5B.6 REAL TIME CLUTTER IDENTIFICATION AND MITIGATION FOR NEXRAD

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1. INTRODUCTION

Mitigation of anomalous propagation clutter (AP) is an ongoing problem in radar meteorology. AP clutter routinely contaminates radar data masking weather returns causing poor data quality. The problem is typically mitigated by applying a clutter filter to all radar data but this also eliminates weather data at zero velocity. With the advent of fast digital receivers capable of real time spectral processing, the real time identification and elimination of AP clutter is now possible. A fuzzy logic algorithm is used to distinguish between clutter echo and precipitation echoes. Based on this classification, clutter filters can be applied to only those radar resolution volumes where clutter is present, in real time. In this way weather echoes are preserved while clutter echoes are mitigated. The clutter filters used in this paper are spectral based, i.e., they are applied in the spectral domain. In many cases, after the clutter echoes are filtered, the underlying weather echo signatures are revealed thereby significantly increasing the visibility of weather echo. This paper describes the Fuzzy Logic algorithm for clutter echo identification and the technique is illustrated with experimental data from the Denver NEXRAD KFTG and S-Pol, NCAR's (National Center for Atmospheric Research) S-band polarimetric radar.

2. BACKGROUND

Clutter filters for weather radars typically operate in the time domain, i.e., the digitized I and Q samples (in phase and quadrature) are passed through some type of IIR (Infinite Impulse Response) filter. These filters work fairly well typically yielding 50 dB of clutter rejection or better. Different stop-band filter widths are possible but the clutter filter is typically applied to all of the radar data, i.e, the clutter filters are either on or off all the time. If the clutter filters are on all the time, weather signals along the zero velocity isodop are also be removed. Additionally, as weather conditions vary, AP clutter can appear and subsequently disappear. Radar operators have attempted to monitor AP clutter and then turn on a clutter filter when the AP conditions were significant. Later the clutter filter is turned off. Such human driven decisions are prone to error. Ideally one wants to filter only those radar gates that are clutter-contaminated and only when the clutter power dominates any overlaying weather signal. This is why trying to apply a clutter filter to those gates that lie on a previously constructed map of NP (Normal Propagation) clutter can eliminate important weather signals. For example, there may be a radar gate that shows 35 dBZ on a clutter map but then it is overlaid with a 40 dBZ or greater weather signal. In this case, a clutter filter likely should not be applied. The solution is to use signal processing to identify those gates that are dominated by clutter and then to apply a clutter filter to those gates in real time.

2.1 Spectral Clutter Filters

The new generation of radar processors now have enough processing power to calculate spectra, process them, and subsequently apply a clutter filter if needed. The I and Q samples can be put into a buffer while the data is processed and clutter affected gates are identified. After identification, the buffered data is clutter filtered. The additional processing power also allows for cluttering filtering in the "frequency" or velocity domain, i.e., the I and Q samples are Fourier transformed via a FFT algorithm after which the signal spectrum can be processed. The new spectral clutter filters not only remove power around zero velocity in the spectra but also use an interpolation scheme to fill in the spectral points that were "notched" out (i.e., set to zero) (Siggia and Passarelli 2004). Such filters can first adaptively set a filter notch width according to the characteristics of the spectrum, and then fit a Gaussian shaped curve to the remaining assumed weather signal. The fitted Gaussian curve is used to interpolate across the notch left in the spectrum due to the clutter filter. Figures 1 and 2 illustrate this process. Shown in Fig. 1 are a weather spectrum (red), a clutter signal spectrum (green) and the combination of these two spectra (blue). Fig. 2 shows the same spectra but with the Gaussian fitted curve in red dots and the resultant clutter filtered spectrum in black. If the interpolated area (around zero velocity) were replaced with a notch (set to zero), an obvious bias in both power and velocity estimates of the weather echo would occur. Such an adaptive spectral based clutter filter is used in this paper.

3. FUZZY LOGIC IDENTIFICATION

To identify the gates that are contaminated with clutter, a Fuzzy Logic based algorithm termed CMD (Clutter Mitigation Decision) is employed. First it it noted that narrow spectrum width, zero velocity weather echoes (such as from stratiform rain) are

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very difficult to distinguish from clutter based solely on their spectra. To identify clutter echoes and distinguish them from narrow spectrum width, zero velocity weather echoes, three variables are used: 1) spatial texture of reflectivity, 2) the so-called SPIN of reflectivity (Steiner and Smith 2002) and 3) the Clutter Phase Alignment (CPA). The texture of the reflectivity (TDBZ) is computed as the mean of the squared reflectivity difference between adjacent gates,

$$TBDZ = \left[\sum_{j}^{L} \sum_{i}^{M} (dBZ_{i,j} - dBZ_{i-1,j})^2 \right] /N(1)$$

where dBZ is the reflectivity, L is the number of radar beams or rays used, M is the number gates used and $N = L * M$. TDBZ is computed at each gate along the radial with the computation centered on the gate of interest. SPIN is a measure of how often the reflectivity gradient changes sign along a direction in space (in this case the radar radial) (Steiner and Smith 2002).

The Clutter Phase Alignment (CPA) is calculated from a length L time series x_i as

$$CPA = |\sum_{i=1}^{L} x_i| / \left[\sum_{i=1}^{L} |x_i| \right] \quad (2)$$

If the $\arg\{x_i\}$ is the same for all x_i then $CPA = 1$. For clutter, CPA is usually greater than 0.95 and is about zero for noise. Only weather echoes with velocity magnitude $< 0.3m/s$ (approximately) and spectrum widths less than about 0.5 m/s have CPA values that are in the 0.95 range. Thus, the texture fields are needed to distinguish these echoes from clutter. In any event, CPA is nearly always significantly less than 0.95 for weather time series that are collected over times that are significantly longer than the decorrelation time of the precipitation particles in the radar resolution volume. This variable was first used in (Fabry 2004) as a measure of clutter phase stability for the calculation of refractivity from radar returns.

CMD also uses a power ratio calculated from the spectra termed Power Ratio Narrow (PRN). PRN is the ratio of power from the spectrum at and close to 0 velocity, typically the 0 velocity point and one point on either side, to the power from two points adjacent on each side of this (four total spectral points). If this ratio is large, clutter is possibly present, if not, then a clutter filter is not applied. Thus, this ratio is used as a hard decision boundary. The other hard decision boundary used is the SNR (signal-to-noise ratio). The Fuzzy Logic inputs are centered around the radar resolution volume of interest (Dixon et al. 2006). The general steps of the CMD algorithm are as follows:

1. Check SNR $>$ 3 dB, otherwise no filtering at this gate.
2. Compute clutter ratio narrow (CRN).
3. Check CRN $>$ 6 dB , otherwise no filtering at this gate.
4. Compute feature fields, using a kernel of 1 beam wide by 9 gates long of dBZ texture (TDBZ), dBZ SPIN and clutter phase alignment (CPA)
5. Apply interest mapping to convert features to interest fields.
6. Compute CMD field by applying Fuzzy Logic to interest fields.
7. Threshold CMD at 0.5 to produce CMD clutter flag.
8. Apply clutter filter where CMD flag is set.

4. EXPERIMENTAL DATA

The following one half degree elevation angle PPI data were gathered with KFTG on 26 October 2006 in a wide-spread snow storm along the Eastern Foothills of the Rocky Mountains in Colorado. The times series data were gathered and the CMD algorithm was run during post processing. However, the algorithm is designed to run in real time and does so now on S-Pol. Figs. 3 and 4 show unfiltered reflectivity and velocity, respectively. The x- and y-axes span 250 km and the range rings are in 30 km increments. The Rocky Mountains are easily seen in the left portion of the PPIs. Peak reflectivities are about 40 dBZ in the storm (wet snow) while the reflectivity due to the mountain clutter is in excess of 65 dBZ. The velocity plot shows a clear 0 velocity isodop through the center of the plot (in gray). It is this 0 velocity weather that the CMD should *not* identify as clutter. Fig. 5 is clear air reflectivity which shows the location of clutter, i.e., it is a clutter map for the region displayed in Figs. 3 and 4 and is shown for reference. Fig. 5 shows the resulting reflectivity when a clutter filter is simply applied everywhere. Note the reflectivity that has been eliminated along the 0 velocity isodop. This then shows the problem when clutter filters are applied everywhere.

Figures 7, 8, 9 and 10 show the feature fields of TDBZ, SPIN, CPA and CRN for the data of Fig. 3. Note how well the CPA feature field identifies the clutter. These feature fields are used by CMD to create the clutter map shown in Fig. 11 with yellow marking the regions to be clutter filtered and this can be compared to Fig. 5. A spectral based clutter filter is now applied to the data at the gates indicated by Fig. 11 and the resulting reflectivity and velocity PPIs are shown in Fig. 12 and 13, respectively, and should be compared to Figs. 3 and 4. Both the reflectivity and velocity fields are by-in-large preserved while the clutter has been eliminated.

4.1 Dual polarization data

The above clutter mitigation algorithm was designed for use with single polarization data, however, provision was also made for the inclusion of dual polarization parameters. The dual polarization inputs can be either “activated” or “deactivated” depending on the type of data processed. It was found that the spatial texture of copolar differential reflectivity

(Z_{dr}) and copolar differential phase (ϕ_{dp}) are excellent discriminators of clutter and weather. In out tests we found that 7 or 9 gates of data along a radial produced good discrimination between weather and clutter echoes. It was also found that the copolar correlation coefficient, ρ_{hv} was not as good a discriminator as the standard deviations of Z_{dr} and ϕ_{dp} and therefore is not included in the Fuzzy Logic algorithm.

The following data was gathered by S-Pol on 5 May 2006 in dual polarization mode. Figure 14 shows non-clutter filtered reflectivity. Figure 15 shows the clutter map created by the dual polarization CMD algorithm. Clutter filters are then applied to region designated in Fig.15 and the resulting clutter filtered reflectivity is shown in Fig. 16. As can be seen the clutter is nicely mitigated leaving the meteorological echoes of interest.

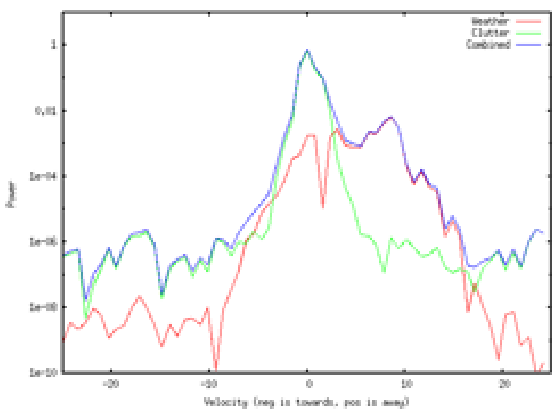

Figure 1: Example of weather and clutter spectra.

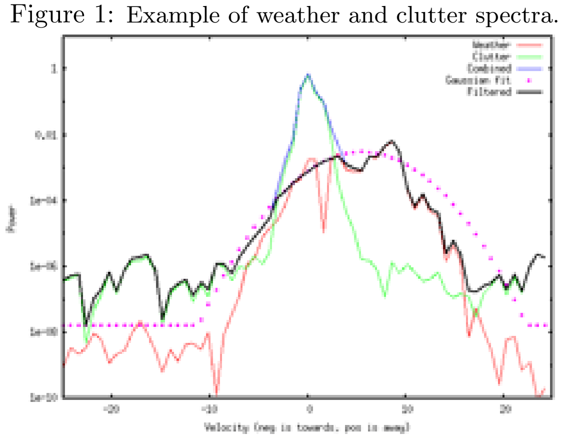

Figure 2: Example of spectral filter.

5. CONCLUSIONS

The Fuzzy Logic based Clutter Mitigation Decision (CMD) algorithm can effectively identify clutter in radar data. If a high speed processor is used, the CMD identified clutter contaminated data can be clutter filtered in real time. After the clutter filter has been applied to the data the radar moments can then be recalculated so that any remaining weather data may be revealed. The CMD algorithm used here employs a new feature field called Clutter Phase Alignment (CPA) which is an excellent discriminator of clutter.

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References

Dixon, M., C. Kessinger, and J.C. Hubbert, 2006: Echo classification within the spectral domain to discriminate ground clutter from meteorological targets. 86^{th} AMS Annual Meeting, IIPS, Atlanta, GA.

Fabry, F., 2004: Meteorological value of ground clutter target measurements by radar. *JTECH*,V21:591-604.

Siggia, A. and R. Passarelli, 2004: Gaussian model adaptive processing (GMAP) for improved ground clutter cancellation and moment calculation. Pro. of Third Euro. Conf. on Radar in Meteo. and Hydro (ERAD 2004). 67–73, Visby, Gotland, Sweden.

Steiner, M. and J.A. Smith, 2002: Use of three-dimensional reflectivity structure for automated detection and removal of non-precipitating echoes in radar data. *JTECH*, 9(5):673-686.

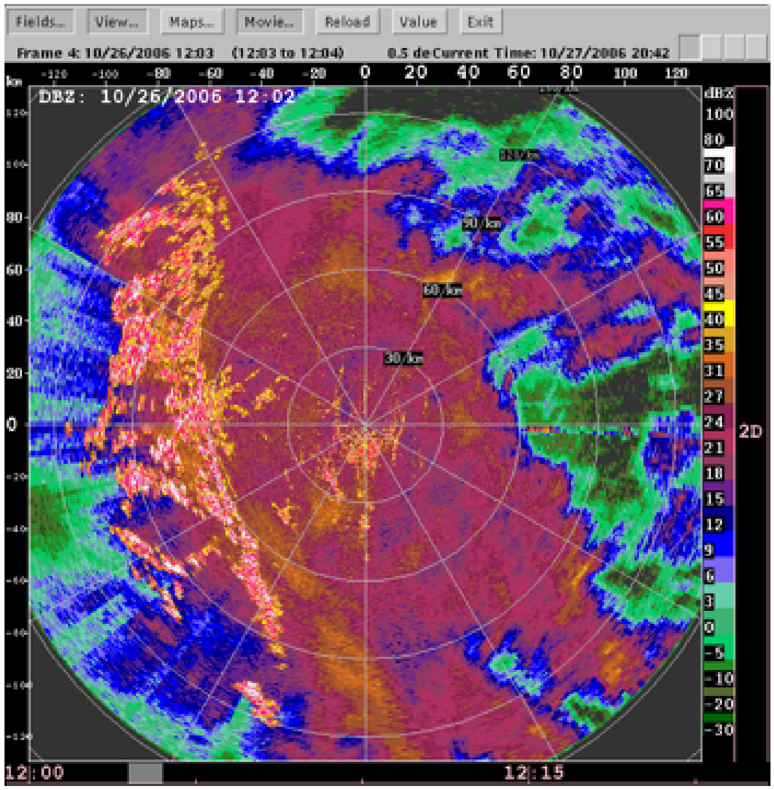

Figure 3: Unfiltered reflectivity.

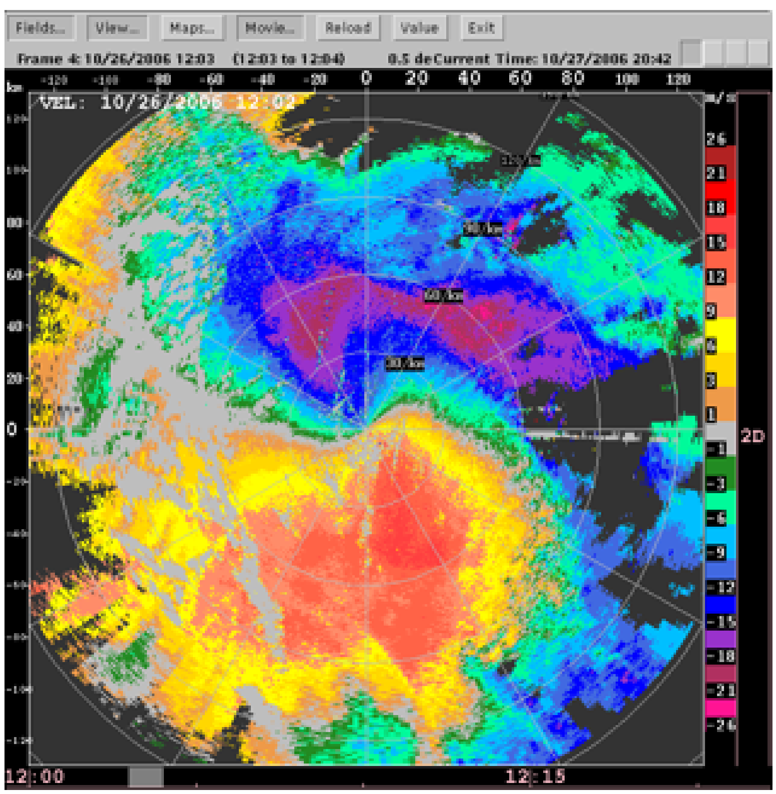

Figure 4: Unfiltered velocity.

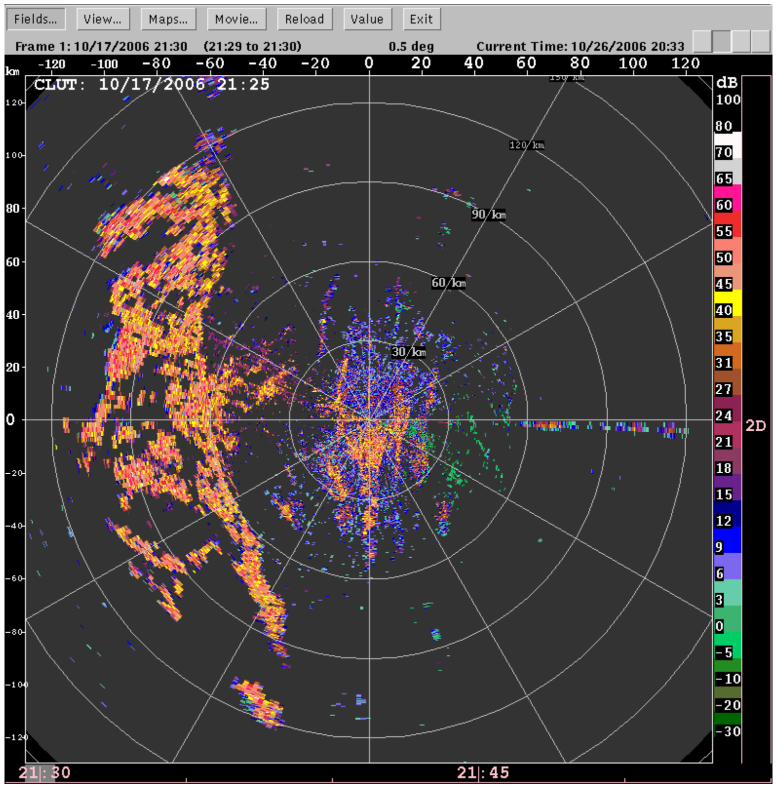

Figure 5: PPI clutter map for KFTG.

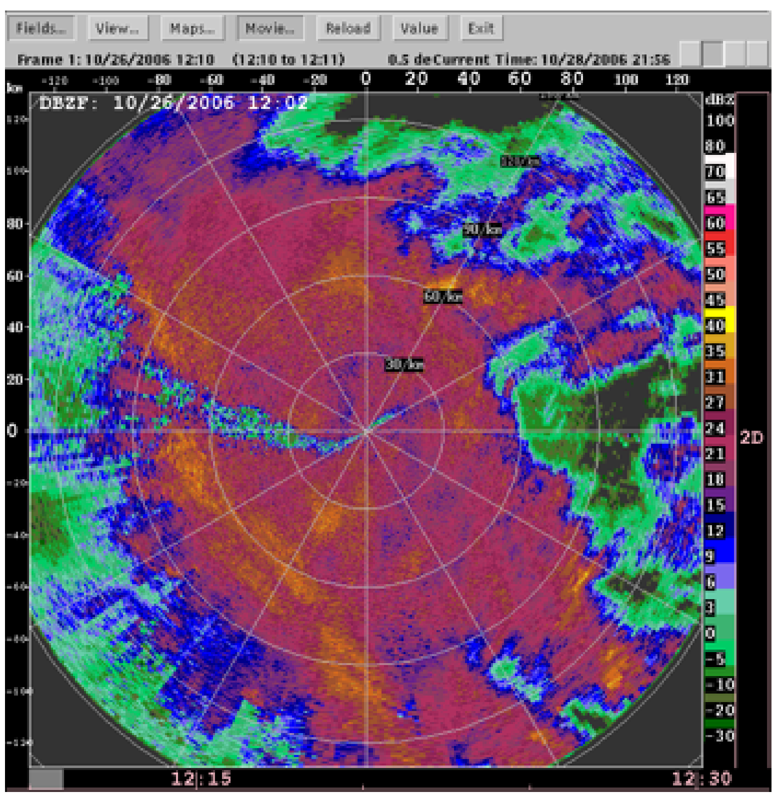

Figure 6: Reflectivity filtered everywhere for data of Fig. 3.

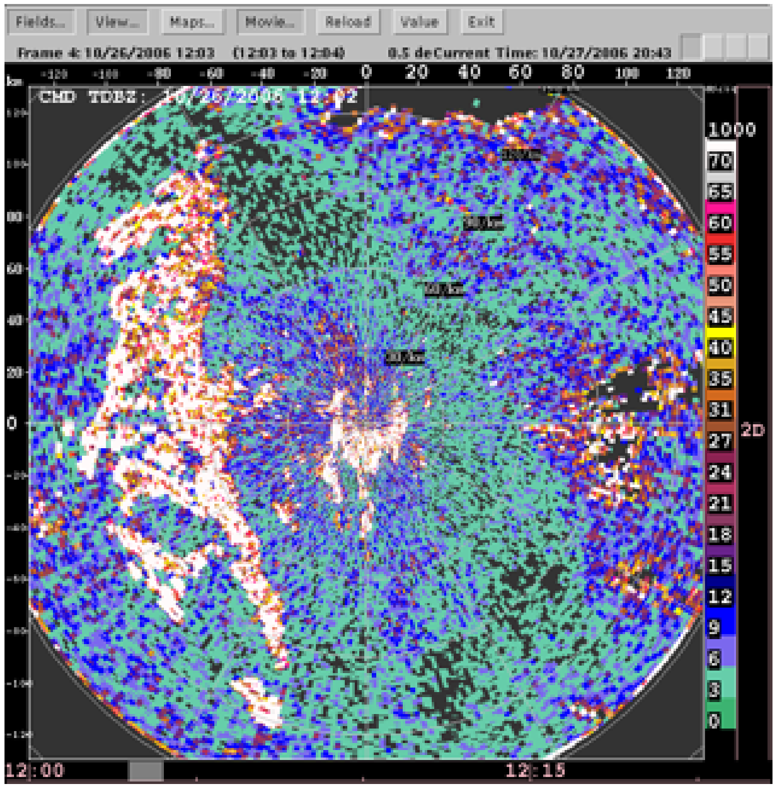

Figure 7: The texture of the reflectivity field (TDBZ) shown in Fig. 3.

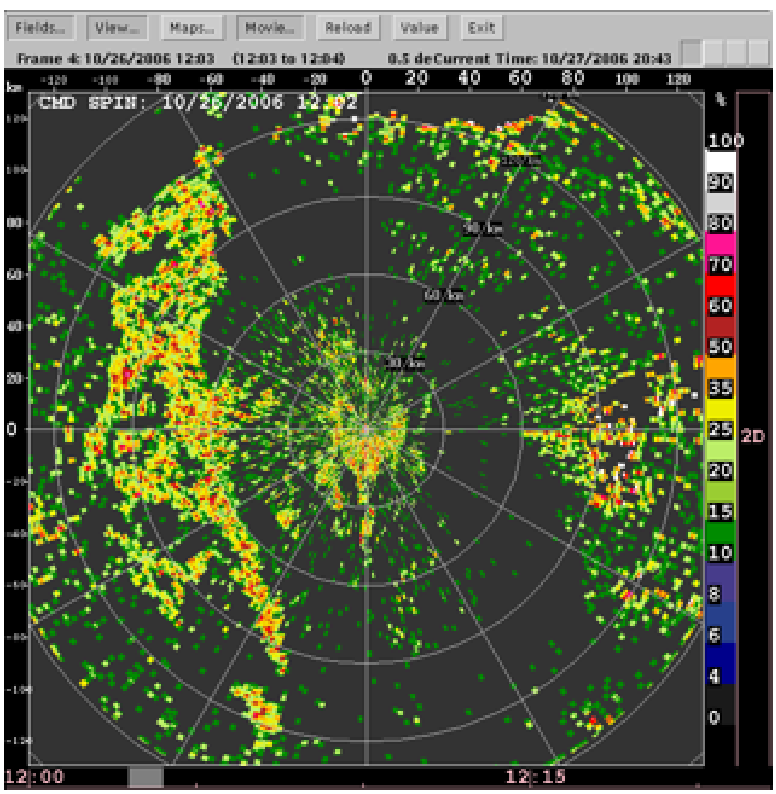

Figure 8: The feature field SPIN for data of Fig. 3.

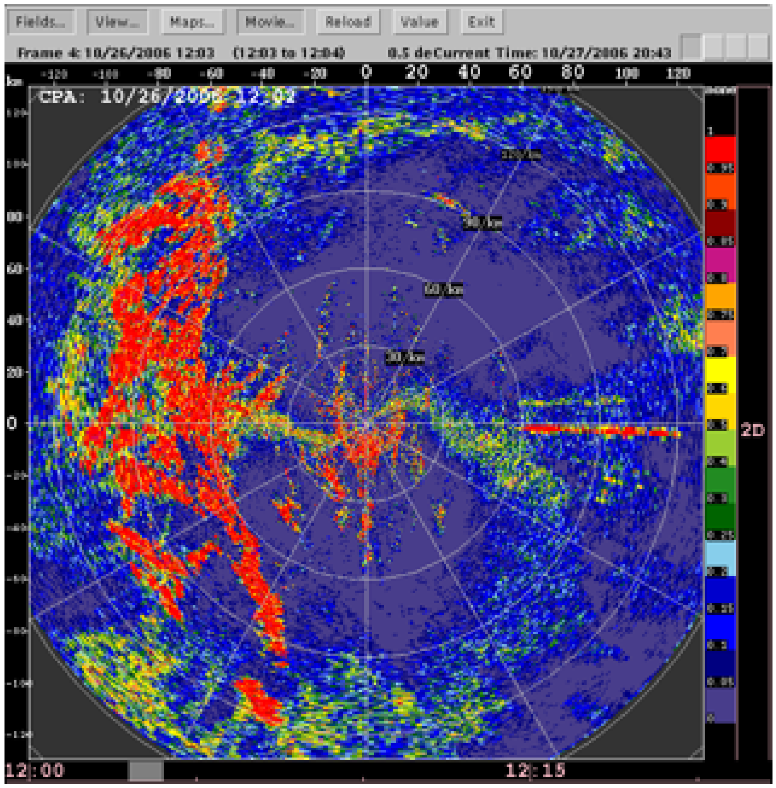

Figure 9: The feature field Clutter Phase Alignment (CPA)for data of Fig. 3.

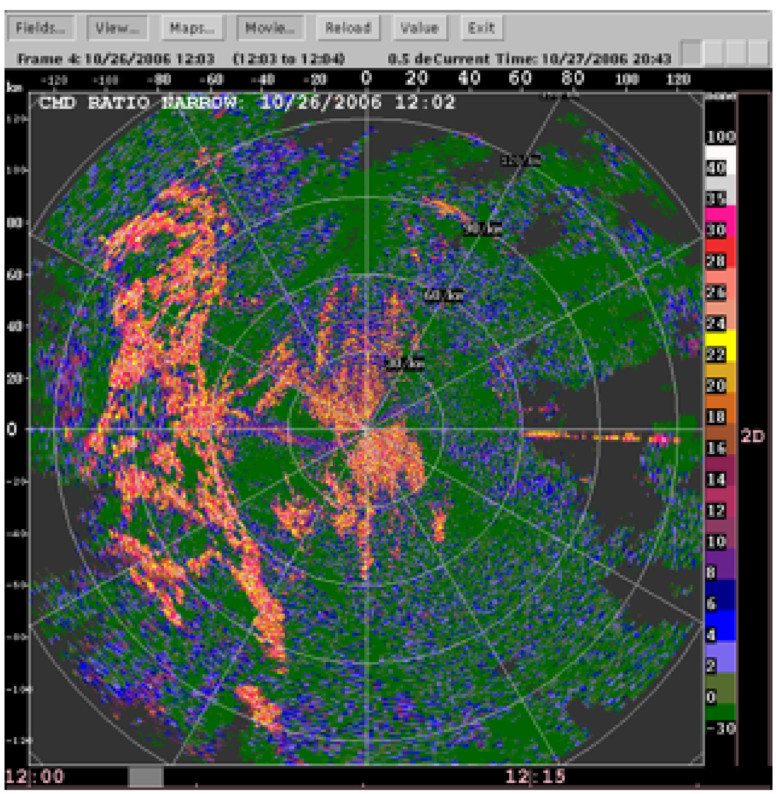

Figure 10: The field Clutter Ratio Narrow for data of Fig. 3.

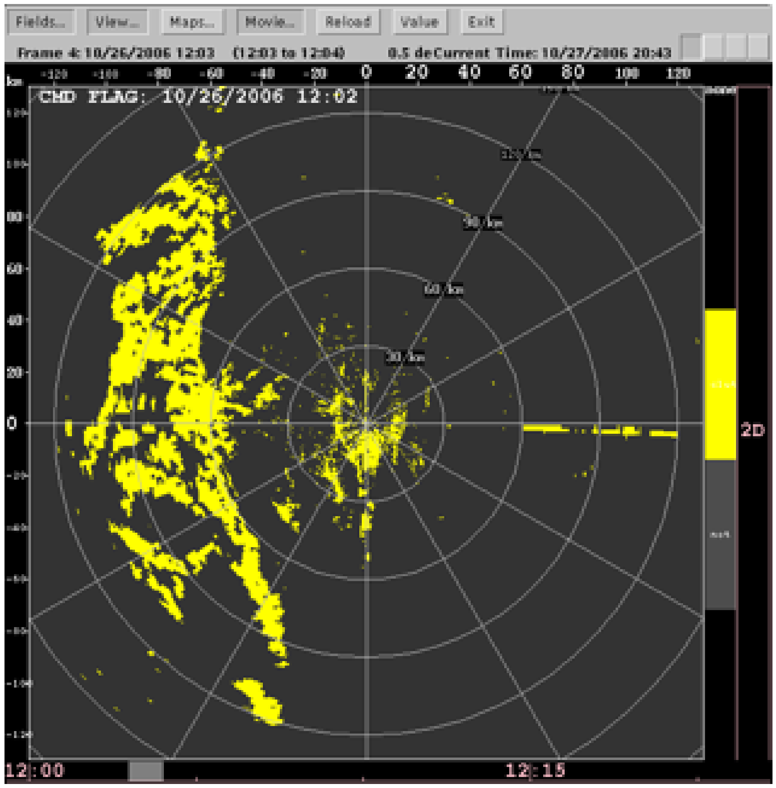

Figure 11: The CMD flag, i.e., the clutter filter is applied at those gates in the yellow regions.

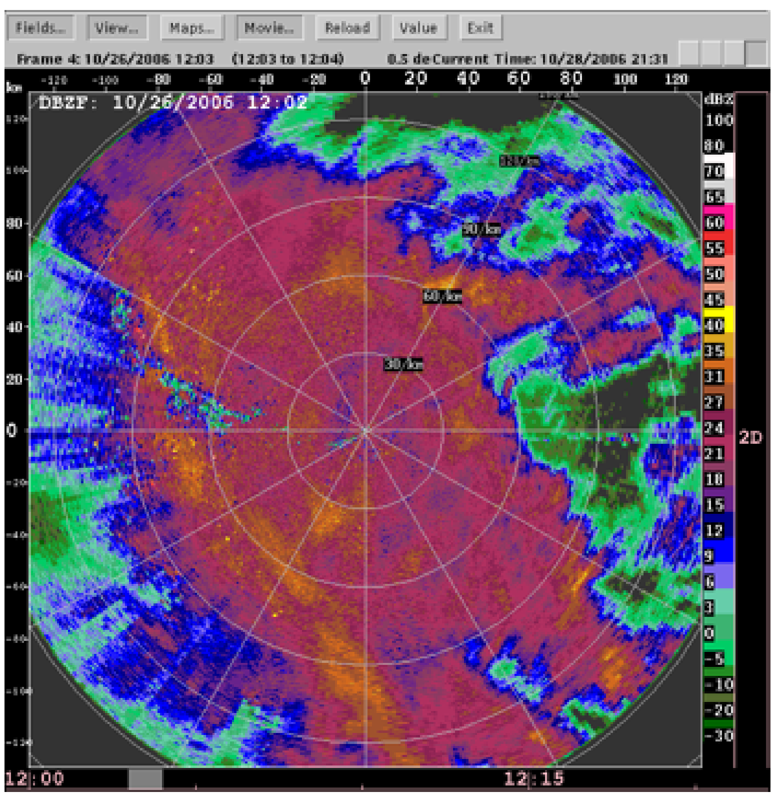

Figure 12: CMD filtered dBZ for data of Fig. 3.

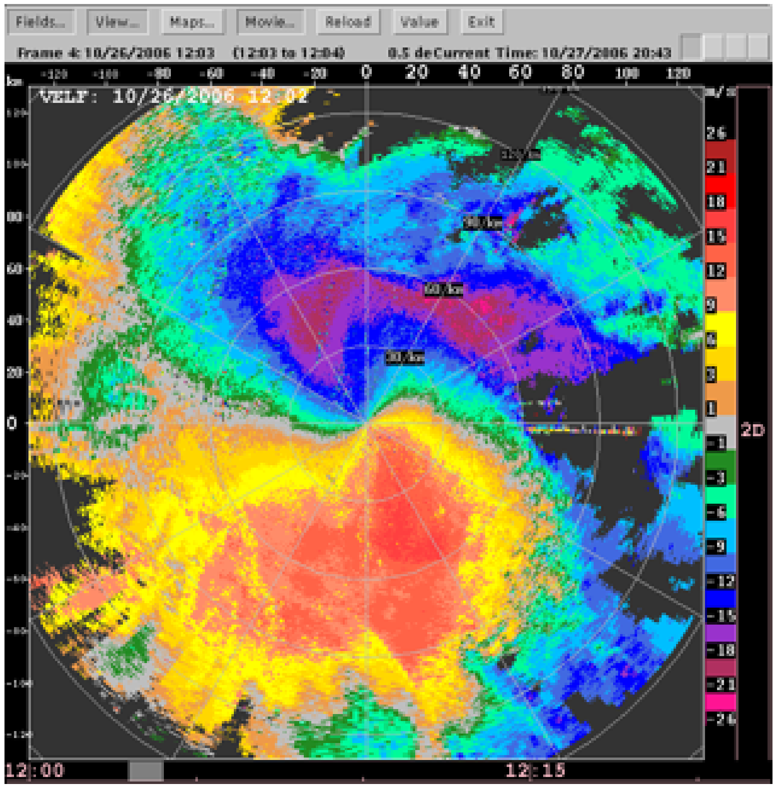

Figure 13: CMD filtered velocity for data of Fig. 3.

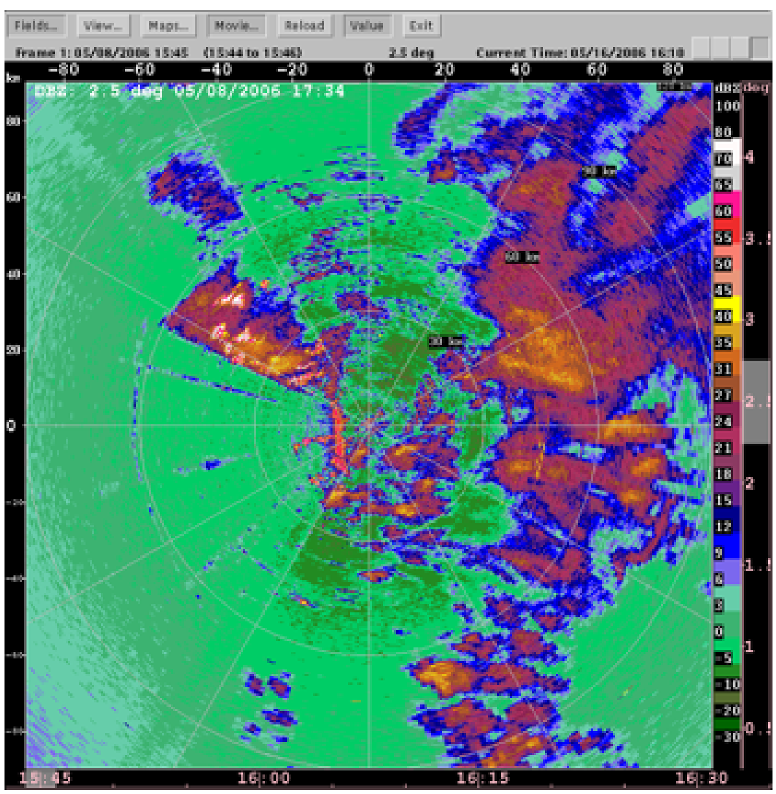

Figure 14: Dual pol. case, reflectivity.

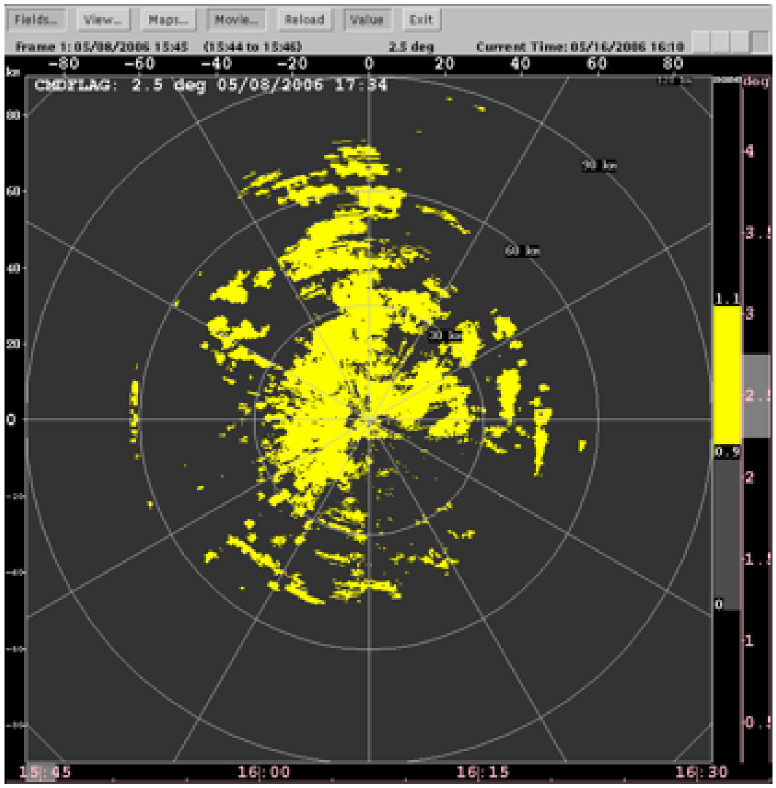

Figure 15: CMD dual pol. clutter flag.

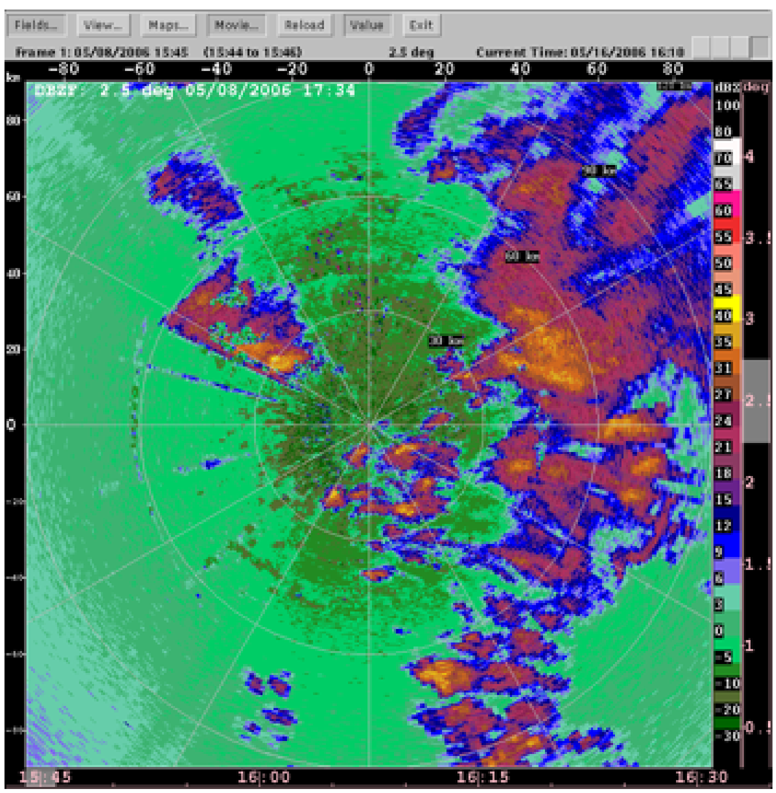

Figure 16: Dual pol. reflectivity filtered.