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# DATA DRIVEN ADAPTIVE IDENTIFICATION AND SUPPRESSION OF GROUND CLUTTER FOR WEATHER RADAR

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## 1. INTRODUCTION

An innovative approach for the suppression of ground clutter (GC) contributions from weather radar data is presented. Most of the existing adaptive spectral GC filters (GCF) need a prior knowledge of clutter position, strength and its spectral characteristics. This knowledge is irrelevant for the presented approach because the identification and suppression are entirely data driven. The new approach is referred to as data driven ground clutter filtering (DD-GCF). Before presenting this novel DD-GCF, we provide a brief summary on the existing relevant methods and on the filtering needs of the future.

### *1.1. Current state of filtering on NEXRAD*

The National Weather Service (NWS) operates an unattended network of 150+ S-band Weather Surveillance Radar 1988-Doppler (WSR-88D), or the Next Generation Radar (NEXRAD). NEXRAD use selected scanning patterns to provide radar data from which numerous radar products are derived (BASC 2008, BASC 2002). Radar data from low elevation angles often contain returns from GC. These returns are generally filtered if a predetermined clutter map indicates that the clutter is expected (FCM 2006). The current NWS clutter filter operates on Doppler power spectrum, uses rank order statistics and clutter modeling to identify a portion of the spectrum with GC, removes this portion and interpolates over the gap using a Gaussian fit (Siggia and Passarelli 2004, FCM 2006, Ice at al. 2007). The filter is referred to as Gaussian Model Adaptive Processing (GMAP) and has shown to provide good clutter suppression in weather radar data for one polarization.

NWS is currently upgrading 171 radars in the network to dual polarization (Business Wire 2007). Dual polarization is used to classify echoes in categories such as rain, snow, ice, biological (Schuur et al 2003, Ryzhkov et al 2005). To obtain polarimetric measurements, a radar resolution volume is illuminated simultaneously by a series of horizontally (h) and vertically (v) polarized waves. The resulting reflections are received by h and v channels, sampled into two series of complex voltages and used to estimate the legacy data (reflectivity, velocity and spectral width) and polarimetric data (differential phase, co-polar correlation coefficient, and differential reflectivity) (Doviak and Zrnic 1993, Bringi and Chandrasekar 2001). In a presence of GC, both h and v series must be filtered. GMAP could be applied separately to h and v channels to filter GC. However, such application is impractical for the following reason: GMAP performs on powers, and not on complex voltages. Such polarimetric variables as differential phase and co-polar correlation cannot be estimated from powers and must be estimated from complex voltages (Doviak and Zrnic 1993, Moisseev et al 2000, Bringi and Chandrasekar 2001, Bachmann and Zrnic 2007). Therefore, GC filtered sequences cannot be directly used for estimation of polarimetric variables and echo classification.

### *1.2. Filtering in h and v channels*

The signatures of GC at different polarizations can be quite different. With the current clutter filter NWS will have several choices, among which are filtering clutter of the same clutter width (the same number of spectral coefficients) from both channels, and filtering clutter of adaptively identified clutter widths in each channel. In both situations polarimetric variables estimated after filtering could be biased or incorrect due to many factors. To name a few, the loss of phase information after interpolation in the clutter region could be significant and there could be errors on the slopes of the clutter spectral peak.

### *1.3. Filtering weak clutter*

It is a fact that on the NEXRAD systems clutter filtering is performed only on strong GC returns while weak returns are ignored (FCM 2006). Such an approach has shown to be suitable for NEXRAD because of the adaptive power threshold (FCM 2006, Bachmann and Zrnic 2008). Why bother filtering if a weak clutter alone is not displayed anyway? Weak GC in a presence of strong weather signals has an insignificant contribution and therefore could be ignored. Weak weather in a presence of strong GC is also not displayed due to the increased adaptive power threshold. However, due to the fact that in its recent report, the National Research Counsel indicated a need in improved low level coverage and clear air observation (BASC, 2008, page 60), it is apparent that a weak GC will have to be filtered. Clearly, to increase low level coverage, radar elevation scans could be adjusted to point lower, which will increase GC contamination (Doviak and

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Zrnic 1993). To provide clear air observations, power thresholds could be re-evaluated, which will create data quality issues especially in locations with ground clutter (FCM 2006, Ivic et al 2008).

### *1.4. Inadequacy of current GCF for some tasks*

It is evident that the current clutter filtering will be inadequate for 1) accurate estimation of polarimetric variables and classification of echoes from the clutter filtered sequences, 2) improved low level coverage over the urban areas with increased clutter contamination, and 3) observations of weak clear air echoes. There is a need for a filter that could effectively filter GC and preserve the properties of the echoes to provide reliable polarimetric estimates for strong and weak weather echoes.

### *1.5. Current improvements*

Recently NWS improved GCF by deploying a sophisticated scheme for clutter map generation (Hubbert, et al 2007). The scheme is referred to as the clutter mitigation decision (CMD) algorithm. It uses fuzzy logic on several fields (texture of reflectivity, reflectivity gradient, and clutter phase alignment) to create the most accurate maps of ground clutter (Hubbert, et al 2007). However, this sophisticated scheme leading to an accurate decision is followed by an application of the old power-based GMAP. In a dual polarization radar GC is detected in both channels. The question of filtering in a dual polarization scenario remains. A simple solution is to use GMAP in the h channel to identify the spectral coefficients with clutter, to notch indicated spectral coefficients in both polarization channels and to compute polarimetric variables from the remaining spectral coefficients (Groginsky and Glover, 1980). We propose a different solution.

### *1.6. Proposed solution*

The adaptive spectral data driven ground clutter filter (DD-GCF) pinpoints the exact spectral coefficients containing signatures that are primarily caused (or dominated by) ground clutter returns (See section 2 for details). These coefficients are replaced with the new complex spectral coefficients constructed to preserve the statistics of the remaining spectrum, the process defined here as re-filling (See section 2 for details). The novel approach can be used effectively with data from single or dual polarization radars, with strong or weak clutter. The re-filling can be used with the GMAP based clutter identification scheme if so desired. The re-filled sequences are complex-valued, meaning that both phase and amplitude information is preserved. The best way to judge the effectiveness of this method is to visually examine the range-Doppler fields of polarimetric spectral densities (Moisseev et al 2000, Unal and Moisseev 2004; Yanovsky et al 2005; Bachmann and Zrnic 2007). Examine the locations of former GC in these fields to assess the effectiveness of filtering and reconstruction. The range-Doppler fields of polarimetric spectral densities after DD-GCF reveal signatures that show no evidence of disorder, interpolation, jumps or other artifacts and dramatically extend the amount of data available for further processing.

## 2. DATA DRIVEN GROUND CLUTTER FILTER

### *2.1. Clutter identification*

The phase-based clutter identification algorithm was introduced for the spectra of the electronically steerable phased array radar (Bachmann et al. 2008, Bachmann 2008). An extension of this algorithm is presented here to identify and suppress clutter from data of conventional mechanically steered weather radar. The near zero values of the intrinsic differential phase between the spectral coefficients of the two-phase-poli-phase decomposition of the original time series, also referred as phase coherence, indicate clutter-like contribution (Bachmann et al. 2008). To estimate such phase, the received time-series sequence is split onto two half-sequences containing samples from even-indexed pulses and from odd-indexed pulses.

The complex spectral coefficients obtained from the discrete fast Fourier transformation (DFT) of each half-sequence weighted by a windowing function are used to estimate the differential phase in every Doppler bin. The DFT of the complete sequence and the half-sequences have the same Doppler resolution but different maximum Doppler frequencies (Doppler velocities). Because of that, the spectral signatures of GC in the entire sequence and in the half-sequence occupy the same Doppler bins and have matching powers. Therefore, the Doppler bins with near-zero differential phases indicate the Doppler bins with GC in the complete spectrum. The threshold of differential phase for clutter identification is set to 0.1 radians. In Bachmann et al. (2008) it was shown that due to statistical uncertainties and due to a slope in the curve of differential phase, the weather with zero mean velocity could be mistakenly identified as GC. To reduce this inaccuracy, DD-GCF considers the following properties. The cotangent of the complex spectral coefficient containing signatures of ground clutter is either very small (<.06) or significantly large (>.1). The spectral width of clutter is expected to be somewhat symmetric around zero Doppler. The mean of the entire clutter signature is smaller than the dc coefficient. If these expectations are not met, the identified spectral coefficients are not due to ground clutter. The resulting clutter identifier can be characterized as extremely sensitive, non-symmetric, and non-identical-in-polarization-channels. The amount of filtering can be adjusted by changing values of thresholds of differential phase and amplitude.

***2.2. Clutter re-filling –*** this section is removed – patent pending procedure.

### *2.3. General notes*

The suppression is performed in the frequency domain and requires a sufficient number of samples for spectral processing. The presented suppression technique induces minimal disturbance to the spectral polarimetric fields and therefore allows for a more accurate computation of polarimetric variables used for echo classification schemes. The presented approach can also be used to construct clutter maps that indicate clutter power and the intrinsic spectral width of clutter. The presented approach was tested on data acquired with a rotating parabolic antenna of KOUN (S-band polarimetric prototype weather radar in Norman, OK).

## 3. EXAMPLES

In the following examples we used data from a clear air case observed using S-band dual polarization prototype KOUN, on September 8 2004, at 04 UTC. The pulse repetition time was 780 microseconds. The number of pulses was variable and is indicated for each example.

### *3.2. DD-GCF for dual polarization*

An example of a weak-clutter-suppression is shown in Fig. 1. The blue line indicates filtered spectrum, while the red line highlights the GC contribution. The shape of the spectra in the h and v channels, shown in the top and bottom panels respectively, indicates significant differences in the echo power and a noticeable difference in the clutter power and the clutter spectral width. DD-GCF successfully identifies the weak clutter contribution and suppresses it from both channels. An example of a strong-clutter-suppression is shown in Fig. 2. The spectra from the h and v channels are shown in the top and bottom panels respectively. The clutter peak extends above the axis. In this case, DD-GCF recovers a portion of the weather signature that was concealed by strong GC. Note the differences in spectral signatures in the h and v channels.

### *3.3. Range-Doppler plots for dual polarization*

Fig. 3 shows the range-Doppler plots for the following spectral densities: h channel power, differential reflectivity, differential phase and co-polar correlation coefficient. The definitions of the polarimetric spectral densities are from Bachmann and Zrnic (2007). The mean of a polarimetric spectral density is equivalent to the value of a corresponding polarimetric variable computed in the time domain. The top panels depict unfiltered range-Doppler, while the bottom panels show range-Doppler after clutter suppression. Only 25 km in range are shown to exemplify GC and demonstrate how a strong GC could mask other returns. The high values of the correlation coefficients in the range locations with GC in the top panel are due to the spectral spillage of strong echo powers from the adjacent weaker ones. It could be corrected by an aggressive windowing function. After the suppression of GC, the range-Doppler plots reveal other signatures. In this case the scatterers are a mix of nocturnal insects, birds and clear air (Bachmann and Zrnic 2007).

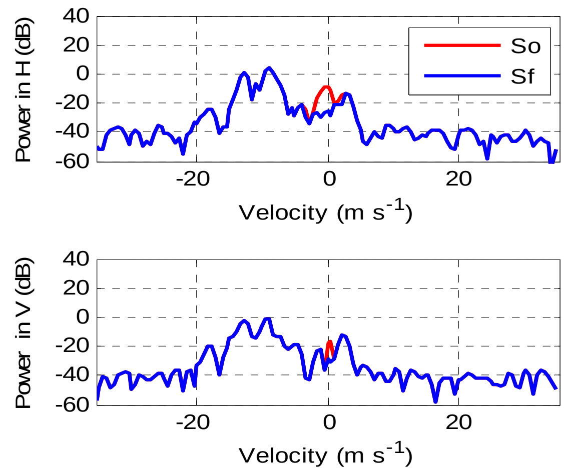


Fig. 1. Examples of Doppler spectra in the h (top panel) and v (bottom panel) channels before and after suppression of weak clutter. Data is from azimuth 106. range 23 km, 128 pulses.

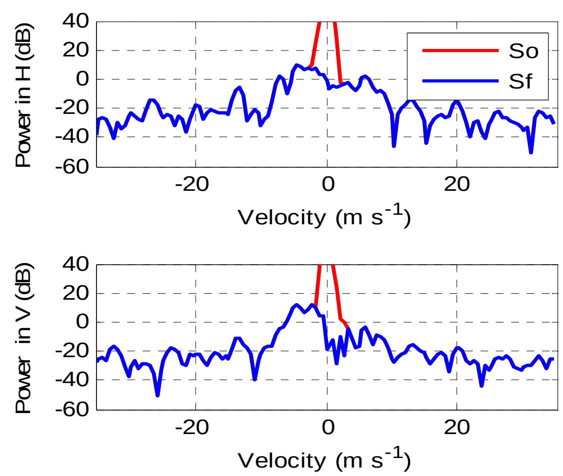


Fig. 2. Examples of Doppler spectra in the h (top panel) and v (bottom panel) channels before and after suppression of strong clutter. Data is from azimuth 106. range 4 km, 128 pulses.

### *3.4. Plan Position Indicators*

Plan position indicators (PPI) with GC signatures before and after DD-GCF are shown in Fig. 4 in the top and bottom panels respectively. The name of the variable is indicated above each group of PPIs. The range ring is at 20 km. The vertical line with strong powers is from the traffic on the interstate road I-35. This can be suppressed by adjusting the spectral floor level (Bachmann and Zrnic 2008). Fig. 5 depicts the scatter plots comparing the filtered (vertical axis) and the unfiltered (horizontal axis) fields presented in Fig. 4. The scatter plots are color coded to expose large occurrences. The warmer colors indicate a higher occurrence. The interpretation of the revealed echoes is out of the scope of this work. It is evident that the accurate clutter suppression can increase the total area of useful echoes. Polarimetric variables of scatterers other than GC can be estimated for the regions with GC contamination.

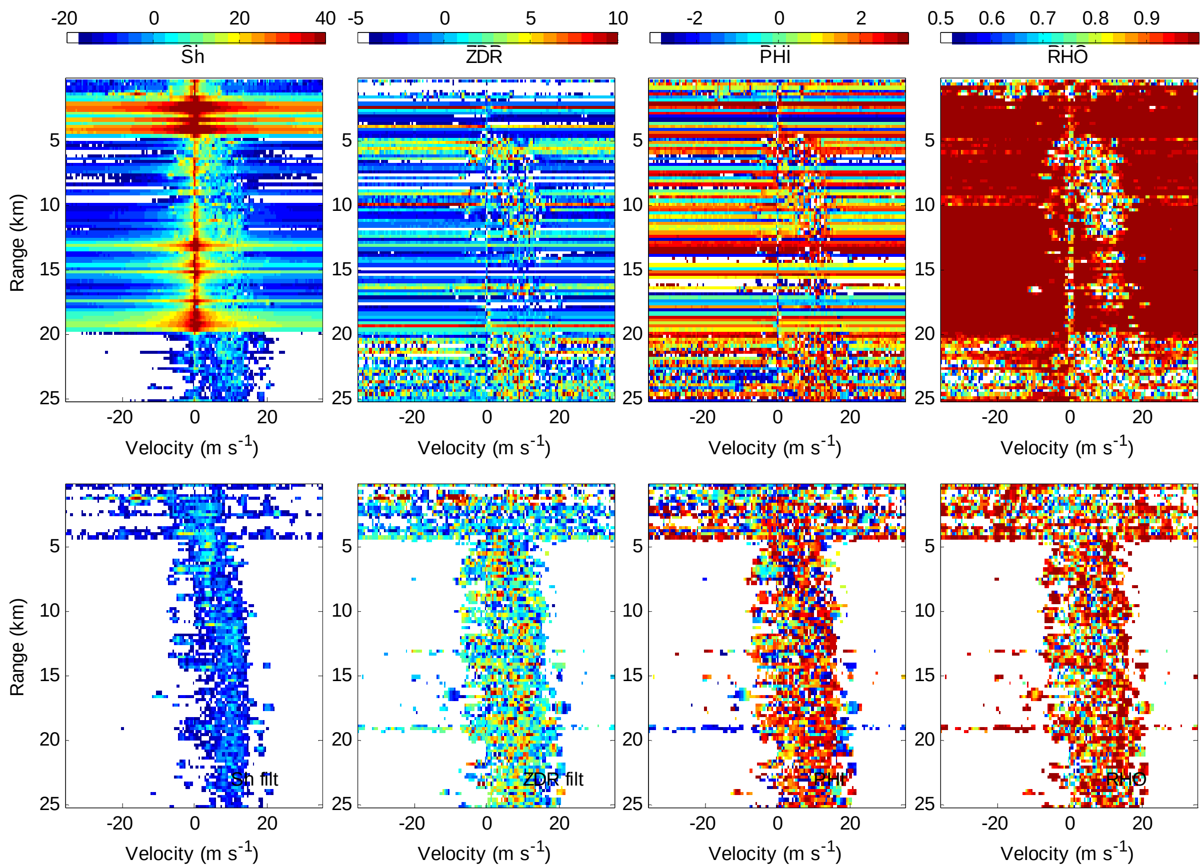

Fig. 3. Example of range-Doppler for the first 25 km of a radial. Polarimetric spectral densities estimated from original (unfiltered) spectra are shown in the top panels. Polarimetric spectral densities computed for filtered spectra are depicted in the bottom panels. The panels show (left to right): a) power spectra in the h channel, b) spectral density of differential reflectivity, c) spectral density of differential phase, and d) spectral density of co-polar correlation coefficient.

## 4. CONCLUSION

A new methodology for the suppression of ground clutter that is entirely data driven is presented. The main highlight of this methodology is the availability of complex spectral coefficients after filtering. This allows for the estimation of polarimetric spectral densities and polarimetric variables that are not contaminated by ground clutter.

Any available method could be used for the clutter identification in the Doppler spectrum (i.e., GMAP). We suggest using the combination of phase-based and amplitude-based identification schemes to identify GC. The identified GC coefficients are suppressed via re-filling. Re-filling allows for a more accurate estimation of polarimetric spectral densities and purified polarimetric variables. The resulting polarimetric variables do not have imprinted bias towards the properties of GC.

*AKNOWLEGEMENT*

The author acknowledges the administration of Lockheed Martin MS2 Syracuse Technical Operations for support. The author greatly appreciates Aaron Altus of Lockheed Martin MS2 Syracuse Global Sustainment for his valuable technical advice and inspiration. The author thanks graduate student Shawn Walters of Cornell University for his enduring review and helpful suggestions to improve the readability of this letter.

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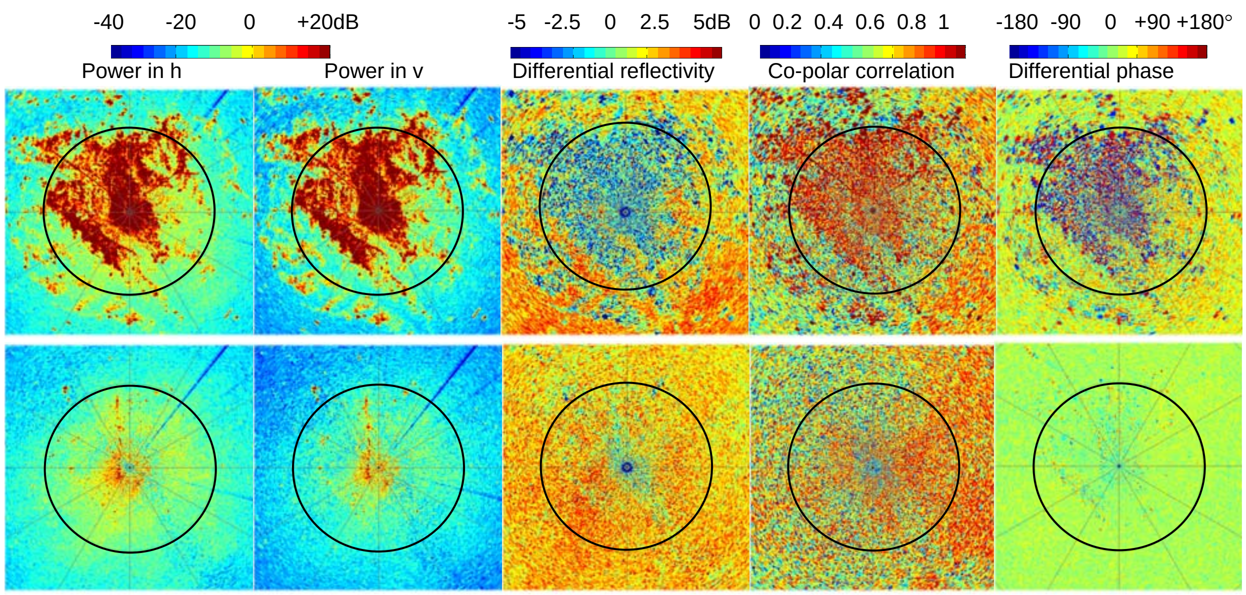


Fig. 4. Suppression of GC exposed by PPIs: PPIs with GC (top panel) and PPIs with suppressed GC (bottom panel). The range ring is at 20 km.

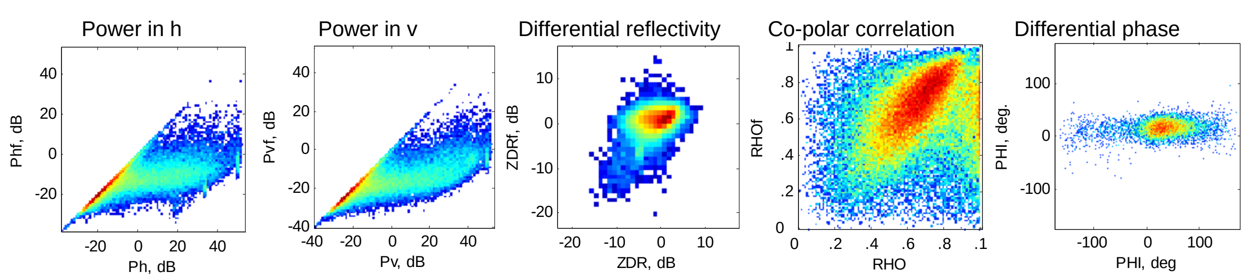


Fig.5. Color coded scatter plots for PPIs in Fig.5 that expose how clutter suppression affects mean values of polarimetric variables.