# CLUTTER MITIGATION IN DIVERSE ENVIRONMENTS

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**Abstract**: The effects of ground clutter on weather radar data can be mitigated by applying a ground clutter filter to the data. Various types of filter can operate either on the time domain signal or the equivalent frequency domain data. However, such filters typically at best can reduce the clutter signal by about 45dB. Since clutter signatures are frequently above 70 dBZ there are many cases where significant residual clutter power remains after filtering. This paper investigates and characterizes ground clutter from several radars and examines the residual clutter problem. A technique for removing residual ground clutter is investigated.

## 1 INTRODUCTION

Most ground clutter targets which affect weather radars have a narrow spectral signature centered at 0 m/s. Clutter filters are designed to remove power from that narrow band. The GMAP adaptive filter proposed by Siggia and Pasarelli (2004) is an example of such a filter. It is very effective in dealing with narrow-width clutter signatures.

However, some clutter targets have a power spectrum in which a significant fraction of the power is distributed across the entire frequency range. An adaptive notch filter will not remove the power at these other frequencies, with the result that the estimated mean power is too high.

To demonstrate this effect we present clutter signatures from a number of different radars in varying clutter environments, all of which are challenging because of large ground targets at relatively close range.

We examine the time series and spectra for strong clutter targets and suggest reasons for the spread of the power across the spectrum. We also introduce a simple mitigation method which has been successfully tested on research radars.

## 2 RADARS USED IN THIS STUDY

We considered data from 4 radars, as follows:

- NWS KFTG NEXRAD radar, Denver, Colorado.
- CSU/CHILL, Greeley, Colorado.
- Australian BOM CP2 radar, Brisbane, Australia.
- NCAR SPOL radar, TIMREX field experiment, southern Taiwan.

All are 10cm Klystron radars with approximately 1 degree beam widths. KFTG is a single polarization radar. The others are dual polarization research radars operating in fast alternating mode.

## 3 PPI CLUTTER SIGNATURES FOR EACH RADAR

Figures 1 through 4 show the reflectivity and clutter maps for each of the 4 radars used in this study.

Figures 1 (a) through (d): KFTG

Figures 2 (a) through (d): CHILL

Figures 3 (a) through (d): CP2

Figures 4 (a) through (d): SPOL/TIMREX

In each figure, the following panels are shown:

(a) Unfiltered reflectivity

(b) Clutter removed using adaptive filter similar to GMAP (Siggia and Pasarelli, 2004)

(c) Residual clutter power spread across the frequency spectrum.

(d) Filtered reflectivity after removing both clutter power types: d = a - (b + c)

The decision to filter or not is based on the CMD method described by Hubbert et al, 2009b.

Figures 1 through 4 demonstrate the following:

(a) The residual clutter power varies significantly from one radar to the next. CHILL has very low residual values, followed by KFTG, with higher values for CP2 and SPOL/TIMREX.

(b) The effectiveness of the adaptive filter varies significantly from radar to radar. For CP2, the maximum clutter suppression from the filter is about 35 dB, while it is above 45 dB for the other radars.

In the case of SPOL at TIMREX, the residual clutter power is very high at ranges close to the radar.

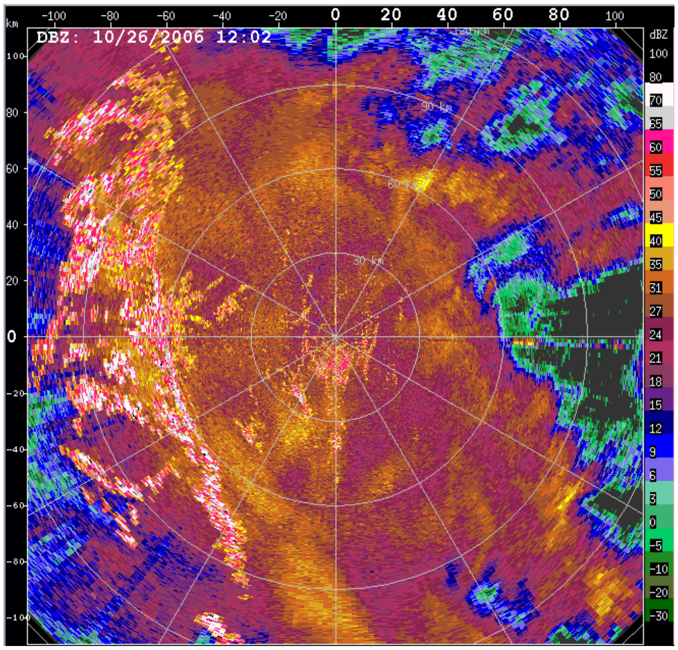


*Figure 1a: KFTG unfiltered reflectivity*

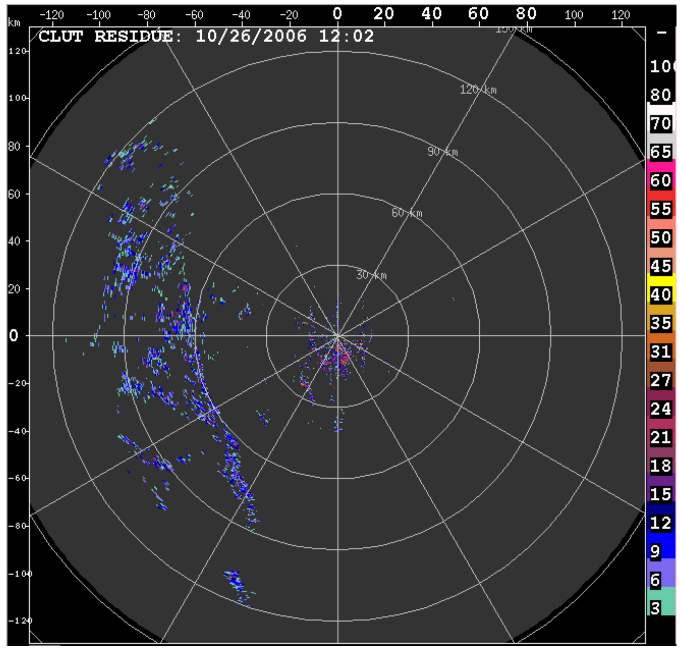


*Figure 1c: KFTG residual clutter power*

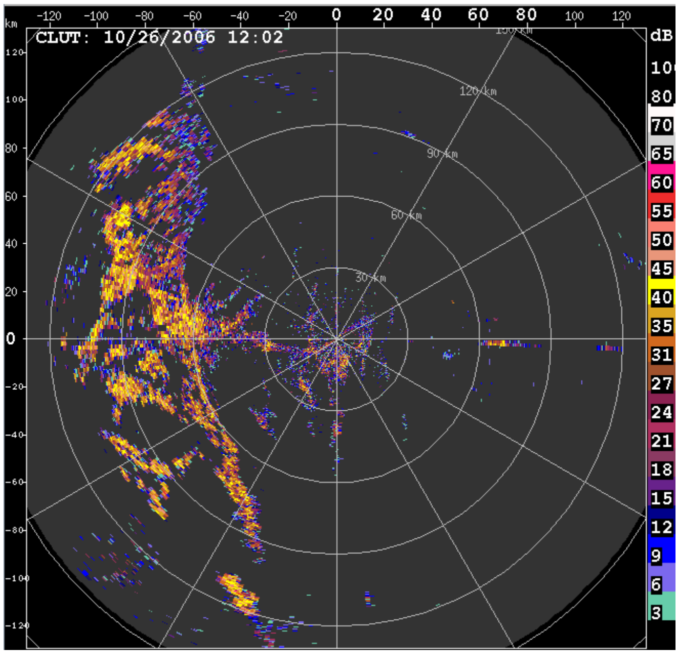


*Figure 1b: KFTG clutter removed by adaptive filter*

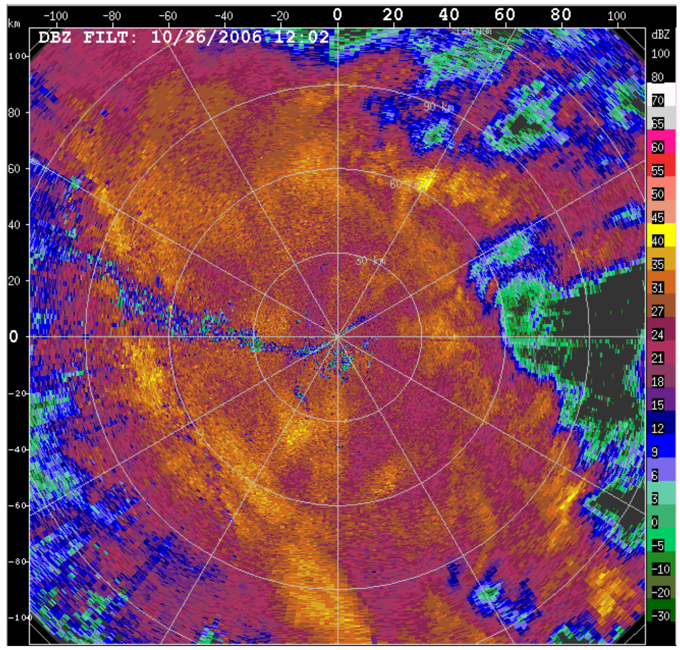


*Figure 1d: KFTG filtered reflectivity*

Note: maximum suppression from the adaptive filter is about 45 dB.

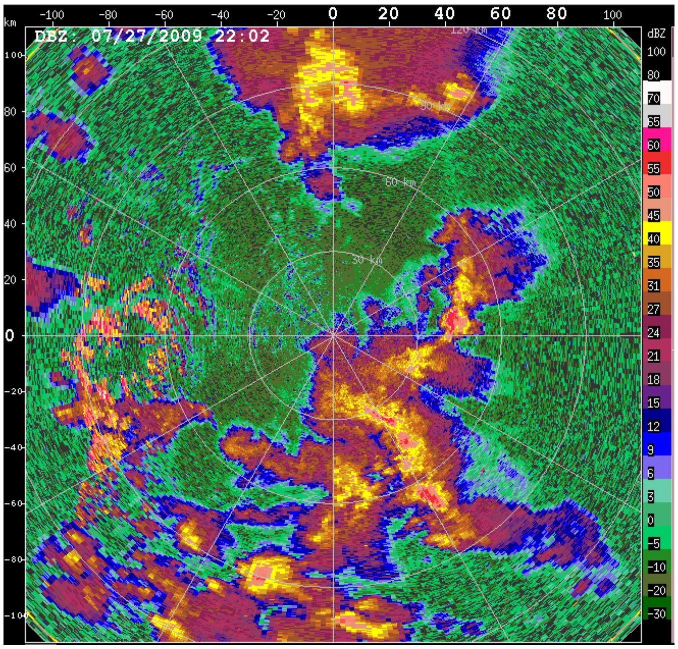


*Figure 2a: CHILL unfiltered reflectivity*

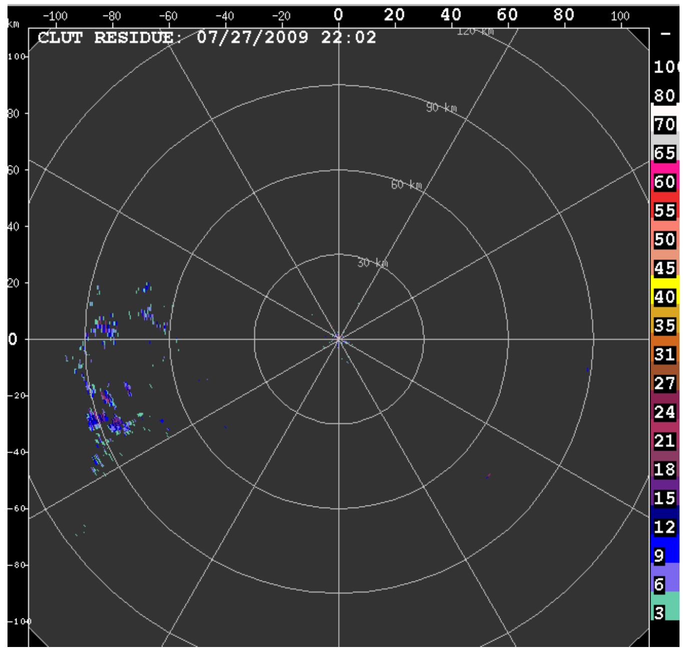


*Figure 2c: CHILL residual clutter power*

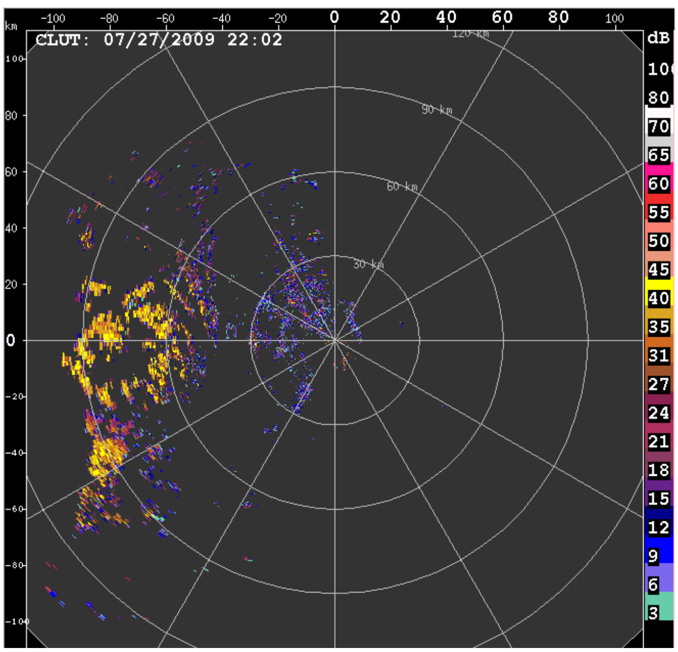


*Figure 2b: CHILL clutter removed by adaptive filter*

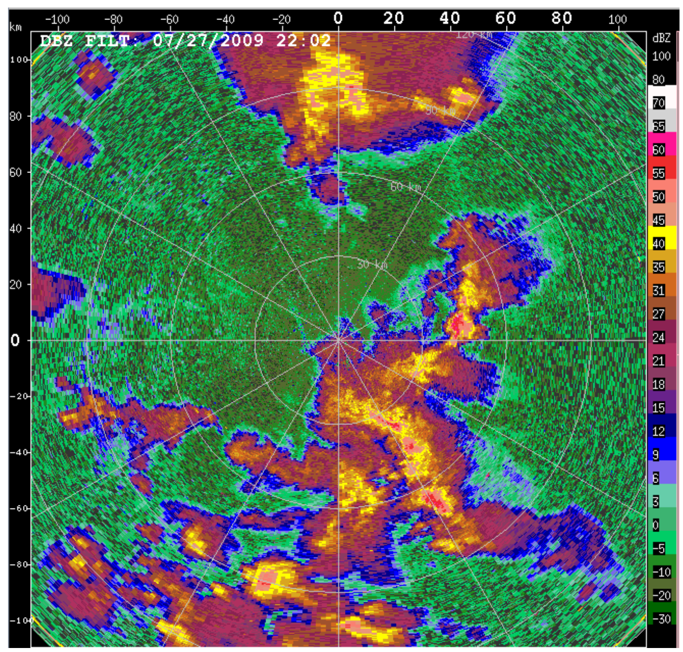


*Figure 2d: CHILL filtered reflectivity*

Note: maximum suppression from the adaptive filter is about 45 dB.

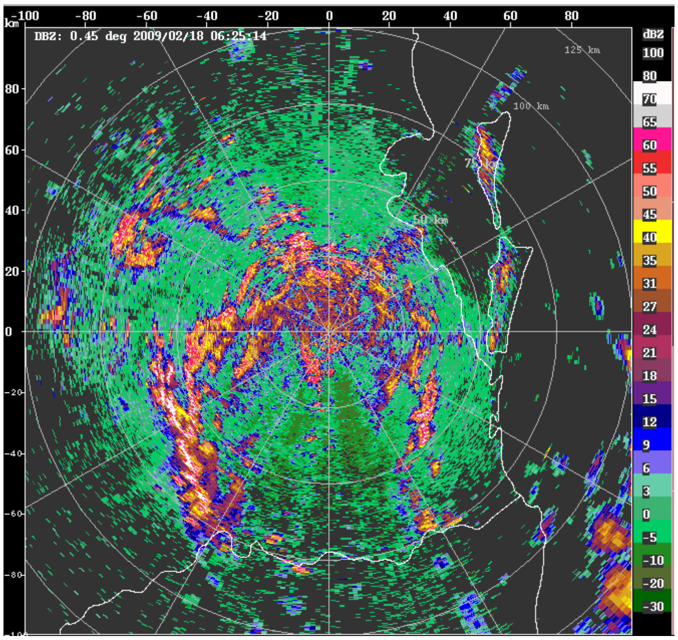


*Figure 3a: CP2 unfiltered reflectivity*

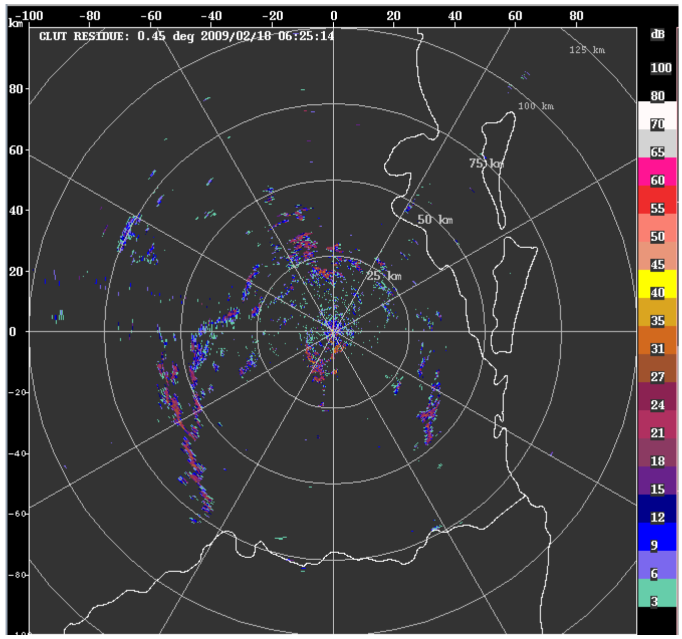


*Figure 3c: CP2 residual clutter power*

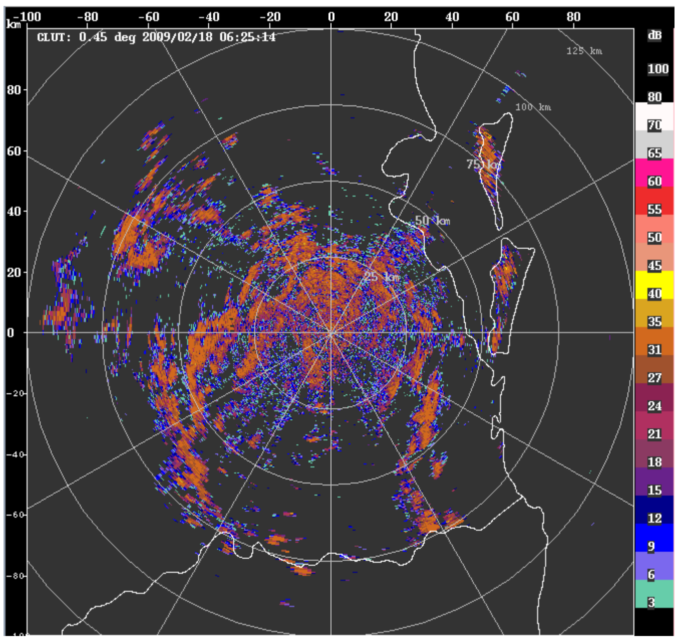


*Figure 3b: CP2 clutter removed by adaptive filter*

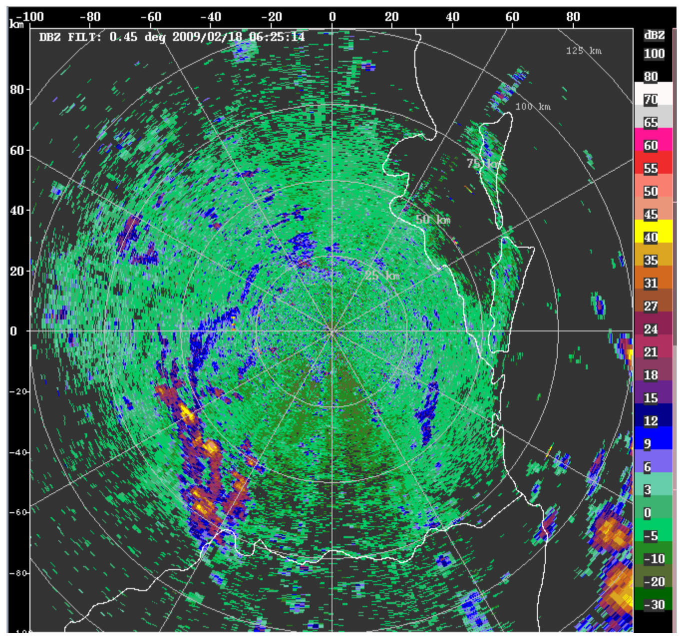


*Figure 3d: CP2 filtered reflectivity*

Note that the adaptive filters appears to be about 10 dB less effective at CP2 than the other radars. At CP2, the maximum suppression is about 35 dB, while for all other radars it is about 45 dB.

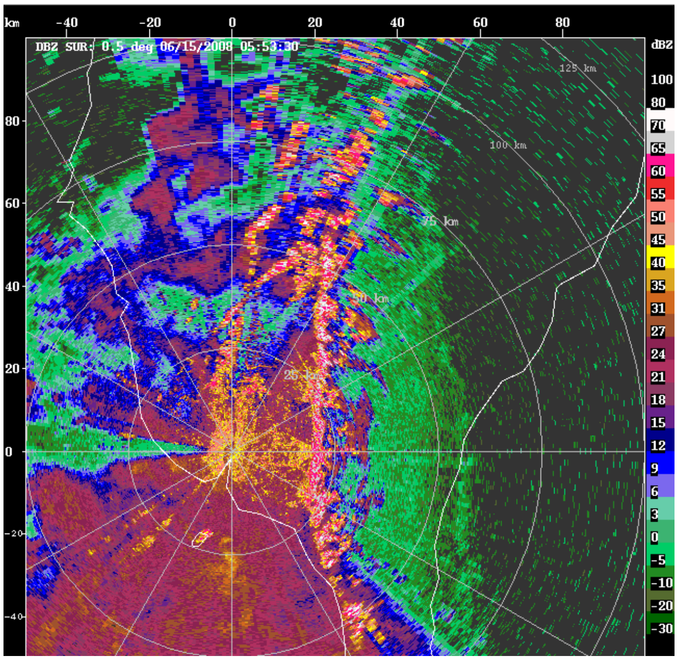


*Figure 4a: SPOL TIMREX unfiltered reflectivity*

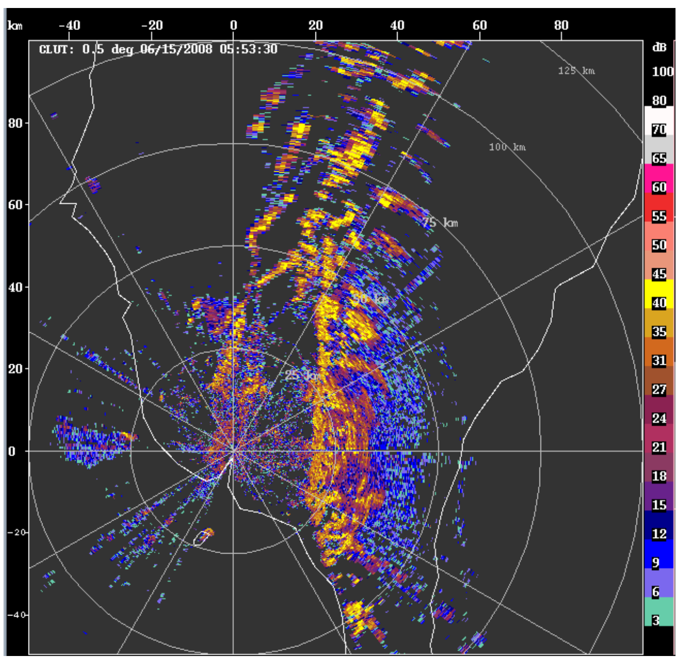


*Figure 4b: SPOL TIMREX clutter removed by adaptive filter*

Note: maximum suppression from the adaptive filter is about 45 dB.

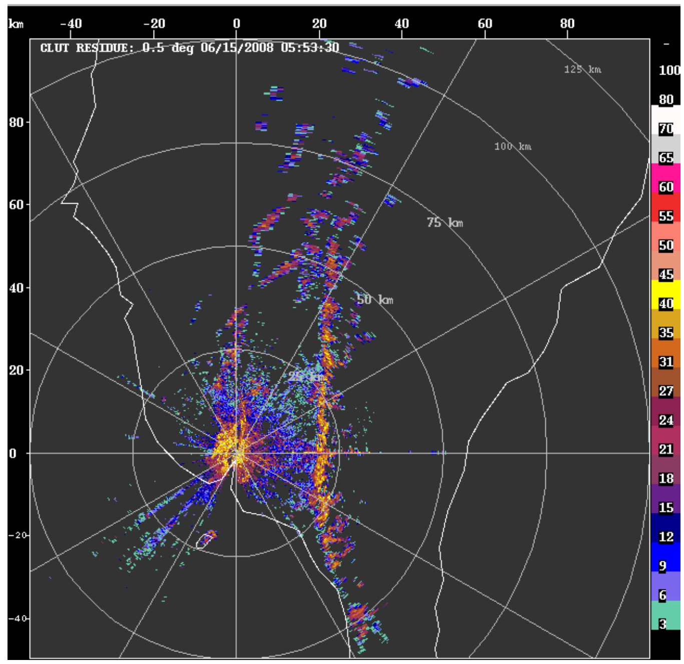


*Figure 4c: SPOL TIMREX residual clutter power*

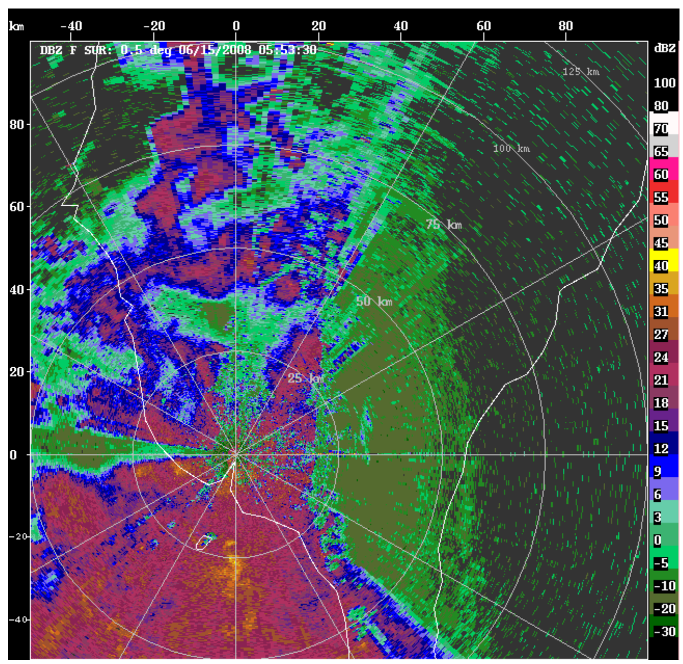


*Figure 4d: SPOL TIMREX filtered reflectivity*

Note that for SPOL/TIMREX, the residual power is large for many gates at ranges close to the radar. This leads to significant gaps in the filtered reflectivity.

## 4 SPECTRAL AND TIME SERIES CLUTTER SIGNATURES

Figures 5 through 9 show a spectral and time series views of selected weather and clutter cases.

Each figure has 7 panels. The top panel shows spectra in the frequency domain. All other panels show time series in the time domain.

Panel 1 (top): Red – original spectrum, including clutter. Pink: filtered spectrum after applying both an adaptive notch filter and a correction for residual clutter power. Orange: spectrum after applying a polynomial regression filter (Torres and Zrnic, 1999) without any correction for residual power. The brown horizontal line shows the calibrated noise floor. Note: the VonHann window is applied to all time-series data before computing the spectrum.

Panel 2: Green – time series of power ($I^2$ x $Q^2$) for the unfiltered data.

Panel 3: Orange – time series of phase for the unfiltered data.

Panel 4: White – time series of unfiltered I (in-phase) component. Magenta – $5^{th}$ order polynomial regression fit to I.

Panel 5: White – time series of unfiltered Q (quadrature) component. Magenta – $5^{th}$ order polynomial regression fit to Q.

Panel 6: Cyan – time series of residual I (in-phase) component, after removing polynomial fit.

Panel 7: Cyan – time series of residual Q (quadrature) component, after removing polynomial fit.

The polynomial regression filter (Torres and Zrnic, 1999) is useful here in 2 respects: (a) it could be used as an alternative to the adaptive filter; (b) the polynomial fit, and the residual I/Q values from the fit, provide clues about what is causing the residual clutter power problem.

The orange line in the top panel shows the spectrum of the data after application of the $5^{th}$ order polynomial regression filter.

Inspection of the I and Q time series panels in Figures 5 through 9 (white) show that the values tend to oscillate at a higher frequency around a smoothly-varying, lower frequency trend line. The higher frequency variations are generally the weather signal while the lower frequency trend is the clutter signal. The polynomial fit estimates the low frequency clutter trend, which is caused by the fact that clutter targets come in and out of view as the radar rotates (Hubert et al, 2009a).

The I/Q residuals (cyan), if predominantly periodic in nature, are the result of scattering from hydrometeors moving with respect to the radar. If the residuals are not periodic in nature, they indicate noisiness in the system, probably in the form of phase noise in the transmit/receive components of the radar. This may be the result, partially at least, of receiver saturation at high return power.

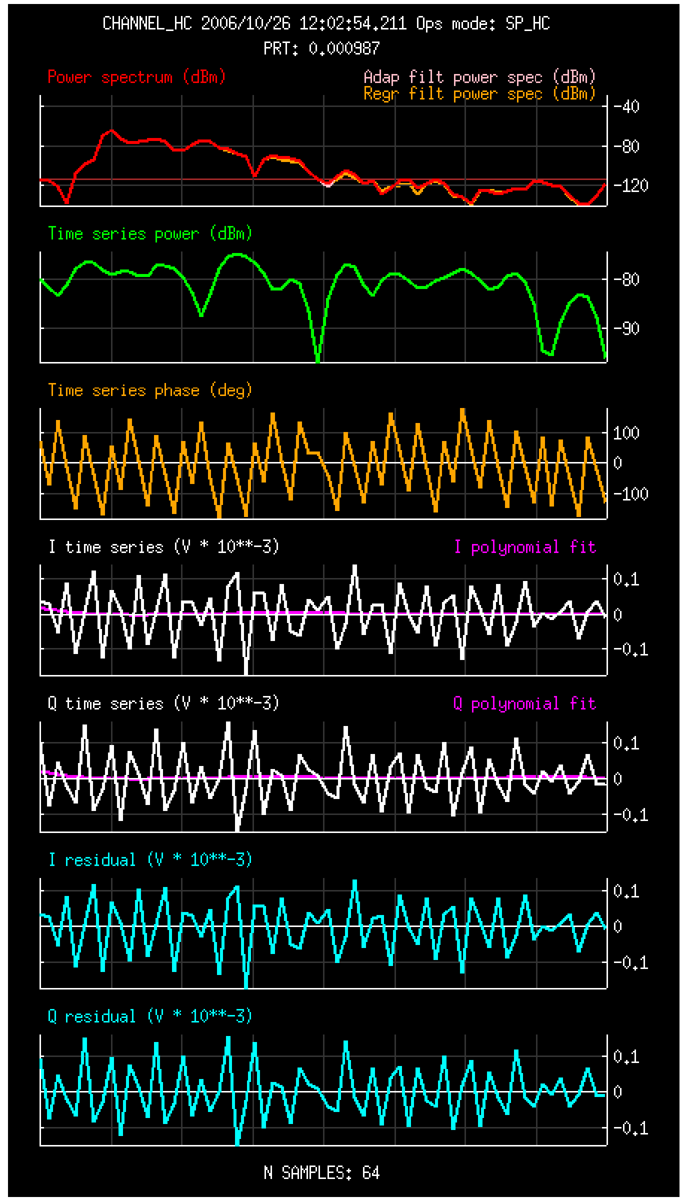


*Figure 5: spectra and time series plot KFTG, weather only*

Figure 5 shows a typical example of weather only, from KFTG.

The power spectrum (red) shows the weather signal with little evidence of clutter

The I/Q time series (white) exhibits the rapid change in phase associated with weather having a significant velocity. The power of the I and Q series, on the other hand, has little overall trend – i.e. the polynomial fit (magenta) is flat. The residual I/Q series (cyan) is virtually identical to the original time series (white).

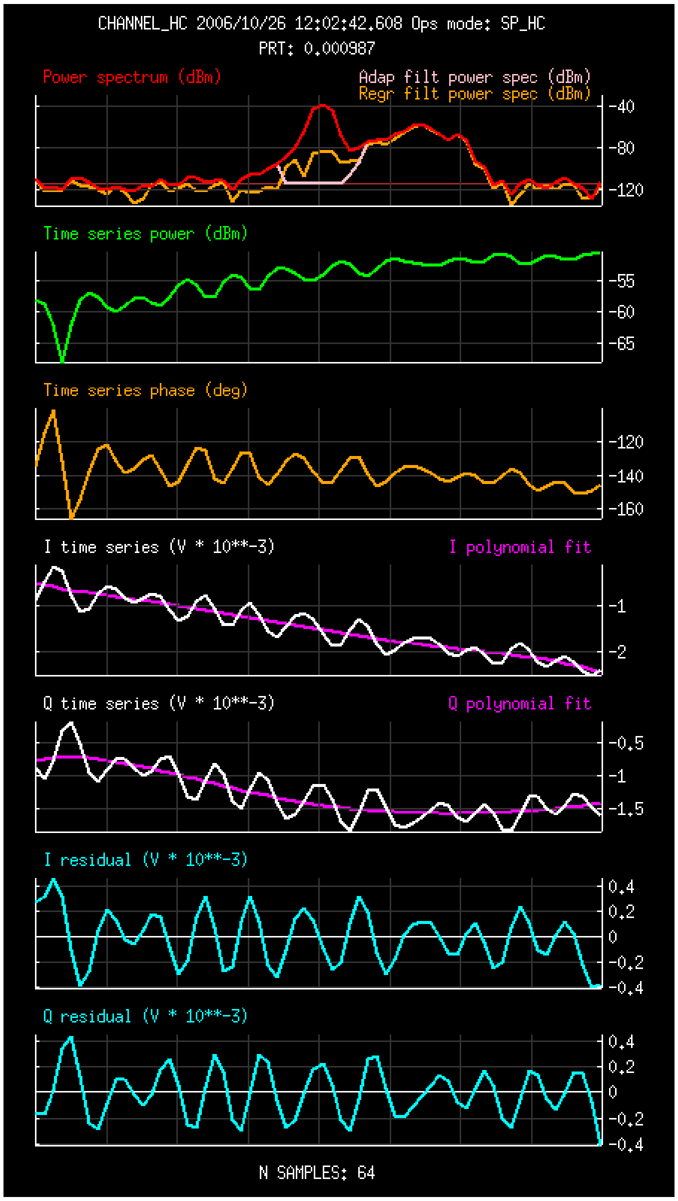


*Figure 6: spectra and time series plot*
*KFTG – weather and clutter combined*

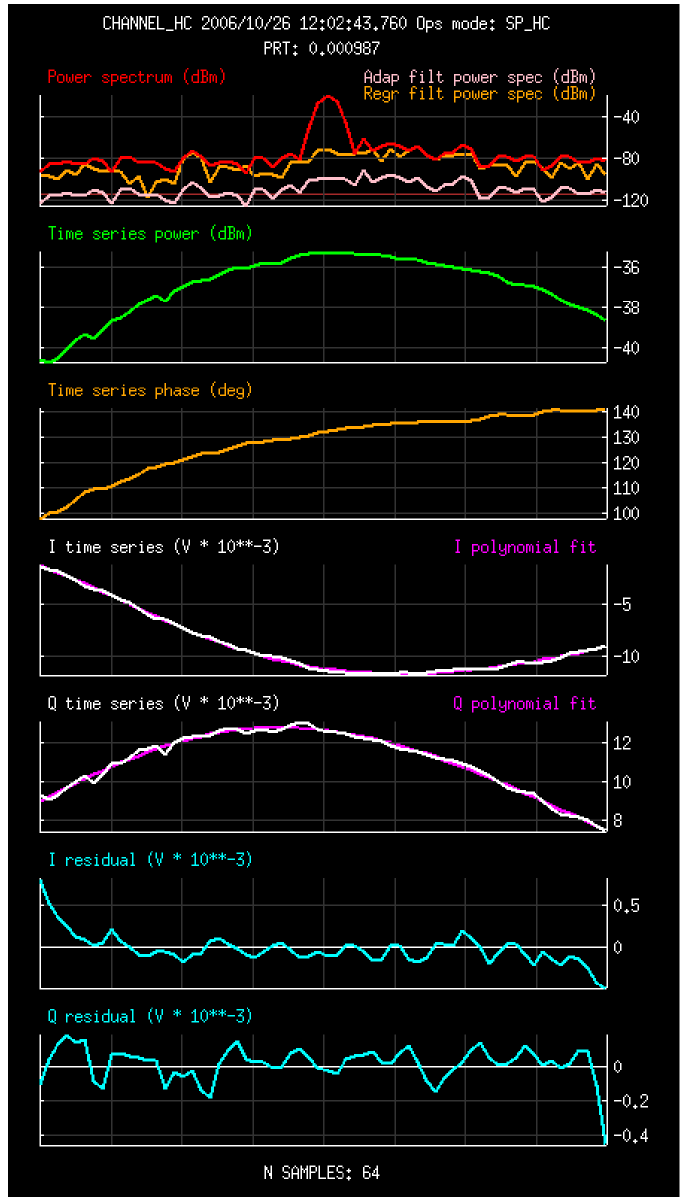


*Figure 7: spectra and time series plot*
*KFTG –strong clutter with residual power*

Figure 6, also from KFTG, shows a combination of clutter and weather at a single gate, with most of the clutter power contained in frequencies close to 0 m/s. At the spectral tails the power is approximately the same as the noise level (brown).

The I/Q time series (white) shows a significant low-frequency clutter trend (magenta polynomial fit), with the weather signature superimposed on this.

The adaptive filter removes the clutter power down to the noise floor in the notch close to 0 m/s (pink). The polynomial regression filter (orange, top panel) removes less power and is probably more accurate in this instance.

No residual clutter is apparent – the tails of the original spectrum (red) reaches the calibrated noise floor (brown line).

Figure 7 shows an example from KFTG of strong clutter with an elevated noise floor in the unfiltered spectrum (red). The pink (filtered) spectrum is 20 to 30 dB below the original (red) spectrum, the difference being the residual power remaining after applying the adaptive filter.

The IQ time series (white) has a significant power trend which is well described by the polynomial fit (magenta). However, in contrast to Figure 6, there is considerable jitter in the residual power (cyan), at multiple frequencies. This leads to the spreading of the power spectrum across all frequencies.

This jitter in the IQ signal is indicative of phase noise. It should be noted that the power is high – around -36 dBm, so the receiver is probably near saturation at the high end.

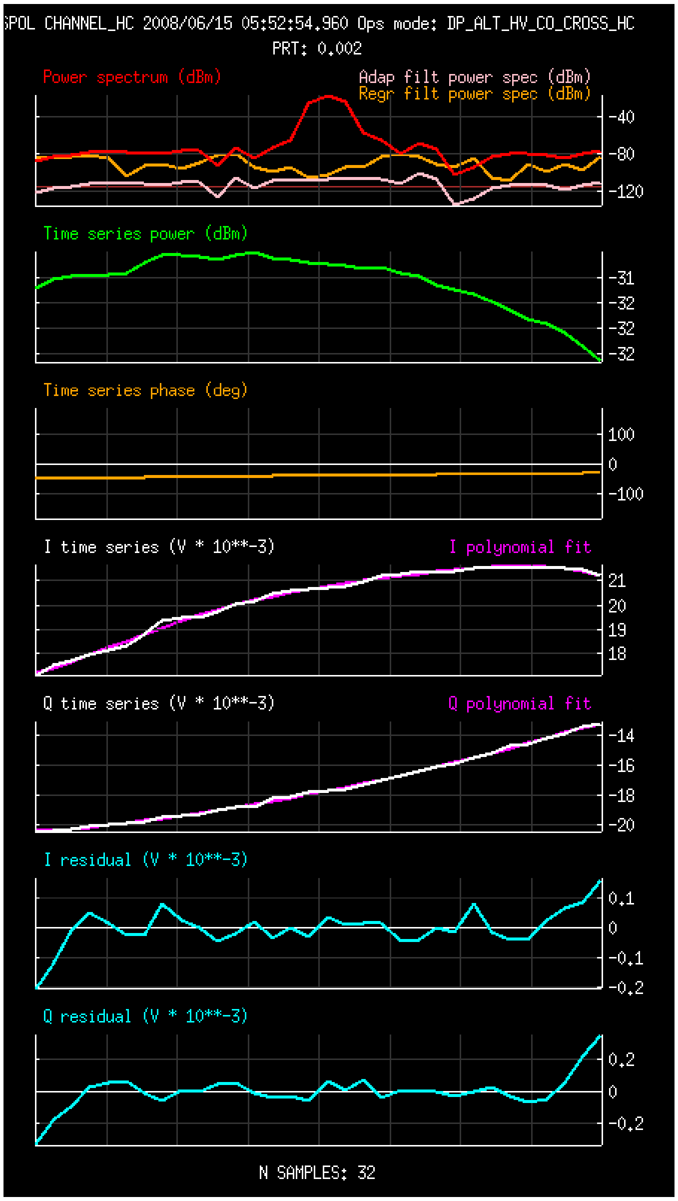


*Figure 8: spectra and time series plot*
*SPOL TIMREX –strong clutter with residual power*

Figure 8 shows an example of strong clutter from SPOL at TIMREX. As in Figure 7, the raw power spectrum (red) shows elevated tails, while the spectrum after applying both the adaptive filter and the residual power correction (pink) is about 35dB below that.

As in Figure 7, there is considerable jitter around the polynomial fit (cyan), leading to the raised power levels in the tails of the raw power spectrum (red).

The jitter in the residual IQ data indicates the likelihood of phase noise being a significant factor contributing to the spread of clutter power across the spectrum. The high power levels (> -32 dBm) suggest possible receiver saturation (green).

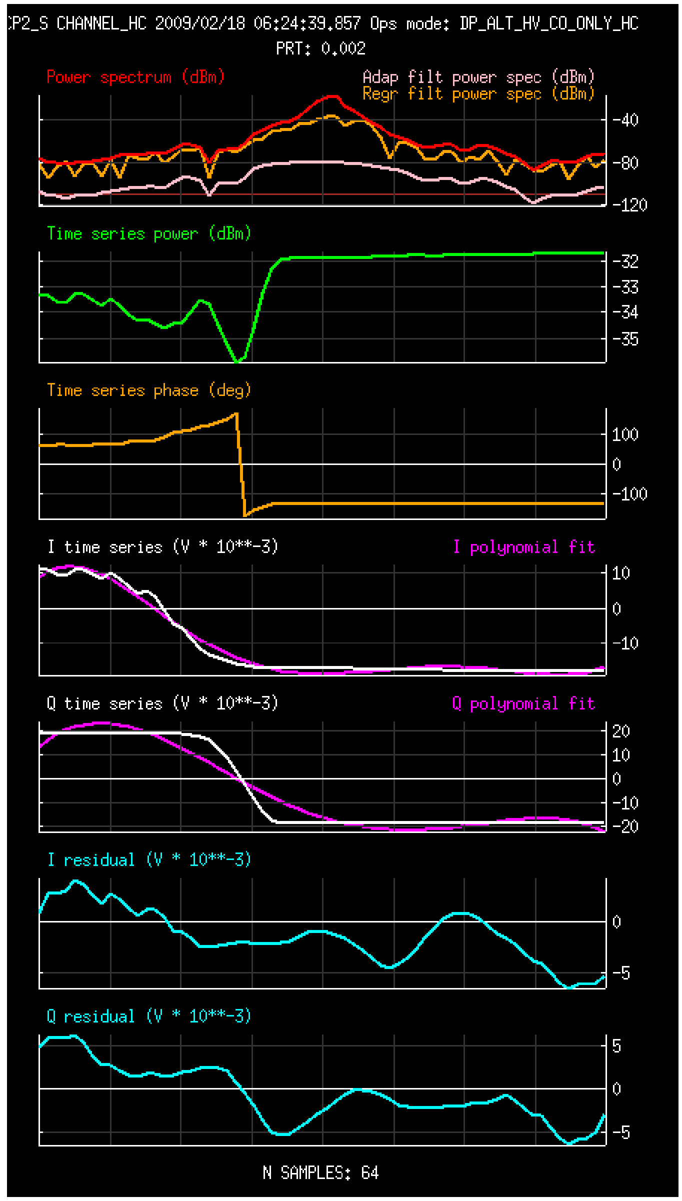


*Figure 9: spectra and time series plot*
*CP2 –strong clutter with residual power*
*Receiver probably saturated.*

Figure 9 shows an example of very strong clutter from CP2 for a gate close to the radar.

In this case, the time series of the power (green) shows that the receiver was very likely saturated, since the latter half of the time series is almost constant at around -31.5 dBm.

The IQ time series, the polynomial fit, and the residual IQ time series, all show evidence of abnormal conditions, as a result of the receiver saturation.

The phase noise in this case is extreme, and the residual power after applying the clutter filter is in excess of 40 dB.

## 5 ESTIMATION OF RESIDUAL CLUTTER POWER

The following heuristically-derived procedure was developed and tested in order to mitigate the effect of the residual clutter power.

All values are in dB.

- Compute the clutter-to-weather ratio (CWR) from application of the adaptive filter.
- Estimate the spectral noise (SN) using a method such as that proposed by Hildebrand and Sekhon (1973).
- Obtain the calibrated noise from the calibration (CN).
- Compute the spectral excess SE = (SN – CN).
- If CWR is less than 6 dB, then
  residual clutter power = 0 dB.
- If CWR exceeds 12 dB, then
  residual clutter power = SE.
- If CWR is between 6 and 12 dB, then
  residual clutter power = SE * (CWR – 6) / 6

This procedure was used to compute the residual power plotted in Figures 1c, 2c, 3c and 4c.

## 6 CONCLUSIONS

When return power from clutter is large, power may be spread across the spectrum because of phase noise and/or receiver saturation effects. This leads to an under-estimate of clutter power if an adaptive notch-type filter is used without correction. It is therefore important to estimate and to correct for residual clutter power.

Application of a polynomial regression technique to the time series provides useful insights into the nature and causes of the problem.

A heuristically-derived procedure has been developed to correct for residual clutter power. This has been tested in the field and shows promise.

Filtering therefore becomes a 3-stage process:

- Apply the adaptive filter
- Estimate the residual power
- Subtract the residual power

## ACKNOWLEDGEMENTS

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