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ALPHATECH, Inc.

KASSPER Workshop Presentation

Incorporating Past CPI Data into Knowledge-Aided STAP Processing

April 15, 2003

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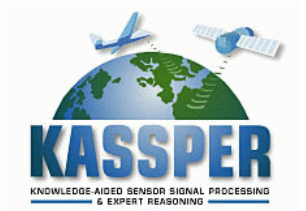
Problem Summary

- **Standard STAP performance is degraded in nonhomogeneous terrain environments**
  - Single CPI training data is limited, due to range-varying clutter returns and limited range resolution
- **Past CPI data cubes contain information that, if exploited, could reduce training errors**
  - Strong clutter returns from urban areas, highly sloped terrain, etc. will be correlated over multiple CPIs
- **Challenges remain in utilizing past data:**
  - Location of clutter ridge in Doppler-angle space varies with CPI, due to varying platform geometry
  - Direct averaging of past-CPI samples into covariance estimate is not effective
- **Develop a technique that overcomes these challenges and improves clutter estimates (and consequently, STAP performance)**

Summary of Approach for Incorporating Past-CPI Data



- **Build an earth-referenced "clutter 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 several 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
  - Algorithm applied to the KASSPER Data Set 2

Steps in Formation of a Geodetic Clutter Map Based on Past-CPI Data

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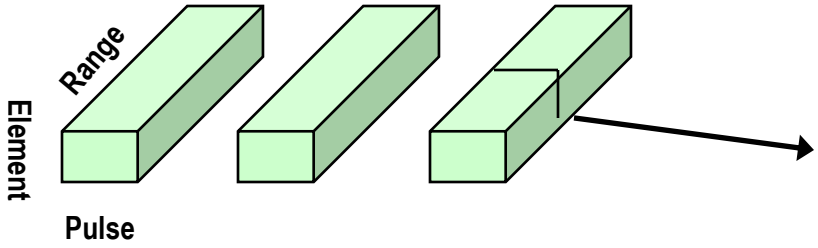
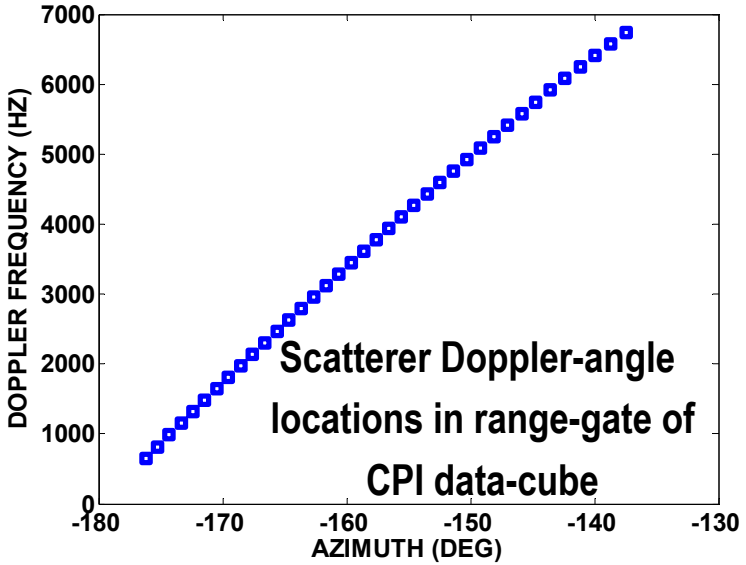
1. In each range-gate of past-CPI data-cube, define a set of point scatterers along the clutter ridge
2. Register the scatterer locations to an earth-based coordinate system
3. Estimate scatterer strengths using measured data
4. Form an earth-based clutter map

•Detailed description of these steps follows

1. Define Clutter Scatterer Locations

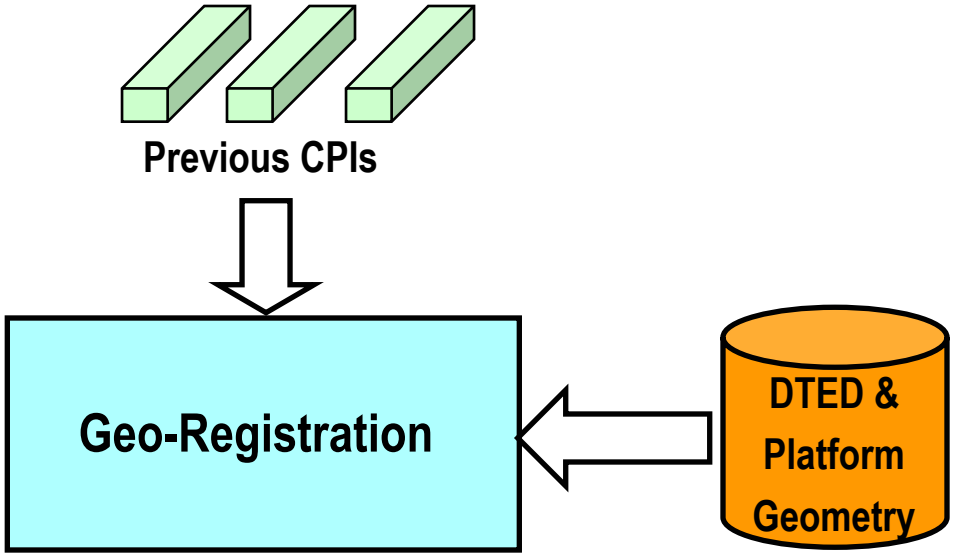


Previous CPI Data-cubes



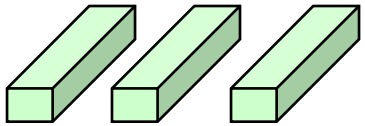
- In each range-gate of past-CPI data-cube, define a set of point scatterers along the clutter ridge
  - Defined by range/Doppler locations
  - Choose Doppler extent to span area of significant clutter (may be several Doppler ambiguities)

2. Geo-Register Scatterer Locations



- **Register the scatterer locations to an earth-based coordinate system**
  - Requires computing intersection of range sphere, Doppler cone, and the earth's surface
  - Range sphere and Doppler cone defined by platform location and velocity
  - Earth's Surface is defined by digital terrain database (DTED)
  - Iterative approach required, as radius of earth surface varies with ground location

3 & 4. Estimate Clutter Reflectivities and Form Clutter Map

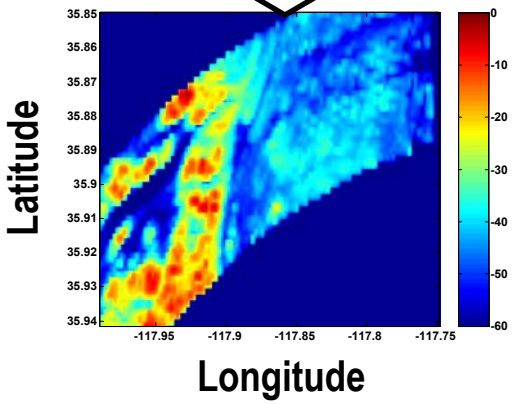


Previous CPIs

Geo-Register &
Estimate Scattering strengths

$$\alpha_i = \sum_j [S^{-1}]_{ij} \cdot \vec{s}_j{}^H \vec{x}$$

DTED &
Platform
Geometry



- Estimate scatterer strengths using measured data
  - Space-time responses defined by azimuth and elevation angles, & Doppler
  - Strengths estimated using a minimum squared error criterion

- Form an earth-based clutter map
  - Normalize scatterer strengths by their area on the ground to obtain reflectivity estimates
  - Each cell of the map is an averaged reflectivity over multiple CPIs

Predicting Clutter Statistics of Current CPI Using Geodetic Clutter Map

- **Define current-CPI scatterers along the clutter ridge**
  - Geodetic locations calculated as described on previous slide
- **Compute reflectivity of scatterers by indexing into geodetic clutter map**
- **Form covariance matrices by adding contributions from each scatterer:**

$$\widetilde{R} = \sum_i \rho_i \cdot A_i \cdot \vec{s}_i \vec{s}_i^{\,H}$$

$\rho_i \equiv$ reflectivity of scatterer i

$A_i \equiv$ area of scatterer i

$\vec{s}_i \equiv$ space - time steering vector of scatterer i

Measured Range-Doppler Spectra of Four Different CPIs of KASSPER Data Set 2

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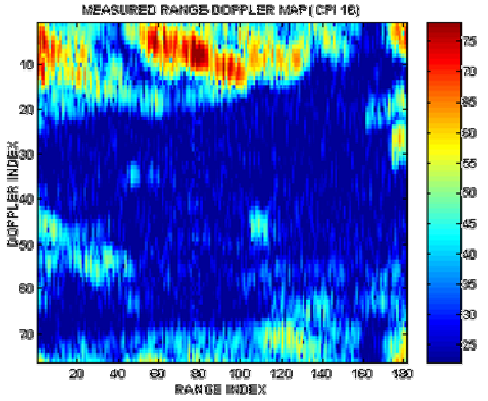
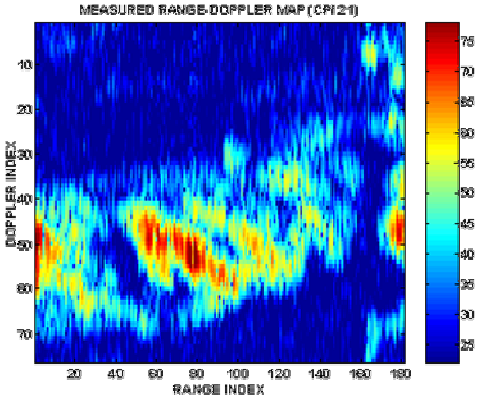
Mis-registration of clutter ridge is evident in these plots

Measured (CPI 16)



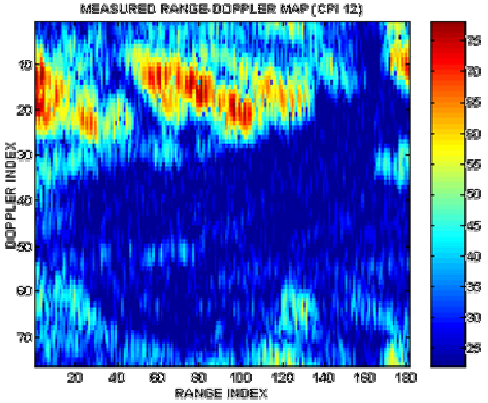
Measured (CPI 21)



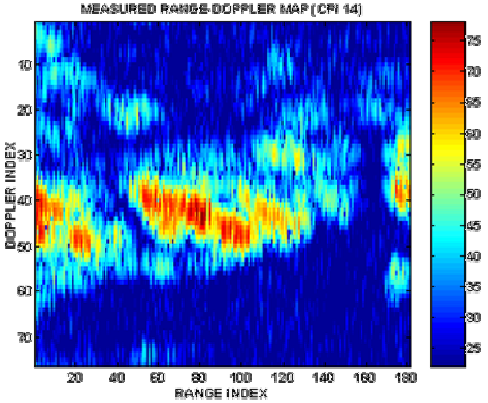
Doppler Index

Range-gate

Measured (CPI 12)



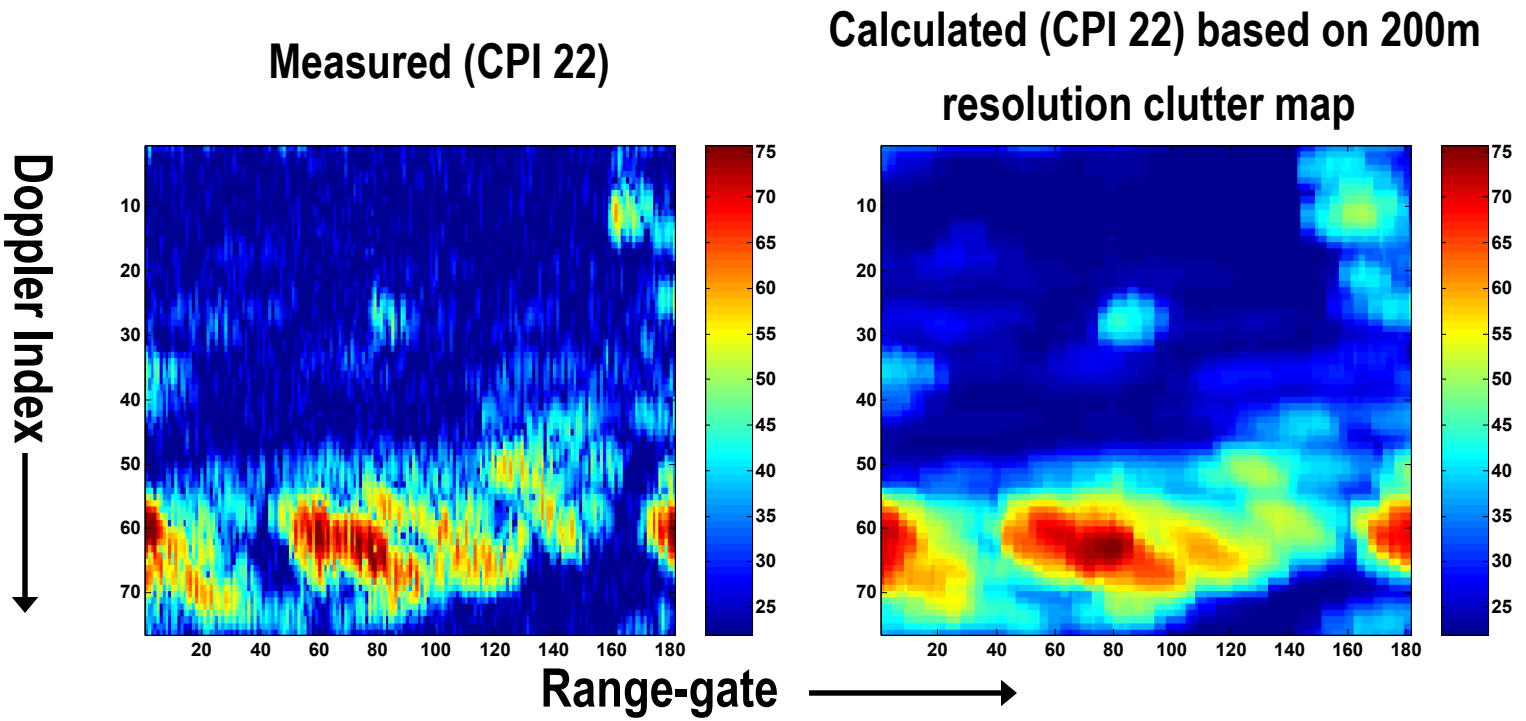
Measured (CPI 14)



Doppler Index

Range-gate

Comparison of Measured Spectrum With Predicted Reflectivity Map



- **Procedure has registered the different CPIs and produced a smoothed estimate of the clutter spectrum**
  - Results above reflect a 200 meter resolution map (approximately matching the width of a Doppler filter on the ground)
  - Allows improved prediction of range varying clutter statistics over standard range-averaging procedure, which smoothes features over much wider range

Incorporation of Calculated Covariance Matrices Into STAP Processing

- Using covariance matrices directly in STAP vector ($w=R^{-1}s$) does not produce good performance
  - Due to steering vector errors, varying internal clutter motion (ICM), etc.
- Calculated matrices were used to pre-whiten the data using the method of [1], with the following additional techniques employed:
  - A covariance taper [2] was applied prior to pre-whitening to account for ICM
  - A reduced degree of freedom (DOF) post-Doppler, extended-factored (or "multi-bin") algorithm was employed
  - A separate pre-whitening transformation was performed in each Doppler filter

[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

[2] J. R. Guerci, "Theory and Application of Covariance Matrix Tapers for Robust Adaptive Beamforming", IEEE. Trans. Signal Processing, Vol. 4, No. 4, April 1999

Evaluation of Algorithm Performance

- **Performance of standard STAP vs. KASTAP was evaluated on KASSPER Data Set 2**
  - 5 adjacent filters employed in the post-Doppler algorithm, yielding 60 DOFs
  - Training window extent was 3 times number of DOFs (test cell excluded from covariance estimate)
  - Diagonal loading at noise floor employed
- **SINR Loss versus range and Doppler**
- **Detections and false alarms**
  - Adaptive matched filter (AMF) statistic used to determine threshold crossings
  - Receiver operating characteristic (ROC) curves obtained over 23 CPIs
- **Additionally, preliminary tracking performance was obtained using ALPHATECH's MHT tracker testbed**
  - Two-target scenario over 23 CPIs

Comparison of SINR Loss (clutter-only training, CPI 22)

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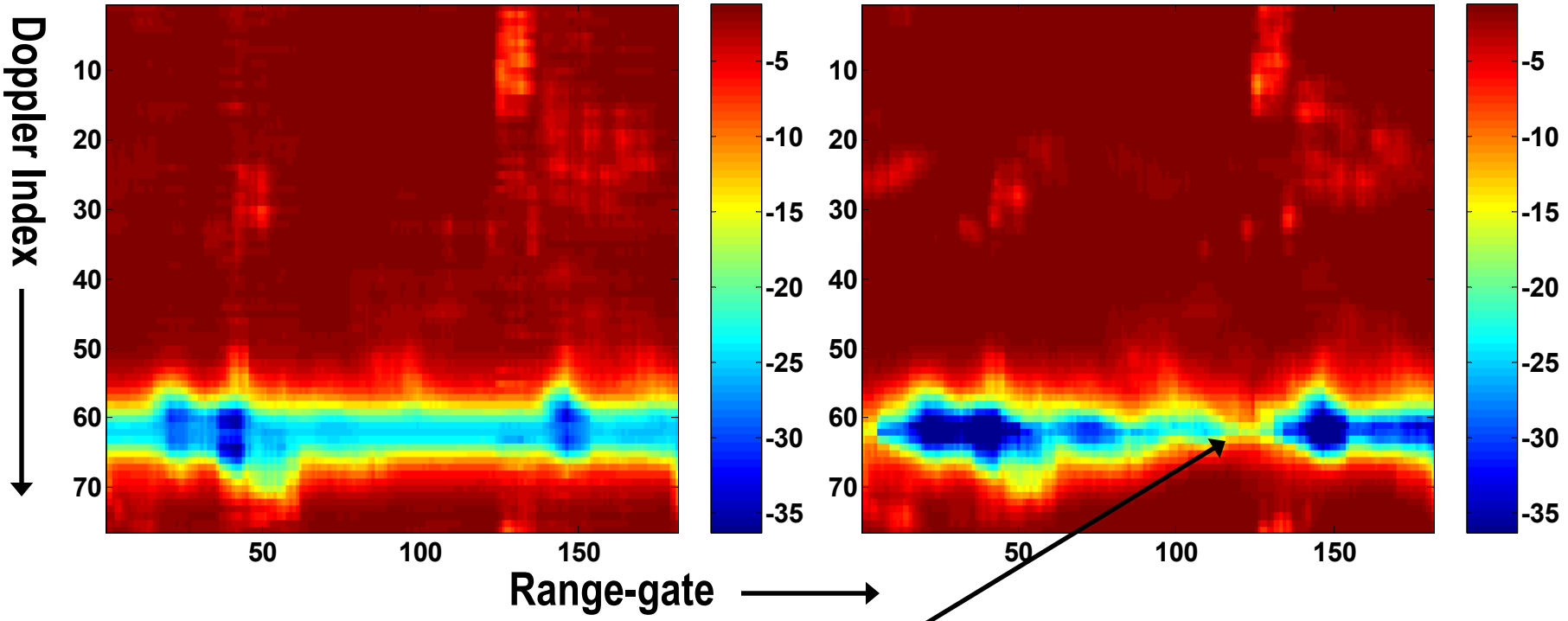
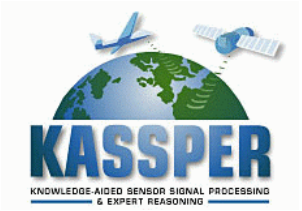
Standard STAP

Knowledge-aided STAP utilizing past-CPI data



•SINR Loss improved significantly, resulting in reduced MDV

Contamination of Training Data by Targets and Discretes



- The large number of targets (~1200) in KASSPER Data Set 2 challenge the STAP training procedure
- Masking of detections was investigated to reduce contamination of training data by targets and discretes
  - With such a large number of targets, range-only masking causes excessive reduction of training data
  - In a post-Doppler framework, separate masking of the detections can be performed in each Doppler filter
  - The reduction in training data is much less severe
  - This Technique can be incorporated into a tracker feedback loop ("Tracker-in-the-Loop")

Detection vs. False Alarms (high target density region of CPI 67)

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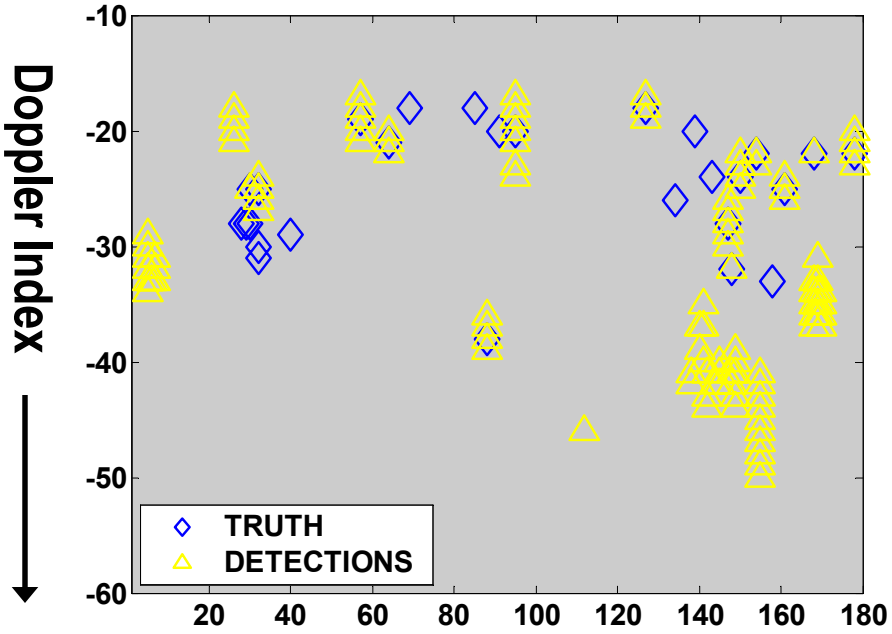
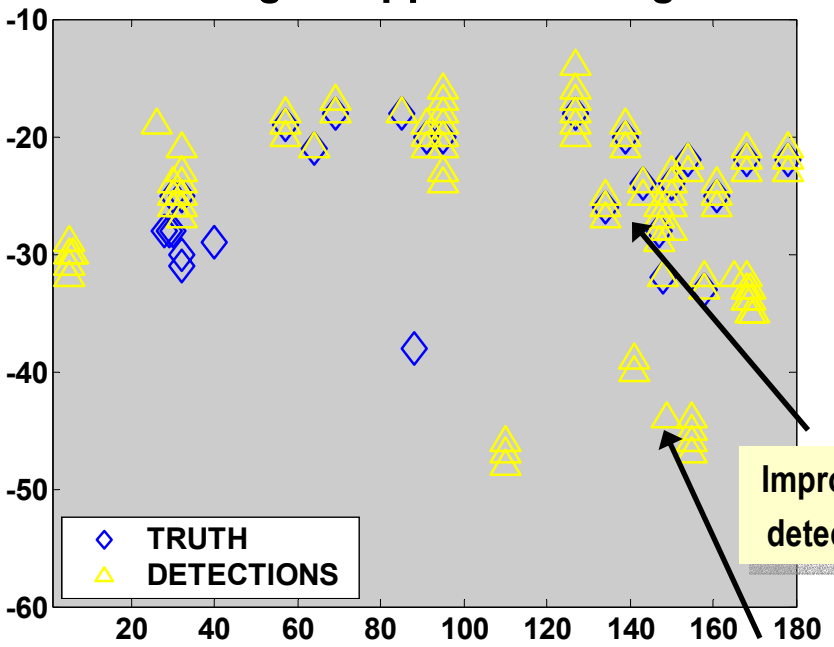
Standard STAP



KASTAP with pre-whitening and range-Doppler masking

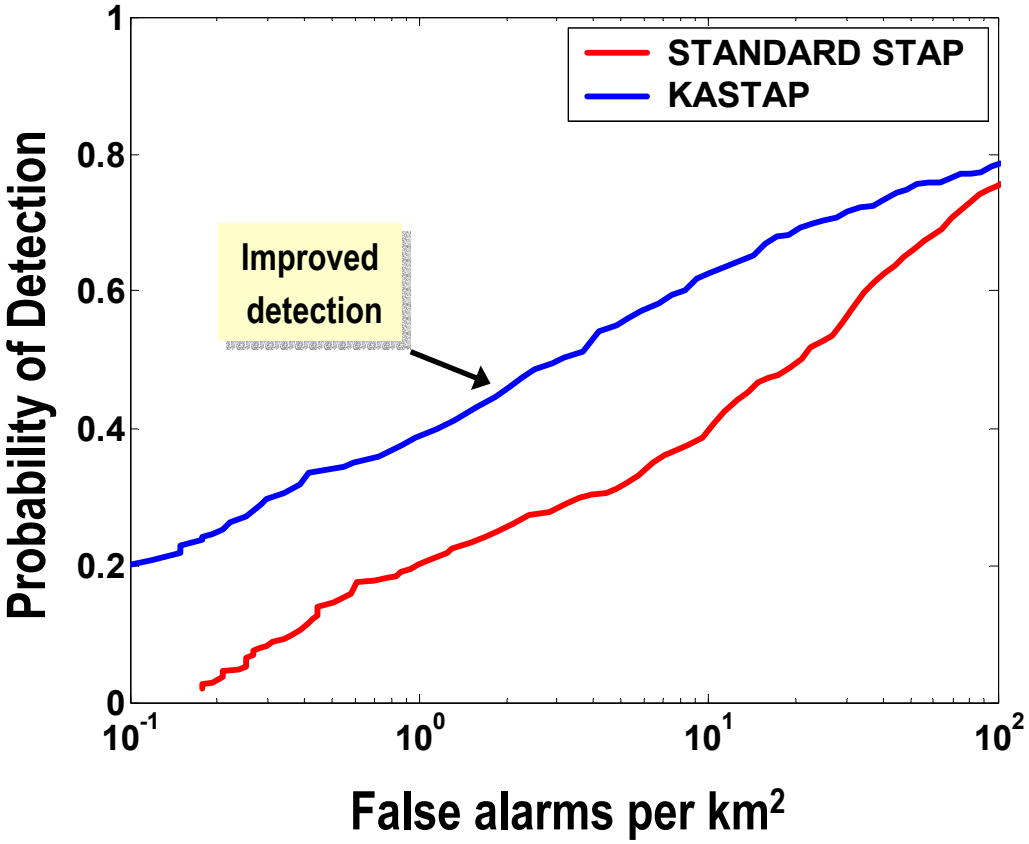


Doppler Index ↓

Range-gate →

- A significant benefit is seen from employing KASTAP in this region

ROC Curves



Performance computed over 23 CPIs (3 km²/CPI)

AMF test statistic used

Summary of Tracker Performance STAP vs. KASTAP

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STAP:

Detection Performance:

Target 1: 10 detections 13 misses

Target 2: 15 detections 8 misses

False alarms: 11

Tracker Performance:

Target 1: Track starts at CPI 11

Target 2: Track starts at CPI 6

Tracks maintained

KASTAP:

Detection Performance:

Target 1: 15 detections 8 misses

Target 2: 15 detections 8 misses

False alarms: 5

Tracker Performance:

Target 1: Track starts at CPI 6

Target 2: Track starts at CPI 6

Tracks maintained

Movie of Tracker Performance with Standard STAP Processing

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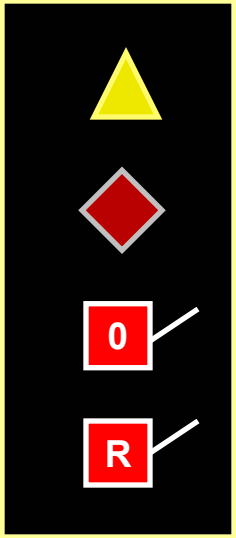
Tracker Legend

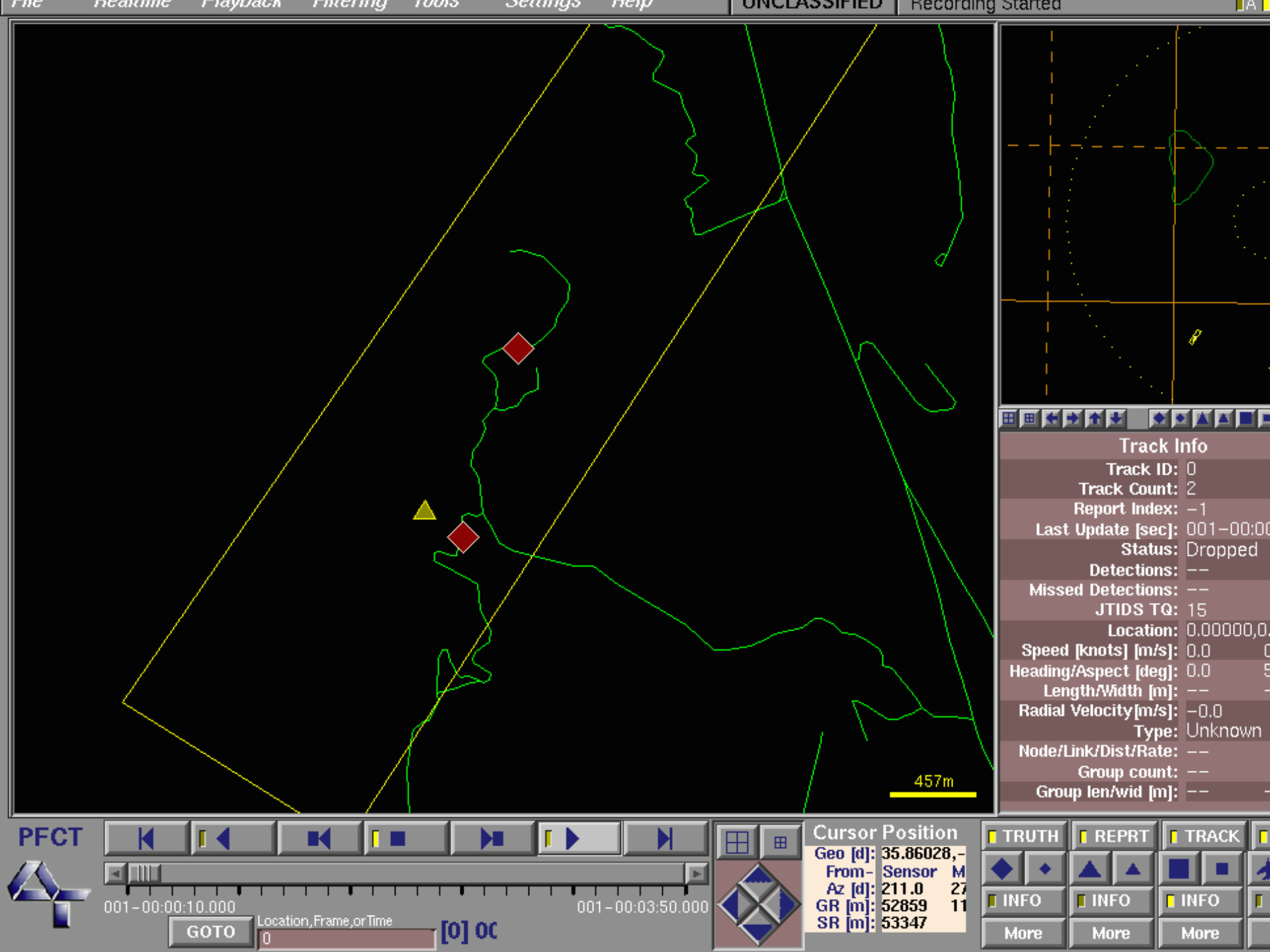


Detection Report

Truth

Track Report (Off-Road)

Track Report (On-Road)


File
Realtime
Playback
Filtering
Tools
Settings
Help
UNCLASSIFIED
Recording Started
457m
Track Info
Track ID: 0
Track Count: 2
Report Index: -1
Last Update [sec]: 001-00:00
Status: Dropped
Detections: --
Missed Detections: --
JTIDS TQ: 15
Location: 0.00000,0.
Speed [knots] [m/s]: 0.0
Heading/Aspect [deg]: 0.0
Length/Width [m]: --
Radial Velocity[m/s]: -0.0
Type: Unknown
Node/Link/Dist/Rate: --
Group count: --
Group len/wid [m]: --
PFCT
001-00:00:10.000
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GOTO
Location,Frame,or Time
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[0] 0C
Cursor Position
Geo [d]: 35.86028,-
From- Sensor M
Az [d]: 211.0 27
GR [m]: 52859 11
SR [m]: 53347
TRUTH
REPRT
TRACK
INFO
INFO
INFO
More
More
More

Movie of Tracker Performance with Knowledge-Aided STAP Processing

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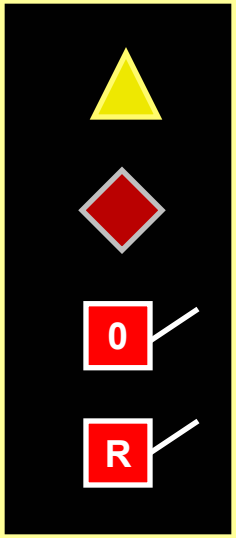
KNOWLEDGE-AIDED SENSOR SIGNAL PROCESSING & EXPERT REASONING

Tracker Legend

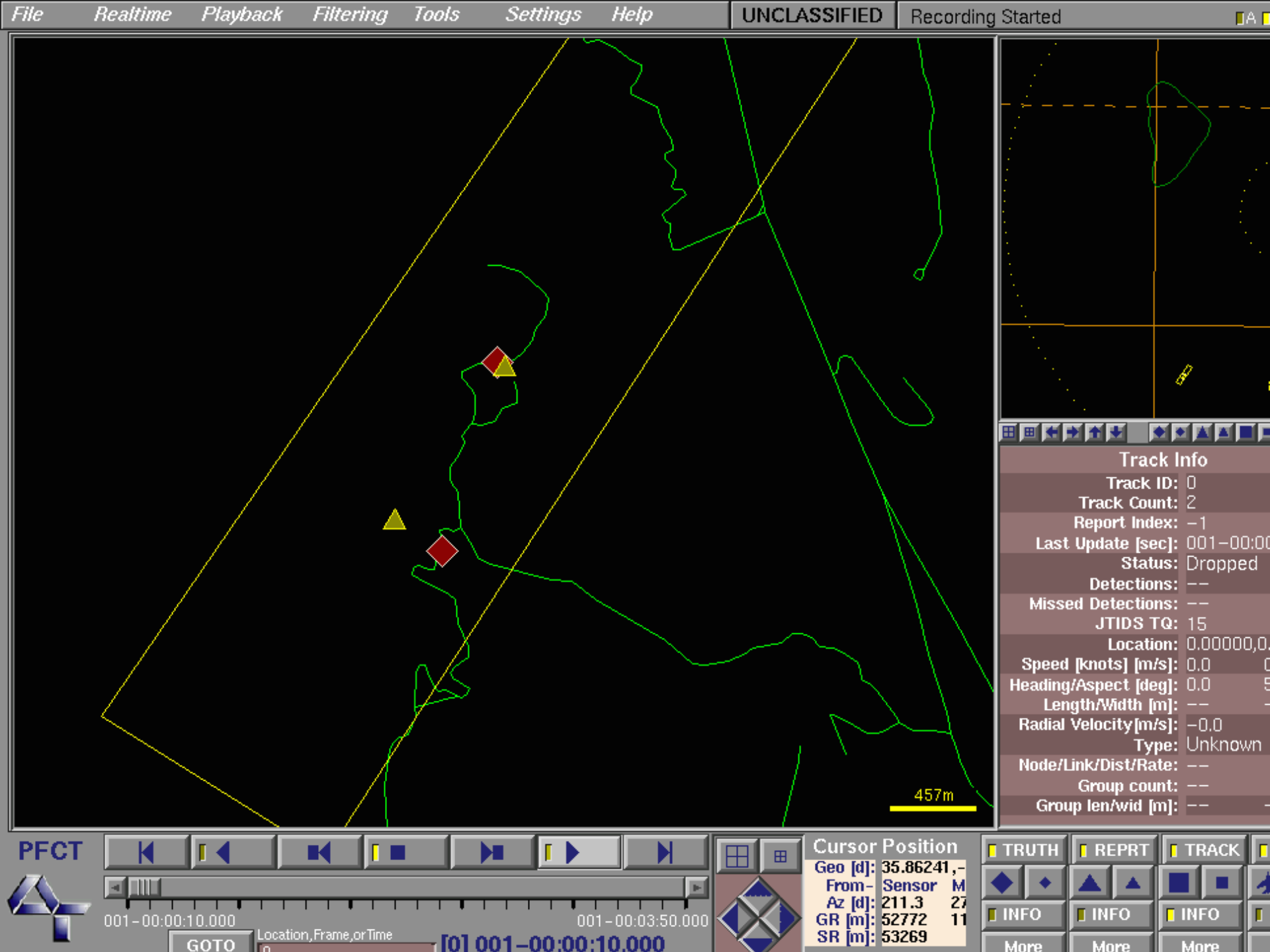


Detection Report

Truth

Track Report (Off-Road)

Track Report (On-Road)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Radial Velocity[m/s]: -0.0
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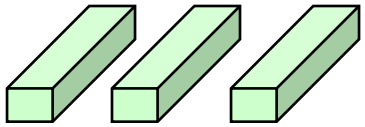
Node/Link/Dist/Rate: --
Group count: --
Group len/wid [m]: --
457m
PFCT
001-00:00:10.000
001-00:03:50.000
GOTO
Location,Frame,or Time
[0] 001-00:00:10.000
Cursor Position
Geo [d]: 35.86241,-
From- Sensor M
Az [d]: 211.3 27
GR [m]: 52772 11
SR [m]: 53269
TRUTH
REPRT
TRACK
INFO
INFO
INFO
More
More
More

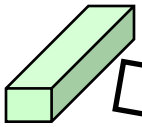
Summary

- A technique to incorporate past-CPI data into knowledge-aided STAP processing has been described
  - Algorithm employs a clutter map, based on multiple CPIs, in a knowledge-aided pre-whitening procedure
- This technique has been applied to KASSPER Data Set 2 with encouraging results
  - Improved performance in a post-Doppler framework has been demonstrated
- Preliminary tracking performance has been obtained using ALPHATECH's MHT tracker testbed
- More extensive evaluations will be conducted

Utilizing Past-CPI Data to Predict Clutter Statistics



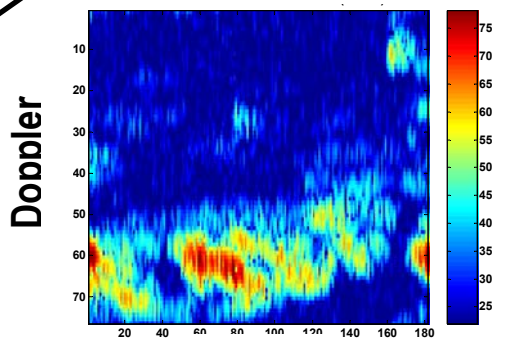
Previous CPIs



Current CPI

Current CPI Data

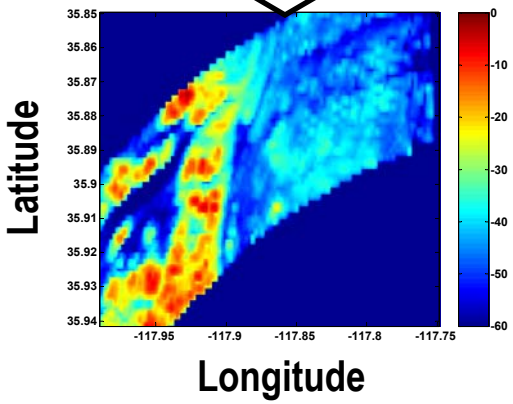
CPI 22, KASSPER Data Set 2



Geo-Register &
Estimate Scattering strengths

$$\alpha_i = \sum_j [S^{-1}]_{ij} \cdot \vec{s}_j{}^H \vec{x}$$

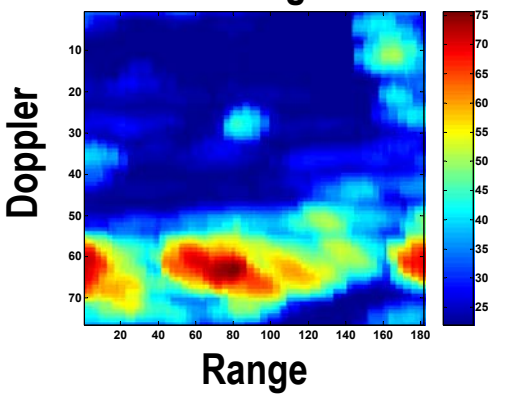
DTED &
Platform
Geometry



Perform coordinate x-forms &
Calculate covariance matrices

$$\tilde{R} = \sum_i \rho_i \cdot A_i \cdot \vec{s}_i \vec{s}_i{}^H$$

Predicted signature



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Combining Clutter Predictions to Improve STAP Performance

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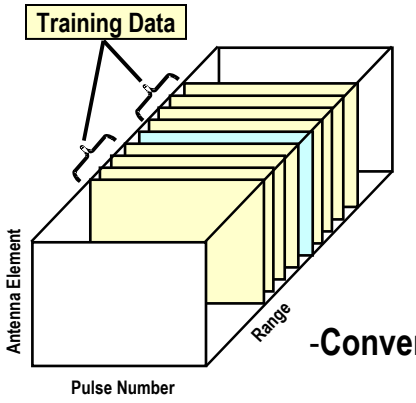
Current CPI Data-Cube



Incorporate knowledge into STAP weight vector calculation

Calculate STAP weights

-Conventional covariance estimates

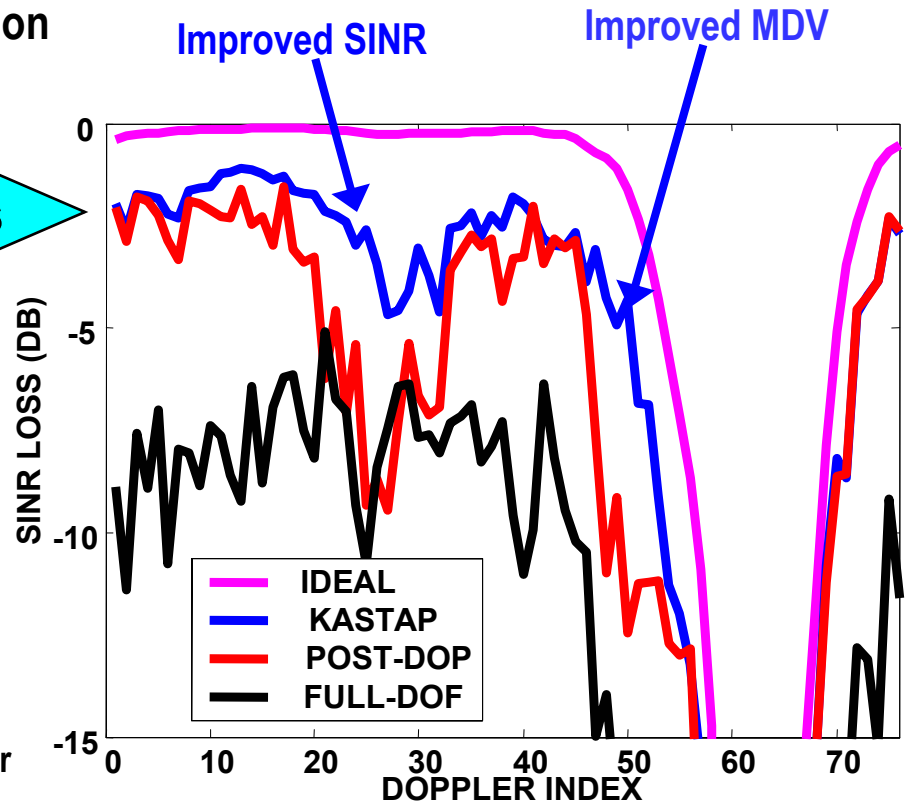
$$\hat{R} = \frac{1}{K}\sum_i \vec{x}_i \vec{x}_i^{\,H} + \gamma \cdot I$$

-Knowledge-derived covariance matrices

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

-Tracker predictions of target range/Doppler locations

SINR Loss Performance (KASSPER Data Set 2, CPI 22, range 1035)



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