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IMPROVING POLARIMETRIC RADAR PARAMETER ESTIMATES AND TARGET IDENTIFICATION : A COMPARISON OF DIFFERENT APPROACHES

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1. Introduction

The relative performances in clutter mitigation and polarimetric radar parameter estimation of three approaches, namely, the McGill spectral filter (Fabry and Gaudoury 2009), the CLEAN-AP filter (Warde and Torres 2009) and the multilag correlation estimators (Lei et al 2012), are evaluated. Our main motivation is to find optimal ways of combining these approaches to achieve good target identification, clutter mitigation and improved estimates of polarimetric parameters, especially at low SNR values, for McGill Radar data.

2. Clutter Mitigation

For clutter mitigation at the McGill Radar Observatory, we have been using the spectral filtering technique (Fabry and Gaudoury 2009) which uses the observation that the standard deviations of Z_{DR} and φ_{DP} of spectral components that are contaminated with ground clutter are higher than those of the precipitation spectral components. The McGill Radar has a rapid scanning rate of 6 RPM and time series data is collected at a range resolution of 125 m for 24 elevation scans in 5 minutes. The lower 10 elevation scans are performed at 1200 and 600 PRFs alternately and the rest at 1200 PRF. $DP_r(k)$ is the complex ratio of the horizontal and vertical polarization Fourier terms $H_r(k)$,$V_r(k)$ per 125m x 1deg at gate r and it is computed as

$$DP_r(k) = H_r(k)/V_r(k) = 10^{ZDR_r(k)/20}\exp(j\varphi_{DPr}(k))$$

The normalized standard deviation NSD over 8 range gates in a 1 km bin of DP(k) is computed as

$$NSD[DP_r(k)] = \sqrt{\frac{\sum_{i=-\frac{m}{2}+1}^{m/2}\left\|DP_{r+i}(k) - \overline{DP_r(k)}\right\|^2}{m\left\|\overline{DP_r(k)}\right\|^2}}$$

and it is used as a measure of the variance. A fuzzy logic approach based upon NSD (with higher weight), SNR and Z_{DR} is used for the classification of the spectral components into 3 basic categories (clearly precipitation, clutter and noise) and 3 mixed categories (precipitation or ground, precipitation or noise, ground or noise) and an undetermined category. The next step is the classification and computation of moments of pixels. At this stage the usage of the radar products could dictate the scheme used for the classification of the pixels . For operational use we use the following scheme. A pixel is classified as noise pixel if all the spectral components have noise classification and as clutter if it has only clutter, noise, clutter-noise, clutter-precipitation spectral components. A pixel is classified as Precipitation if it has at least 1 precipitation or precipitation-noise spectral component. For pixels classified as precipitation , if there are sufficient precipitation spectral components , a Gaussian shaped fit over the precipitation components is used and the clutter components are replaced with the values from the fit. Otherwise the clutter components are replaced with the average noise value. Section 3 has a description of the dynamic computation of the average noise as a function of azimuth and elevation. Polarimetric parameters are computed from the precipitation spectral components . Reflectivity and Doppler velocity are computed from all spectral components after the replacement of the clutter components as described above. Figure.1 illustrates the

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the classification scheme and some of the characteristics of the McGill Radar. The 45 year old McGill radar antenna has significant side lobes through which clutter is observed. The large phase noise in our system also introduces frequency side lobes . These frequency side lobes from the strong clutter targets within 20 km and between 50-60 km from the Adirondack mountains in the south are seen in the power spectrum and in NSD and these are correctly classified as clutter. The clutter classification of targets at ~ 53 km with Doppler velocity of ~ 20 m/sec turned out to be windmills south of our radar. Fig 2 has the unfiltered and filtered PPIs of reflectivity and Doppler velocity. Even though most of the clutter is filtered out, some point targets such as power lines at azimuth ~38 deg between 20-28 km are missed. An examination of the spectral components reveals that sometimes clutter does have low variance in Z_{DR} and φ_{DP}.

Hence we explored the possibility of using the CLEAN-AP filter (Warde and Torres 2009) to compensate for some of the weaknesses of our spectral filtering technique. The CLEAN-AP filter uses the Auto correlation Spectral Density (ASD) at lag-1 to differentiate between ground clutter at zero Doppler velocity with narrow spectrum width and precipitation which typically has wider spectrum widths and Doppler velocities anywhere in the Nyquist co-interval. The lag-1 ASD aids in identifying the spectral coefficients with ground clutter contamination around the zero Doppler velocity. We realized that the phase noise present in our system limits the amount of clutter that can be effectively removed by the CLEAN-AP filter as seen in Fig 3. The narrow beam width of the McGill radar and the reduced number of pulses per degree (32 at 1200 PRF and 16 at 600 PRF) due to the rapid scanning rate of the antenna reduce the efficacy of the CLEAN-AP filter. This is especially evident on the precipitation echoes at zero isodop where a reduction of power is sometimes observed (Fig. 3).

However CLEAN_AP filter is very effective in removing the point targets as seen in Fig 4. Hence we decided to use it selectively in the regions of permanent ground clutter as well as in the regions of very high DC power to Noise power ratio in order to capture the AP regions as well. In these regions, the CLEAN-AP filter's identification of clutter contaminated spectral components is integrated into our spectral classification. This helped in the mitigation of clutter from point targets in the N-E and in other regions as seen in Fig. 4. We need to further investigate for the optimal procedure to combine both techniques to achieve good clutter mitigation without negatively biasing the power estimates of precipitation echoes along the zero isodop.

3. Better estimation of polarimetric parameters at low SNR values

The McGill spectral filtering method described in Section 2 above computes the polarimetric parameters from the precipitation spectral components only. This does reduce the bias in the estimation of polarimetric parameters compared with conventional methods because noise spectral components are excluded. But it is not sufficient especially at low SNR values if noise power is not subtracted. Noise power varies with temperature and emissivity of mountains, precipitation and wet radome etc. Hence we attempted to determine the noise power dynamically as a function of azimuth and elevation during the volumetric scan data collection. Ideally one could collect noise power along each radial (1 deg for example) by considering only the gates with all spectral components classified as noise by the McGill spectral filter. However, in stratiform cases such noise gates may not be available when there is complete precipitation coverage in a PPI scan. Thus noise estimation was done based on the noise power of spectral components identified as noise with extra restrictions such as having a low ρ_{HV} and low SNR. Fig. 5 shows noise power on a clear day as a function of azimuth determined for the McGill Radar elevation scans in a 5 minute volumetric scan. Significant noise contribution from the Mount Royal at ~ 70^0, the Adirondack mountains in the south and the hills in the NE is seen in the lower elevation scans. Noise power decreases with elevation as expected.

This method of noise power estimation takes into account the emissivity from precipitation and wet radome.

Dynamically determined noise power is used in noise correction of the Horizontal and Vertical powers used in the computation of reflectivity, Z_{DR} and ρ_{HV} . The Multilag Correlation estimators (Lei Lei 2012) offer another methodology for better estimates of meteorological parameters at low SNR regime. We wanted to evaluate their performance for the McGill Radar data with small number of pulses per degree due to the operational rapid scanning rate. For comparing the performances of these approaches we chose a scatter plot of ρ_{HV} Vs SNR, as the expected value of ρ_{HV} in precipitation, excluding bright band, is nearly 1. The scatter plots in Fig. 6 are based on the 10 high elevation scans of the McGill radar for a stratiform event. These scans are performed at 1200 PRF and the number of pulses per degree is 32 . Clutter and bright band pixels are excluded. The standard deviation and mean per 1 dB SNR bins are indicated on the plot. Noise corrected Pulse Pair estimation of ρ_{HV} does not eliminate the bias completely. Spectral filtered estimations of ρ_{HV} do achieve a good reduction in the bias up to ~0 db SNR. Usage of dynamic noise power determined as a function of azimuth and elevation gives better results than using a single value per volumetric scan. Multilag estimators also provide good results with 32 pulses, even though the standard deviation is higher than that of the spectral filter estimates. For SNR ~ < 0 dB multilag estimation is the one to be used because the bias in the noise corrected spectral filter estimates is high. Noise correction is possible only if the total power is greater than the noise power and this is the limitation of noise corrected spectral filters. Multilag correlation estimation does not have this limitation.

4. Conclusions

This evaluation of the merits of different approaches for the improvement of the McGill radar data has given us a good understanding of the data characteristics as well as the workings of the algorithms we have considered. The McGill Spectral filter and the CLEAN-AP filter use different characteristics of clutter in their identification of clutter contaminated spectral components. Hence their combination is complementary and has the potential for yielding a better clutter mitigation. The optimal procedure to combine the two techniques needs further investigation.

The computation of polarimetric parameters based only on the precipitation spectral components identified by the McGill Spectral filter reduces the bias as noise components are excluded. Noise correction with dynamically determined noise power as a function of azimuth and elevation results in good reduction in noise bias for polarimetric parameters up to ~ 0 dB SNR. We have used ρ_{HV} for comparison with Multilag correlation estimators. Multilag estimators' reduction in noise bias is good but the standard deviation is higher up to ~ 0 dB SNR. The performance of Multilag correlation estimator is superior below 0 dB SNR.

5. Acknowledgements

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6. References

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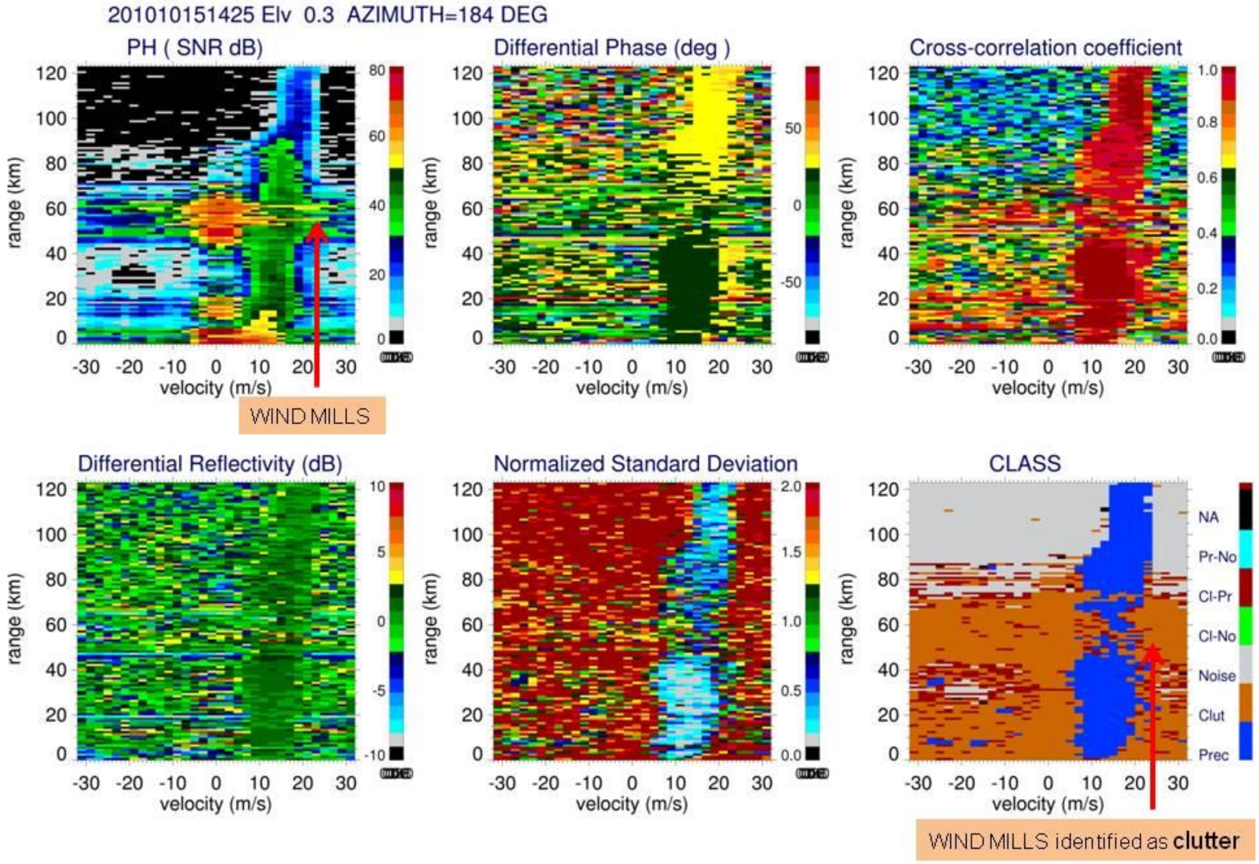
201010151425 Elv 0.3 AZIMUTH=184 DEG

PH (SNR dB)

Differential Phase (deg)

Cross-correlation coefficient

Differential Reflectivity (dB)

Normalized Standard Deviation

CLASS

WIND MILLS

WIND MILLS identified as **clutter**

Fig. 1. Spectral decomposition vs. range of echo intensity (top left), differential phase (top middle), cross correlation coefficient (top right), differential reflectivity (bottom left), normalized standard deviation (NSD) of the ratio of the raw complex time series at H and V polarizations (bottom middle), the classification of the spectral components (bottom left). The Power spectrum is computed over 32 pulses in 1 deg (1200 PRF) for 1 ray at 184 ^{0} and elevation 0.3 ^{0}. " Figure 1 illustrates the classification scheme and some of the characteristics of the McGill Radar. The 45 year old McGill radar antenna has significant side lobes through which clutter is observed. The large phase noise in our system also introduces frequency side lobes . These frequency side lobes from the strong clutter targets within 20 km and between 50-60 km from the Adirondack mountains in the south are seen in the power spectrum and in NSD and these are correctly classified as clutter. The clutter classification of targets at ~ 53 km with Doppler velocity of ~ 20 m/sec turned out to be windmills south of our radar."

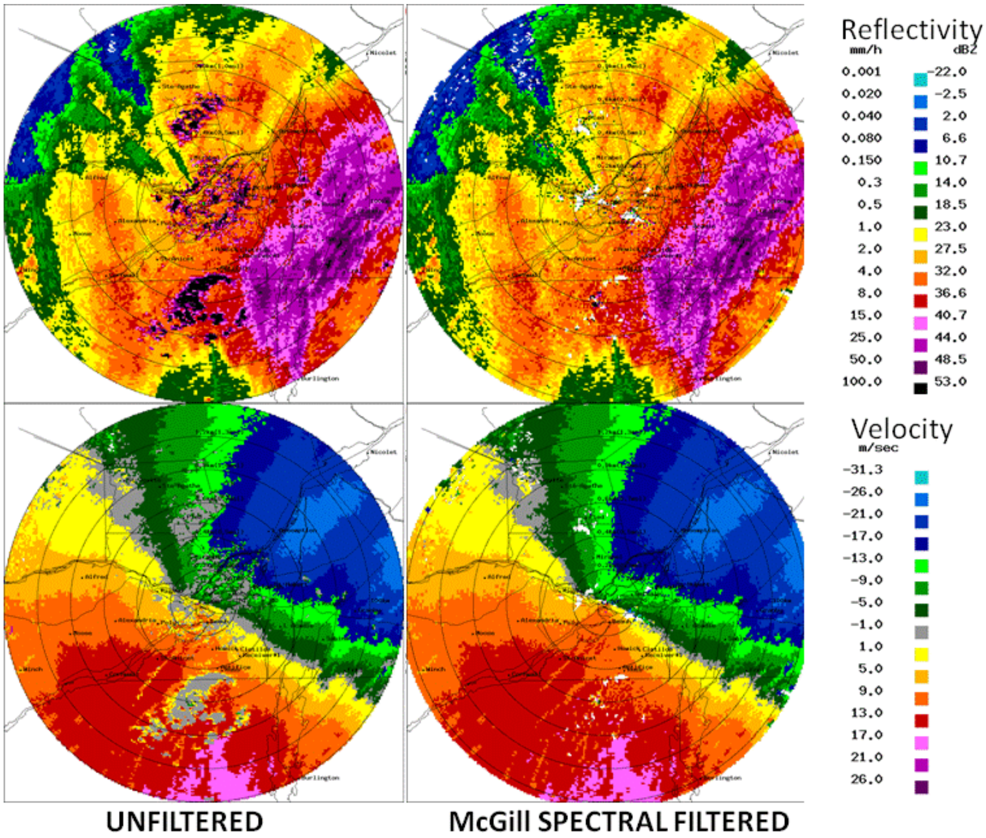

Fig. 2. Reflectivity and Doppler velocity PPIs (240 x 240 km) at 0.3^0 elevation. White pixels indicate regions where proper clutter mitigation is not possible.

"Fig 2 has the unfiltered and filtered PPIs of reflectivity and Doppler velocity. Even though most of the clutter is filtered out, some point targets such as power lines at azimuth ~38 deg between 20-28 km are missed. An examination of the spectral components reveals that sometimes clutter does have low variance in Z_{DR} and φ_{DP}."

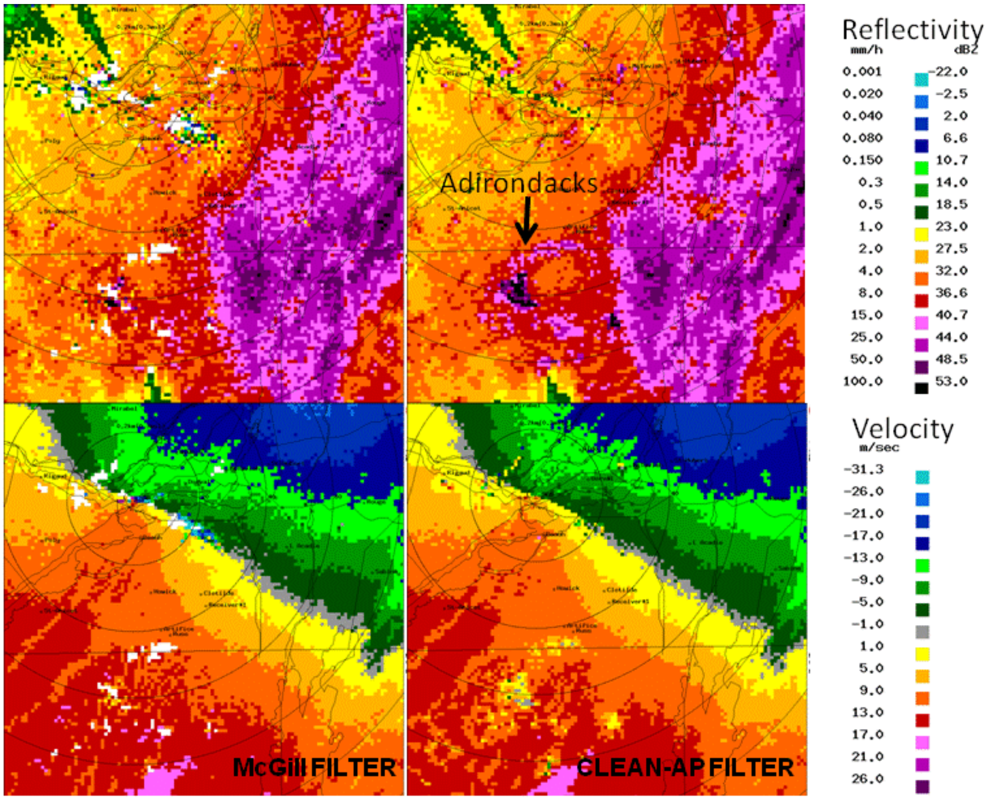

Fig. 3. Reflectivity and Doppler velocity PPIs (120 x 120 km) of the Adirondack mountain region. Images on the left are Spectral filtered. The frequency side lobes of the strong clutter returns from the mountains are not eliminated in the CLEAN-AP filtered images on the right.

"We realized that the phase noise present in our system limits the amount of clutter that can be effectively removed by the CLEAN-AP filter as seen in Fig 3. Also the narrow beam width of the McGill radar and the reduced number of pulses per degree (32 at 1200 PRF and 16 at 600 PRF) due to the rapid scanning rate of the antenna, reduce the efficacy of the CLEAN-AP filter. This is especially evident on the precipitation echoes at zero isodop where a reduction of power is sometimes observed."

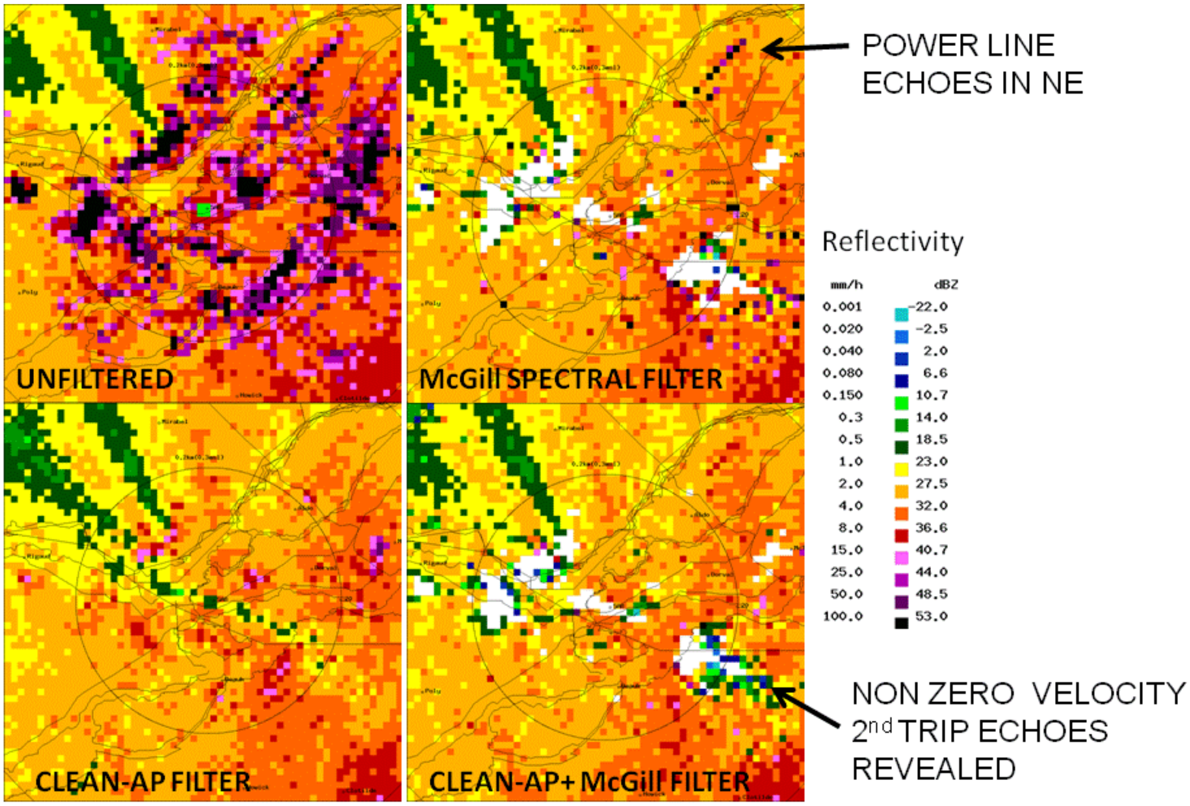

Fig. 4. Reflectivity PPIs(60 x 60 km). The power line echoes in the N-E seen in the unfiltered image (top left) are not eliminated in the spectral filtered image (top right). These are eliminated in CLEAN-AP filtered image (bottom left) and spectral + CLEAN-AP filtered image (bottom right).

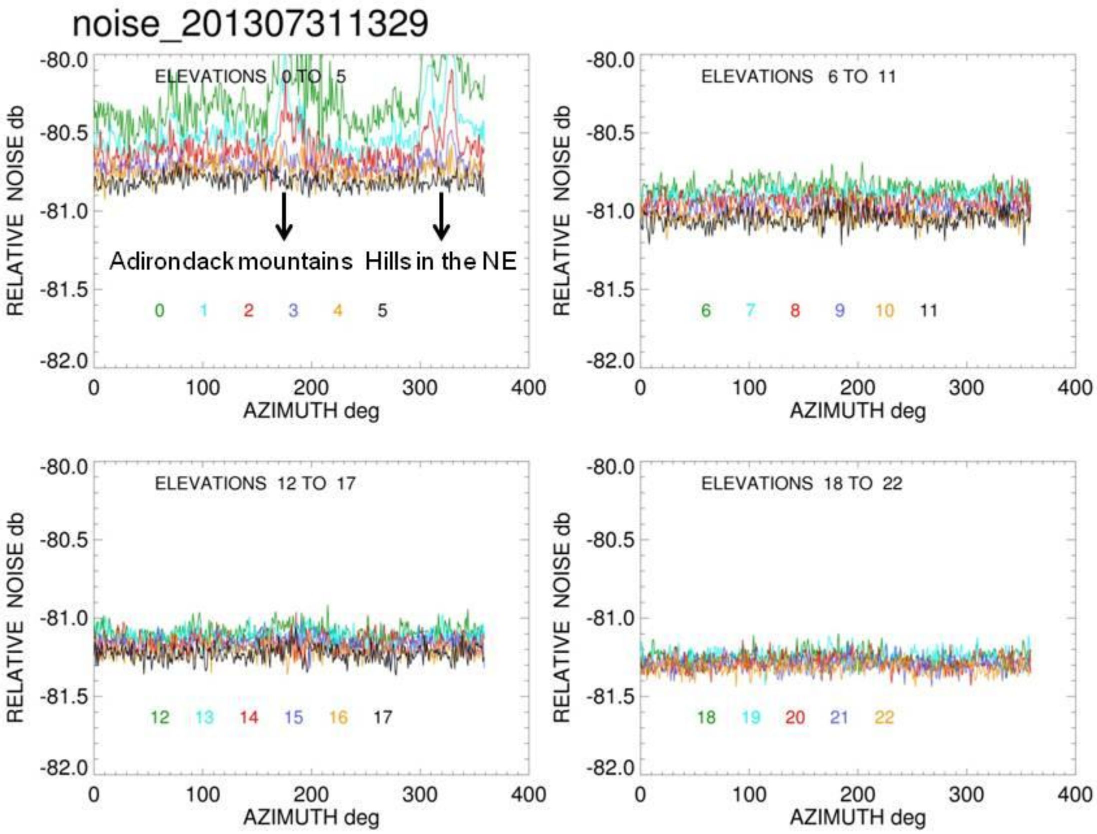

Fig. 5. Relative Noise power (in dB) Vs azimuth (360 degrees) for McGill Radar elevation scans in a volumetric scan collected in 5 minutes.

"Fig. 5 shows noise power on a clear day as a function of azimuth determined for the McGill Radar elevation scans in a 5 minute volumetric scan. Significant noise contribution from the Mount Royal at ~ 70^0, the Adirondack mountains in the south and the hills in the NE is seen in the lower elevation scans. Noise power decreases with elevation as expected."

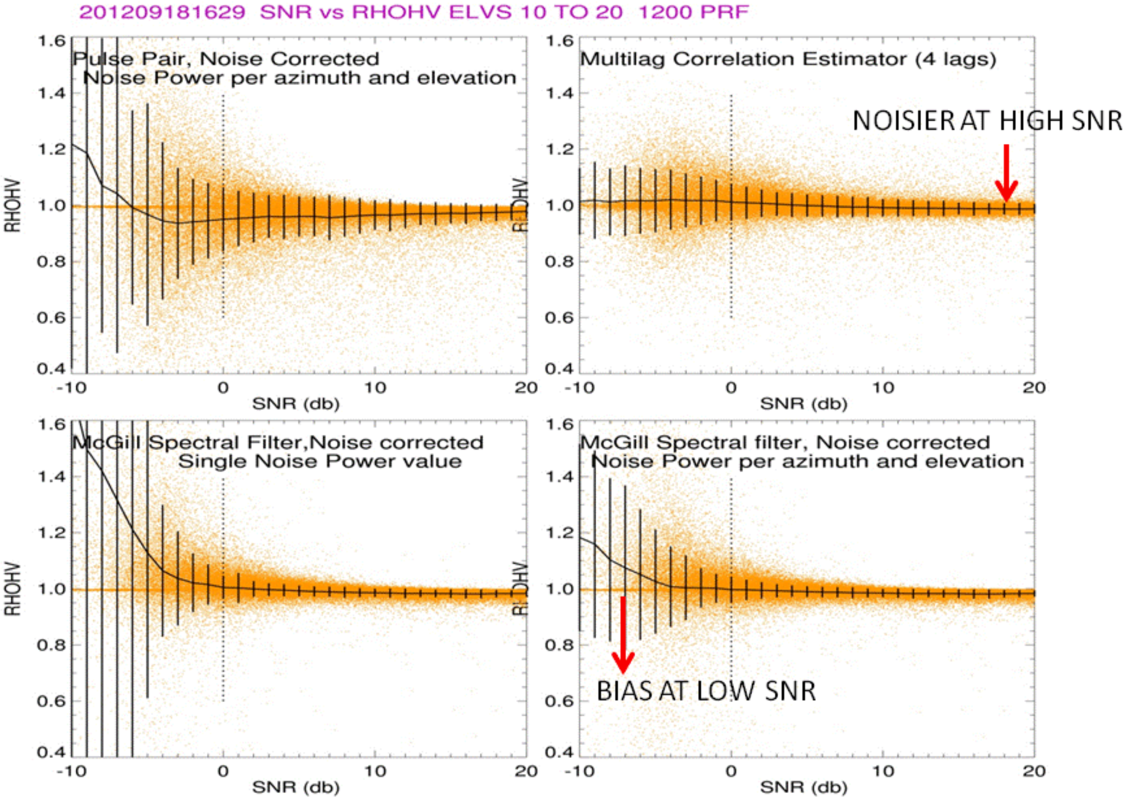

Fig. 6. Scatter plots of ρhv Vs SNR(db). Procedures used for the computation of ρhv are Pulse Pair, Noise corrected (top left), McGill Spectral filter, Noise corrected with single noise power value (bottom right), McGill Spectral filter, Noise corrected, noise power as a function of azimuth and elevation (bottom right), Multilag (4 lag) correlation esimator (top right).

"The scatter plots in Fig. 6 are based on the 10 high elevation scans of the McGill radar for a stratiform event. These scans are performed at 1200 PRF and the number of pulses per degree is 32 . Clutter and bright band pixels are excluded. The standard deviation and mean per 1 db SNR bins are indicated on the plot. Noise corrected Pulse Pair estimation of ρ_{HV} does not eliminate the bias completely. Spectral filtered estimations of ρ_{HV} do achieve good reduction in the bias up to ~0 db SNR. Usage of dynamic noise power determined as a function of azimuth and elevation gives better results than using a single value per volumetric scan. Multilag estimators also provide good results with 32 pulses, even though the standard deviation is higher than that of spectral filter estimates. For SNR ~ < 0 db multilag estimation is the one to be used as the bias in the noise corrected spectral filter estimates is high. "