P4R.14 INVESTIGATING EXTERNAL AND DUAL POLARIZATION CALIBRATION OPTIONS FOR THE WSR-88D

Richard L. Ice*
RS Information Systems, Inc. Norman, Oklahoma

David A. Warde
SI International, Norman, Oklahoma

Frank Pratte
National Center for Atmospheric Research, Boulder, Colorado

INTRODUCTION

Maintaining the calibration accuracy of the WSR-88D network is an important activity for all organizations involved in NEXRAD. The Radar Operations Center (ROC) is active in establishing calibration procedures and assists the field with calibration related issues. Additionally, the ROC Engineering Branch has been working to improve calibration related guidance ever since deployment began in the early 1990's. Technical manuals used by the WSR-88D field technicians have been continuously improved. However, the existing initial calibration process is essentially an "internal" calibration check, with results dependent on careful adherence to manual procedures. Once a radar is properly calibrated, the system is designed to maintain its calibration state automatically within the limitations of the hardware. The system adjusts for hardware drifts as long as the errors occur in components within the main signal path and not in parts of the test and monitoring subsystem. With the exception of the antenna gain sun check measurement, the NEXRAD program does not currently employ an external verification of subsystem calibration accuracy.

This paper summarizes a recent, comprehensive survey of potential external instrument calibration techniques and presents the status of a current effort to generate proposals for development of four new calibration capabilities, which may prove useful to maintaining desired WSR-88D network calibration consistency.

MOTIVATION

The benefits of establishing highly accurate and repeatable reflectivity calibration for a national weather radar network are well known. Studies completed in the early stages of the NEXRAD program development quantified the monetary benefits of establishing and maintaining a well-calibrated network. Using updated data from Hudlow, et al, 1984, Figure 1 (Pratte and Ice, 2005) depicts the quantitative hydrologic benefits of calibration accuracy. The graph shows the estimated annual hydrologic benefits as a function of uncertainty in the measurement of equivalent reflectivity. This includes instrument uncertainty (radar calibration) along with propagation and meteorological signal statistical uncertainties. As an example, reducing overall uncertainty from 2.8 to 2 dB can provide an estimated $700M annual economic benefit. Early NEXRAD program planners placed the standard instrument uncertainty requirement at less than 1 dB, partly for this reason.

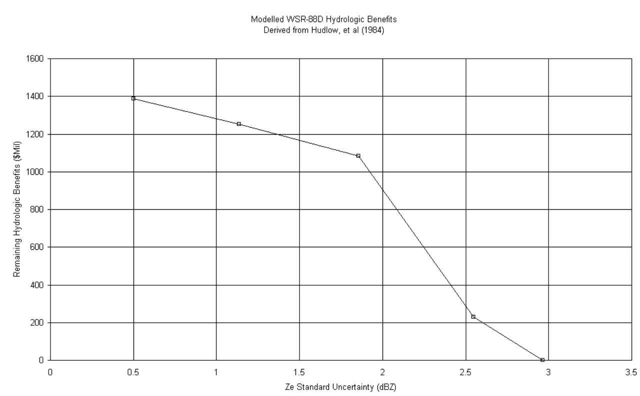

Figure 1 - Benefits of Z_E Measurement Accuracy

Due to the obvious advantage of maintaining instrument uncertainty below 1 dB, system support managers and engineers are highly motivated to maintain the system requirement of 1 dB for instrument calibration uncertainty. However, experience shows that this is not always achieved in practice. Scientists and engineers at the ROC frequently assist field sites with calibration issues. The ROC hotline responds to requests for support for system data quality issues on a routine basis. In some cases, radar data quality problems are traced to calibration errors, frequently due

* Corresponding Author Address: Richard L. Ice, RS Information Systems, Inc., WSR-88D Radar Operations Center, 3200 Marshall Ave. Norman, OK, 73072; Richard.L.Ice@noaa.gov

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to improperly adjusted antenna gain (Ray, 2005). The antenna gain used in reflectivity calculations in the radar signal processor was originally set to the manufacturer's specifications, which were based on antenna range measurements of the first article. Use of the specification value assumes the operational antenna was properly assembled at the site, has not degraded due to dirt, corrosion, or damage, and that the radome performance has not degraded. Currently, the only way to check antenna gain in the field is through the use of the aforementioned "sun check". The site technicians are permitted to update the antenna gain based on results of a specified number of solar scans. The present maintenance guidance is the result of a series of engineering tests done by the ROC (Sirmans and Urell, 2001). However, ROC team members have identified errors in the antenna gain measurement in a number of cases. There appears to be a need for a better means of verifying antenna gain in the field. In addition, the current on-line monitoring systems does not check any portion of the radar system above the point of test signal injection, which is presently at the input to the receiver low noise amplifier. Most of the pedestal waveguide sections, the rotary joints, and the entire antenna structure are not monitored.

Recently, the ROC began using a new tool to monitor the measurement quality of network radars. This is a software system which ingests level 2 reflectivity from most of the network radars in a near real time basis (Gourley, et al, 2003). This tool examines common volumes of measured reflectivity between adjacent radars and provides analysis products for assessing how well these systems agree with regard to reflectivity estimates. Figure 2 is an example of a national monitoring product.

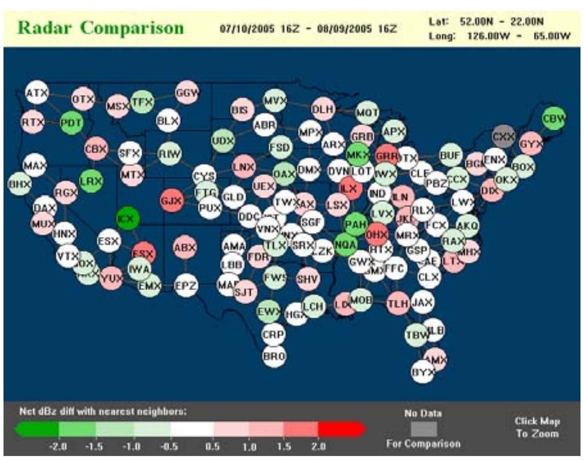

Figure 2 - National Reflectivity Comparisons

A quantitative measure of how well any particular radar agrees with its nearest neighbors is depicted in the color code, with white indicating agreement within +/- 0.5 dB. This example shows reflectivity consistency as averaged over a one-month period in the summer of 2005. As seen, a significant portion of the network is fairly consistent, with agreements within the required 1 dB deviation. However, some sites are not consistent with their nearest neighbors as evidenced by the number of sites indicating the various shades of red and green. This may indicate that these sites need instrument calibration, but other factors could also be the reason. Meteorology, anomalous propagation, and clutter filter management can also contribute to the observed differences. The ROC uses this tool as only a part of a comprehensive data quality support program. These and other results of system monitoring efforts point to a need for a method of externally validating a particular radar's calibration state.

The planned WSR-88D Dual Polarization upgrade will require yet tighter methods of calibrating the system. Requirements for the uncertainty of Z_{DR} measurements can be as tight as 0.1 dB (Melnikov, 2003). Efforts are underway at the National Severe Storms Laboratory (NSSL) and NCAR to develop methods of accurately determining the bias imparted to differential reflectivity estimates due to differences in transmit and receive paths of the two polarization channels (Hubbert, 2004, Zrnic, 2005). At least one of the techniques recommended for development in the survey, the calibration test set, may have a positive impact on the dual polarization calibration question. The dual polarization project will likely derive significant benefits from a robust external calibration capability. Additionally, the dual polarization retrofit will require significant modifications to the antenna feed, waveguides, rotary joints and receiver front ends, done as a field installation. The authors believe an external method to verify performance of the modified transmit/antenna/receive subsystem in the field is an important component of the dual polarization retrofit effort.

CALIBRATION TECHNIQUES SURVEY

In mid 2004, the ROC Engineering Branch requested that RS Information Systems (RSIS), the current engineering support contractor, conduct a study into potential methods of externally calibrating the WSR-88D. Finding a practical, universally accepted way to externally calibrate weather radars is a daunting task. Practical methods have eluded the community for nearly the entire history of weather radar, although some researchers have been moderately successful. Atlas (2002) reported on early work with various external targets such as spheres. Spherical targets were placed in the radar beam by various methods. He reports on using pellets shot from BB pistols. Atlas was puzzled by his observation at the 2001 Calibration Workshop (RADCAL2001, Joe, 2001) that so many current workers were unfamiliar with such techniques. However, no system deemed practical for a large network operation such as NEXRAD has been identified.

RSIS partnered with the National Center for Atmospheric Research (NCAR), whose members conducted a comprehensive survey of industry, government, and academia. The resulting survey report covers a significant number of potential methods and includes a complete reference list as a resource for project engineers (Pratte and Ice, 2005). The focus was on the instrument; on-site WSR-88D equipment and software, and not generally propagation or meteorological target effects. Methods investigated included use of external RF transponders, celestial targets such as the sun, moon, and stars, objects in earth orbit, and various other passive targets including balloon borne spheres and tower mounted reflectors. One particularly interesting approach was the concept of lunar reflections. Experiments at the Mile High Radar in the mid 1990's showed that a usable return signal could be obtained by directing the radar pulse at the Moon. The technique required long integration times in order to obtain usable signal to noise ratios, but appeared quite feasible. Due to the need for development of a weak echo processing model and a lack of community understanding of the lunar face as a target, this option was set aside in favor of other, more "down to earth" methods. However, because the Moon is universally accessible, has a consistent cross section (same face towards Earth), and is essentially "free", the authors believe this concept merits future investigation.

The various other methods were analyzed and compared using a number of criteria, including technical feasibility, cost, compatibility with the WSR-88D, ease of use, and automation potential. The investigation team concluded that a number of complementary techniques were technically feasible, potentially cost effective, and desirable. Results were presented in late 2004, and the team recommended four techniques for further investigation.

The four methods recommended are: (1) Independent Calibration Test Set, (2) Free Floating Sphere, (3) Near Field Antenna Pattern Measurement, and (4) Calibration Monitoring Software. Of these four techniques, the calibration software was not originally considered as part of an external calibration method. During the course of the investigation, team members concluded that such a capability clearly was necessary.

RECOMMENDED CALIBRATION METHODS

Calibration Test Set – This concept is for development of a specialized set of microwave hardware and signal processing equipment, which would be used as a "traveling standard" for accomplishing an initial set up of a targeted radar system. It would contain all functions necessary for verifying complete system performance as referenced to a common calibration port near the antenna. The test set would consist of modules which could be attached to a radar for the purpose of injecting well-calibrated signals, measuring results and recording data. The system would be designed to be easily installed, transportable, and traceable to national standards.

Free Floating Sphere – The sphere provides the almost ideal external target since it can, in theory, be used to calibrate "end-to-end" all radar subsystems including the transmitter, antenna, and receiver. The radar cross section of a sphere can be well characterized and it is potentially affordable. Spheres can be attached to helium balloons similar to upper air systems used by weather stations every day. The main issue with the use of spheres relates to the problem of keeping the sphere in the main beam of the radar and accurately measuring the range from the radar to the sphere. This will be a technical challenge with the WSR-88D because it is not designed to be a target tracking radar. However, with the advent of easily programmable radar controllers and signal processors incorporated in the network by the impending Open RDA deployment, this is certainly achievable.

Near Field Antenna Pattern Measurement – Recent advances in signal processing and laser based position measurement have made the characterization of antennas using near field measurements practical. Traditionally, antenna parameters such as gain, beam width, and sidelobe levels have been measured using far field ranges. For large antennas operating at centimeter wavelengths such as the WSR-88D, this has been the only practical method, with measurement probes or signal sources placed at a distance sufficient to ensure the far field pattern of the antenna has formed and the far field assumptions hold true. This is difficult to accomplish with the WSR-88D since the far field is considered to be on the order of a kilometer or more. Far field measurements for many, if not most of the WSR-88D network radars, are not practical because finding suitable mounting locations for the far field probes would prove problematic. Near field techniques employ a probe scanner, operated very near the antenna, taking measurements within the near field region. Through the use of a complex mathematical transformation, these near field measurements can be converted to an equivalent far field pattern with a high degree of accuracy. The transformation is computationally expensive, but the advent of inexpensive, high-speed processors has made this much less of an issue. The position of the probe relative to the antenna under test must be known to a high degree of accuracy, but technology has advanced to the point where this is not an issue. Affordable, highly accurate laser tracking systems suitable for this work are currently available.

Calibration Monitoring Software – Team members propose development of a software tool capable of obtaining key radar performance parameters in near real time from the network. The software tool would ingest a number of parameters deemed important to system calibration from each radar, possibly through the national network distribution of level 2 data. The level 2 data stream already incorporates all adaptable parameters from the radar into each volume scan reported. Some parameters of interest include system noise, antenna gain, system path losses and gains, and transmitter power. Additional values such as results from off-line external measurement procedures could be added. Output analysis products from the tool could prove useful for the local site technicians and central network support activities as a means of detecting important trends in the performance of particular radars.

ASPECTS OF EXTERNAL CALIBRATION METHODS

The ROC/NCAR engineering team has begun research and planning for the next phase of development, which is the creation of project plans and specific proposals. The team recently met with members of the technical staff at the National Institute of Standards and Technology (NIST) to discuss technical aspects of near field pattern measurements for the WSR-88D antenna. NIST engineers have significant experience in this area and operate a near field pattern measurement range.

Near field measurements for the WSR-88D will be challenging due to the limited amount of space within the radome. There is only a moderate amount of clearance between the antenna reflector and protective dome structure for mounting the probes and associated position tracking hardware. The NIST team recently examined the Denver Colorado WSR-88D antenna and identified several aspects of the development and some potential solutions. The overall impression at this point is that near field measurements are possible within the confines of the radome.

The ROC/NCAR team also met with NIST and members of the Colorado State University (CSU) CHILL (University of **CH**icago, **ILL**inois State Water Survey) radar facility to discuss antenna pattern measurements and sphere calibrations. The CHILL radar is a suitable platform for conducting proof of concept testing for both near field pattern measurements as well as the free floating sphere methods. CHILL engineers have investigated use of spheres for radar calibration with some success. Adapting the free floating sphere method to NEXRAD, and making it useable in the field, will require development of an active tracking capability in the balloon-sphere instrument package as well as integrating tracking and target analysis software into the radar.

CONCLUSION

The authors hope to support formation of a joint project to address external calibration and begin development of the four techniques discussed in this paper and in the survey report. We conclude that, while development of all these techniques is feasible and highly desirable, success of the program hinges on obtaining the right mix of technical and administrative resources. At a minimum, the authors plan to clearly define the underlying WSR-88D instrument uncertainty components and propose methods of characterizing them.

The ROC Engineering Branch has requested development of project proposals for these four methods. However, the development of any of these capabilities will depend on availability of program funding and identification of suitable technical resources. Development partners will have to be identified and appropriate agreements established among the various organizations. However, it appears at this point that all four of the recommended techniques are technically feasible and merit further consideration.

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