2.7 EVALUATION OF POLARIMETRIC CAPABILITY ON THE RESEARCH WSR-88D

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1. Introduction

One of the enhancements to the WSR-88D weather radar is a polarimetric capability to improve rainfall estimation and identify precipitation type. Implementation of the proof of concept scheme (Fig. 1) has been made on the NSSL's Research &Development WSR-88D, and tests are being conducted to determine the quality of this upgrade. The radar transmits and receives horizontally and vertically polarized waves simultaneously. A high voltage power splitter is used to form two channels in the WSR-88D's transmitter, one for the horizontal H, the other for the vertical V mode. To process vertically polarized waves, a second receiver, identical to the existing one, has been added (Fig. 1). A commercial (Sigmet RVP-7) processor is passively connected (in parallel with a power PC based processor) to allow sooner test of the engineering quality of the system. This processor requires a sum of offset IF signals, one for the H the other for the V channel. Therefore we have retained the initial 57.54 MHz IF for the H channel and have designed circuits to generate a 63.30 MHz IF for the V channel. The following variables are available on the RVP-7 processor: reflectivity Z_h , Doppler velocity V, and spectral width σ_v, all three at horizontal polarization (as is the case on the WSR-88D network), differential reflectivity Z_{DR} , differential phase shift φ_{dp} , and correlation coefficient ρ_{hv}, between voltages in horizontal and vertical channels (see Doviak and Zrnic 1993, for the definition of these variables).

Two waveguide switches in the transmit chain are used to bypass the power splitter to that only H waves can be transmitted. Nonetheless, in this mode both H and V waves are received and processed to obtain the linear depolarization ratio L_{dr} and the co to cross correlation coefficient ρ_{xv} in addition to the three spectral moments and the differential phase. In this configuration, the transmitter and the co-polar channel are essentially identical to the legacy system; the second channel receives the depolarized waves.

There are two simple polarization parameters indicating the quality of the dual-polarization radar design: minimal value of L_{DR} and maximal value of ρ_{hv} measured in light precipitation. Melnikov et al. (2001) reported minimal reliably measured L_{DR} values better than –30 dB in light rain which is an indication of a good isolation between two orthogonal channels. Typical maximal values of the cross-correlation coefficient ρ_{hv} measured in light rain with strong *SNR* are about 0.995. This ensures high accuracy of the measurements of the two basic polarimetric variables that are used for rainfall estimation and hydrometeor classification: K_{DP} and Z_{DR} (Bringi and Chandrasekar, 2001).

The accuracy of the radar reflectivity measurements on the WSR-88Ds is 0.5 dB (Crum et al., 1993). In polarimetric mode, the accuracy of the difference of reflectivities in the horizontal and vertical channels should be better than 0.2 dB. This accuracy is required for discrimination of frozen

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precipitation and light rain. Thus the technical issue to solve has to do with relative calibration of the two receiver channels over the full dynamic range of input signals. In this paper, we describe various calibration procedures aimed to solve this problem and report on stability of the channels.

To calibrate the WSR-88D radar receivers we have used several schemes including test signals of the built-in RF signal generators, external RF and IF generators, solar flux, and measurements in the near field of the antenna. The transmitted powers have been measured with the bolometers (ports 9 in Fig. 1), and with horn antenna in the radar near field.

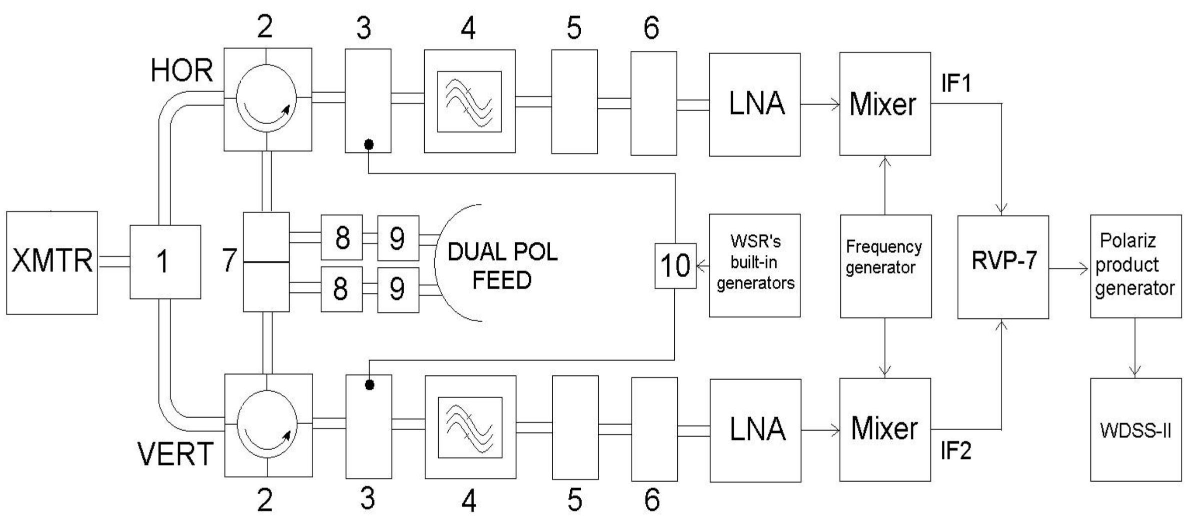

Fig. 1. Polarization diversity configuration for the NSSL's research WSR-88D

1 - power splitter 2 - circulator 3 - crossguide coupler 4 - passband filter 5 - receiver protector 6 - RF limiter
7 - dual channel Az rotary joint 8 - El rotary joint 9 - power monitor port 10 - coax power splitter
LNA - low noise amplifier WDSS-II - warning decision support system, integrated information XMTR - radar transmitter

2. Calibration with the test signal

In these measurements, a low voltage power splitter (box 10 in Fig. 1) supplies test signals to the two channels simultaneously. The two test signals at the input to the directional couplers are equal. The difference of attenuation of two couplers is less than 0.2 dB (the manufacturer's specification). Using the WSR-88D's built-in CW generator we have obtained the receiver response curves. Both curves are linear for sufficiently strong signals; the bias of the Z_{DR} is about -0.3 dB. The receiver noise levels are not equal and further at low SNR there is a question of receiver's linearity which is being addressed. Throughout the warm season (May to September) the receiver response curves have been very stable and we plan to monitor these through the cold months ahead. Calibration with the test signal leaves out the circulators, rotary joints, and antenna. Thus the deduced Z_{DR} bias of -0.3 dB needs to be added to the part caused by these unaccounted components. Nonetheless, frequent monitoring by the build in generator of the partial bias is recommended so that any change (in these active components) can be detected and corrected.

3. Sun scans

The solar flux measurements can be used to verify the coincidence of the radar beam axes for horizontally and vertically polarized waves and check the stability of the receiver channels. To check alignment of the radar beams (for the H and V polarizations) in the transverse direction, the antenna scans in azimuth through the solar disk while signals in the two channels are recorded. The positions of signal maxima coincided hence we concluded that the azimuthal alignment is satisfactory. Similar measurements of solar flux in the elevation direction confirmed that the two beams are aligned.

Here we report only on the imbalance between the two receiver channels deduced from solar flux measurements. The solar signal is 12 to14 dB above radar noise level so this natural source provides one measurement point at the low end of the receiver dynamic range. The noise levels in the two channels are different and this is accounted for in the Z_{DR} measurements as follows

$$Z_{DR} = 10\log\frac{P_h + N_h}{P_v + N_v} = Z_{DR_n} + 10\log\frac{SNR_h + 1}{SNR_v + 1},$$

where P_h and P_v are measured powers in H and V channels respectively (they are different due to different gains of the channels), N_h and N_v are noise levels in the channels, and SNR_h and SNR_v are the measured signal-to-noise ratios. The Z_{DRn} is the Z_{DR} for the atmospheric and system noise. We measure the Z_{DRn} at the antenna park position (Az=0, El=22.5 deg). The measured Z_{DRn} for the radar varies between 0.9 and 1.3 dB.

We used the solar flux measurements to monitor the stability of the receiver contribution to the system Z_{DR} . Fig. 2 presents the results of the measurements during the warm period of 2002. The solar flux values at 2700 MHz have been taken from the NRC/DRAO observatory web site at www.spacew.com. One can see from Fig. 2 that the variations of measured Z_{DR} lie in the interval of –0.2 to 0.2 dB.

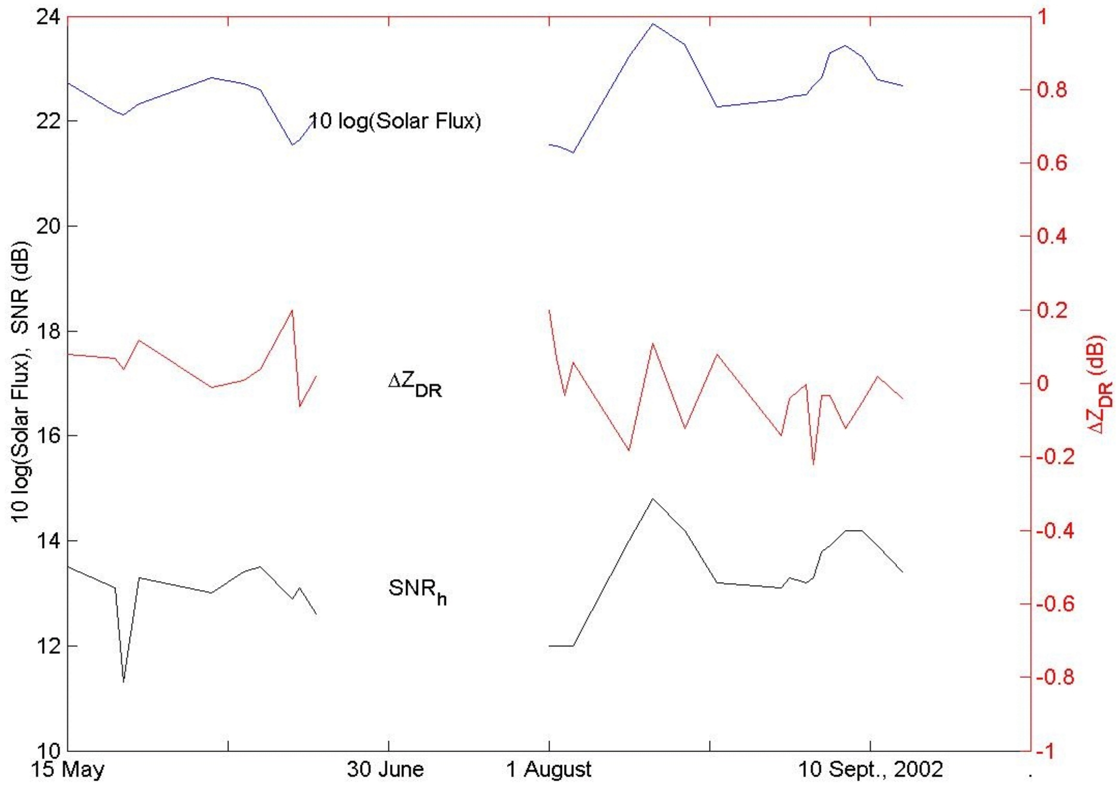

Fig. 2. Measured SNR_h and ΔZ_{DR} for the solar flux. The solar flux is in sfu units.

4. Z_{DR} calibration using the ground clutter

The Z_{DR} calibration using the test signals and solar flux do not close the calibration loop. The transmitter chains are left out of the loop. The measurements of outgoing powers at the ports 9 Fig.1 have the accuracy of 0.5 dB which is considerably larger than required for precise Z_{DR} measurements. A metal sphere lifted with a balloon could be used for total calibration but this is complicated and permission from the FAA is required for each case of the lift. Therefore we opted to use natural object in the radar vicinity.

Can the ground clutter be used as such an object? The answer is no if a point Z_{DR} is considered because the ground clutter has very variable Z_{DR} properties; the Z_{DR} can exceed 10 dB and be positive or negative. But a field of Z_{DR} from ground clutter offers attractive possibilities. We have been recording the clutter since May 2002. One full rotation of the antenna is used to collect data at low elevation. Only echoes with the *SNR* larger than 30 dB were processed so that the effects of noise are insignificant. An example of the output histogram of Z_{DR} is shown in Fig. 3.

The RVP-7 processor presents the Z_{DR} values in the interval of -7.94 to 7.94 dB. Because ground clutter has some Z_{DR} values outside of this interval the histogram has the long "horns" due to clipping in the processor. The median value of the histogram, *M*, was calculated for the whole data set with clipped values. The M_2 is for data in the interval of -7 to 7 dB, t.e without clipped values. The *Mean* value is also for the data in the interval -7 to 7 dB. In Fig. 4, these three values are shown over the time from May 2002 to September 2002. Clearly the mean values over this time period are close to 0.1 dB. The mean values have the lowest standard deviations of 0.15 dB. These measurements suggest that the ground clutter could be a good candidate for Z_{DR} calibration. We are continuing the measurements to include the cold season so that seasonal statistics and long term variation of the Z_{DR} could be determined.

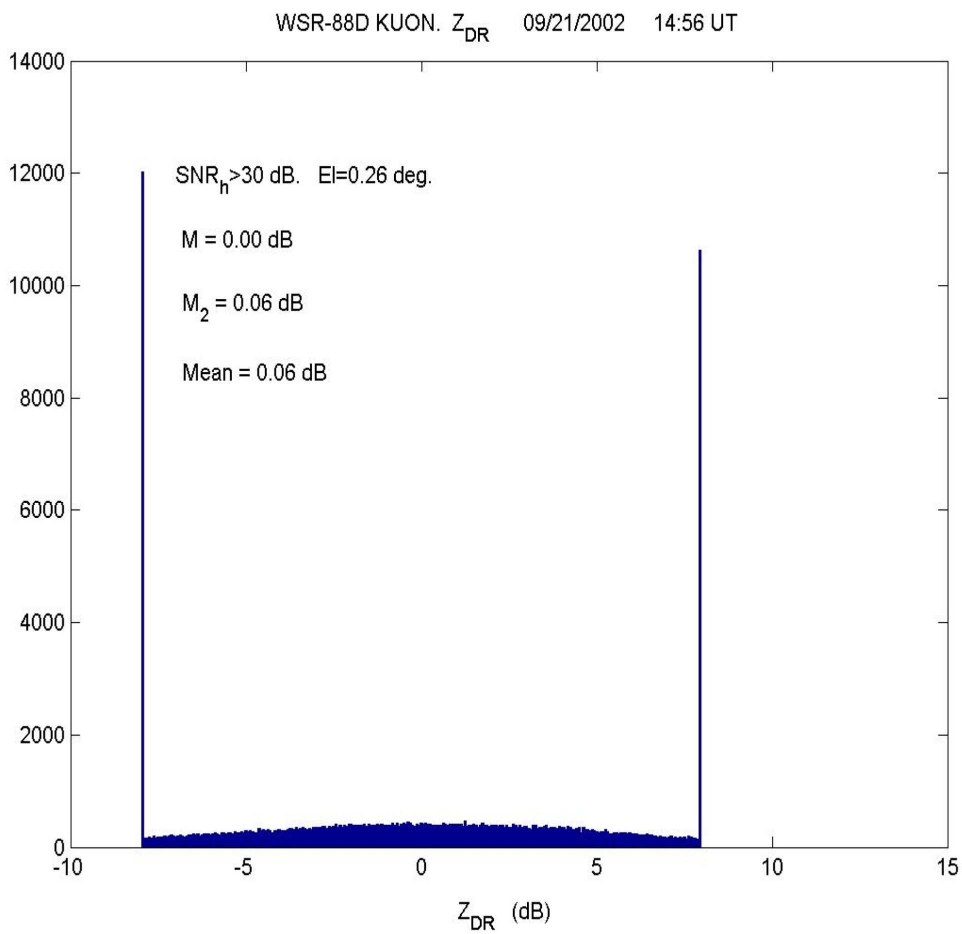

Fig. 3 Histogram of measured Z_{DR} of ground clutter for one full antenna revolution

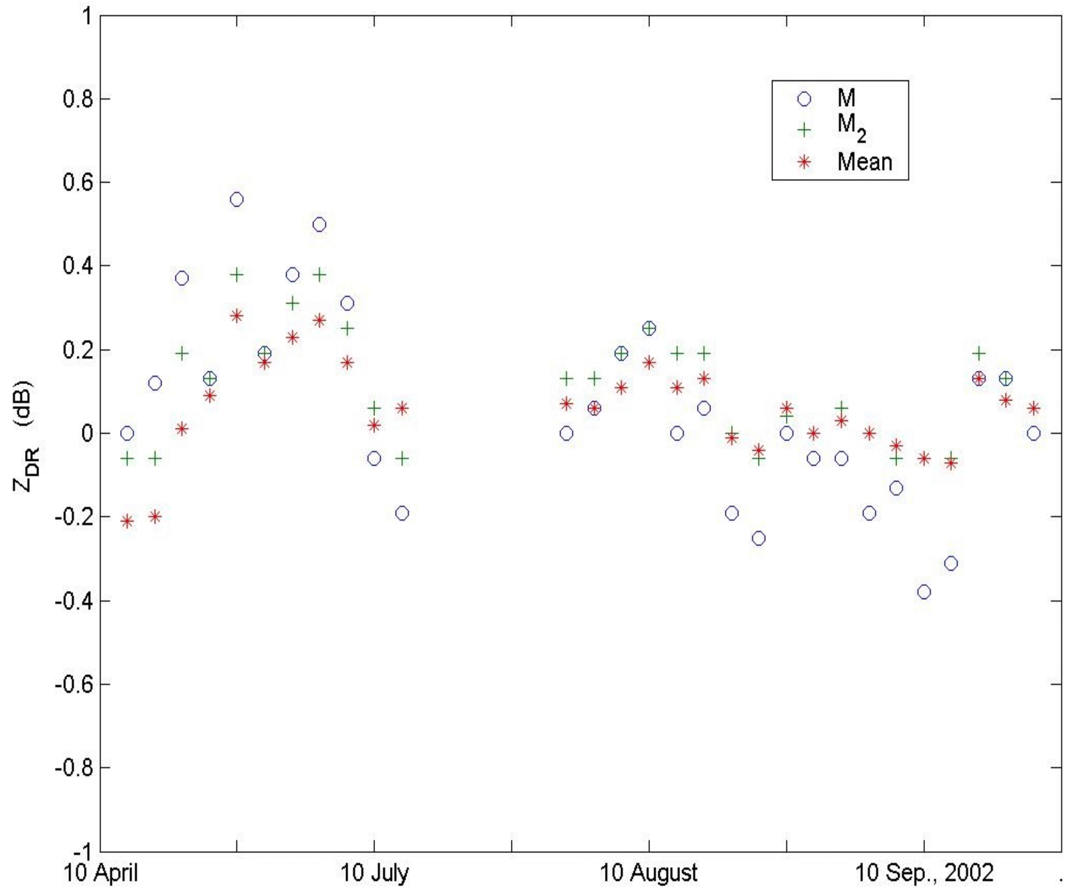

Fig.4. Variations of the *M*, *M₂* , and *Mean* values of measured Z_{DR} for ground clutter

5. Z_{DR} calibration using weather objects

Measurements at vertical incidence in rain are often used to establish the overall system bias of Z_{DR} (Bringi and Chandrasekar 2001). Due to mechanical constraints, the WSR-88D radar can elevate its antenna only up to 60º. Still, there are means to check Z_{DR} calibration at this less than ideal elevation as follows.

The differential reflectivity decreases with elevation angle for all types of hydrometeors. For oblate spheroidal particles with a mean vertical orientation, this dependence is expressed by the following formula that can be simply derived using Bringi, Chandrasekhar 2001:

$$Z_{dr}(\theta) \approx \frac{Z_{dr}(0)}{(Z_{dr}(0)^{1/2}\sin^2\theta + \cos^2\theta)^2}$$

where $Z_{dr}(0)$ and $Z_{dr}(\theta)$ are differential reflectivities at elevation angles of 0 and θ respectively. Here Z_{dr} is expressed in linear scale. It can be easily shown from above equation that $Z_{DR}(\theta = 60^o) \approx 0.25\ Z_{DR}(\theta = 0^o)$, where Z_{DR} is expressed in logarithmic units. Atmospheric scatterers with low variability of intrinsic Z_{DR} can serve as a natural target for Z_{DR} calibration. Dry aggregated snow is probably the best choice because its Z_{DR} usually varies between 0 and 0.5 dB at grazing angles (Ryzhkov and Zrnic 1998 a,b) and it can be easily identified within the cloud in the regions slightly above the melting level. Our observations show that the melting level can be easily detected at higher elevation tilts (including 60º) by a sharp drop of the cross-correlation coefficient. Thus, in the 2 – 3 km height interval above the melting layer, the expected value of Z_{DR} at the 60º elevation angle should vary in the narrow range between 0 and 0.15 dB.

Fig. 5 shows an example of such measurements. According to radar data the melting layer was at height below 3 km. Three curves of Z_{DR} as functions of azimuth are presented in the figure wherein there is no azimuth dependency. The upper curves are displaced by 1 dB from each other to easy viewing. The brackets denote azimuthal averaging. The system $Z_{DR\ sys}$ is estimated to be near to 0 dB (after introducing -0.3 db of the Z_{DR} bias described in section 2).

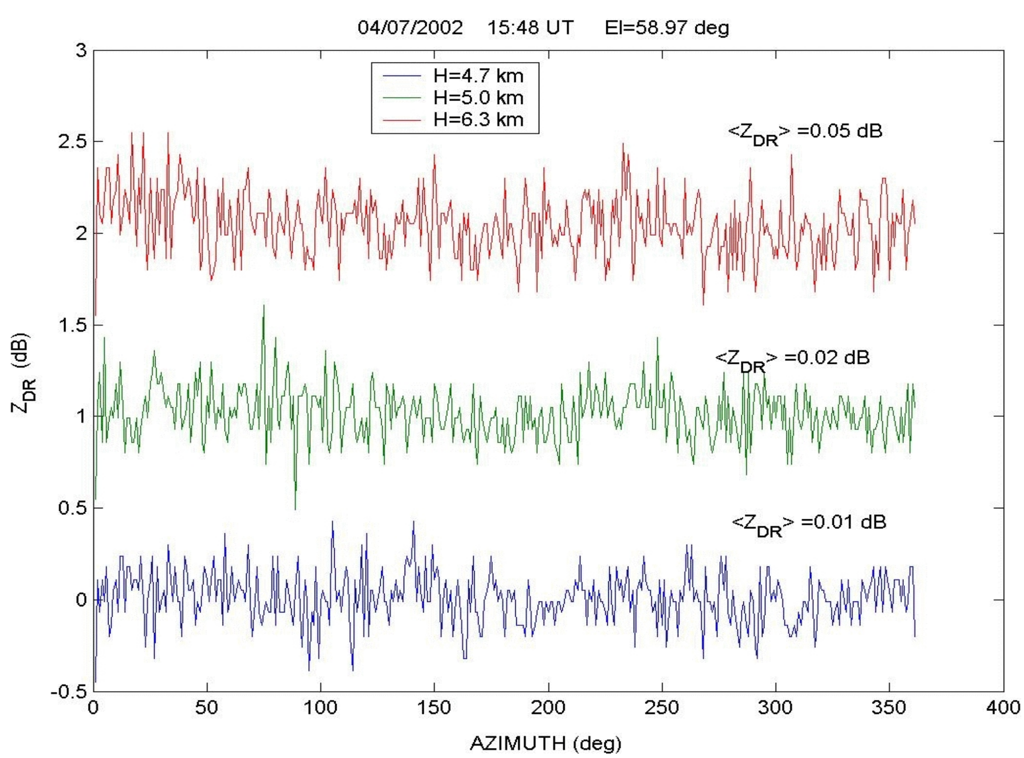

Fig. 5. Azimuthal variations of Z_{DR} above the melting layer for the highest elevation of the WSR-88D (the upper curves are displaced by 1 and 2 dB)

6. Conclusions

The NOAA's research WSR-88D with polarization capabilities has high isolation between polarization channels. High values of the ρ_{hv}, (0.995) in light rain exhibit good polarization purity of the radar. To measure the Z_{DR} with the accuracy of 0.2 dB, precise calibration of the two receive chains is needed. To find the system Z_{DR}, several methods were used. From test signals we determined the receive channel contribution to the system Z_{DR}. These measurements along with calibrations by the solar flux show satisfactory stability of the system at least for a warm season. To close the transmit - receive Z_{DR} calibration loop, two methods have been applied: 1) histogram of the Z_{DR} of ground clutter in the interval of -7 to 7 dB and 2) high elevation azimuthal scans in clouds above the melting layer. By measuring the Z_{DR} in clouds at the highest possible elevation angle (60 degrees for the WSR-88D) and above the melting layer, the system Z_{DR} can be determined with the accuracy of 0.1 dB.

Polarimetric system parameters of the research WSR-88D and their stability show that the radar can be successfully used for polarimetric measurements.

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