

# Radar Cross Section Statistics of Ground Vehicles at Ku-band

## SPIE Defense & Security Symposium April 25, 2011, 2:10 PM

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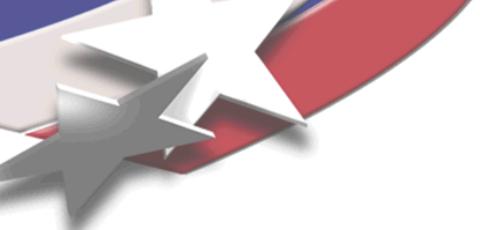




# Outline

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- Problem Statement
- State-of-the-Art
- Military and Civilian Data Acquisition
- Distributions, Statistics, Swerling Target Number
  - Vehicle Size
  - Vehicle Configuration
  - Vehicle Pose (azimuth and grazing)
  - Radar Resolution
  - Radar Polarization
  - Scene Clutter
  - Overall
- Summary



# Problem & Motivation

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- **Ground-moving target indication radar for ground vehicles in border, facility, and battlefield monitoring applications requires setting proper thresholds**
- **Detection requires an understanding of the distribution of vehicle RCS and general statistics**
- **Current literature is anemic at Ku-band, in which many GMTI radars operate, with most work based on models and simulations (e.g. Xpatch) or chamber measurements, or limited experimental data sets**
- **Radar measurements needed to corroborate the accuracy and suitability of simulations, controlled chamber experiments, and limited empirical results**



# Data Set Acquisition

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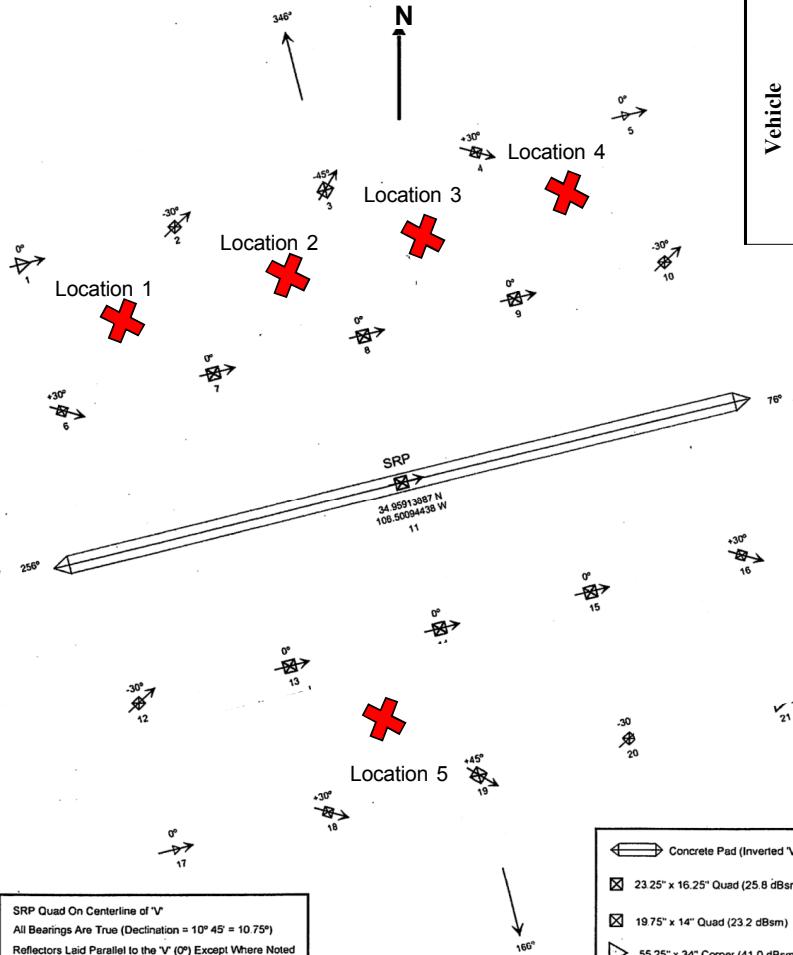
- Sandia National Laboratories' Automatic Target Recognition Database
  - MSTAR
  - General Atomics Lynx Data Collects
  - Sandia Test-bed Radar Data Collects
- X-band and Ku-band Calibrated RCS Data
- Multiple vehicle chips with varying
  - Polarization (HH, HV, VV)
  - Vehicle Pose (0-360 degree AZ, 5-50 degree EL)
  - Resolution (4", 1', 1.5', & ability to coarsen)
  - Clutter
- Primarily large vehicle target types

# Data Set Target & Clutter Types

<ul style="list-style-type: none"><li>• Military vehicles<ul style="list-style-type: none"><li>– Tanks</li><li>– Launchers</li><li>– Armored vehicles</li><li>– Fuelers</li><li>– Trucks</li><li>– Transporters</li></ul></li><li>• Civilian vehicles<ul style="list-style-type: none"><li>– Bulldozers</li><li>– Flat-bed trucks</li><li>– School buses</li><li>– Trailers</li><li>– Large pick-up trucks</li></ul></li></ul>	<ul style="list-style-type: none"><li>• Grass</li><li>• Asphalt</li><li>• Desert with Vegetation</li><li>• Fields</li><li>• Clay</li><li>• Gravel</li><li>• Sand</li></ul>
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**CALIBRATED RCS OF VARIOUS LARGE VEHICLES AND CONFIGURATIONS  
IN DIVERSE CLUTTER TYPES AND SCENES SETTINGS.**

# Personal Vehicle Experiment



Vehicle

Location 1	Location 2	Location 3	Location 4	Location 5
Chevrolet Express Large Van	Ford F350 Pick-up Truck	Pontiac Grand Am Mid-size Sedan	Dodge Caravan Mid-size Van	Dodge Ram Pick-up Truck
				

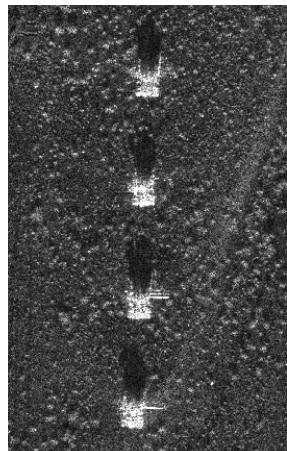
- **TWO SPOTLIGHT CIRCLE PASSES EVERY 10 DEGREES IN AZIMUTH, 4" RESOLUTION, HORIZONTAL POLARIZATION, KU-BAND, AND DESERT CLUTTER WITH VEGETATION**
- **20 AND 30-DEGREE GRAZING ANGLES**
- **RADAR CALIBRATION SITE MULTIPLE QUAD AND SINGLE CORNERS IN SCENE FOR ABSOLUTE RCS.**
- **TWO VANS, TWO TRUCKS, 1 SEDAN**

Concrete Pad (Inverted 'V')

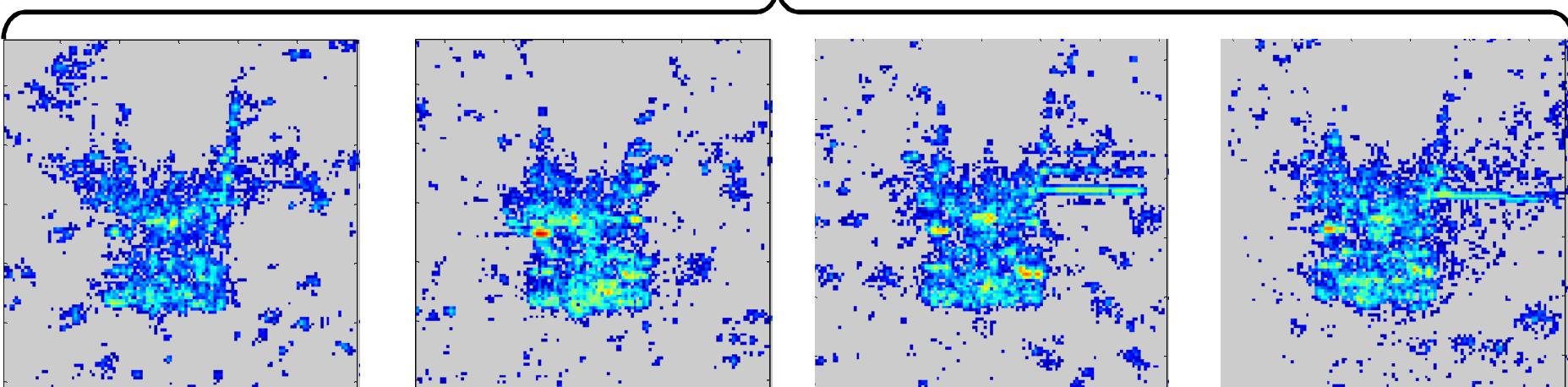
- ☒ 23.25" x 16.25" Quad (25.8 dBsm)
- ☒ 19.75" x 14" Quad (23.2 dBsm)
- ▷ 55.25" x 34" Corner (41.0 dBsm)
- ▷ 23.0" x 16.5" Corner (25.8 dBsm)



# Military Vehicle SAR Image Chip Example



- Column of Derelict M-47 Tanks at 17.3 Grazing and 85.3 Squint.
- SAR Image Chips with Dynamic Range limited from -20 to 25dBsm.
- Chips consist of many scattering centers, with most exhibiting a dominant scatterer.

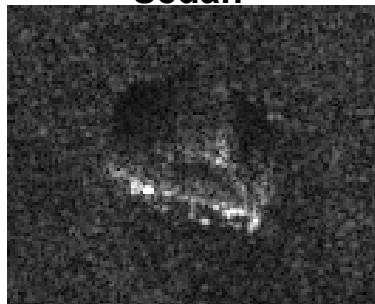


**PEAK DETECTION USED FOR RCS DISTRIBUTIONS AND STATISTICS.**

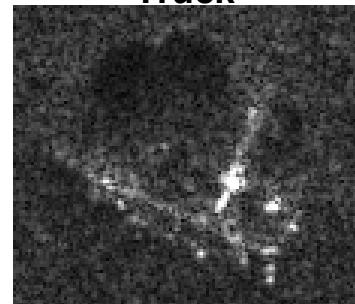
# Civilian Vehicle SAR Image Chip Examples

Side Oblique Angle

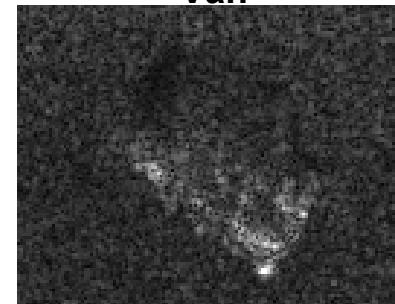
Sedan



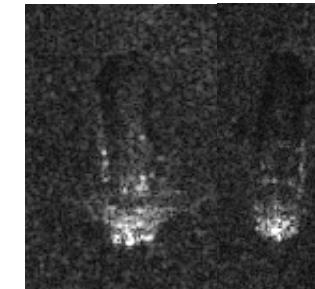
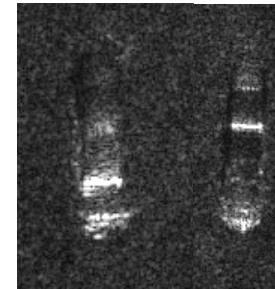
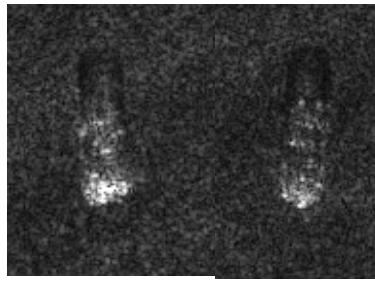
Truck



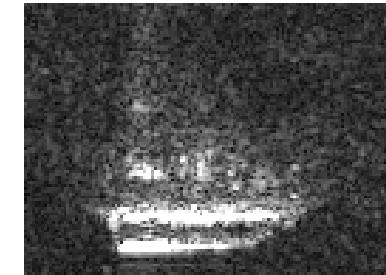
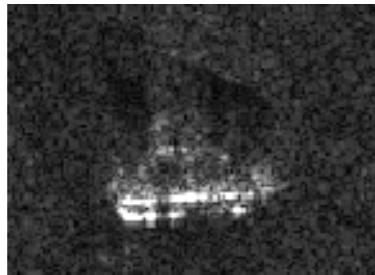
Van



Back/Front Flash

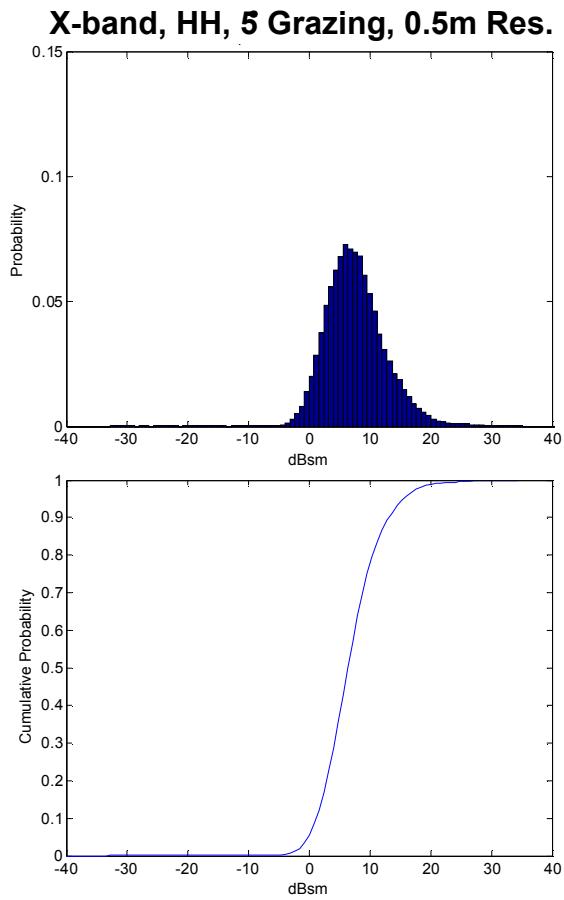


Side Flash

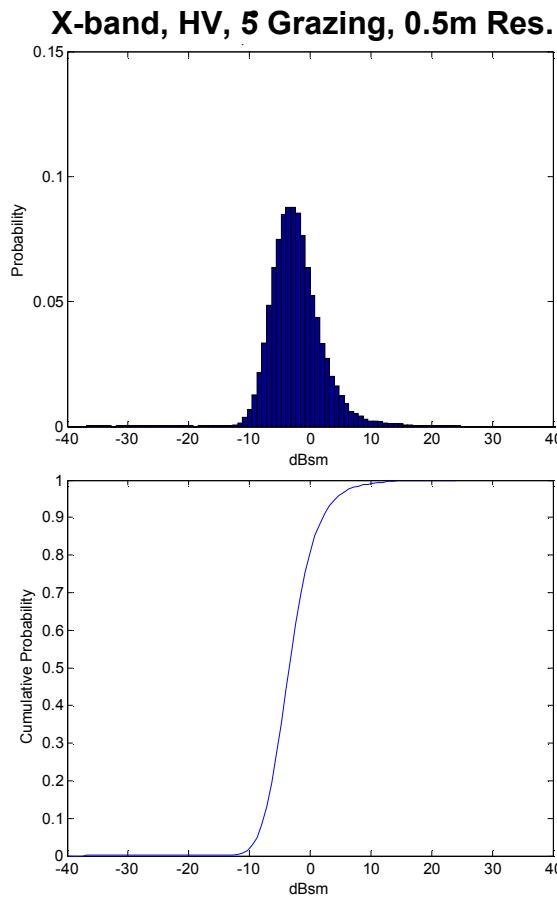


**CHIPS CONSIST OF MANY SCATTERING CENTERS, WITH MOST EXHIBITING A DOMINANT SCATTERER.**

# RCS Variation with Polarization (X-Pol, Co-Pol)



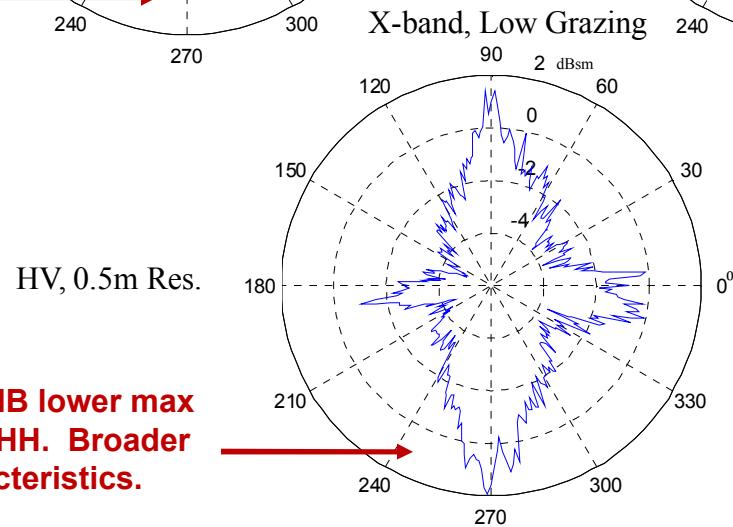
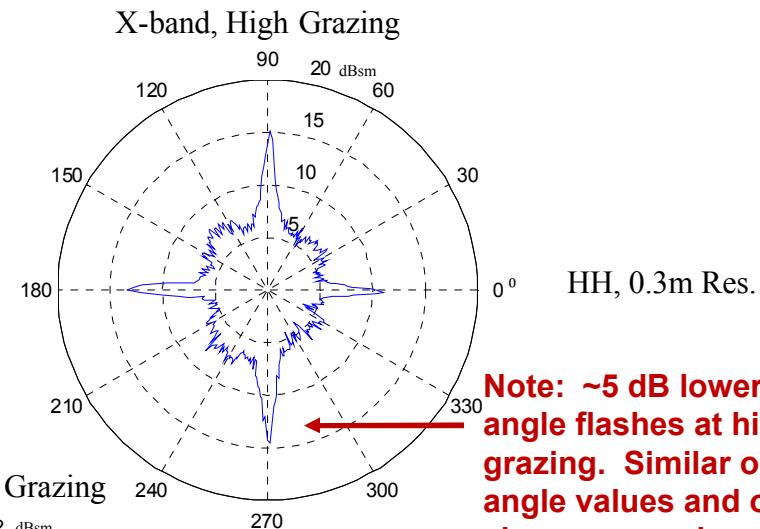
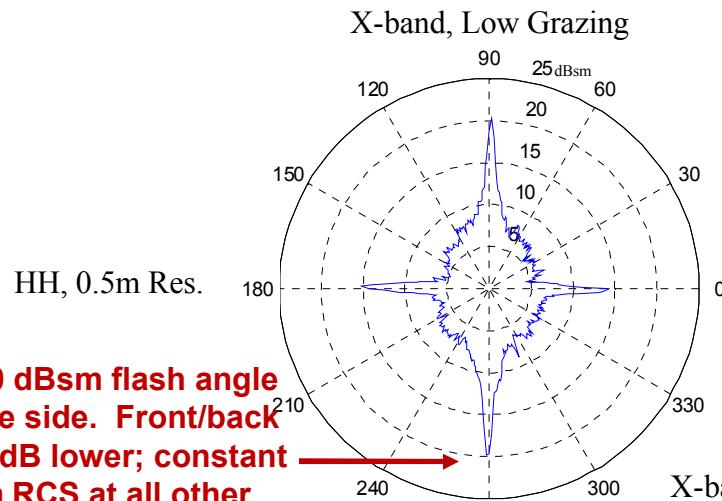
(6.2, 11.9, 7.6, 4.9)  
 [Median (dBsm), Arithmetic Mean (dBsm), Geometric Mean (dBsm), Standard Deviation (dB)]



(-3.7, 0.7, -2.3, 4.1)

**RCS DISTRIBUTION AND STATISTICS ~10DB LOWER FOR X-POL VS. CO-POL.  
 CO-POL HH and VV SIMILAR ACCORDING TO THE LITERATURE.**

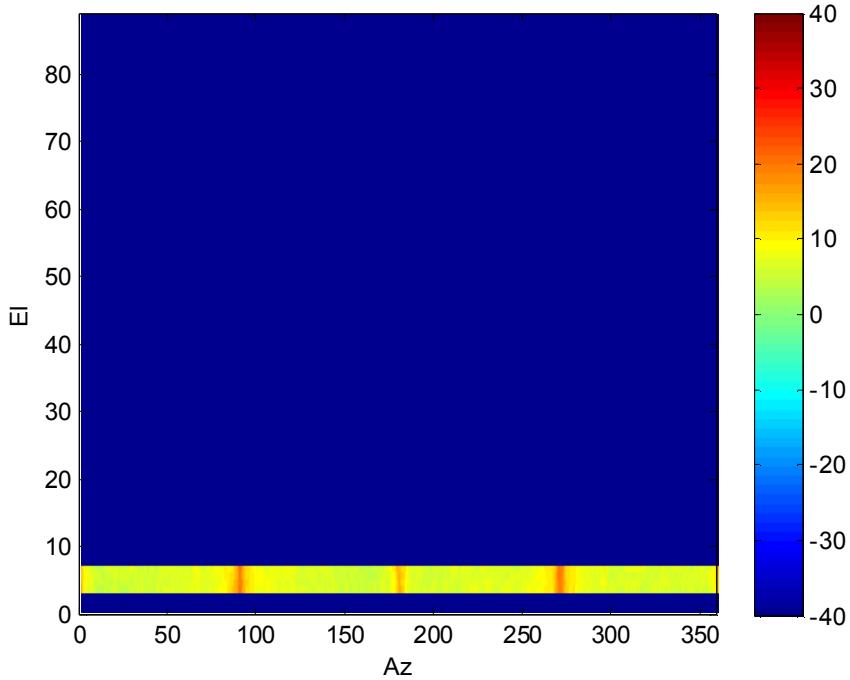
# RCS Variation with Pose (Azimuth)



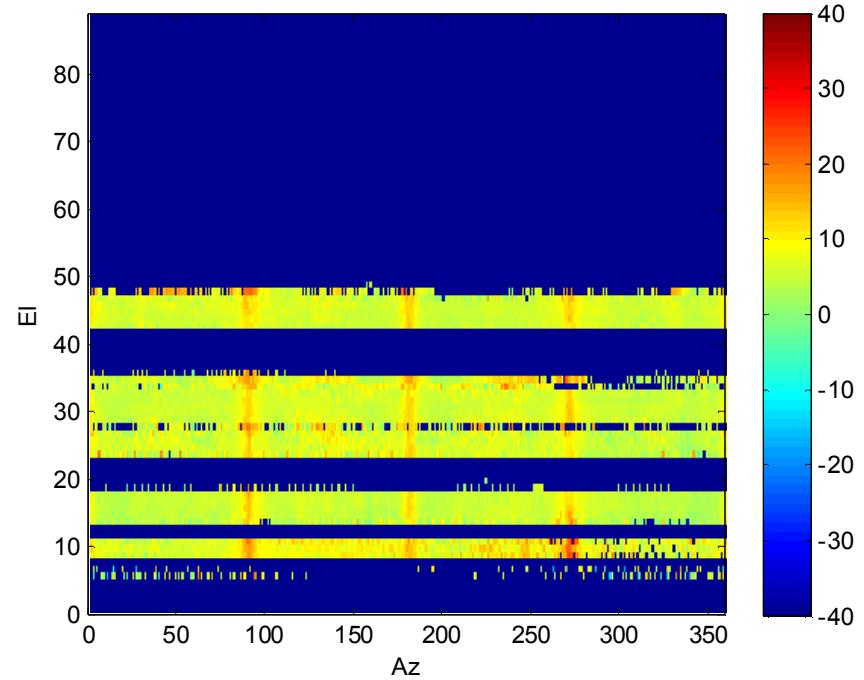
**RCS VARIES WITH: X-POL AND CO-POL IN SHAPE AND MAGNITUDE; GRAZING IN MAGNITUDE AT CARDINAL ANGLES; AND OBLIQUE VERSUS CARDINAL ANGLES**

# RCS Variation with Pose (Grazing)

X-band, HH, Low Grazing, 0.5m Res.



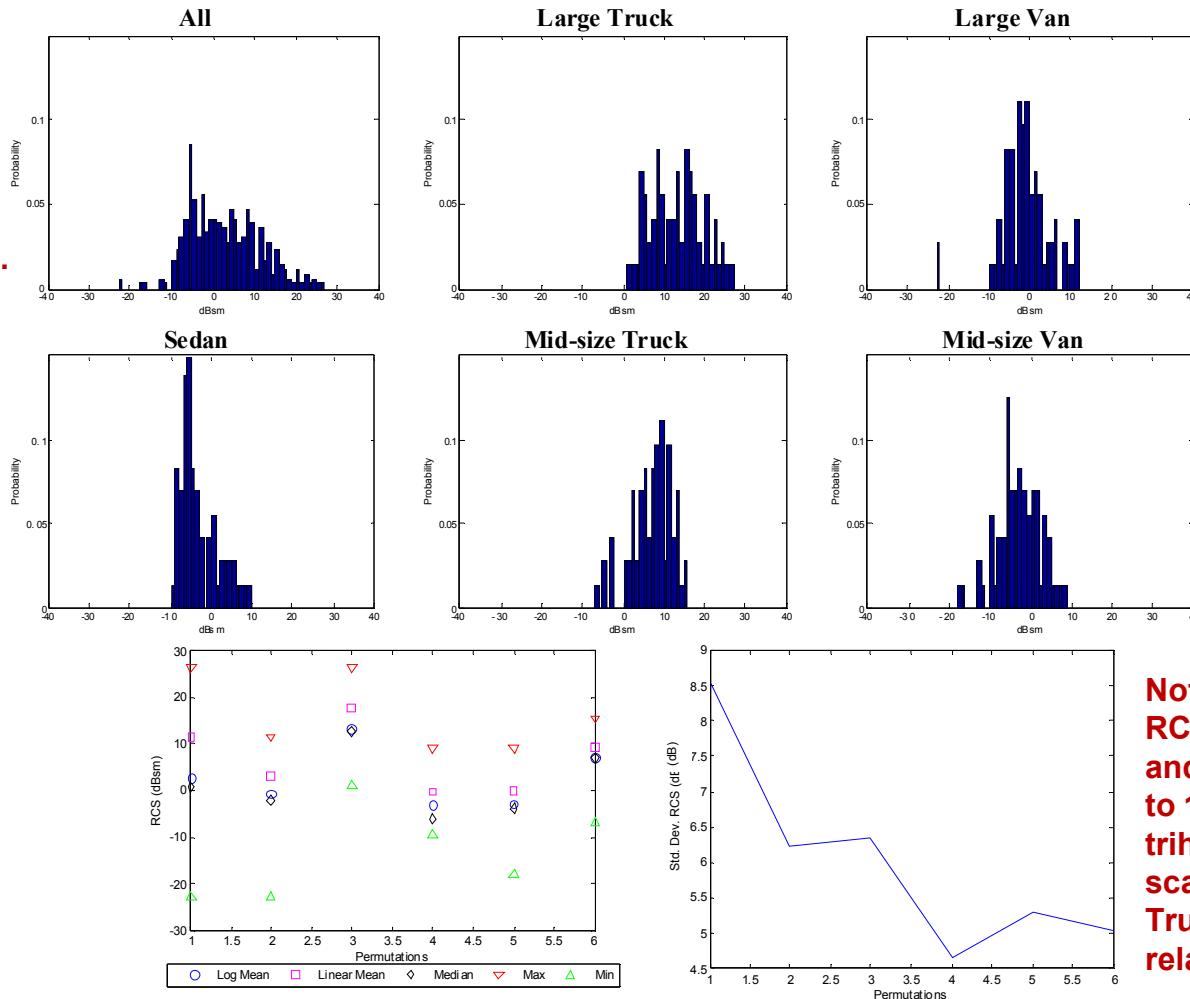
X-band, HH, High Grazing, 0.3m Res.



**RCS VARIES MINIMALLY WITH GRAZING ANGLE.  
ALL OBLIQUE ANGLES CONSISTENT.  
FLASH ANGLES (~5 DB LOWER AT WORST BETWEEN 5 AND 45).**

# RCS Variation of Vehicle Type & Size

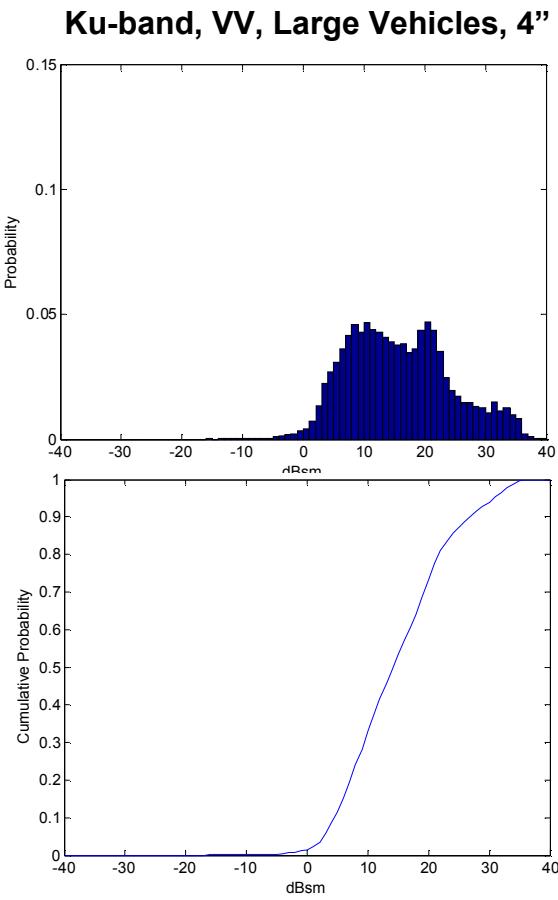
**Note: Multi-vehicle distribution non-Gaussian and with large spread due to diverse individual vehicle distributions.**



Vehicle Type Permutations: 1. All, 2. Large Van, 3. Large Truck, 4. Sedan, 5. Mid-size Van, 6. Mid-size Truck

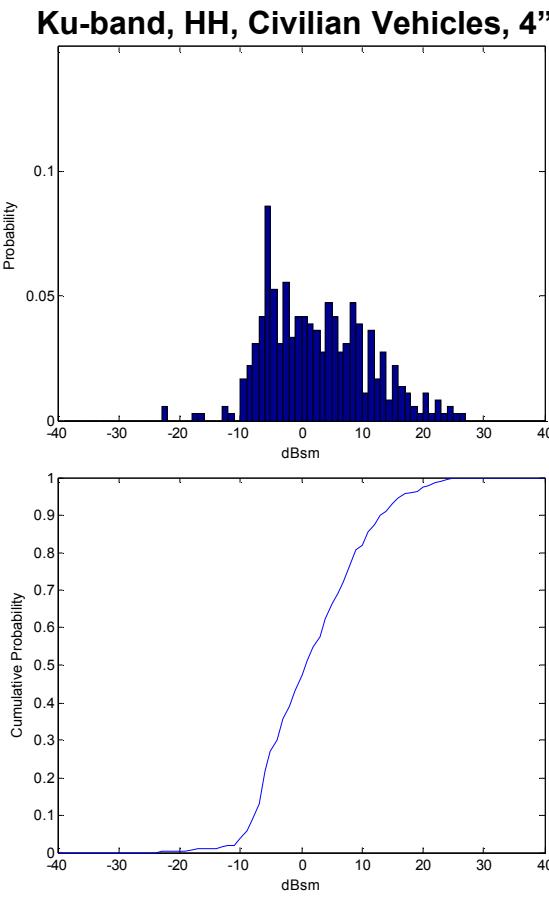
**RCS DISTRIBUTION & STATISTICS SHIFT ~13 DB WITH VEHICLE SIZE & TYPE**

# RCS Variation of Vehicle Type & Size (cont'd)



(14.1, 23.9, 15.8, 8.4)

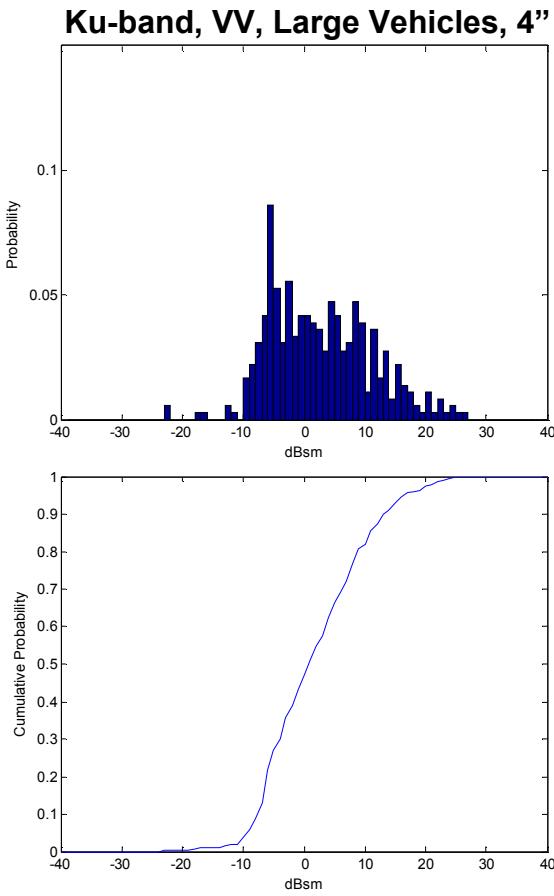
[Median (dBsm), Arithmetic Mean (dBsm), Geometric Mean (dBsm), Standard Deviation (dB)]



(0.7, 11.4, 2.6, 8.5)

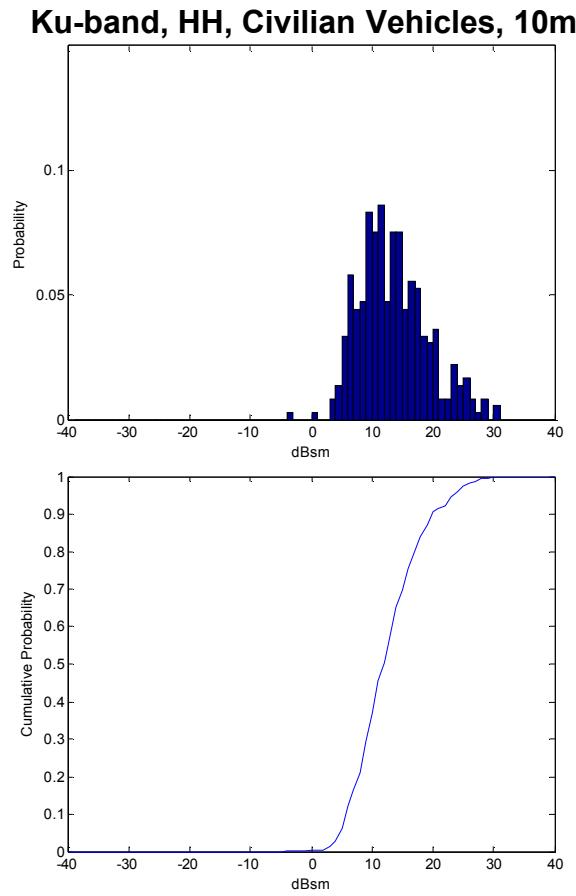
**RCS DISTRIBUTION AND STATISTICS NON-GAUSSIAN DUE TO  
DIFFERENT TARGET TYPES.**

# RCS Variation with Resolution



(0.7, 11.4, 2.6, 8.5)

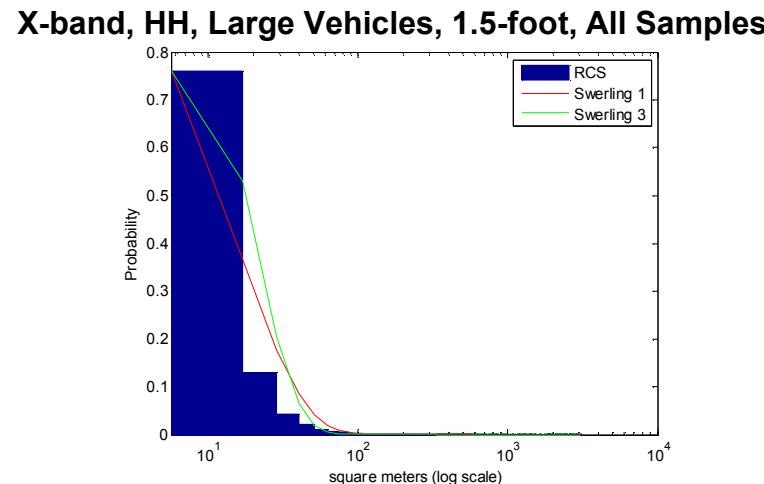
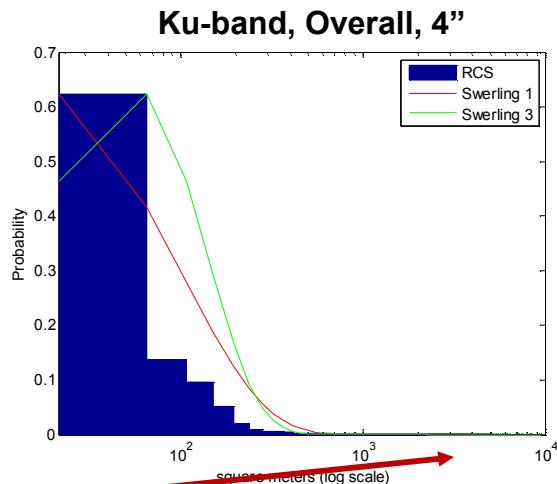
[Median (dBsm), Arithmetic Mean (dBsm), Geometric Mean (dBsm), Standard Deviation (dB)]



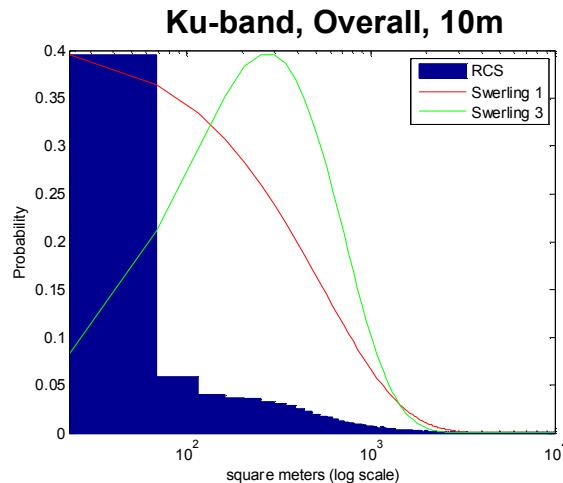
(11.9, 17.7, 13.5, 5.6)

**RCS DIST. AND STATS 10 DB HIGHER FOR 10M RESOLUTION  
 --- TARGET IN SINGLE RESOLUTION CELL.**

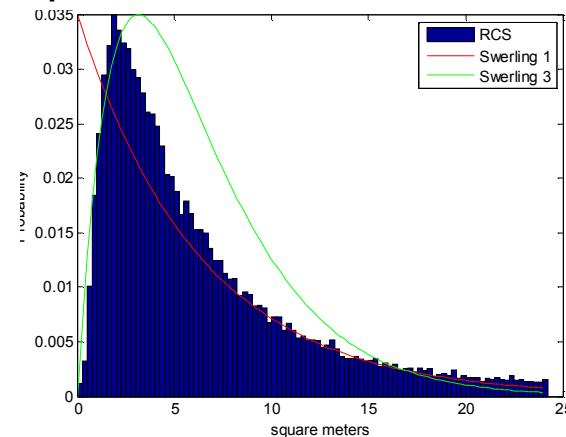
# Swerling Target Variation with Resolution



**Note: Long tails in distribution due to cardinal angle flashes.**

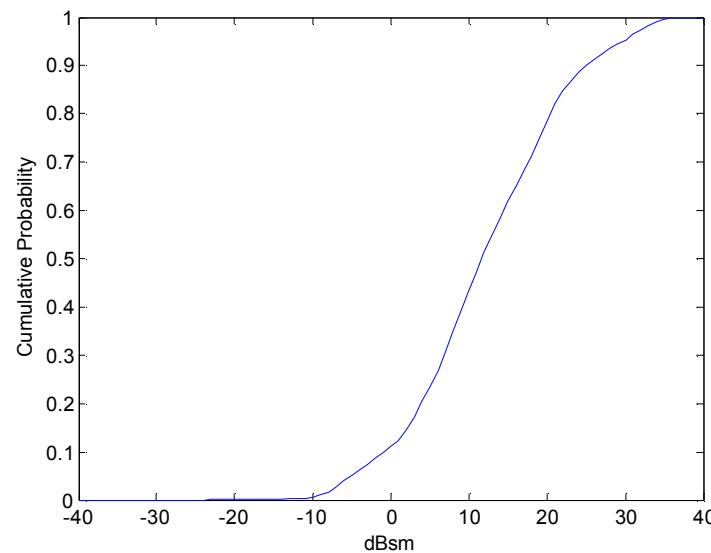
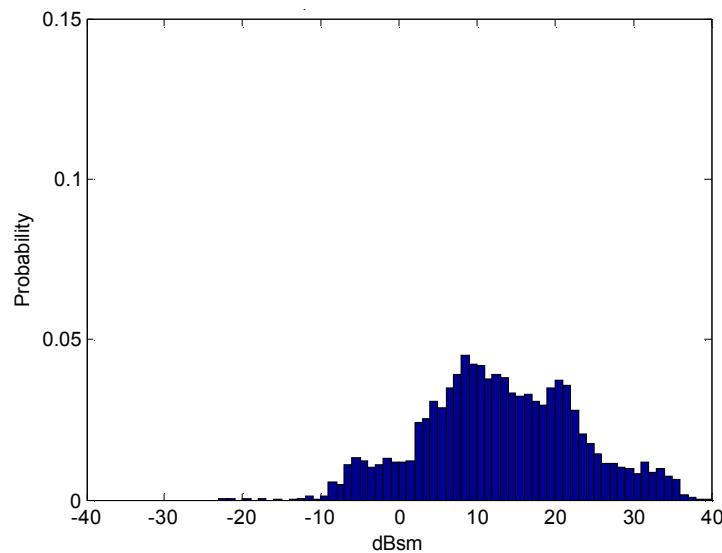


**Samples Below 90% in CDF for Above Case**



**SWERLING 1 CONSERVATIVE MODEL CHOICE FOR ALL DATA SETS.**  
**SWERLING 3 POSSIBLE FOR SNR AND PD CONSIDERATIONS AT MOST ANGLES.**

# Overall 4" Resolution RCS Results

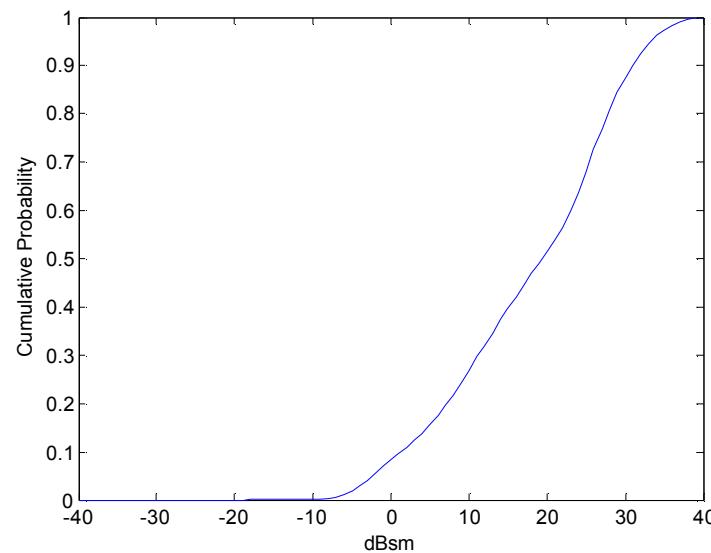
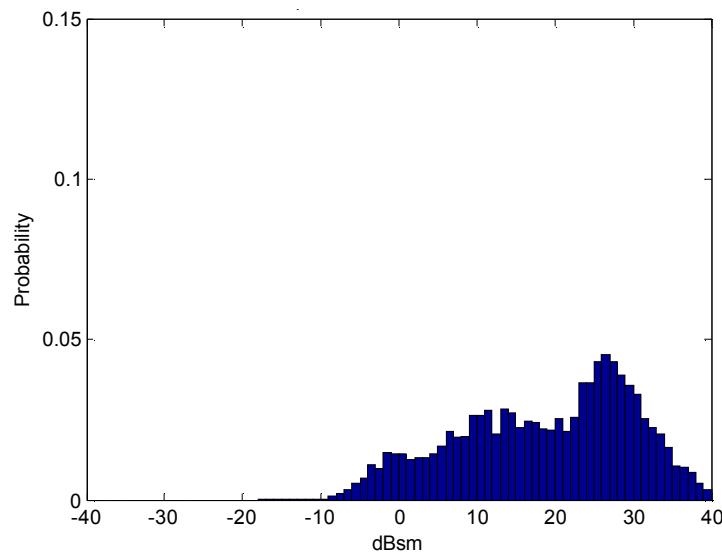


## RCS Summary (All Experiments and Variations)

Arithmetic Mean: 22.9 dBsm	Swerling Target: 1
Geometric Mean: 13 dBsm	90% $P_d$ Threshold: 13.1 dBsm
Median: 11.7 dBsm	10% $P_{\text{exceeding}}$ Upper Limit: 26.5 dBsm
Std. Dev.: +/- 9.9 dB	Conclusions: Distribution & statistics generally vary across size, type, pose, and cross-polarization.
Range: -10 to 40 dBsm	

**EXPERIMENTAL RCS CHARACTERISTICS --- VEHICLE IN MANY RESOLUTION CELLS**

# Overall 10m Resolution RCS Results



## RCS Summary (All Experiments and Variations)

Arithmetic Mean: 27.5 dBsm	Swerling Target: 1
Geometric Mean: 18.7 dBsm	90% $P_d$ Threshold: 17.7 dBsm
Median: 19.4 dBsm	10% $P_{\text{exceeding}}$ Upper Limit: 31.1 dBsm
Std. Dev.: +/- 11.1 dB	Conclusions: Distribution & statistics generally vary across size, type, pose, and cross-polarization.
Range: -10 to 40 dBsm	

## EXPERIMENTAL RCS CHARACTERISTICS --- VEHICLE IN SINGLE RESOLUTION CELL

# Summary

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- **Vehicles RCS Distributions and Statistics Vary with:**
  - Vehicle Size and Type (large/small or boxy/smooth)
  - Grazing Angle (minimally)
  - Azimuth Angle (large RCS at cardinal angles, fairly constant at oblique angles)
  - Radar Resolution (larger RCS at coarser resolutions)
  - Radar Polarization (X-Pol RCS drastically smaller and different azimuthal pattern, Co-Pol fairly similar)

4" Resolution	10m Resolution
Arithmetic Mean: 22.9 dBsm	Arithmetic Mean: 27.5 dBsm
Geometric Mean: 13 dBsm	Geometric Mean: 18.7 dBsm
Median: 11.7 dBsm	Median: 19.4 dBsm
Std. Dev.: +/- 9.9 dB	Std. Dev.: +/- 11.1 dB
Range (.1<P<.9): 13.1 to 26.5 dBsm	Range (.1<P<.9): 17.7 to 31.1 dBsm
Swerling Target: 1	Swerling Target: 1

- Swerling 1 Target Model an overall conservative design choice (target number varies with azimuth angle and resolution)
- Observations in literature consistent

# References and Acknowledgements

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## References:

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## Thanks To:

- *General Atomics Aeronautical Systems, Inc. (ASI) Reconnaissance Systems Group (RSG) for funding this work*
- *Sandia National Laboratories for use of the automatic target recognition database acquired using various X and Ku-band test-bed radar systems*
- *The ground team at Sandia for a civilian vehicle collect in 2011 with a Ku-band test-bed radar system*