Coherent Power Measurements with a Compact Airborne Ka-Band Precipitation Radar (KPR)

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Problem:
Radar Reflectivity Factor (*Z*) is most commonly calculated from noise subtracted power (NSP) measurements. Low peak power solid state radars often average many hundreds or even thousands of samples to boost sensitivity, thereby extending the signal power measurement range 10 to 20 dB below the receiver noise floor. As a result, a significant portion of the measurements are made well below unity SNR, where to avoid large errors in the estimated signal power, the required noise component measurement accuracy can be difficult to achieve. For example, when integrating 2000 pulses, signals that are 10 dB below the noise level can be detected with a high probability of detection (>90%) at a false alarm rate of 0.01. However, at this low SNR level, a ±0.25 dB error in the estimated noise component introduces approximately +2 to -4 dB error in the calculated signal power.

Coherent Power:
The Coherent Power (CP) technique is an alternative method for measuring the radar received signal power without the need for estimating the noise power.
CP can be implemented with dual-polarized radars operating in simultaneous transmit and receive (STAR) mode by computing the lag-0 cross correlation magnitude, aka copolar power (Keranen and Chandrasekar 2014), or using time delayed CP by computing the lag-1 autocorrelation magnitude. The time delayed CP estimate is the magnitude of the autocorrelation function at lag mT_s:

$$\hat{P}_{cp} = \left|\frac{1}{N}\sum_{k=1}^{N} V^*(k)V(k+m)\right|,$$

where $V(k)$ is the complex voltage sample, consisting of the zero mean Gaussian I and Q signal and noise components: $V(k) = I_s(k) + jQ_s(k) + I_n(k) + jQ_n(k)$.

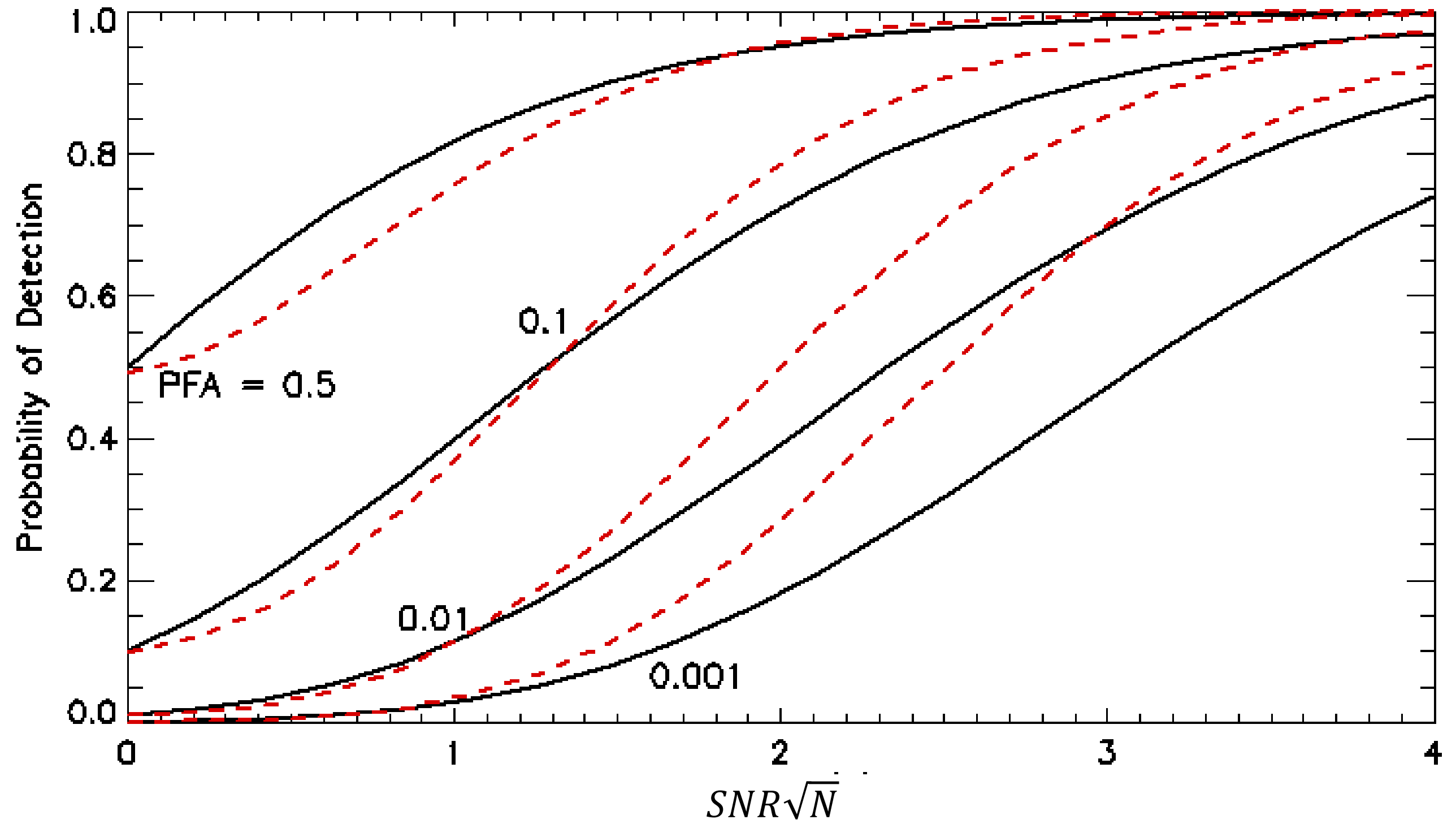

Figure 1. NSP (solid black) and CP technique (dashed red) probability of detection for thresholds corresponding to 0.5, 0.1, 0.01 and 0.001 false alarm (*PFA*) rates and 1000 independent samples averaged. When properly implemented, NSP technique is slightly more sensitive at high false alarm rates, but CP is more sensitive when the threshold level is increased to achieve low false alarm rates. But these differences are les significant than the fact that CP does not require independent estimation of the noise power.

Figure 2. The University of Wyoming Ka-Band Precipitation Radar (KPR) is a compact, dual-beam Doppler radar that operates from a standard PMS (Particle Measurement Systems) probe canister.

CP Thresholding:

$$T \approx \frac{P_n}{\sqrt{N}}\sqrt{-ln(PFA_{cp})},$$

CP Noise Bias $\approx \frac{\sqrt{\pi}}{2}\frac{P_n}{\sqrt{N}}$

Standard Deviation $\approx \frac{\sqrt{4-\pi}}{2}\frac{P_n}{\sqrt{N}}$

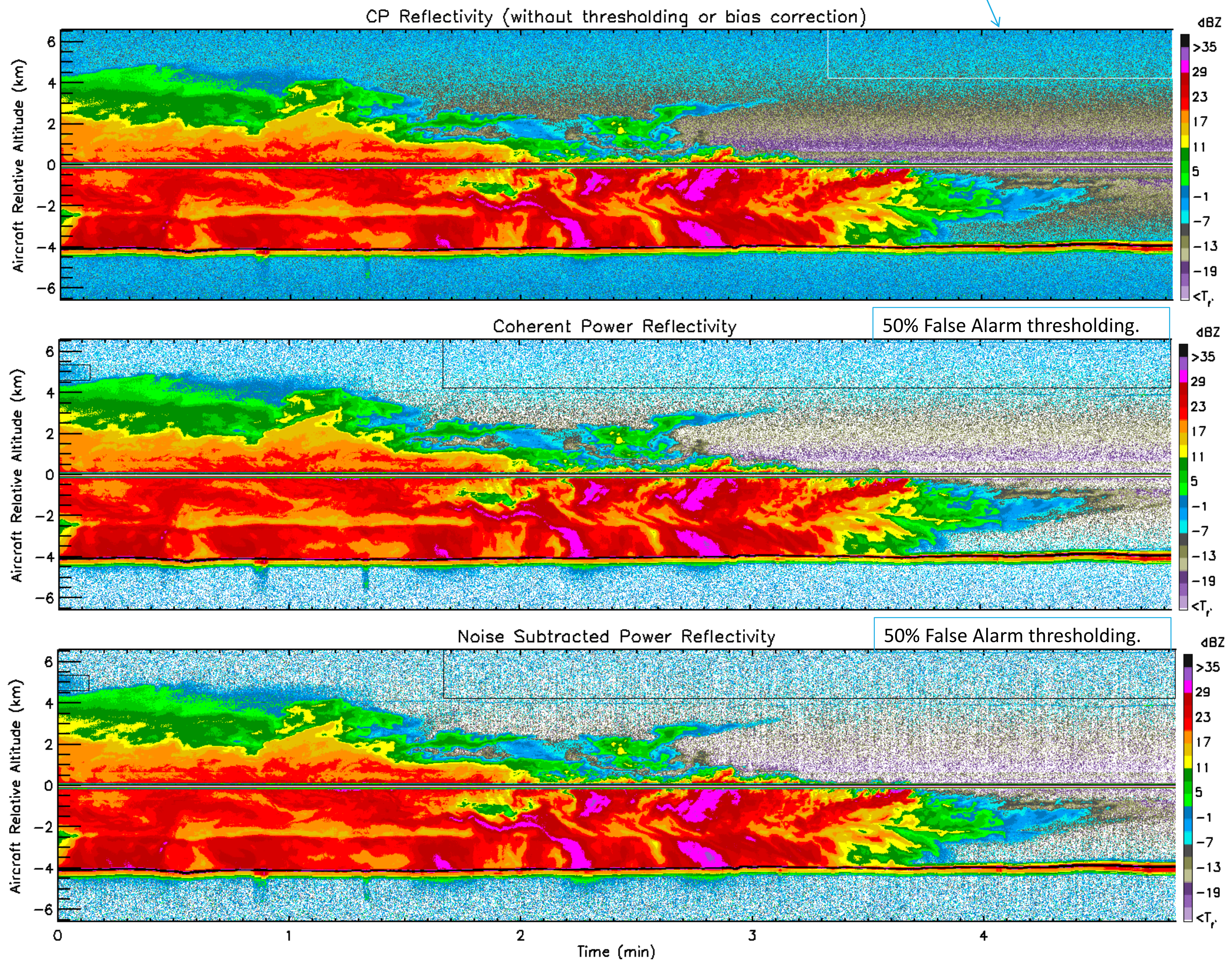

Figure 3. NSP and CP techniques are similarly sensitive when the CP pulse-pair spacing is small relative to the signal decorrelation time and when the noise of the NSP technique is estimated to an error that is much less than the signal plus noise measurement standard deviation. This data set was collected on September 4, 2016 in southeastern Wyoming, about 50 km East of Rawlins. The aircraft was flying through convective cells approximately 4 km above ground and ~2.2 km above the melting layer in -11° C flight level temperature. The radar PRF was constant 20 kHz, transmitting alternating pairs of pulses to the up and down antennas.