BAE SYSTEMS

6 New England Executive Park Burlington, MA 01803-4562 781-273-3388
3811 N. Fairfax Drive, Arlington, VA 22203 703-524-6263

Recent Results in Multi-CPI Knowledge-Aided STAP GMTI Processing

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Douglas Page

Outline of presentation

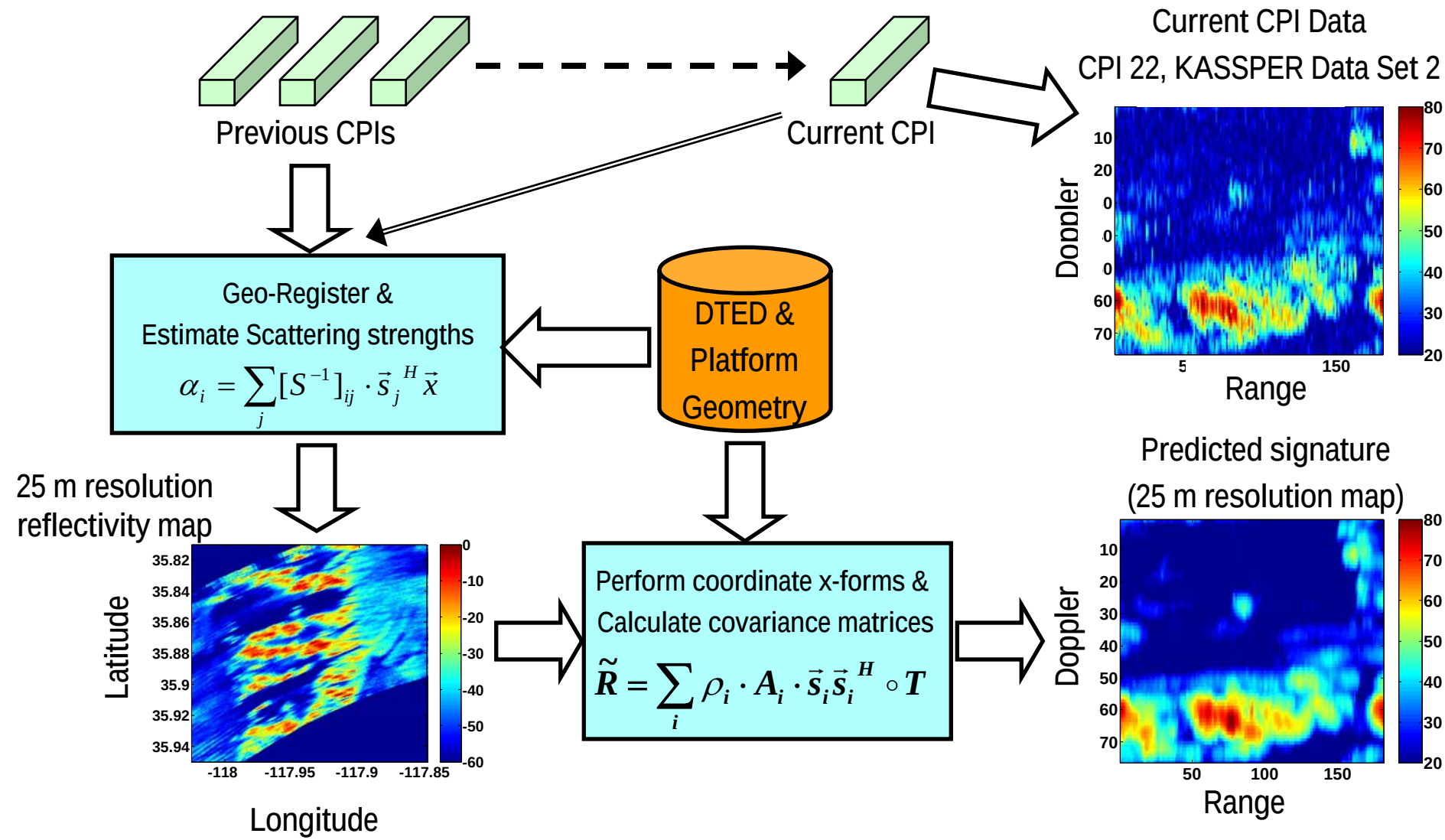
- Review of approach for incorporating multi-CPI data into knowledge-aided STAP (KASTAP)
- Summary of results applied to the Kassper Data Set 2
- Results of processing the Kassper Data Set 3
- Summary

Summary of approach for building multi-CPI clutter maps [1]

- Use an earth-based reference system to define the maps
  - 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
- Use an adaptive method of incorporating current CPI data into the reflectivity maps
  - A generalized likelihood ratio test (GLRT) used to detect large reflectivity changes due, e.g. to onset of shadowing
- Form predicted clutter estimates on current CPI by indexing into clutter map
  - Calculate range-dependent covariance matrices

1. D. Page, S. Scarborough, S. Crooks, "Improving Knowledge-Aided STAP Performance using Past CPI Data", 2004 IEEE Radar Conference, pp. 295-300, April 26-29 2004

Estimating clutter statistics using multiple CPI data-cubes



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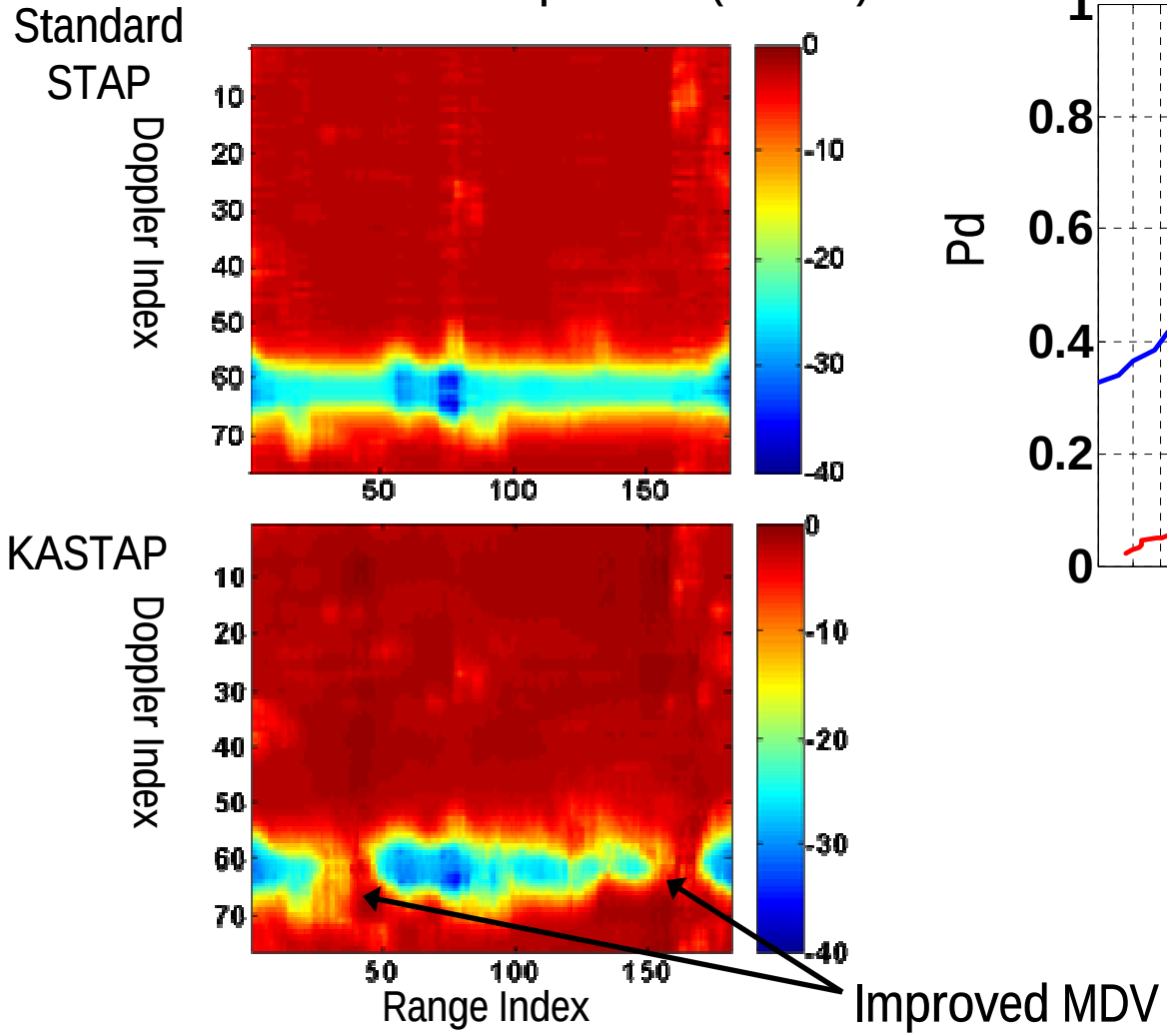
Summary of approach for calculating KASTAP filter weights

- Perform adaptive estimation and correction for channel and Doppler-dependent gain/phase errors [1]
  - Technique develops maximum likelihood estimates of channel and Doppler-dependent gain and phase errors
  - Covariances derived from clutter reflectivity map used as a reference
  - Corrects for unknown model errors (such as calibration errors) that may not be known in advance to required accuracy
- Incorporate predicted covariance matrices into KASTAP weight vector calculation
  - Perform knowledge-aided pre-whitening via colored loading [2] in post-Doppler framework
  - Reduce target contamination of training data using range-Doppler masking
  - Perform eigenvalue rescaling to further improve covariance estimates [1]

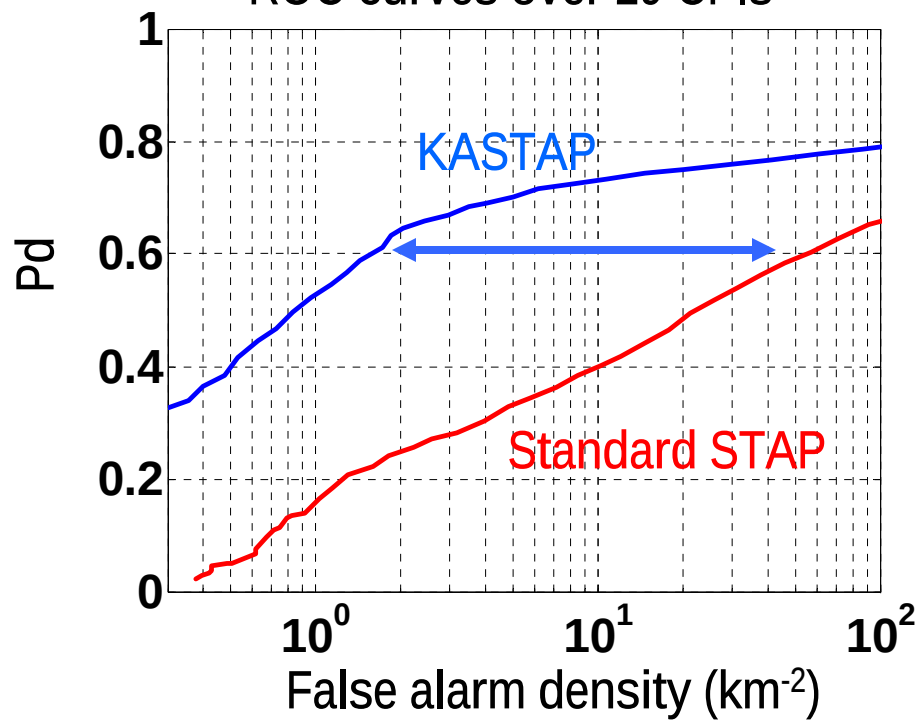
2. J. Bergin, J. Guerci, P. Techau, C. Teixeira, "Space-Time Beamforming with Knowledge-Aided Constraints", Adaptive Sensor Array Processing Workshop 2003, 11-13 March 2003

Results of applying KASTAP processing to the KASSPER Data Set 2

SINR Loss Comparison (CPI 22)



ROC curves over 29 CPIs



False alarm density at Pd=60%:

Standard STAP: 55/km^2

KASTAP: 1.5/km^2

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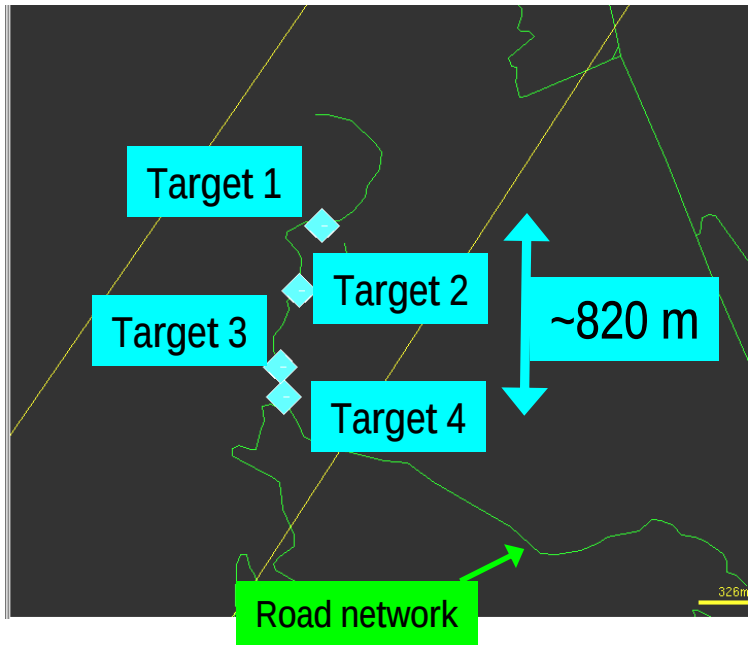
Summary of Tracker Performance STAP vs. KASTAP (Kassper Data Set 2)

Target locations on DM++ display



Tracking summary

	Standard STAP	KASTAP
Target #1 Detections	12	22
Target #1 Time in track	130 sec	230 sec
Target #2 Detections	17	19
Target #2 Time in track	230 sec	230 sec
Target #3 Detections	17	21
Target #3 Time in Track	220 sec	210, 20 sec*
Target #4 Detections	7	17
Target #4 Time in Track	60 sec	210 sec
False Alarms	28	10

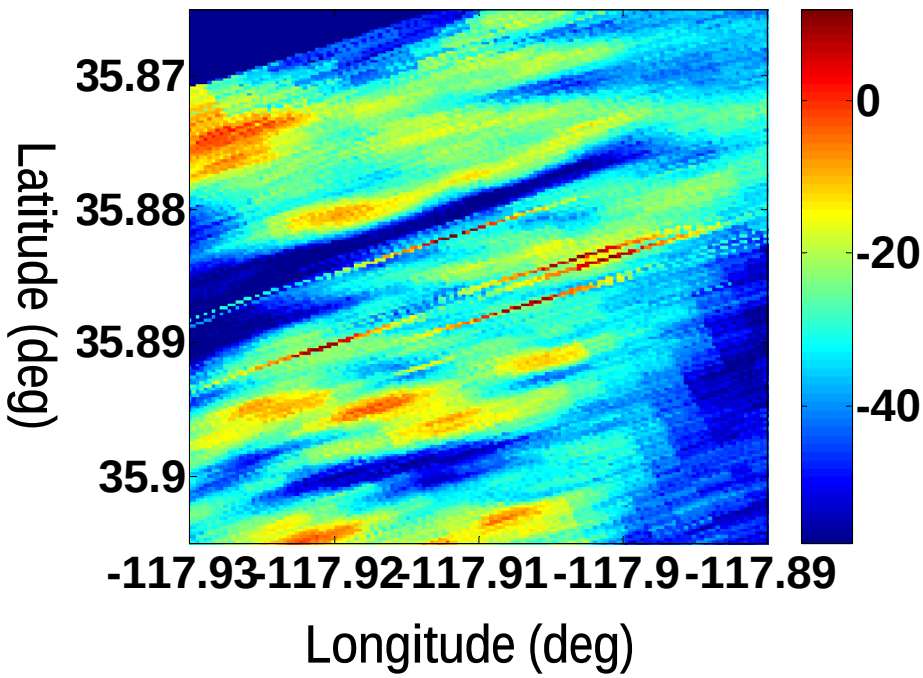
*two tracks formed on target

Summary of approach developed for mitigating effect of large discretes

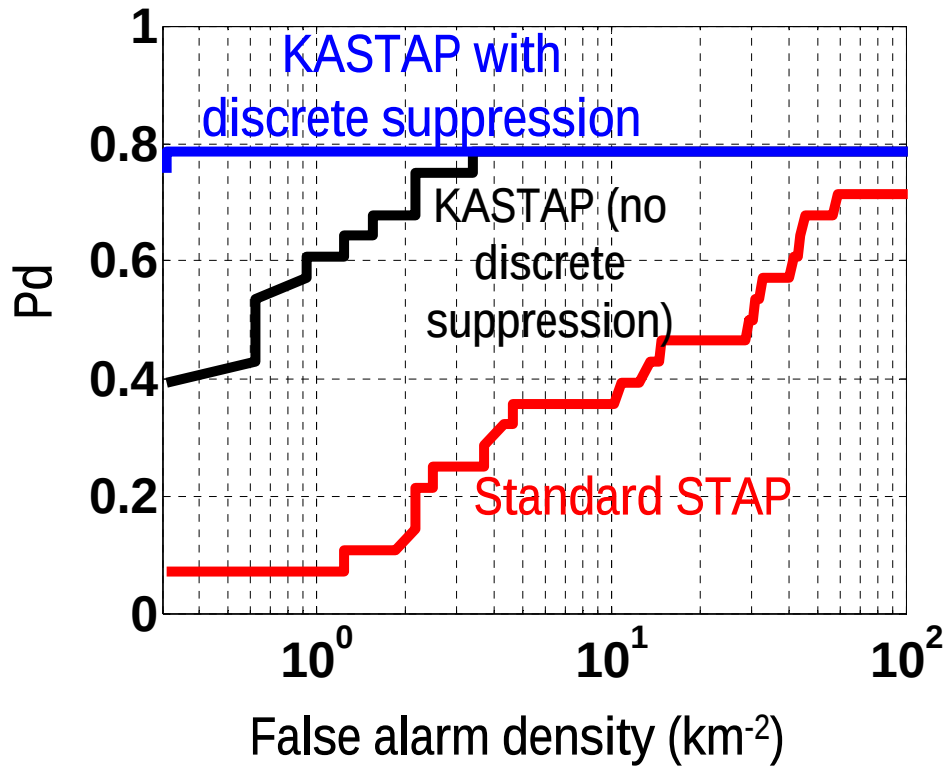
- 1. Identify range-gates containing likely discretes (such as buildings) using clutter reflectivity estimates on each CPI
- 2. Estimate discrete locations on clutter ridge, complex amplitudes
- 3. Subtract estimated discrete contributions to clutter reflectivity
- 4. Estimate channel-dependent gain and phase errors on each detected discrete
  - Errors determined for distributed clutter not accurate enough to provide adequate nulling of discretes
- 5. Modify KASTAP weight vector to produce deterministic nulls on detected discretes

Results of applying KASTAP with discrete suppression processing to CPI #22 of the Kassper Data Set 2

Reflectivity map portion showing discrete contamination



ROC curves



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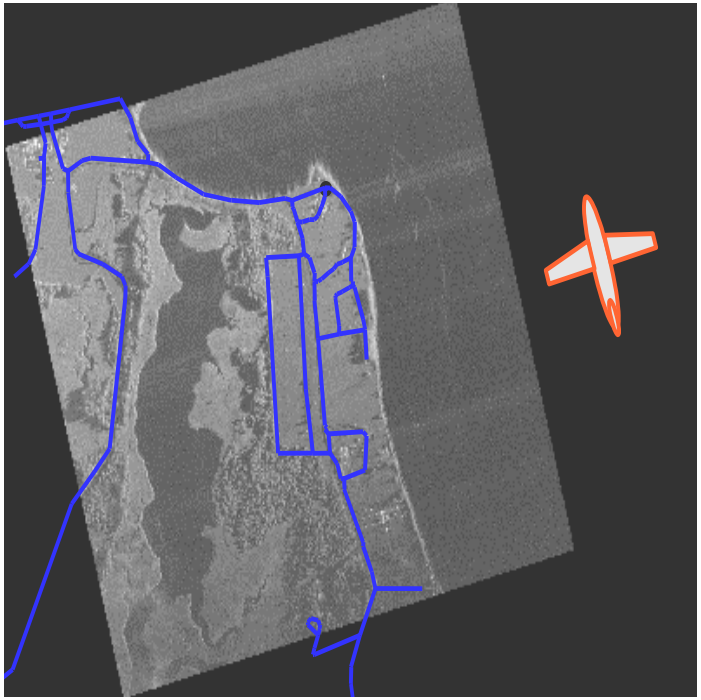
Processing of Kassper Data Set 3

- Data set developed by ISL based on SAR imagery that we delivered
  - SAR images were geo-registered
  - Alignment of images to correct for registration errors was also performed
- We applied our KASTAP approach to the data set
  - Modification of adaptive gain/phase estimation procedure was found to be necessary
- Results shown on following slides

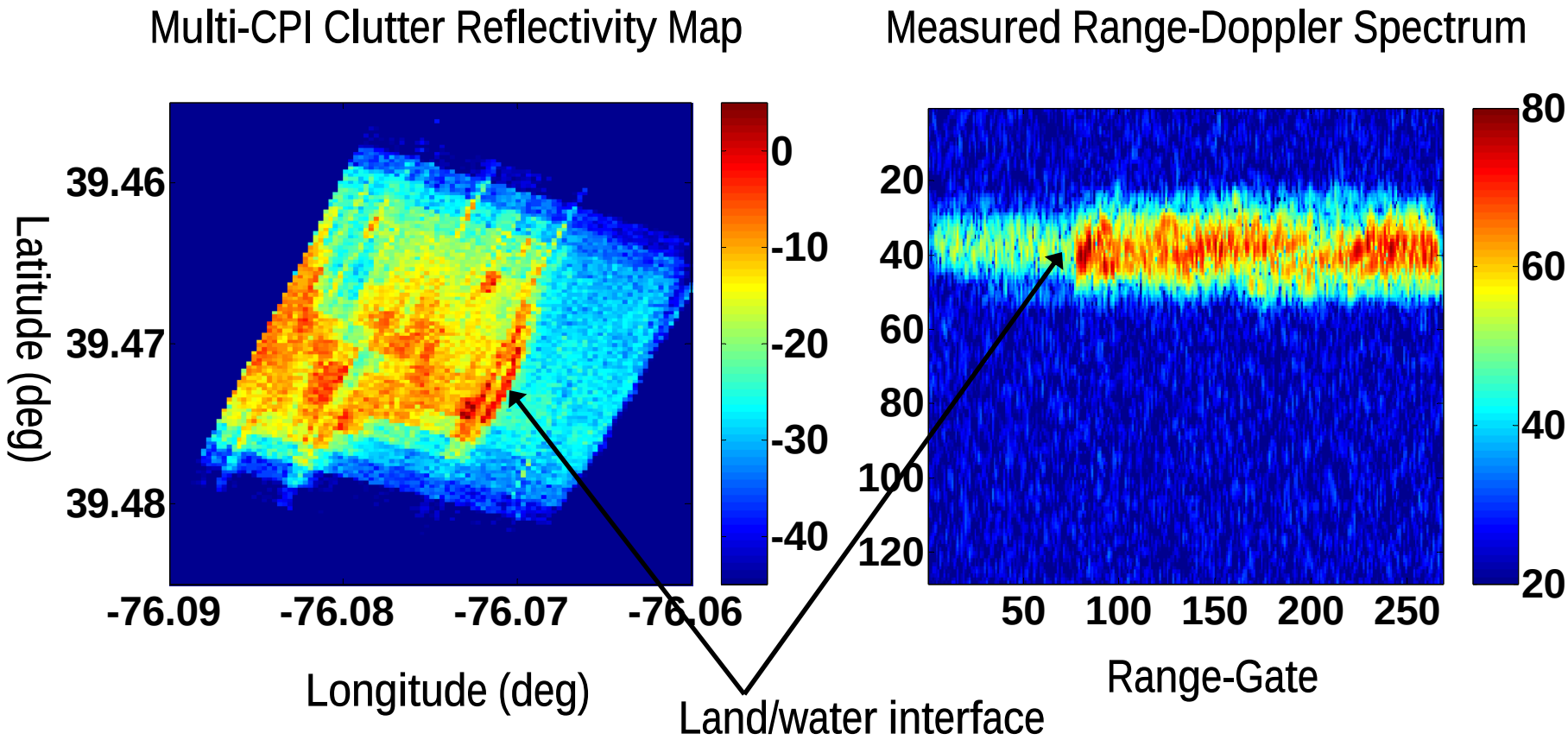
One of the SAR Images from the collection used to develop the Kassper Data Set 3. A USGS road network and approximate SAR aircraft viewing angle are shown



Differences between Kassper Data Sets 2 & 3

- Bigger antenna but fewer spatial DOFs (antenna subarrays, 6 vs. 12)
- Overlapped subarrays
  - Correlated noise statistics
- Land/water boundary
- Less terrain elevation variation (Aberdeen area is flat)
- Lower input clutter to noise ratio (CNR)
  - Standard STAP performs fairly well
  - Estimation of channel-dependent gain and phase errors more difficult
  - We modified the error estimation procedure to improve performance

Multi-CPI clutter reflectivity map and measured range-Doppler spectrum



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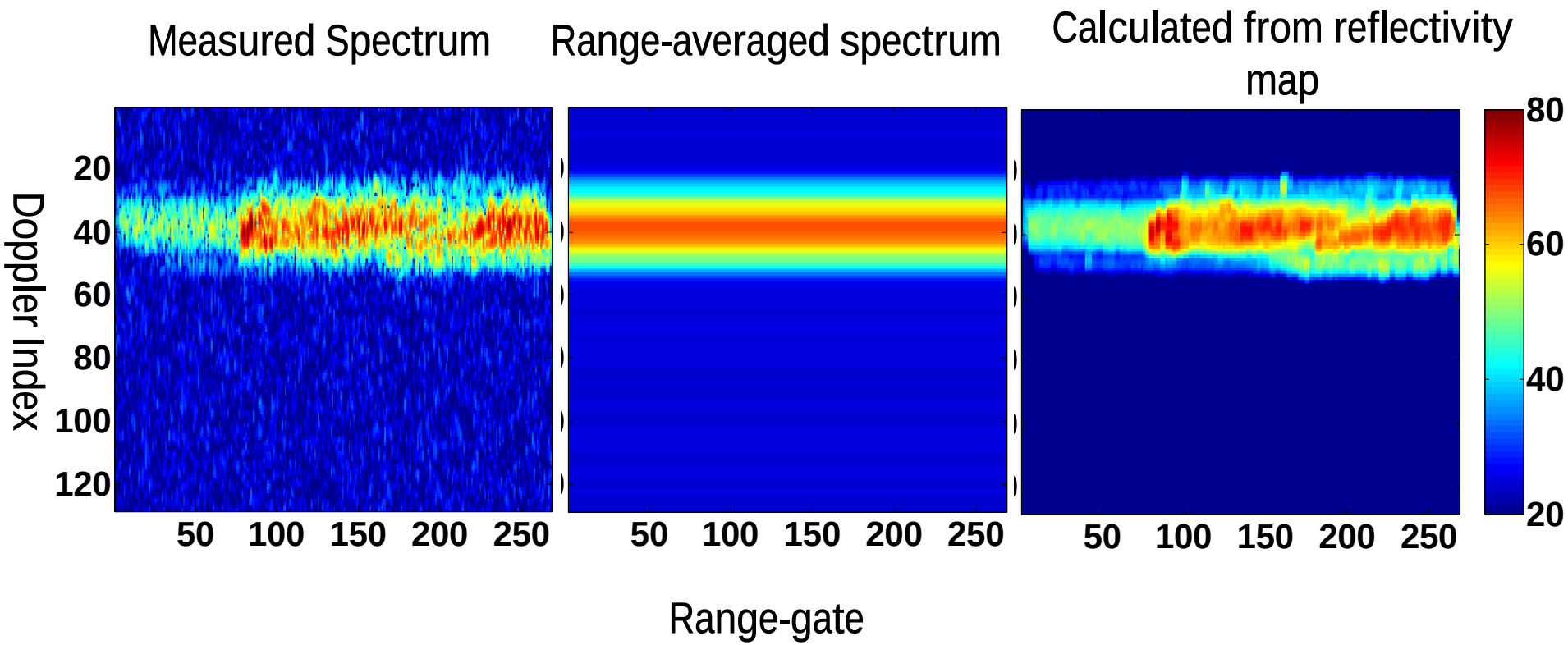
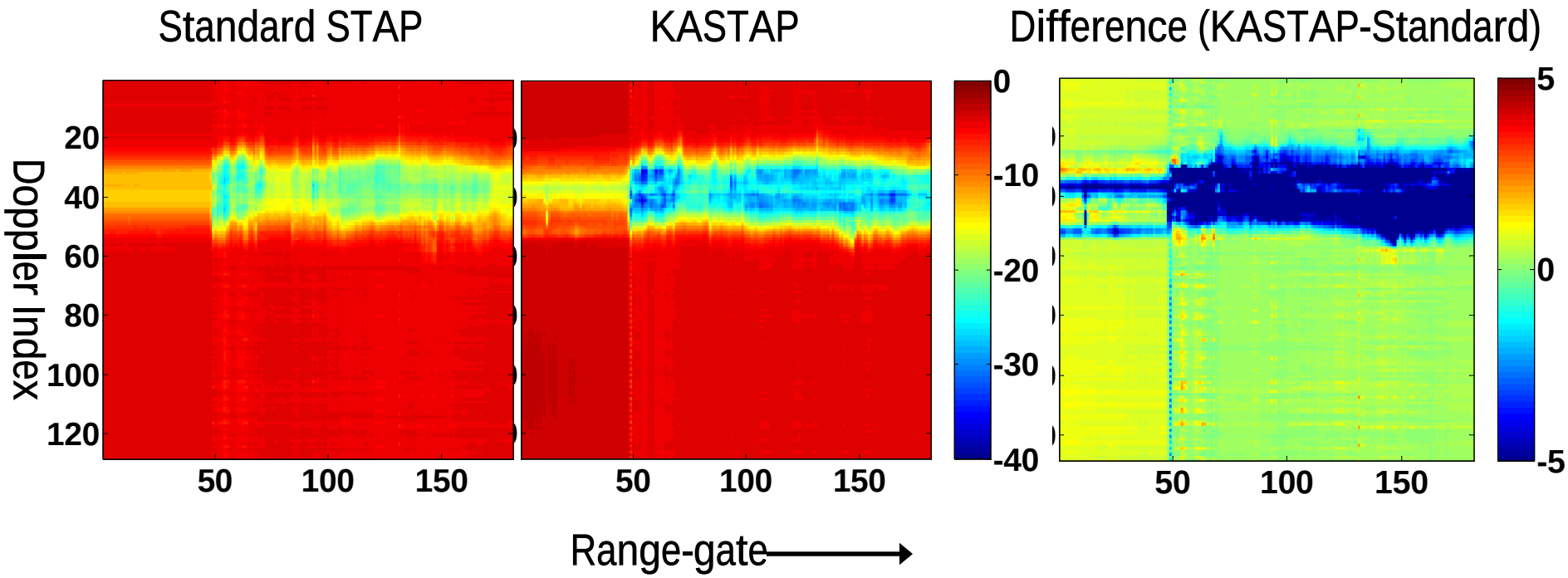
Comparison of range-Doppler spectra



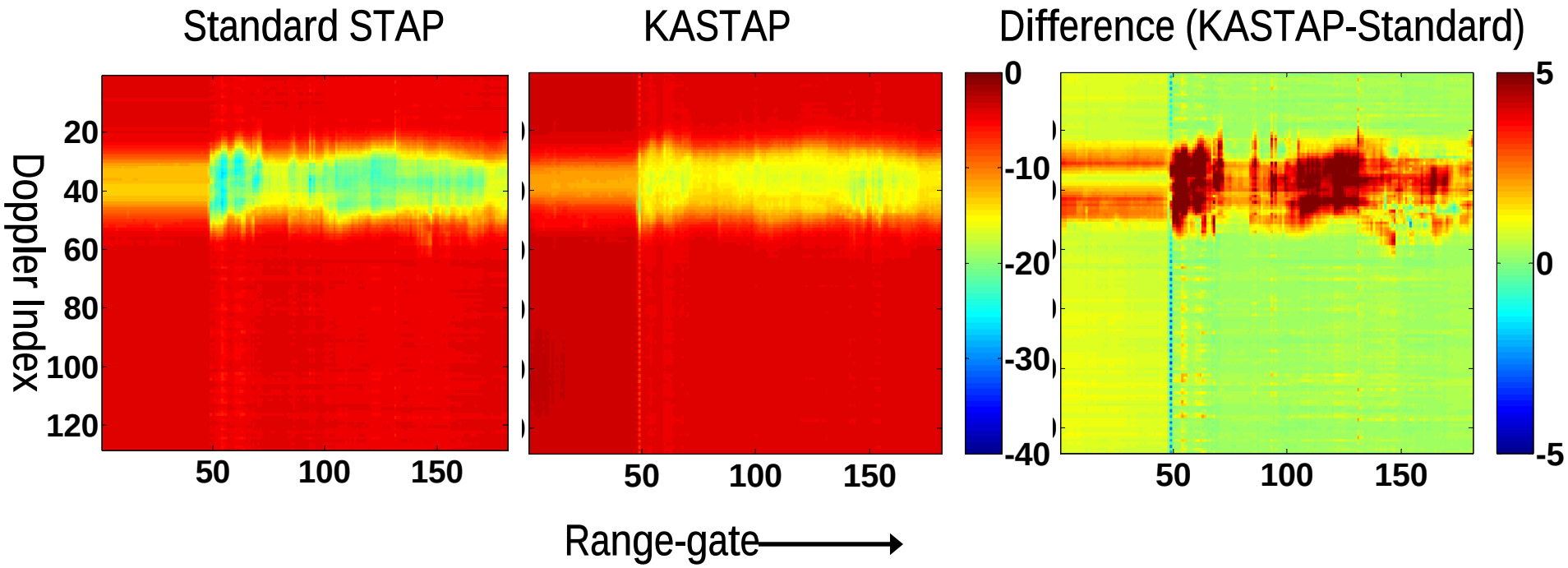
- Covariance matrices derived from clutter reflectivity map allow much better prediction of range-Doppler spectrum than “standard” sample range-averaged covariance matrices

SINR Loss (Standard vs. KASTAP with previous gain/phase error estimation method)



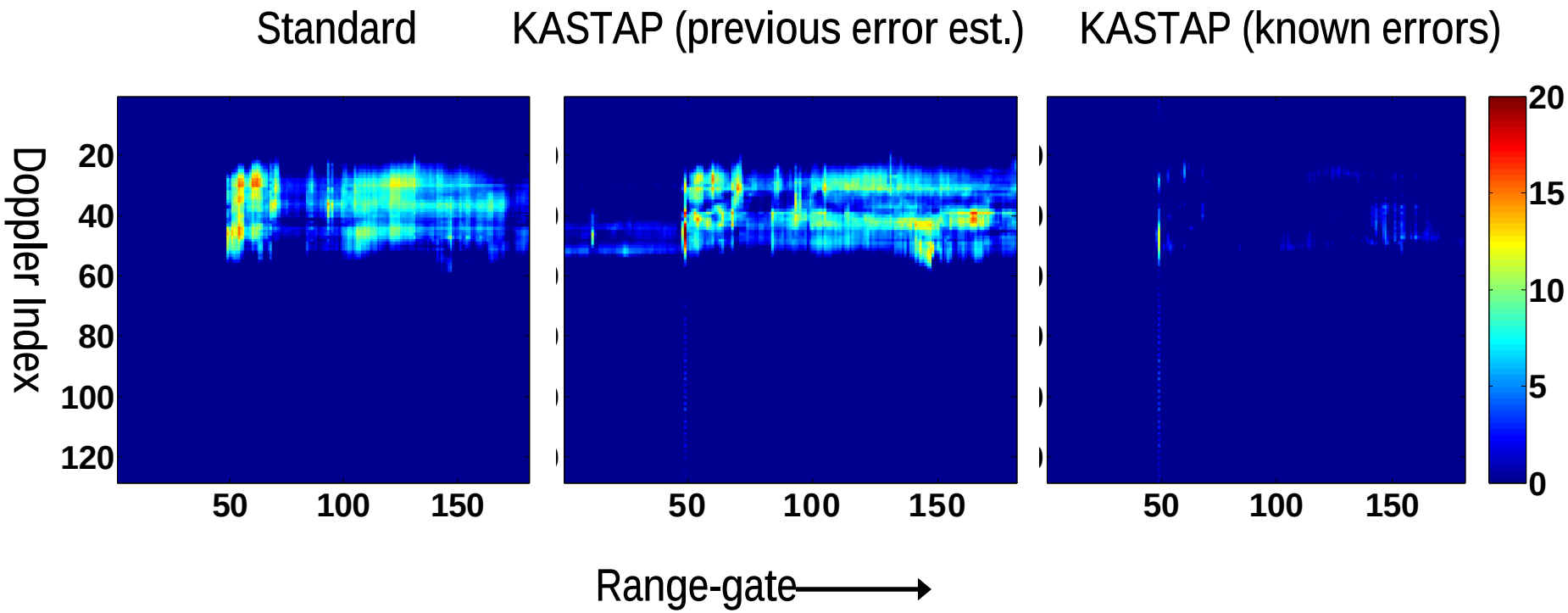
- KASTAP performance found to be lacking using existing approach
  - Degradation was traced to inadequate estimation of channel-dependent gain and phase errors

SINR Loss (Standard vs. KASTAP using known gain/phase errors)



- Note dramatic improvement in KASTAP performance when known errors are incorporated into calculated covariance matrices

Residual CNR after STAP



- Significant residual CNR remains if errors not corrected for accurately

Modification to channel-dependent error estimation algorithm

- Previous method applied error terms to calculated covariance derived from clutter reflectivity map
  - Linearized maximum likelihood approach was used to estimate gain and phase errors
- Difficulties with Kassper Data Set 3
  - Overlapped subarrays lead to a noise covariance not proportional to the identity matrix (previous method assumed phase errors could be applied to noise as well as clutter)
  - Smaller CNR requires more data to estimate errors
- Modified technique applies errors to reduced-DOF data vectors instead of covariance matrices
  - Maximum likelihood estimates of error terms derived using data over multiple CPIs
  - Allows arbitrary noise covariance matrix

Equations for modified error estimation

- Error terms applied to reduced-DOF steering vectors in each Doppler filter:

$$[\vec{u}_i(k)^{(corr.)}]_{n+(f-1)\cdot N} = (1+\varepsilon_n)\cdot[\vec{u}_i(k)]_{n+(f-1)\cdot N}$$

- Data model consists of superposition of scatterer contributions and additive noise:

$$\vec{y}(k) = \sum_i \alpha_i(k)\cdot\vec{u}_i(k)^{(corr.)} + \vec{n}(k)$$

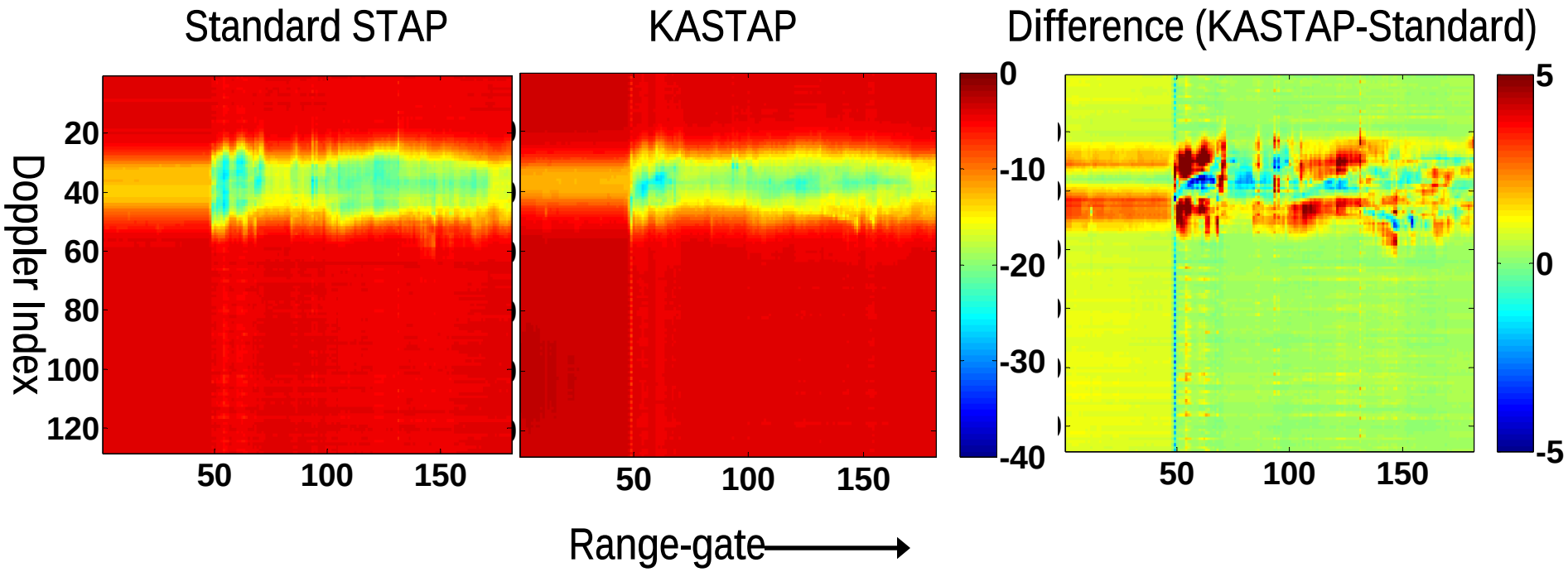
- Error terms calculated to maximize likelihood function:

$$\varepsilon_n = [M^{-1}V]_n$$

$$M_{n,n'} = \frac{1}{\sigma_\varepsilon^2}\cdot\delta_{n,n'} + \sum_{i,j,k,f,f'} \alpha_i(k)^*[\vec{u}_i(k)]_{n+(f-1)\cdot N}^{\ *}\cdot[R_{ns}^{-1}]_{n+(f-1)\cdot N,n'+(f'-1)\cdot N}\cdot\alpha_j(k)\cdot[\vec{u}_j(k)]_{n'+(f'-1)\cdot N}$$

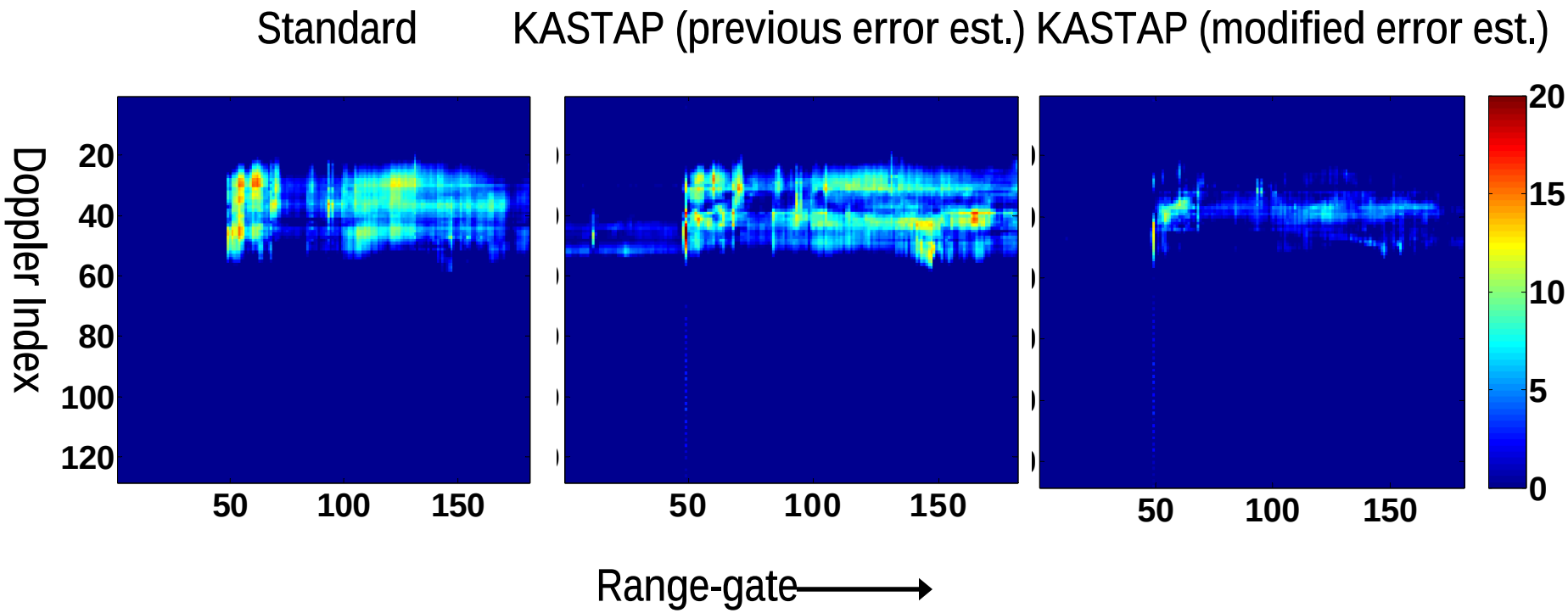
$$V_n = \sum_{i,k,f}\alpha_i(k)^*\cdot[\vec{u}_i(k)]_{n+(f-1)\cdot N}^{\ *}\cdot[\hat{R}_{ns}^{-1}(\vec{y}(k)-\sum_j\alpha_j(k)\cdot\vec{u}_j(k))]_{n+(f-1)\cdot N}$$

SINR Loss (Standard vs. KASTAP using modified error estimation)



- CPIs 1-17 used to derive gain and phase errors
- KASTAP results seen to be greatly improved over previous method

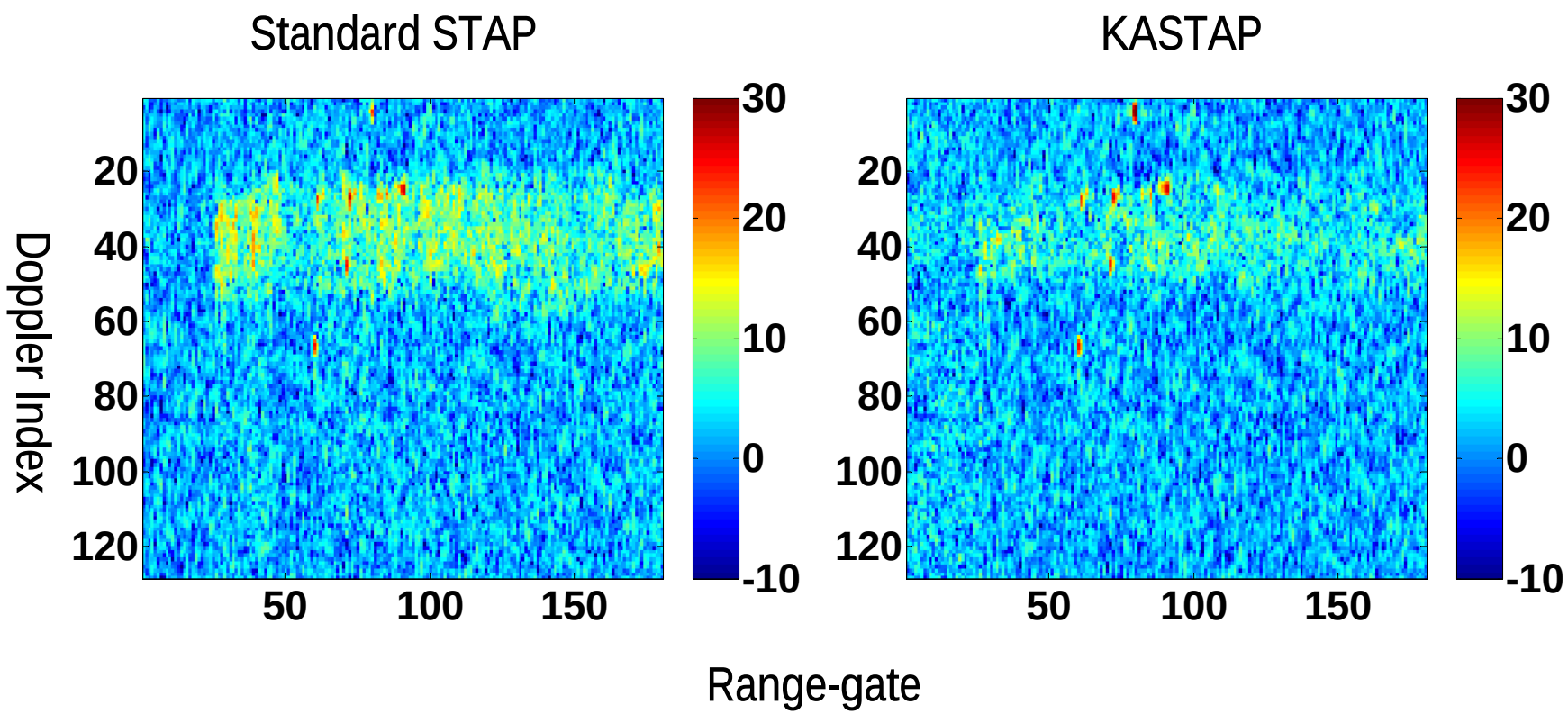
Residual CNR after STAP improves using modified error estimation



- Residual CNR significantly improved using new method
  - Less false alarms will occur, improving detection performance

Output Amplitude to Noise Ratio on CPI #17

- Clutter residue noticeably reduced for KASTAP compared to standard STAP
  - Target truth, detections, and false alarms shown on next slide



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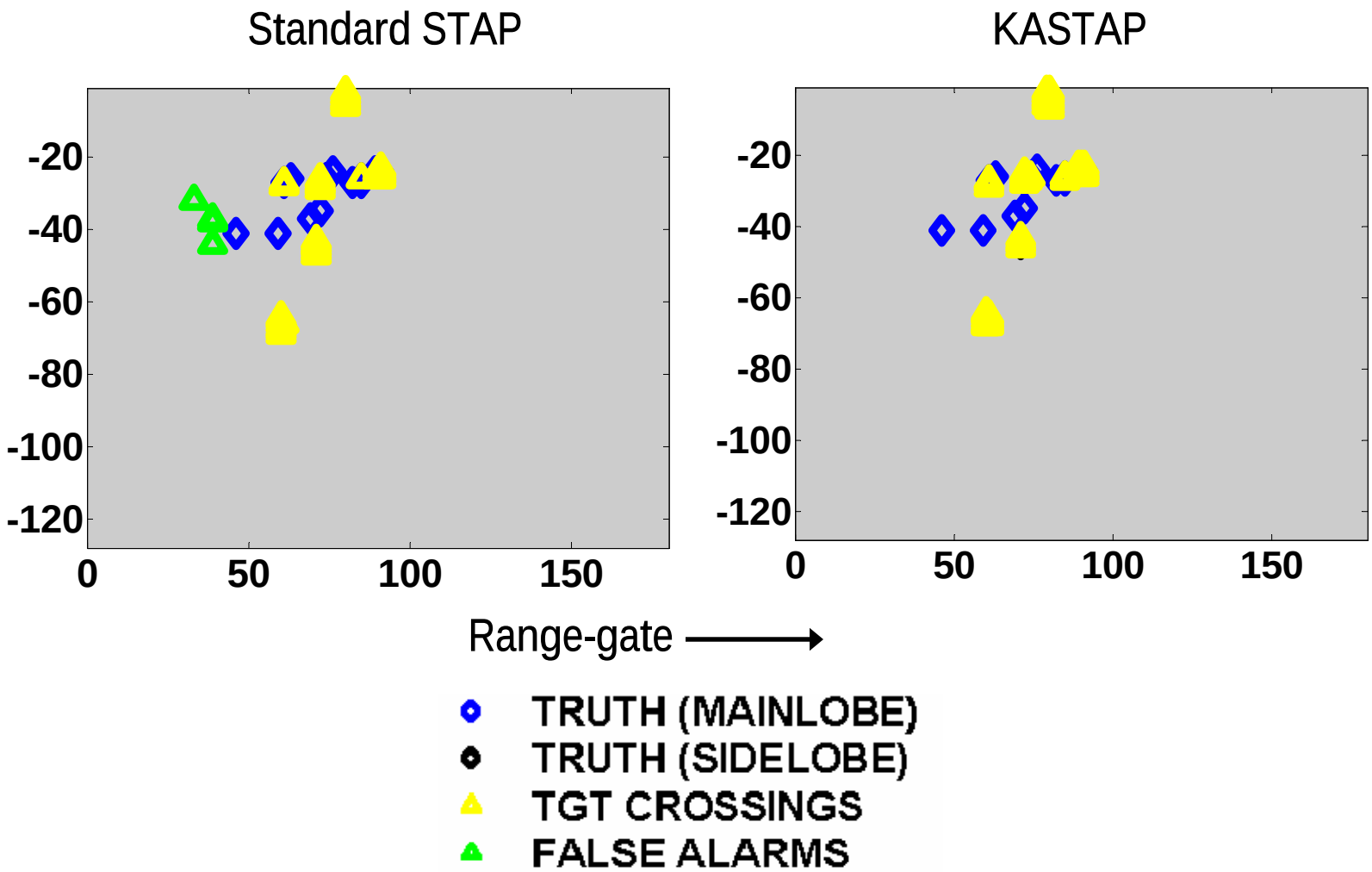
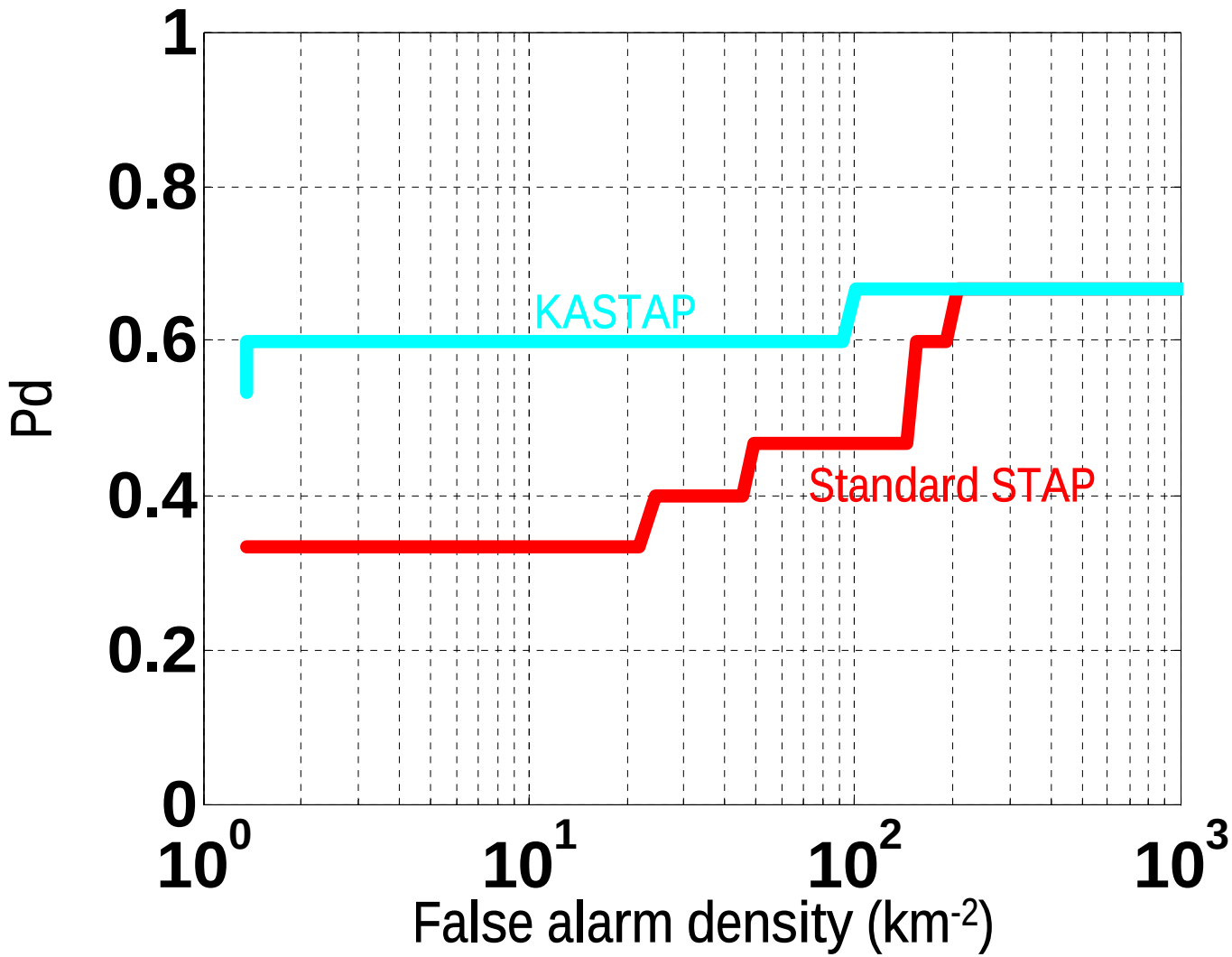
Detections and false alarms for CPI #17



ROC curves for CPI #17



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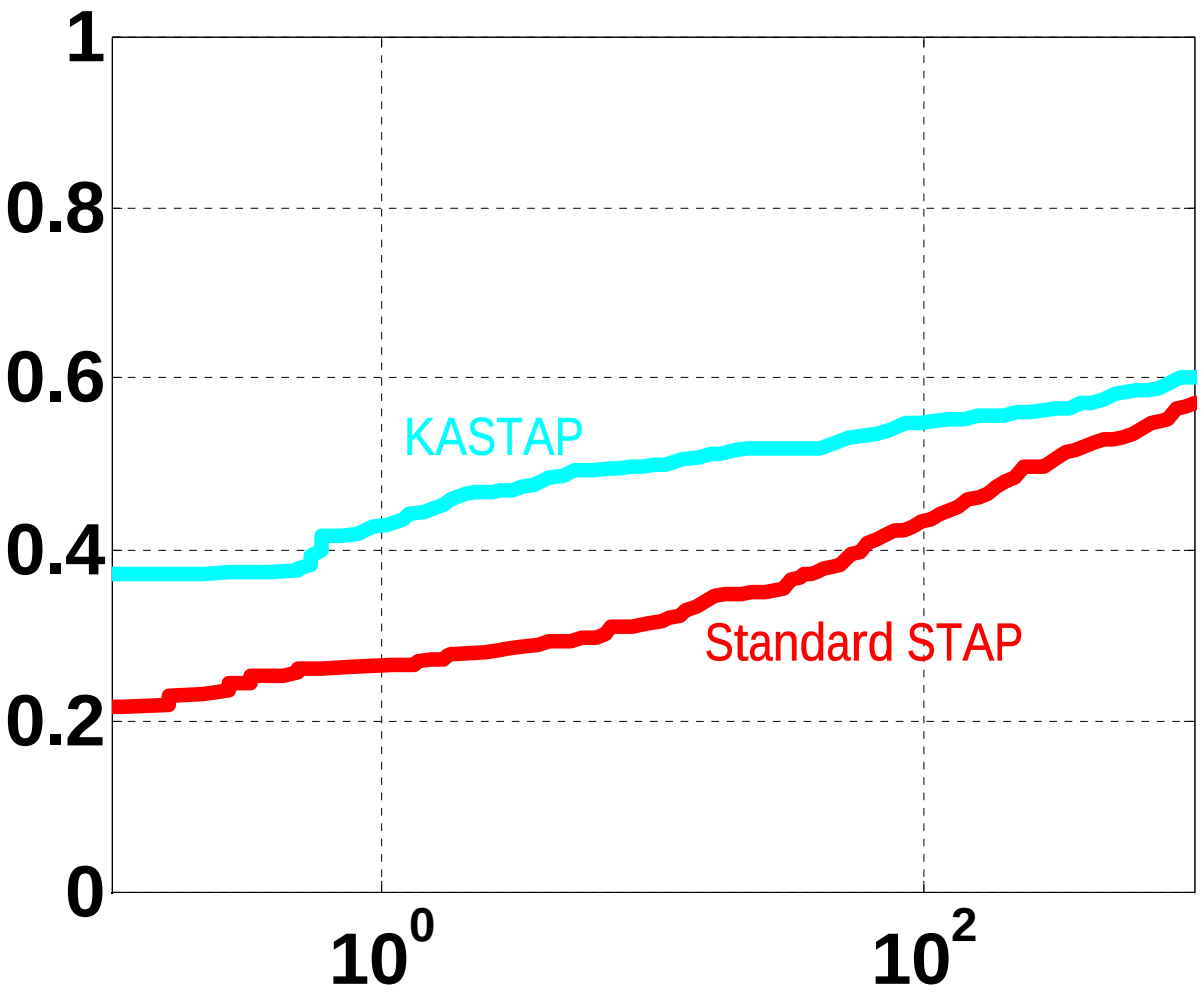
ROC curves over 25 CPIs of the Kassper Data Set 3



Summary

- Our KASTAP approach has been applied to both Kassper Data Sets 2 & 3
  - Combines a number of different techniques to produce robust performance in real-world environments
- KASTAP performance has been compared to that of standard STAP
  - SINR loss functions
  - Residual clutter levels
  - Detections/false alarms, ROC curves
- Substantial benefits over standard STAP processing have been demonstrated
  - More than an order of magnitude reduction in false alarm density for both Kassper data sets