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IMPROVEMENTS TO A KNOWLEDGE-AIDED STAP APPROACH BASED ON MULTI-CPI CLUTTER MAPS

2004 KASSPER WORKSHOP

April, 2004

Douglas Page

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Outline of Presentation

- Review of approach for incorporating multi-CPI data into knowledge-aided STAP
- Description of improvements to approach
  - Improved calculation of clutter reflectivity maps
  - Adaptive correction for steering vector errors
  - Eigenvalue rescaling after knowledge-aided pre-whitening
- Results of processing KASSPER Data Set 2
- Summary

Summary of Approach for Incorporating Past-CPI Data

- Build an earth-referenced "clutter reflectivity map" based on multiple CPIs
  - Requires registration of each CPI to a geodetic coordinate system
  - Estimate clutter reflectivity separately on each CPI
  - Average clutter reflectivity estimates over many CPIs to obtain smoothed estimates
  - May be generalized to parameters other than reflectivity
- Form predicted clutter estimates on current CPI by indexing into clutter map
  - Calculate range-dependent covariance matrices
- Incorporate predicted covariance matrices into STAP weight vector calculation
  - Knowledge-aided pre-whitening

Estimating clutter statistics using multiple CPI data-cubes

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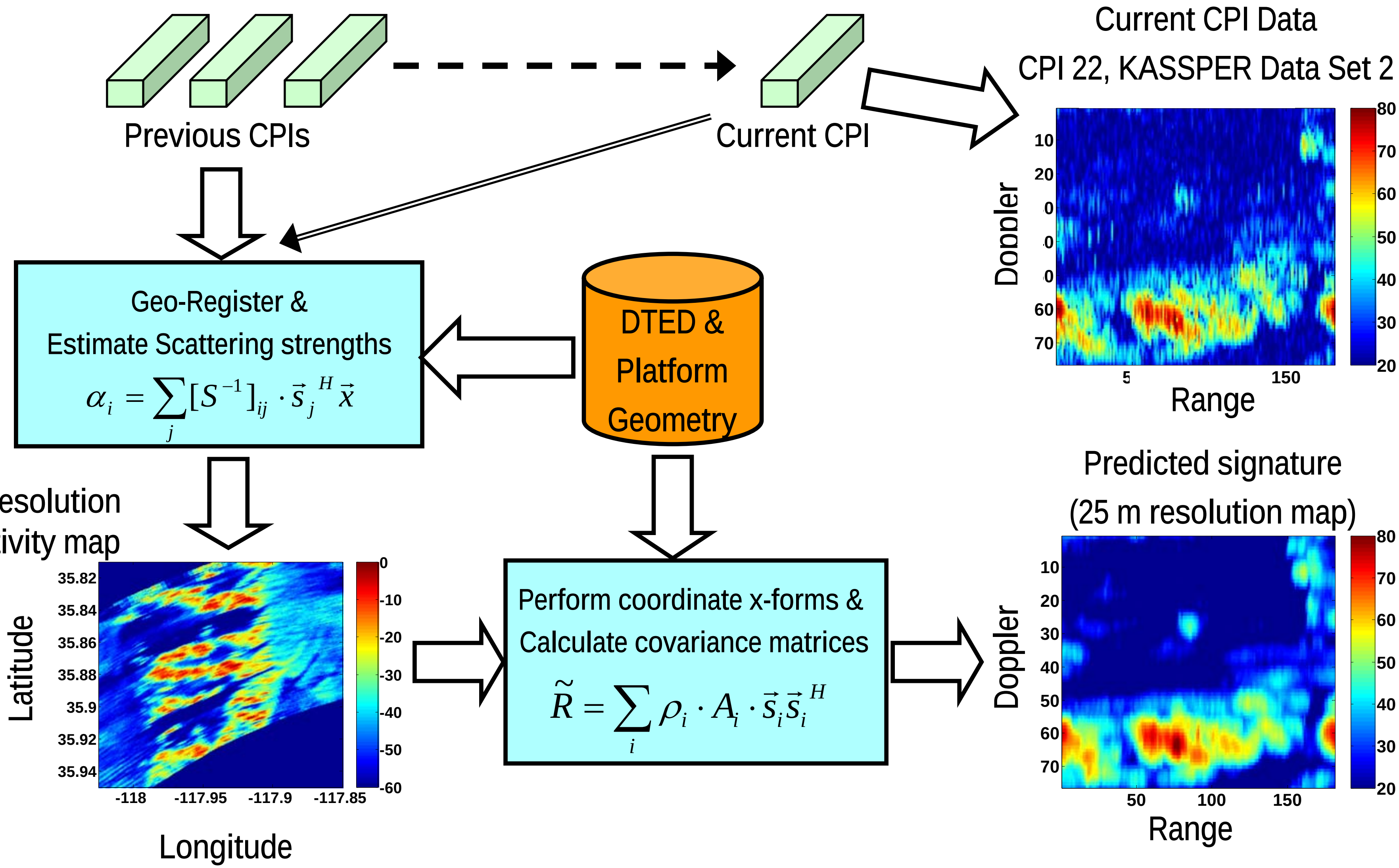

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Combining Clutter Predictions to Improve STAP Performance

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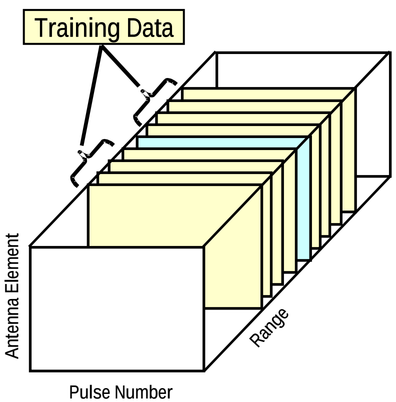
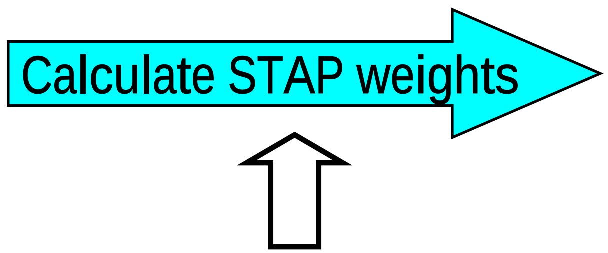
Current CPI Data-Cube



Incorporate knowledge into STAP weight vector calculation



-Conventional covariance estimates

$$\hat{R} = \frac{1}{K}\sum_i \vec{x}_i \vec{x}_i^{\,H} + \gamma \cdot I$$

-Knowledge-derived covariance matrices

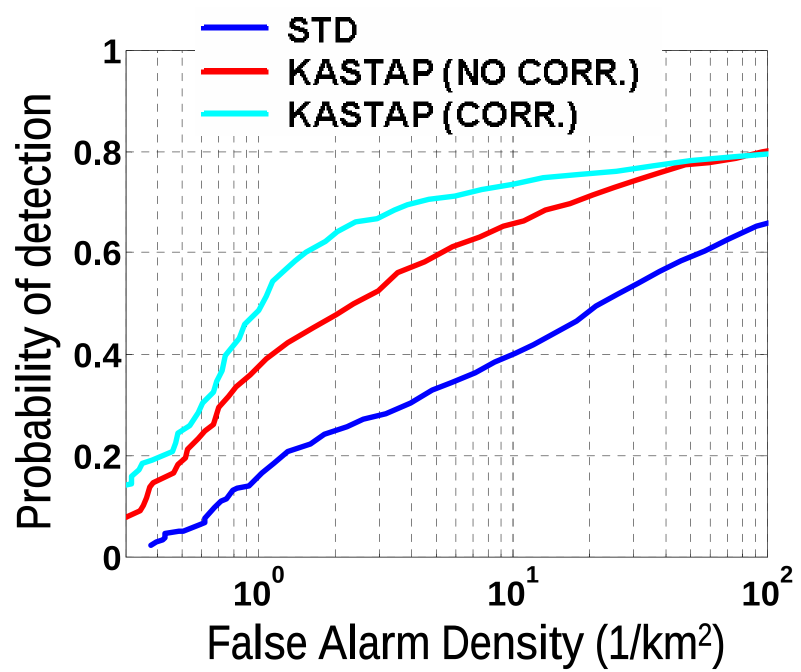
$$\tilde{R} = \hat{R} + \alpha \cdot \sum_i \rho_i \cdot A_i \cdot \vec{s}_i \vec{s}_i^{\,H} \circ T + \beta \cdot I$$

-Range-Doppler masking to reduce target contamination of training data

-Adaptive estimation and correction for steering vector model errors

-Eigenvalue rescaling to improve covariance estimates

ROC Performance over 29 CPIs of the KASSPER Data Set 2



Calculation of reflectivity maps

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- Modified sampling to allow formation of higher resolution reflectivity maps
  - Resolution of reflectivity maps improved from 200 to 25 m
  - Previous sampling method mapped radar cells to earth-based cells and produced “gaps” in reflectivity maps at 25m resolution
  - New sampling technique maps each ground cell to radar coordinates on each CPI and accesses estimated reflectivity of radar cells
- Included current as well as past CPIs into reflectivity maps calculation
  - Antenna beam limits changing from CPI to CPI
  - Used to model new clutter that is moving into the antenna beam on the current CPI (and was in the sidelobes on past CPI)
  - Adaptive selection of number of CPIs averaged in each earth-based cell currently under investigation (target contamination appears to be an issue)

Adaptive Estimation of Model Errors

- Steering vector errors are present due to antenna calibration effects, propagation effects, etc.
- Without correction, fusion of calculated and range-averaged covariance matrices leaves significant residual clutter-to-noise ratio (CNR)
- A technique to adaptively estimate and correct for the errors was developed and applied to the KASSPER Data Set 2
  - Complex gain and phase errors on each antenna element adaptively estimated separately in each Doppler filter
  - Errors applied to spatial covariance derived from clutter reflectivity map
  - Maximum likelihood criterion used to estimate the errors using current CPI data and multiple-CPI clutter reflectivity map
  - After correction of calculated covariance, residual CNR is <u>significantly</u> reduced and KASTAP detection performance improved

CPI 22 SINR LOSS (no correction for model errors)

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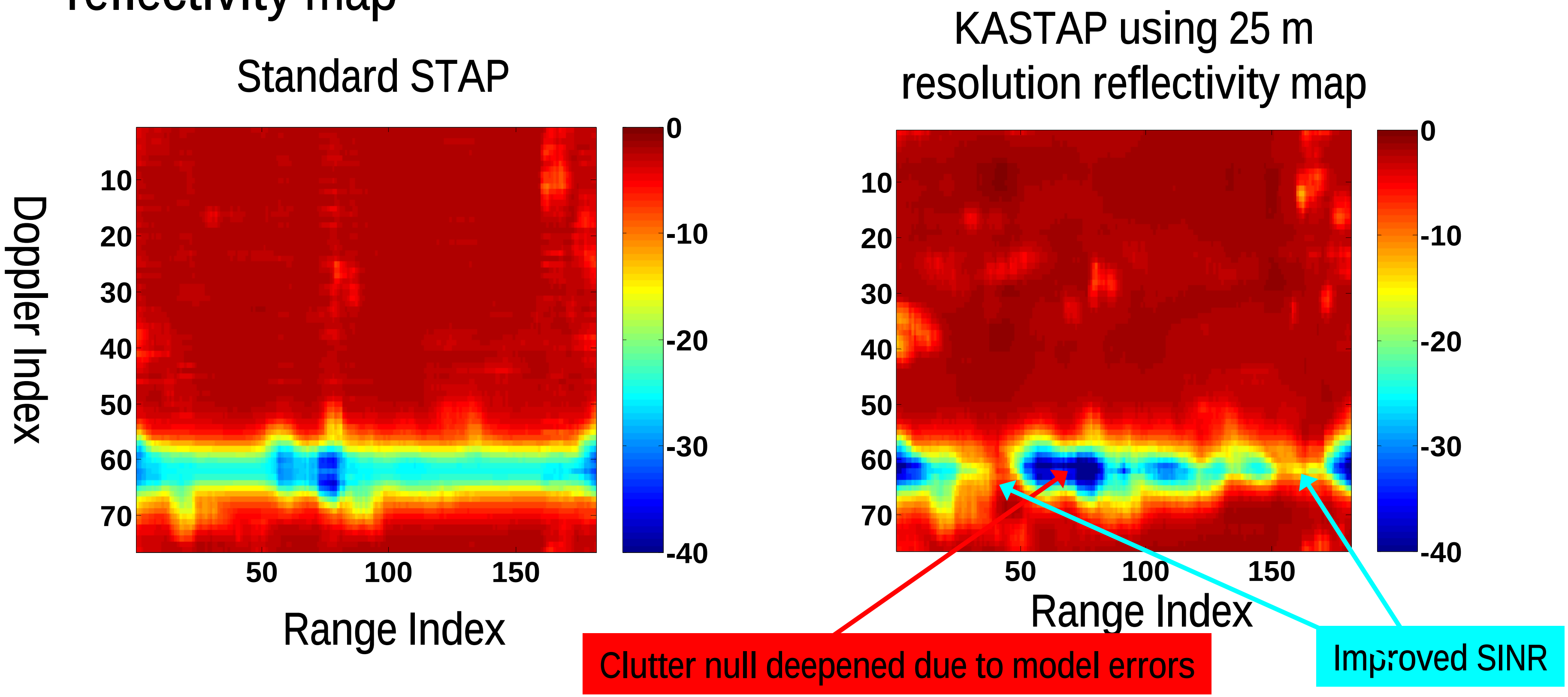
- KASTAP with colored loading [1] used to fuse range-averaged covariance with calculated covariance derived from the clutter reflectivity map



[1] J. Bergin, J. Guerci, P. Techau, C. Teixeira, “Space-Time Beamforming with Knowledge-Aided Constraints”, Adaptive Sensor Array Processing Workshop 2003, 11-13 March 2003

CPI 22 Residual CNR (no correction for model errors)

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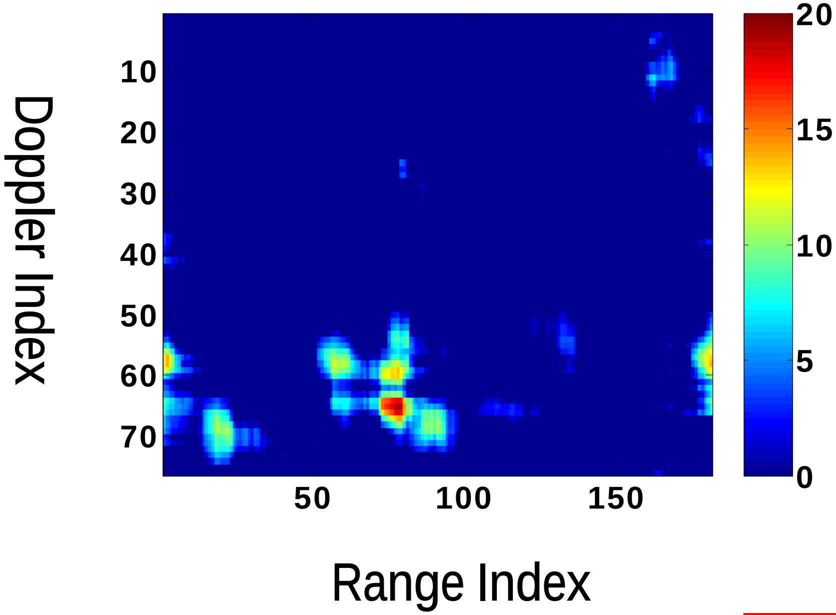
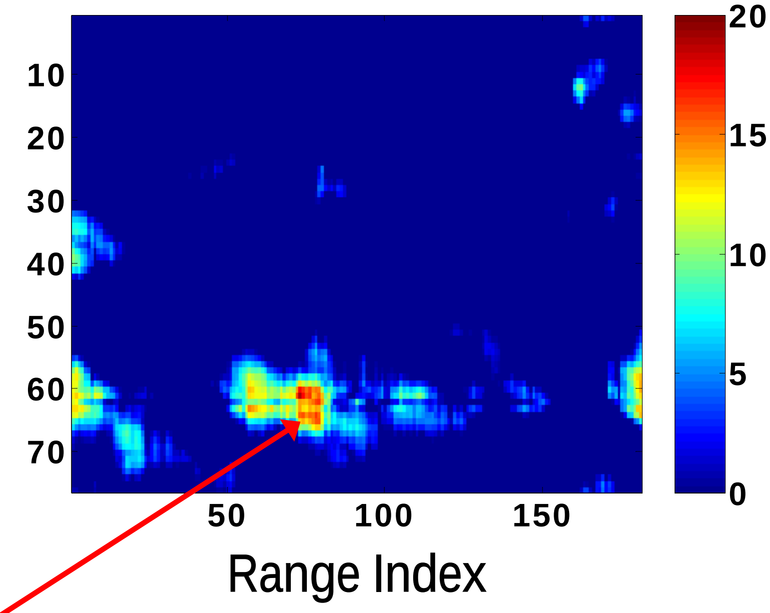
- CNR after STAP calculated using clutter-only data-cube provided with the KASSPER Data Set

Standard STAP



KASTAP using 25 m resolution reflectivity map



Significant residual CNR remains

Estimated gain and phase errors as a function of Doppler and antenna element

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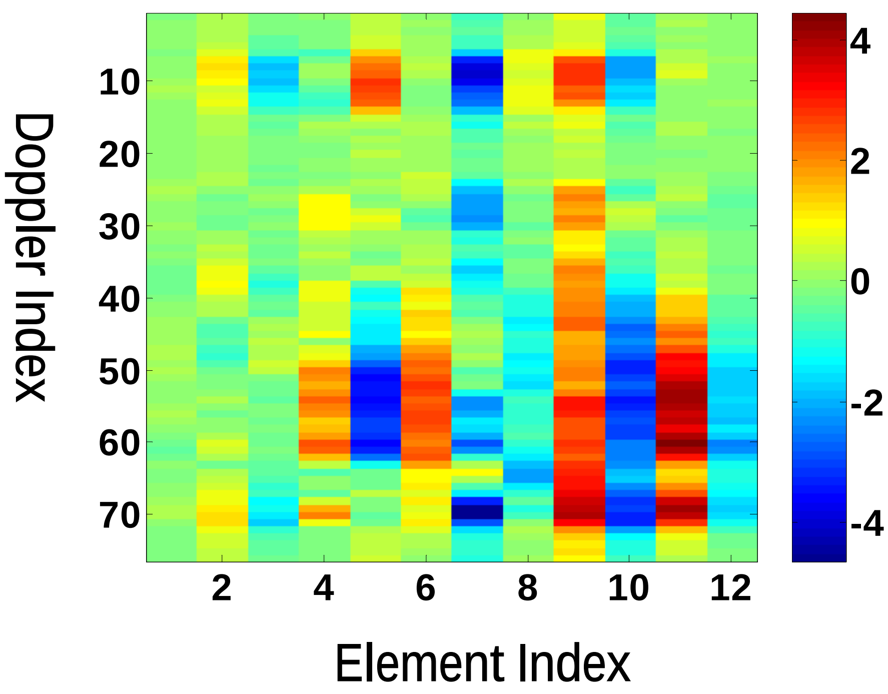
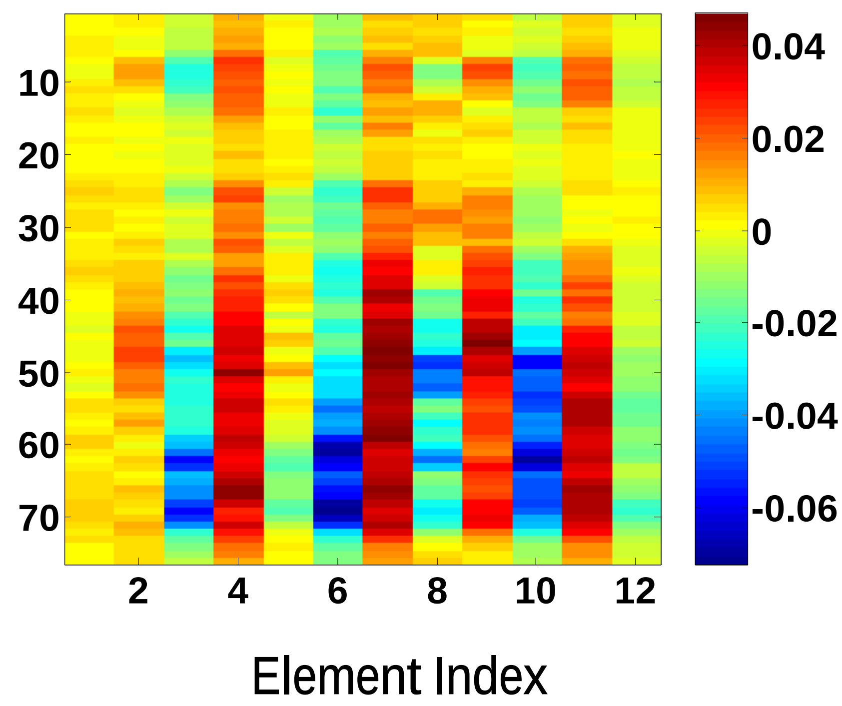
- A 2.7 km range window was used to estimate complex gain and phase errors depending on antenna element and Doppler filter
  - Likelihood function maximized for current CPI data using corrected covariance matrices derived from multiple CPI clutter reflectivity map

Phase Error (degrees)



Log Amplitude error



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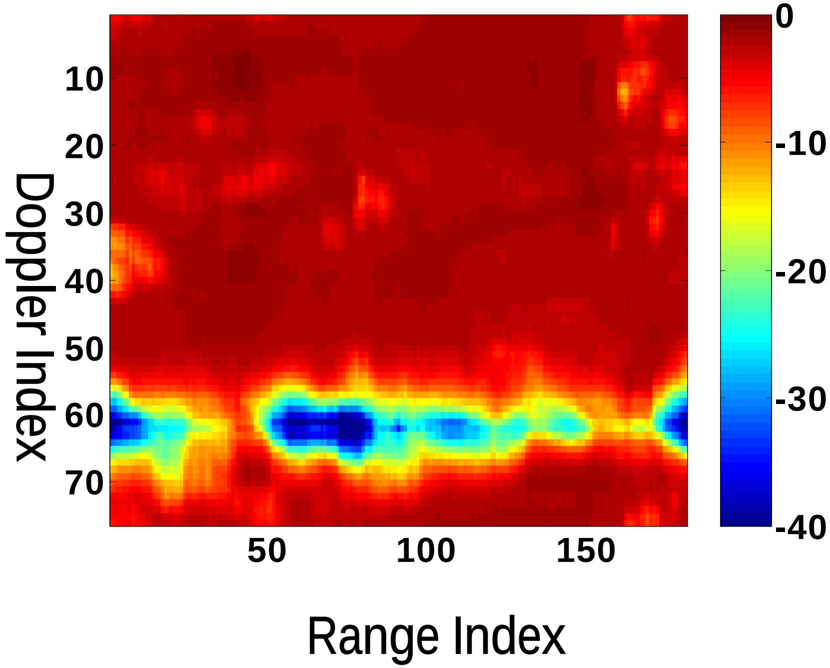
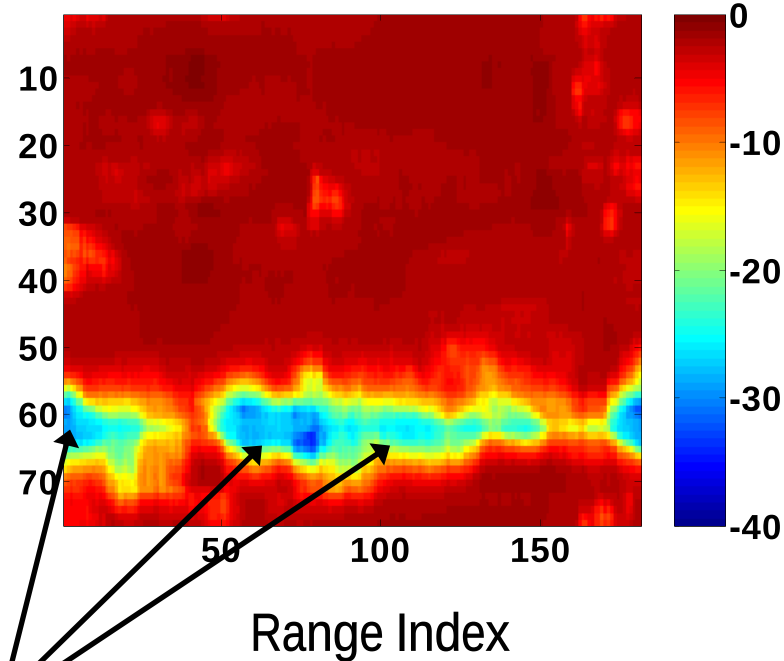
KASTAP SINR LOSS (CPI 22, with and without model error correction)

KASTAP (no model error correction)



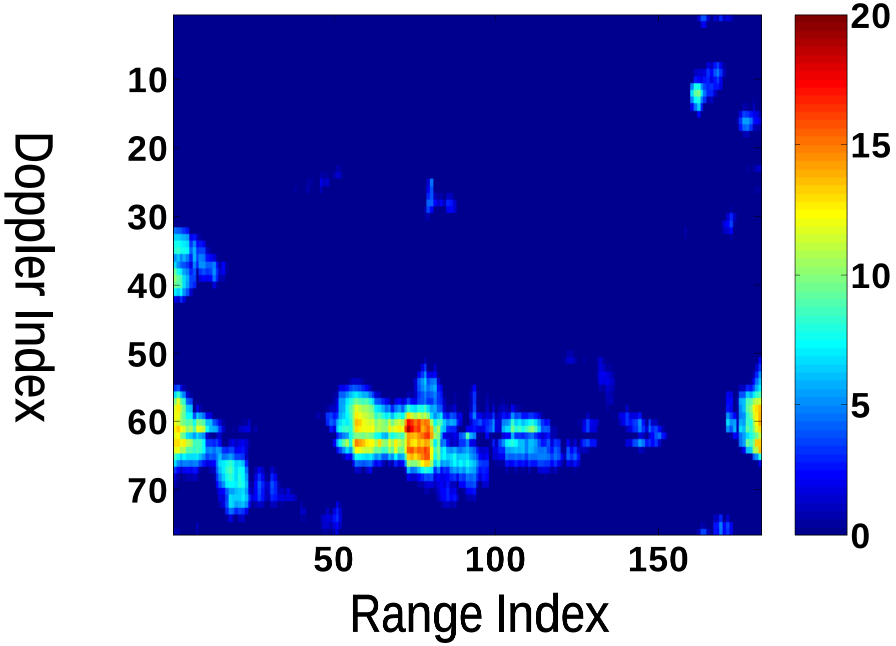
KASTAP (with gain and phase error correction)



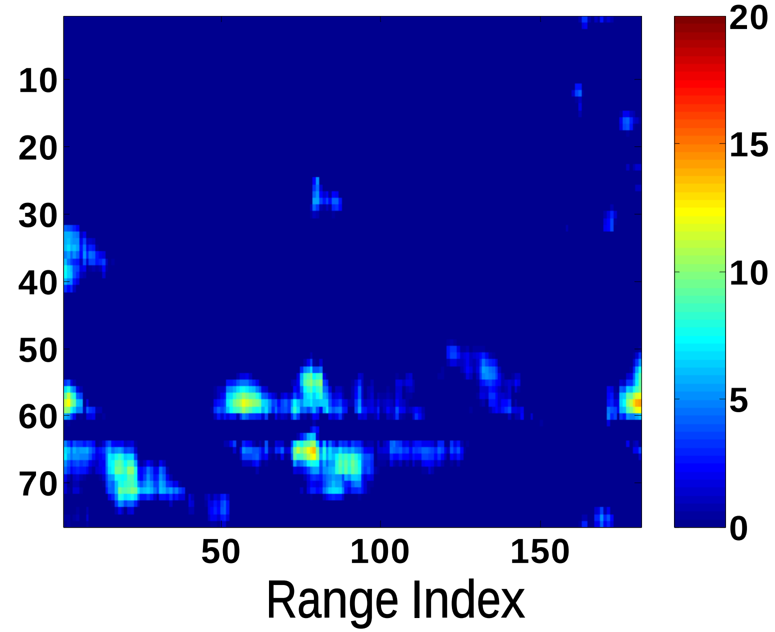
Clutter null shallower due to model error correction

KASTAP Residual CNR (CPI 22, with and without model error correction)

KASTAP (CPI 22, no model error correction)



KASTAP (CPI 22, with Doppler-dependent gain and phase error correction)



Residual CNR significantly reduced due to model error correction

Eigenvalue rescaling to further improve KASTAP performance

- Calculated covariance based on clutter reflectivity map provides better knowledge of overall clutter amplitude variation with range and Doppler
- Range-averaged covariance contains additional knowledge of space-time response of clutter returns
- To produce improved covariance estimates, the eigenvalues of the colored loading covariance estimate are rescaled using the calculated covariance:

$$\boldsymbol{R}_{CL} = \boldsymbol{R}_{rng-avg} + \alpha \cdot \boldsymbol{R}_{calc} + \beta \cdot \boldsymbol{I}$$

$$\boldsymbol{R}_{CL} \hat{\boldsymbol{e}}_n = \lambda_n \hat{\boldsymbol{e}}_n$$

$$\lambda_n' = \hat{\boldsymbol{e}}_n^H \boldsymbol{R}_{calc} \hat{\boldsymbol{e}}_n$$

$$\boldsymbol{R}_{CL}' = \sum_n \lambda_n' \cdot \hat{\boldsymbol{e}}_n \hat{\boldsymbol{e}}_n^H$$

Eigenvalue rescaling improves knowledge of clutter eigenspectrum

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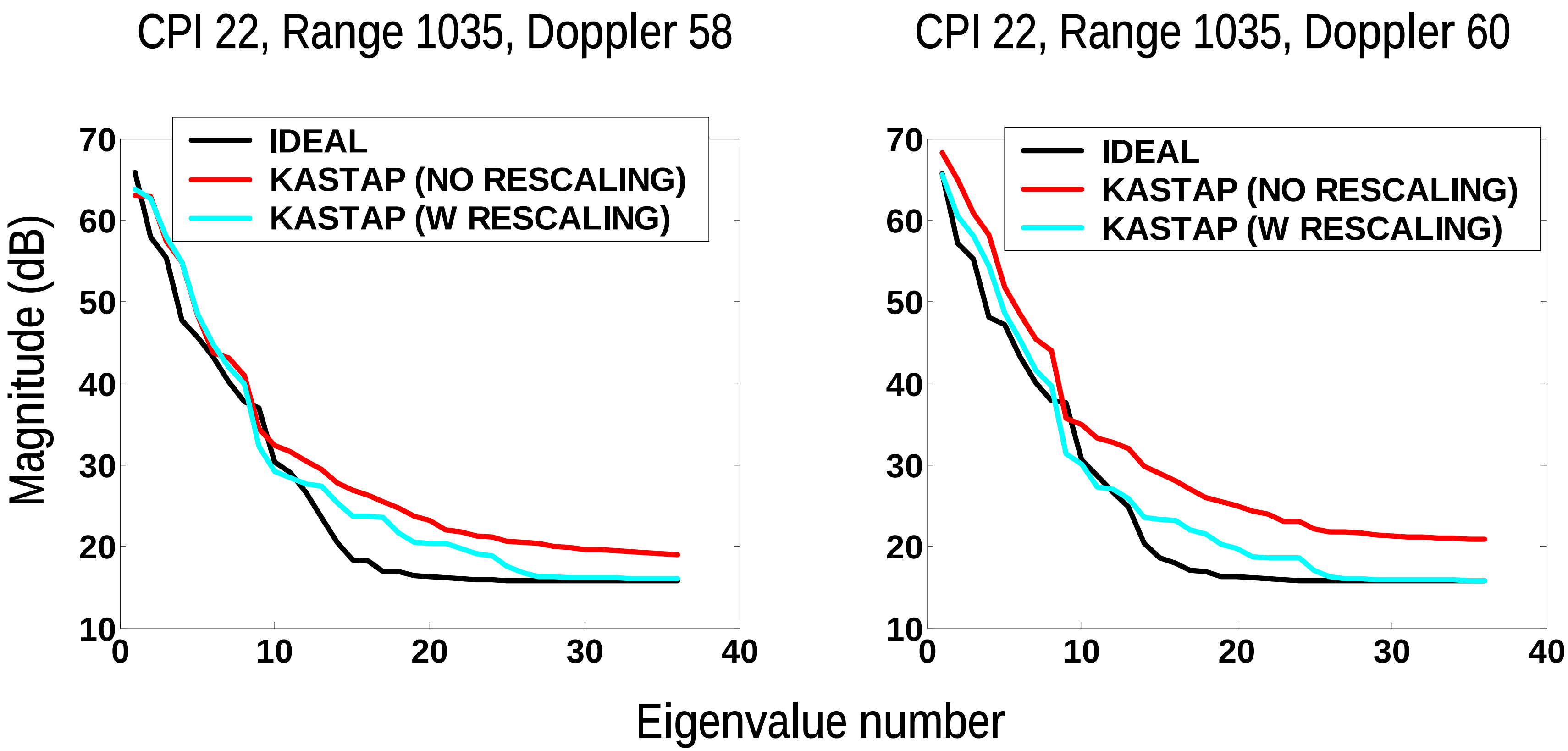

KASTAP SINR LOSS (CPI 22, with and without eigenvalue rescaling)

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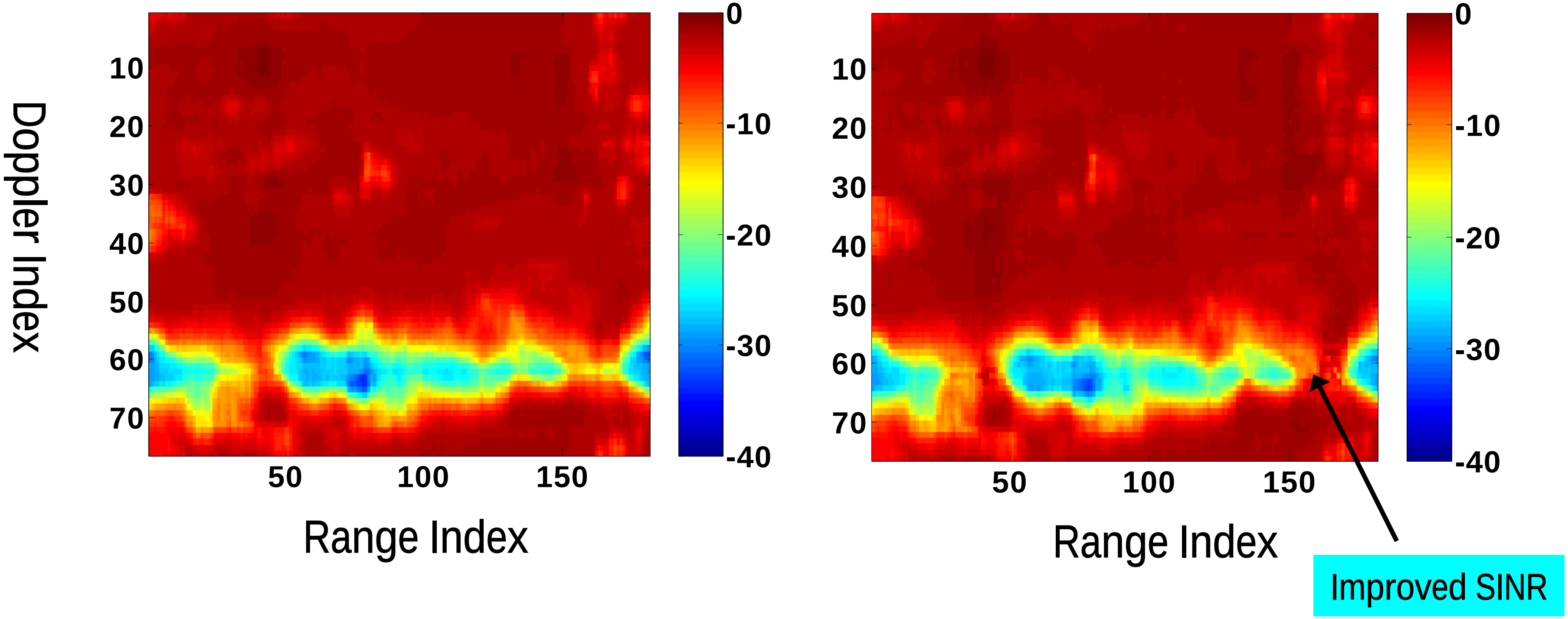
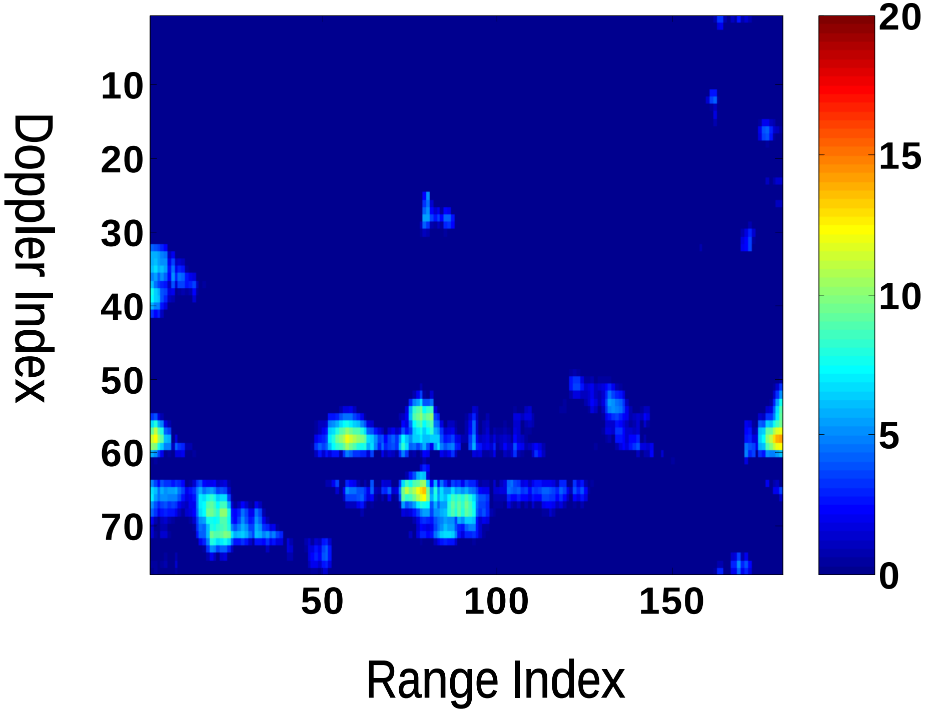
KASTAP (model error correction only)

KASTAP (model error correction and eigenvalue rescaling)

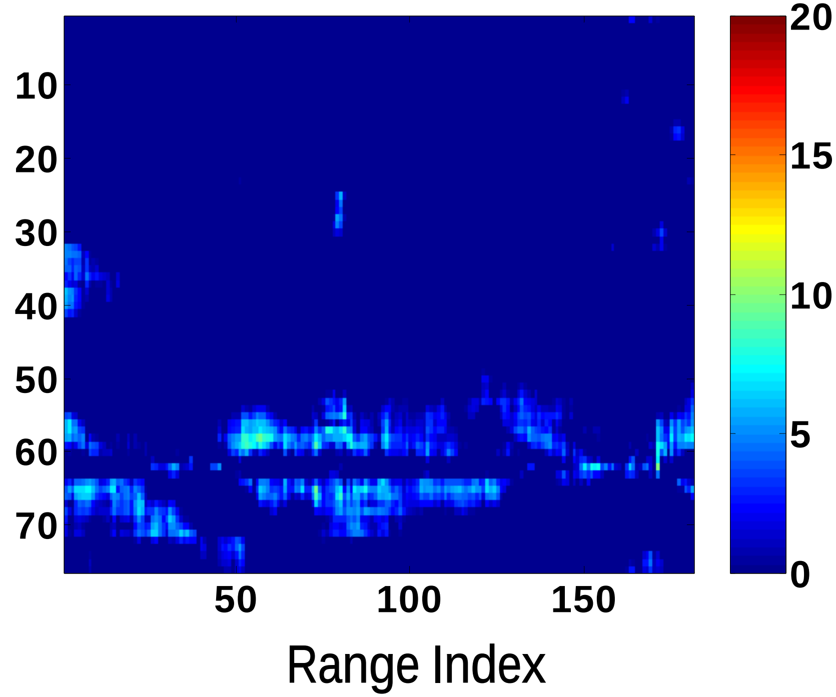


Eigenvalue rescaling reduces residual CNR after KASTAP processing

KASTAP (CPI 22, model error correction only)



KASTAP (CPI 22, with model error correction and eigenvalue rescaling)



Residual CNR further reduced due to eigenvalue rescaling

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Detection/false alarm performance

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- Target truth locations provided with KASSPER Data Set 2
  - Both mainlobe (within 1.35 deg of center steering azimuth) and sidelobe (within 5 deg) targets considered
- Output STAP amplitudes normalized so that noise is at 0 dB
  - Conventional adaptive matched filter (AMF) statistic produces a varying noise level
  - Search performed over 12 steering directions spanning a 1.5 degree azimuth sector
- A range-only CFAR is performed in each Doppler filter
- For each algorithm, detection threshold is varied and number of (mainlobe) targets detected and false alarms determined
  - Target sidelobe detections not counted as false alarms

Standard STAP Output Amplitude (Noise=0 dB)

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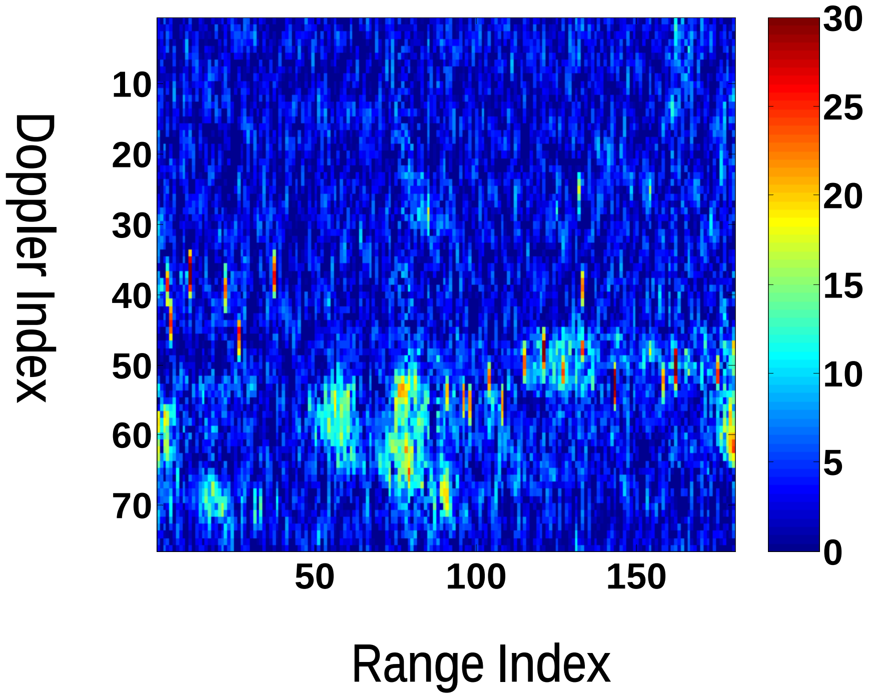
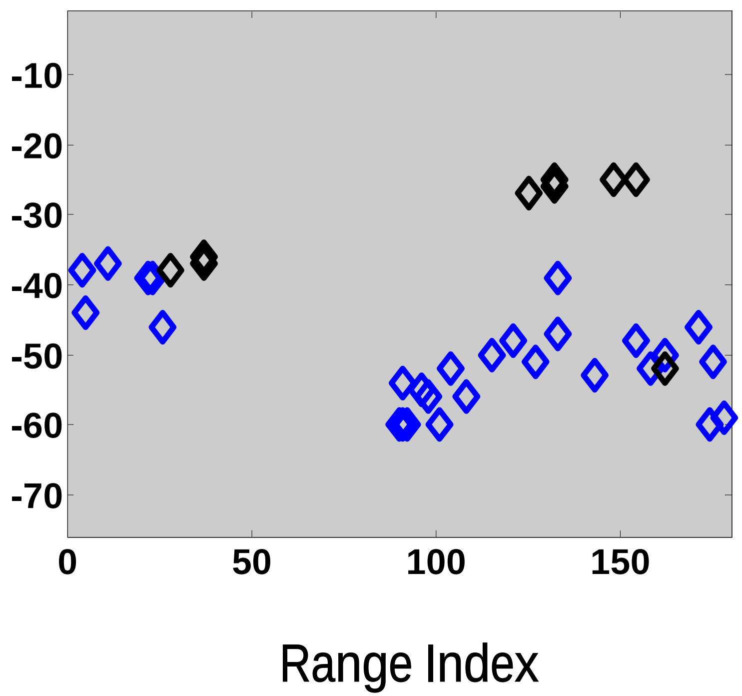
After standard STAP Processing



Target truth locations



KASTAP (no corrections applied) Output Amplitude (Noise=0 dB)

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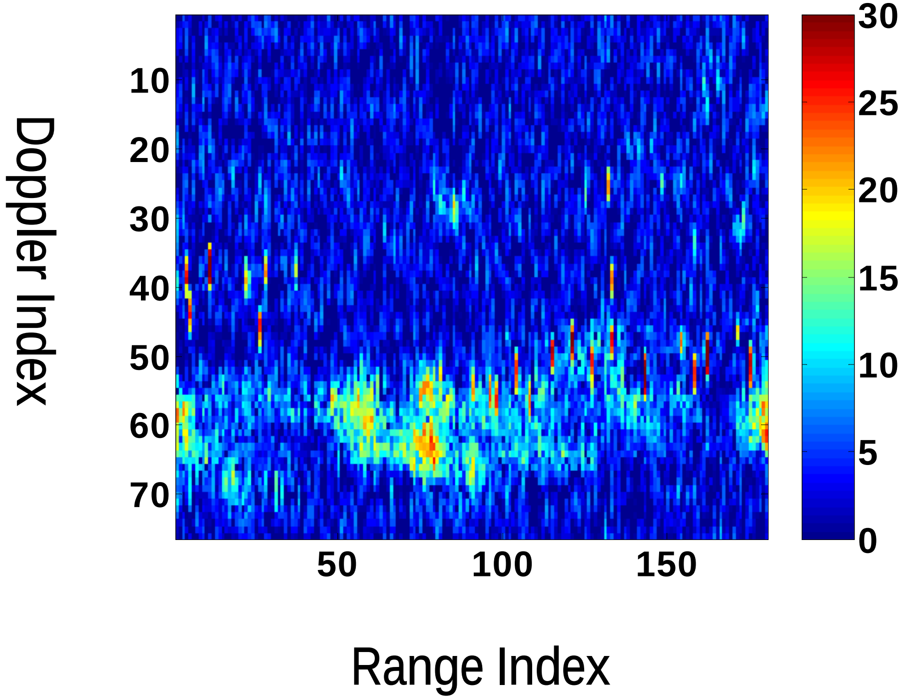
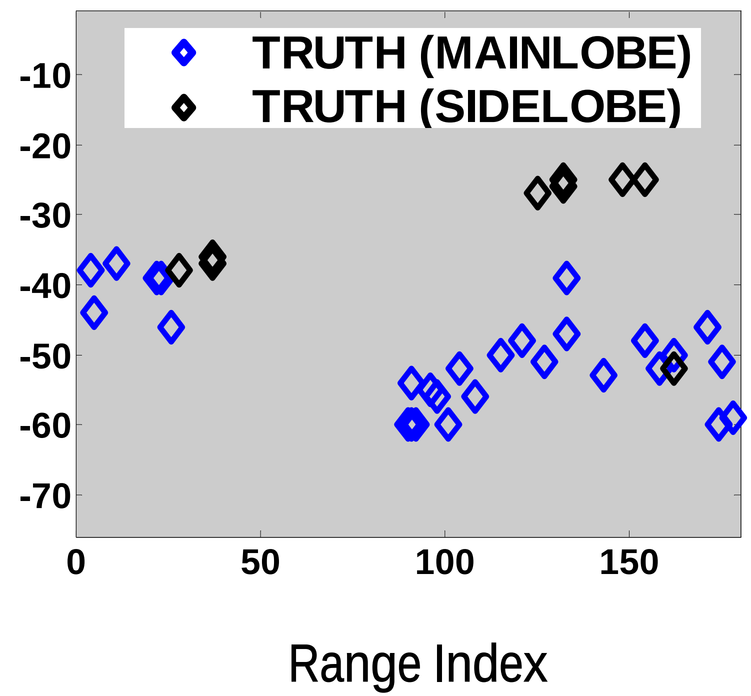
After KASTAP Processing



Target truth locations



Target amplitudes improved over standard STAP, but residual CNR remains, and will cause false alarms

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KASTAP (corrections applied) Output Amplitude (Noise=0 dB)

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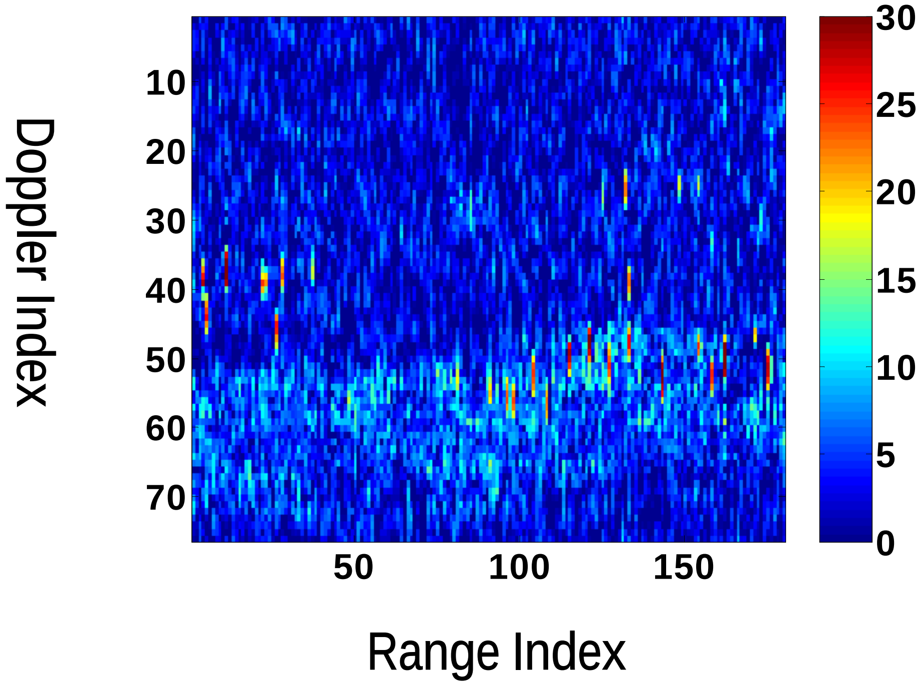
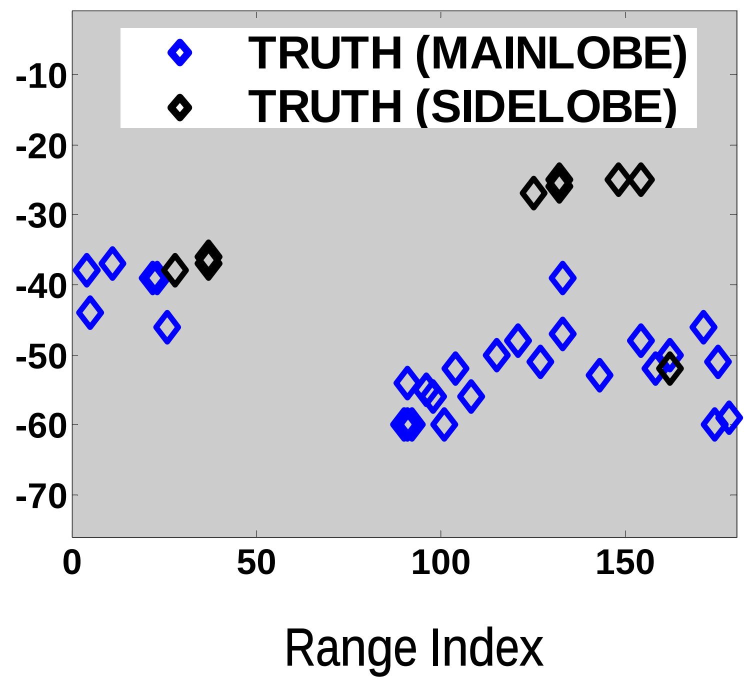
After KASTAP Processing



Target truth locations



Target amplitudes improved over standard STAP, and residual CNR <u>significantly</u> reduced (thus reducing false alarms)

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Threshold crossing locations

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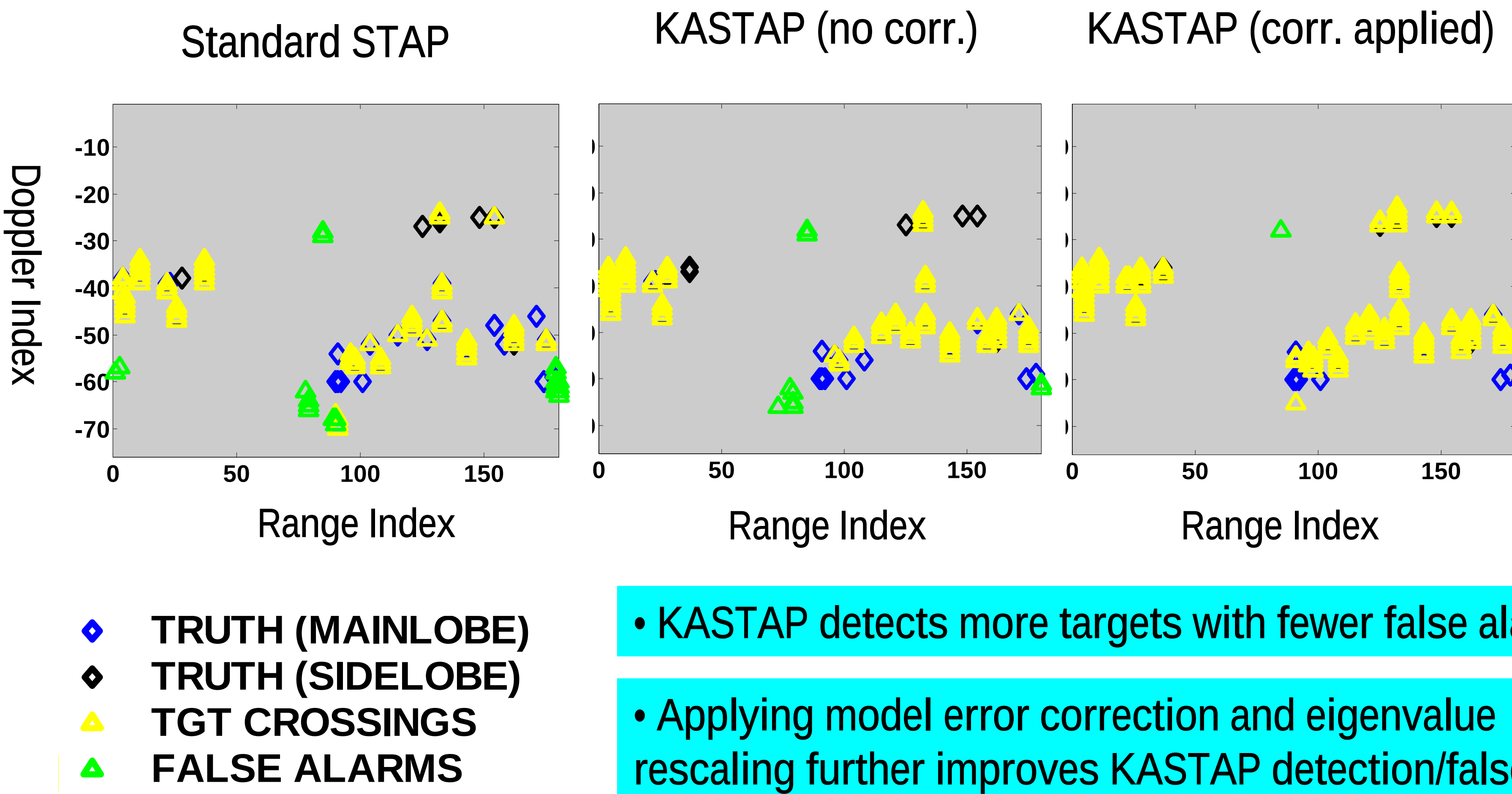

- KASTAP detects more targets with fewer false alarms
- Applying model error correction and eigenvalue rescaling further improves KASTAP detection/false alarm ratio

ROC curves (CPI 22)

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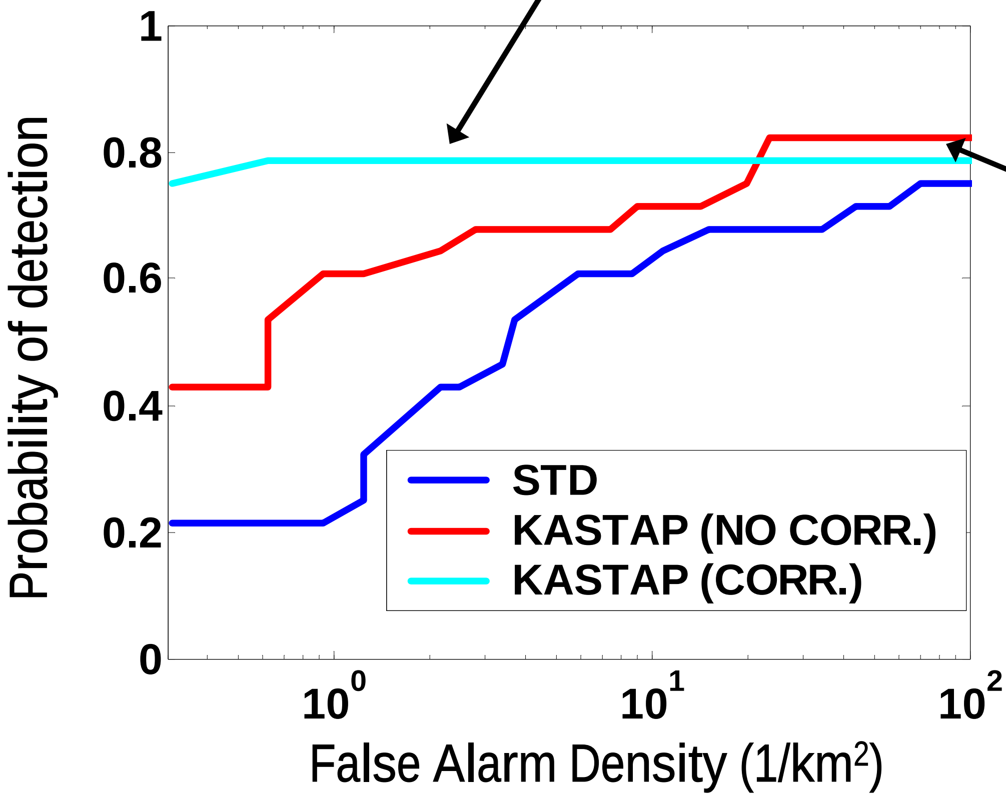
Significantly improved target detection performance results from using KASTAP with model error correction and eigenvalue rescaling



Clutter crossings counted as target detections, since targets located in area of significant residual clutter

ROC curves over 29 CPIs (CPIs 4,7,…88, 3 km^2/CPI)

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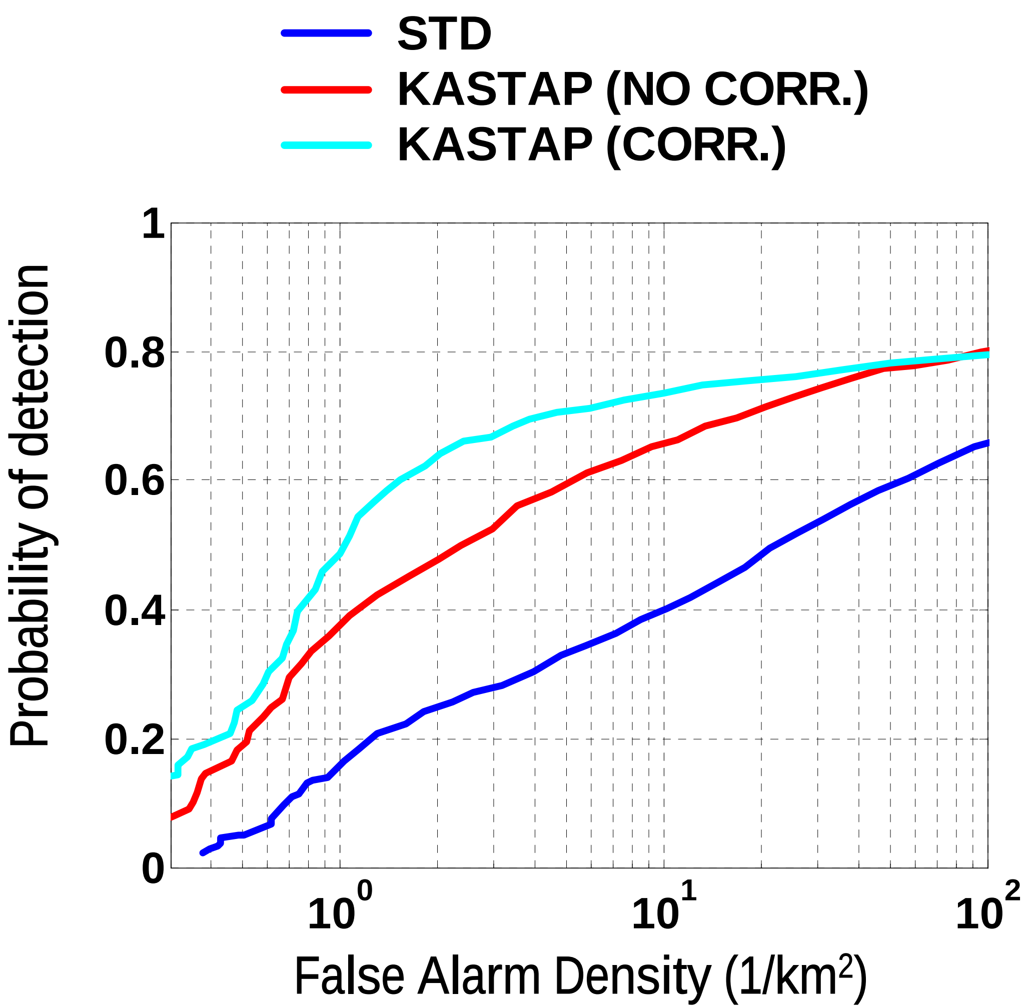

<u>False alarm density at Pd=0.6:</u>

Standard STAP: 55.2 per km^2

KASTAP (no corr.): 5.3 per km^2

KASTAP (w corr.): 1.5 per km^2

Summary of Tracker Performance
STAP vs. KASTAP

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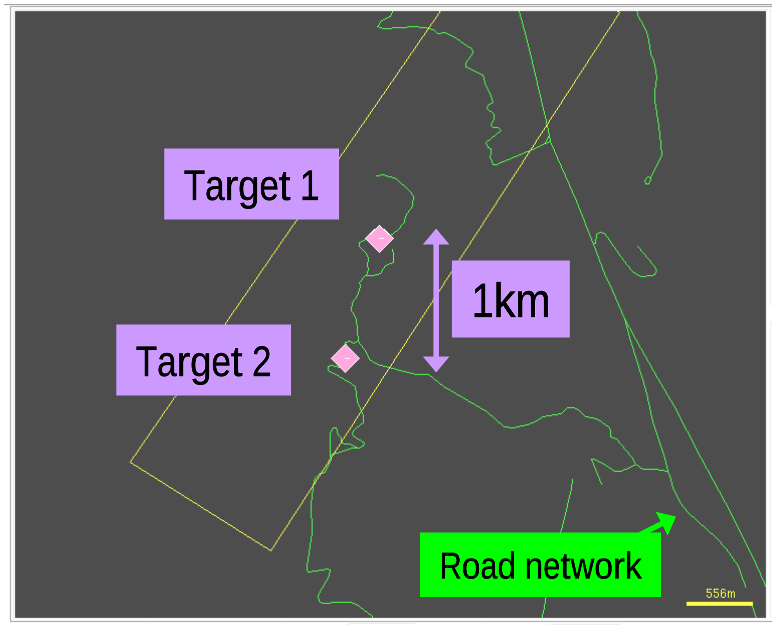
Target locations on DM++ display



Tracking summary

	Standard STAP	KASTAP
Target #1 Detections	12	18
Target #1 Misses	11	5
Target #1 Time in track	90 sec	220 sec
Target #2 Detections	15	17
Target #2 Misses	8	6
Target #2 Time in track	210 sec	220 sec
False Alarms	11	5

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Summary

- Significant progress has been made in using multiple CPI data to improve knowledge-aided STAP processing
  - Improved resolution reflectivity maps formed
  - Clutter reflectivity maps used along with current CPI data to adaptively estimate and correct for model errors
  - Eigenvalue rescaling technique used to further improve knowledge-aided covariance estimates
- Evaluations using the KASSPER Data Set 2 have demonstrated significantly improved KASTAP performance
  - Improved SINR loss
  - Reduced levels of residual clutter
  - Improved detection/false alarm and tracking performance
- Ongoing work will further refine technique and perform additional evaluations using KASSPER data sets