Rethinking Clutter Filtering and Improving Signal Statistics

John Hubbert, Greg Meymaris, Mike Dixon, Scott Ellis

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
Boulder, Colorado

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Spectra-Based Clutter filtering

- Since the advent of fast digital receivers this has been the standard, e.g., GMAP
- Replaced time domain filters
- Very common in weather radars
Discrete Fourier Transform

- Use FFT algorithm
- *Turns a finite length time series into a periodic repeating function*
- What are the consequences of this???

Fourier Transform pair

\[
X(mF) = \sum_{n} x(nT) e^{-j2\pi mnF} \\
x(nT) = \frac{1}{N} \sum_{m} X(mF) e^{j2\pi mnFT}
\]

Frequency domain
Time domain, i.e., sum of sinusoids
Real Part of a S-Pol Time Series.
Real Part of a S-Pol Time Series. DFT creates a periodic signal.
In order to create a sum of sinusoids that can replicate this jump discontinuity, many higher frequency sinusoids are required.
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Hanning Windowed Time series
The smooth curve spectrum is an artifact of the jump discontinuity.
Typical Clutter I and Q Signals

Scan of Rocky Mountains by S-Pol at 8 deg/sec.

(a) (b)

Typical Clutter I and Q Signals

Scan of Rocky Mountains by S-Pol at 8 deg/sec.
What is Regression Filtering?

Clutter + Weather
Weather Only

Regression fit

Amplitude vs. Time (ms)

512
Represent the I and Q Signals as a Sum of These Orthogonal Polynomials

Fast, low round off error algorithm: http://jean-pierre.moreau.pagesperso-orange.fr/
Regression Clutter filtering

- Regressions filters have a history in **biomedical field**

- And weather radar
Regression Filter Example on S-Pol Data

Power Spectrum

Time series

Raw Spectrum

Real Part

Imaginary Part
8th order polynomial fit

Real Part

- Raw data
- Fitted data

Volts (uncalibrated)

Time (ms)
Subtracting the polynomial fit from the time series.....

Real residuals

Imaginary residuals
Regression Filtered versus Raw Spectrum

Regression filtered power spectrum

8\textsuperscript{th} order fit

weather

Power (dB, uncalibrated)

Doppler Velocity

Raw Spectrum

Power (dB, uncalibrated)

Doppler Velocity
Blackman Window and Notch Technique

Blackman windowed
(5.23 pow. reduction)

Power spectrum

weather

Notched filtered
Blackman windowed
Power spectrum
(5.23 pow. reduction)

weather

Power (dB, uncalibrated)

Doppler Velocity

m/s

Power (dB, uncalibrated)

Doppler Velocity

m/s
Comparison

Regression

Window and Notch

Regression filtered power spectrum

8\textsuperscript{th} order fit

weather

Notched filtered

Blackman windowed
Power spectrum
(5.23 pow. reduction)

Power (dB, uncalibrated)

Doppler Velocity

m/s

Power (dB, uncalibrated)

Doppler Velocity

m/s
Regression versus Window and Notch

• Spectra seem similar! What’s the difference?
• WHY USE A REGRESSION FILTER???
Signal Statistics

• Blackman window: 5.23 dB attenuation
  About 50% increase in variance!

• Hanning window: 4.19 dB attenuation
  About 35% increase in variance!
Regression Frequency Response

64 point time series for polynomial orders 3 - 7
Frequency Response 2

64 point time series for polynomial orders 9, 11, 13, 15, 19

Frequency response depends on sequence length and polynomial order
Modified Regression Filtering

**Standard technique:** Take length N sequence, fit a polynomial to it and subtract to remove the low frequency clutter components.

1 2 3 4 ..... time series .... N

**Modified technique:** Break the sequence into blocks, let’s say 4 for this example:

1  N/4  N/2  3N/4  N

block 1  block 2  block 3  block 4

1. Do 4 regression fits, thus suppressing the ground clutter in each block
2. Concatenate the blocks back into one sequence
3. Calculate radar variables
The Blocks Can Be Overlapped and Weighted

This is to reduce slight discontinuities at end points.

Length N sequence broken into overlapping blocks. The overlap is m points and these regions are shown in green. After filtering, overlapping pairs of points are averaged so that a N point filtered sequences is created. This is done to smooth the transition from one block to the next.
S-Pol Clutter Environment at Marshall

22 April 2018
0.5 elevation
Compare Clutter Rejection of the Regression and GMAP like filters (notch width is constant)
Scatter Plots Regression vs Window and Notch
(4 blocks of 16)
KFTG Data. “Bomb Cyclone” 13 March 2019

Short PRT data from VCP 212
KFTG LPRT Data VCP212, 20 deg/sec, 16 points

Raw

Blackman-Nuttall

6th order

9 pt notch
Unfiltered data

KFTG 227 Az. 0.45 elev
13 March 2019

![Graph showing data metrics](image-url)
A Comparison of Regression versus Window and Notch Clutter Filters

5th order regression filter

Blackman window 7 point notch
Smearing Effects of Windowing

S-Pol data

Raw data (rectangular window)

Blackman-Nuttall Window
Resulting Implications for the Clutter Filter Bandwidth

Window function spreads the clutter power so that wider bandwidth is needed

5 pt notch insufficient!!
Modeling Efforts Have Begun

64 points
30 dB SNR weather
30 dB CNR clutter
Blackman Window, 9pt notch
Regression 7th order

\[ V_{\text{max}} - V_{\text{max}} \]

Weather 2 m/s
Clutter 0.25 m/s

\[ -28 \text{ m/s} \rightarrow 0 \rightarrow 28 \text{ m/s} \]

64 points
30 dB SNR weather
30 dB CNR clutter
Blackman Window, 9pt notch
Regression 7th order

\[ V_{\text{max}} - V_{\text{max}} \]

\[ -28 \text{ m/s} \rightarrow 0 \rightarrow 28 \text{ m/s} \]

\[ \sim 50\% \text{ increase in STD} \]

\[ \sim 30\% \text{ increase in STD} \]
Application to Data Sets Has Begun

Bomb Cyclone Level 2 Data

Times Series Processed with Regression Filter

KFTG
Frequency Compensation

An interesting possibility

After regression filtering, FFT the resulting time series and compensate the frequencies as desired as guided by the frequency response of the regression filter.
Conclusions

• Regression and Window and Notch have equivalent clutter
• Because there is no window applied for the regression filter, much better signal statistics can be achieved.
• Windowing the data, while containing “clutter leakage”, spreads the clutter (causes wider clutter bandwidth). This then requires a wider bandwidth notch as compared to regression filtering.
• Thus underlying weather signal is more effectively recovered with a regression filter
• W & N for 16-point times series typically removes a very large part of the spectrum; a regression filter offers vastly superior recovery statistics.