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Radar Cross Section Statistics of Dismounts at Ku-band

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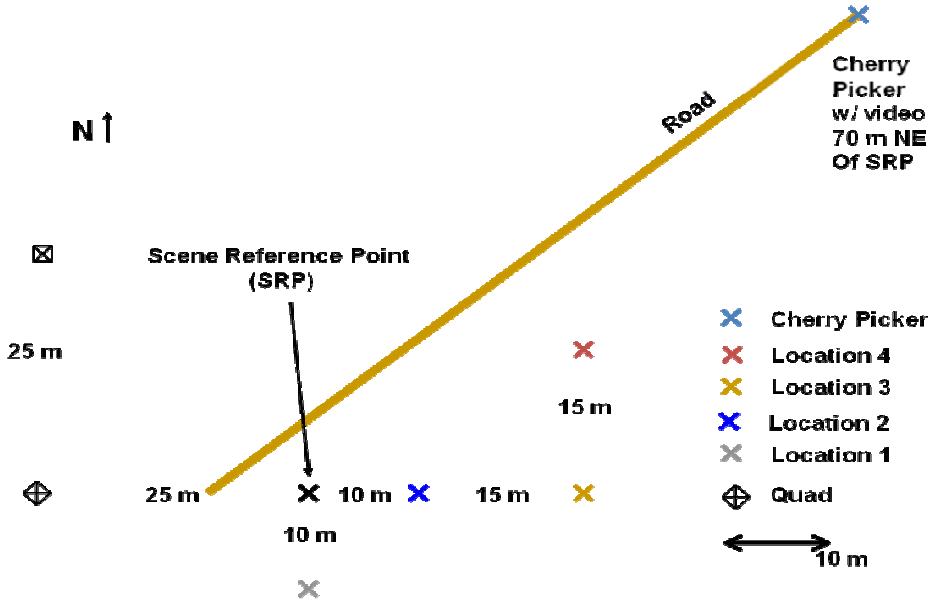
Outline

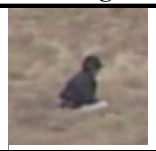
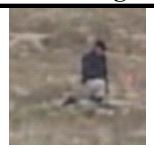
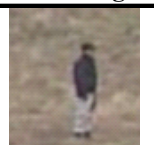
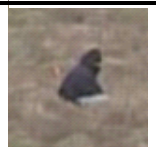
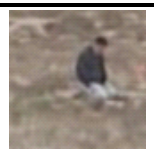
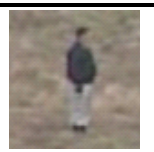
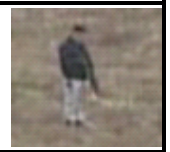
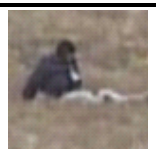
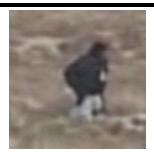
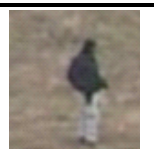
- Problem Statement
- State-of-the-Art
- Calibrated Data Collection Experiments
- Distributions, Statistics, Swerling Target Number
  - Dismount Stance
  - Dismount Size
  - Dismount with Device
  - Dismount Pose (azimuth and grazing)
  - Radar Resolution
  - Radar Polarization
  - Scene Clutter
  - Overall
- Summary

Problem & Motivation

- Ground-moving target indication radar for dismount detection (DMTI) in border, facility, and battlefield monitoring applications requires setting proper thresholds
- Humans are slower in velocity (0-1.5 m/s) and lower in RCS than traditional GMTI targets such as vehicles (~10x) , and inherently mobile targets with a variable scattering return and non-linear phase response, making them more challenging to detect
- Detection requires an understanding of the distribution of dismount RCS and general statistics
- Current literature is anemic at Ku-band, in which many DMTI radars operate, with most work based on models and simulations (e.g. Xpatch)
- Radar measurements needed to corroborate the accuracy and suitability of simulations and limited empirical results

Data Collection Experiment #1



Subject	Sitting	Kneeling	Standing	Rifle
Small				
Medium				
Large				

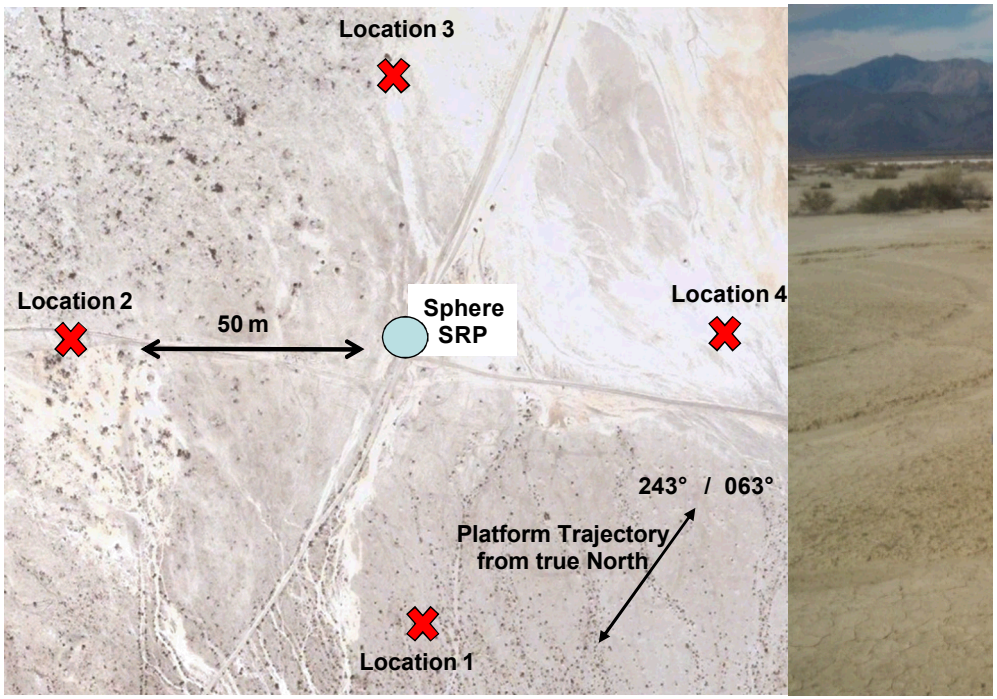
Circle Pass	Location 1	Location 2	Location 3	Location 4
A	Vacant	Small/Rifle	Medium/Standing	Large/Kneeling
B	Vacant	Medium/Rifle	Large/Standing	Small/Kneeling
C	Vacant	Large/Rifle	Small/Standing	Medium/Kneeling
D	Medium/Sitting	Large/Sitting	Small/Sitting	Vacant

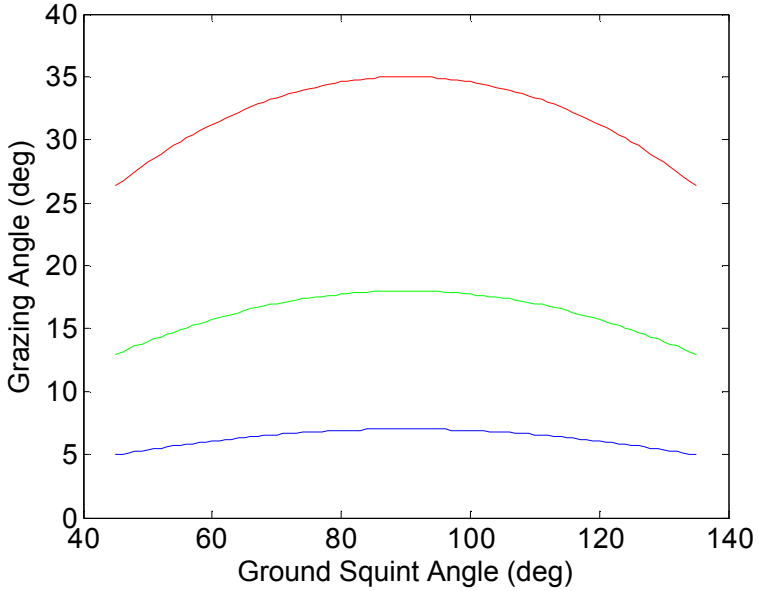
	Small	Medium	Large
Height (ft, in.)	5'4"	5'8"	6'
Weight (lbs)	110	160	220

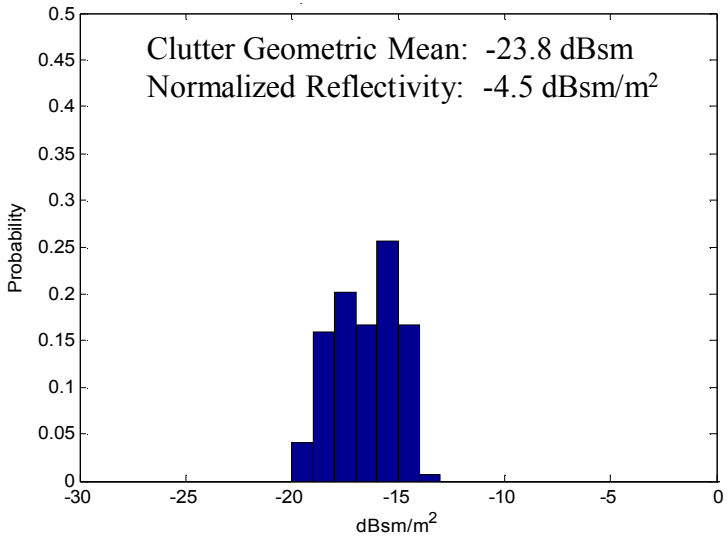
Clutter Geometric Mean: -40.1 dBsm
Normalized Reflectivity: -20.4 dBsm/m^2

FOUR SPOTLIGHT CIRCLE PASSES EVERY 12 DEGREES, AT 18-DEGREE GRAZING, 4" RESOLUTION, AND VERTICAL POLARIZATION WITH SIZE, STANCE, DEVICE, AND LOCATION VARIATIONS OF THREE DISMOUNTS.
TWO QUAD CORNERS IN SCENE FOR ABSOLUTE RCS.

Data Collection Experiment #2

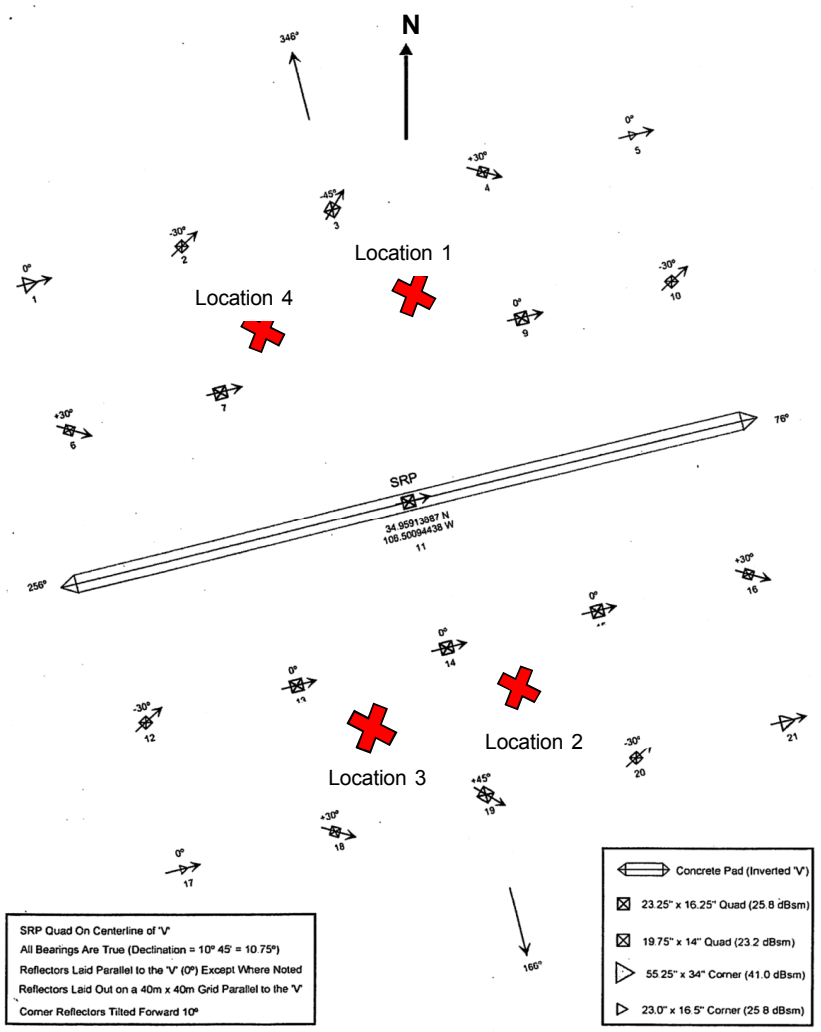


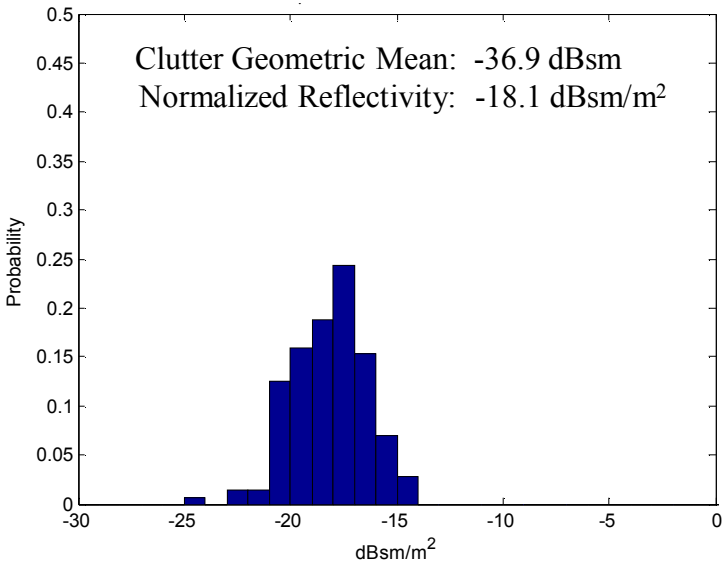




FIVE SPOTLIGHT PASSES EVERY 10 DEGREES AT 7, 18, AND 35 DEGREES CENTER APERTURE GRAZING, 4" RESOLUTION, AND VERTICAL POLARIZATION WITH SIZE AND SCENE CLUTTER VARIATIONS OF FOUR STANDING DISMOUNTS. SPHERE CALIBRATOR FOR ABSOLUTE RCS. LIMITED AZIMUTHAL DATA OF 90 to 180 DEGREES.

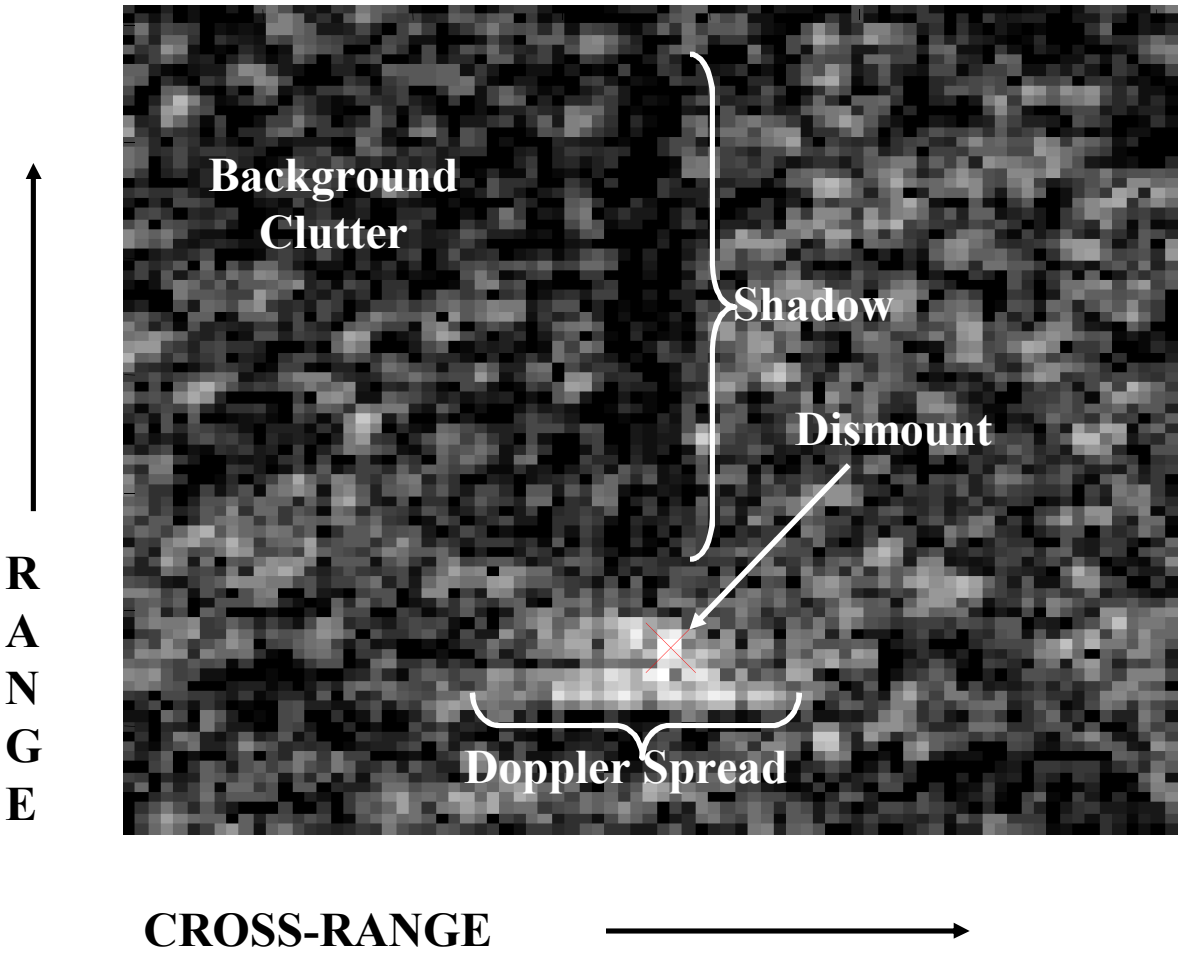
Data Collection Experiment #3





FOUR SPOTLIGHT CIRCLE PASSES EVERY 10 DEGREES, AT 35-DEGREE GRAZING, 4" RESOLUTION, HORIZONTAL POLARIZATION, AND SIMILAR CLUTTER TYPE TO EXPERIMENT #1, WITH SIZE VARIATIONS OF FOUR STANDING DISMOUNTS. RADAR CALIBRATION SITE MULTIPLE QUAD AND SINGLE CORNERS IN SCENE FOR ABSOLUTE RCS.

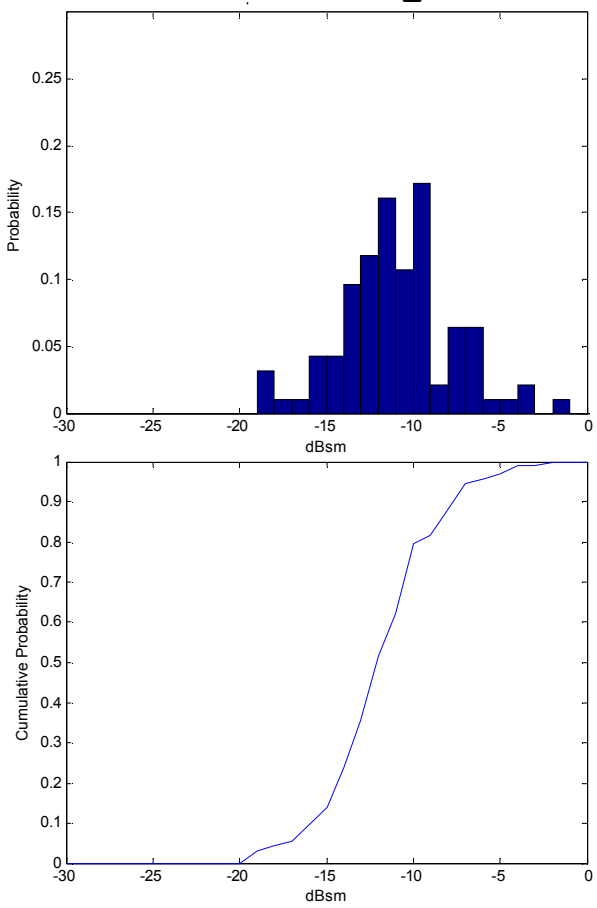
Typical Dismount SAR Image Chip



PEAK DETECTION USED FOR RCS DISTRIBUTIONS AND STATISTICS
(X = PEAK RCS PIXEL)

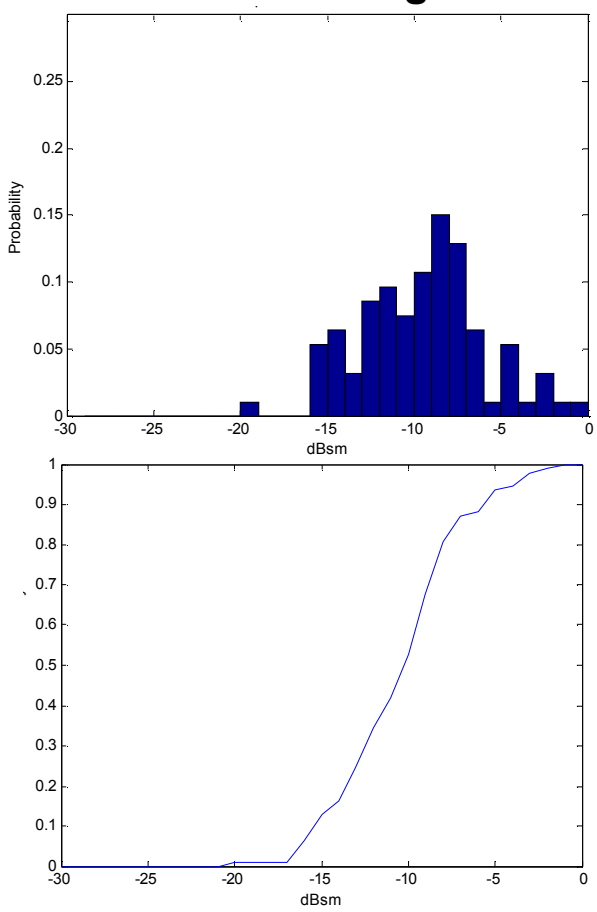
RCS Variation with Stance

Standing



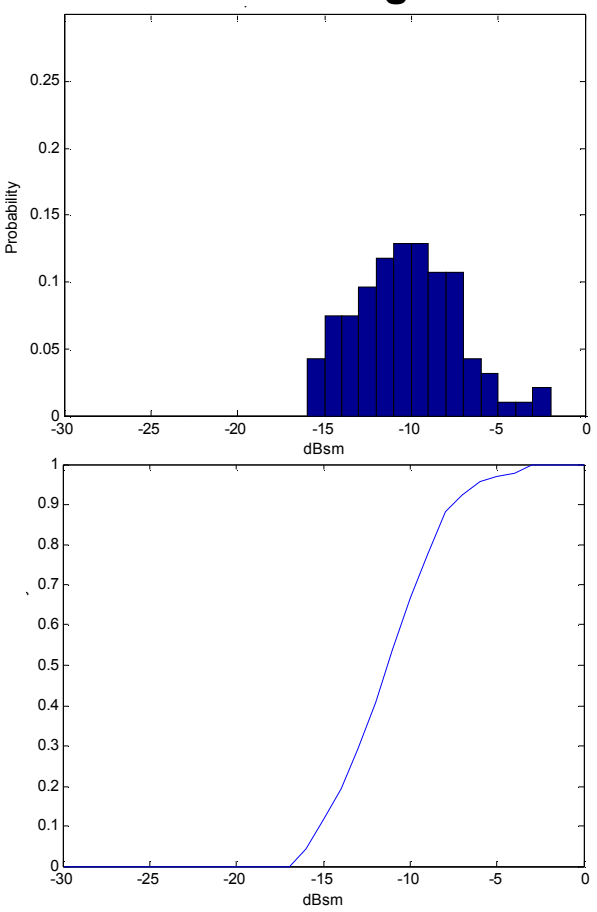
(-12.1, -9.6, -10.9, 3.2)

Kneeling



(-10.3, -8.1, -9.5, 3.5)

Sitting

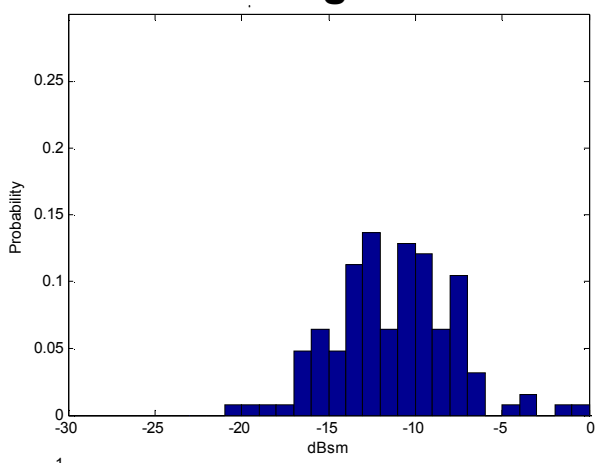
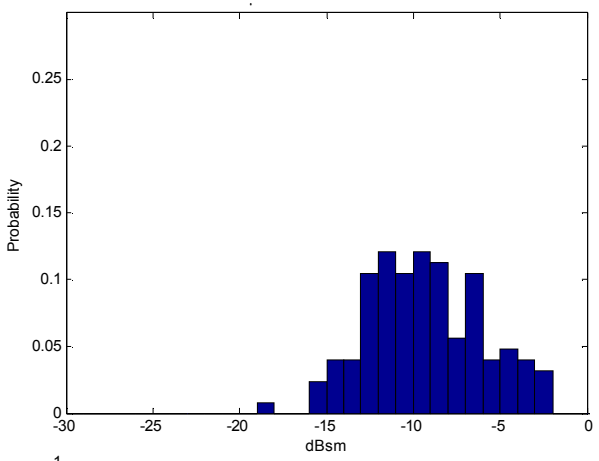
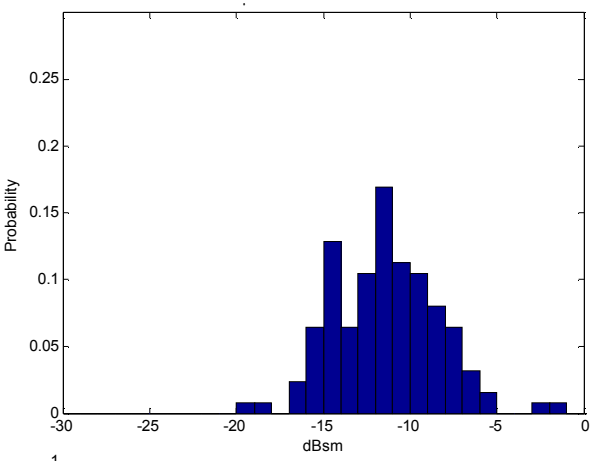
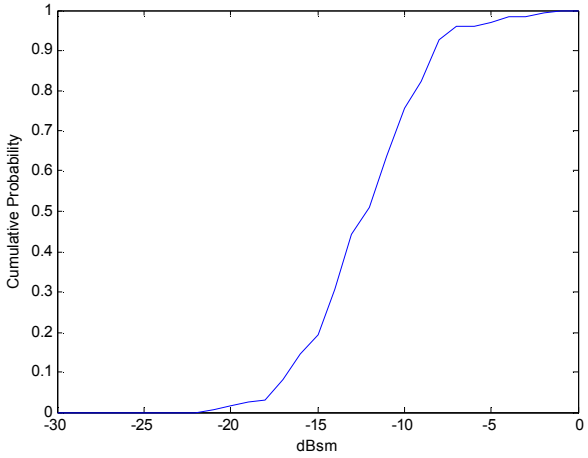
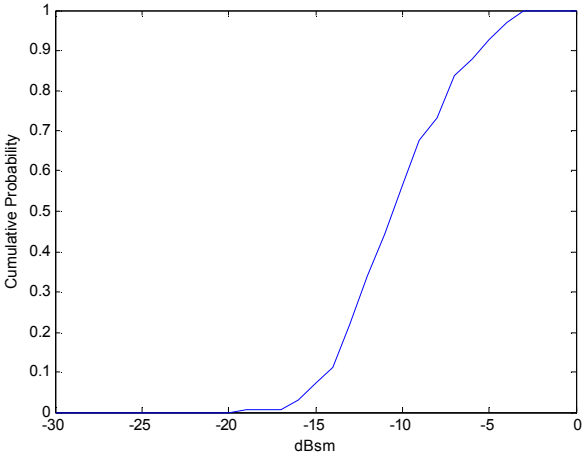
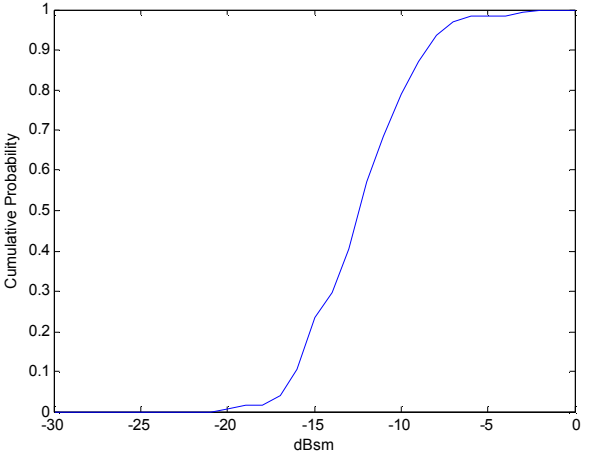


(-11.3, -9.2, -10.2, 2.9)

[Median (dBsm), Arithmetic Mean (dBsm), Geometric Mean (dBsm), Standard Deviation (dB)]

RCS DISTRIBUTIONS AND STATISTICS CONSISTENT ACROSS STANCE.

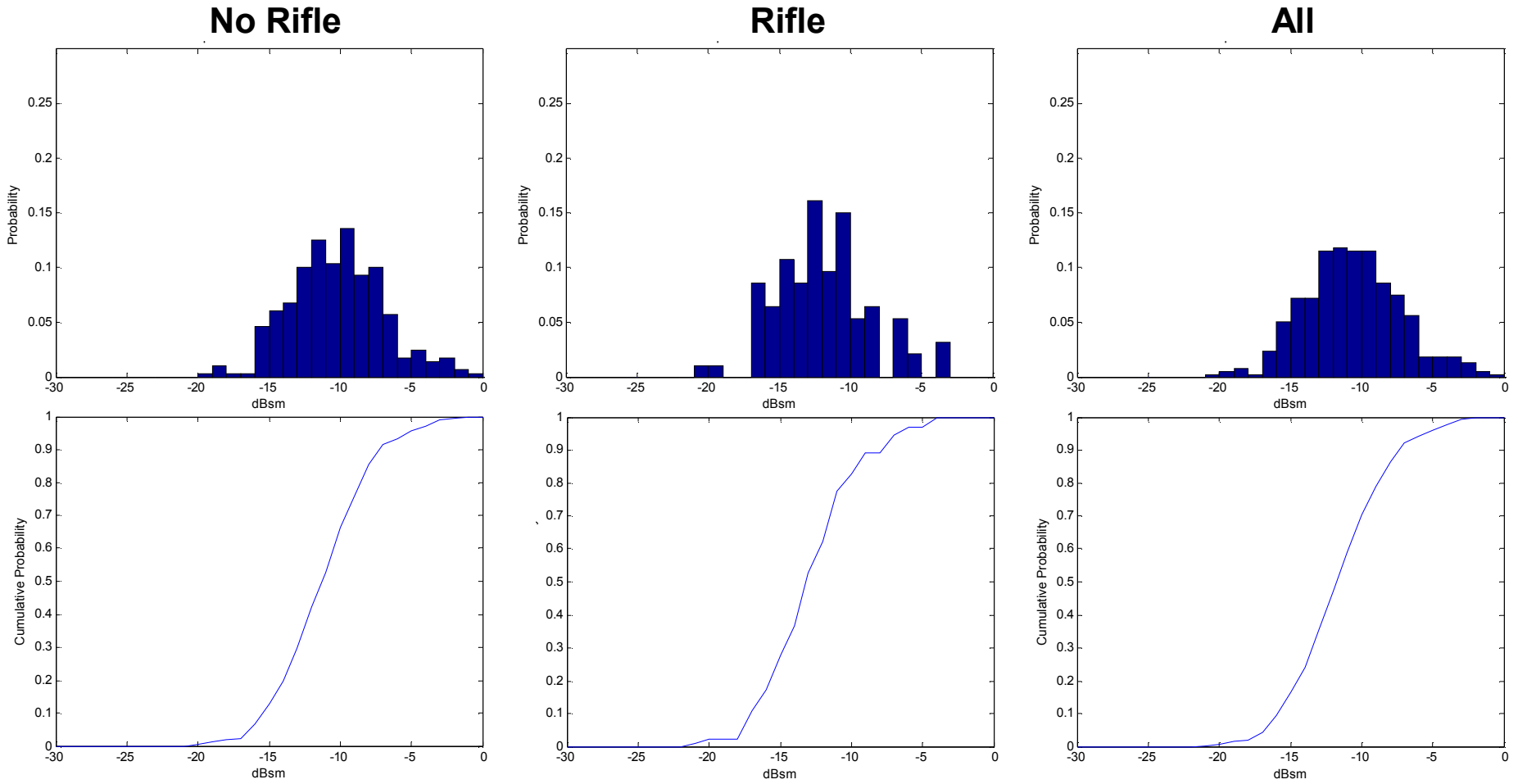
RCS Variation with Size

Large	Medium	Small
		
		
(-12.1, -9.8, -11.3, 3.4)	(-10.5, -8.1, -9.3, 3.3)	(-12.4, -10.2, -11.3, 3.0)

[Median (dBsm), Arithmetic Mean (dBsm), Geometric Mean (dBsm), Standard Deviation (dB)]

RCS DIST. AND STATS CONSISTENT ACROSS SIZE --- WIDTH MATTERS.

RCS Variation with Devices

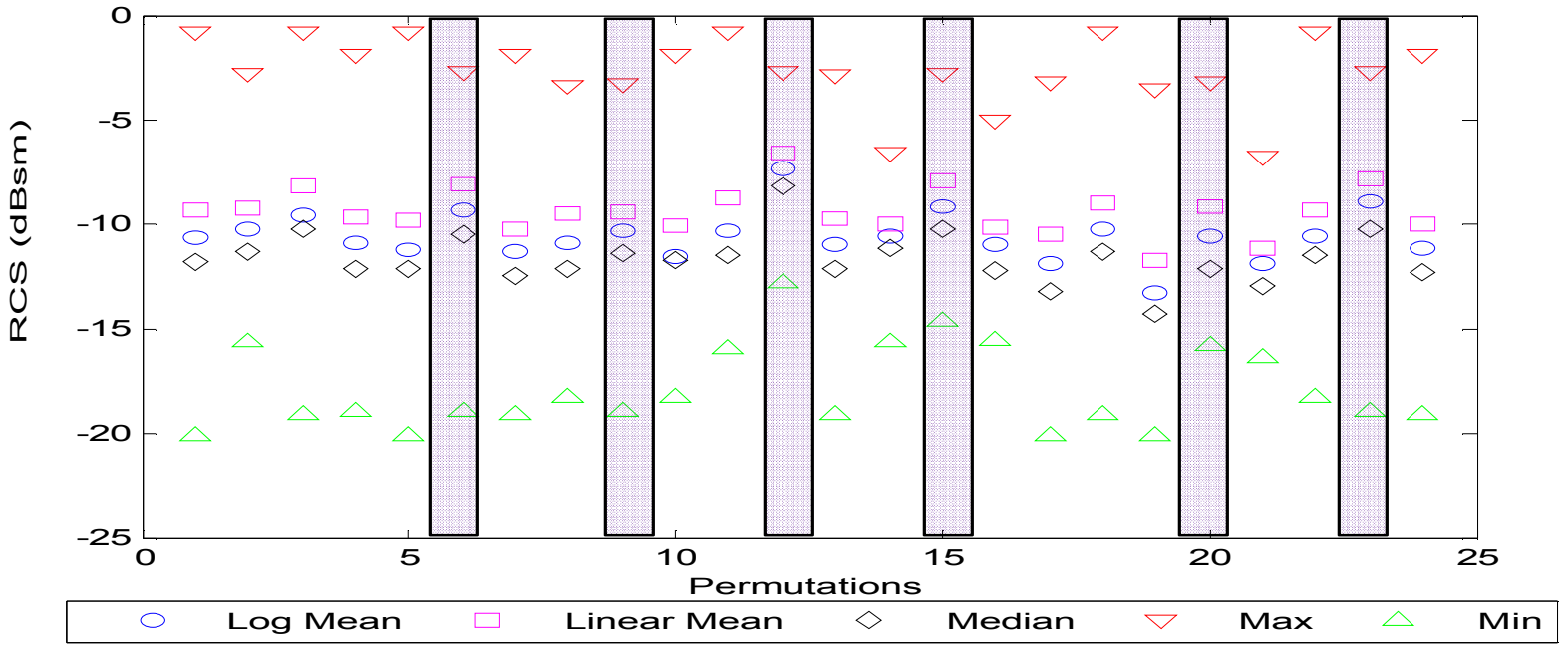


(-11.3, -8.9, -10.2, 3.3) (-13.1, -10.5, -11.8, 3.3) (-11.8, -9.3, -10.6, 3.4)

[Median (dBsm), Arithmetic Mean (dBsm), Geometric Mean (dBsm), Standard Deviation (dB)]

RCS DISTRIBUTIONS AND STATISTICS CONSISTENT ACROSS DEVICE.

RCS Variation with Permutations Summary

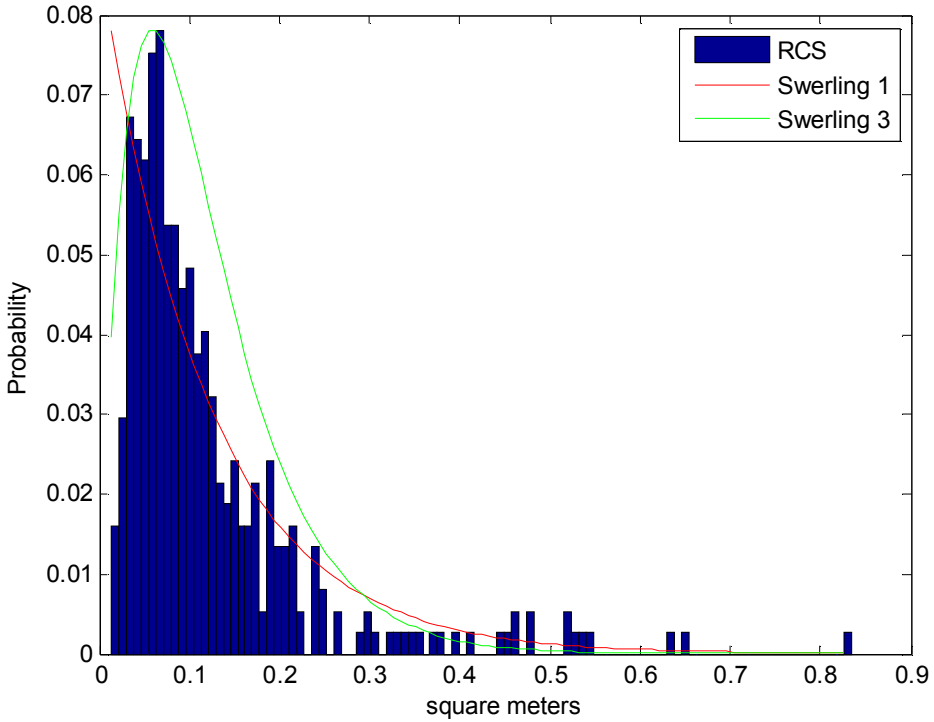


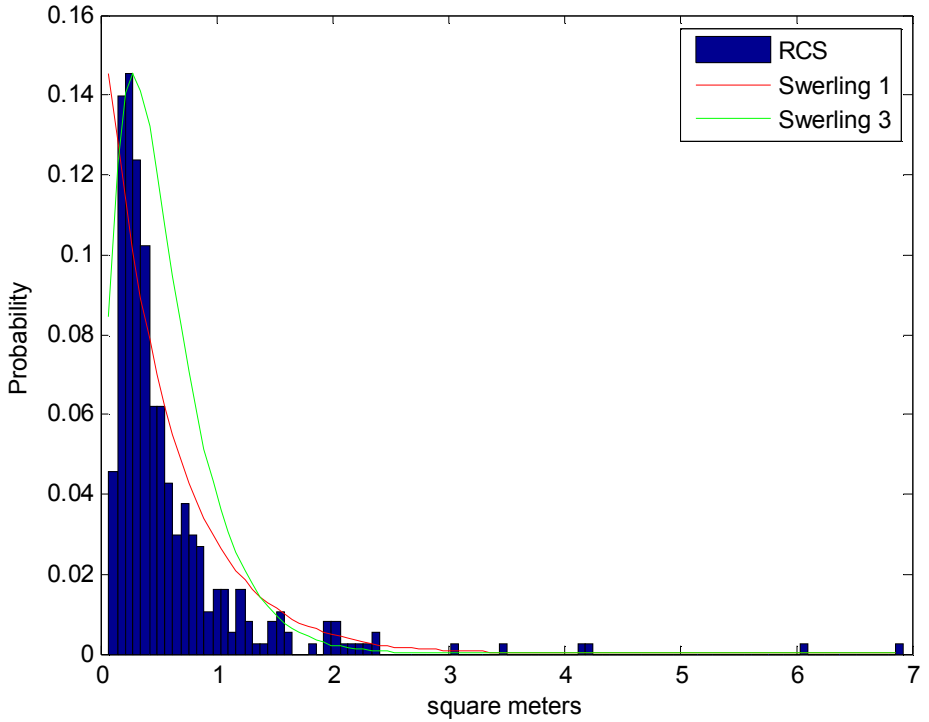
Permutations

1. All Sizes, Stances, Devices
2. Sitting, All Sizes
3. Kneeling, All Sizes
4. Standing, All Sizes
5. Large Person, All Stances, Devices
6. Medium Person, All Stances, Devices
7. Small Person, All Stances, Devices
8. Large Person, Standing
9. Medium Person, Standing
10. Small Person, Standing
11. Large Person, Kneeling on Both Knees
12. Medium Person, Kneeling on Haunches
13. Small Person, Kneeling on One Knee
14. Large Person, Sitting Legs Open
15. Medium Person, Sitting Legs Crossed
16. Small Person, Sitting Legs Crossed
17. Rifle, All Sizes
18. No Rifle, All Sizes, All Stances
19. Rifle, Side Carry, Large Person
20. Rifle, Front Carry, Medium Person
21. Rifle, Shooting, Small Person
22. No Rifle, Large Person, All Stances
23. No Rifle, Medium Person, All Stances
24. No Rifle, Small Person, All Stances

RCS DISTRIBUTIONS AND STATISTICS CONSISTENT ACROSS STANCE, DEVICE, AND SIZE --- WIDTH MATTERS MOST.

Swerling Target Variation with Resolution

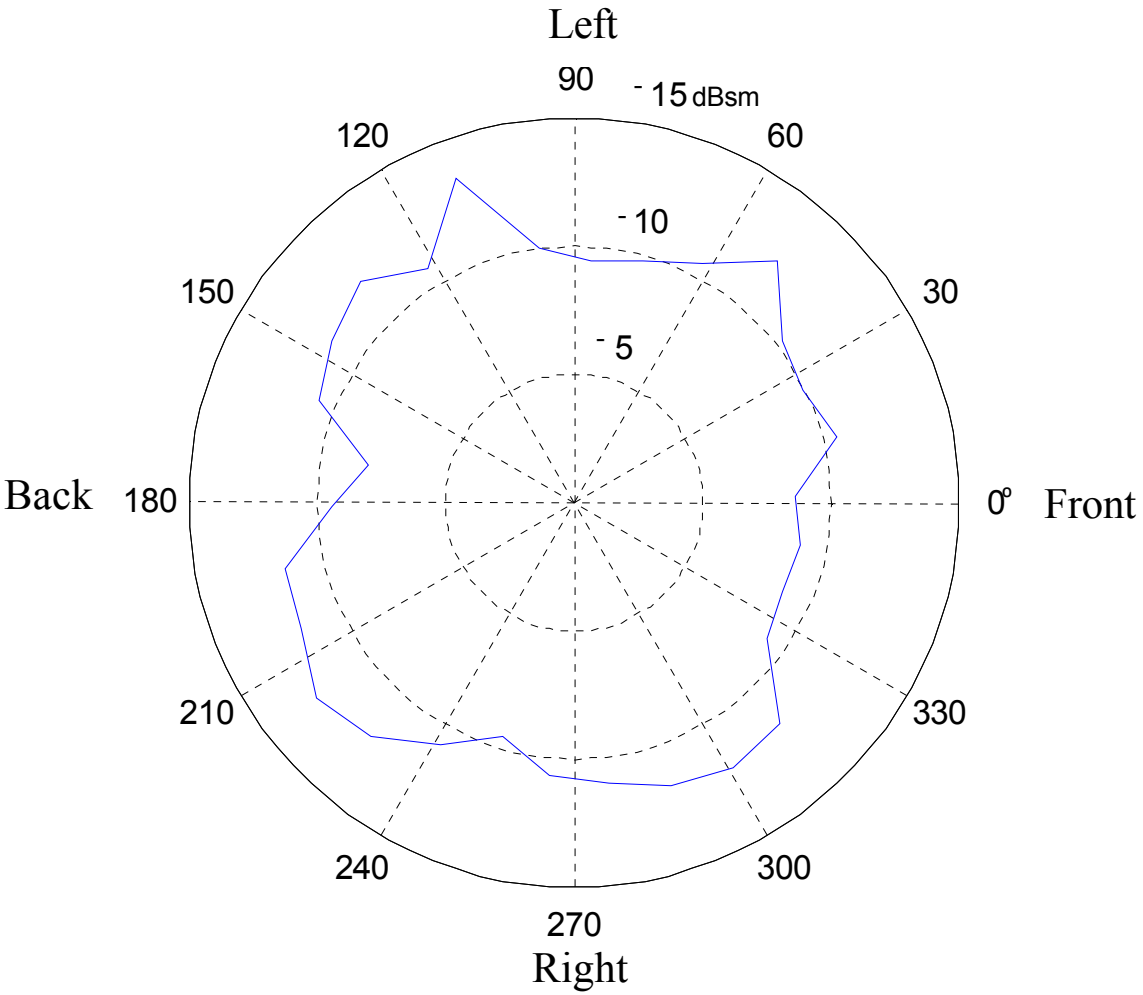




$$f_{\text{Swerling\_1}}(\sigma) = \frac{1}{\sigma_{\text{avg}}} e^{-\frac{\sigma}{\sigma_{\text{avg}}}} \quad , \quad f_{\text{Swerling\_3}}(\sigma) = \frac{4\sigma}{\sigma_{\text{avg}}^2} e^{-\frac{2\sigma}{\sigma_{\text{avg}}}}$$

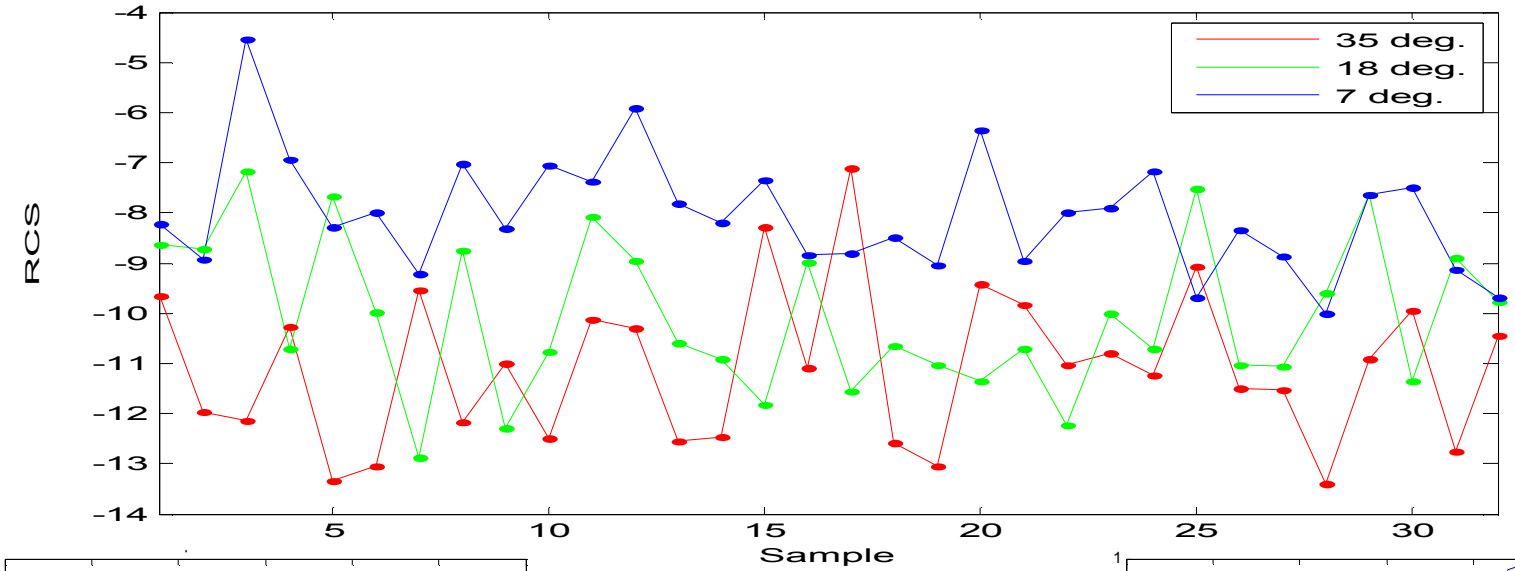
RCS DISTRIBUTION CONSISTENTLY A SWERLING 3 TARGET (DOMINANT SCATTERER, PULSE TO PULSE CORRELATION)

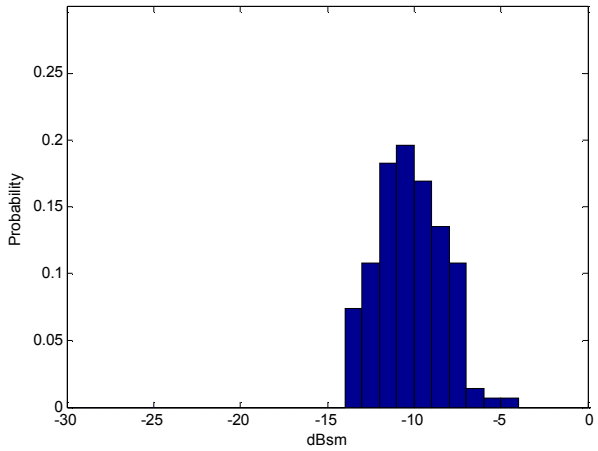
RCS Variation with Pose (Azimuth)



MEAN RCS CONSISTENT ACROSS AZIMUTHAL POSE
(4" RESOLUTION LIMITED ANGULAR ACQUISITION EVERY 12 DEGREES)

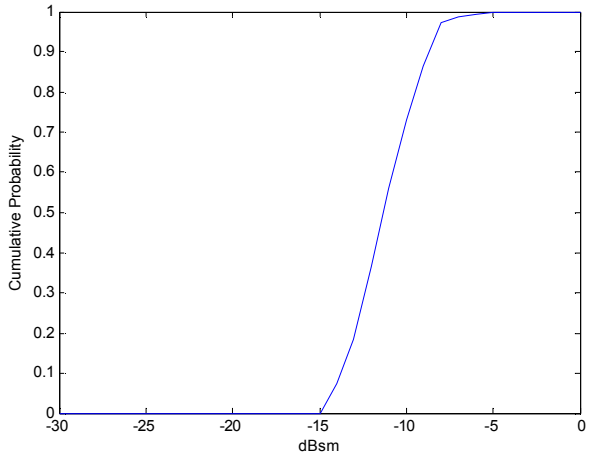
RCS Variation with Pose (Grazing)





(-11, -9.8, -10.2, 1.8)

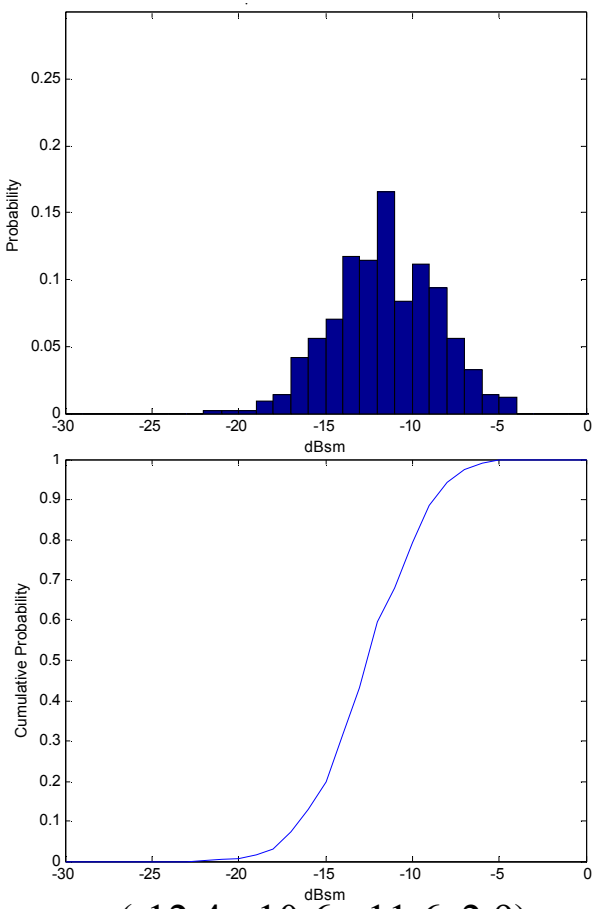
[Median (dBsm),
Arithmetic Mean (dBsm),
Geometric Mean (dBsm),
Standard Deviation (dB)]



RCS TREND IS TO DECREASE WITH INCREASING GRAZING ANGLE.
DISTRIBUTIONS AND STATISTICS STILL CONSISTENT ACROSS POSE.

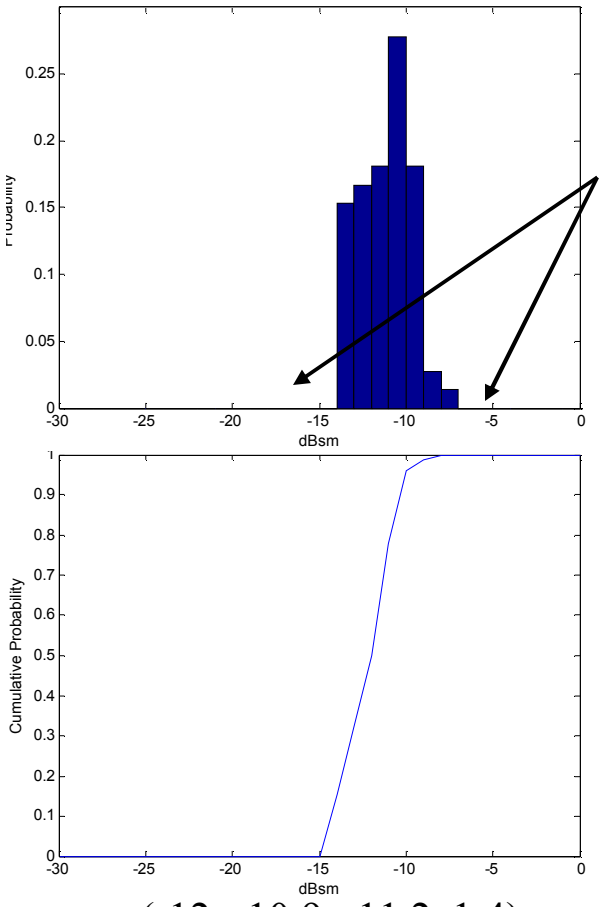
RCS Variation with Polarization (HH, VV)

Horizontal (35)



(-12.4, -10.6, -11.6, 2.9)

Vertical (35)



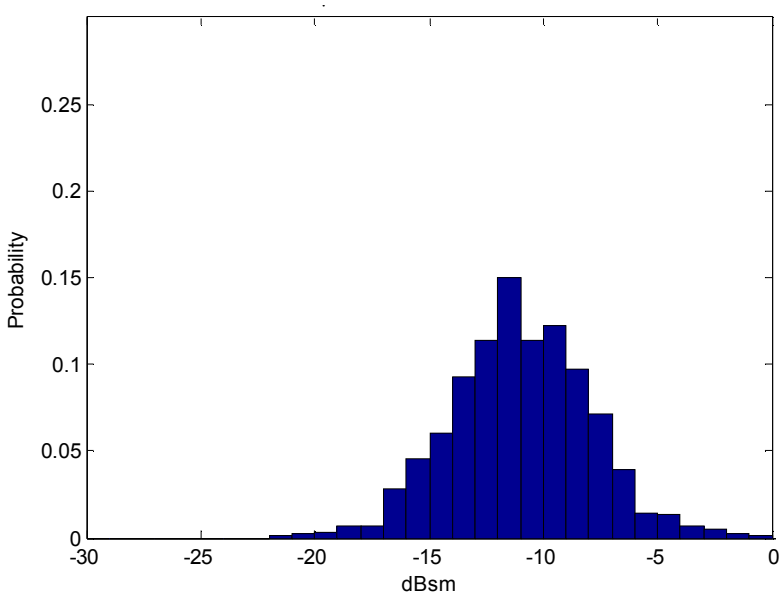
(-12, -10.9, -11.2, 1.4)

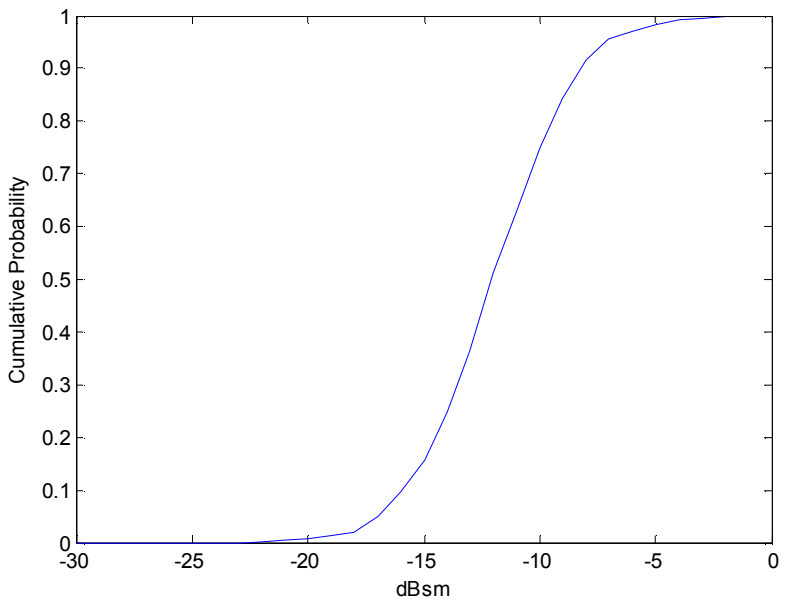
NOTE:
Distribution Tails Not Well-defined for Experiment #2 due to Sparse Data with Limited Azimuthal Extent –Impacts Std. Dev. and Range. This is also true for prior slide on grazing angle.

[Median (dBsm), Arithmetic Mean (dBsm), Geometric Mean (dBsm), Standard Deviation (dB)]

RCS DIST. AND STATS CONSISTENT ACROSS POLARIZATION.
SIMULATIONS CLAIM 4 TO 5 DB ADVANTAGE FOR HH --- NOT SO?

Overall 4” Resolution RCS Results

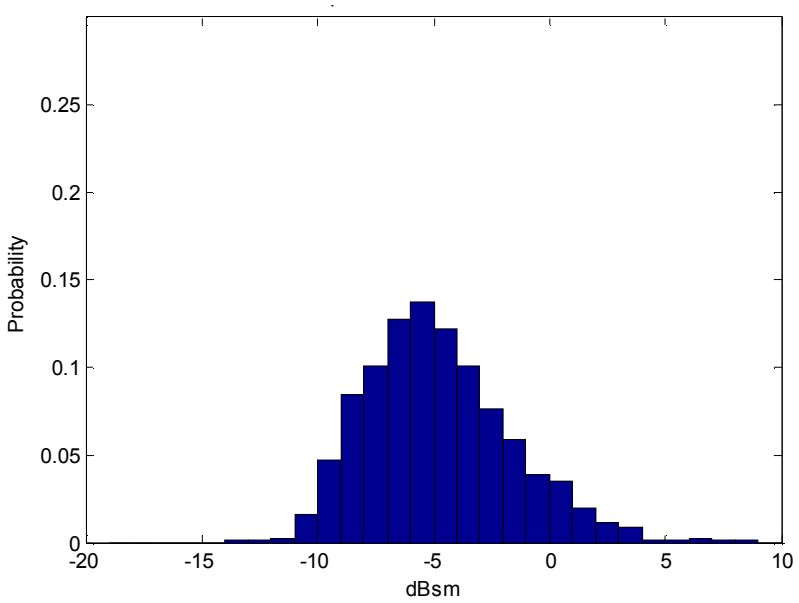


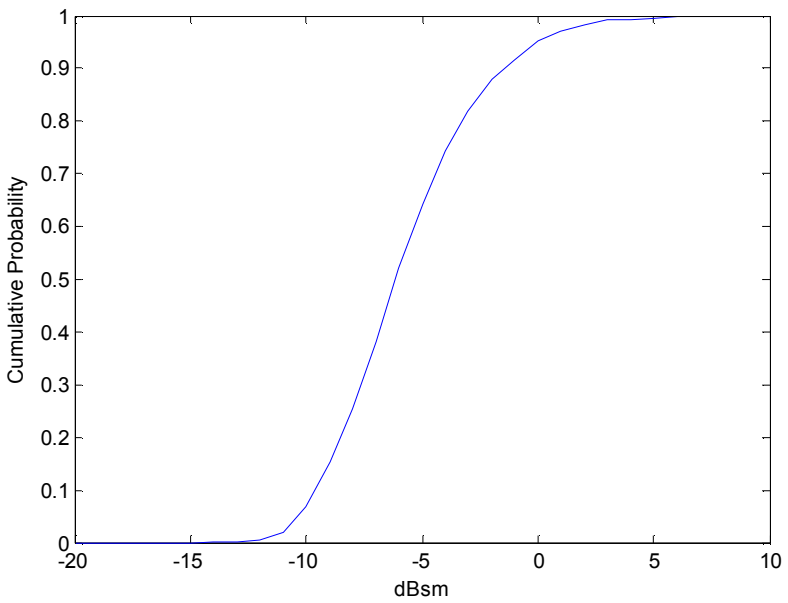


RCS Summary (All Experiments and Variations)	
Arithmetic Mean: -9.9 dBsm	Swerling Target: 3
Geometric Mean: -11 dBsm	90% P_d Threshold: -15.7 dBsm
Median: -12.1 dBsm	10% $P_{exceeding}$ Upper Limit: -7 dBsm
Std. Dev.: +/- 3 dB	Conclusions: Consistent distribution & statistics across size, stance, device, pose, polarization, and clutter.
Range: -20 to 0 dBsm	

6 DB LOWER EXPERIMENTAL RCS CHARACTERISTICS VERSUS SIMULATION LITERATURE --- DOPPLER SPREAD IN RESOLUTION CELLS

Overall 3' Resolution RCS Results





RCS Summary (All Experiments and Variations)	
Arithmetic Mean: -3.4 dBsm	Swerling Target: 3
Geometric Mean: -4.8 dBsm	90% P_d Threshold: -9.2 dBsm
Median: -6.1 dBsm	10% $P_{exceeding}$ Upper Limit: -0.5 dBsm
Std. Dev.: +/- 3.2 dB	Conclusions: Consistent distribution & statistics across size, stance, device, pose, polarization, and clutter.
Range: -12 to 7 dBsm	

EXPERIMENTAL RCS CHARACTERISTICS VERSUS SIMULATION LITERATURE CONSISTENT --- DISMOUNT IN SINGLE RESOLUTION CELL

Summary

- **Dismount RCS Distributions, Statistics, and Swerling Target Number Consistent Across:**
  - **Dismount Stance**
  - **Dismount Size (width more important)**
  - **Dismount with Device**
  - **Dismount Pose (azimuth and grazing)**
  - **Radar Resolution (for Swerling number, which is consistently Swerling 3)**
  - **Radar Polarization**
  - **Scene Clutter**

4” Resolution	3’ Resolution
Arithmetic Mean: -9.9 dBsm	Arithmetic Mean: -3.4 dBsm
Geometric Mean: -11 dBsm	Geometric Mean: -4.8 dBsm
Median: -12.1 dBsm	Median: -6.1 dBsm
Std. Dev.: +/- 3 dB	Std. Dev.: +/- 3.2 dB
Range (.1<P<.9): -15.7 to -9.2 dBsm	Range (.1<P<.9): -9.2 to -0.5 dBsm

- **Simulation 5 dB gain in HH polarization not observed --- further investigation is required**
- **Observations in literature consistent for 3’ resolution --- values 6 dB lower for 4” resolution due to Doppler spread across cells**

References and Acknowledgements

References:

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