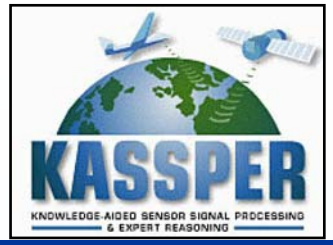

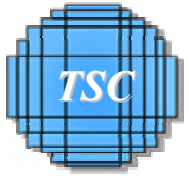

2004 KASSPER CONFERENCE

GENERATION OF DIGITAL ELEVATION MAPS FROM RADAR DATA: A KEY TO KASSPER

CONTRACT NO. F30602-02-C-0034

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PRESENTED AT: **CLEARWATER, FL**
ON: **APRIL 6, 2004**
BY: **CHUCK MORGAN &**
PAUL MOUNTCASTLE

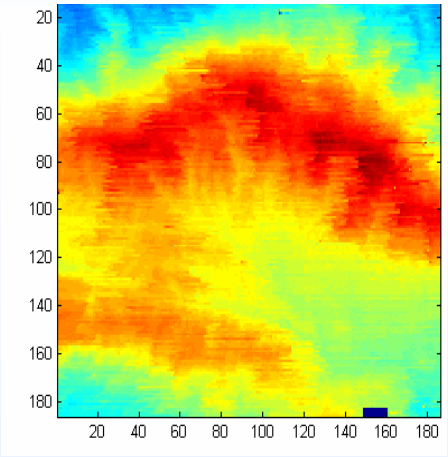
OUTLINE

- **INTRODUCTION**
- **DIGITAL ELEVATION MAP (DEM) GENERATION RESULTS**
  - TSC HAS INVESTIGATED TWO METHODS OF GENERATING DEM'S FROM GMTI CLUTTER MAPS
  - STEREO PROCESSING RESULTS
  - INTERFEROMETRIC PROCESSING RESULTS
- **WHY THIS WORK IS KEY TO KASSPER**
- **SUMMARY**

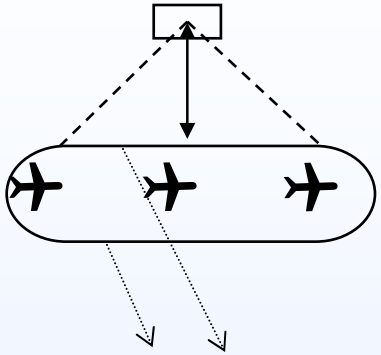
INTRODUCTION

- **TERRAIN ELEVATION MAPS ARE IMPORTANT KNOWLEDGE SOURCES FOR KB-STAP ALGORITHMS**
  - ID OF HIGH MOBILITY AREAS FROM TERRAIN SLOPE (**INFLUENCES STAP RESOURCE ALLOCATION**)
  - **PROVIDES A KEY MEANS FOR REAL TIME CORRELATION AND REGISTRATION OF RADAR DATA WITH ROAD AND DTED DATABASES**
- **TSC HAS INVESTIGATED TWO METHODS OF GENERATING DEM'S FROM GMTI CLUTTER MAPS**
  - STEREO PROCESSING
  - INTERFEROMETRIC PROCESSING

NONCOHERENT TOMOGRAPHY CONCEPT

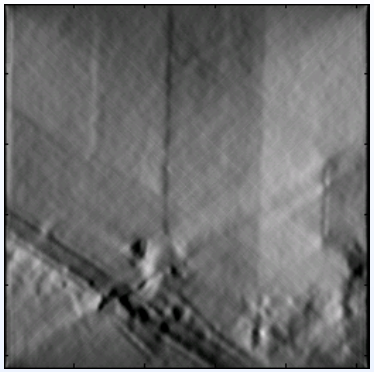


STEREO DEM



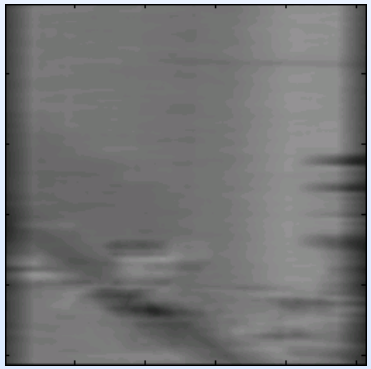
PATH AVERAGES

TOMOGRAPHY RESULTS



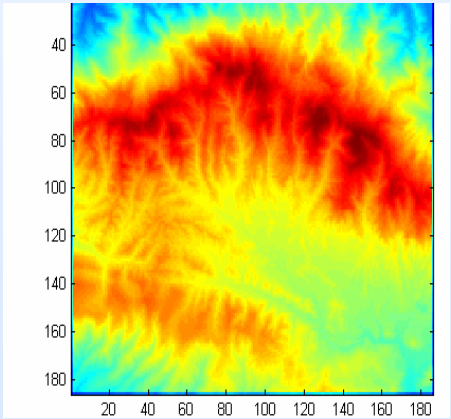
120°

180°



Single-Look GMTI Map

High Resolution SAR Map



LEVEL-3 DTED (IDEAL)

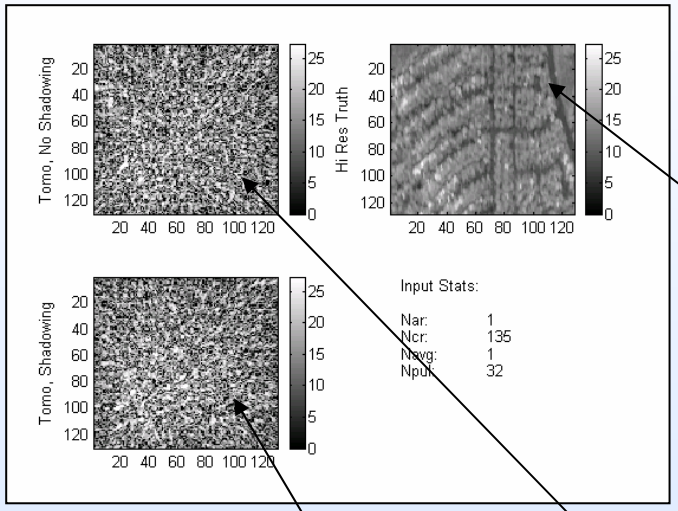
KASSPER
KNOWLEDGE-AIDED SENSOR SIGNAL PROCESSING & EXPERT REASONING

DETAILED SIMULATION RESULTS FOR TOMOGRAPHIC SHARPENING TECHNIQUE

- **TSC'S PREVIOUS INVESTIGATION OF TOMOGRAPHIC SHARPENING OF GMTI CLUTTER MAPS CONSIDERED ONLY IFSAR MAGNITUDES (NO SPECKLE OR SHADOWING)**
  - RESULTS SHOWED CROSS RANGE ENHANCMENT WAS POSSIBLE, BUT ONLY FOR INTEGRATION ANGLES APPROACHING 180 DEGREES
  - LARGE INTEGRATION ANGLES REQUIRED AN EXTENDED FLIGHT PATH SUCH AS A CIRCULAR ARC
- **SIMULATED PROCESSING OF COMPLEX DATA CONTAINING DROPOUTS CAUSED BY SHADOWING SHOWED DEGRADED PERFORMANCE**
  - COHERENT SUMMATION OF COMPLEX DATA WITHIN EACH RESOLUTION CELL PRODUCES SPECKLE ARTIFACTS
    - NONCOHERENT INTEGRATION OVER MULTIPLE LOOKS IS REQUIRED TO REDUCE SPECKLE EFFECTS
  - DEGRADATION DUE TO SHADOW EFFECTS IS MORE SERIOUS
    - THE EFFECT OF SHADOWING ON TOMOGRAPHY CAN'T BE RESTORED BY INTEGRATION

EFFECTS OF SPECKLE AND SHADOWING ON TOMOGRAPHIC SHARPENING

SINGLE LOOK PROCESSING

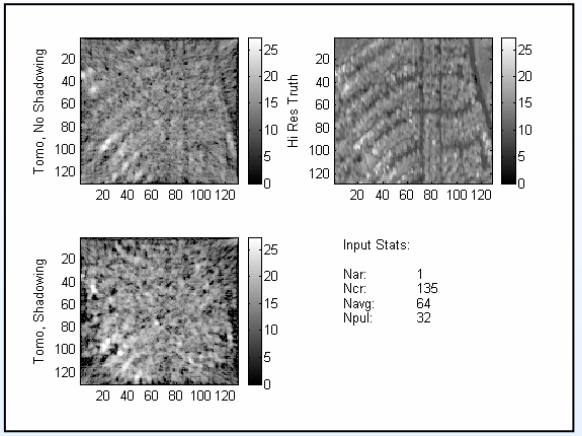


ORIGINALHIGH-RES SAR IMAGE

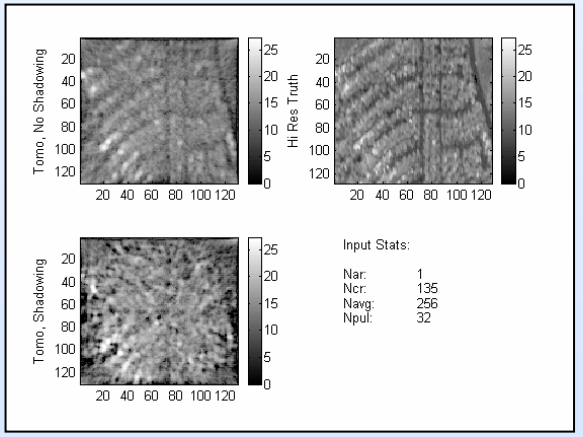
MTI CLUTTER MAP WITHOUT TERRAIN SHADOWING

MTI CLUTTER MAP WITH TERRAIN SHADOWING

NON-COHERENT INTEGRATION

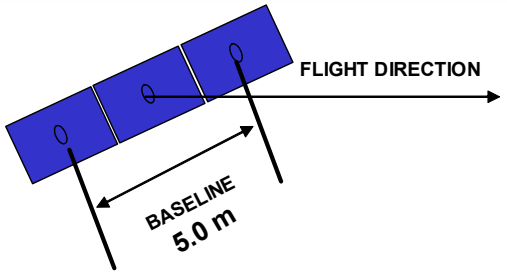


64 LOOKS



256 LOOKS

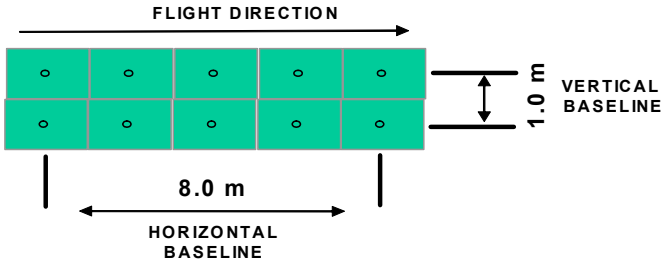
SINGLE-LOOK DATA COLLECTION INTERFEROMETRY



PITCH: 7 degrees
CRAB: 5 degrees

SIMULATION PARAMETERS FOR ULA RADAR

HORIZONTAL BASELINE (m)	5.0
AIR SPEED (m/s)	230
RADAR FREQUENCY (GHz)	10
ALTITUDE (km)	10
RANGE (km)	100
PRF (Hz)	600
NUMBER OF PULSES	64
AZ BEAMWIDTH (mrad)	15
EL BEAMWIDTH (mrad)	45

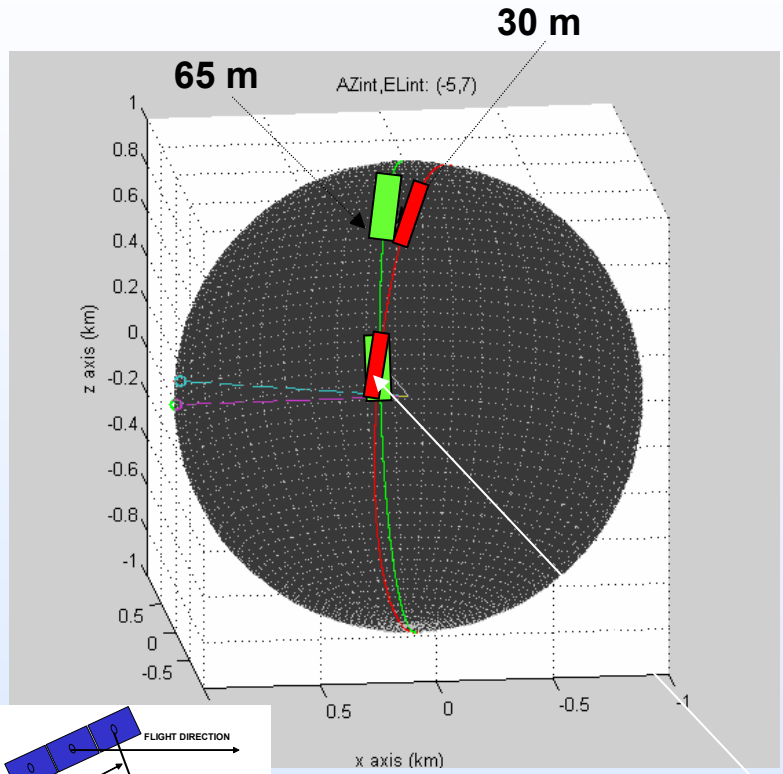


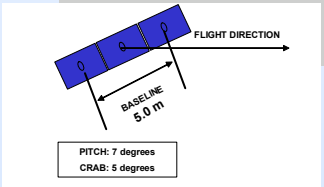
SIMULATION PARAMETERS FOR PLANAR ARRAY

HORIZONTAL BASELINE (m)	8.0
VERTICAL BASELINE (m)	1.0
AIR SPEED (meters/sec)	230
RADAR FREQUENCY (GHz)	10
ALTITUDE (km)	10
RANGE (km)	100
PRF (Hz)	600
NUMBER OF PULSES	64
AZ BEAMWIDTH (mrad)	45
EL BEAMWIDTH (mrad)	45

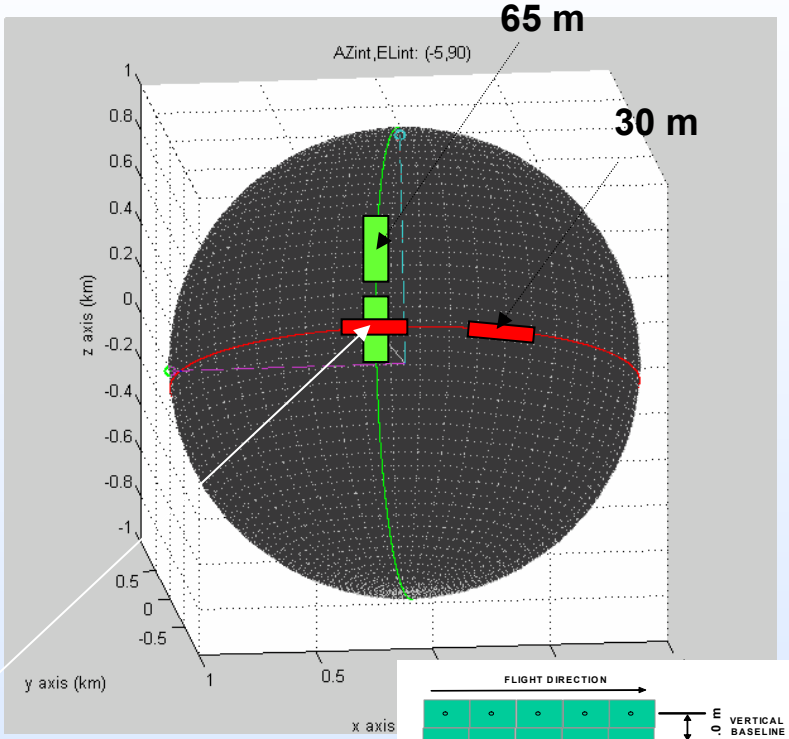
INTERFEROMETER AND DOPPLER CONE INTERSECTIONS WITH RANGE SPHERE: TWO RADAR GEOMETRIES

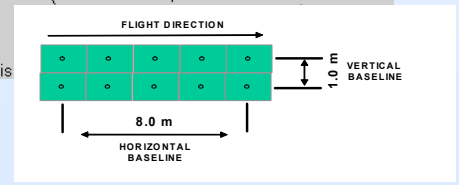
CURRENT JSTARS





NEAR-TERM MP-RTIP





ERROR VOLUME

DOPPLER FILTER WIDTH => THICKNESS OF GREEN LINE

PHASE VARIANCE => THICKNESS OF RED LINE

THE DTED STANDARD

DTED LEVEL	POST SPACING	ABSOLUTE ACCURACY X/Y	ABSOLUTE ACCURACY Z	RELATIVE ACCURACY X/Y	RELATIVE ACCURACY Z
1	100 m	25 m	10 m	15 m	10 m
2	30 m	15 m	10 m	10 m	7 m
3	10 m	10 m	10 m	3 m	2 m
4	3 m	10 m	5 m	2 m	0.8 m
5	1 m	5 m	5 m	0.5 m	0.33 m

POST SPACING: THE SEPARATION BETWEEN AVAILABLE INDEPENDENT TERRAIN HEIGHT VALUES

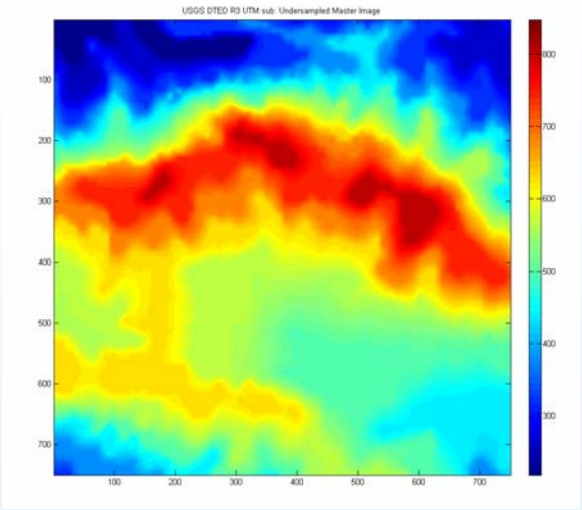
ABSOLUTE ACCURACY: ABSOLUTE CELL ERROR (POSITION IN WGS84 COORDINATES)

RELATIVE ACCURACY: CELL-TO-CELL ERROR (DIFFERENCE BETWEEN TWO POST POSITIONS)

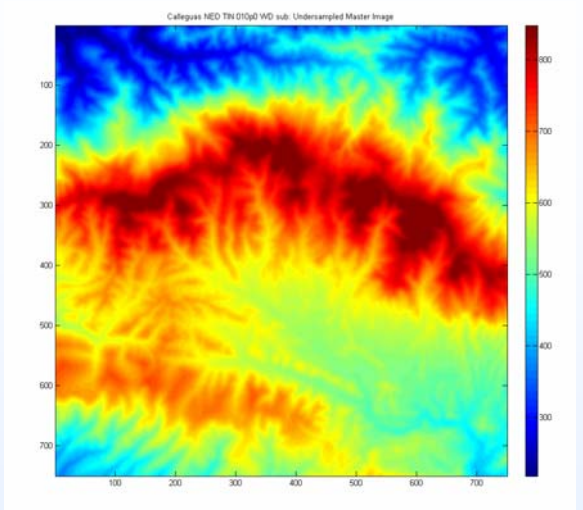
CE90: HORIZONTAL IN-PLANE CIRCULAR ERROR 90-TH PERCENTILE

LE90: VERTICAL LINEAR ERROR 90-TH PERCENTILE

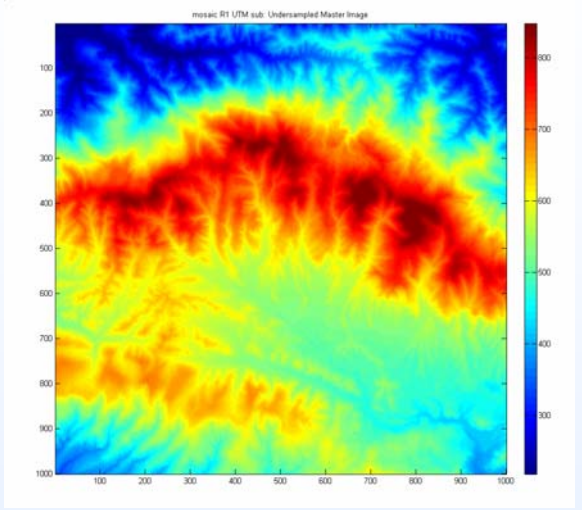
COMPARISON OF DTED LEVELS 1-3 FOR TARGET REGION



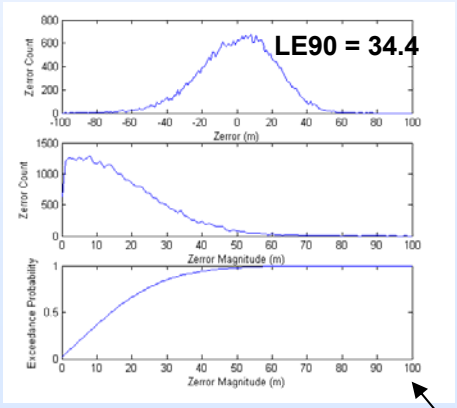
LEVEL-1 DTED/USGS

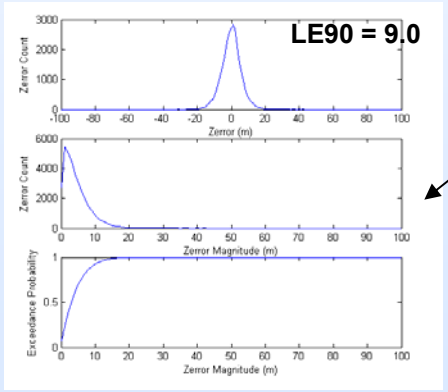


LEVEL-2 DTED/NED



LEVEL-3 DTED/IFSAR



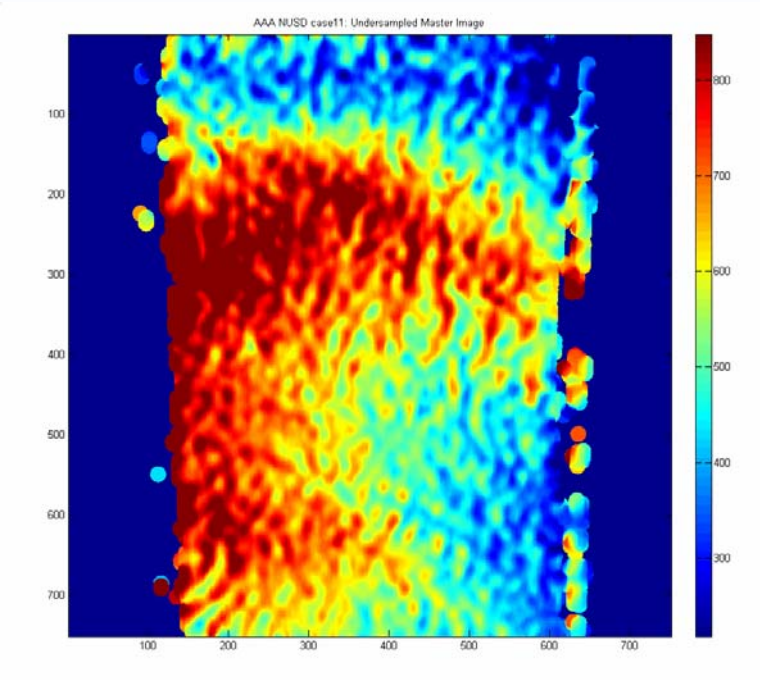


LEVEL-2/ LEVEL-3 DTED ERRORS

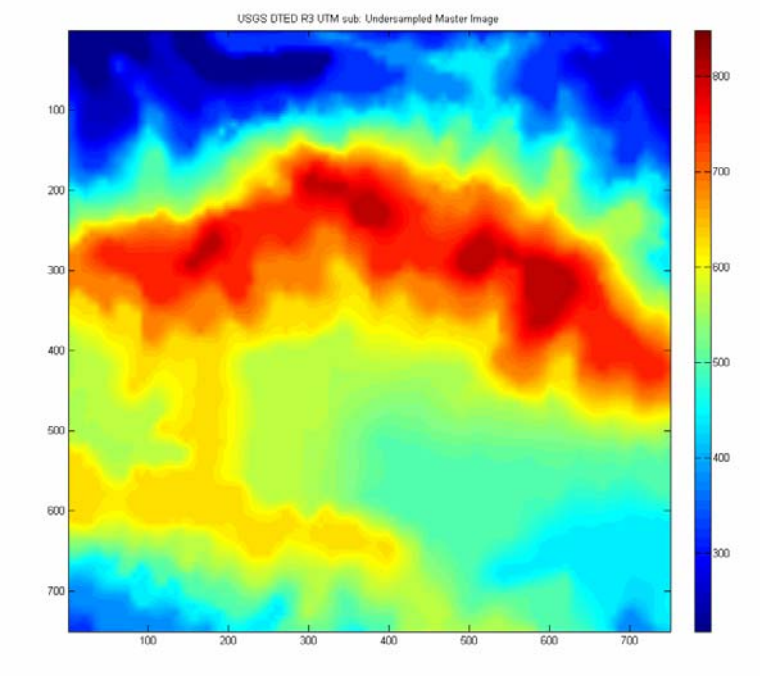
LEVEL-1/LEVEL-3 DTED ERRORS

KASSPER
KNOWLEDGE-AIDED SENSOR SIGNAL PROCESSING & EXPERT REASONING

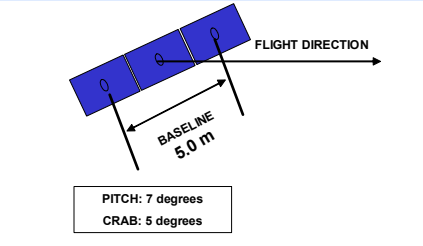
JSTARS DEM, 0.10 SEC INTEGRATION, COMPARED TO LEVEL 2 DTED



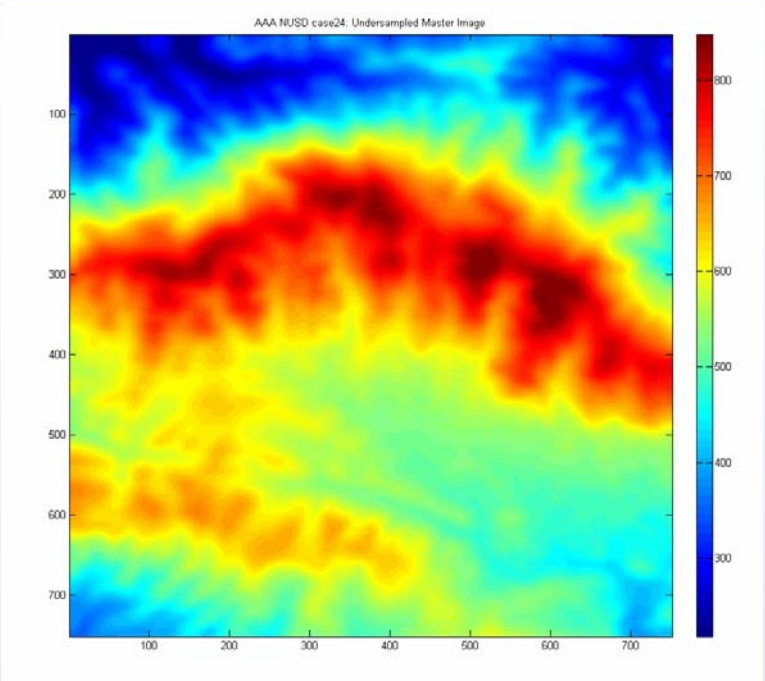
T = 0.10 SEC



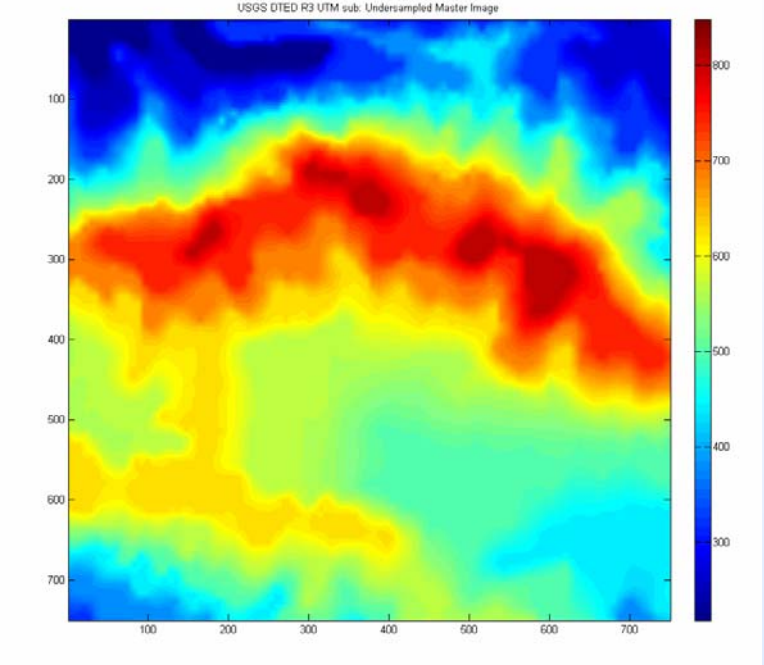
LEVEL-2 DTED



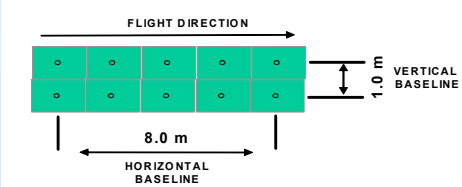
MP-RTIP DEM, 0.10 SEC INTEGRATION, COMPARED TO LEVEL 2 DTED



T = 0.10 SEC



LEVEL-2 DTED



RESULTS

- **TOMOGRAPHIC ENHANCMENT OF GMTI CROSS RANGE RESOLUTION IS IMPRACTICAL, MAINLY BECAUSE OF SHADOWING EFFECTS**
- **INTERFEROMETRIC DEM GENERATION HAS ADVANTAGES OVER STEREO**
  - DOESN'T REQUIRE REGISTRATION OF MULTIPLE CLUTTER MAPS
  - INSENSITIVE TO TEMPORAL DECORRELATION
- **INTERFEROMETRIC PROCESSING OF GMTI CLUTTER MAPS CAN GENERATE ACCURATE DEMS**
  - DEM QUALITY DEPENDS ON SEVERAL FACTORS, INCLUDING:
    - INTERFEROMETER VERTICAL BASELINE OR HORIZONTAL BASELINE AND TILT ANGLE
    - COHERENT INTEGRATION PERIOD
    - IMAGING GEOMETRY
  - **JSTARS GMTI RADAR REQUIRES A LONG INTEGRATION TIME TO ACHIEVE LESS THAN LEVEL-1 DTED QUALITY**
  - **NEAR-TERM MP-RTIP SYSTEM CAN APPROACH LEVEL-2 OR BETTER DTED QUALITY WITH THE SAME INTEGRATION TIME**

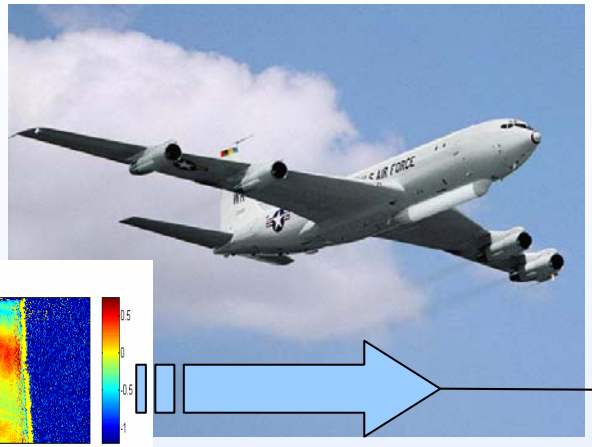
OUTLINE

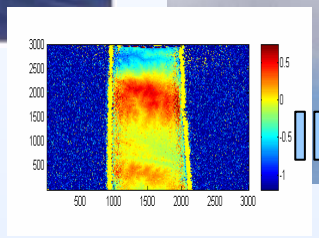
- **INTRODUCTION**
- **DIGITAL ELEVATION MAP (DEM) GENERATION RESULTS**
- **WHY THIS WORK IS KEY TO KASSPER**
  - A KASSPER OPERATIONAL CONCEPT
  - WHY BLEND KNOWLEDGE WITH ADAPTIVITY?
  - MAP REGISTRATION AND KASSPER
- **SUMMARY**

HIGH FIDELITY KNOWLEDGE-BASED ALGORITHM ASSUMPTIONS

- GOAL: IMPROVED GMTI DETECTION AND PARAMETER ESTIMATION BY APPLICATION OF HIGH-FIDELITY PRIOR KNOWLEDGE.
- FOCUS: REALISTIC NEAR-TERM GMTI PLATFORMS
  - **FIXED WING LONG BASELINE (8 meter) ADVANCED ARRAY (JSTARS/RPTIP)**
  - **UAV SMALL ARRAY (1 meter) (GLOBAL HAWK)**
  - **MECHANICALLY REALIZABLE SUBARRAY GEOMETRIES**
- ASSUMES REAL-TIME AVAILABILITY OF HIGH QUALITY MAP DATA
  - **TERRAIN ELEVATION MAPS TO LEVEL 2 OR 3 FROM IFSAR/ LIDAR.**
  - **CO-REGISTERED SAR REFLECTIVITY MAPS.**
  - **TERRAIN TYPES WITH BOUNDARIES.**
  - **ACCURATE ROAD MAPS.**
- DATA REGISTRATION IS KEY
- PROCESSING REQUIREMENTS MAY BE LARGE
  - **EXPLOIT GROUND-BASED PROCESSING WITH UPLINK-DOWNLINK**
  - **ASSUME LARGE FAST MEMORY AND HIGH THROUGHPUT**

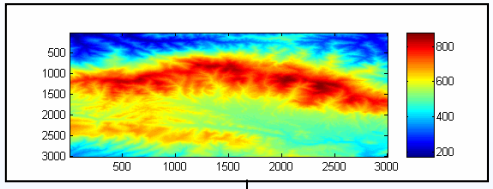
HIGH FIDELITY MAP KNOWLEDGE OPERATIONAL CONCEPT



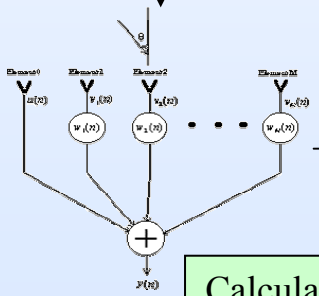


GMTI Data Cube Map Products

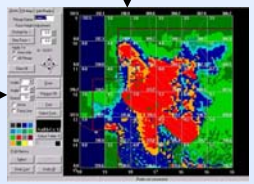
High-Fidelity Knowledge Store



Ground-Based Computer



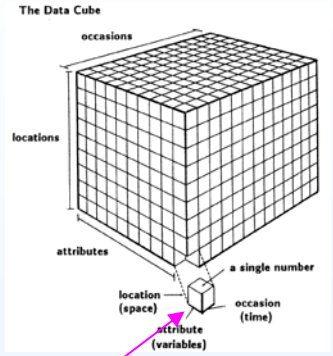
Calculate Weights from High Fidelity Data!

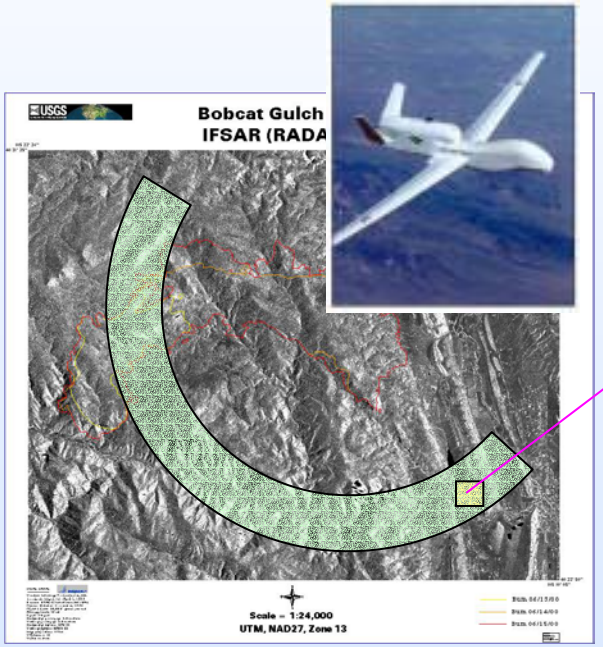


Moving Target Indicator

KNOWLEDGE-BASED DATA CUBE

Sensor Element Positions
From INS/GPS $\mathbf{x}(e,\tau)$





High Fidelity Data Scene

$$\hat{C}_K(R) = \sum_{\substack{\text{SAR cells} \\ \text{at Range}}} |e \otimes \tau\rangle\langle e \otimes \tau|$$

- High Fidelity SAR data, Terrain Elevations and GPS/INS Data contribute.
- Data Cube and Covariance are based on KNOWLEDGE, Not measured data

WHY BLEND KNOWLEDGE WITH ADAPTIVITY?

- **PERFECT KNOWLEDGE provides IDEAL Training Data**
- **KNOWLEDGE is IMPERFECT**
  - Historical as opposed to current
  - Sensitive to Array Calibration Errors.
  - Sensitive to Registration errors
  - Limited by INS/GPS Fidelity
  - Does not reflect ELECTRONIC ATTACK environment
  - Potentially High Computational load
  - Increased complexity

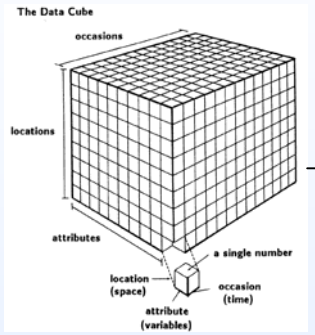
- **ADAPTIVE Technique provides prompt Response to Environment**
- **ADAPTIVITY is IMPERFECT**
  - Limited to Fidelity of GMTI surveillance data collection
  - Degraded by sophisticated ELECTRONIC ATTACK strategies
    - Mainbeam Jamming
    - Spatial Incoherence
    - Hot Rocks
  - Limited Training Data
  - Spatial NONSTATIONARITY
  - STATISTICAL MODEL-Dependent

CLASS OF COHERENT KNOWLEDGE-ADAPTIVE COMBINERS

GMTI MEASURED DATA CUBE

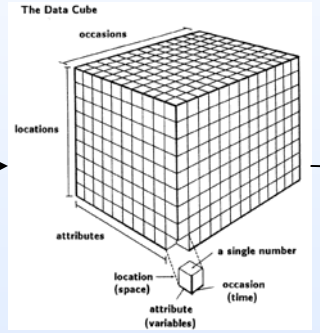
APPLY WEIGHTS

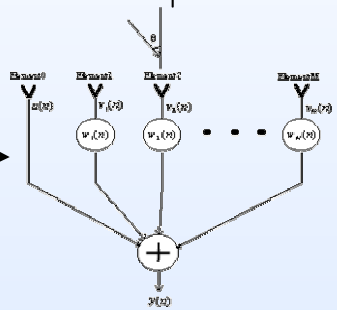
Geometric Correlation / Registration

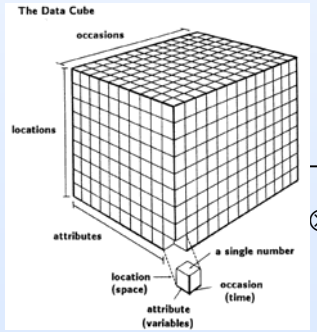


$\otimes \frac{1}{\sqrt{1+\lambda^2}}$

COMBINED DATA CUBE







$\otimes (-1) \frac{\lambda}{\sqrt{1+\lambda^2}}$

KNOWLEDGE-BASED DATA CUBE

Optimize λ
Optimize
fine registration.

$$\hat{C}_R = \sum_R |e \otimes \tau\rangle\langle e \otimes \tau|$$

$$|W\rangle = \hat{C}_R^{-1} |v\rangle$$

COMPUTE ADAPTIVE WEIGHTS

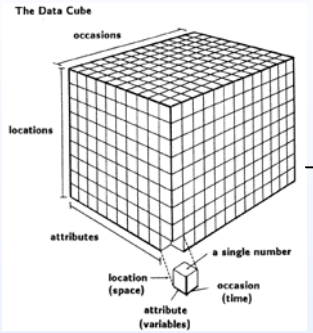
CLASS OF STATISTICAL KNOWLEDGE-ADAPTIVE COMBINERS

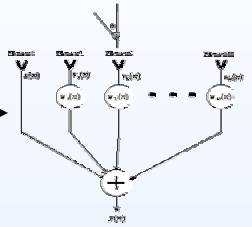
GMTI MEASURED DATA CUBE

MEASURED COVARIANCE

APPLY WEIGHTS

Geometric Correlation / Registration

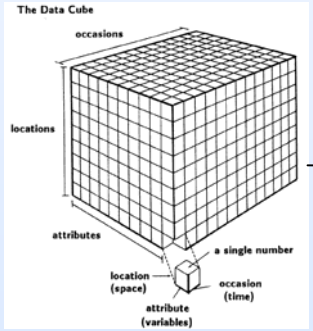


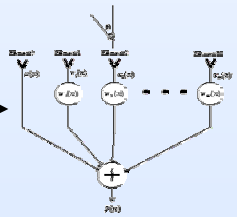


$$\hat{C}_M(R) \otimes \frac{1}{\left\|\hat{C}_M\right\|} 1-\lambda$$

$$\hat{C}$$

$$|W\rangle = \hat{C}^{-1}|v\rangle$$



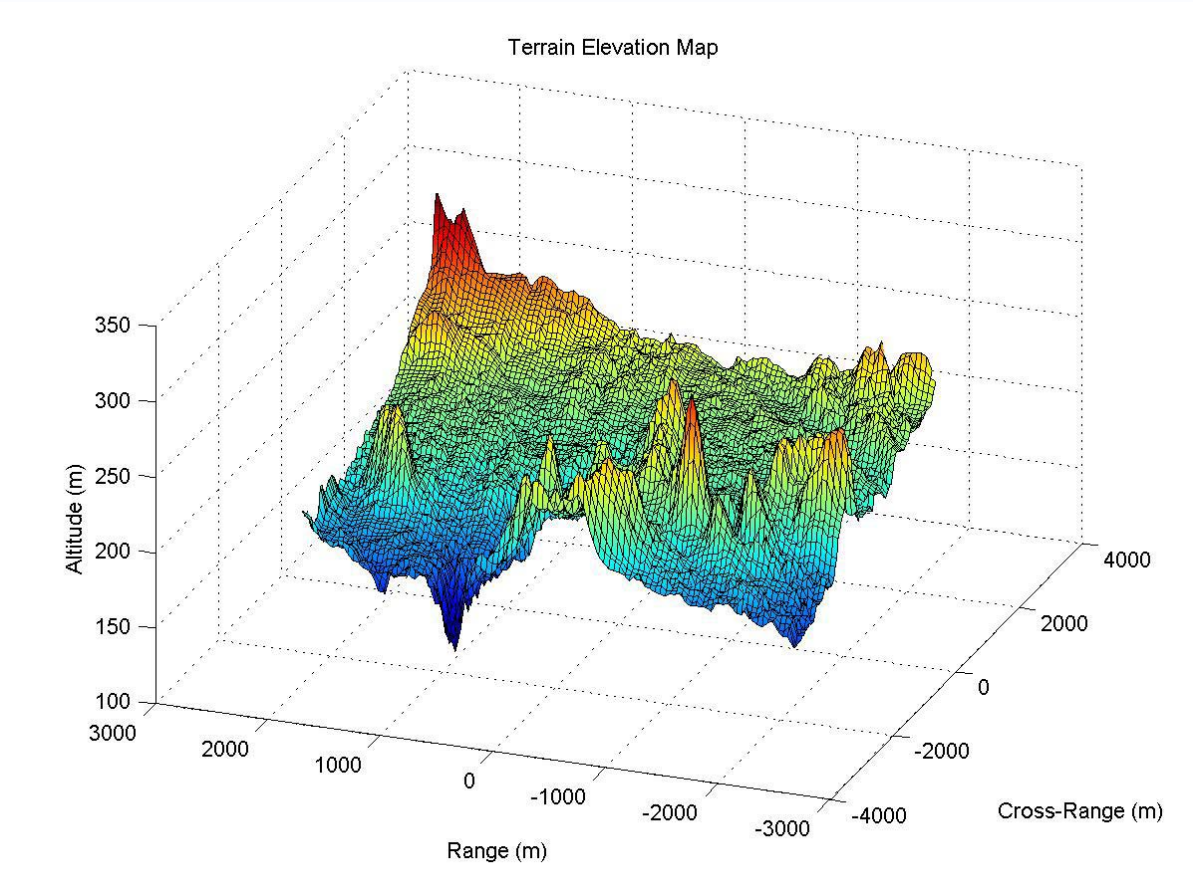


$$\hat{C}_K(R) \otimes \frac{1}{\left\|\hat{C}_K\right\|} \lambda$$

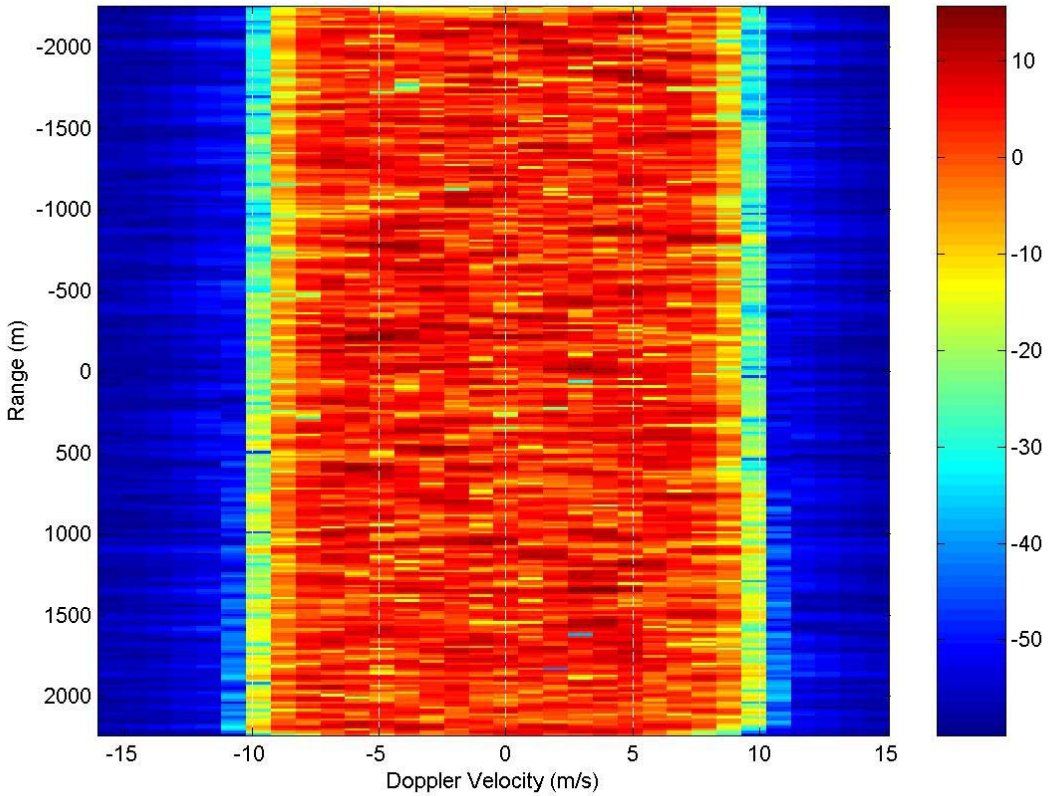
KNOWLEDGE-BASED DATA CUBE

KNOWLEDGE-BASED COVARIANCE

HIGH FIDELITY ELEVATION MAP



REALISTIC GEOMETRY SPREADS CLUTTER



SUMMARY

- **TSC is Studying Algorithms which Employ IFSAR or other high-resolution SAR and terrain Elevation maps in the loop.**
- **Registration is key to Exploiting Map Knowledge.**
- **A direct approach is to use the GMTI data cube for geometrical registration, then switch to the stored maps for computing STAP Weights.**
- **Knowledge alone and Adaptivity Alone have advantages and Drawbacks. A better approach is to combine them. TSC is pursuing a coherent combiner (CKAC) and a statistical combiner (SKAC) as front-end processors to STAP.**
- **The method of Soft Constraints provides a means of utilizing other auxilliary map data to reduce false alarms.**
- **TSC has actively developed tools for High-resolution Algorithm Development and design. These include fast Data Cube Generation methods and new approaches to Internal Clutter Motion Modeling.**