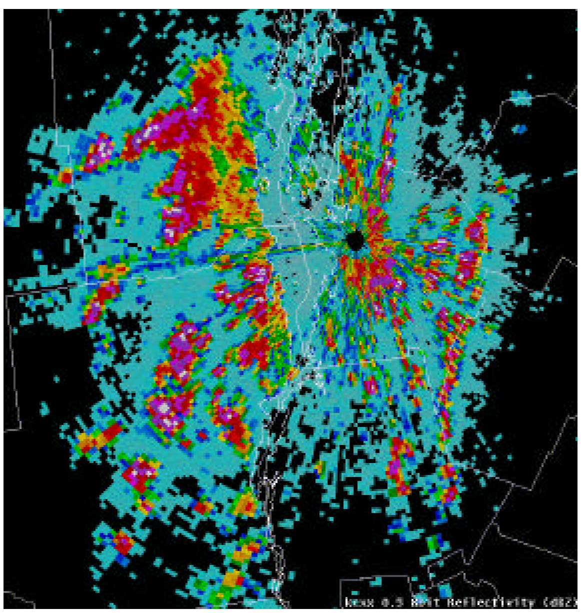

Figure 7. KCXX with no clutter suppression

Two senior staff members at the site explicitly stated that the terrain had been a problem since they arrived, many years ago, and they strongly doubted whether the system was capable of removing the clutter. On the initial test, the ROC team found that with no suppression, more than 75 dBZ was returned from the local terrain, with around 65 dBZ of residual clutter remaining after maximum suppression. At best, the system was only removing 15-25 dBZ from the mountains.

Site technicians joined the ROC technician, as they looked for problems in the alarm free radar. The symptoms of this problem appeared very similar to the situation at Albuquerque, so the ROC technician expected to find that the cause of the problem was the PCR. However, the PCR values in this system were stable, and relatively good, with a numeric difference of 57 dB. Summary transmitter and PCR alignments had no positive affect on the problem.

After extensive troubleshooting over several days, consisting of transmitter, receiver, PCR, klystron, and path loss alignments/adjustments, the problem persisted. The solution was finally found in the Automatic Gain Control (AGC) clock settings. The DIP switches, which control the clocks, were reversed.

Once the clocks were adjusted, the system's clutter suppression increased significantly. Figure 8 shows the site with maximum suppression after the clock adjustment and can be compared to Figure 6 to note the improvement in suppression capability.

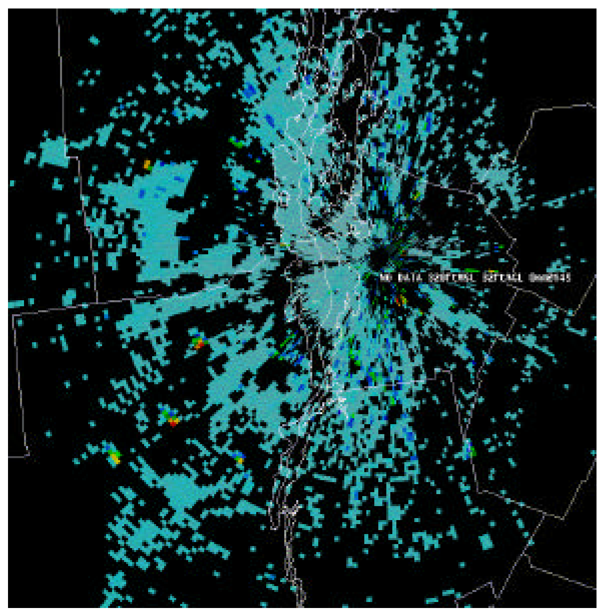

Figure 8. KCXX with maximum suppression, after AGC alignment

Suppression	Point 1 (dBZ)	Point 2 (dBZ)	Point 3 (dBZ)
Zero	79	82	75
Low	49	48	47
Medium	0	14	0
High	0	0	0

Table 2. Notchwidth suppression levels compared: KCXX

Similar to Table 1, Table 2 shows that three strongly reflective terrain points were almost completely removed by medium suppression, and completely removed by high suppression. Interestingly enough, these results closely supported the results found at Albuquerque; however, the end "fix" which optimized the suppression capabilities of the two systems was completely different.

5.3 *Oklahoma City (Twin Lakes - KTLX), OK*

5.3.1 *Radar Reflectivity Comparison Tool (RRCT) Background*

The RRCT operates on the principle that between any two radars, discrete areas or "bins" in space can be located which are approximately equidistant from each. When valid data (weather) is present in these bins, the information, as observed by each radar, is collected and disseminated via the RPG's Base Data Distribution System. The National Severe Storms Laboratory ingests the data in near real time via the Internet2 network (Crum et al, paper 12B.3). There are restraints/tests applied to ensure the comparisons are valid. For example, comparisons of data from adjacent radars must be within six minutes; echoes must have a reflectivity level of at least 10 dBZ; and the compared returns must be within 8 dBZ of each other.

5.3.2 *Field Investigation*

The work conducted to improve the data quality for the Oklahoma City radar (KTLX) further demonstrates the importance of a coordinated team effort to recognize and improve radar performance. The radar was operating with no alarms, normal operating parameters, and verified calibration results. All standard checks, alignments, and calibration routines showed no apparent problems. However, from a meteorological perspective, the radar appeared to be approximately 2 dBZ "hot".

A team, consisting of senior field engineers and meteorologists, evaluated the operational performance of the KTLX WSR-88D in an effort to determine why the data from the radar *appeared* to be hot. The investigation found the radar to be in meticulous condition. All alignments (transmitter, receiver, pedestal, and receiver signal processor calibration) were well within tolerance. All calibration tests and data were well within specifications. The ONLY change made to the system was a 1 dB increase in antenna gain. The field engineer predicted this would make an approximately 2 dB change in product returns, making them cooler, which would serve to remove the "warm" bias previously noted.

The work on the KTLX radar was completed on Aug 5, 2004. Figure 9 is a time series of raw data (units in dB and unfiltered) from the RRCT which compares the KTLX radar with the Tulsa (KINX) system both before and after the system changes. In the figure, the label (KINX – KTLX) means literally, "the values observed by the KINX radar MINUS those values observed by the KTLX radar." The difference is plotted. The red line represents the day on which the work was completed (Aug 5, 2004). This objective comparison shows that before the adjustment, KINX was approximately 2 dB cooler (negative) than KTLX. Shortly after the work, the graph shows that KTLX and KINX compare favorably, with the average difference hovering around zero.

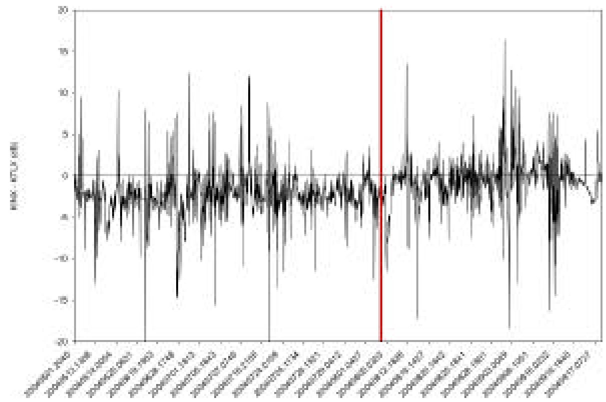

Figure 9. Time series; KINX compared to KTLX

Similarly, a time series was generated for a comparison between the Vance AFB radar (KVNX) and KTLX (Figure 10). In this series, the calculation is "KTLX MINUS KVNX." The time series comparison indicates that prior to the work being done, KTLX was on the order of 1.5 db warm. Afterwards, the comparison to the KVNX radar indicated that KTLX is about 0.5 dB cool, for a total difference of around 2 dB. In both instances, the change predicted by the field engineer was that the KTLX radar would cool off by almost 2 dB. The time series data independently support that estimate.

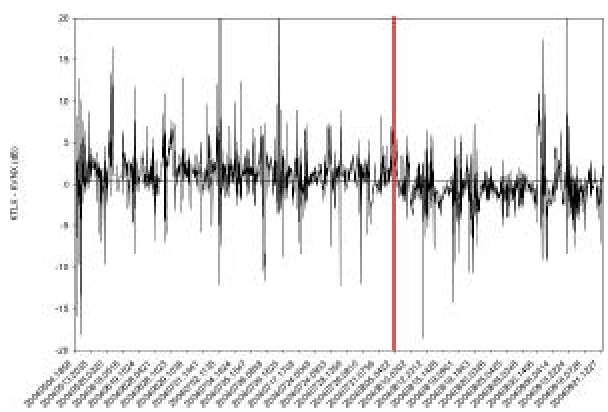

Figure 10. Time series; KTLX compared to KVNX

Using the RRCT, data was collected for a one month period prior to, and for a one month period following, Aug 5, 2004. The following radars are compared to KTLX: Frederick, OK (KFDR); Ft Worth, TX (KFWS); Tulsa, OK (KINX); Ft. Smith, AR (KSRX); and Vance AFB, OK (KVNX). The table indicates, for example, that KTLX – KFDR results in KTLX being about 0.7 dB cooler than KFDR before the work, and after the work, it was on the order of 1.8 dB cooler than KTLX. The result is that, averaged over time, KTLX cooled off by approximately 1.1 dB, as compared with KFDR.

(KTLX Minus …)	Difference prior to Aug 05	Difference after Aug 05	Change (dBZ)
KTLX - KFDR	-0.7	-1.8	-1.1
KTLX - KFWS	+0.5	-1.0	-1.5
KTLX - KINX	+2.2	+0.5	-1.7
KTLX - KSRX	+1.8	+0.5	- 1.3
KTLX - KVNX	+1.3	-0.6	-1.9
		AVG	-1.5

Table 3. KTLX compared to adjacent radars

Considering the objective comparisons between five independent radar sites, the results of the change made at KTLX were surprisingly predictable, giving an average 1.5 dB decrease in reflectivity level (compared to the engineer's estimate of "approximately" 2 dB).

Data quality improvements related to antenna gain have been observed at a few other sites. Work is still in progress, but preliminary results have shown that all suspect sites, were "off" by approximately 2 dB. The major error was found to be the improper setting of antenna gain. Measurements and tests were conducted to re-establish the parameter to near baseline values calculated during system installation.

The ROC is currently reviewing the antenna gain check procedure. Besides validating its accuracy and dependability, methods are being developed to improve its effectiveness and reliability.

6. LESSONS LEARNED

A great deal of information was obtained by the field investigations; the most pertinent for field technicians and meteorologists are discussed below:

a) Radars without alarms, aren't necessarily optimized.

b) The WSR-88D is capable of filtering 70+ dBZ from terrain. If a radar system is not able to do that, it should be investigated.

c) The PCR filtered and unfiltered numbers may not be representative of the clutter suppression actually being applied to the products. In order to see exactly how much suppression is being applied, meteorologists should: 1) follow national procedures for sending a Free Text Message and/or advising the end users that the system will be taken down for maintenance; 2) download zero clutter suppression for a scan and note a few "hot" points in the terrain; 3) download maximum clutter suppression for a scan, and note how the maximum return from those points is decreased. If the difference is not near or above 70 dBZ, then the system is not doing all it's capable of doing.

d) In most cases an optimized radar site, adjacent to mountainous terrain, needs only to apply medium suppression. When the new, faster Volume Control Patterns (VCPs) are used, operators may need to increase clutter suppression to high, to make up for the broader spectrum widths induced by spinning the antenna faster.

e) A tenacious technician and a critical meteorologist are BOTH required to optimize a system. A WSR-88D has a range of settings at which it will run alarm-free. However, it is believed that each system is fully optimized only at a narrow range within the broad limits. A technician "tweaking" the system, with a meteorologist providing feedback as to how the small changes affect the end products will result in the best quality data.

f) Site technicians should not attempt to troubleshoot precipitation estimation problems. Instead, they should concentrate on optimizing radar calibration and the clutter suppression capabilities of their system. Resolving these issues will positively impact the base data and all products from downstream algorithms, to include the precipitation estimates.

g) When logging a system out for precipitation estimation related problems, site meteorologists should first note whether the system appears to be hot or cold, and then check relevant adaptable parameters prior to initiating hardware troubleshooting.

7. DATA QUALITY ENHANCEMENTS WITH OPEN-RDA IMPLEMENTATION

With the installation of the new Open-RDA (ORDA) system, end users will see hardware, software, and procedural changes, which will improve the quality of the WSR-88D data stream. A new digital receiver replaces most of the legacy components, eliminating the problematic AGC clocks and related circuitry, and significantly improving the stability of the system calibration. New alignment procedures and signal control software will improve the operation of the PCR, which will also serve to optimize the quality of data. ORDA implements new clutter suppression software, "Gaussian Model Adaptive Processing" (GMAP) which is expected to simplify the management of clutter suppression and improve the quality of end products, for both meteorologists and technicians.

8. ACKNOWLEDGEMENTS

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