Exploiting Environmental Knowledge for Improved Signal Processing

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G. T. Capraro
(gcapraro@caprarotechnologies.com)
C. T. Capraro
D. D. Weiner

Agenda

- KBMapSTAP
  - Background/Review & Last Status
- Current Efforts, Results, and Status
  - Guard cells around secondary data
  - Developing image data
  - DEM data algorithm development
- Future Plans
- Summary
- Acknowledgements

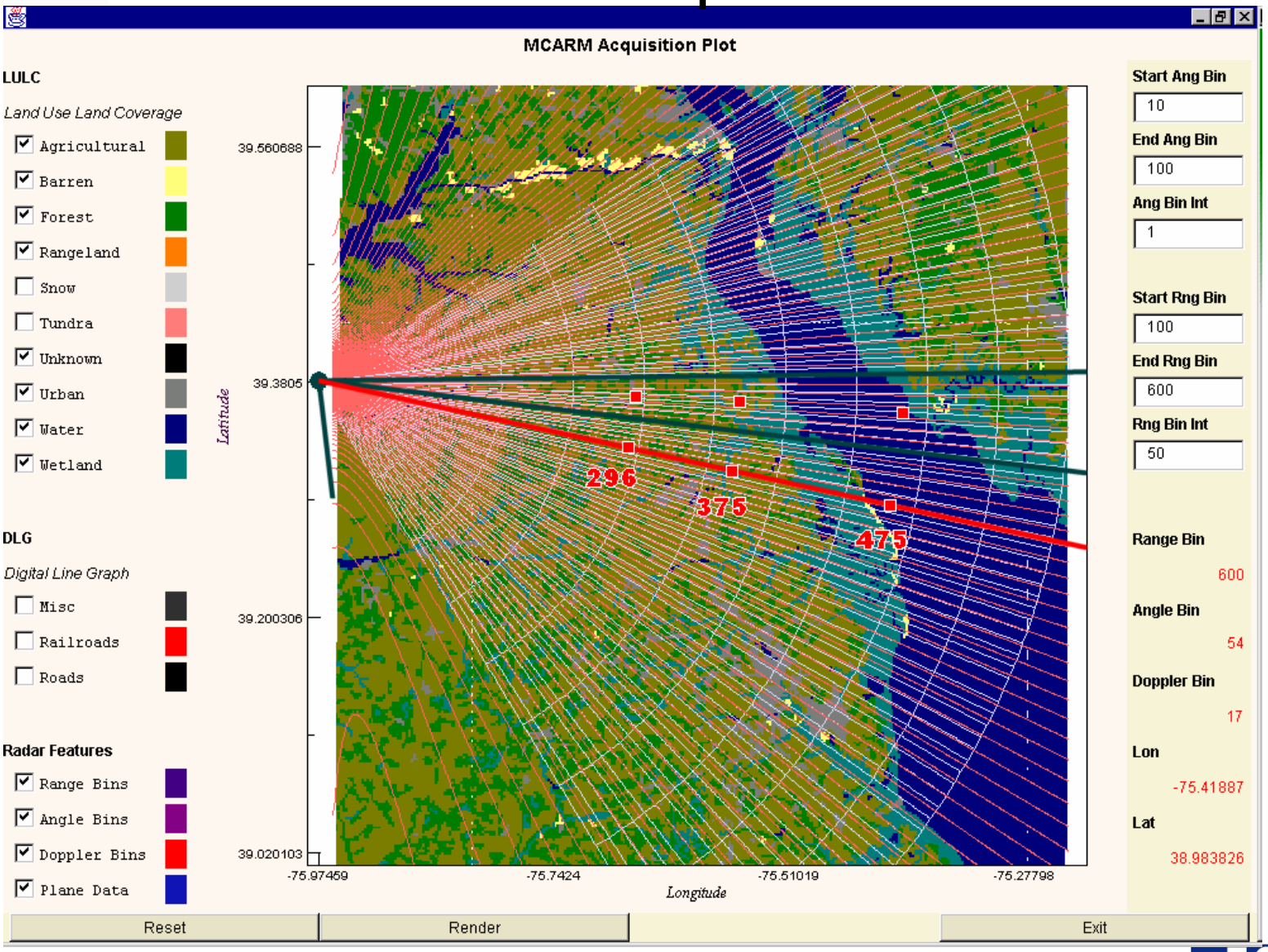
Experimental Results - KBMapSTAP

- Can STAP performance be improved by choosing secondary data based upon a priori map data?
- “Standard Algorithm” - choose secondary data plus & minus N/2 range rings of the test ring (omitting guard cells)
  - Implicit assumption - Nearby range rings of the test ring are homogeneous and are representative of the test ring.
  - Case I - Homogeneous Environment
  - Case II - Heterogeneous Environment

Proposed Algorithm/Conjecture

- Post Doppler Element Space STAP
- Basic Assumption - Major clutter competing with the target cell is due to the patch of earth within the same test ring that passes through the same Doppler filter
- Picking secondary range rings that have the “same” patch of earth and lie along the same Doppler curve as the test ring clutter patch, will provide better performance than the sliding window algorithm.

MCARM Radar Registration With Map Data



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Early Assessment

- Outperformed standard windowing approach within heterogeneous environments (up to 9 dB improvement)
- Performed the same as standard windowing approach within homogeneous environments
- However, there are issues with this approach
  - Map data accuracy – data are not always current
  - Digital elevation data needed in mountainous terrains– shadowing effects
  - Weather data is time dependent
  - Time of year – e.g. snow covered terrain
  - <u>Registration and calibration errors must be assessed</u>
  - <u>Variability in STAP results compared to sliding window</u>
- Need to “see what the radar is seeing”
- Map data is necessary but not sufficient for filtering and detection– also need mapping data for tracking (e.g. roads and railroads)

Further Investigation

- Went from 200 meter data to 30 meter data
- Results were not consistent
- Fine tuned and improved all our models including antenna gain pattern models
- Tried additional CPIs – Recognized target spread issues while investigating known targets, i.e. Moving Target Simulator (MTS)
- Performed analytical investigation of the impact of target spreading on algorithm
- Reworked algorithms accounting for “target” spread However, due to STAP secondary data independence requirement – ran out of a desirable number of samples when using all 22 radar elements with guard cells
- Reduced array to 11 elements thereby allowing for the use of guard cells around each of the chosen secondary range rings.

Results
With and Without Guard Cells
Using
Sliding Window and
MapSTAP

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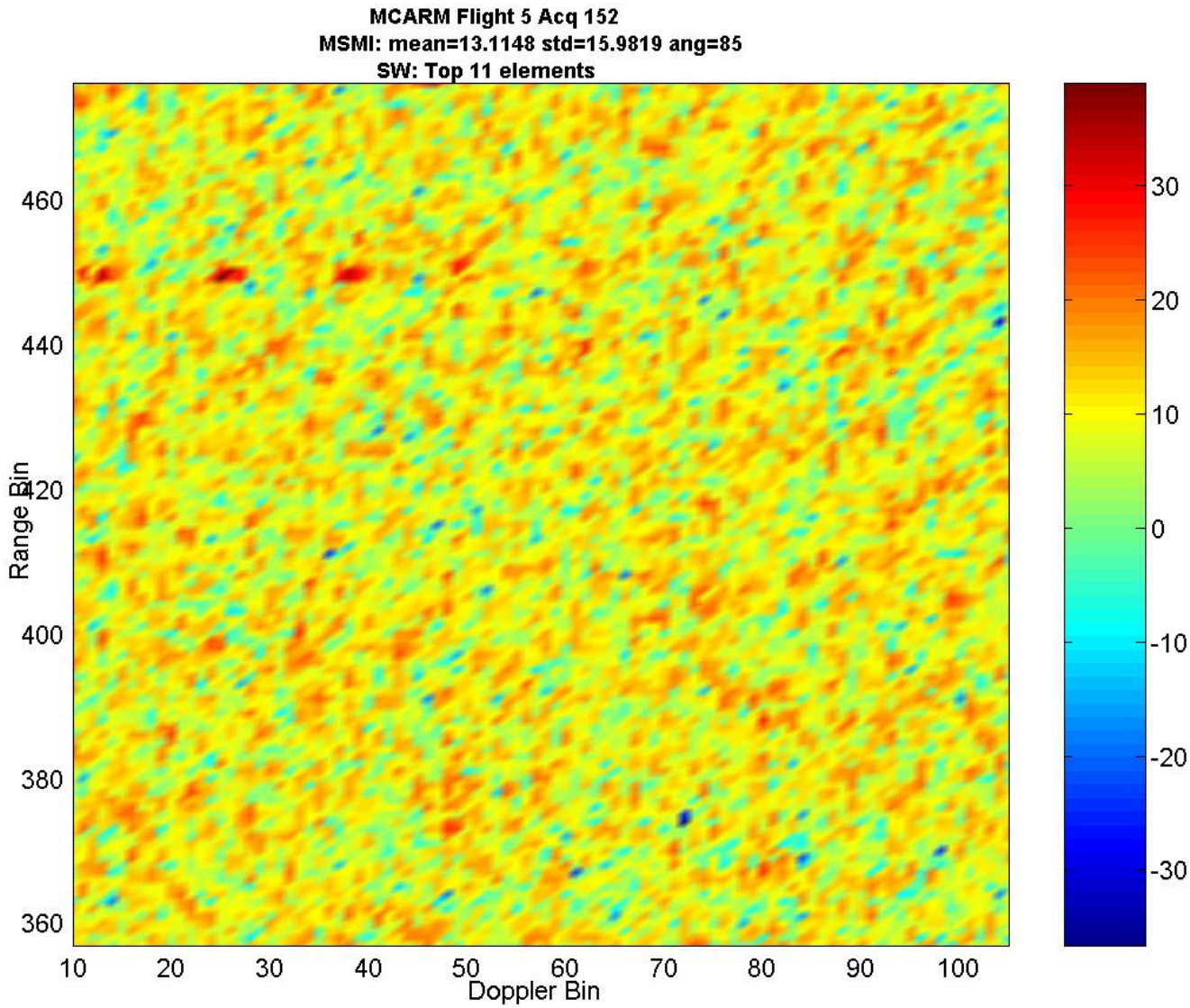
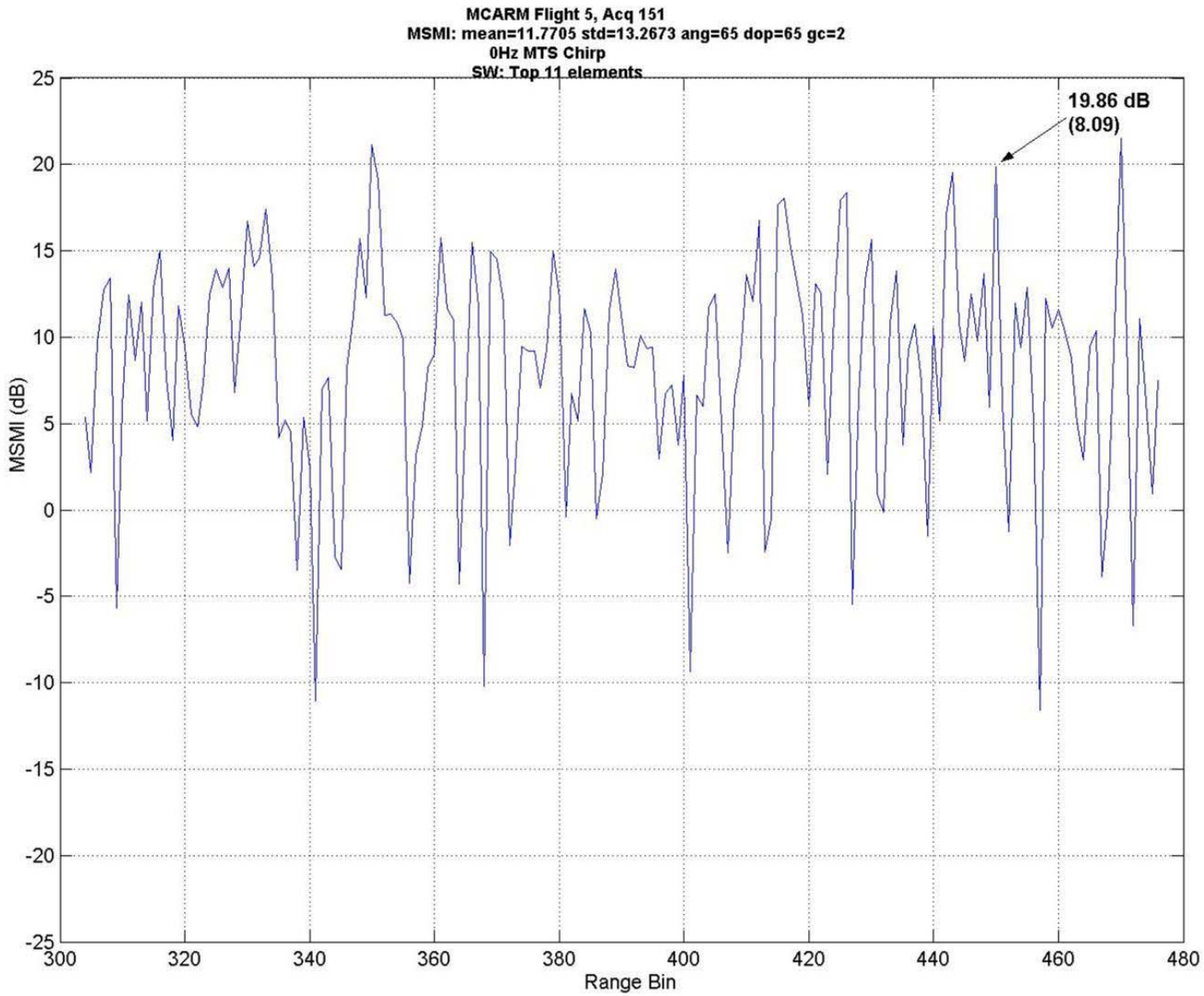
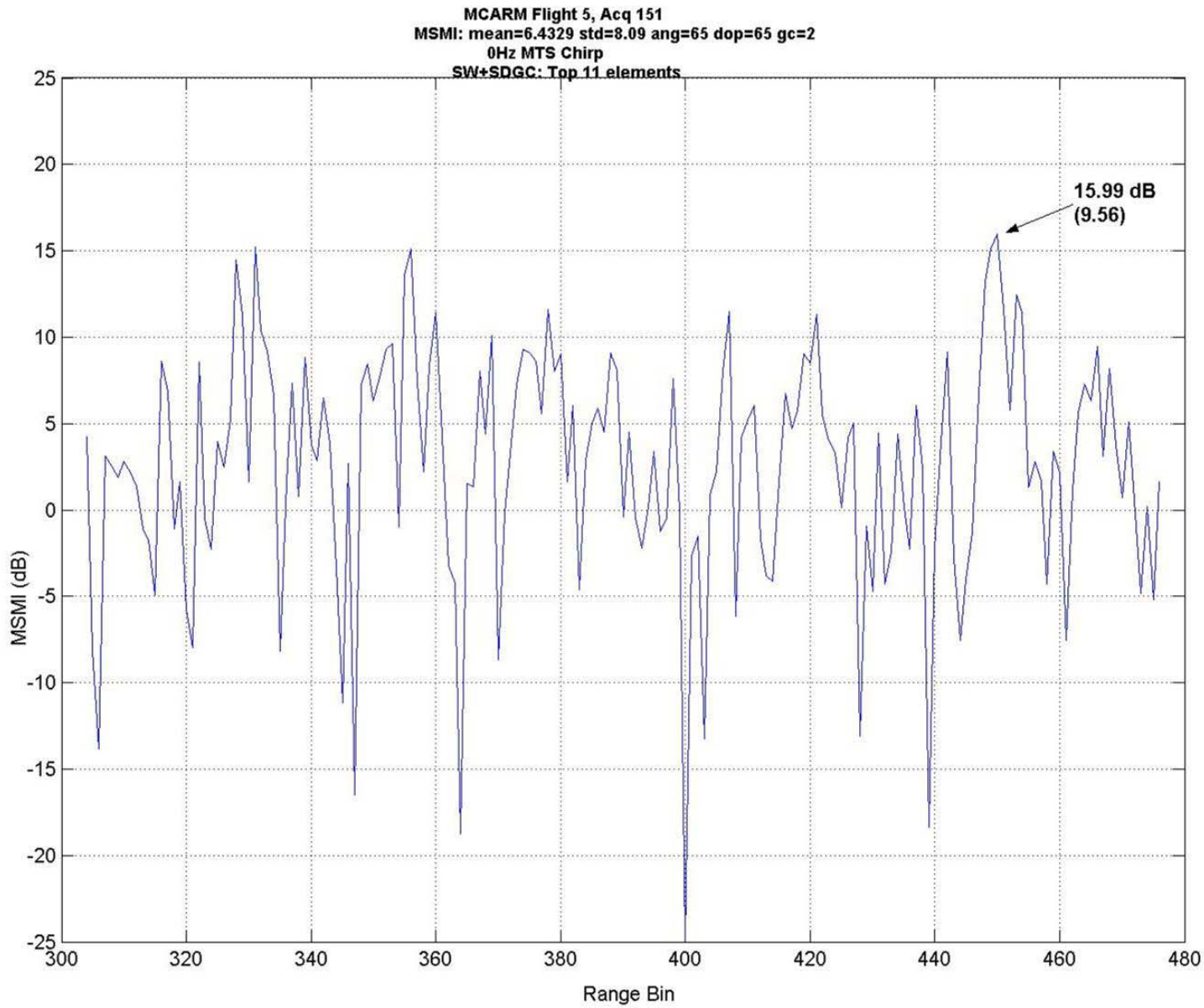
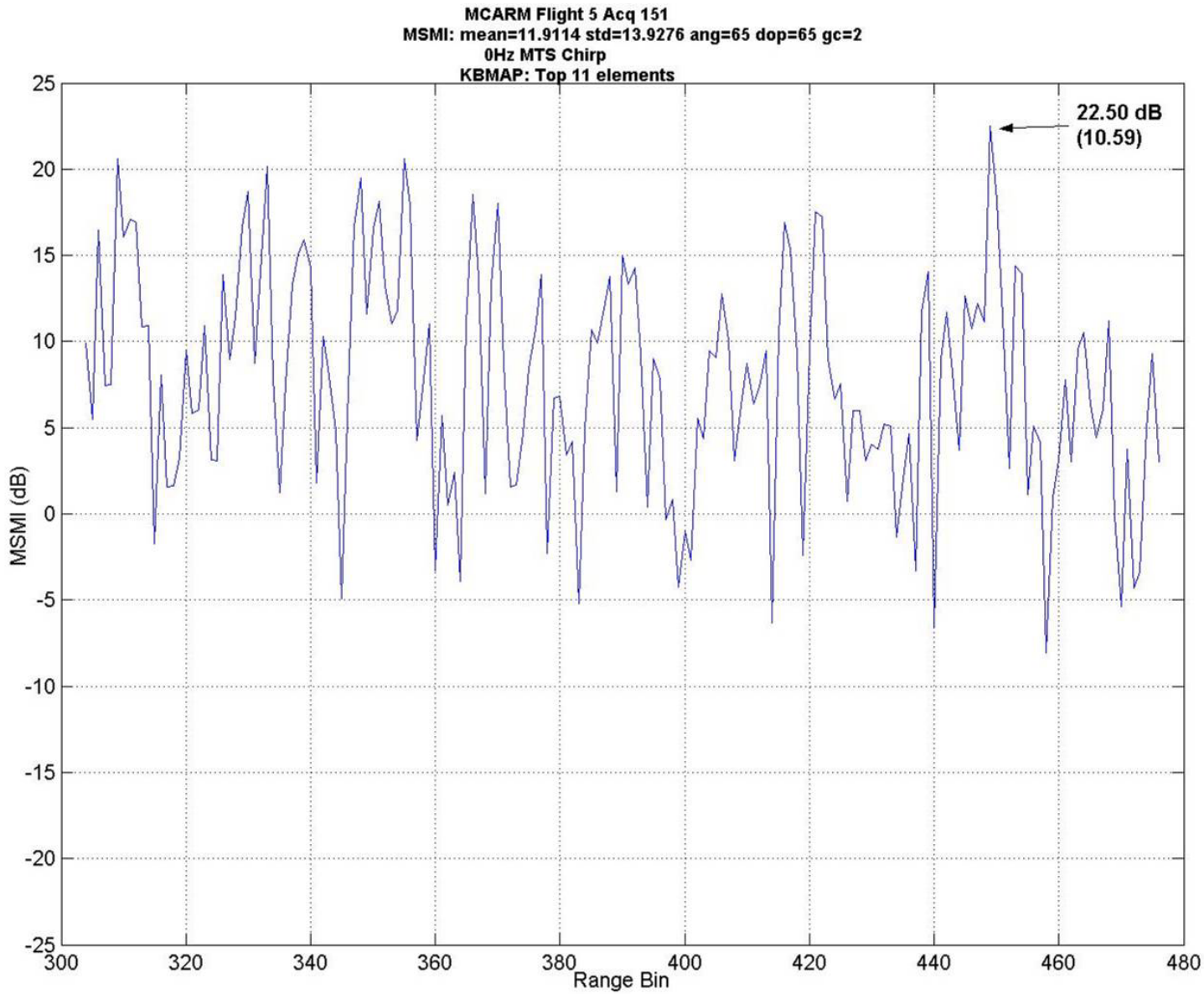
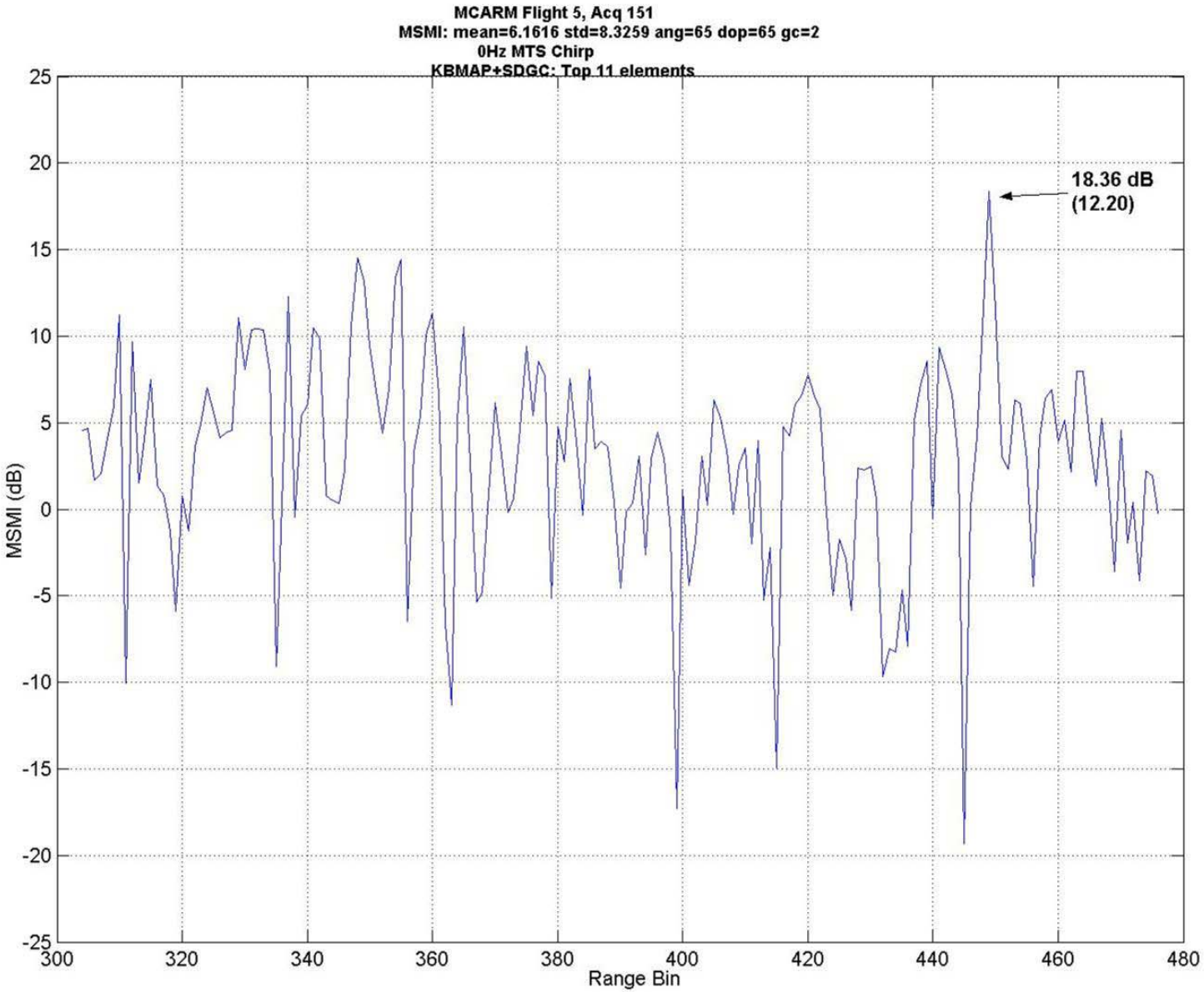
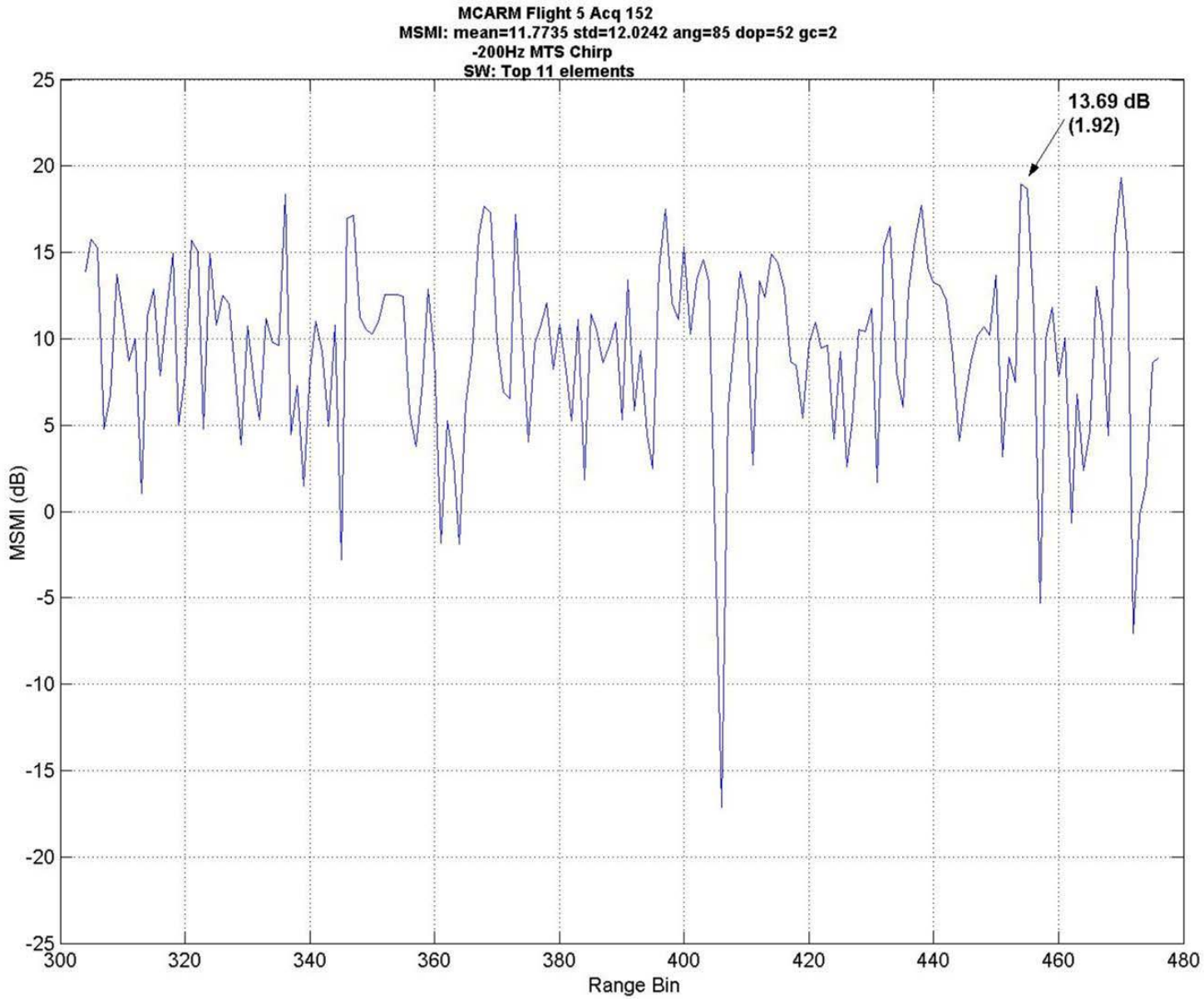

MCARM Flight 5 Acq 152
MSMI: mean=13.1148 std=15.9819 ang=85
SW: Top 11 elements
Range Bin
460
440
420
400
380
360
10
20
30
40
50
60
70
80
90
100
Doppler Bin
30
20
10
0
-10
-20
-30

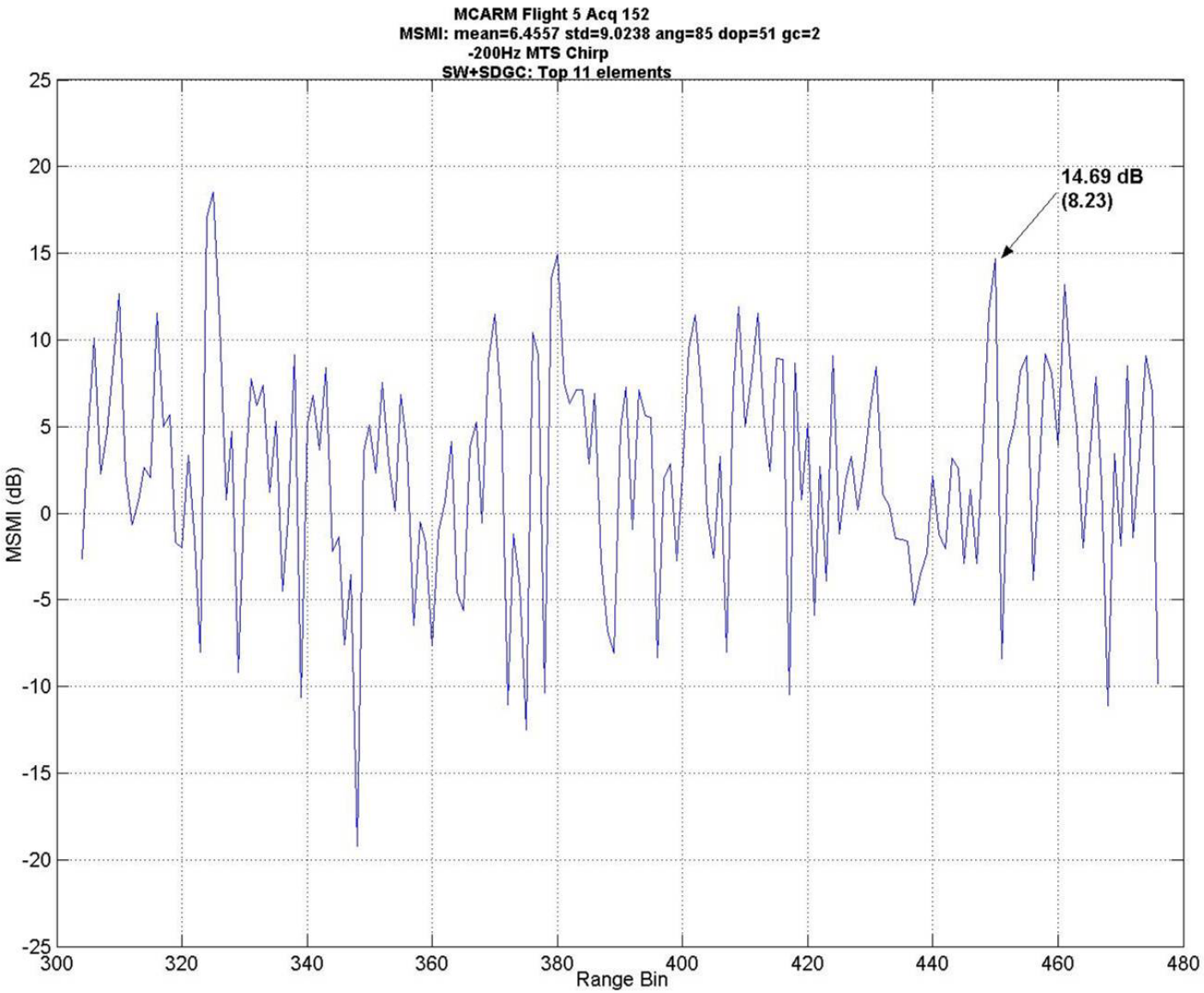

MCARM Flight 5, Acq 151
MSMI: mean=11.7705 std=13.2673 ang=65 dop=65 gc=2
0Hz MTS Chirp
SW: Top 11 elements
19.86 dB
(8.09)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480

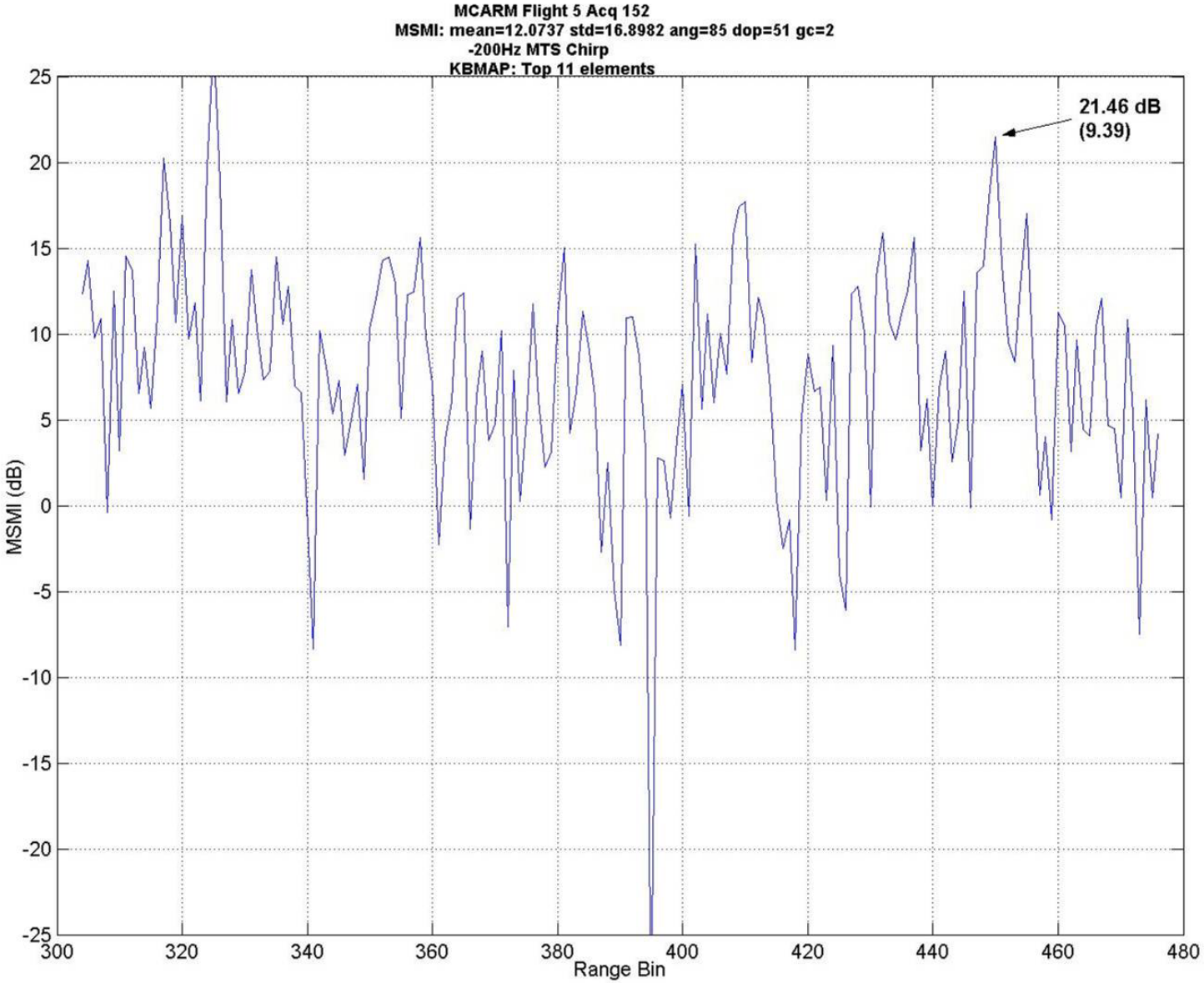

MCARM Flight 5, Acq 151
MSMI: mean=6.4329 std=8.09 ang=65 dop=65 gc=2
0Hz MTS Chirp
SW+SDGC: Top 11 elements
15.99 dB
(9.56)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480

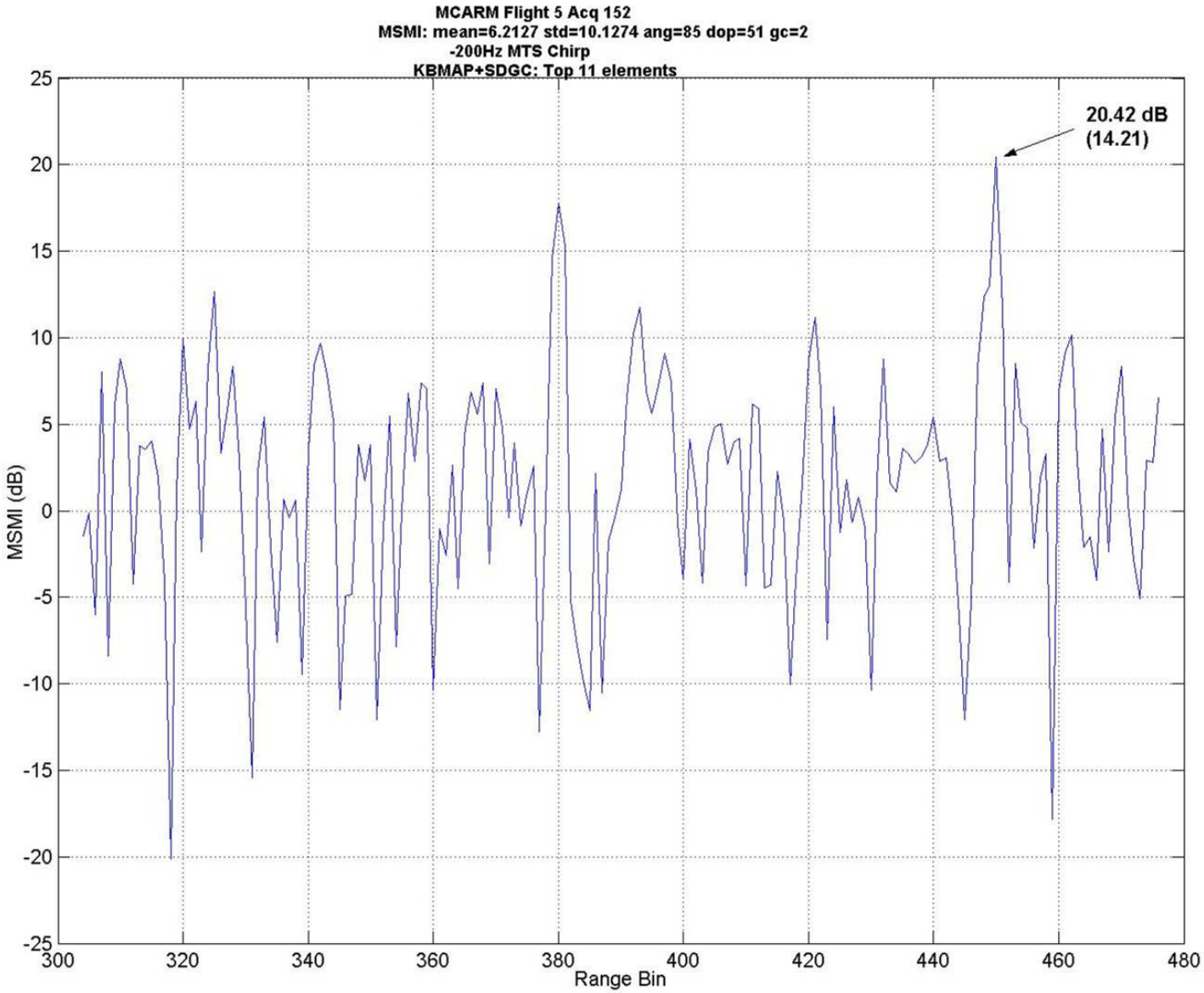

MCARM Flight 5 Acq 151
MSMI: mean=11.9114 std=13.9276 ang=65 dop=65 gc=2
0Hz MTS Chirp
KBMAP: Top 11 elements
22.50 dB
(10.59)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480

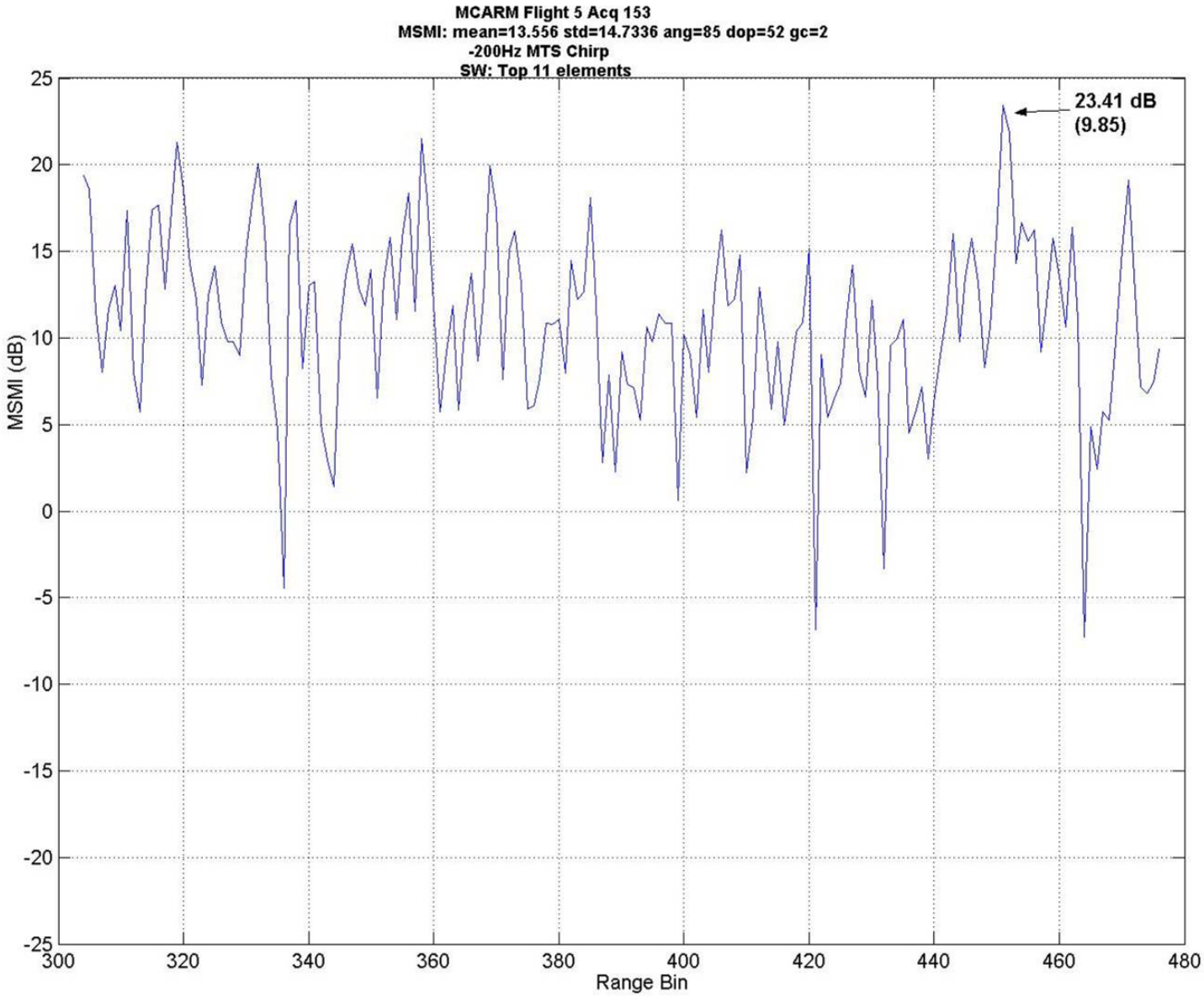

MCARM Flight 5, Acq 151
MSMI: mean=6.1616 std=8.3259 ang=65 dop=65 gc=2
0Hz MTS Chirp
KBMAP+SDGC: Top 11 elements
18.36 dB
(12.20)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480

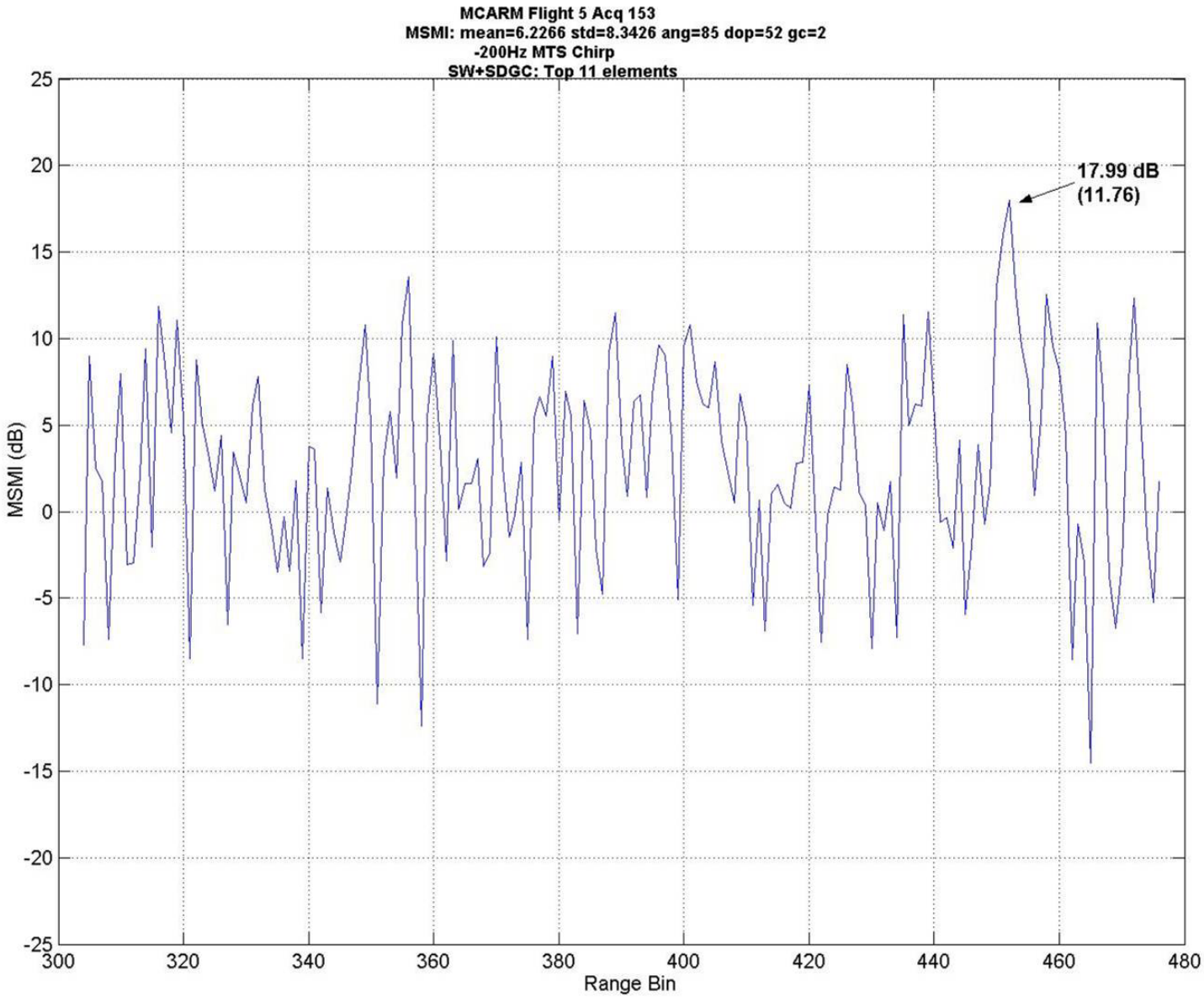

MCARM Flight 5 Acq 152
MSMI: mean=11.7735 std=12.0242 ang=85 dop=52 gc=2
-200Hz MTS Chirp
SW: Top 11 elements
13.69 dB
(1.92)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480

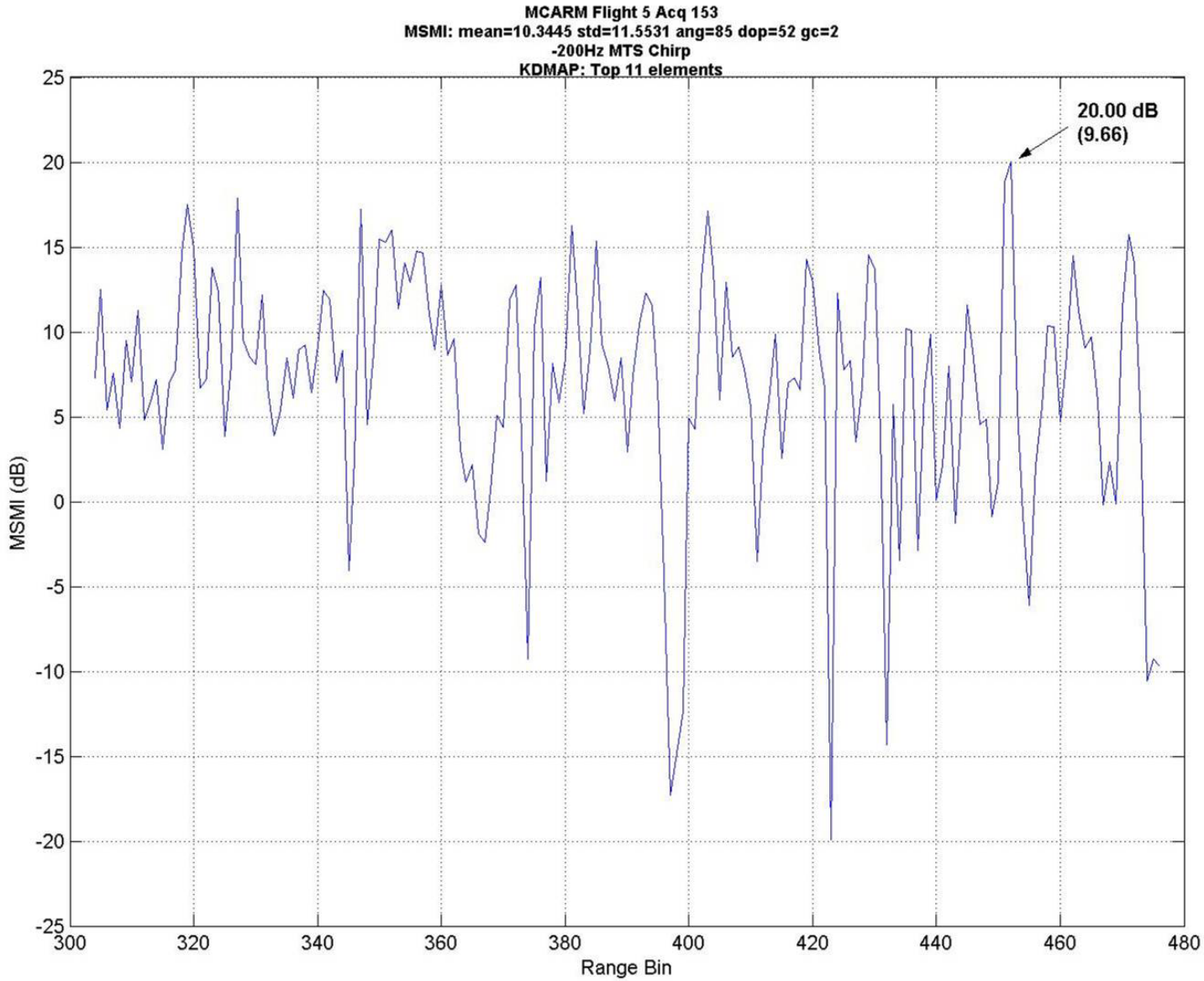

MCARM Flight 5 Acq 152
MSMI: mean=6.4557 std=9.0238 ang=85 dop=51 gc=2
-200Hz MTS Chirp
SW+SDGC: Top 11 elements
14.69 dB
(8.23)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480

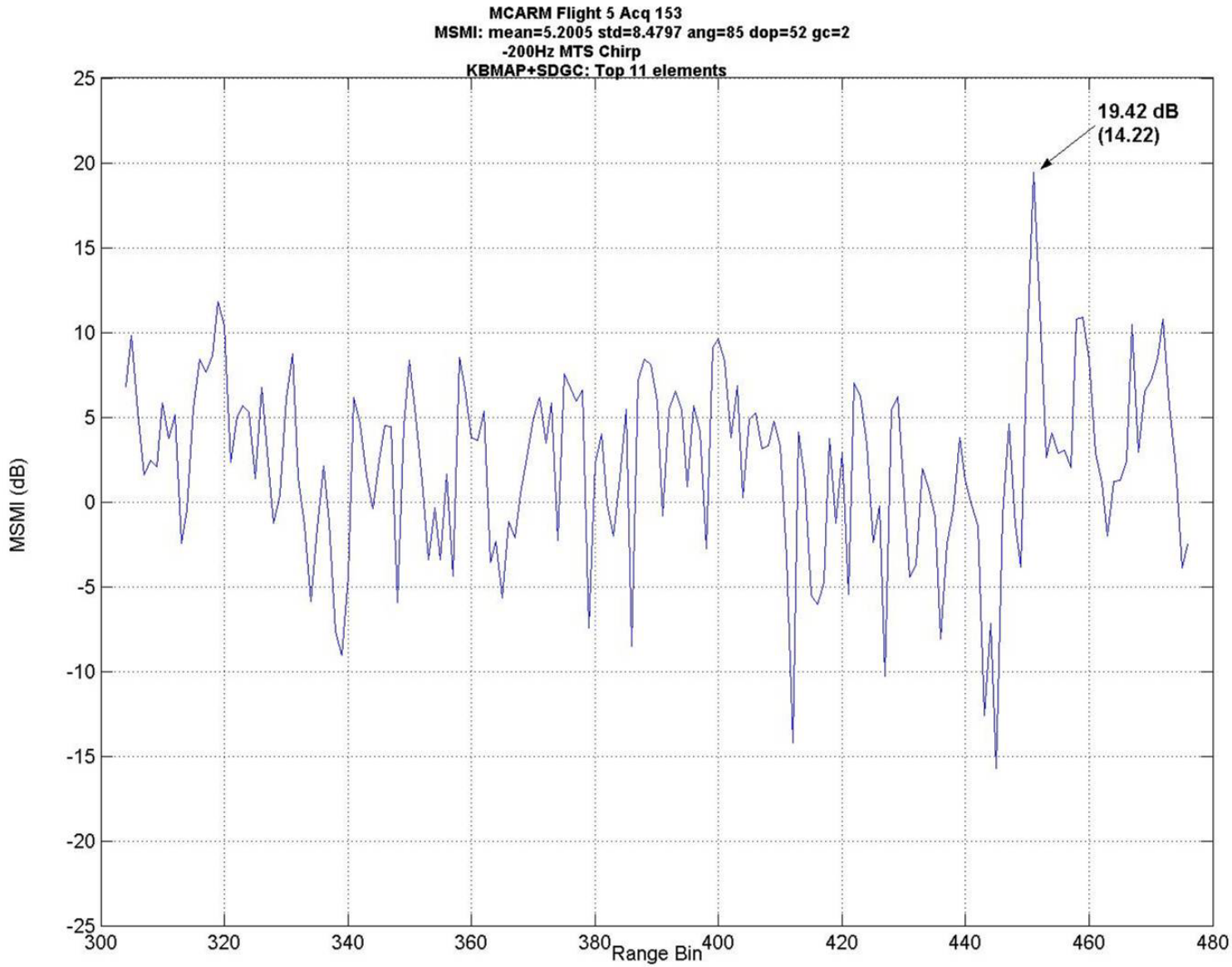

MCARM Flight 5 Acq 152
MSMI: mean=12.0737 std=16.8982 ang=85 dop=51 gc=2
-200Hz MTS Chirp
KBMAP: Top 11 elements
21.46 dB
(9.39)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480


MCARM Flight 5 Acq 152
MSMI: mean=6.2127 std=10.1274 ang=85 dop=51 gc=2
-200Hz MTS Chirp
KBMAP+SDGC: Top 11 elements
20.42 dB
(14.21)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480


MCARM Flight 5 Acq 153
MSMI: mean=13.556 std=14.7336 ang=85 dop=52 gc=2
-200Hz MTS Chirp
SW: Top 11 elements
23.41 dB
(9.85)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480


MCARM Flight 5 Acq 153
MSMI: mean=6.2266 std=8.3426 ang=85 dop=52 gc=2
-200Hz MTS Chirp
SW+SDGC: Top 11 elements
17.99 dB
(11.76)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480


MCARM Flight 5 Acq 153
MSMI: mean=10.3445 std=11.5531 ang=85 dop=52 gc=2
-200Hz MTS Chirp
KDMAP: Top 11 elements
20.00 dB
(9.66)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480


MCARM Flight 5 Acq 153
MSMI: mean=5.2005 std=8.4797 ang=85 dop=52 gc=2
-200Hz MTS Chirp
KBMAP+SDGC: Top 11 elements
19.42 dB
(14.22)
MSMI (dB)
Range Bin
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
320
340
360
380
400
420
440
460
480

Variability in STAP Results

In estimating the covariance matrix, if one wishes to maintain an **average** loss, compared to the optimum, of better than one-half (less than 3 dB), at least 2N samples of data are needed.

I. S. Reed, J. D. Mallet, and L. E. Brennan, "Rapid Convergence Rate in Adaptive Arrays," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 10, No. 6, pp. 853-863, November, 1974.

- In order to demonstrate that knowledge-aided approaches improve STAP performance we need to use real radar data – i.e. for simulated radar data we cannot use the same knowledge sources that produced the simulated radar data.
- If we use real radar data we have no way of knowing what the true covariance matrices are and, therefore, a reliable performance metric is hard to obtain.
- We need to develop a statistical performance measure, when using real radar data, to evaluate STAP algorithms properly. A couple of data points are not sufficient to prove that new approaches are better than current ones.
- However, a statistical performance measure would require a large collection of radar data with accurate truth information about embedded targets. – (addressing this issue with DEM data)

Developing Image Data

- Need to “see what the radar is seeing”
- Map data is not necessarily current
- Weather may be a factor
- May not have image data from other sensors

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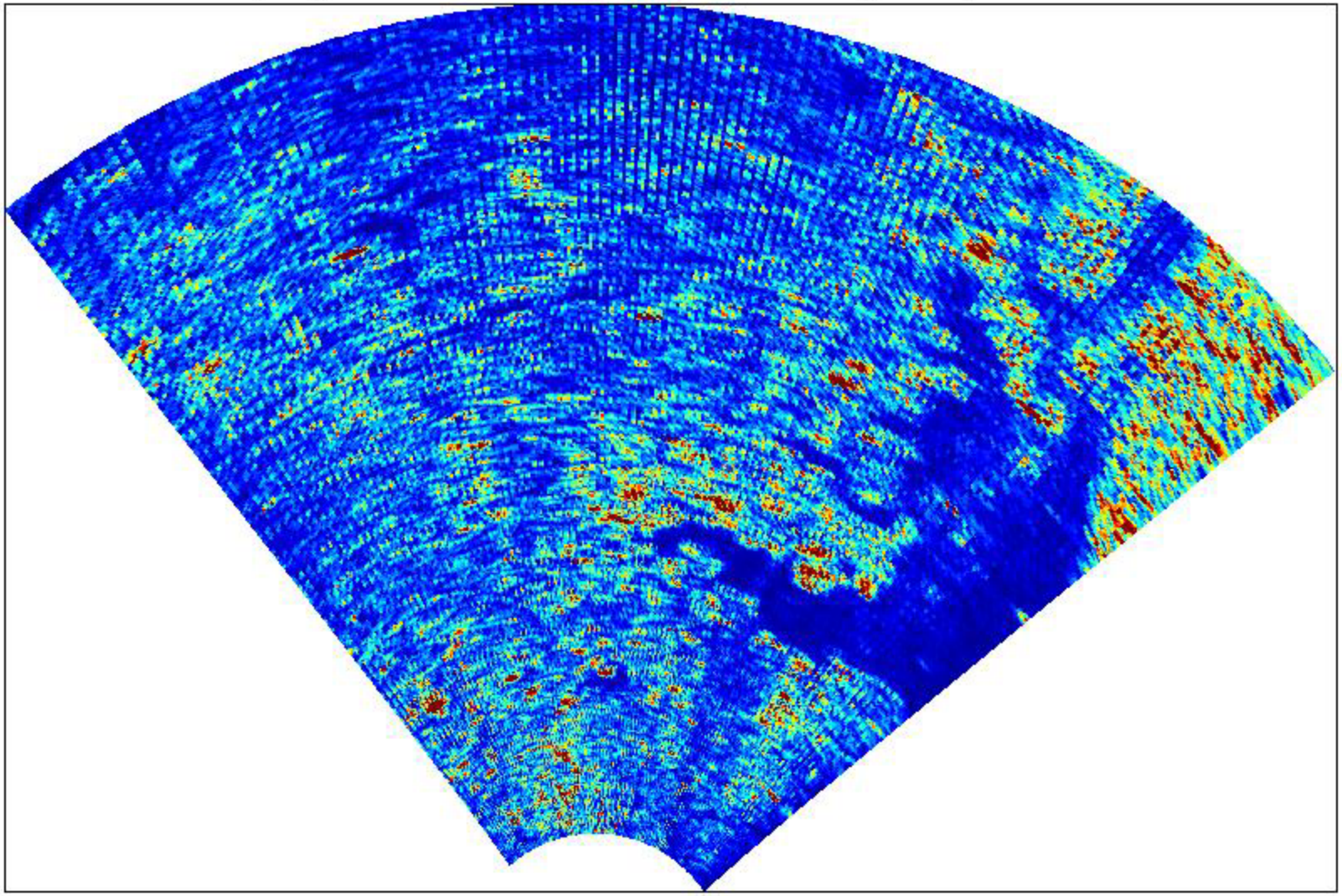
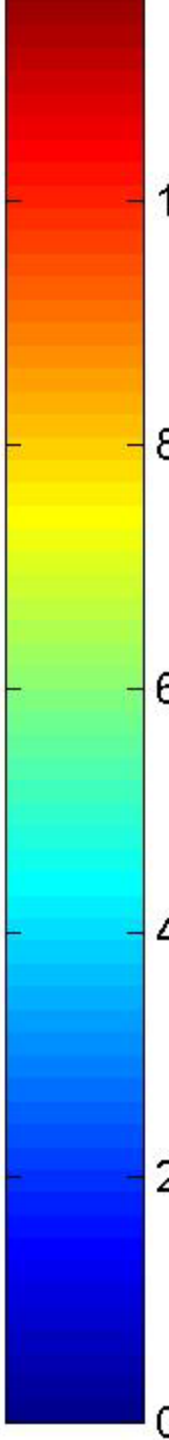
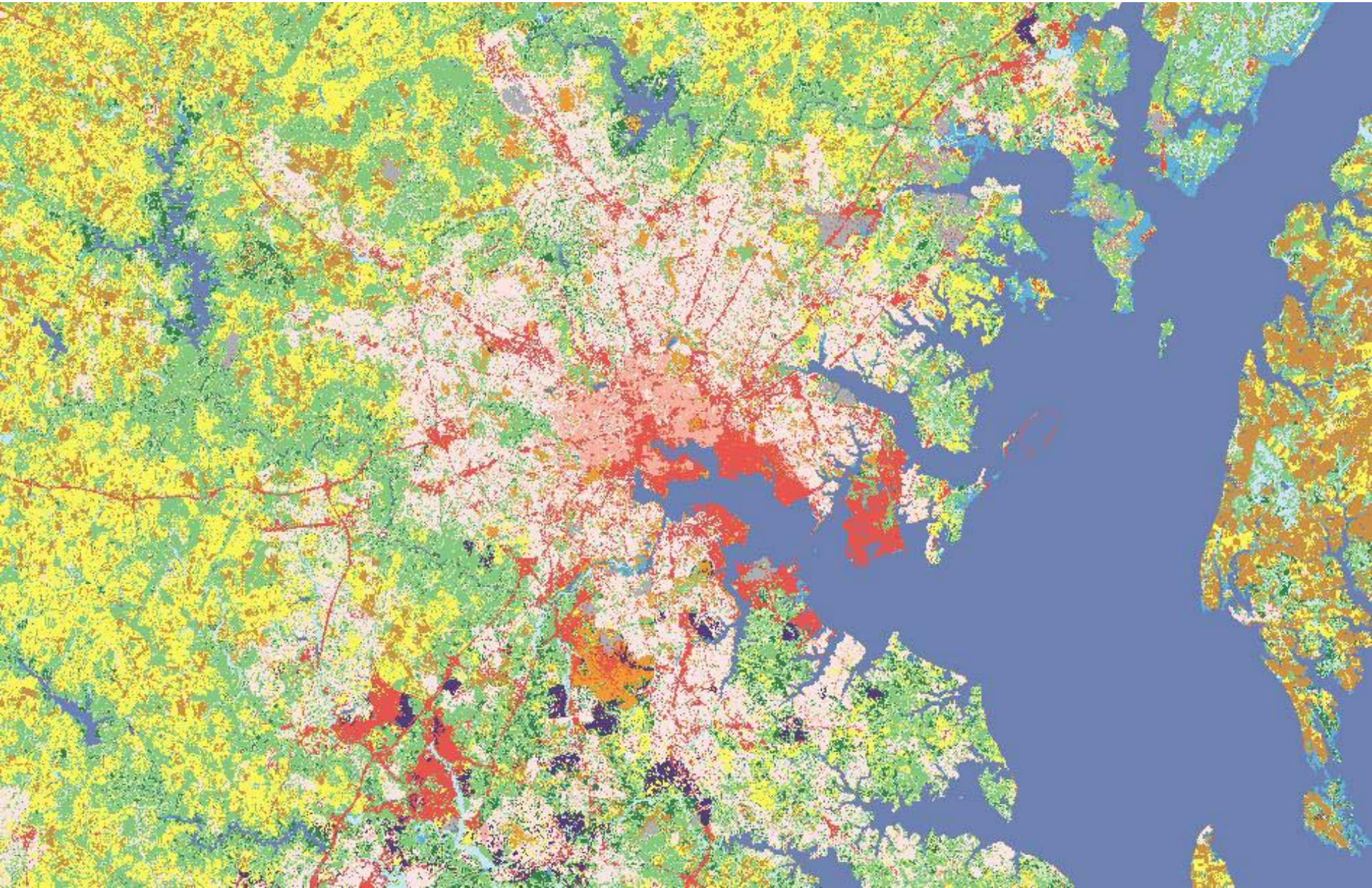
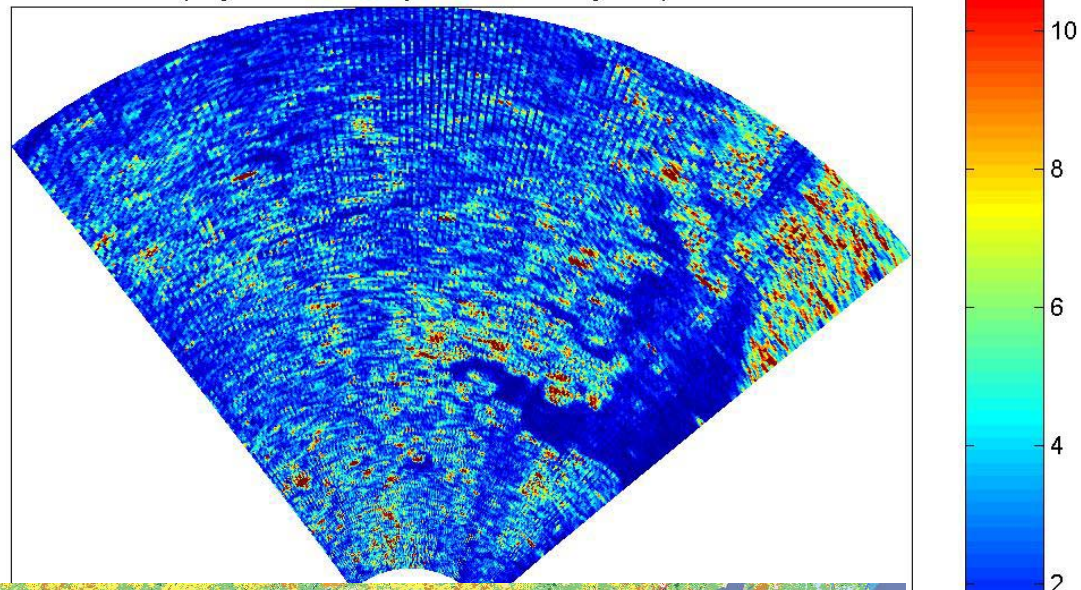
Composite Map Generated from Three MCARM Radar CPIs
Flight 5, Acq. 150, 153, and 157
(Projected in Albers Equal-Area Conic Projection)

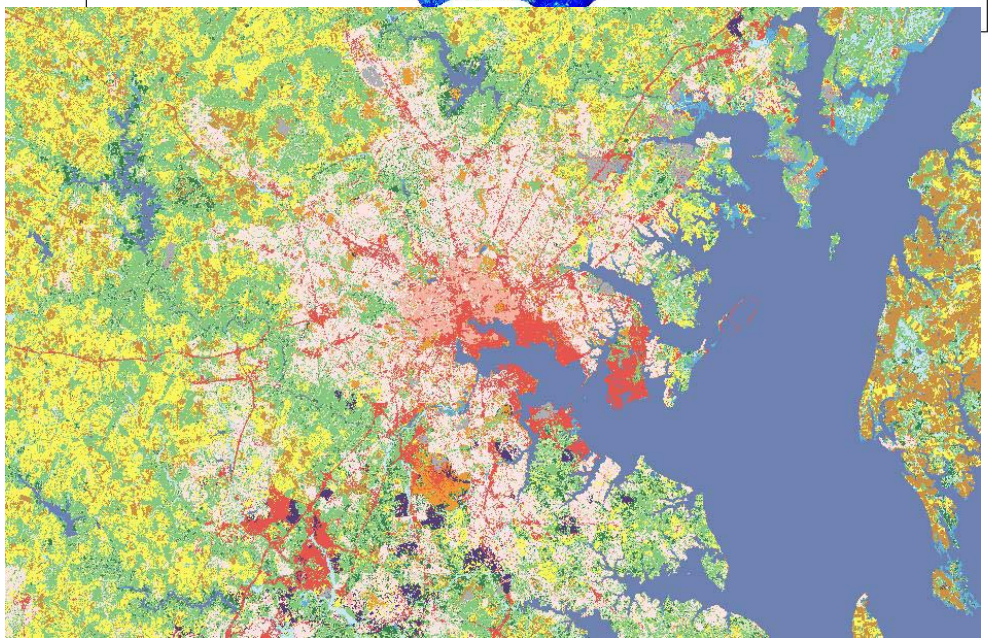






Composite Map Generated from Three MCARM Radar CPIs
Flight 5, Acq. 150, 153, and 157
(Projected in Albers Equal-Area Conic Projection)





DEM Data Algorithm Development

- Chose a mountainous region
- A real radar with multiple CPIs
- Real truth data – more than MTS data
- Minimal variation in LULC data – not included in algorithm
- Preliminary algorithm is automated in MATLAB (based upon % shadowing and reflection angle statistics per range ring)
- Will be integrated into SPEAR facility with Black River Systems

Scene with DEM, LULC and DLG Terrain Data

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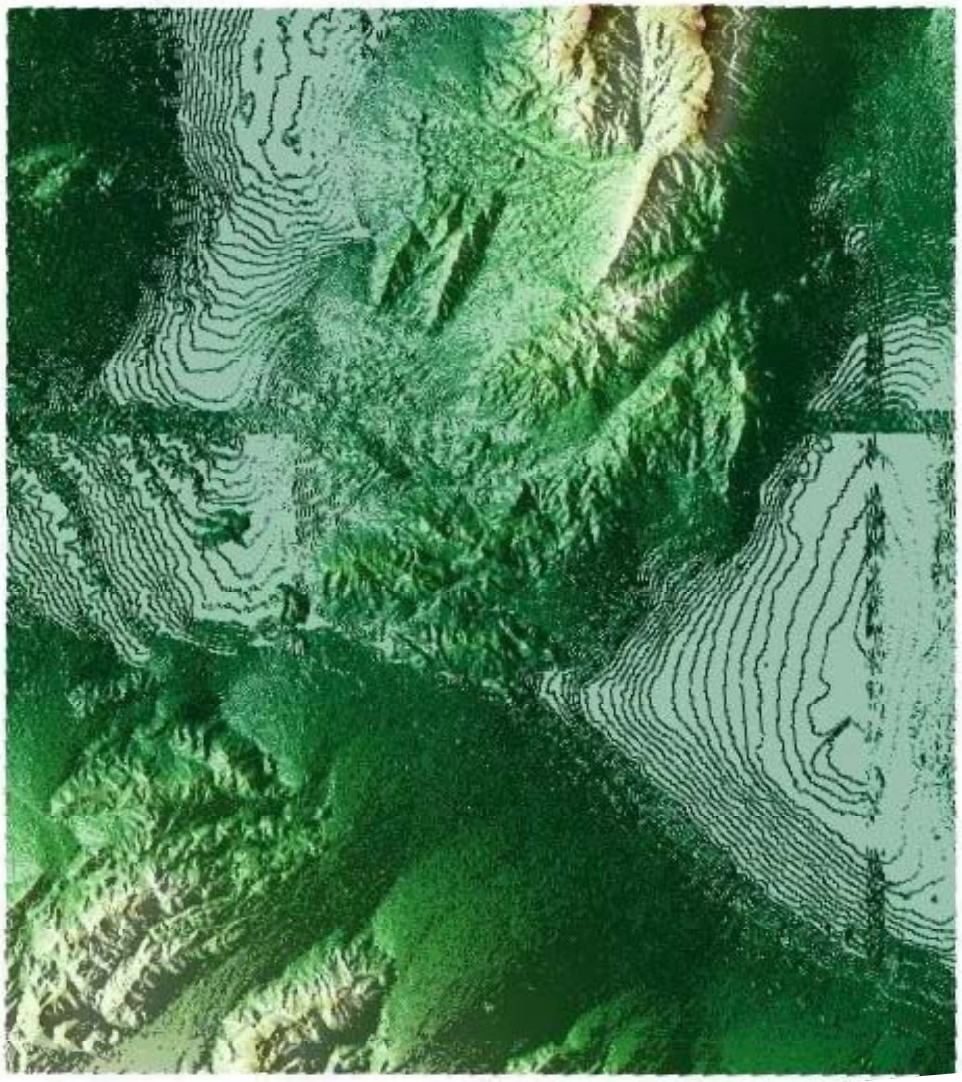
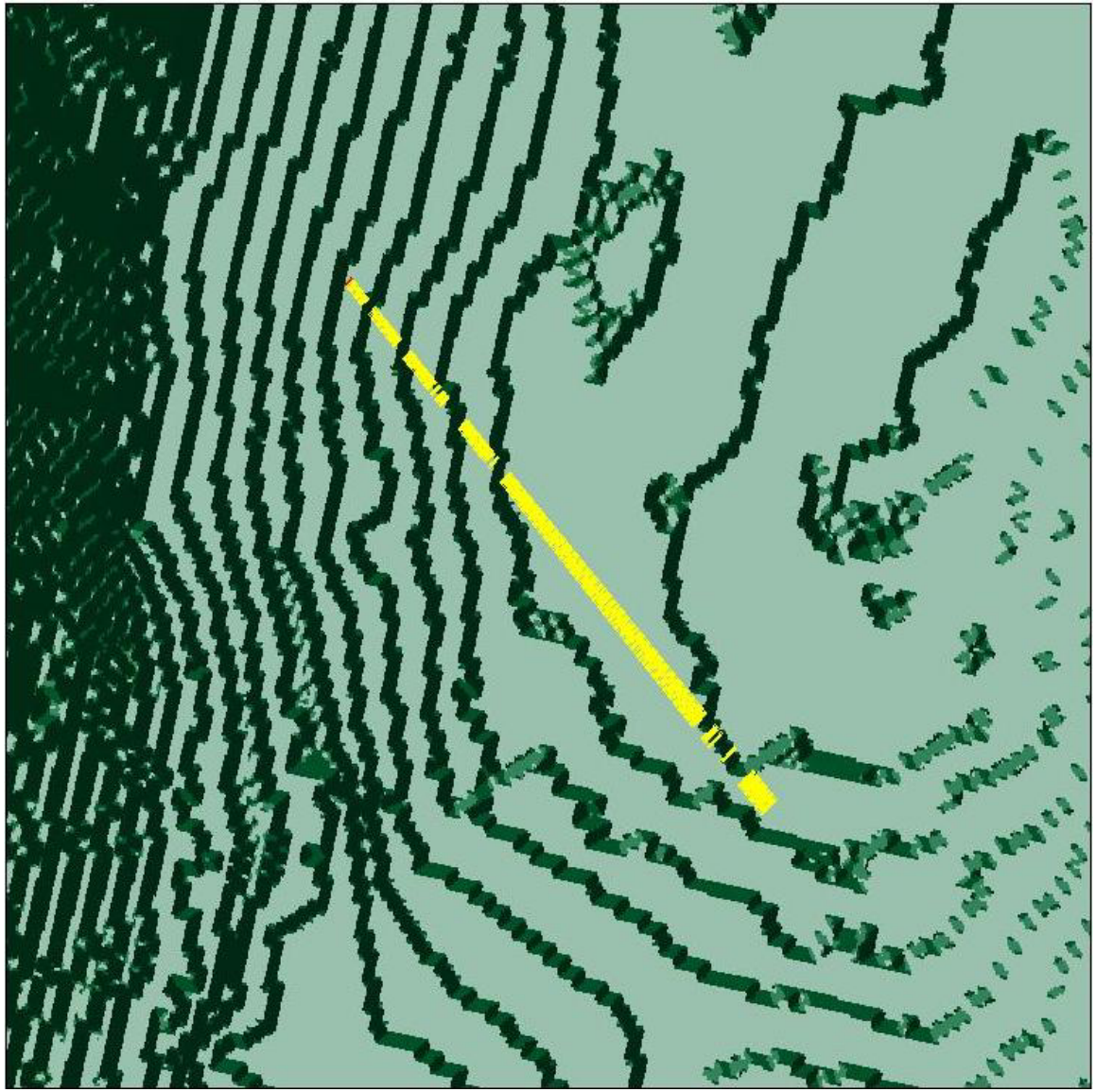
Scene with 10 Meter DEM Terrain Data in MATLAB



Chosen Range Bins on Flat Terrain

(Test Cell Red, Sample Cells Yellow)



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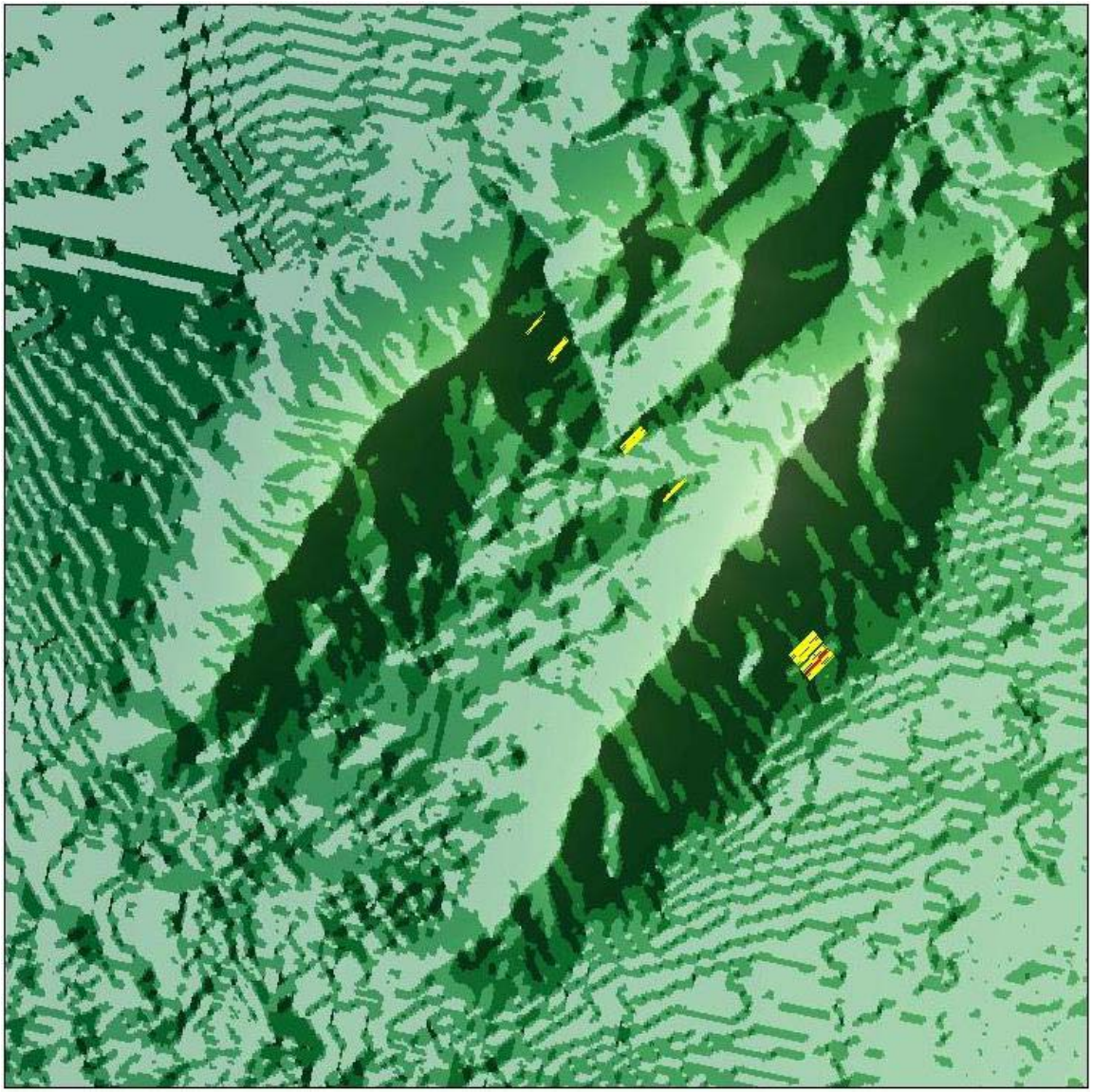
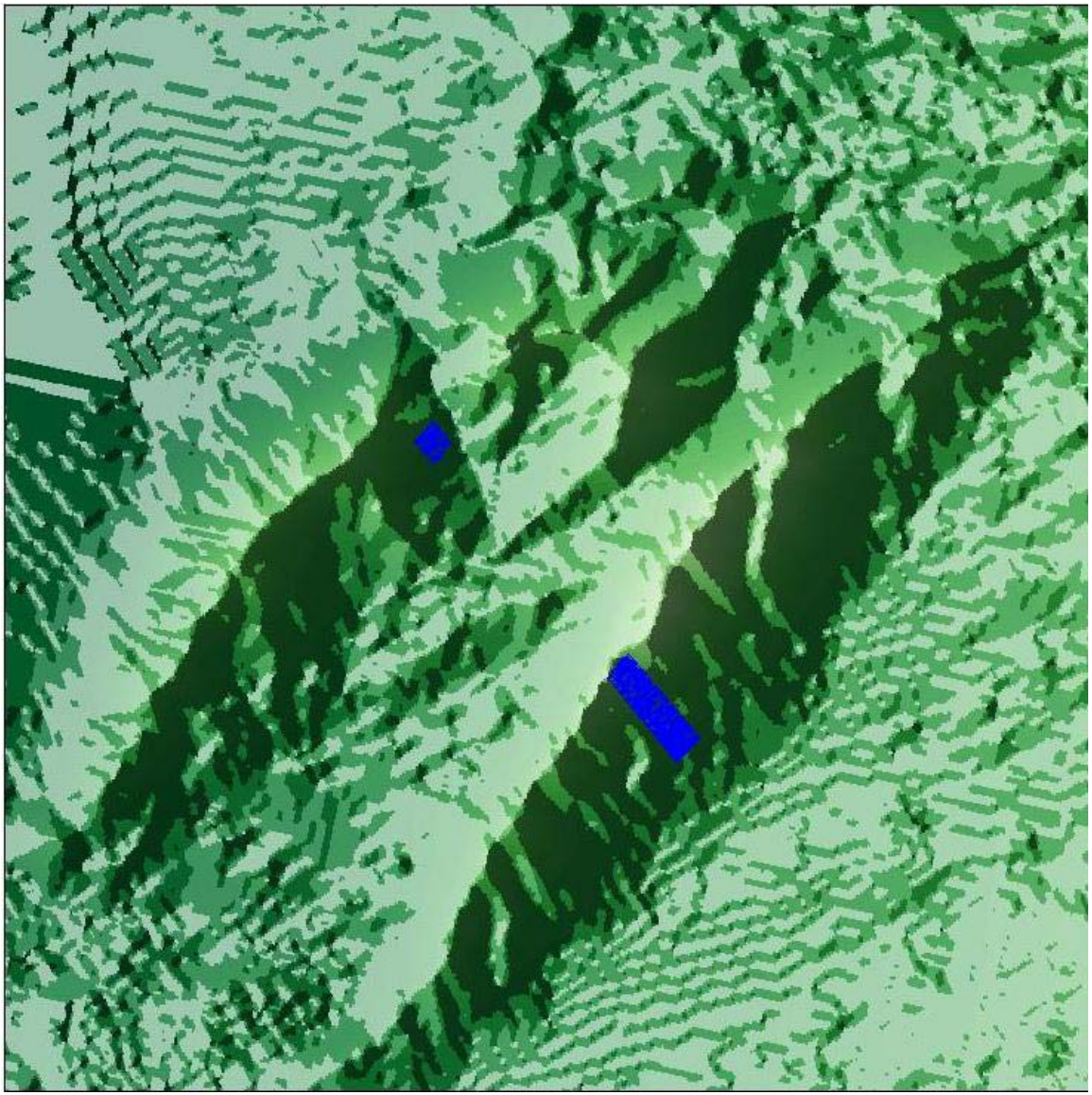
Chosen Range Bins on Mountainous Terrain

(Test Cell Red, Sample Cells Yellow)



Shadowed Range Cells



Summary/Future Plans

- KBMapSTAP
  - Background/Review & Last Status
- Current Efforts, Results, and Status
  - Guard cells around secondary data
  - Developing image data
  - DEM data algorithm development
- Future Plans
  - DEM model development and test in SPEAR facility
  - Continue with image map development
  - Integrate LULC, DEM, and DLG data
  - Extend KB control logic design for total processing chain
- Acknowledgements

Acknowledgements

- Mr. Christopher Capraro – Capraro Technologies, Inc.
- Dr. Donald Weiner – Syracuse University
- Mr. Gerard Genello – AFRL/SNRT
- Mr. William Baldygo – AFRL/SNRT
- Mr. Mark Novak – AFRL/SNRT
- Dr. Michael Wicks – AFRL/SN

END

(Followed by supplemental slides.)

MCARM DATA

- L-Band Airborne Radar
  - Twenty Two Channel Phased Array
  - 20 KW peak power
  - Low PRF ~ 1 KHz
  - Moderate Bandwidth ~ 1 MHz
- In Scene Calibration
  - Ground Based Active Radar Calibrator
  - Airborne Test Targets

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Performance Measure
Modified Sample Matrix Inversion

$$\mathrm{MSMI}_i = \frac{\left| s^H \hat{R}^{-1} x_i \right|^2}{s^H \hat{R}^{-1} s}$$

where: $\hat{R}$ is an estimate of the clutter covariance matrix,

s is the steering vector,

s^H is the complex conjugate transpose of the steering vector,

χ_i is the radar return vector from the ith range ring,

$\hat{R}^{-1}$ is the inverse of the estimate of the clutter covariance matrix.

MSMI is computed for each range ring - has a thresholding or detection quality, similar to CFAR.

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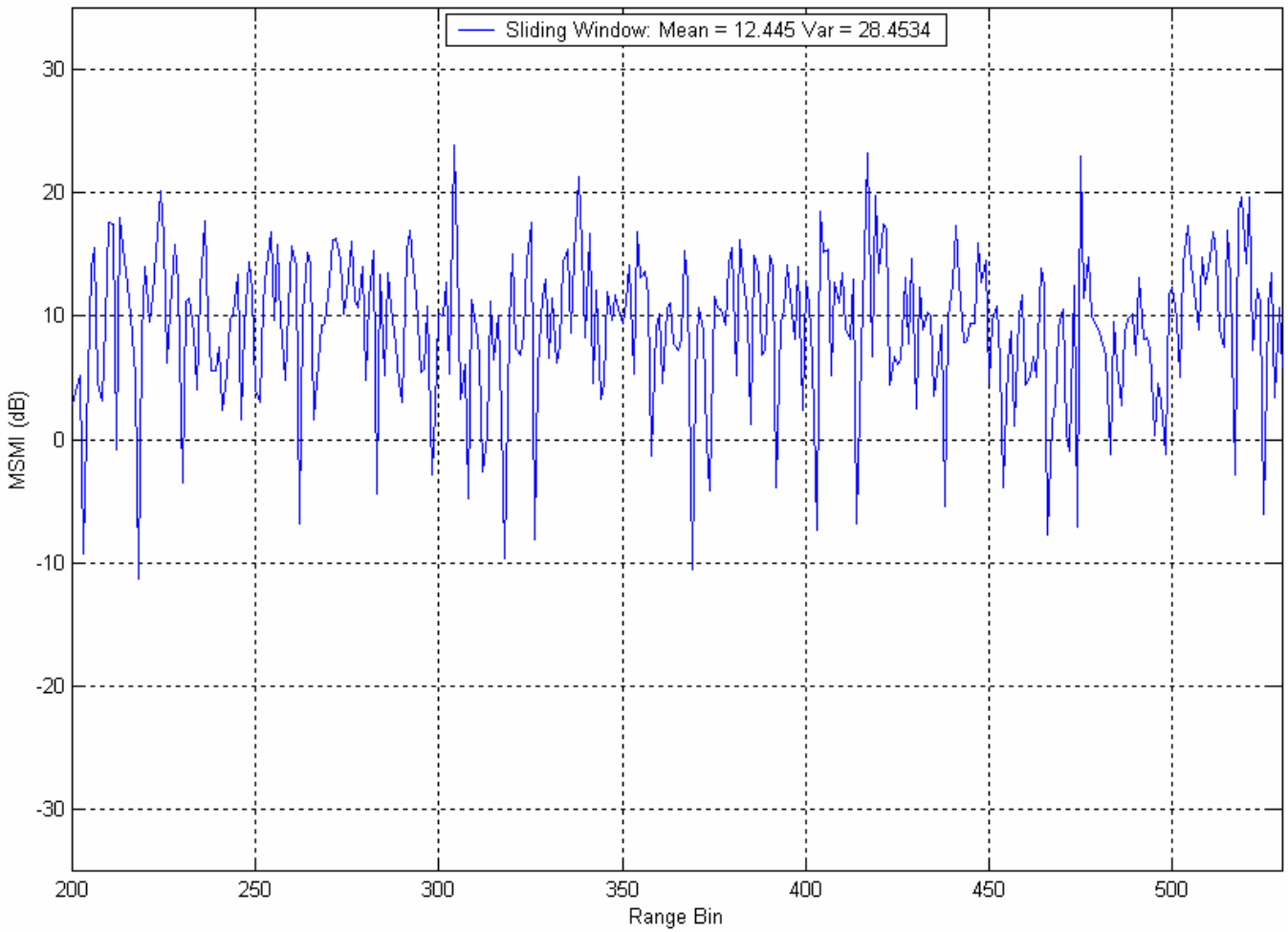
MSMI Output Using Sliding Window Algorithm With Injected Target At Range Bin 475



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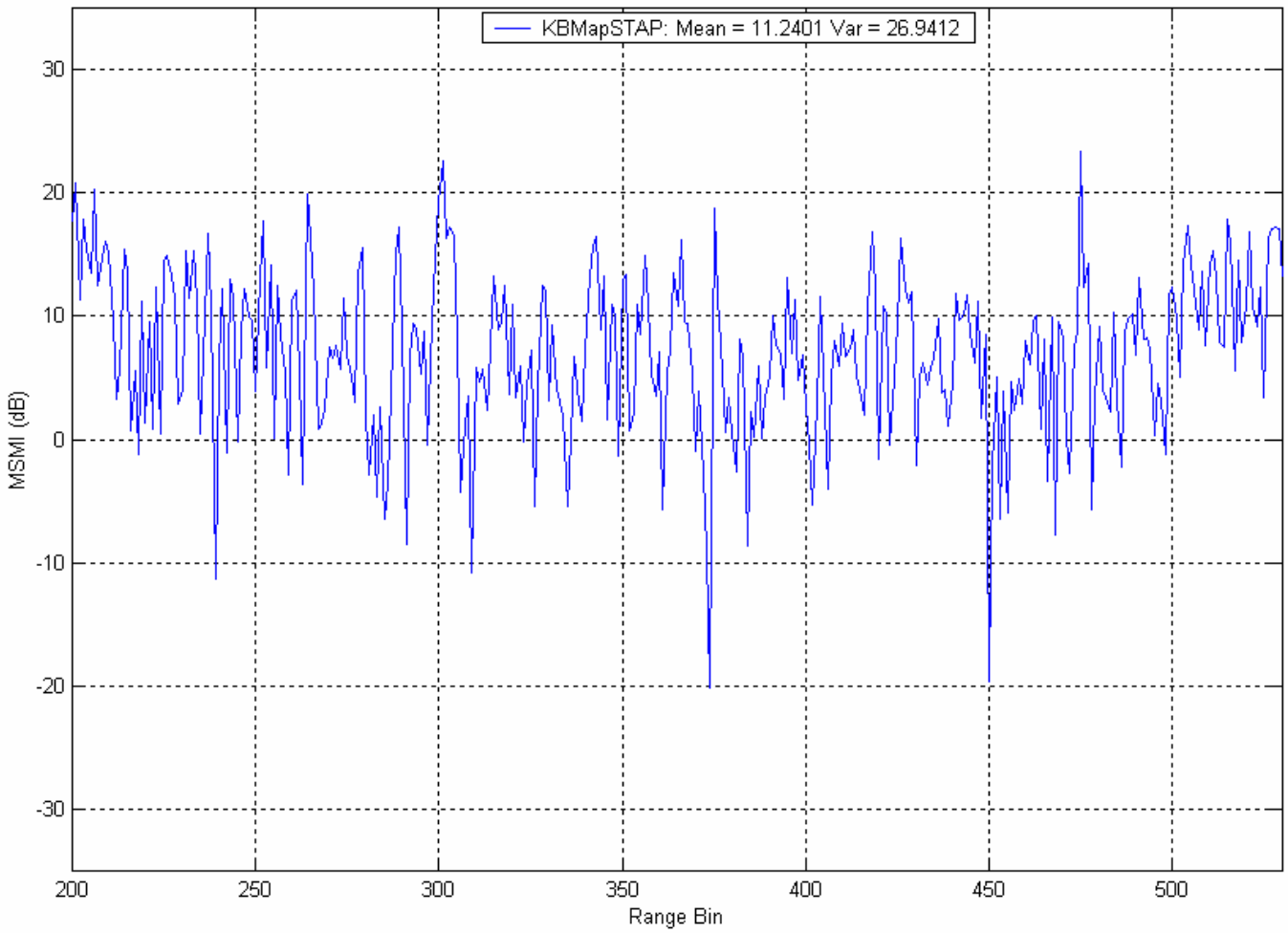
MSMI Output Using KBMapSTAP Algorithm With Injected Target At Range Bin 475



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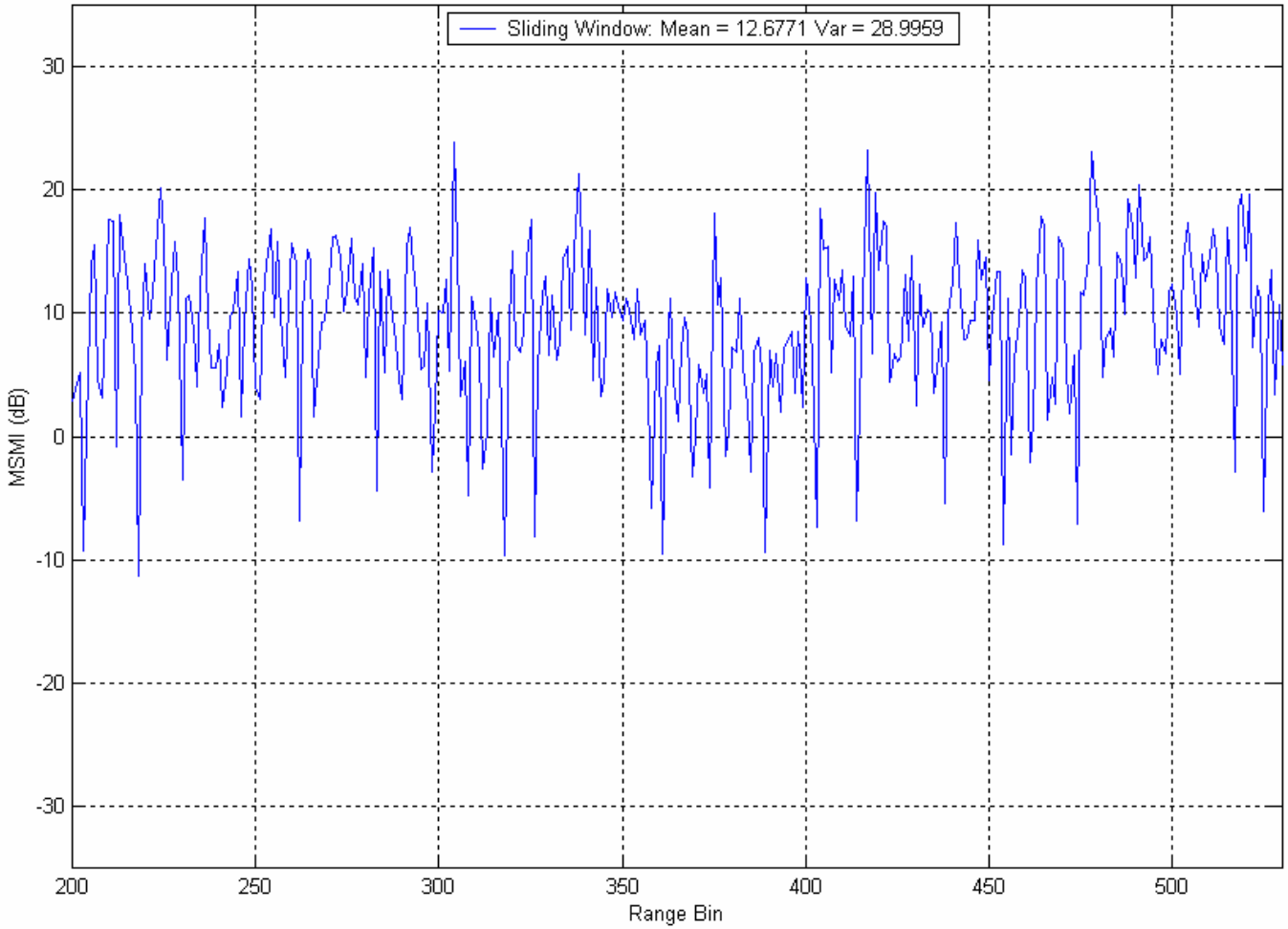
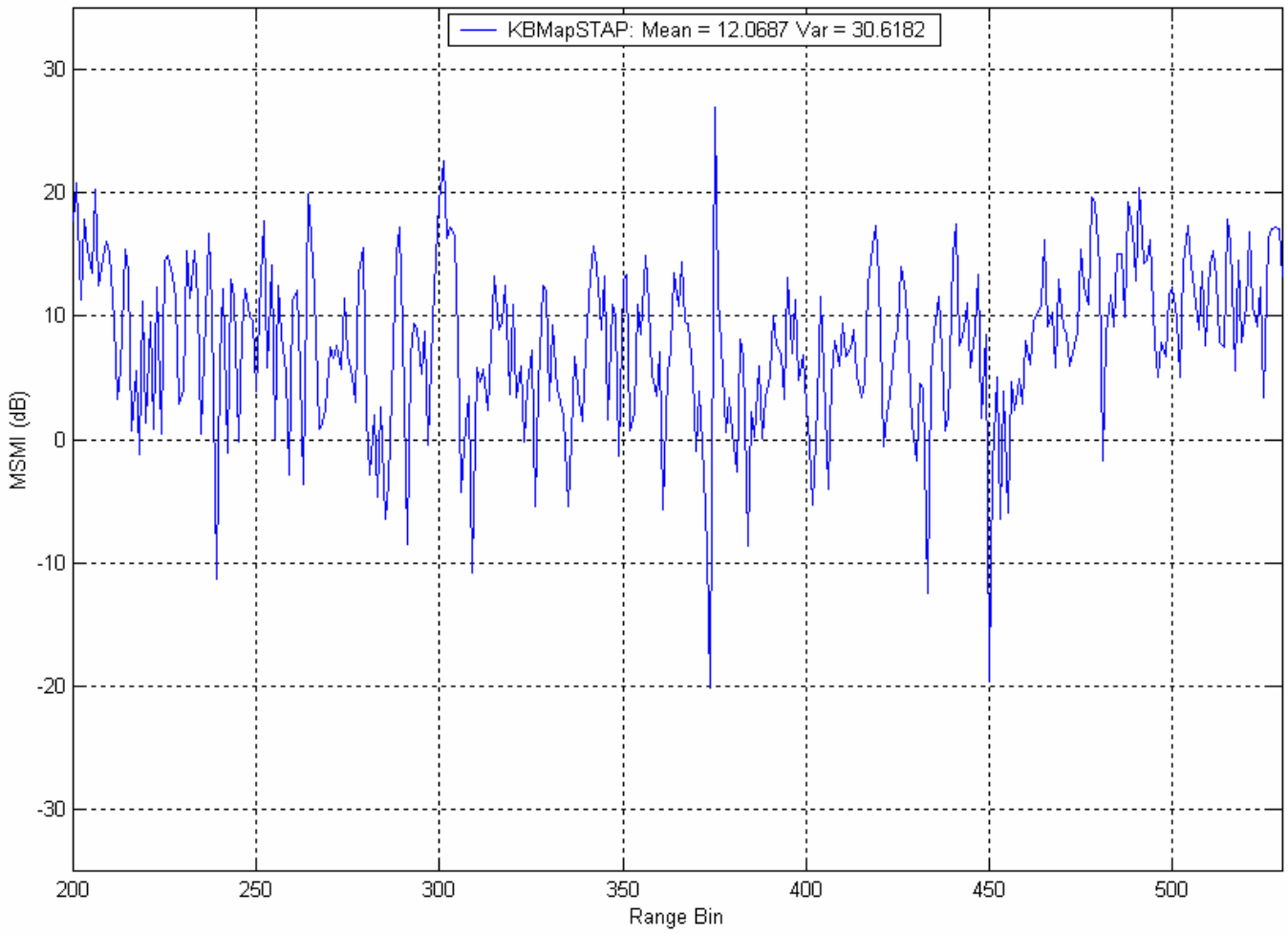
MSMI Output Using Sliding Window Algorithm With Injected Target At Range Bin 375



MSMI Output Using KBMapSTAP Algorithm With Injected Target At Range Bin 375



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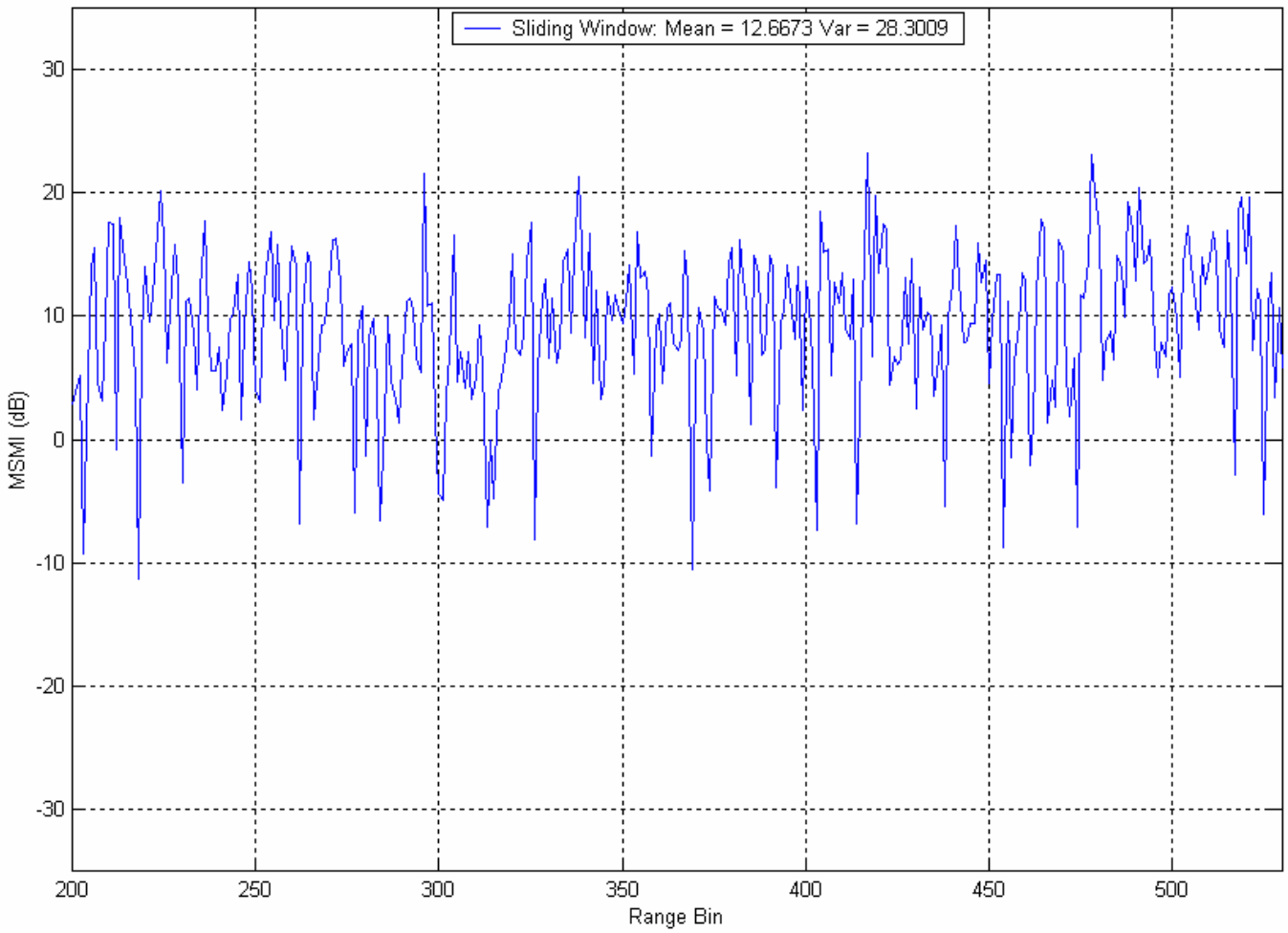
MSMI Output Using Sliding Window Algorithm With Injected Target At Range Bin 296



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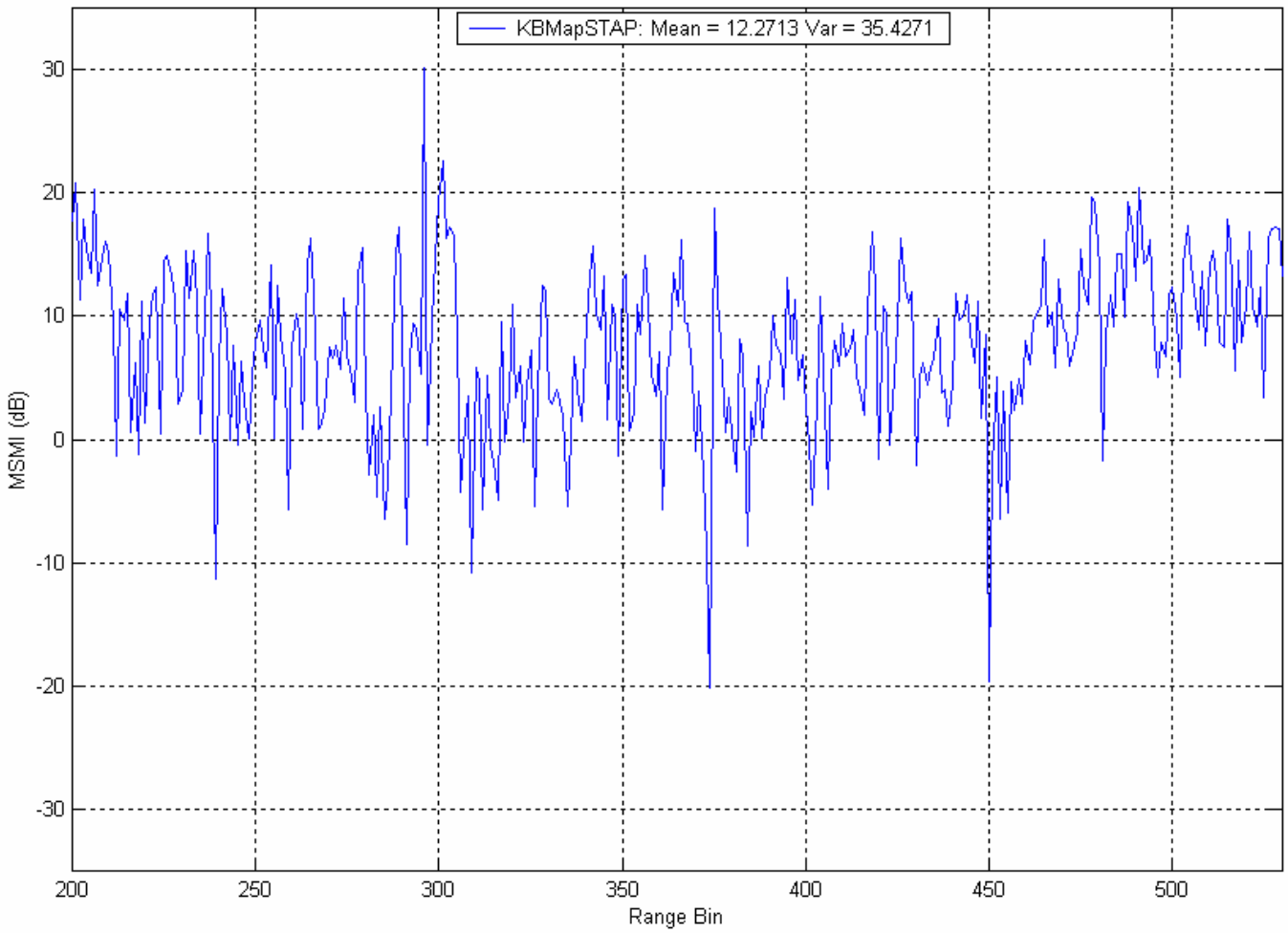
MSMI Output Using KBMapSTAP Algorithm With Injected Target At Range Bin 296



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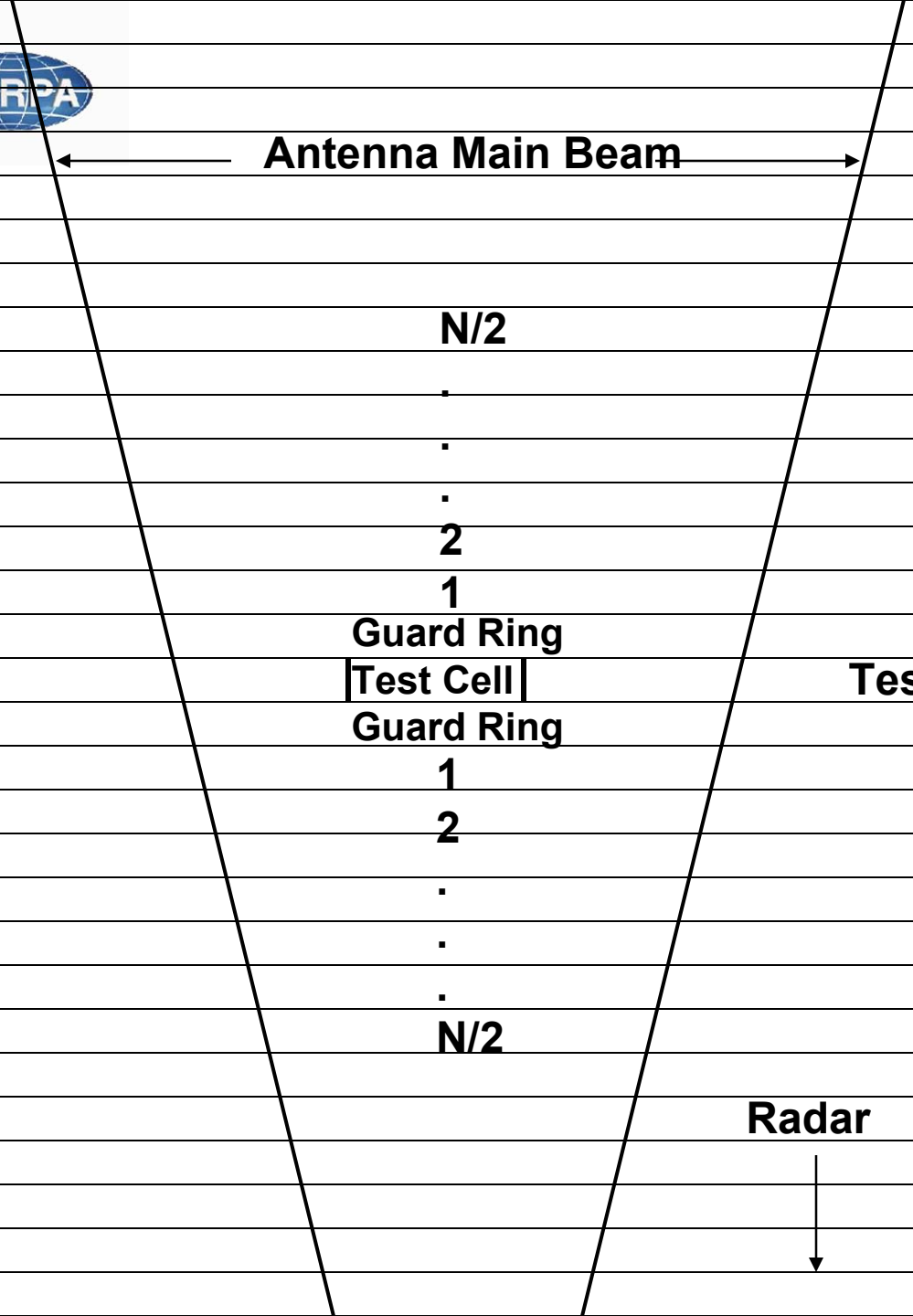
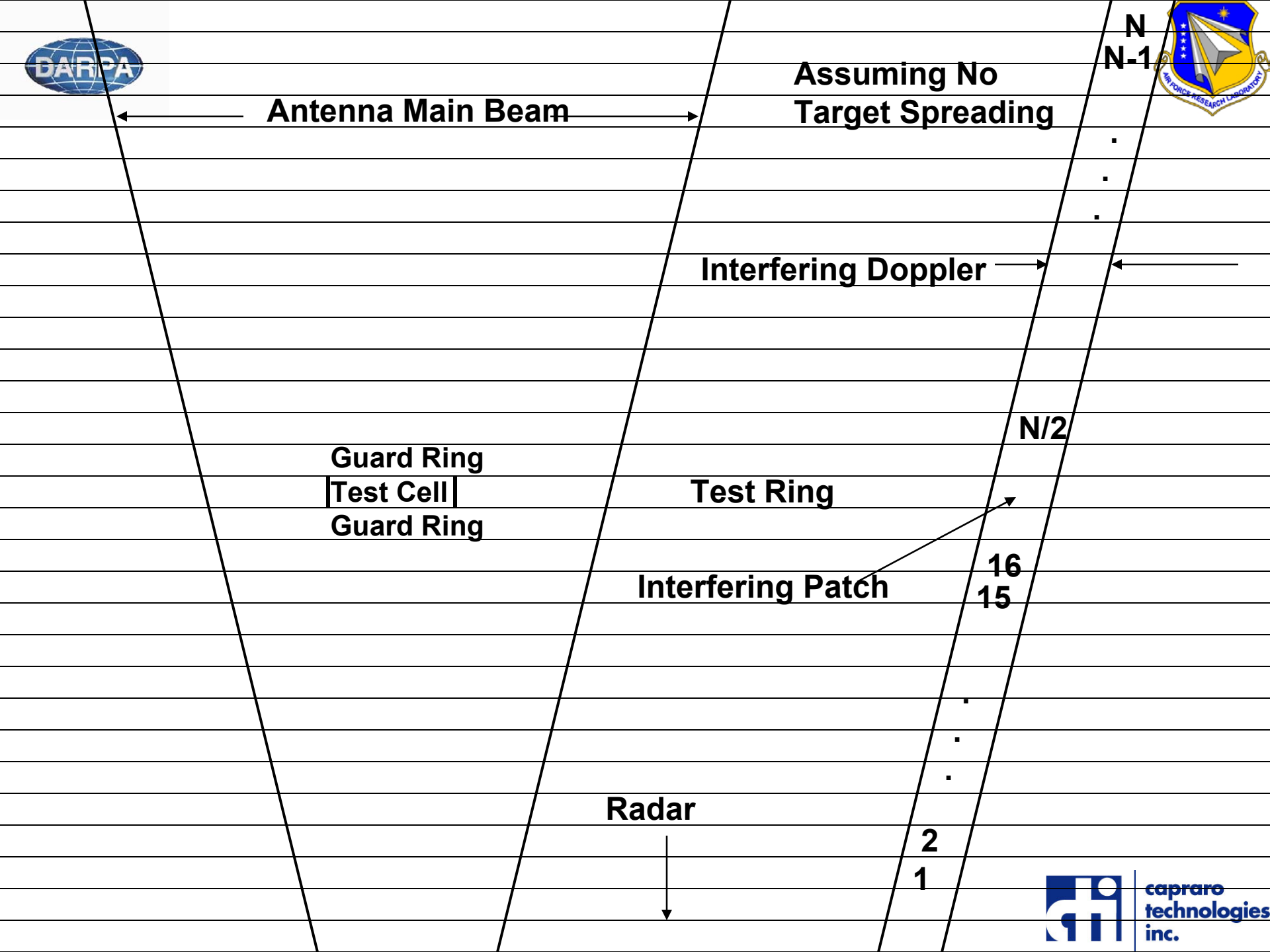
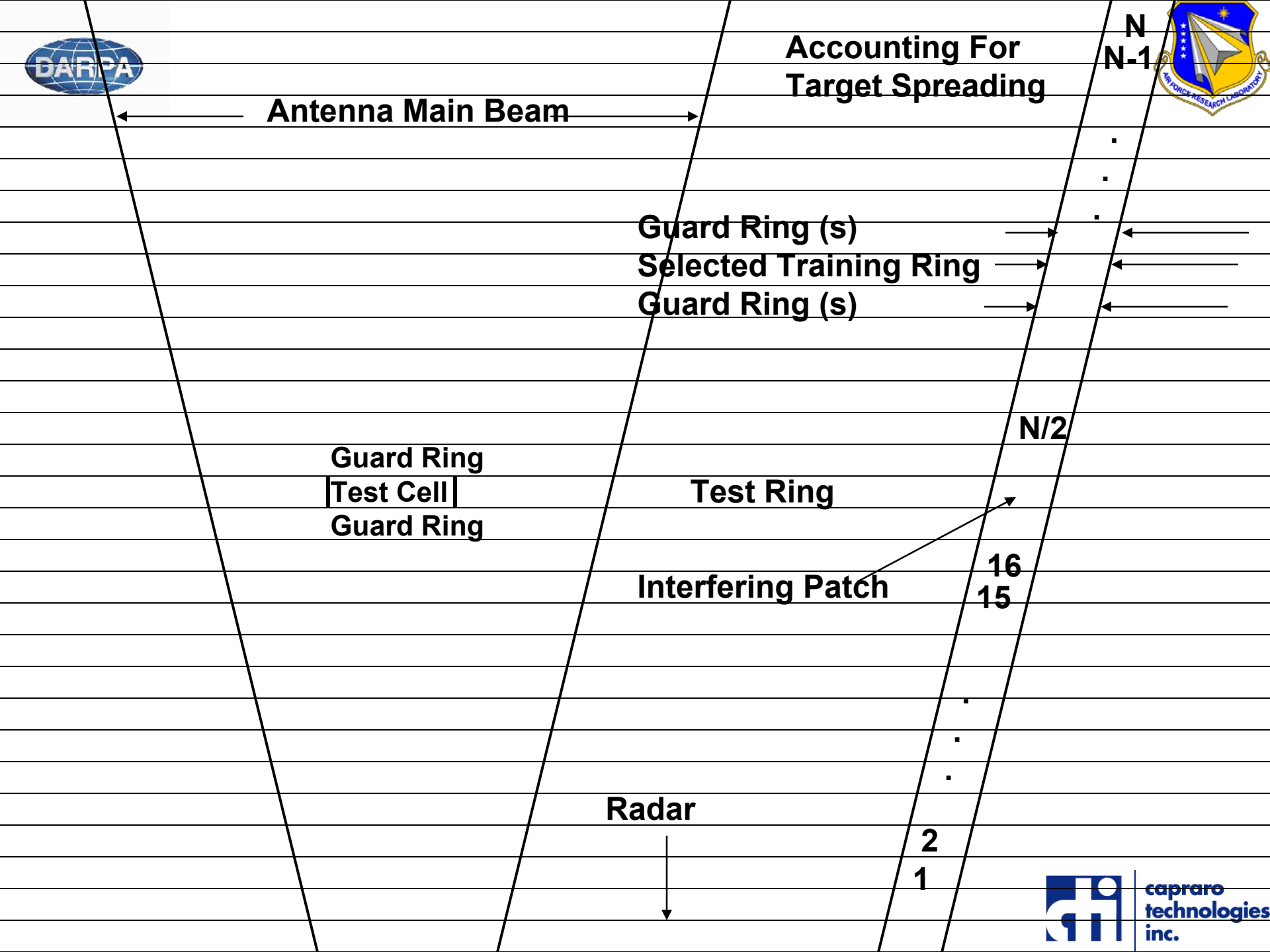


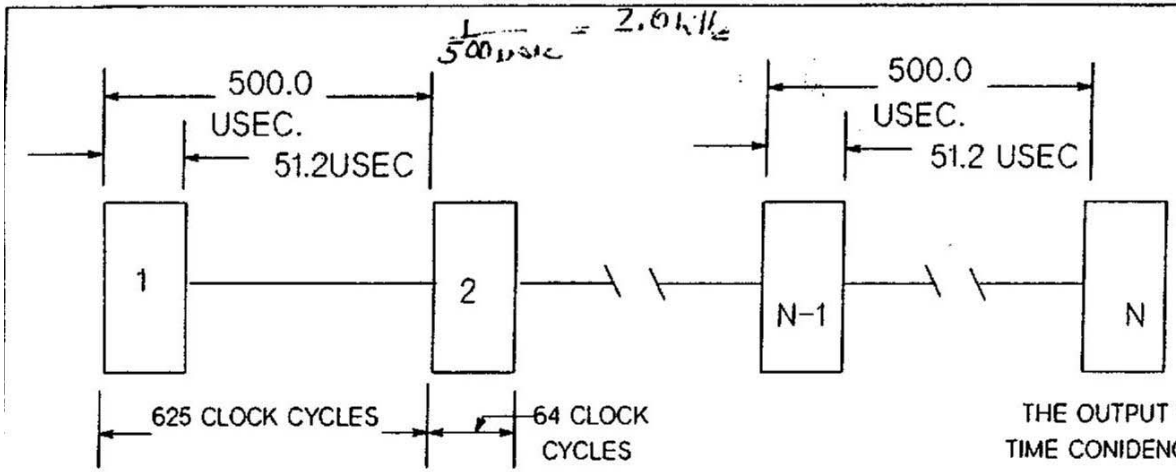
Sliding Window Algorithm (Baseline for comparison)

Test Ring

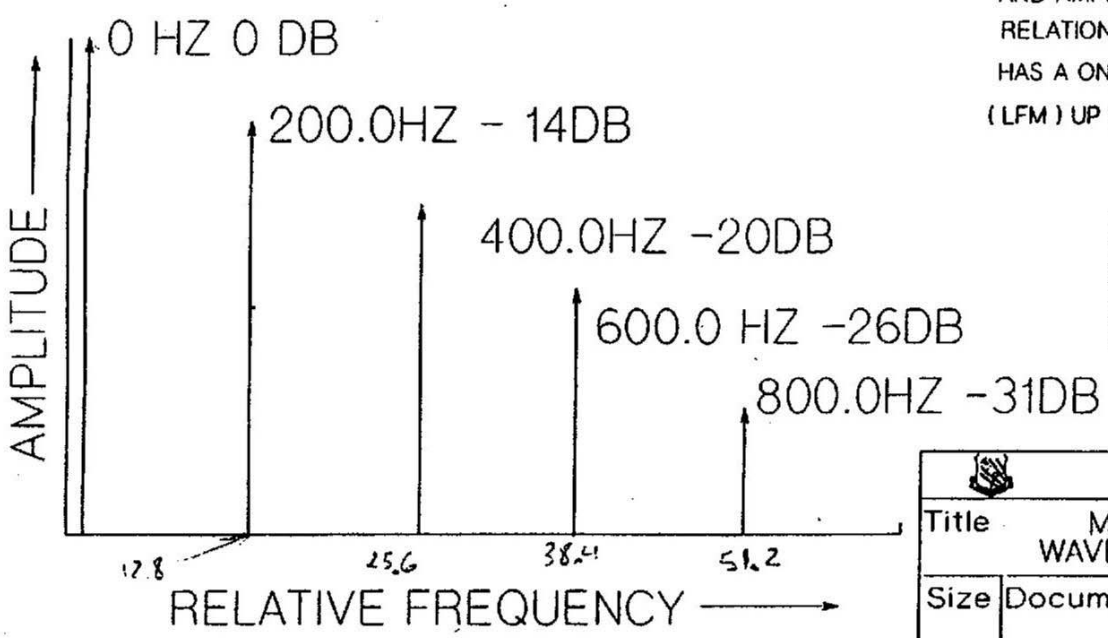

Antenna Main Beam
Assuming No
Target Spreading
N
N-1
Interfering Doppler
N/2
Guard Ring
Test Cell
Guard Ring
Test Ring
Interfering Patch
16
15
Radar
2
1

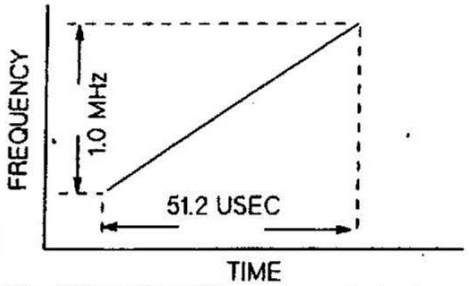

Accounting For
Target Spreading
N
N-1
Antenna Main Beam
Guard Ring (s)
Selected Training Ring
Guard Ring (s)
N/2
Guard Ring
Test Cell
Guard Ring
Test Ring
Interfering Patch
16
15
Radar
2
1

Monostatic, MTS tones



THE OUTPUT WAVEFORM IS COMPOSED OF FIVE (5) TIME CONIDENCE PULSES,(ie 5 DIFFERENT TARGETS IN THE SAME RANGE CELL) HAVING THE FREQUENCY AND AMPLITUDE, (ie RELATIVE DOPPLER AND RCS) RELATIONSHIP SHOWN AT THE LEFT.EACH PULSE ALSO HAS A ONE (1.0) MHz LINEAR FREQUENCY MODULATION (LFM) UP CHIRP.(SEE DIAGRAM BELOW)





0 Hz RELATIVE FREQUENCY CORRESPONDS TO 1240.000000 MHz

Rome Laboratory		
Title	MOVING TARGET SIMULATOR WAVEFORM PARAMETERS MCARM	
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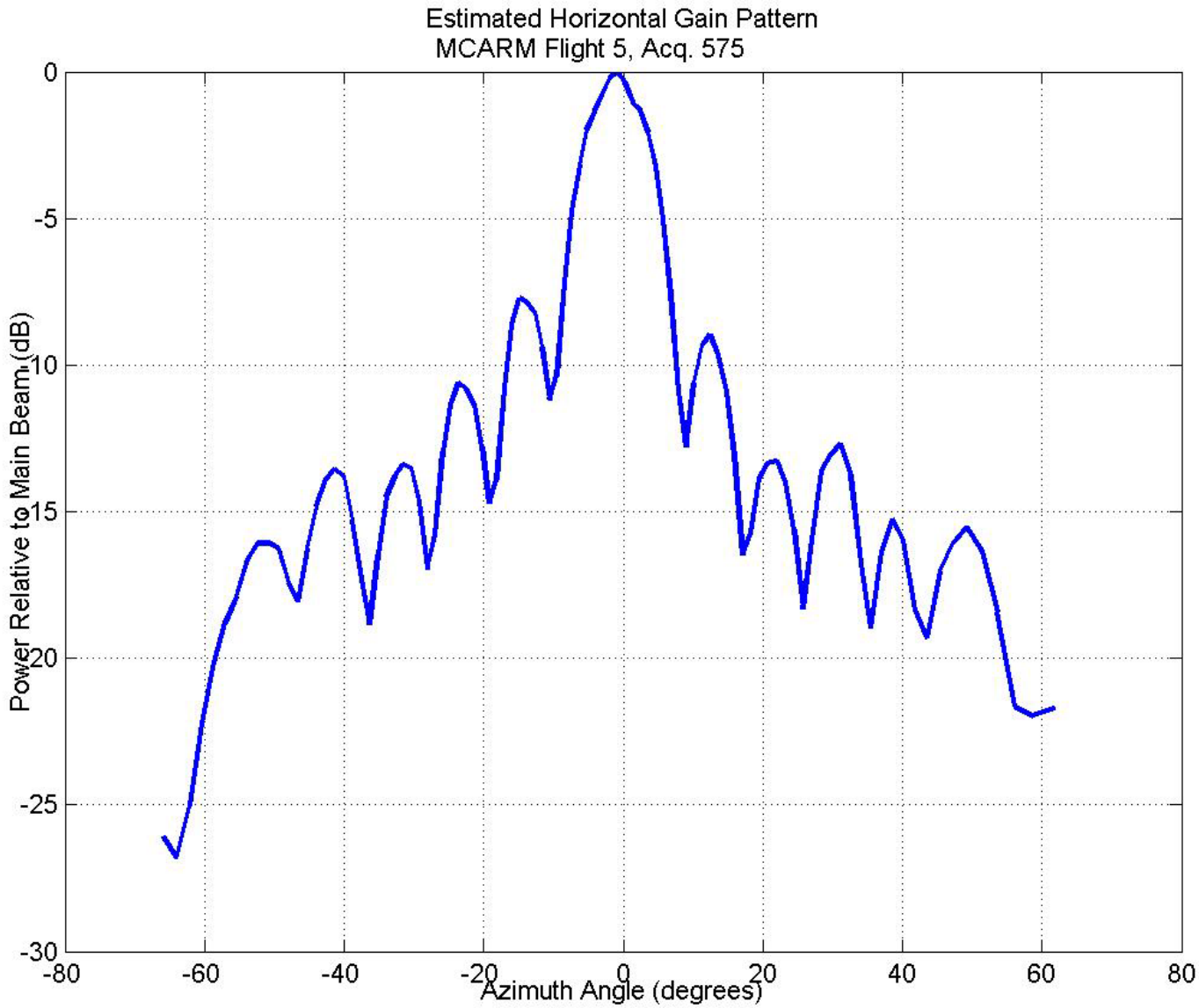
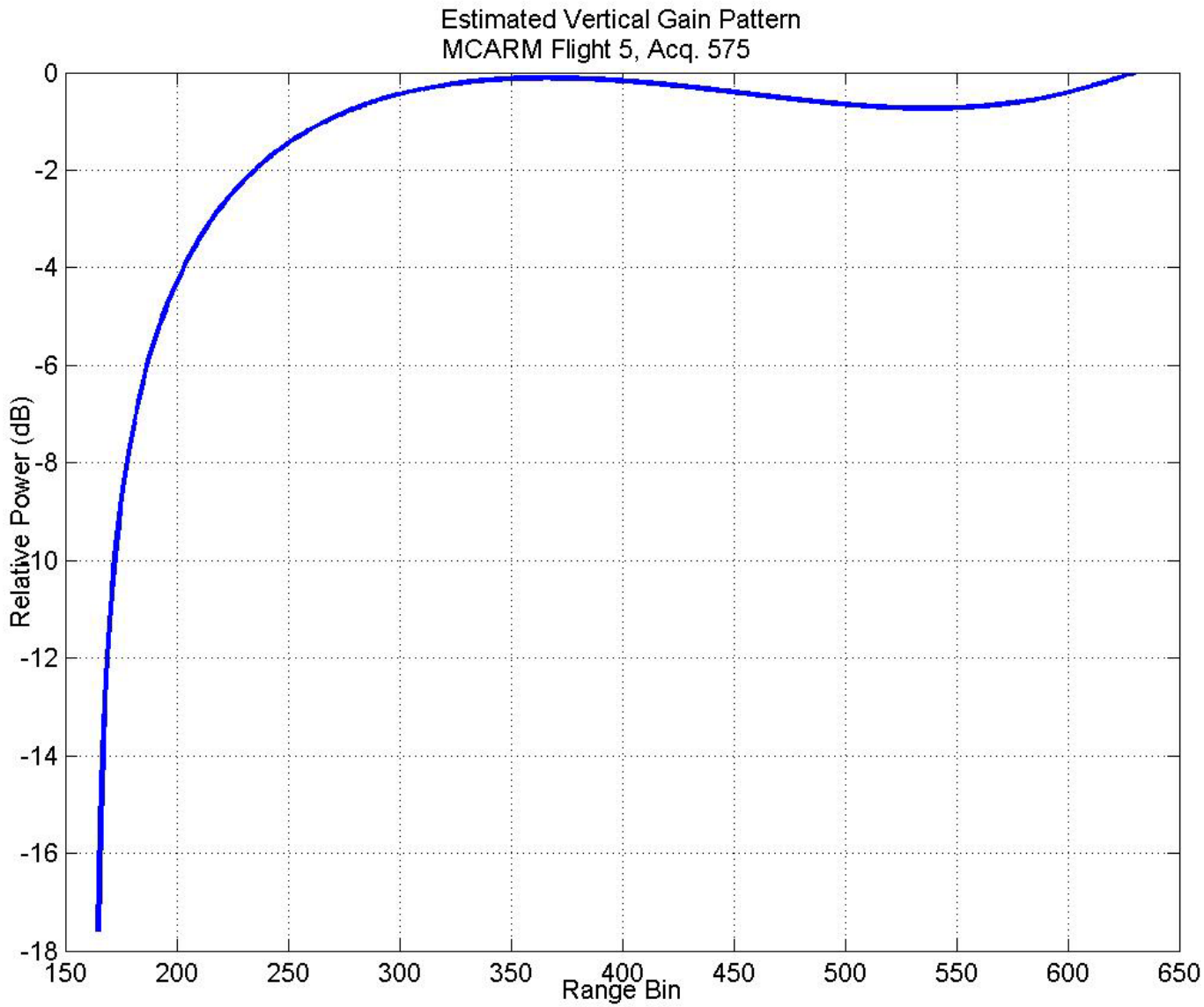
Date: 2 JUNE 1995		Sheet 7 of 8


Estimated Horizontal Gain Pattern
MCARM Flight 5, Acq. 575
Power Relative to Main Beam (dB)
0
-5
-10
-15
-20
-25
-30
-80
-60
-40
-20
0
20
40
60
80
Azimuth Angle (degrees)


Estimated Vertical Gain Pattern
MCARM Flight 5, Acq. 575
Relative Power (dB)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
150
200
250
300
350
400
450
500
550
600
650
Range Bin