EVALUATION OF THE SELF-CONSISTENCY PRINCIPLE FOR CALIBRATION OF THE CASA RADAR NETWORK USING PROPERTIES OF THE OBSERVED MEDIUM

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The Center for Collaborative and Adaptive Sensing of the Atmosphere (CASA) deployed a Distributive, Adaptive and Collaborative Sensing (DCAS) network of four radars capable of polarimetric and Doppler measurements in central Oklahoma. The system aims to improve weather detection and prediction in the lower troposphere with special attention to weather hazards that affect citizens' lives (e.g. tornadoes, convective cells, supercell detection) and alleviate current WSR-88D radar limitations while advancing radar technology [1].

Polarimetric weather radars have demonstrated the capability to improve weather detection and prediction, in particular, Quantitative Precipitation Estimation (QPE) [2]. Dual-polarized measurements based on propagation phase can perform better than power-based measurements in the presence of poorly calibrated radars, beam blockage, rainfall attenuation and hail contamination [3]. Rainfall algorithms based on the combination of radar observables (e.g. $R(Z_H\text{-}Z_{DR})$, $R(K_{DP}, Z_{DR})$ or $R(Z_H, Z_{DR}, K_{DP})$) can produce an additional improvement. In addition, CASA has demonstrated that radar networks can provide the capability for attenuation correction and reflectivity retrieval based on multi-radar measurements [4].

Before using any rainfall composite algorithm for QPE, the reflectivity and differential reflectivity radar observables require evaluation for system bias errors. Bias in the radar observables is mostly caused by the difficulty of precisely calibrating the radar hardware and its respective system operation time variability. These errors translate into errors in rainfall estimation. Recent studies [5] have demonstrated a required accuracy of 1 dB and 0.2 dB for reflectivity (Z_H) and differential reflectivity (Z_{DR}), respectively, for the discrimination of light rain and aggregated dry snow. In addition, storm identification of rain from mixed-phase states is essential for properly addressing the QPE problem. Moreover, the specific differential phase (K_{DP}) is the range derivative of the differential phase between the H and V channel and, because it is a phase measurement, it is independent of radar calibration.

In order to evaluate the absolute calibration of the CASA radars, the self-consistency principle was applied to rainfall data. Scarchilli et al. [6] demonstrated that starting from the same radar volume, the estimation of rain rate obtained using Z_H and Z_{DR} must be the same as the rain rate estimation using K_{DP}. In other words, polarization diversity measurements of rainfall vary in a constrained three-dimensional space. Equation (1) shows the proposed functional relation for the constructed K_{DPc} [7]:

$$K_{DP_c} = aZ_H^b Z_{DR}^c \tag{1}$$

where, the parameters a, b and c depend on the size, shape and distribution of raindrops and can be computed using rain simulations with a Gamma drop-size distribution (DSD) and a fixed drop axis ratio relation. Z_H and Z_{DR} are in linear units. The bias in Z_H, δ_Z, can be obtained using the following relation:

$$\delta Z\ (\mathrm{dB}) = \frac{10}{b}\log_{10}\left(\frac{K_{DP_m}}{K_{DP_c}}\right) \tag{2}$$

where, K_{DPm} is the computed specific differential phase using the measured radar differential phase.

Before Eq. 1 is used in Eq. 2, Z_{DR} needs to be corrected for any bias. Two different methods were evaluated for Z_{DR} bias correction: the intrinsic properties of dry aggregated snow present above the melting layer and light rain measurements close to the ground. Results showed a Z_{DR} calibration accuracy of 0.2 dB or less for both analyzed events when both methods are compared. The Z_{DR} calibration approach was presented in [8].

The self-consistency principle was applied for each of the four CASA radars and two rainfall weather events. A dryline event with periods of convective development from May 07, 2008 and a stratiform event from May 25, 2008 with low to mid mean measured reflectivity were selected. This selection allows us to analyze the calibration methods in both convective and stratiform type rainfall events. The parameters a, b and c were selected as 2.22×10-4, 1 and -4.39, respectively. Only data sets with the following characteristics were selected: signal-to-noise ratio (SNR) greater than 10 dB, cross correlation coefficient (ρ_{HV}) greater than 0.95 and less than 0.995, Z_H greater than 28 dBZ, and time periods with no rain over the radar in order to eliminate any wet radome effects [9]. Subsequently, scatter plots of the estimated bias in Z_H using the self-consistency principle are plotted against the time of each PPI scan at 2° antenna elevation angle and the mean and standard deviation of all the scatters were estimated. The radars' Z_H bias is taken as the mean of the scatter plots. Figure 1 shows the scatter plots and the estimated bias and standard deviation in Z_H for each of the four CASA radars during the May 25, 2008 event. Results show that we can obtain the Z_H mean bias during the time of the weather event with a standard deviation of less and 1 dB. For the results obtained using the CASA radars, the error was less than 0.6 dB as shown in the figure.

The CASA radar network was strategically deployed between the coverage of two WSR-88D weather radars located at Frederick (KFDR) and Oklahoma City (KTLK). In order to validate the previous results in estimating the Z_H mean bias in the CASA radars, a different approach was investigated by comparing X-band data from CASA radars with S-band data from WSR-88D radars. After performing the comparison, the S-band radar that shows the smaller standard deviation with respect to the X-band radar was selected for the Z_H bias estimation. By comparing the mean Z_H difference between the CASA X-band radars and the S-band radars, the mean Z_H bias can be estimated and compared with the results obtained with the self-consistency principle. Only data sets with a Z_H in the range of 20 to 40 dBZ were selected to limit the errors due to uncertainty in low Z_H returns and the deviation from Rayleigh scattering of big drops at high Z_H returns in the X-band data. In addition, a threshold for ρ_{HV} greater than 0.5 was applied to the X-band data to eliminate any errors influenced from non-meteorological scatters. WSR-88D Z_H data were selected from the lowest antenna elevation angle of 0.5°. Both radars' data was mapped to the same pixel area and only data pixels that met the described requirements were selected.

Plots for the radar Z_H mean bias estimation using the X- and S-band comparison approach are shown in Figure 3 for the May 25, 2008 event. The statistics of the Z_H bias estimation for each radar are included in each plot. Results show that the Z_H bias computed using this approach can be estimated with a standard deviation of less than 1 dB.

Table 1 summarizes the Z_H calibration results obtained for both rainfall events and by both the self-consistency principle and the X- and -S-band data comparison approaches. Results show a maximum difference of 0.61 dBZ or less when the bias computed from both approaches is compared. The results validate the Z_H bias estimation using the self-consistency principle and demonstrate the applicability of the principle to the estimation of the Z_H bias for the CASA X-band radars with an error in estimation of less than the required 1 dBZ for QPE applications.

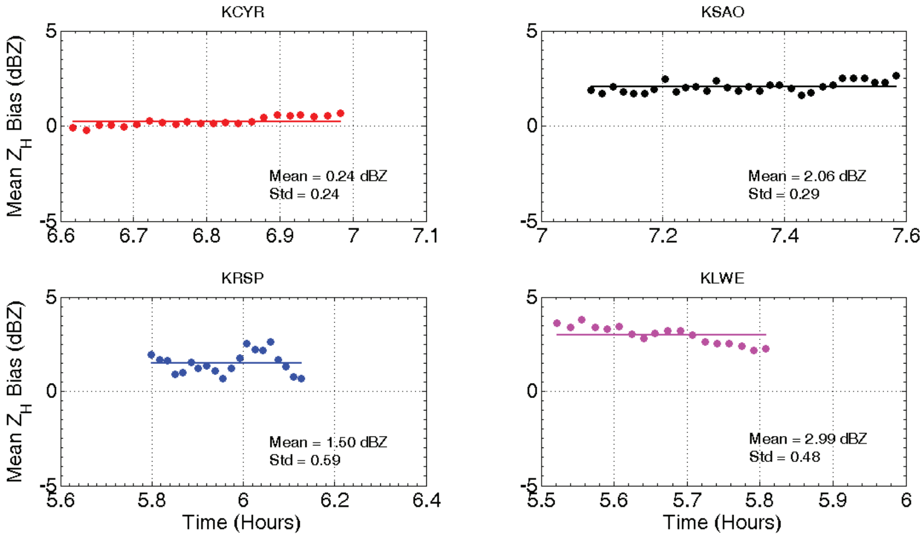

Figure 1. Z_H bias estimation using the self-consistency principle for the 4 CASA radars during the May 25, 2008 event.

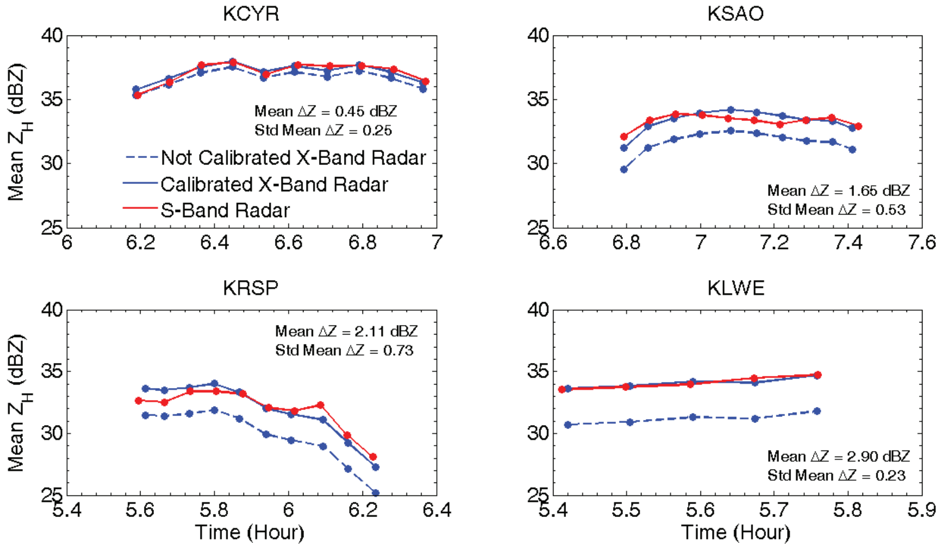

Figure 2. Z_H bias estimation using the X- and S-band approach for the 4 CASA radars during the May 25, 2008 event.

Table 1. Z_H bias estimation results for the CASA radars data during the May 07, 2008 and May 25, 2008 events.

Rainfall Event Date	May 07, 2008					May 25, 2008				
Z_H Bias Estimation Method	Self-Consistency Principle		X/S-Band Comparison		Methods' Difference	Self-Consistency Principle		X/S-Band Comparison		Methods' Difference
CASA X-Band Radar	Mean ΔZ (dBZ)	Std ΔZ	Mean ΔZ (dBZ)	Std ΔZ	Δ(Mean ΔZ) (dBZ)	Mean ΔZ (dBZ)	Std ΔZ	Mean ΔZ (dBZ)	Std ΔZ	Δ(Mean ΔZ) (dBZ)
KCYR	2.42	0.26	2.28	0.74	0.14	0.24	0.24	0.45	0.25	0.21
KSAO	2.16	0.62	1.82	0.73	0.34	2.06	0.29	1.65	0.53	0.41
KRSP	2.28	0.50	2.36	0.48	0.08	1.50	0.59	2.11	0.73	0.61
KLWE	3.88	0.26	3.53	0.47	0.35	2.99	0.48	2.90	0.23	0.09

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