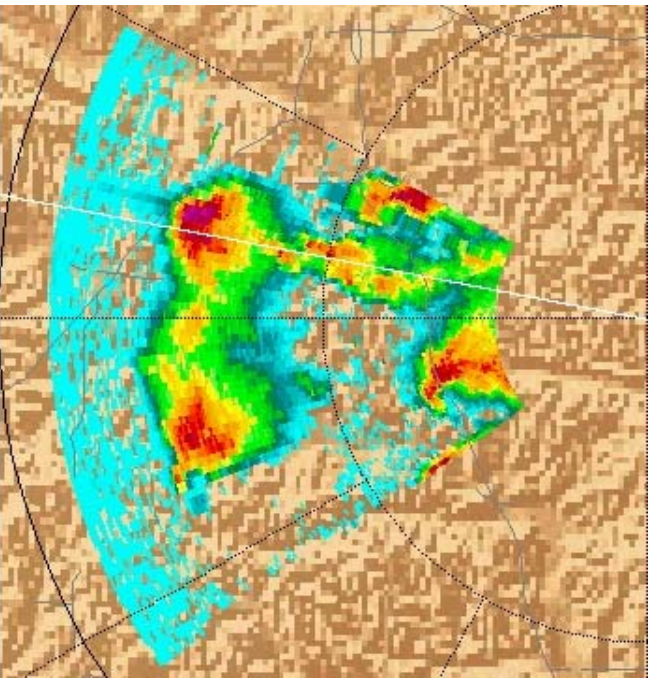
RADAR OPERATIONS CENTER (ROC) EVALUATION OF THE WSR-88D OPEN RADAR DATA ACQUISITION (ORDA) SYSTEM SIGNAL PROCESSING



Briefing for The NEXRAD
Technical Advisory Committee

February 11, 2004

Richard L. Ice
RS Information Systems, Inc. Norman, Oklahoma

WSR-88D Radar Operations Center
Engineering Branch

Objectives

- Review ROC Engineering Study into ORDA RVP8 Signal Processing Performance
  - Two Spectrum Width Estimators
  - New Clutter Filter Approach
- Address Technical Questions

Evaluation Focus

- Spectrum Width Estimators
- Legacy Style (R0/R1)
  - Signal plus Noise
  - Noise Compensated
- "Lag Two" (R1/R2)
- Bias and Standard Deviation Performance

- New Clutter Filters
- **GMAP** - Gaussian Model Adaptive Process
  - Bias
  - Standard Deviation
  - Suppression
  - Processing Windows
  - Comparison to Legacy Performance

→ **Phase 1: Simulations**
Phase 2: Real Data (Archived)

WSR-88D Specifications

Moment Estimates

- Bias
  - Reflectivity 1 dB
  - Velocity 1 ms^{-1}
  - Width 1 ms^{-1}
- Standard Deviation
  - Reflectivity 1 dB
  - Velocity, Width 1 ms^{-1}
- SNR 10 dB
- W = 4 ms^{-1}

Clutter Filters

- Suppression 50 dB
  - Min Usable Velocity 4 ms^{-1}
- Velocity and Width
  - Bias and SD 2 ms^{-1}
- Reflectivity Bias
  - 1 to 10 dB
  - Depends on Width
  - Additional 1 dB from Clutter Residue
- SNR 20 dB
- Test W_c = 0.28 ms^{-1}

Simulation Methodology

SIGMET
RVP8
(and Utilities)

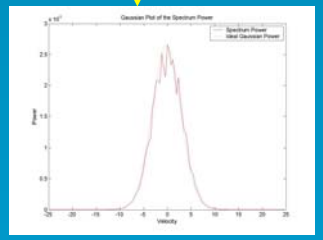
A'scope
Dig Sig Sim
Recorder

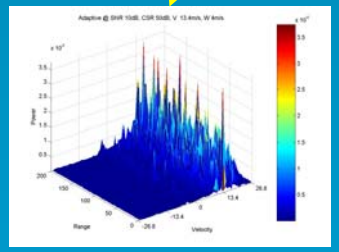
MATLAB

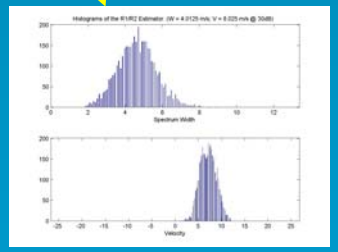
File conversion
Histograms
3-D plots
Calculations

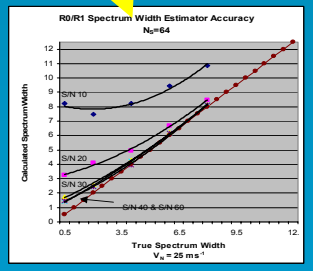
MS EXCEL

Spreadsheets
Graphs









Primary Simulation Parameters

- Spectrum Width
  - R0/R1 and R1/R2
  - PRF: 1000
  - N_S: 64
  - Width: 0.5 – 8.0 ms^{-1}
  - Nyquist Co-interval
  - SNR: 10 – 60 dB
  - Noise: -80 dBm
  - Clutter: off

- GMAP
  - R0/R1 and R1/R2
  - PRF: 322, 450, 1000
  - N_S: 16, 32, 64
  - Width: 4.0 ms^{-1}
  - SNR: 10 – 60 dB
  - CSR: up to 60 dB

Input Time Series Simulated per Sirmans and Bumgarner (1975)

- 4,000 estimates per run
- 200 spectra and time series each file
- 2400 + data files generated

Types of Spectrum Width Estimators

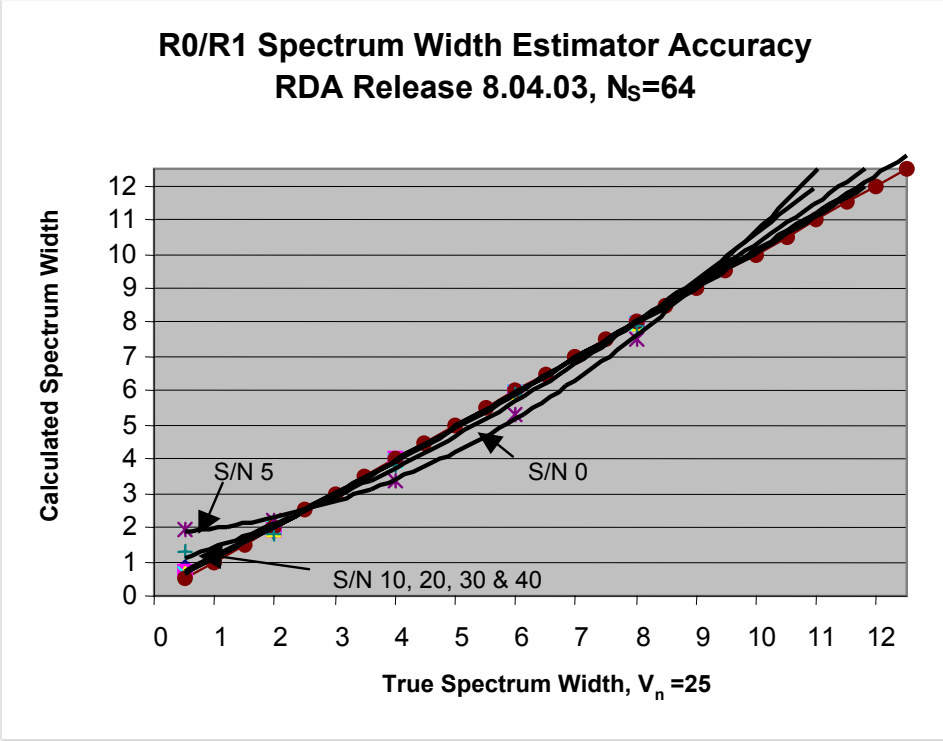
WSR-88D Legacy Type

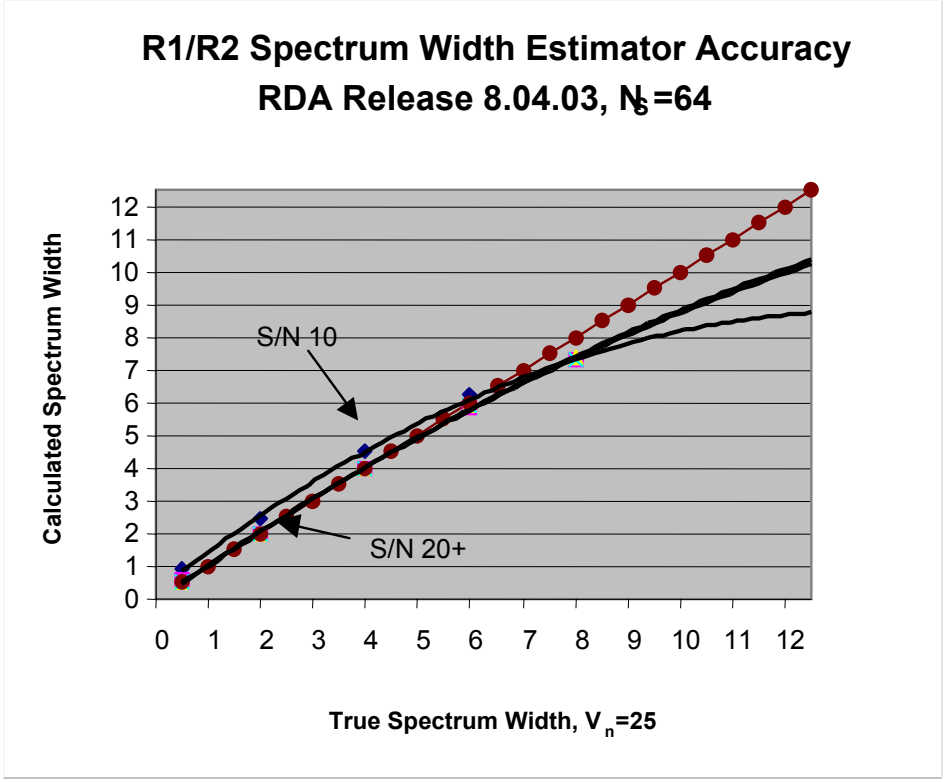
- R0/R1
  - 0th lag autocorrelation
  - 1st lag autocorrelation
- R0 Calculation
  - Affected by Noise Contamination
- Biased at low SNR

Poly Pulse Estimator

- R1/R2
  - 1st lag autocorrelation
  - 2nd lag autocorrelation
- R1, R2 Calculations
  - Not affected by noise contamination
- Biased at higher widths

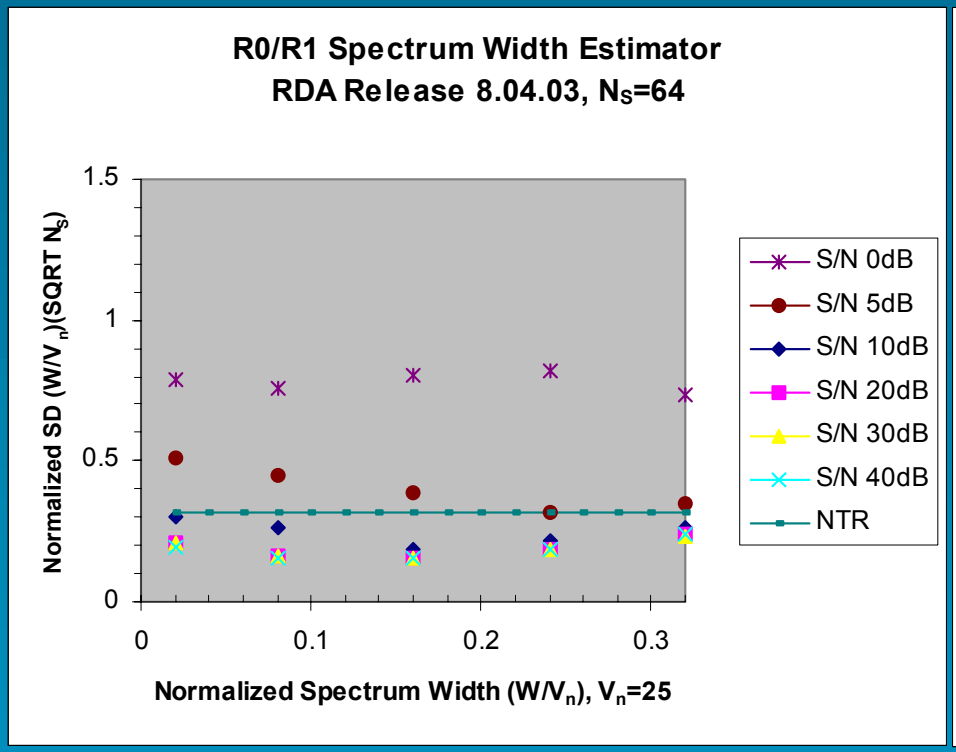
Width Estimator Bias Performance

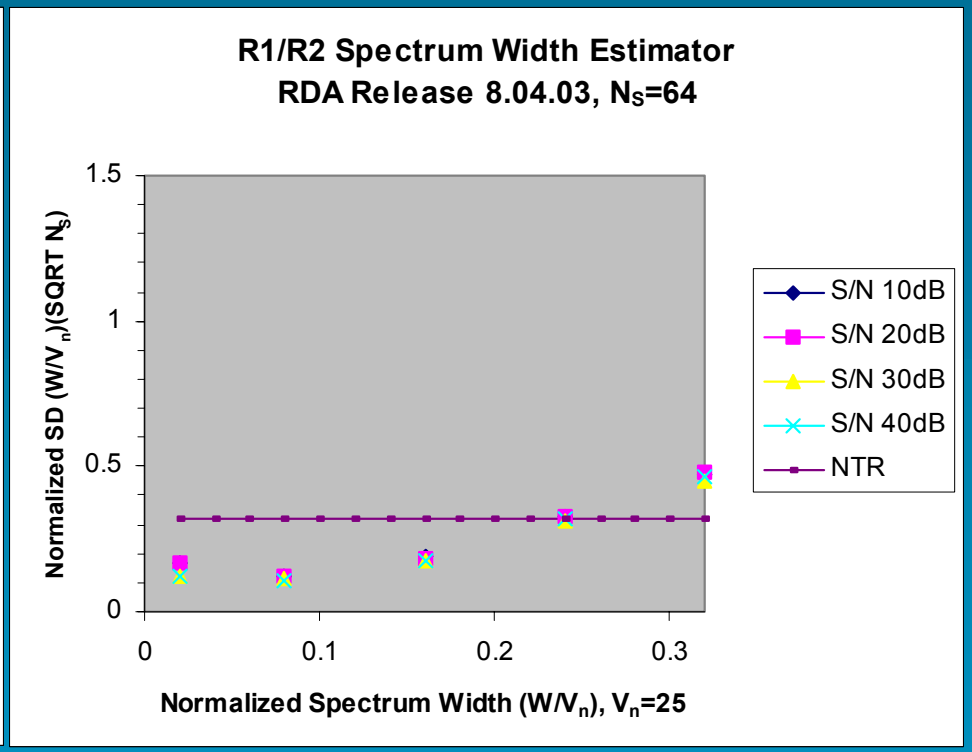




R0/R1 **R1/R2**

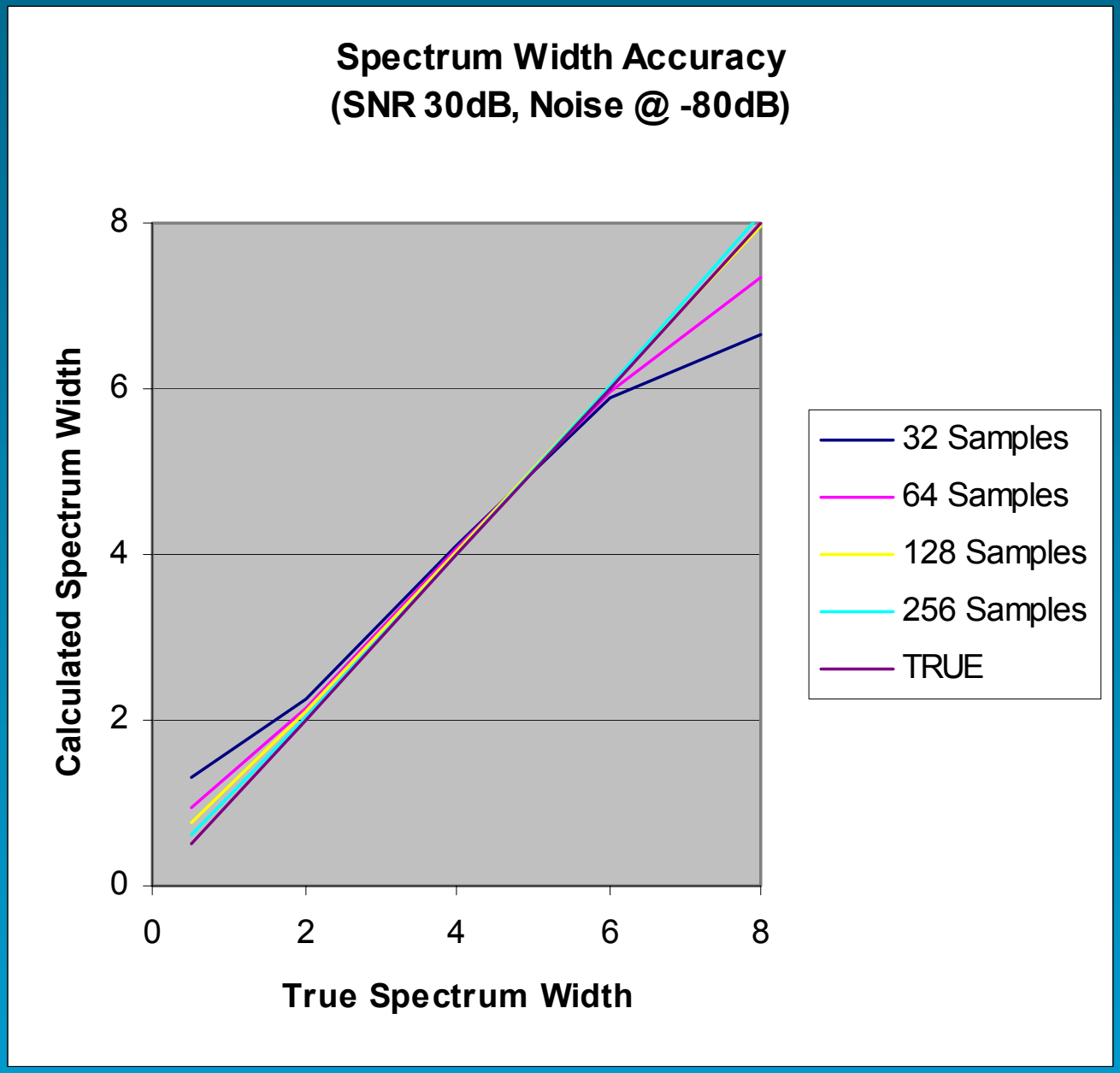
Width Estimator Standard Deviation





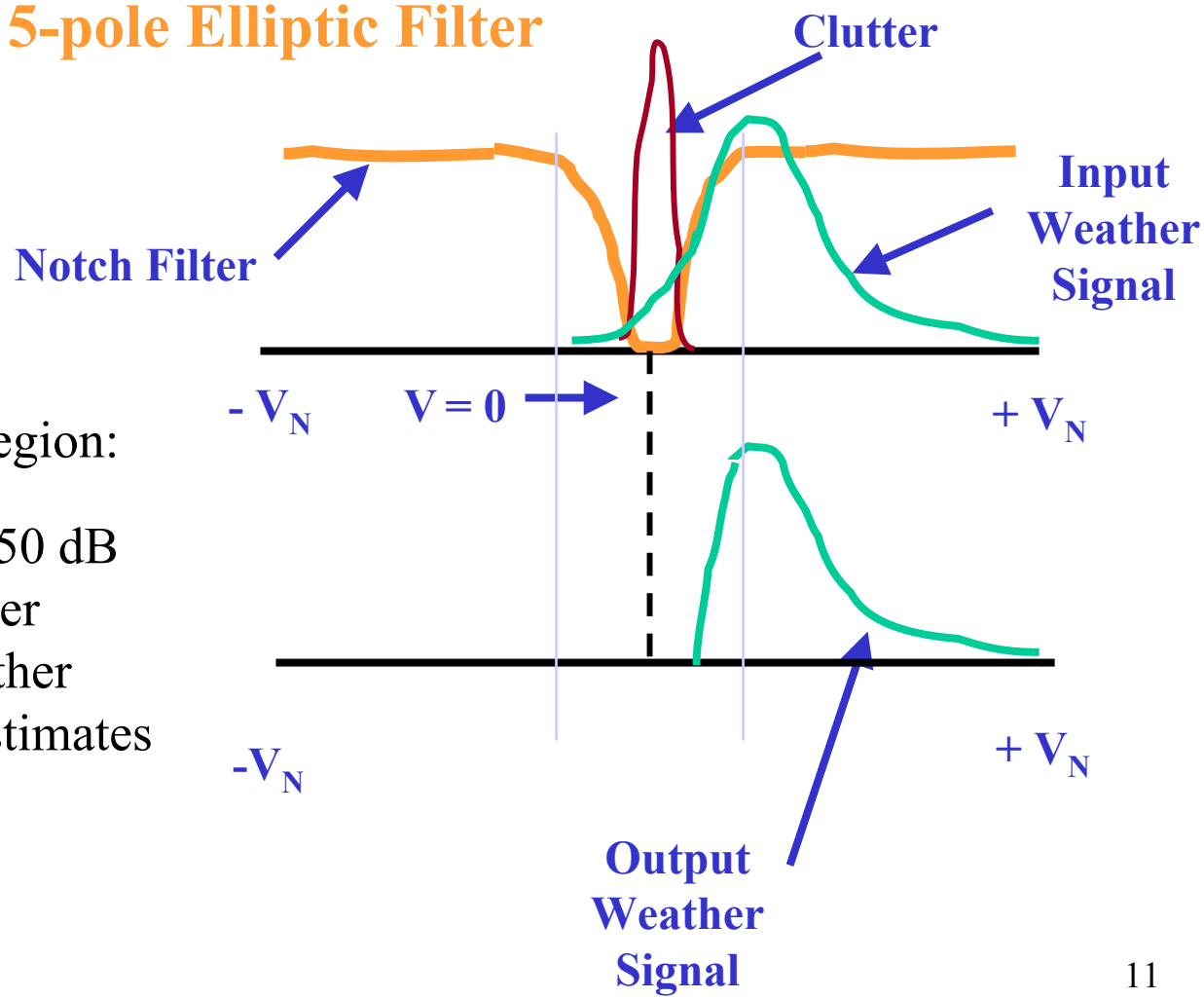
R0/R1 **R1/R2**

R1/R2 Width Estimator Number of Samples Bias



Clutter Filters

WSR-88D Legacy 5-pole Elliptic Filter



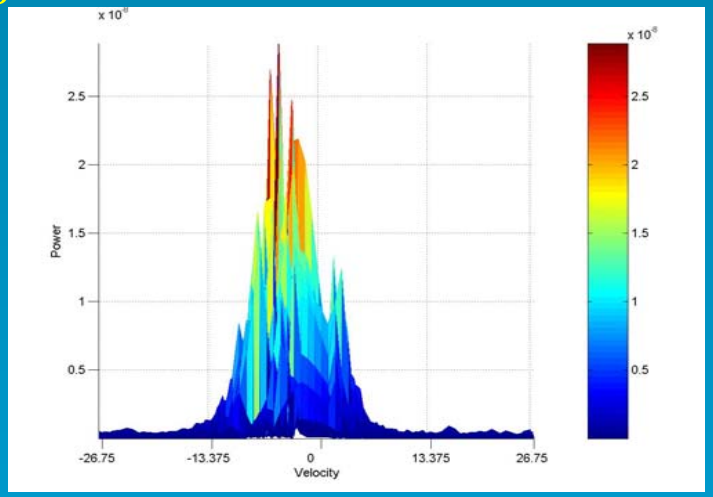
In the Stop Band Region:

- Reduces signal up to 50 dB
- Notch Removes Clutter
- Notch Removes Weather
- Biases all Moment Estimates

GMAP Overview

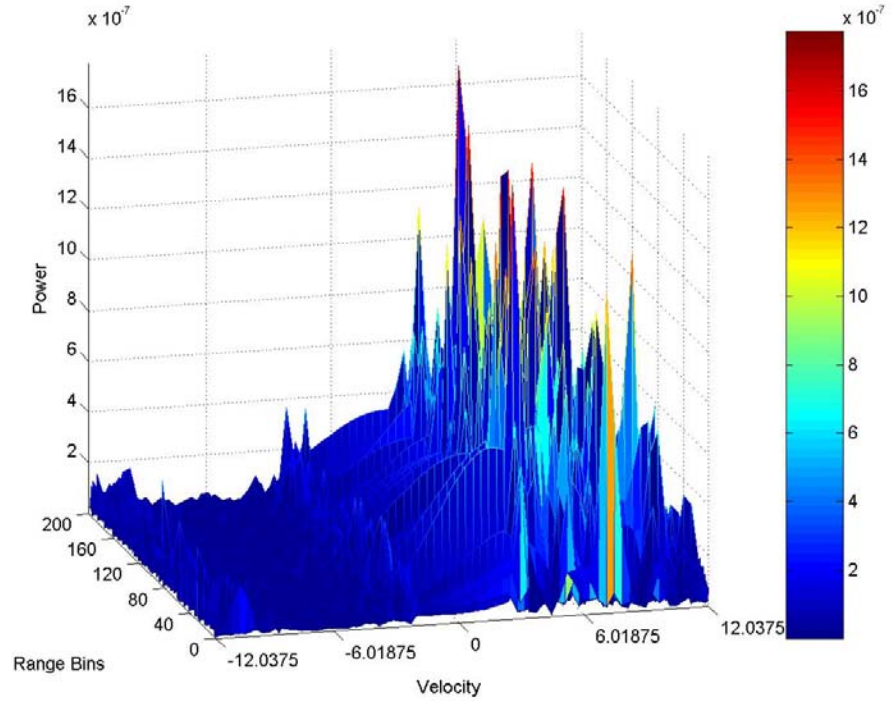
- Not a notch width based scheme
- Frequency domain signal, clutter, and noise analysis
- Uses best window (Blackman, Hamming, Rectangular)
- Models the clutter based on single input parameter
  - expected clutter spectrum width (0.28 m/sec for example)
- Uses system value or a rank order noise estimate
- Removes clutter associated spectral coefficients
- Restores signal spectral coefficients
- Autocorrelation moment estimates

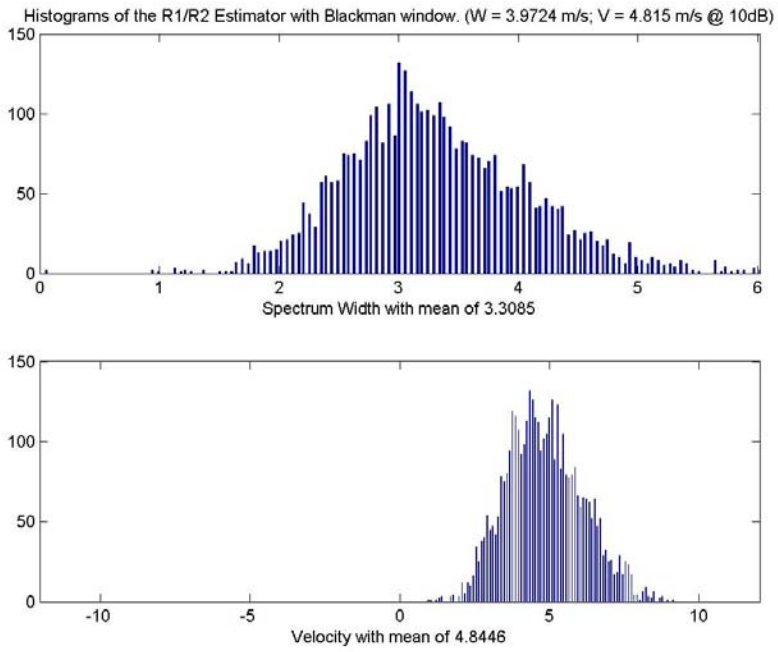
Reduces filter bias effects



200 Spectra Showing Coefficient Restoration

10 dB SNR
PRF 450, CSR 50 dB
V = 4.8 ms^{-1}
W = 4.0 ms^{-1}

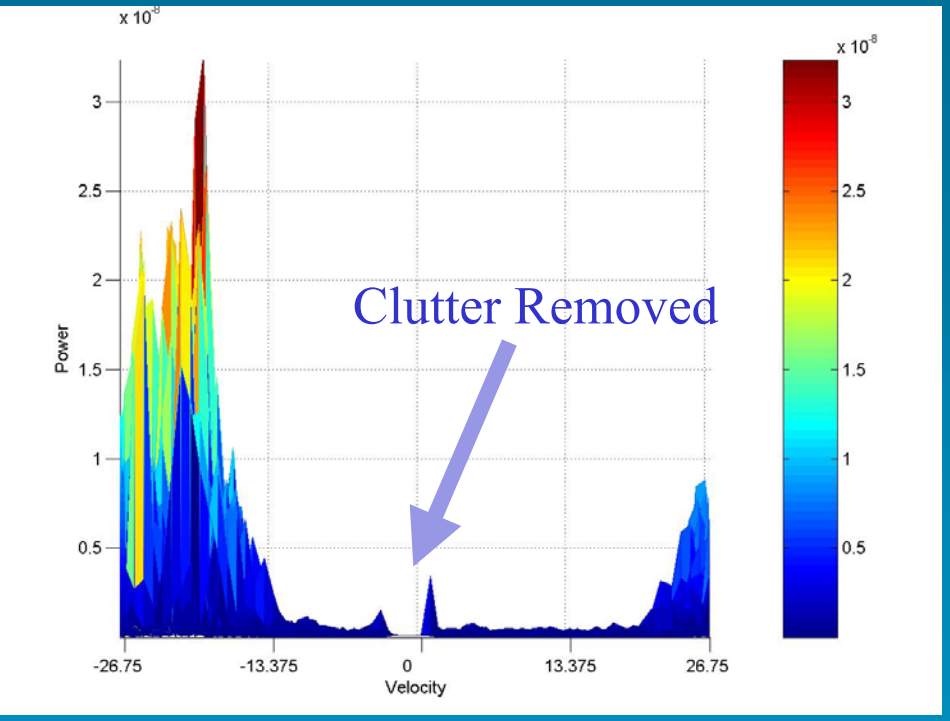


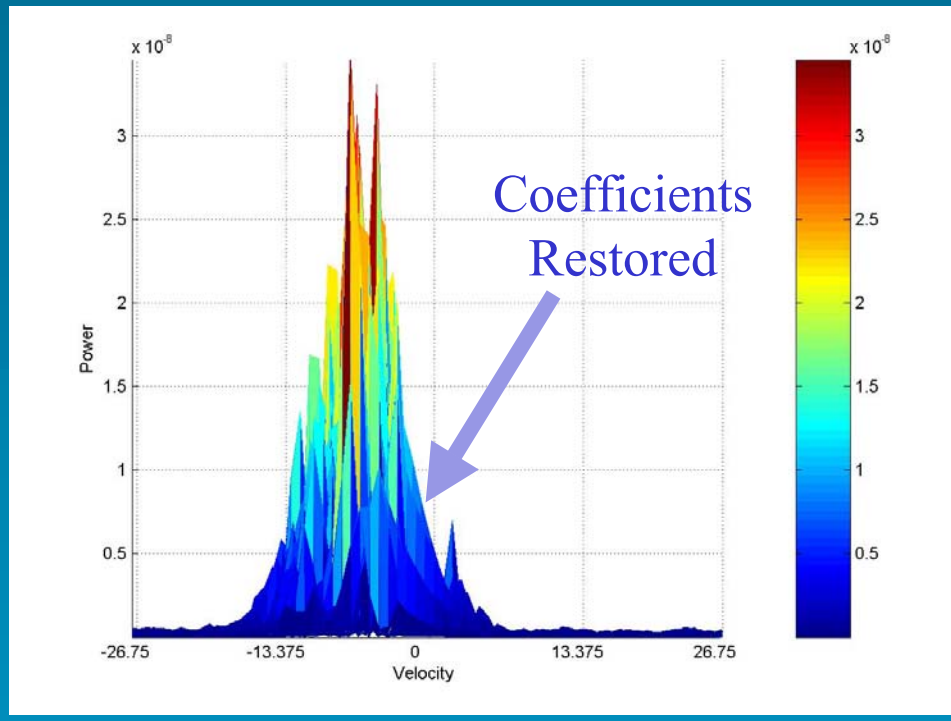


Histogram of 4,000 Velocity and Width Estimator Outputs

Width Estimator Bias: - 0.67 ms^{-1}
Velocity Estimator Bias: 0.03 ms^{-1}

Samples Illustrating GMAP Weather Signal Restoration





SNR = 10 dB, CSR = 10 dB, PRF = 1000 Hz

Surveillance Data – Reflectivity; N = 16, SNR = 10 dB
GMAP Performance - Blackman Window - System Noise as an Input

	CSR= 10 dB		CSR = 30 dB		CSR = 50 dB	
V/V_n	P_{bias} (dB)	SD[P] (dB)	P_{bias} (dB)	SD[P] (dB)	P_{bias} (dB)	SD[P] (dB)
0.0	-0.91	2.85	-1.13	3.29	0.60	3.14
0.1	-0.99	2.91	-1.06	3.36	-0.43	3.18
0.2	-0.88	2.82	-1.24	3.37	-0.43	3.21
0.3	-0.90	2.84	-1.01	3.11	-0.24	3.04
0.4	-0.95	2.71	-0.89	2.94	-0.16	3.05
0.5	-0.70	2.64	-0.8	2.78	-0.17	2.95
0.6	-0.65	2.51	-0.56	2.75	0.21	2.90
0.7	-0.46	2.46	-0.46	2.5	0.45	2.87
0.8	-0.41	2.42	-0.31	2.45	0.59	2.76
0.9	-0.25	2.27	-0.25	2.31	0.68	2.76
1.0	-0.25	2.31	-0.24	2.34	0.64	2.65
Averages	-0.67	2.54 dB	-0.72	2.84 dB	0.16	2.96 dB
Avg 1 km		1.27 dB		1.42 dB		1.48 dB

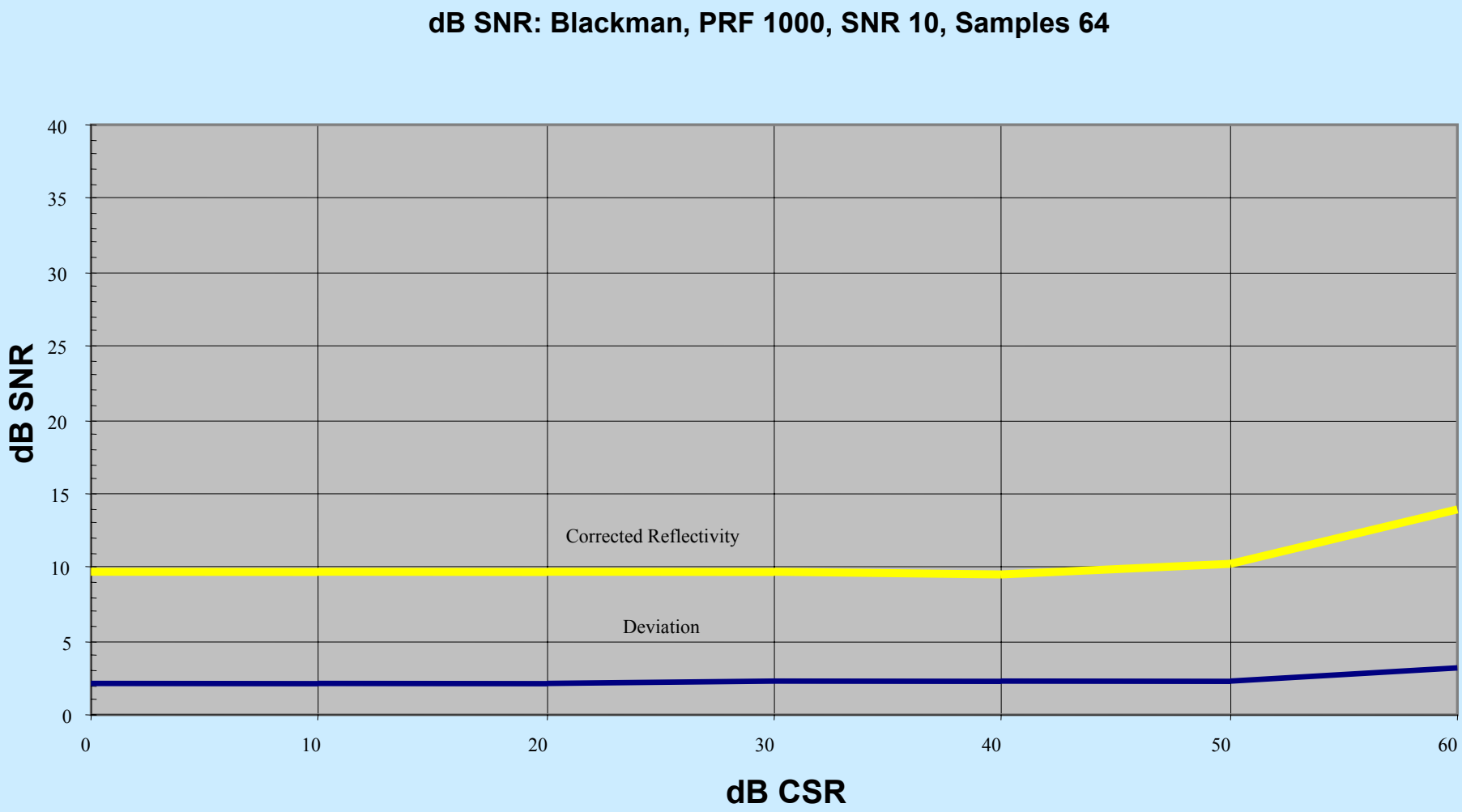
Doppler Data – Velocity; $N_S = 64$, SNR = 10 dB
GMAP Performance - Blackman Window - System Noise as an Input

	CSR= 10 dB		CSR = 30 dB		CSR = 50 dB	
V/V_n	V_{bias} (ms^{-1})	SD[V] (ms^{-1})	V_{bias} (ms^{-1})	SD[V] (ms^{-1})	V_{bias} (ms^{-1})	SD[V] (ms^{-1})
0.0	-0.01	1.13	0.05	1.13	0.04	1.02
0.1	0.12	1.26	-0.24	1.31	0.13	1.21
0.2	0.21	1.37	-0.62	1.47	0.45	1.61
0.3	0.15	1.31	-0.32	1.47	1.02	1.88
0.4	0.04	1.23	-0.04	1.37	1.29	2.01
0.5	0.15	1.18	0.00	1.18	1.34	1.93
0.6	0.07	1.17	-0.02	1.19	1.05	1.90
0.7	0.06	1.21	-0.12	1.13	0.72	1.77
0.8	0.00	1.14	-0.17	1.18	0.47	1.61
Averages	0.09	1.22	-0.16	1.27	0.72	1.66

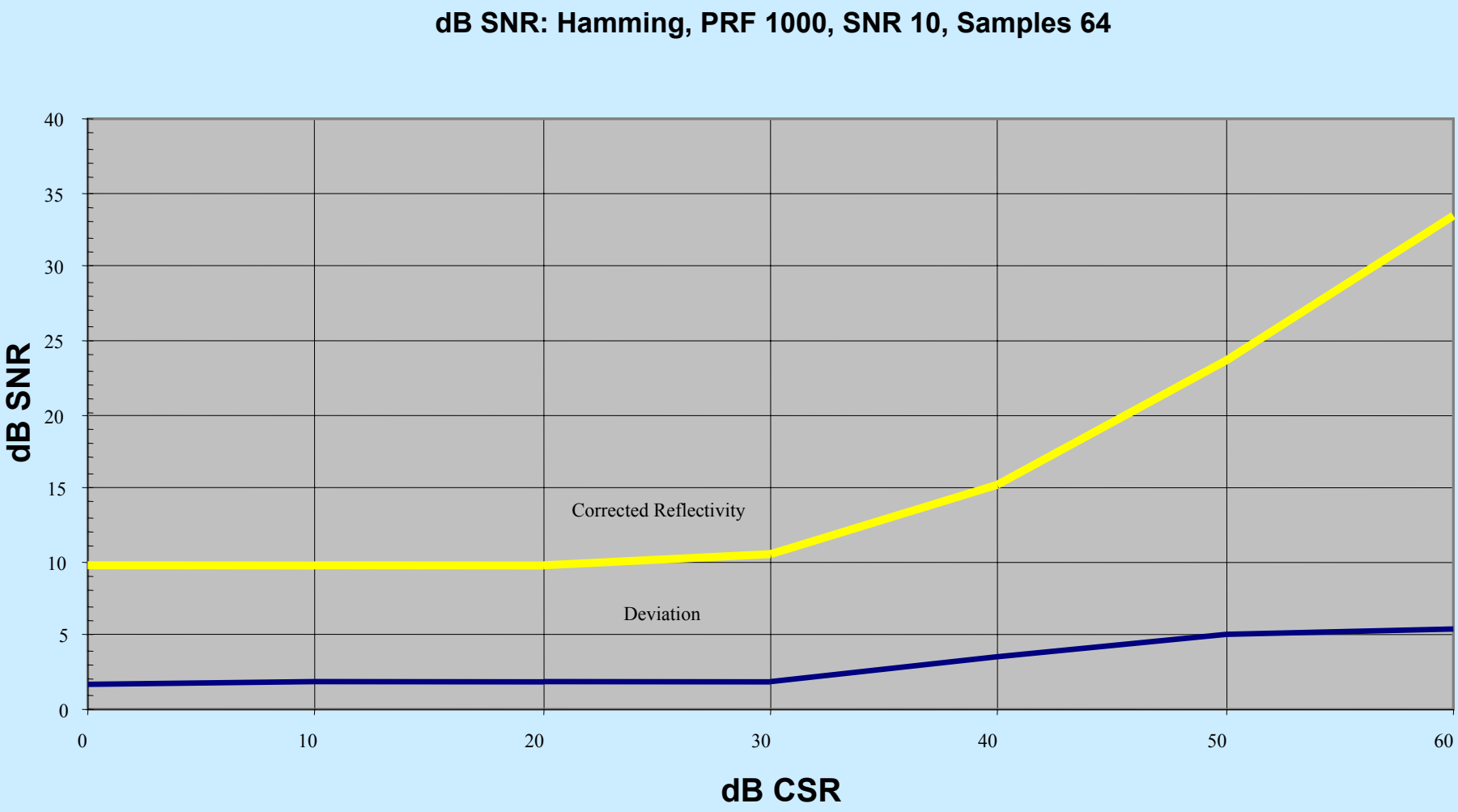
Doppler Data – Velocity; $N_S = 32$, SNR = 10 dB
GMAP Performance - Blackman Window - System Noise as an Input

	CSR= 10 dB		CSR = 30 dB		CSR = 50 dB	
V/V_n	V_{bias} (m/sec)	SD[V] (m/sec)	V_{bias} (m/sec)	SD[V] (m/sec)	V_{bias} (m/sec)	SD[V] (m/sec)
0.0	-0.01	2.12	-0.02	2.20	0.01	2.14
0.1	0.80	2.20	0.80	2.28	1.96	2.30
0.2	1.18	1.98	1.05	2.04	-0.43	2.30
0.3	0.51	2.01	0.51	2.04	-1.34	2.60
0.4	-0.03	1.96	0.01	2.01	-1.88	2.68
0.5	-0.07	1.88	-0.16	1.93	-1.93	2.95
0.6	-0.08	1.69	0.01	1.68	-1.61	2.95
0.7	0.05	1.58	0.02	1.66	-1.13	2.68
0.8	0.02	1.77	0.01	1.77	-0.86	2.95
Averages	0.26	1.91	0.25	1.96	-0.8	2.62

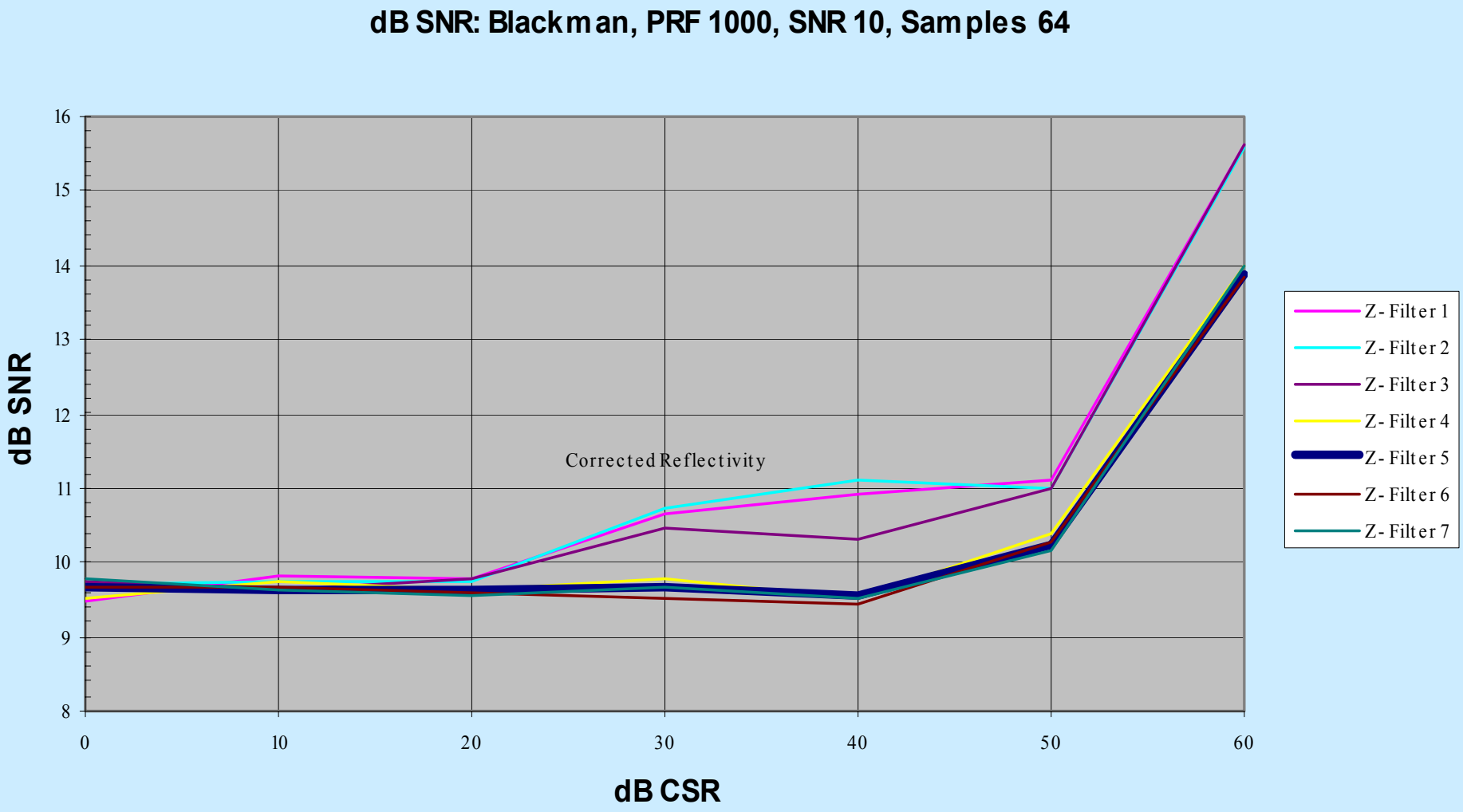
Suppression Level Analysis



Suppression Level Analysis



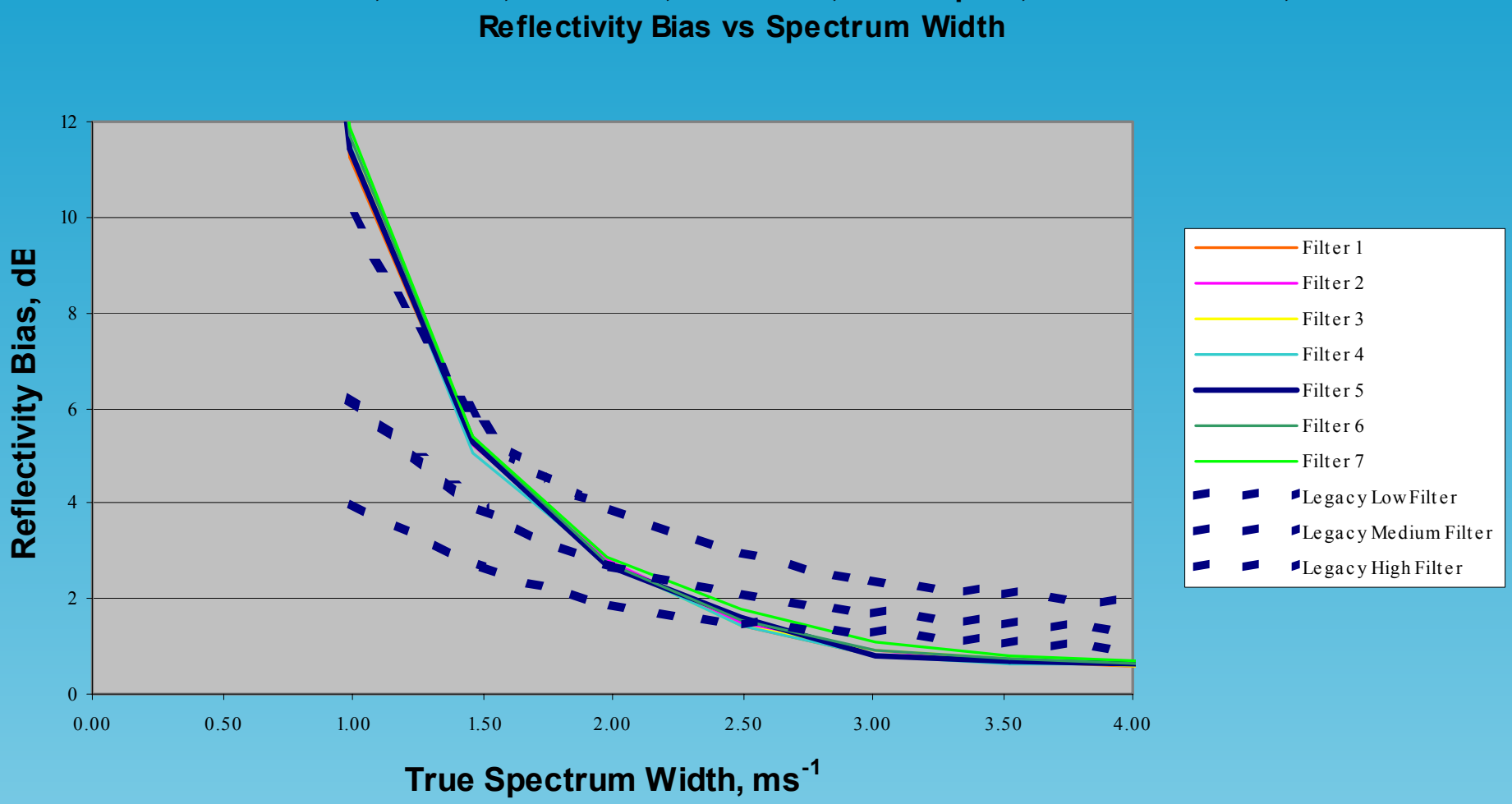
GMAP Filter Width Analysis



Filter Widths 0.1 to 0.4 ms^{-1}

Reflectivity Bias Compared to Legacy Filters

Performance in Zero Isotach in the Absence* of Clutter



* For Example – Clutter Map Error

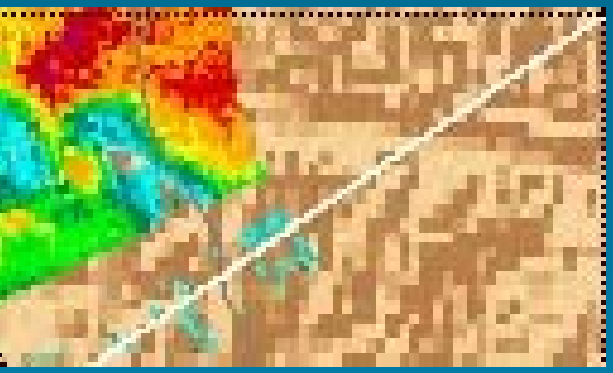
Conclusions from Simulations

- **Width Estimators**
  - Both Estimators Meet Specifications (1 ms^{-1})
  - R0/R1 Estimator Requires Good Noise Compensation
  - R1/R2 Has Advantages at Low SNRs and Narrow Widths
  - R0/R1 Has Less Bias at Higher Widths
  - R0/R1 Meets Variance Goal Over a Wider Range of Input Spectrum Widths
- **Clutter Filters**
  - GMAP Meets WSR-88D Specifications (2 ms^{-1})
  - Can Suppress Clutter up to 55 dB <u>Above</u> the Signal
  - Delivers Essentially Unbiased Estimates in the Presence of Clutter
  - Exhibits Higher Variance in Some Modes
  - Delivers Lower Bias than Legacy for Signals at Zero Velocity w/o Clutter

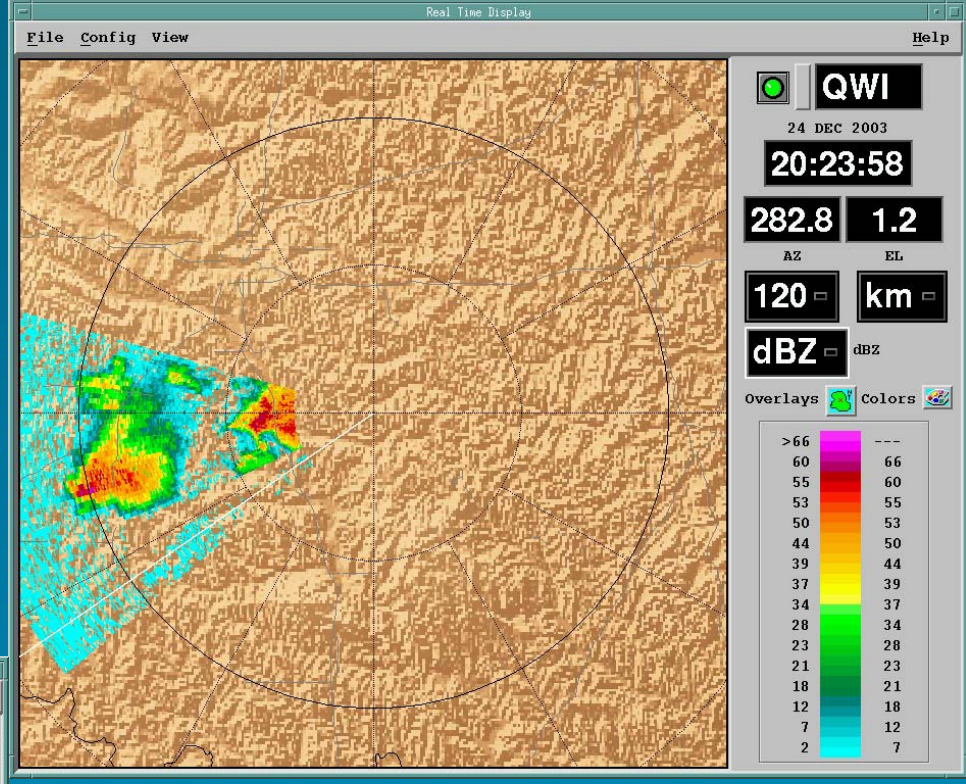
Phase 2 – Radar Data

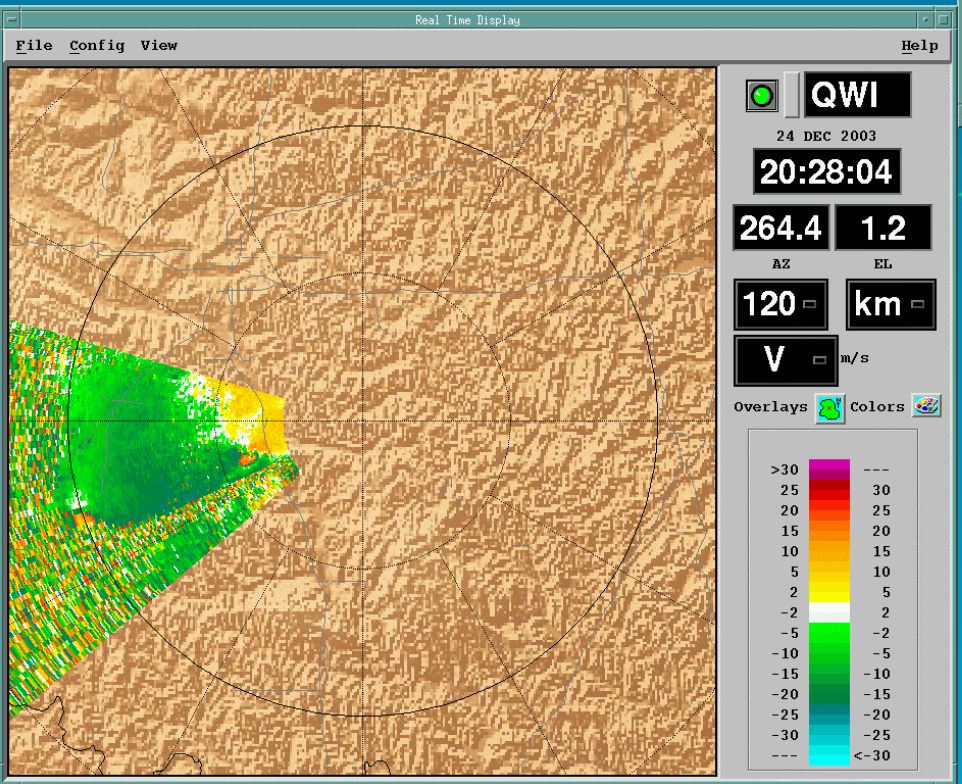
- ROC Applications Branch Leading Study
- Engineering Team Supporting
  - Identifying and Processing Level 1 Data
  - Assist with RVP8 Technical Issues
  - Engineering Tests to Verify Simulated Results
- Possible Paths
  - Legacy Archive 1 (May 97, May 99, Jul 97)
  - New Level 1, 2 Data (L1RP) (KCRI, KOUN, S-POL)
    - NCAR R -V Mitigation Work
    - ORDA System Test
  - NSSL RRDA (KOUN)
    - JPOLE

RVP8 Playback from Legacy A1 Recorder Data, May 3, 1999 Storms



Reflectivity

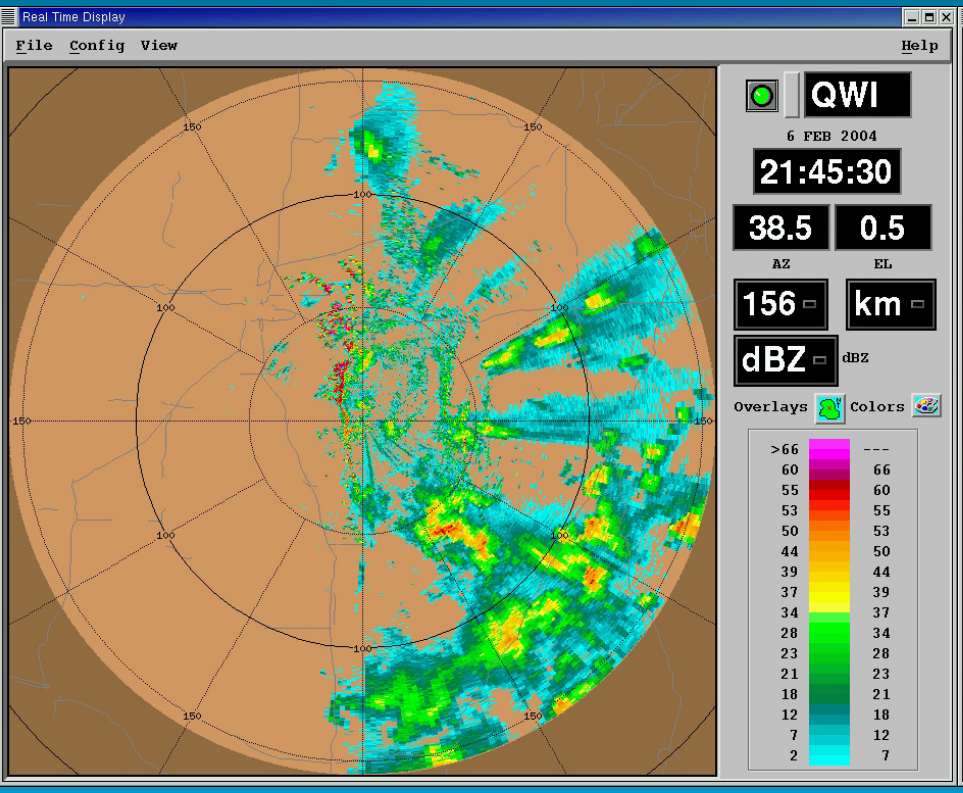




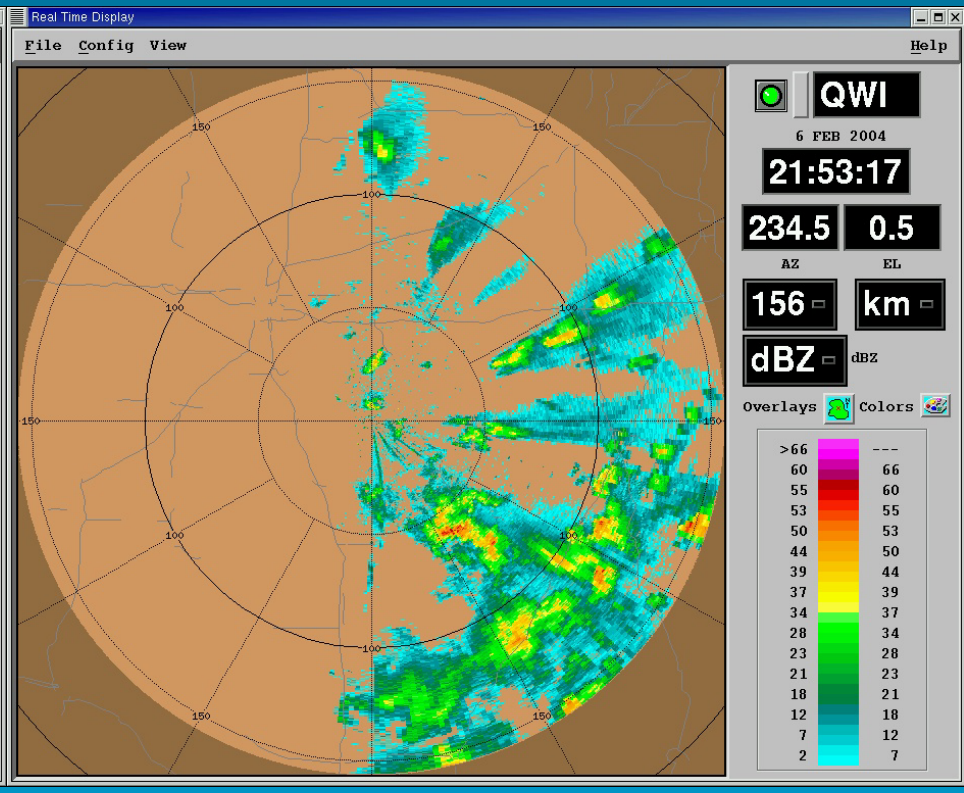
Velocity

S-POL Time Series Playback Into an RVP-8 Reflectivity

Unfiltered

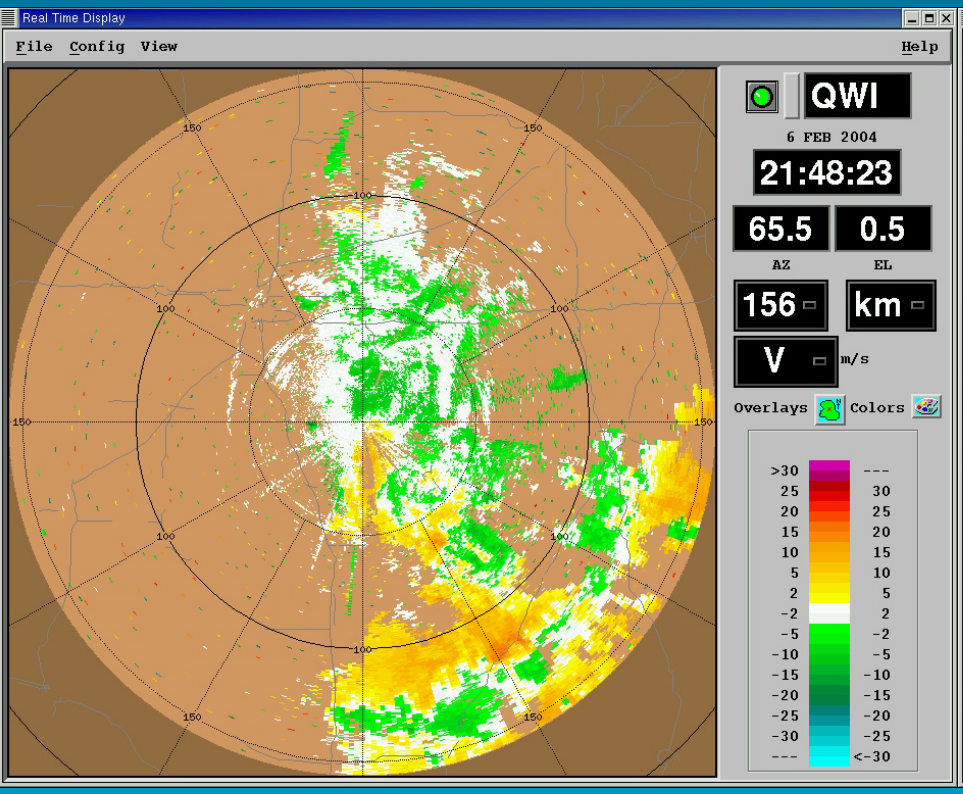


GMAP Filtered

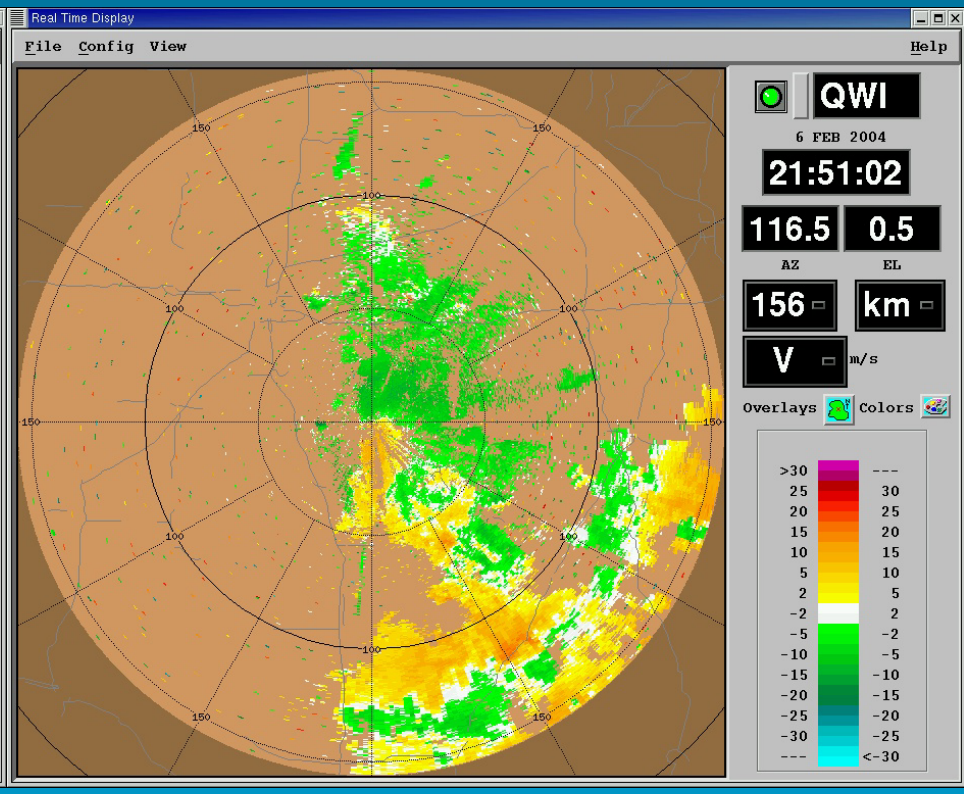


S-POL Time Series Playback Into an RVP-8 Velocity

Unfiltered



GMAP Filtered



Questions and Discussion

Technical Report and Briefings on ROC ENG Web Page:

http://www.roc.noaa.gov/eng/RVP8Evalreports.asp