J5B.4 OPEN RADAR DATA ACQUISITION (ORDA) CALIBRATION ANALYSIS

Robert W. Macemon*
RS Information Systems, Inc., Norman, Oklahoma

Nita K. Patel and John R. Cory RS Information Systems, Inc., Norman, Oklahoma
Alan D. Free and Gordon W. Jim, SI International Norman, Oklahoma

1. ABSTRACT

The WSR-88D Open Radar Data Acquisition (ORDA) upgrade was completed in October 2006. The new ORDA system improves calibration consistency for individual sites and aligns data returns across the NWS radar network. This paper will review ORDA calibration techniques, discuss measurement frequency and show individual site consistency of calibration using actual field data.

2. INTRODUCTION

The WSR-88D Open Radar Data Acquisition fleet upgrade was successfully completed in October 2006. The ORDA upgrade replaced the WSR-88D original design signal processors, control processor, legacy hardware and communication line interfaces and analog to digital converters with modern computers, network devices and other open-system design modules (Patel, 2004).

The WSR-88D ORDA receiver design included an Intermediate Frequency Digitizer, IFD, which eliminated the need for many devices in the legacy receiver chain including the AGCs and IF-to-video components. The new receiver signal path provides a lower System Noise level and increased sensitivity while reducing the effort involved in receiver channel calibration and alignment (Patel, 2005). The extent of this upgrade allowed the ORDA engineering design team to redesign the legacy calibration and diagnostics with the goal of meeting the 1dB calibration accuracy specification, improving calibration consistency, aligning data returns across the fleet, and decreasing downtime associated with performing maintenance.

Extensive ORDA internal data logging has provided a means for engineering analysis that was not available with the original WSR-88D design. Engineering analysis of the ORDA log files shows that these goals have been reached on properly calibrated and maintained systems and the root causes of misaligned radar sites are much better understood through the use of the logs.

* *Corresponding author address:* Robert Macemon, RS Information Systems, 2227 W. Lindsey St., Suite 1500, Norman, OK 73069; e-mail: Robert.W.Macemon@noaa.gov

3. ORDA CALIBRATION

Calibration verifies system accuracy and monitors system performance. Calibration and alignments procedures, using built-in receiver test circuitry, guarantee system data quality. During retrace at the end of the volume coverage scan, the system executes automatic calibration routines that monitor the status of the RDA and correct for hardware component drift. (Free, 2006)

The ORDA automatic calibration sequence measures particular parameters that are necessary to compensate for small calibration drifts. Additionally, the automatic calibration includes measurements that provide early indications of equipment failure.

3.1 Design requirements

In the WSR-88D system, reflectivity calibration accuracy is specified to be within 1dB. That is, computed reflectivity values should be no more than 1dB different from absolute measurements. In order to maintain this level of accuracy, certain system parameters are automatically checked and/or measured periodically to compensate for equipment drift in transmit power, System Noise, and Receiver Gain.

The WSR-88D automatic calibration is dependent on:

1. Healthy and aligned radar system components
2. Alarm free operation with regards to calibration
3. Precise off-line measurement of each component's loss/gain (stored in site adaptation data)
4. Minimal external RF interference

3.2 Calibration frequency

The ORDA system was designed in accordance with Legacy RDA calibration requirements to measure certain parameters contributing to reflectivity accuracy automatically during On-line operation (e.g. at the beginning of each VCP). These parameters include transmitter power, noise level, and Receiver Gain in order to calculate the system calibration constant, dBZ_0.

The system also measures other system health indicators including Noise Temperature, system linearity, Velocity & Spectrum Width Processing, and Power Meter Zero. These slowly varying parameters are measured Off-line. The table below identifies which calibration routines are executed during the On-line calibration and which are executed during the Off-line calibration.

Test	On-line	Off-line
System Noise Calibration		
Short Pulse	☑	☑
Long Pulse	☑	☑
Noise Temperature Check	☑	☑
System Calibration Constant (dBZ_0) Calibration	☑	☑
System linearity		
Linearity Check	☑	☑
Test Attenuator Calibration		☑
Velocity & Spectrum Width		
I/Q Processing Check	☑	☑
External Phase Shifter Check		☑
Power Meter Zero Check	☑	☑
Transmitter Power Calibration	☑	☑
Reflectivity Error Estimate Check		
Short Pulse		☑
Long Pulse		☑
KD Check		
KD power		☑
Clutter Suppression		☑
CW Substitution Check		☑
Suncheck Calibration		
Az/El Offsets		☑
Antenna Gain		☑

3.3 On-Line Calibration

The On-line calibrations include: System Noise, Reflectivity Correction (dBZ_0) and Transmitter Power. On healthy and aligned radars, these calibrations are applied to compensate for transmitter or receiver drifts. Other On-line tests include: Noise Temperature, System Linearity, Velocity/Spectrum Width data processing test, Velocity/Spectrum Width RF signal processing test, and Power Meter Zero. These additional tests provide indications of equipment failure.

3.3.1 System Noise Calibration

Operationally, System Noise is measured with the transmitter off and the antenna above 3.5º elevation. The elevation is important in order to avoid bias due to ground noise. No test signals are injected during the noise measurements. System noise is obtained by computing the power of approximately 5000 I/Q samples along a span of 10 radials (Free, 2006).

ORDA measures both short and long pulse noise independently using the short and long pulse matched filters, respectively. During the ORDA installation, the short-pulse System Noise was adjusted to be 5 to 7 dB above the IFD internal noise level. This adjustment was accomplished by adding an attenuator at the input to the IFD. Once set, the attenuation provides an adequate balance between sensitivity and dynamic range. The ORDA short pulse System Noise measurement is about -81dBm while the long pulse measurement is about -85dBm with generally a +/-1dB variation from site to site.

ORDA also applies a simple 2 pole IIR filter smoothing algorithm to the noise measurements so single anomalies do not have a large effect. Larger external interference noise spikes may cause the appearance of decreased sensitivity lasting a number of VCPs before settling out. Such external interference is rare, but is a reality in radar systems.

3.3.2 Sensitivity, I_0 and Receiver Gain

For calibration, Receiver Gain is added to the System Noise level to determine System Sensitivity, I_0 (Free, 2006). System Sensitivity represents the power level of a 0dB Signal-to-Noise target measured at the receiver input. I_0 provides a measure of the linearity of the system as well as the Noise floor of the system.

The Receiver Gain is the overall gain of the signal path from the Receiver Protector input to the signal's digitization in the IFD. Nominal receiver signal gain for the WSR-88D in the ORDA configuration is 33dB. Therefore, a noise level of -81dBm measured at the IFD corresponds to a noise level of -114dBm at the input to the Receiver Protector. Typical Legacy sensitivity was nominally -113dBm.

Receiver Gain is measured by injecting a test signal with known amplitude into the receiver protector and measuring the resultant signal through the receiver path. In the ORDA design, for the CW test signal used, power is measured off-line by the technician and the value is stored in adaptation data. To reduce variance and detect problems, 10 different test signal powers throughout the linear range are used for each ORDA On-line calibration. During the system Performance Check over 60 points are used to determine Receiver Gain and MDS.

3.3.3 Transmitter Power

The transmitted power, P_a, directly affects system calibration. Along with Noise (N) and Receiver Gain (g), transmitted power can fluctuate during system operation; therefore, P_a is measured periodically.

Transmitter power is measured during the surveillance cut of each VCP and also during the Performance Check. During a VCP cut, the system measures the average power of the transmitter once a second. The samples are averaged together and corrected for the duty cycle to obtain the transmitter peak power. The transmitter peak power is then adjusted by the application data to represent P_a, the transmitted power radiated into space.

The transmitter design was not modified in the ORDA architecture; therefore, the design is the same as the Legacy WSR-88D configuration. For both system configurations, nominal transmitter peak power is 700kW.

Because the WSR-88D system uses an average power meter to measure power, the zero level (i.e., bias) is important. The Power Meter Zero procedure is done during On-line calibration to verify a slight positive bias exists on the power meter thereby ensuring accuracy of power measurements when radiating.

During the INCO period, peak transmitter power drifts were noted at many sites and dBZ_0 correctly compensated for the drifting to maintain correct calibration. These drifts are believed to be due to aged klystrons and other transmitter components that had been off during the installation.

3.3.4 System Calibration Constant (dBZ_0)

The ORDA system outputs 1km reflectivity moment data computed using equation 1.

$$dBZ = 10\log\left(\frac{P_R - N}{N}\right) + 20\log(R) - A \times R + dBZ_0 \tag{1}$$

Where:

Variable	Definition
P_R	Return signal power
N	Noise value corrected for elevation
R	Range
A	Two-way atmospheric loss in dB
dBZ_0	System calibration constant

dBZ_0 represents the reflectivity of a 0dB Signal-to-Noise target at a range of 1km, and includes all the constants in the radar equation (Rinehart, 1997 and SIGMET, 2005). A concise equation for computing the system calibration constant with all inputs measured in dB is given in equation 2 (Free, 2005).

$$dBZ_0 = C + A - P_a - L_{dBr} + I_0 \tag{2}$$

Where:

Variable	Definition
C	Radar Equation Constants
A	Adaptation Data (i.e., wavelength, antenna gain, beamwidth, pulsewidth, matched filter loss, and refractivity)
P_a	Transmit power
L_{dBr}	Receiver loss – antenna to receiver input
I_0	0dB Signal-to-Noise level (Minimum Detectable Signal, MDS)

C, A, and L_{dBr} are considered constants and relatively time invariant; therefore, these parameters are measured in Off-line calibration functions. P_a and I_0 are the variables in the dBZ_0 equation parameters that are measured periodically in On-line calibration functions. I_0 measurements are dependent upon precise System Noise and Receiver Gain calibration measurements. Therefore, System Noise and Receiver Gain are measured periodically as well.

4. ORDA CALIBRATION DATA

Each On-line and Off-line calibration sequence produces data saved in daily log files. The log files are archived by the ORDA system and serve as an aid in analysis and troubleshooting. For this study we reviewed the data logs produced immediately following the ORDA installation retrofit from archive disks produced by the ORDA installation teams. Also, we reviewed archive disks from specific sites months after their ORDA upgrade to analyze their stability and consistency.

4.1 LOG Data

Below is a brief excerpt of On-line calibration data from a WSR-88D system on February 23, 2006 showing the results from the automatic calibration sequences run before two sequential VCPs.

RDALOG_rcpg.02242006:VCPC
02/23/2006 18:27:40
Noise: [-80.589745]dB
Unsmoothed: [-80.635870]
dBZ0: [-47.146282]dB
i_0: [-115.533592]
Peak power: 664.446655
Slope: 1.006703
y int: 0.177024
FE Shared: 35.928785
RDALOG_rcpg.02242006:VCPC
02/23/2006 18:37:25
Noise: [-80.561676]dB
Unsmoothed: [-80.505251]
dBZ0: [-47.123207]dB
i_0: [-115.552101]
Peak power: 658.113708
Slope: 1.003820
y int: 0.081732
FE Shared: 35.941807

The data shows the latest On-line calibration results:

Parameter	Description
Noise	System Noise Measurement
Unsmoothed	System Noise after the noise smoothing algorithm
dBZ0	dBZ_0 calibration constant result
i_0	I_0 calibration constant result
Peak power	Transmitter cabinet peak power measured in previous VCP
Slope	The slope of the linearity curve from the 10 point I_0 calibration
y int	Y intercept of the linearity curve from the 10 point I_0 calibration
FE Shared	Receiver Gain calibration result

The logs contain necessary data to analyze a site's stability and consistency, external noise interference, transmitter stability problems and other systems issues.

4.2 Site Operational Data

Site log data can show the stability of On-line calibration over a period of time. A site with receiver components operating well and very little external interference will have consistent noise and I_0 measurements over time. Likewise, sites with a transmitters operating well are expected to produce consistent transmitter peak power over time. A calibrated and stable radar system will have minimal dBZ_0.

Alternatively, a site with issues will show instabilities in the calibration data. Large external noise interference and serious receiver problems will result in significant variance in noise measurements, I_0 and dBZ_0. Sites with transmitter instabilities will have significant variance in the transmitter power and dBZ_0. Following are operational site data sets showing a good system, a noisy system, and a system with a degraded receiver component drifting with diurnal temperature cycles.

4.2.1 Site Operational Data – GOOD

Figures 1 – 4 are from an operational site showing excellent stability of System Noise, I_0, Transmitter Power and dBZ_0, respectively. This data set spans 1078 consecutive calibrations with the following statistical results:

Calibration Parameter	Data Average	Standard Deviation
System Noise	-80.57 dBm	0.047
Sensitivity, I_0	-115.66 dBm	0.105
Tx Peak Power	663 kW	4.88
dBZ_0	-47.26 dB	0.116

All four calibration parameters are expected to have small standard deviations on a good system, as shown. Generally speaking, dBZ_0 varies by no more than +/- 0.5dB on most systems. Wider variation may be due to a maintenance or interference issue.

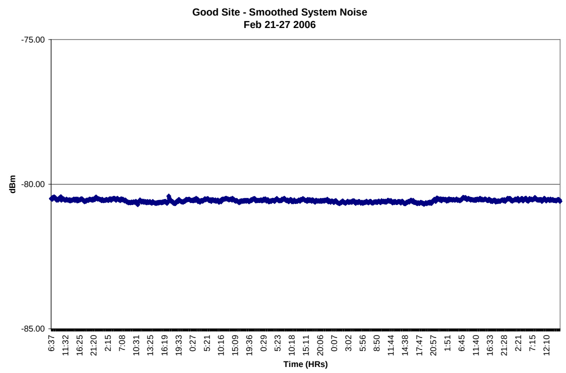

Figure 1: System Noise, Good Site

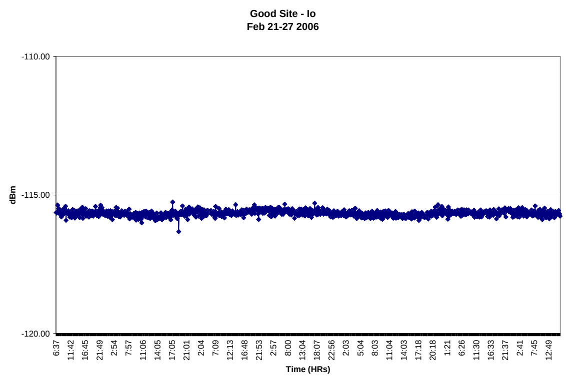

Figure 2: I_0, Good Site

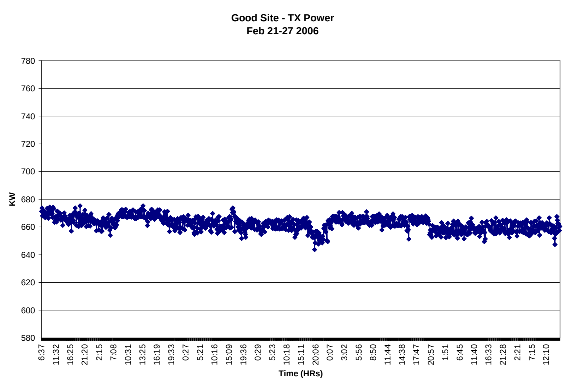

Figure 3: Transmitter Peak Power, Good Site

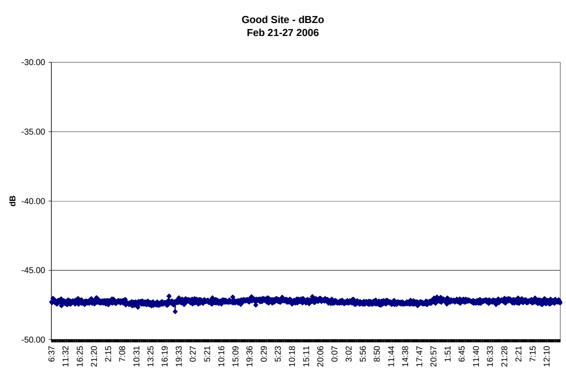

Figure 4: dBZ_0, Good Site

4.2.2 Site Operational Data – NOISY

The operational site represented by this data was discovered to have severe external noise interference problems. Periodically, the noise interference would coincide with the On-line System Noise measurement. As previously mentioned, the result of this problem is reduced sensitivity which may last for a number of VCPs depending upon the site adaptation value settings.

Another nearby radar system was proven to be the cause of the noise interference problem. Figures 5 – 8 show the noisy site data for System Noise, I_0, Transmitter Power and dBZ_0. This data set spans 1604 consecutive calibrations with the following statistical results:

Calibration Parameter	Data Average	Standard Deviation
System Noise	-80.59 dBm	1.99
Sensitivity, I_0	-113.25 dBm	2.14
Tx Peak Power	643 kW	13.18
dBZ_0	-42.99 dB	2.18

The standard deviation for System Noise, I_0 and dBZ_0 are high for this system.

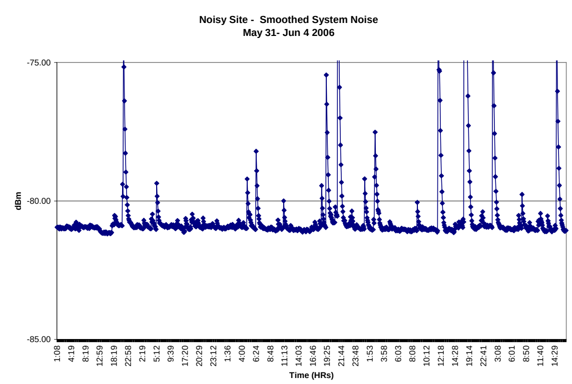

Figure 5: System Noise, Noisy Site

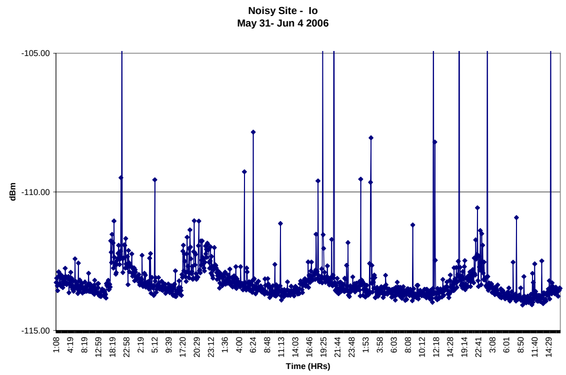

Figure 6: $I_{0,}$ Noisy Site

In addition to the obvious spikes, I_0 also has a scalloped shape because of the noise smoothing algorithm. The smoothing is helpful on most radar systems which have small amounts of noise interference and may be disabled through adaptation data.

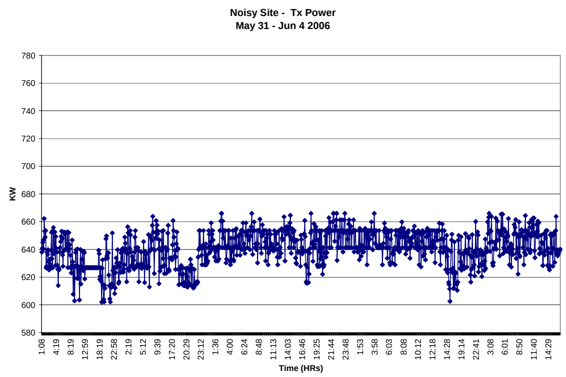

Figure 7: Transmitter Peak Power, Noisy Site

While the transmitter peak power data appears noisier than the Good Site, it is well within norm for the WSR-88D.

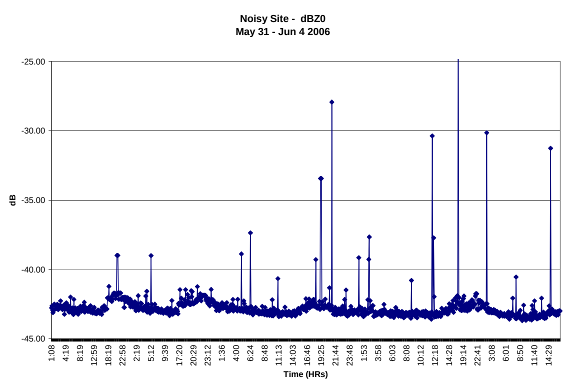

Figure 8: dBZ_0, Noisy Site

4.2.3 Site Operational Data – Receiver Diurnal Variation

Another operational site was studied to determine the cause of dynamic range alarms occurring daily at roughly at the same time. The System Noise was stable as seen in Figure 9, but I_0 shows cyclic variation in Figure 10. Since I_0 represents the sum of System Noise and the Receiver Gain then Receiver Gain is drifting. A degradation of the LNA's internal stabilizer-heater is the expected cause. As expected, dBZ_0 is correctly compensating for the drift as seen in Figure 11. This data set spans 609 consecutive calibrations with the following statistical results:

Calibration Parameter	Data Average	Standard Deviation
System Noise	-81.22 dBm	0.069
Sensitivity, I_0	-112.59 dBm	0.113
Tx Peak Power	663 kW	5.05
dBZ_0	-42.22 dB	0.113

In spite of the diurnal drifts, all four calibration parameters have small standard deviations for this site. This is not surprising since the drift is small.

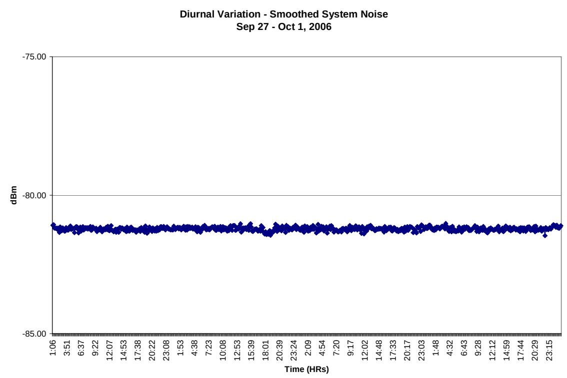

Figure 9: System Noise - Diurnal Variation

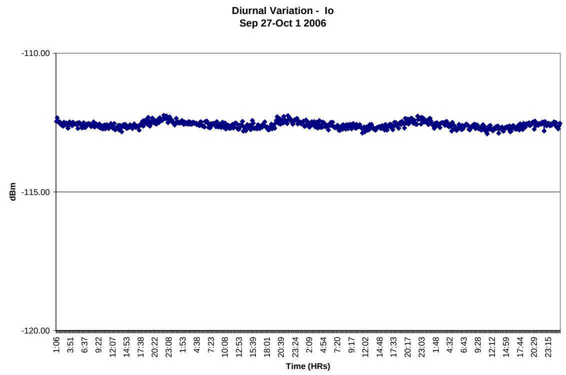

Figure 10: I_0 - Diurnal Variation

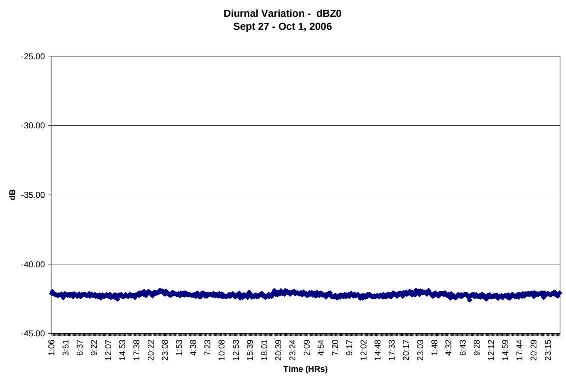

Figure 11: dBZ_0 - Diurnal Variation

5. CONCLUSIONS

The new ORDA system is providing consistent and stable calibration for the WSR-88D network. $dBZ_{\mathbf{0}}$ correctly responds to receiver and component drifts to provide excellent data. The new data logging ability of the ORDA provides a valuable means for engineering analysis and fault isolation.

Engineering analysis of the ORDA log files shows that the design goals for the ORDA system have been reached on properly calibrated and maintained systems and the root causes of misaligned radar sites are much better understood.

6. ACKNOLWEDGEMENTS

The authors would like to acknowledge the ORDA systems engineers and staff for their assistance in developing tools to assist in the calibration accuracy analysis and to the WSR-88D installations teams and site technicians for providing the archive data following each ORDA installation.

Note: The views expressed are those of the author(s) and do not necessarily represent those of the National Weather Service.

7. REFERENCES

Free, A., Patel, N., Macemon, R., 2006: OPEN RADAR DATA ACQUISITION (ORDA) Calibration Consistency, 22nd International AMS Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology

Free, A., Heck, A., and Patel, N., 2005: NEXRAD Open Radar Data Acquisition (ORDA) Receiver Calibration, 21st International AMS Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology

Patel, N., Free, A., Jim, G., 2005: NEXRAD Open Radar Data Acquisition (ORDA) Receiver Characteristics, 21st International AMS Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology.

Patel, N. and Macemon, R., 2004: NEXRAD Open Radar Data Acquisition (ORDA) Signal Processing & Signal Path, 20th International AMS Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology.

Rinehart, Ronald E., 1997: Radar for Meteorologists, 3rd edition, Rinehart Publications, Columbia, MO.

SIGMET, 2005: RVP8 User's Manual