

Power Variable Training STAP

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Abstract For GMTI radar processing, space-time adaptive processing (STAP) is a standard technique to mitigate clutter while preserving moving targets. STAP relies on an accurately estimated covariance matrix, which is traditionally computed from localized training around the range gate under test. This presentation suggests a new approach to covariance training. Power variable training combines phase-selective covariance training, which restricts range gate training to the most powerful range gates that lie on the clutter ridge, and a new technique that scales the covariance matrix power to prevent over-nulling. The new algorithm exhibits improved minimum detectable velocity (MDV) and fewer false alarms from clutter discretized as well as increased performance with extended-range targets. The proposed technique is demonstrated and compared to localized training on Tuxedo data.

Report Documentation Page

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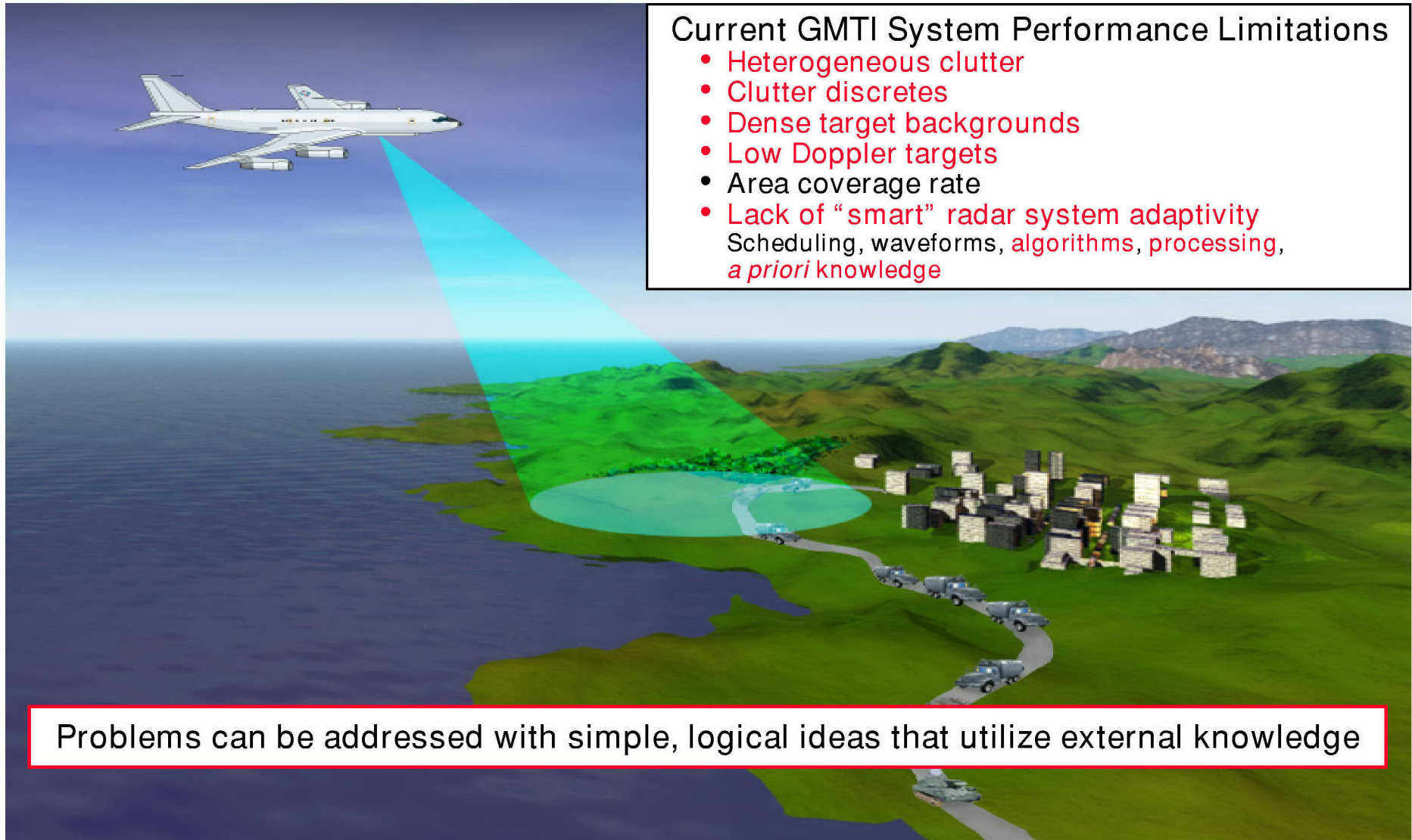
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Ali Yegulalp



Current GMTI Issues



Current GMTI System Performance Limitations

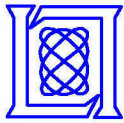
- Heterogeneous clutter
- Clutter discretets
- Dense target backgrounds
- Low Doppler targets
- Area coverage rate
- Lack of “smart” radar system adaptivity
Scheduling, waveforms, algorithms, processing, *a priori* knowledge

Problems can be addressed with simple, logical ideas that utilize external knowledge

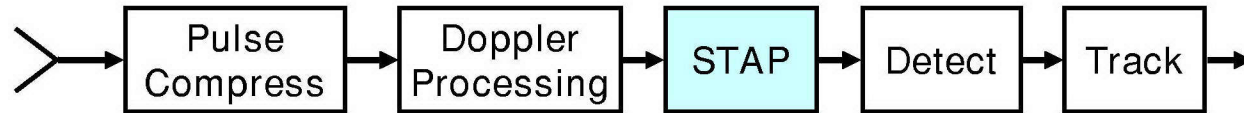


Outline

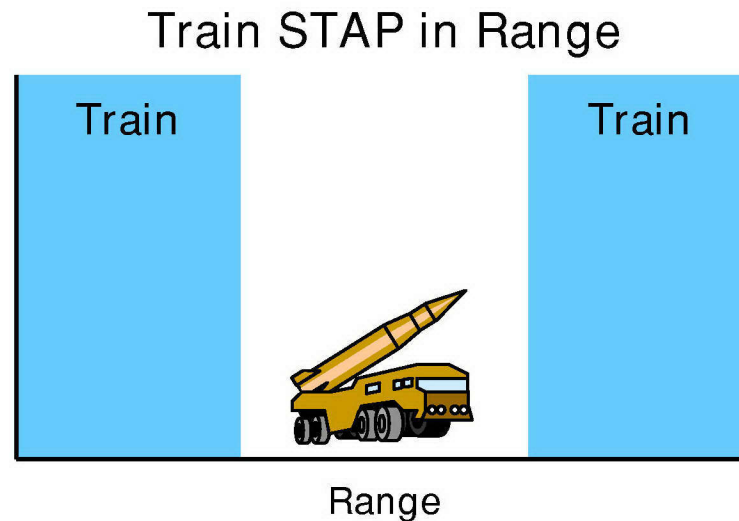
- Current STAP challenges
- Power variable training with excision algorithm
- Detection and angle estimation
- Tuxedo data results
- Conclusions

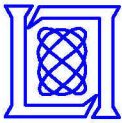


Desirable Features for STAP Training

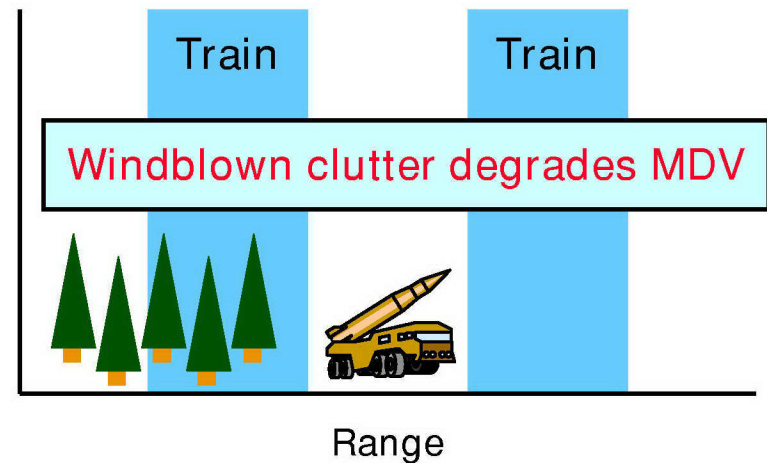
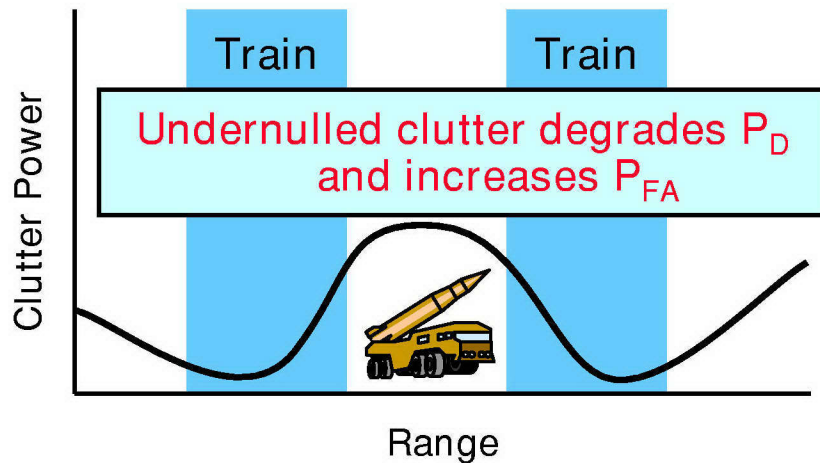
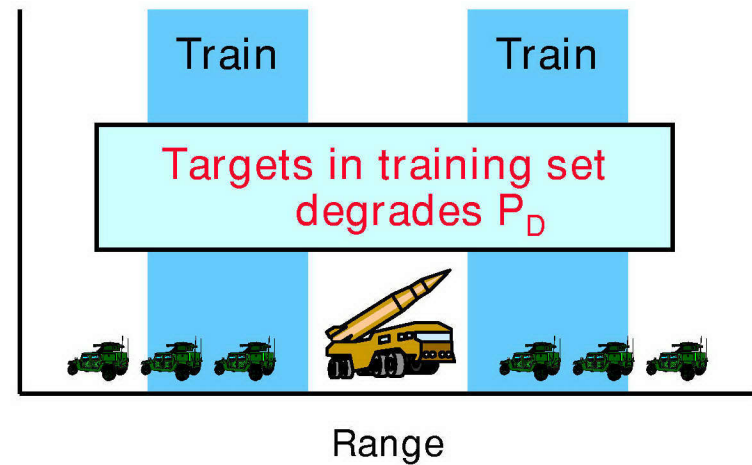
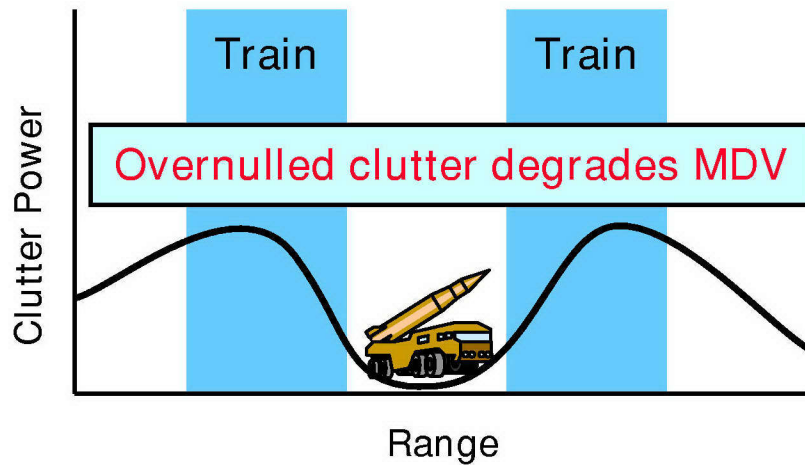


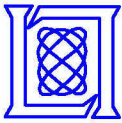
- Training statistics must match the cell under test
 - Angle/Doppler relationship
 - Clutter type (vegetation / mountain / desert)
 - Power
- The training set should NOT include targets or other moving objects





Localized Training Impact





SINR Loss in 50% Wind-Blown Clutter

Target in the clear (no foliage)

Train with 50% wind blown clutter from foliage

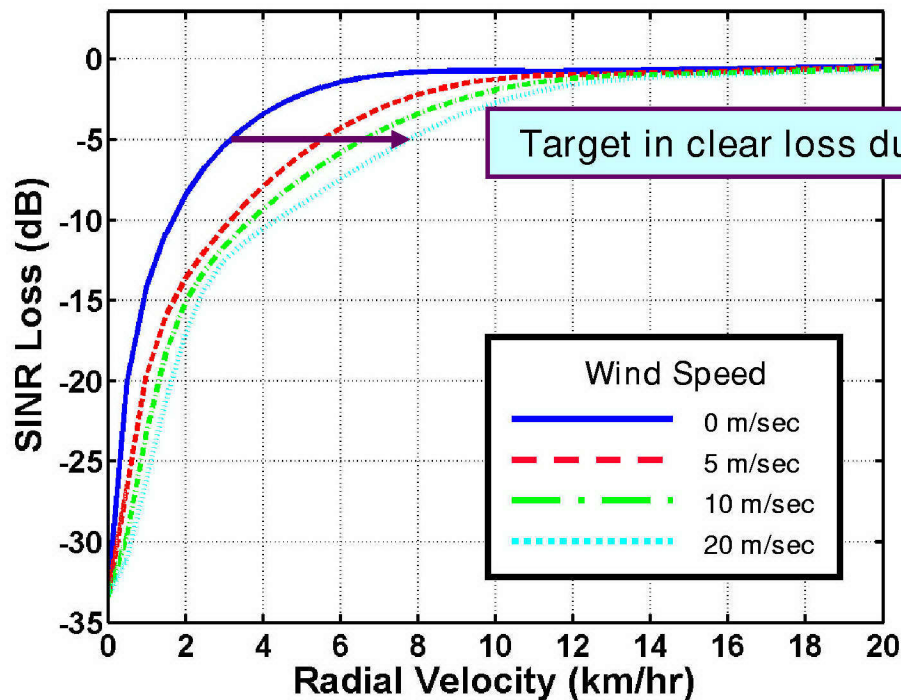
Train



Train



Aperture = 10 feet



Target in clear loss due to foliage training

Platform velocity = 150 m/sec

Altitude = 10 km

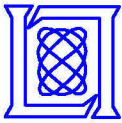
CNR = 35 dB

$f_0 = 10$ GHz

PRF = 2 kHz

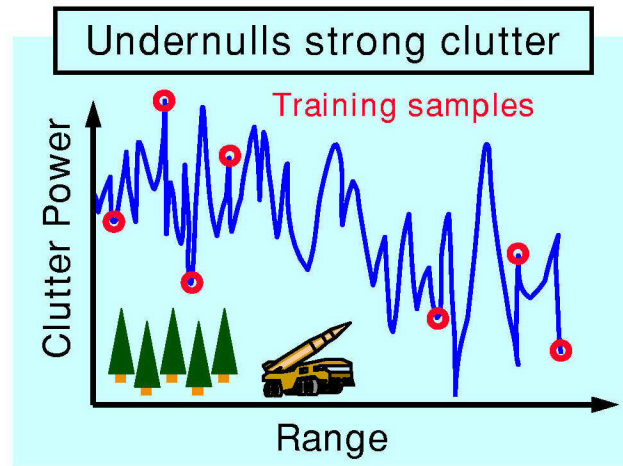
50% mixture (wind-blown & stationary)

Wind blown foliage training degrades performance in clear

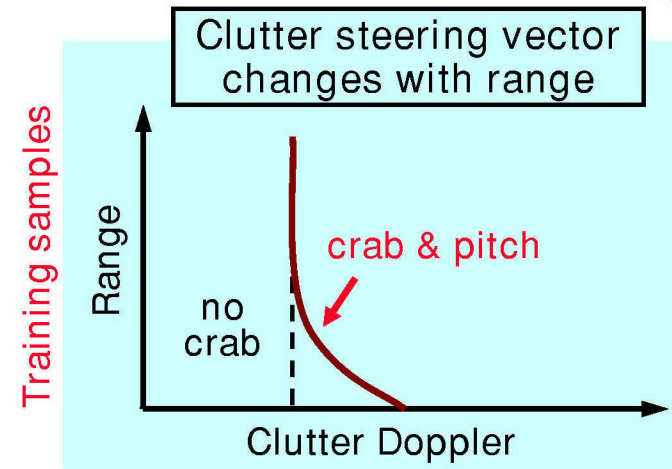


Distributed Training

Random Training

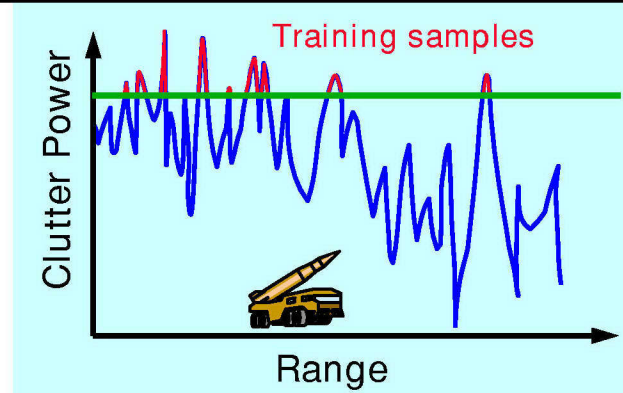


Locus of Constant Cone Angle



Power Selective Training

Overnullled clutter degrades MDV



STAP Training Issues:

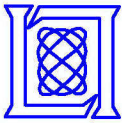
- Windblown clutter
- Angle/Doppler relationship
- Targets included in training
- Correct power

Neither localized nor distributed training address these issues which affect MDV, P_D , and P_{FA}



Outline

- Current STAP challenges
- Power variable training with excision algorithm
- Detection and angle estimation
- Tuxedo data results
- Conclusions

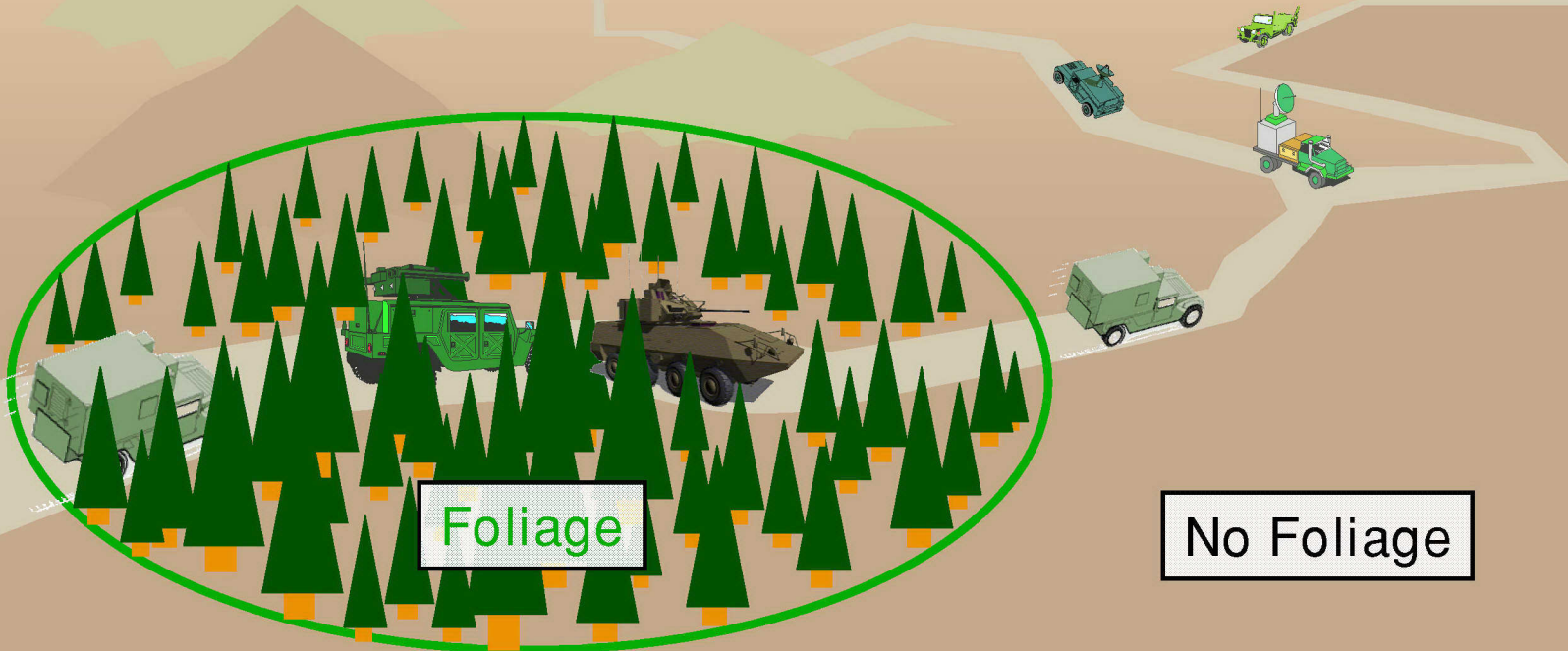


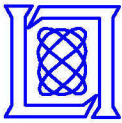
Regionalized Training

TRAINING SAMPLES

- No windblown clutter for targets in clear
- Right angle-Doppler relationship for clutter
- Eliminate targets from training data
- Correct clutter power

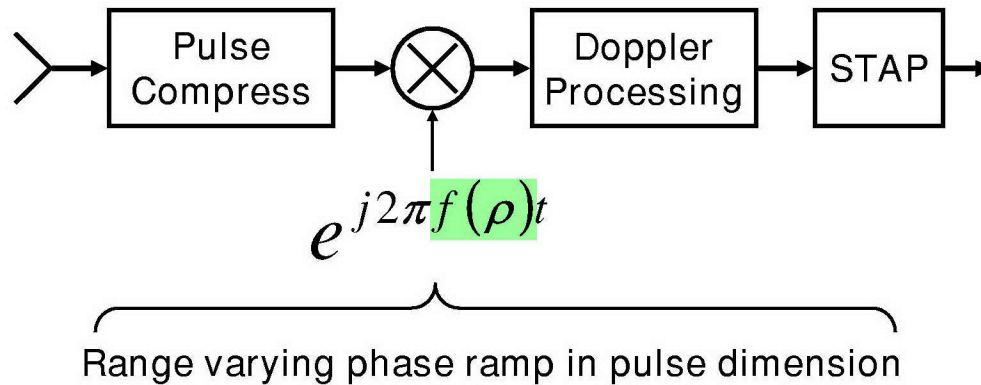
- Classify ground swath regions
 - Foliage
 - No foliage
 - Urban
- Apply STAP separately for each region



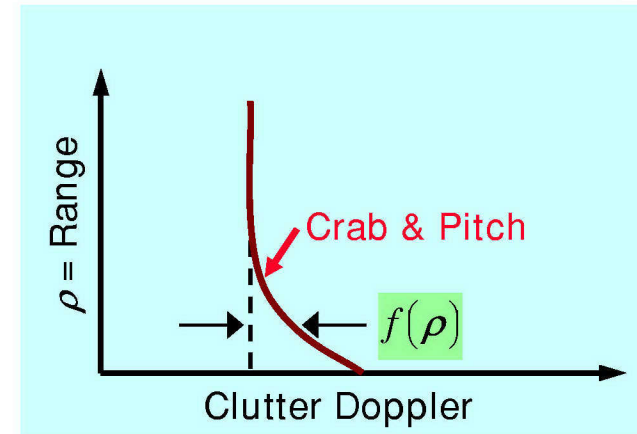


Doppler Warping and Power Selected Training

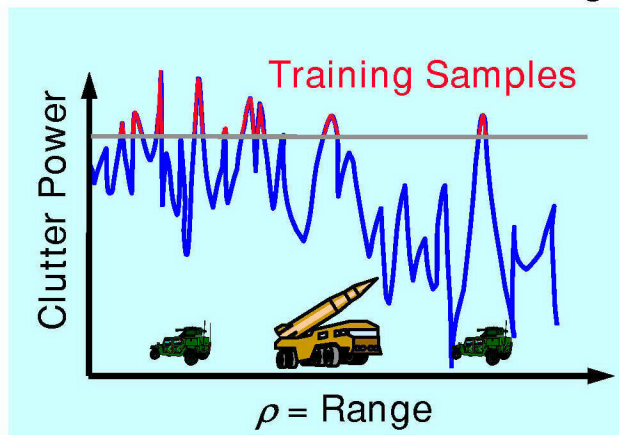
Doppler Warping Aligns Clutter



Locus of Constant Cone Angle

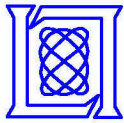


Power Selective Training

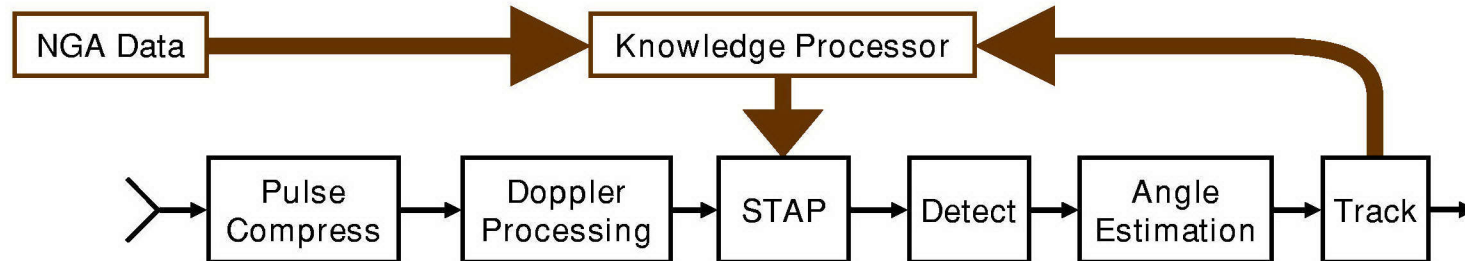


TRAINING SAMPLES

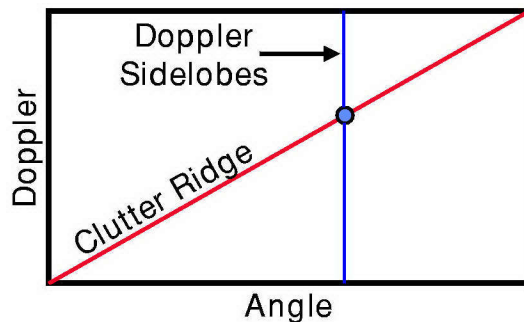
- No windblown clutter for targets in clear
- Right angle-Doppler relationship for clutter
- Eliminate targets from training data
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Mapped Discretes and Tracker Feedback

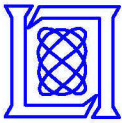


- Don't train or detect on problematic clutter discrete range gates
 - High Doppler sidelobes
 - Clutter discretes may be provided by tracker or external NGA map data
-
- Tracker predicts where targets will exist in future CPIs
 - This knowledge is utilized to prevent known targets from being included in STAP training data



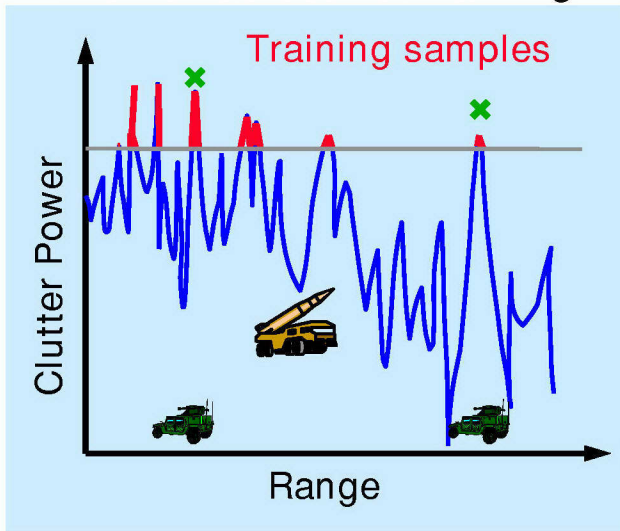
TRAINING SAMPLES

- No windblown clutter for targets in clear
- Right angle-Doppler relationship for clutter
- Eliminate targets from training data
- Correct clutter power



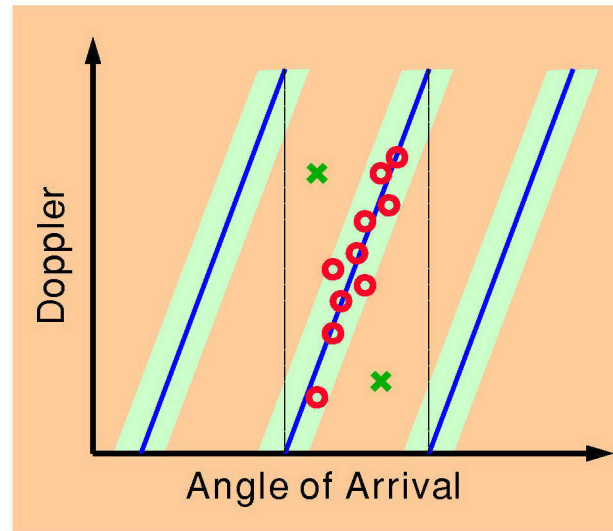
Target Excision

Power Selective Training



Select strongest clutter returns as candidate training samples

Excision

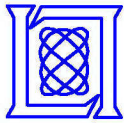


Excise samples away from clutter ridge (potential targets)

TRAINING SAMPLES

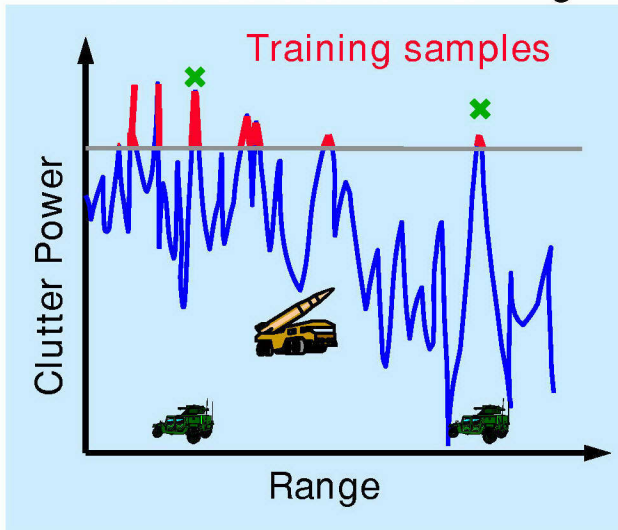
- No windblown clutter for targets in clear
- Right angle-Doppler relationship for clutter
- Eliminate targets from training data
- Correct clutter power





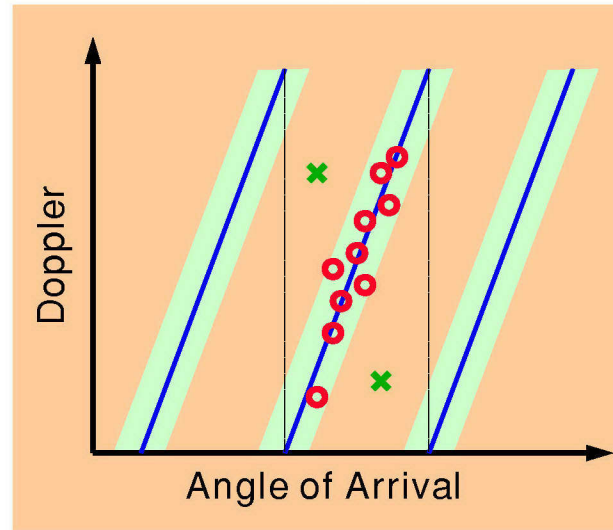
Power Variable Training with Target Excision

Power Selective Training



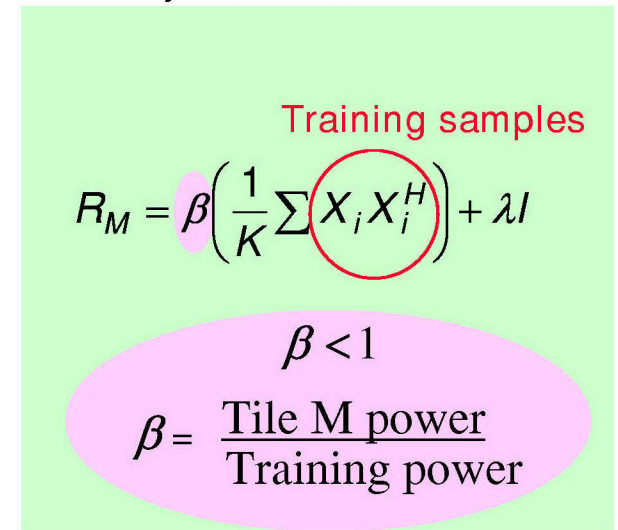
Select strongest clutter returns as candidate training samples

Excision



Excise samples away from clutter ridge (potential targets)

Adjust Clutter Power

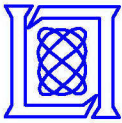


Scale training samples to estimated CNR for Tile

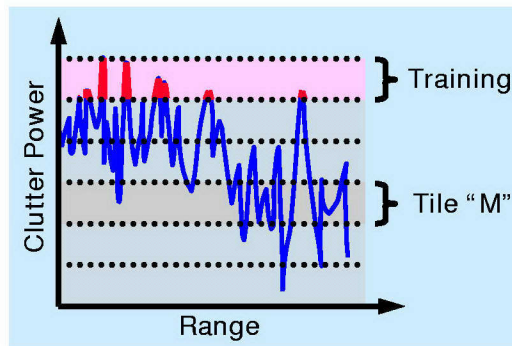
TRAINING SAMPLES

- No windblown clutter for targets in clear
- Right angle-Doppler relationship for clutter
- Eliminate targets from training data
- Correct clutter power





Power Variable Training for STAP



Covariance Matrix:
$$\mathbf{R}_S = \frac{1}{K_S} \sum \mathbf{x}_i \mathbf{x}_i^H$$

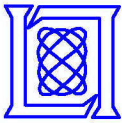
Tile Power:
$$e_M = \frac{1}{K_M} \sum \mathbf{x}_i^H \mathbf{x}_i$$

Estimate Pure Clutter Covariance Matrix	$\mathbf{R}_C = \mathbf{R}_S - \lambda \mathbf{I}$	$\lambda = \text{Estimated Noise Floor}$
Covariance Matrix for Tile "M"	$\mathbf{R}_M = \beta \mathbf{R}_C + \lambda \mathbf{I}$	$\beta = \frac{e_M - N\lambda}{\text{tr}[\mathbf{R}_S] - N\lambda}$
Diagonally Loaded Covariance for Tile "M"	$\mathbf{R}_M = \beta \mathbf{R}_C + (\lambda + \delta) \mathbf{I}$	$\delta = \text{Diagonal Load Level}$
Adaptive Weight for Tile "M" with AMF Normalization	$\mathbf{w}_M = \frac{\mathbf{R}_M^{-1} \mathbf{v}}{\sqrt{\mathbf{v}^H \mathbf{R}_M^{-1} \mathbf{v}}}$	

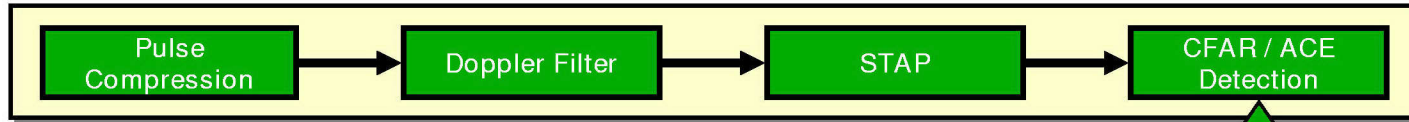


Outline

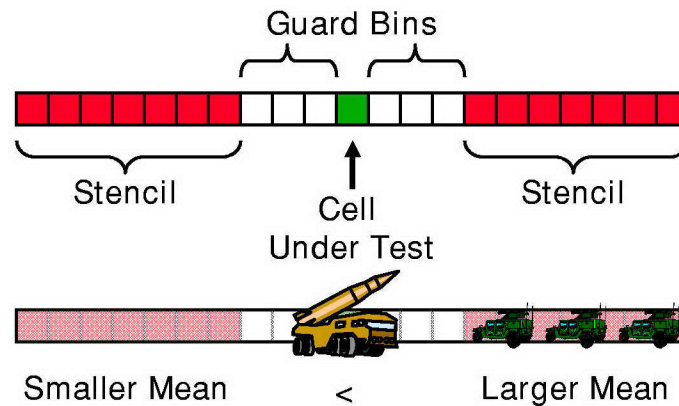
- Current STAP challenges
- Power variable training with excision algorithm
- **Detection and angle estimation**
- Tuxedo data results
- Conclusions



Lesser-Of CFAR Target Detection with ACE

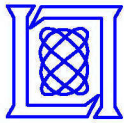


On each side of cell under test:
50 range bin stencil
10 range bin guard
13 dB threshold
0.35 ACE threshold



$$\frac{|W^H X_i|^2}{X_i^H R_M^{-1} X_i} \stackrel{?}{>} \chi_{ACE}$$

- Choose *lesser of* training window means for noise estimate
 - Stencil with lesser mean will be least likely to include targets
- Two pass architecture
 - First pass identifies targets
 - On second pass, exclude first-pass targets from stencils
- Small ACE values implies target is better suited by another beam or is associated with sidelobes
- Targets must satisfy CFAR threshold *and* ACE threshold for detection



Knowledge Aided Detection Management

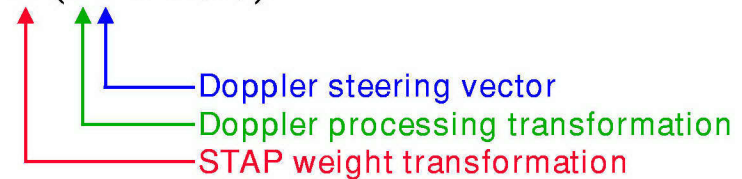
- Estimate arrival angle for each detection:

Spatial Steering Vector:

$$\mathbf{a}(\theta) = \begin{bmatrix} 1 \\ e^{j\theta} \\ \vdots \\ e^{j(N-1)\theta} \end{bmatrix}$$

Apply linear transformations
to match STAP output:

$$\mathbf{h}(\theta) = \mathbf{W}(\mathbf{Fb} \otimes \mathbf{a}(\theta))$$



Find angle that maximizes inner-product:

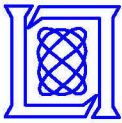
$$\hat{\theta} = \arg \max_{\theta} \left| \mathbf{h}(\theta)^H \mathbf{X}_{STAP} \right|$$

- Delete or flag detections with angle estimates that closely match clutter ridge location
- Use knowledge of road locations to discriminate angle ambiguities



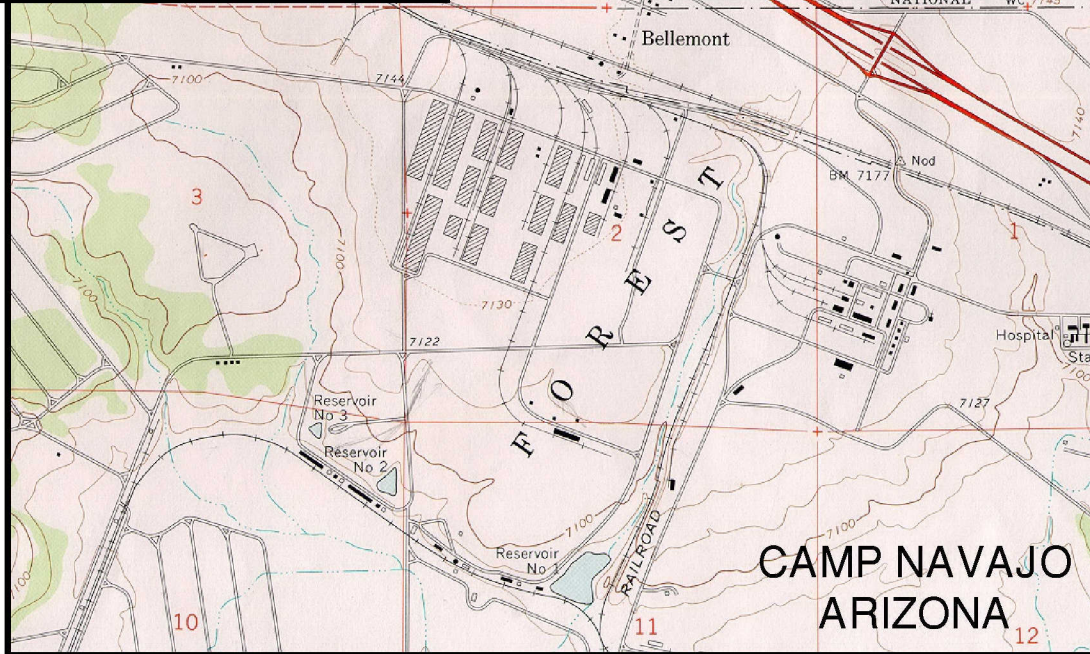
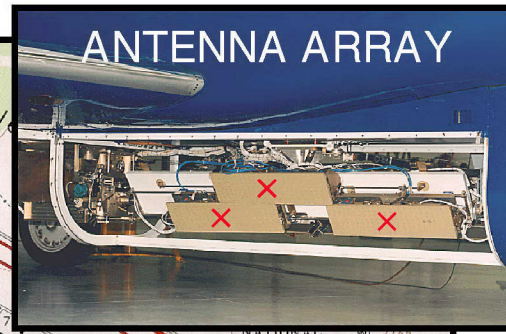
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Tuxedo Data

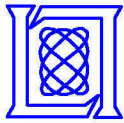
Recorded Data



System Parameters for GMTI Mode

Center Freq.	9.6 GHz
Bandwidth	66 MHz
PRF	1,400 Hz
Tx Apertures	1
Rx Apertures	3
Horiz. Aperture	1.83 m
Vert. Aperture	0.18 m
Az BW	3.6 deg
EI BW	9.1 deg
Polarization	HH
A/C Heading	290 deg
Depr. Angle	15 deg
Recorded Time	40-60 sec

Limited targets in data (up to 5) and uniform terrain type (desert)



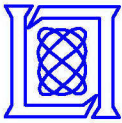
Demonstrated GMTI Enhancements

Demonstrated:

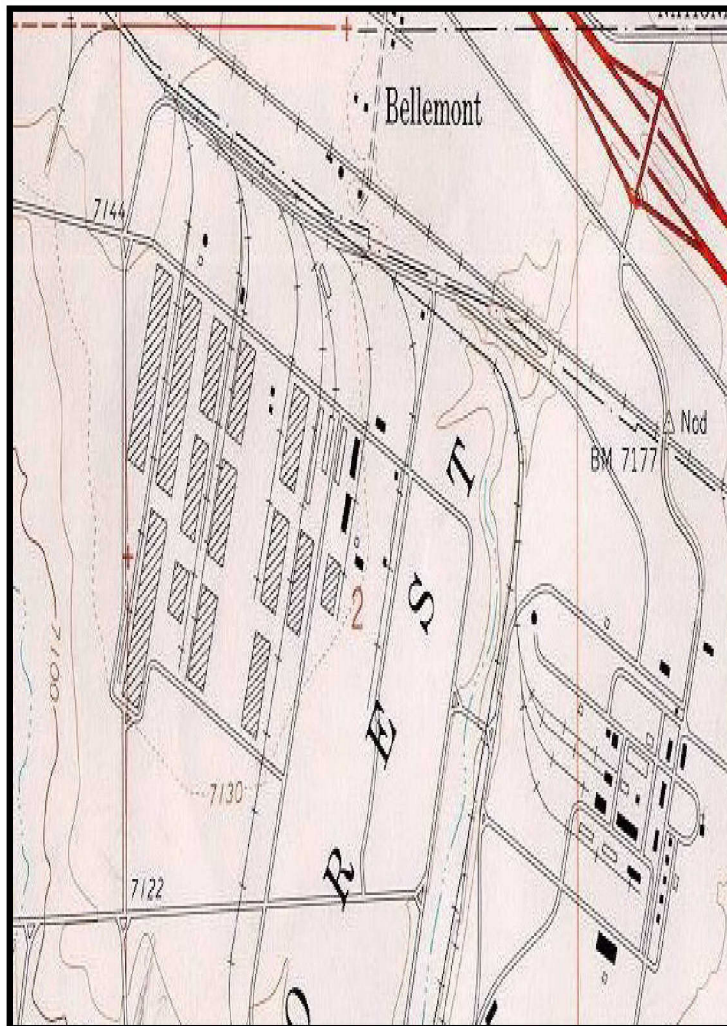
- Power Variable Training with Excision
- Tracker feedback of target locations
- Doppler Warping to account for aircraft crab
 - Near broadside collection
- Angle estimation rejection of clutter discretets
- Prior knowledge of problematic clutter discrete locations
- Use of platform inertial data to estimate clutter ridge location
- Use of road locations to discriminate angle ambiguities

Not Demonstrated:

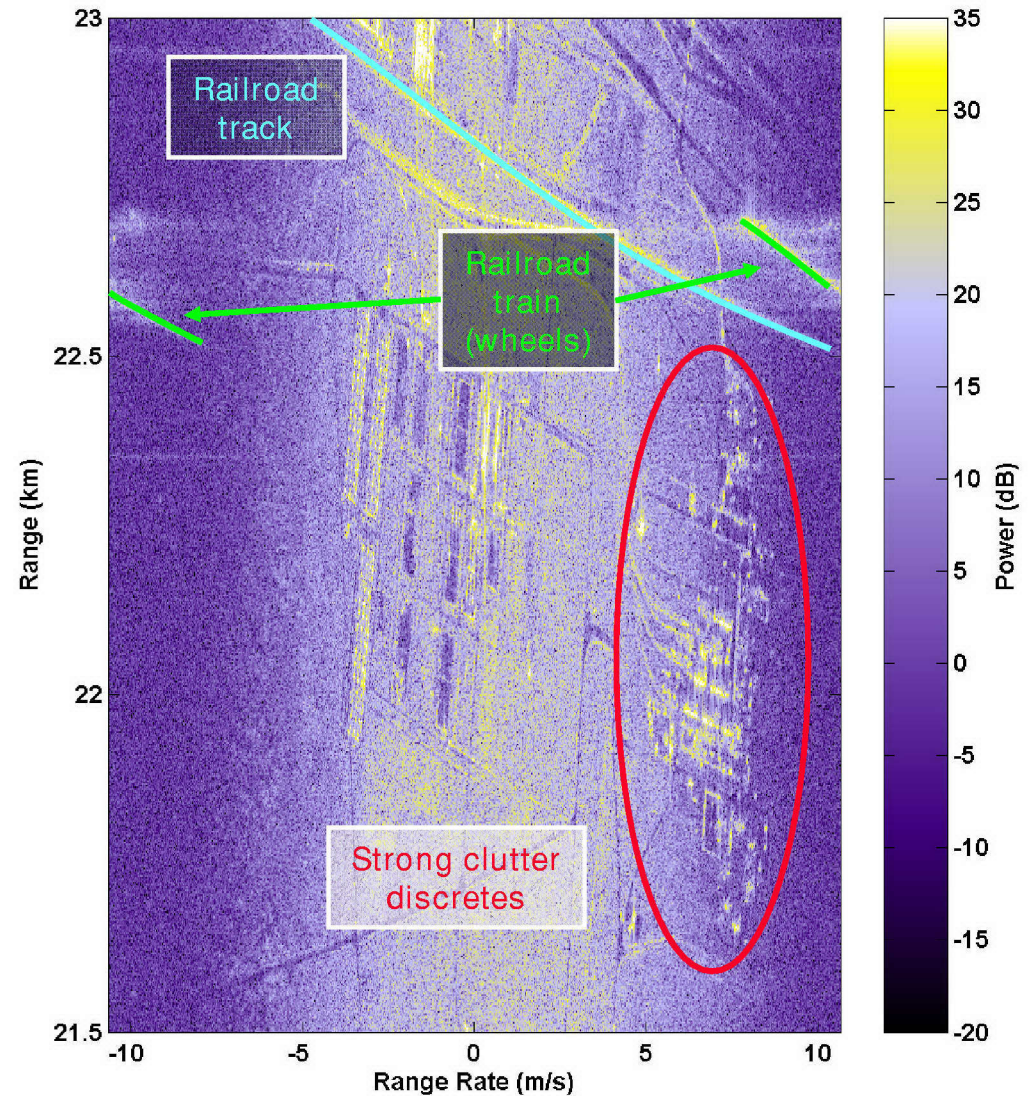
- Separate training for windblown clutter
 - No significant foliage present in data
- DTED enhanced clutter ridge estimation
 - Flat terrain

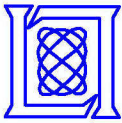


Range-Doppler Image



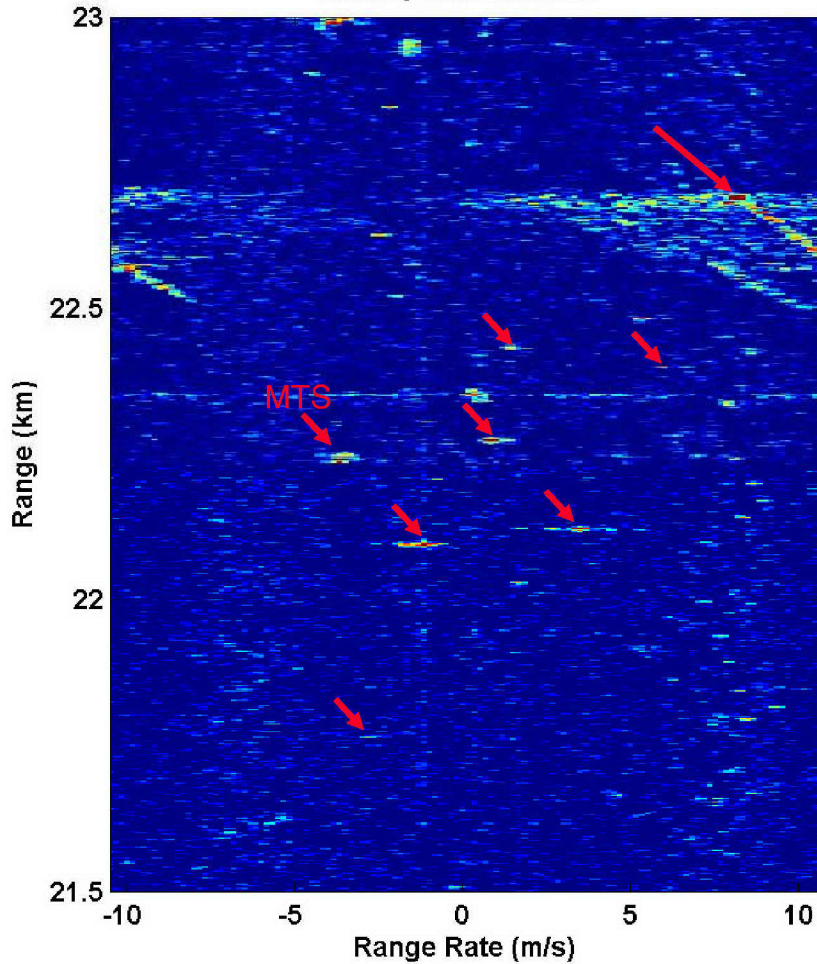
(map cropped and stretched to match data)



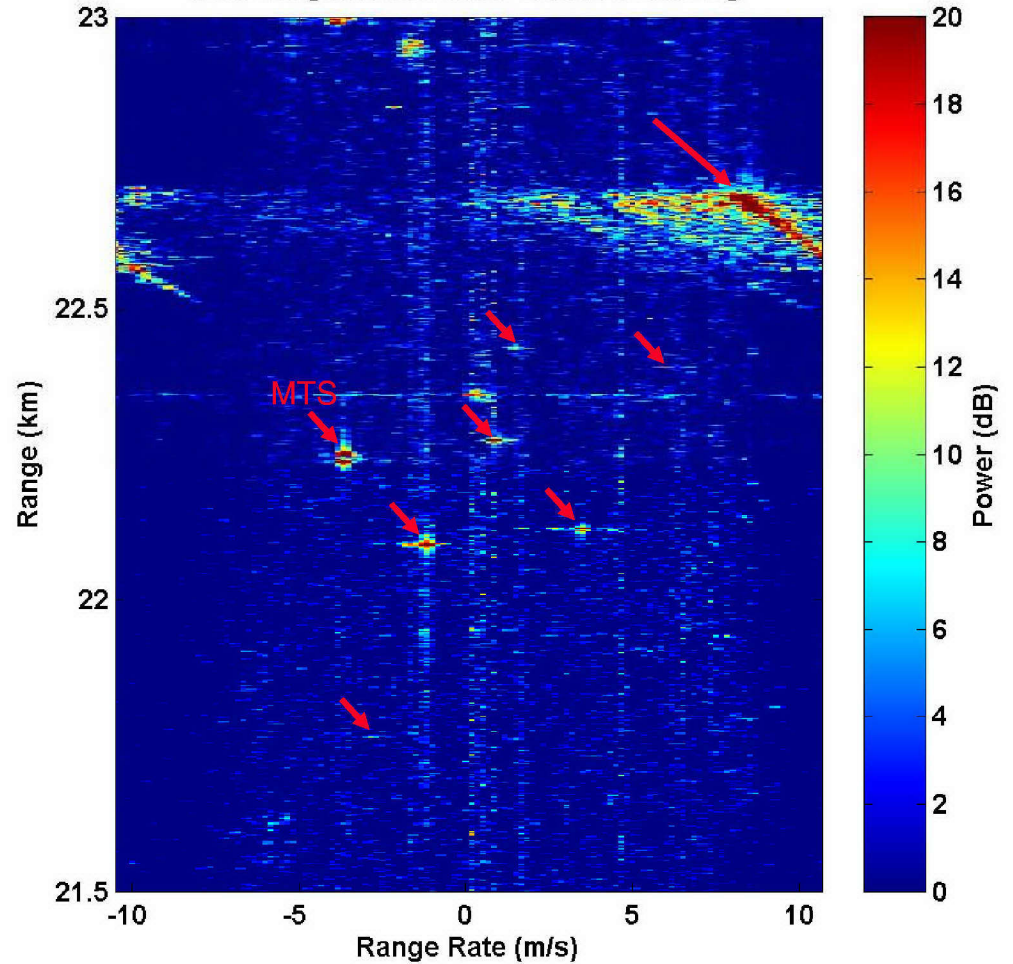


Power Variable Training Comparison: STAP Output

Range: 
Locally Trained STAP



Knowledge Aided Power Variable Training



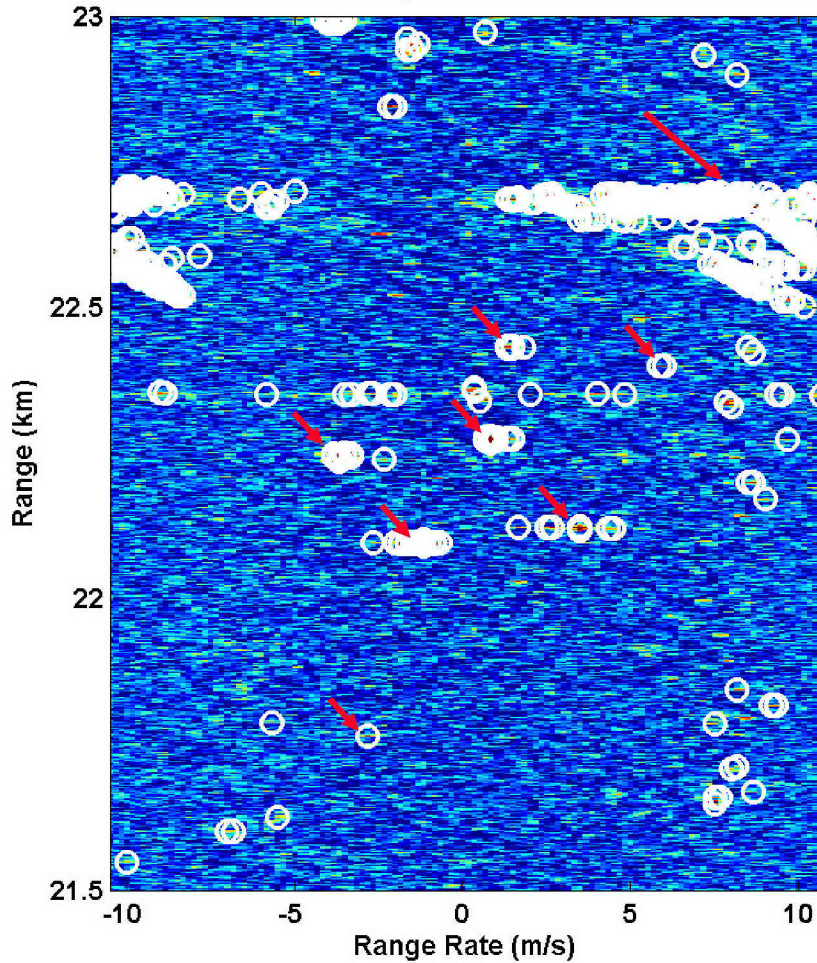
Railroad train self-nulled with localized training



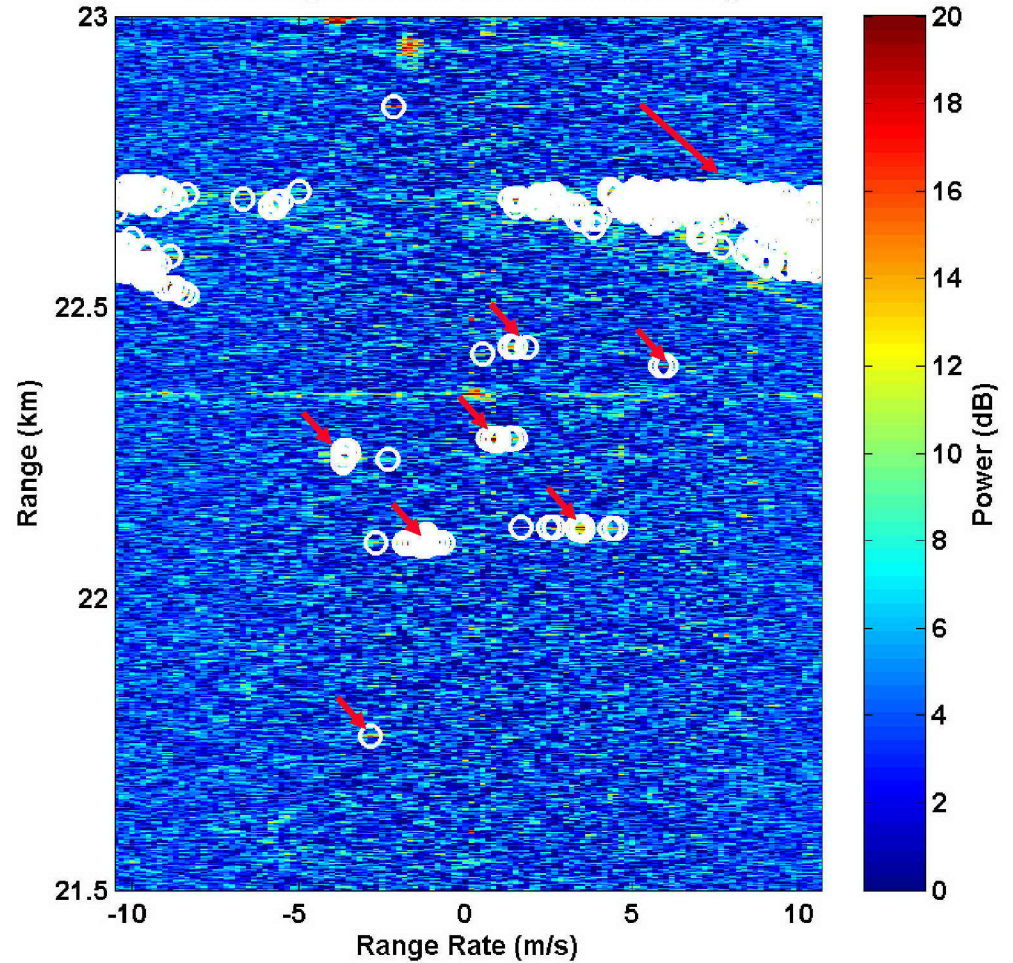
Power Variable Training Comparison: Detector Output

Range: 

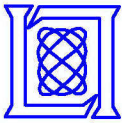
Locally Trained STAP



Knowledge Aided Power Variable Training

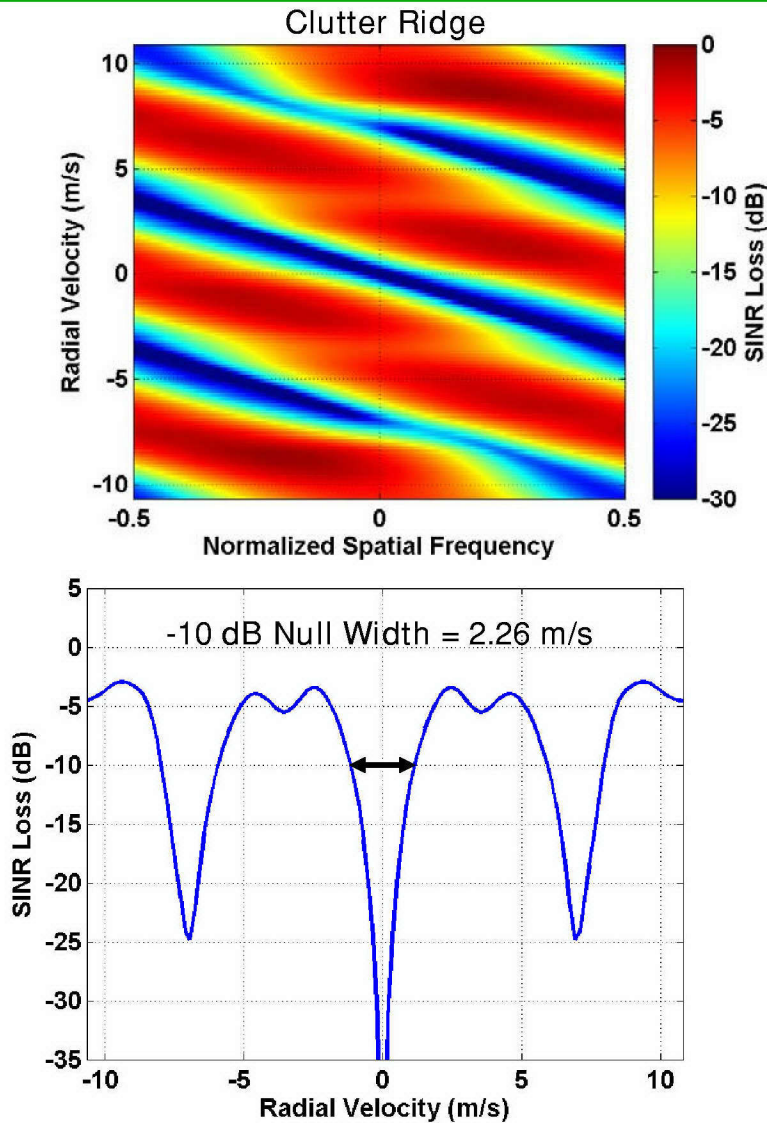


Power variable training dramatically reduces false alarm rate

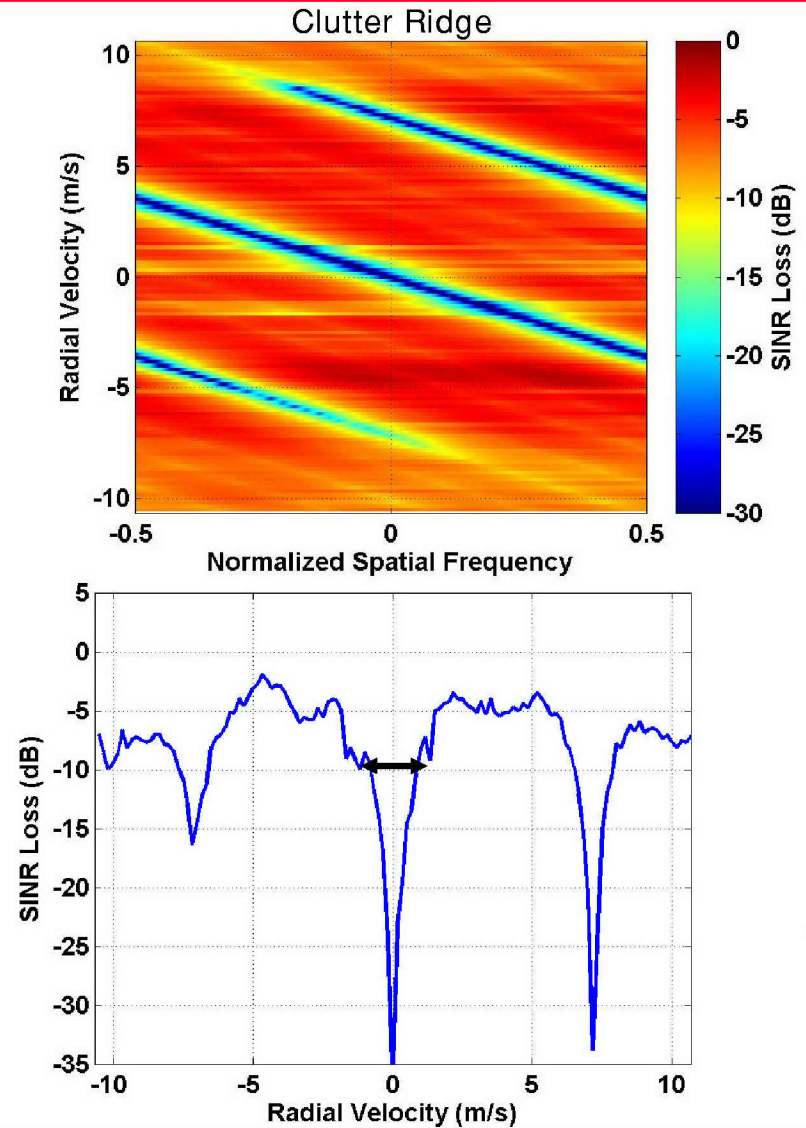


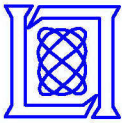
SINR Loss Simulation and Data Results

Simulation

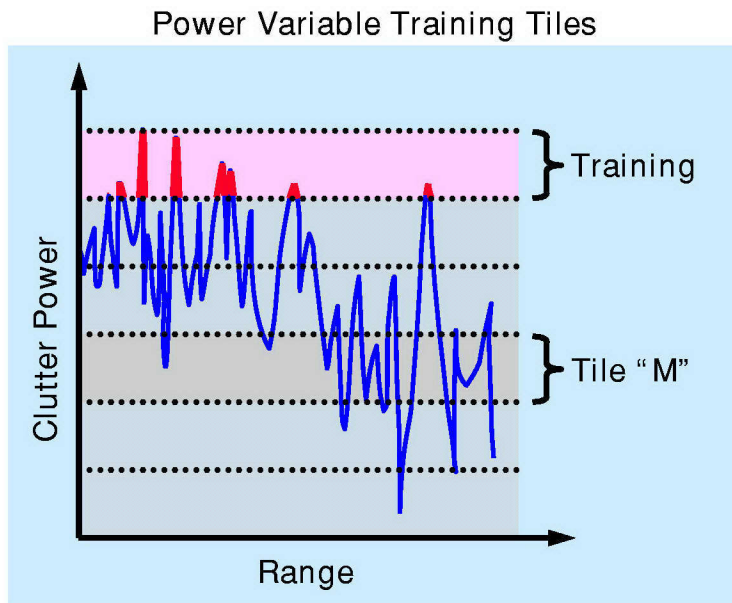


Knowledge Aided Power Variable Training





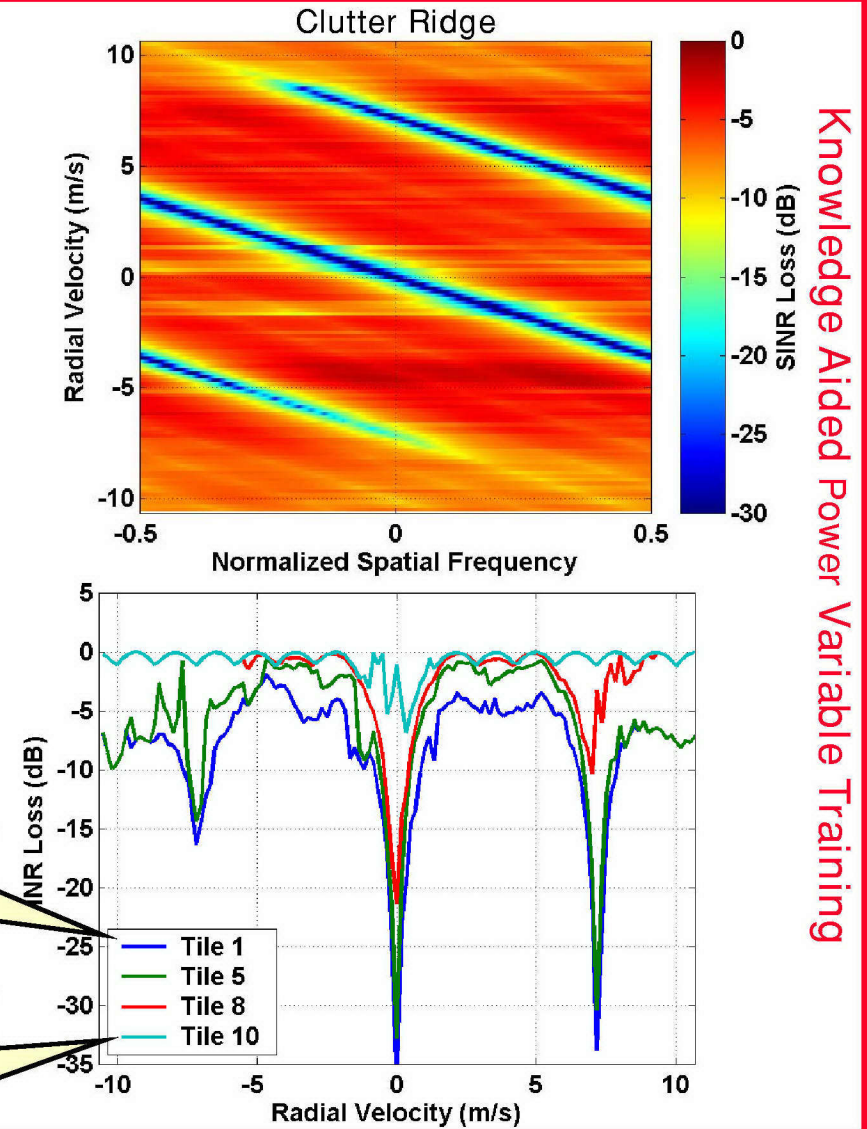
Power Variable SINR Loss Effects

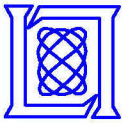


- Tile SINR loss approaches 0 dB as tile power decreases
- Significantly improved MDV for lower power range gates

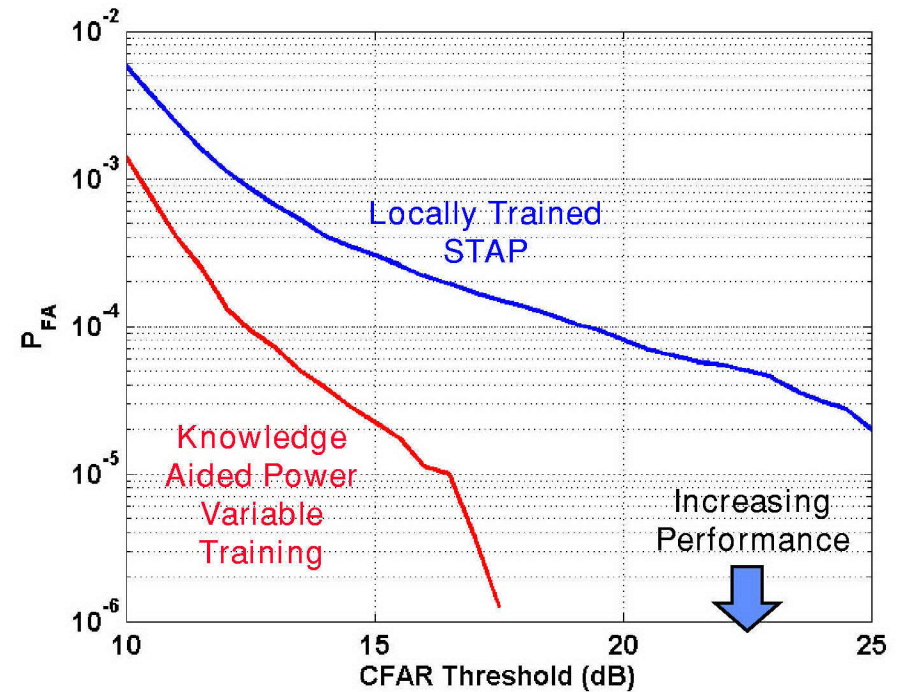
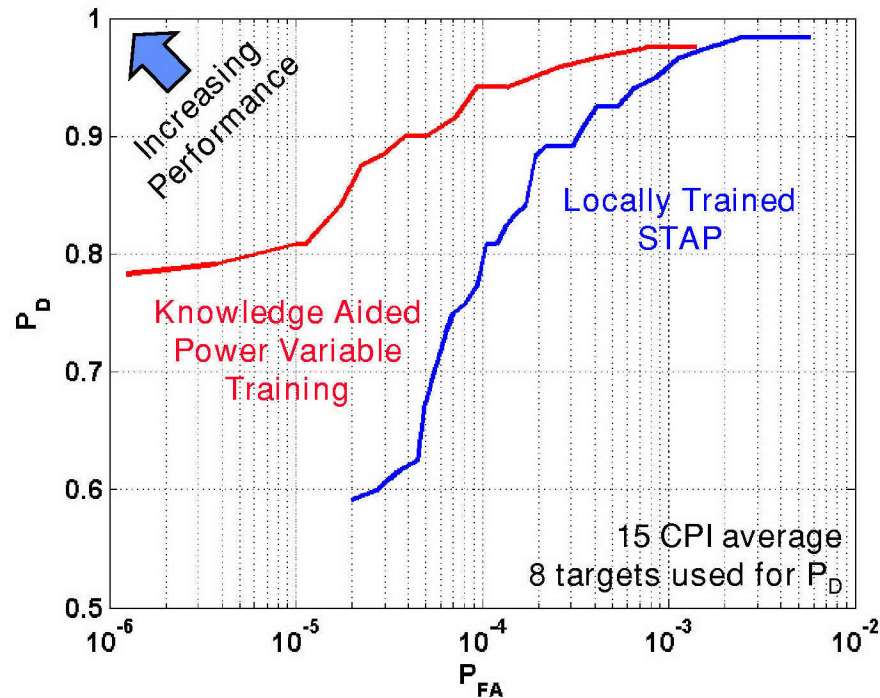
Highest Power

Lowest Power





ROC Comparison

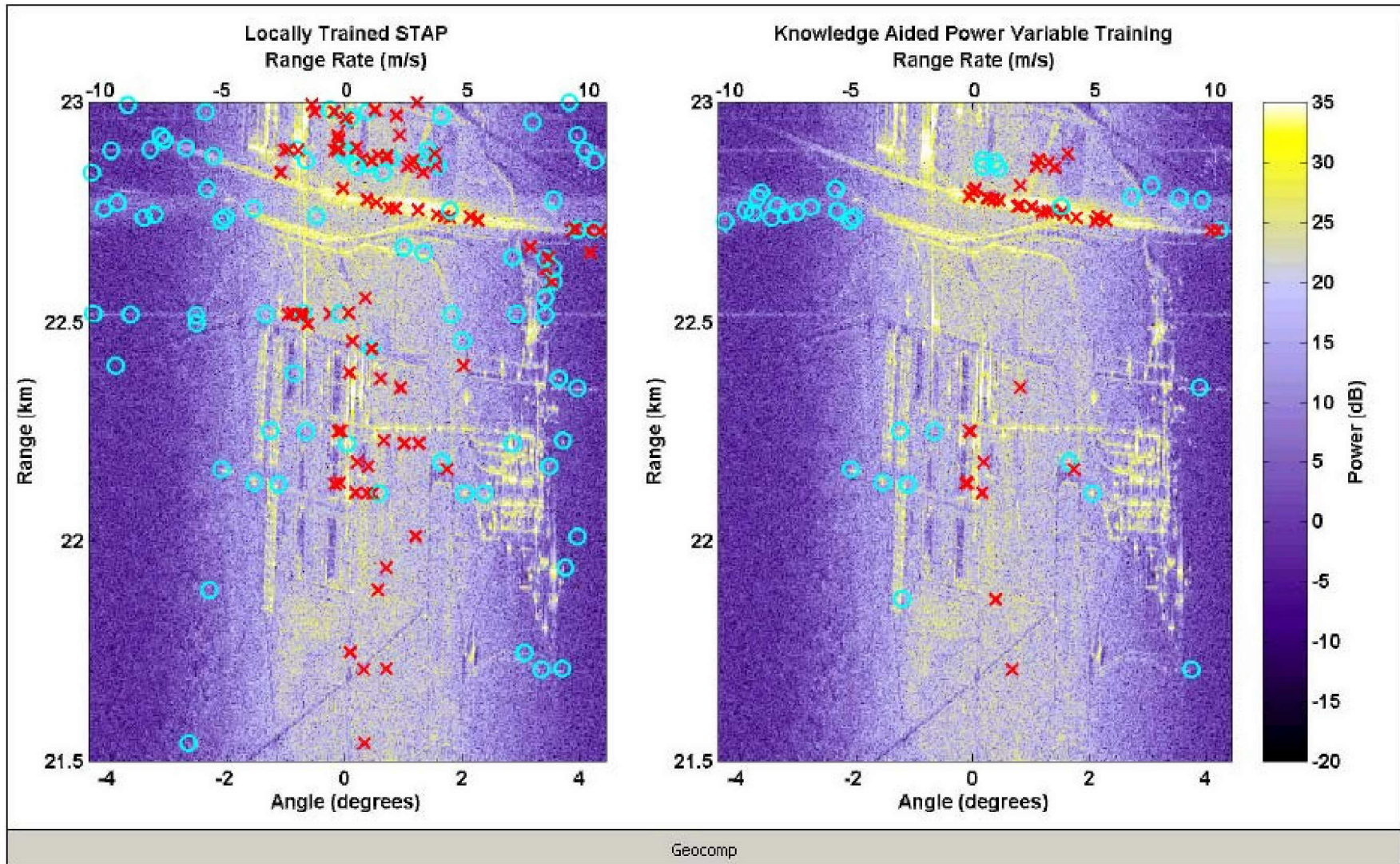


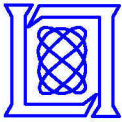
- Overall ROC curve illustrates performance increase
- Significant P_{FA} benefits demonstrated
- Performance gain primarily from P_{FA}



Comparison Movie

- Detection
- × Angle Localization





Conclusions

- Use of internal and external knowledge improves performance
 - Tracker feedback
 - External data maps
- Simple, “smart” enhancements significantly improve overall performance
 - Validated improvements with tuxedo data
- Enhanced algorithm data results
 - Probability of false alarm significantly decreased
 - SINR Loss closely matches predicted performance
 - Targets of interest consistently detected
 - Low MDV observed
 - “Convoy-like” railroad train easily detected and not self-nulled