Terrain Model-Based STAP

LM M&DS-ISR Systems

15 April 2003

Background

- LM M&DS-ISR Systems has developed many MTI and other adaptive radar processing algorithms in recent years

- General approach or philosophy
  - Use all available knowledge of system errors
  - Create the most benign environment possible for the adaptive portion of the processing
  - Take extreme care to make adaptive processing robust

Need for Terrain Model

- Antenna phase centers have a vertical separation
- Terrain has significant vertical diversity relative to range

- Goal of this effort was to demonstrate terrain model integration into proven GMTI methodology

ADSAR Algorithm Structure

- The LM M&DS-ISR System's "ADSAR (Adaptive Differential Synthetic Aperture Radar) algorithm" is not uniquely defined
  - Improvements over time
  - Adoption for specific purposes
- Common features
  - Start with SAR-type processing of Multi-channel endo-clutter MTI data
  - Channels are "channel balanced" using best available system knowledge
  - Detection is performed on "clutter-cancelled" images
  - "STAP combined with radar engineering"

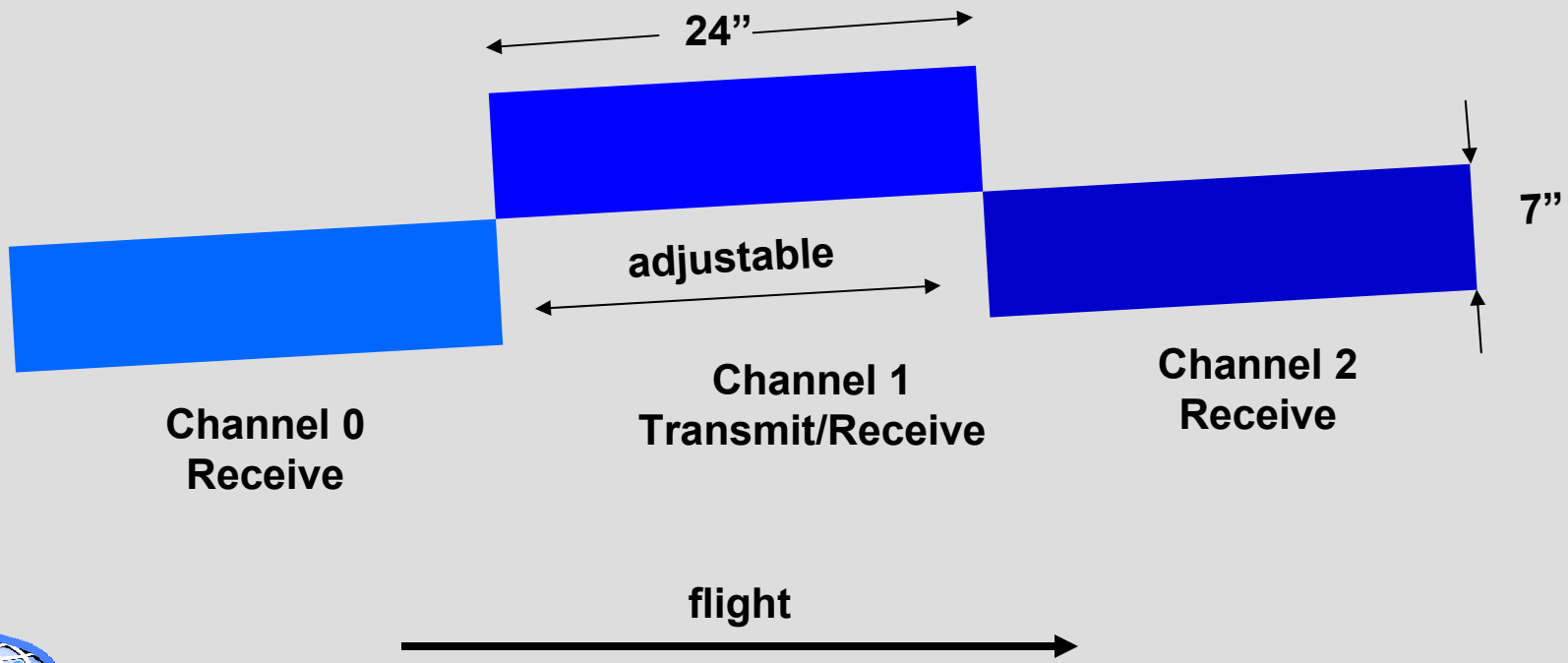
ADSAR Algorithm Structure (2)

- Image-domain channel balance
  - Assumes low-order phase and amplitude imbalance variation with range and Doppler
    - Beam miss-pointing
    - Phase center location uncertainty
  - Early versions of ADSAR averaged image ratios
  - KASSPER version uses eigen analysis on covariance matrices
- Frequency domain channel balance
  - Used in KASSPER version for RF equalization
  - Unknown delays and filter characteristics

ADSAR Rationale

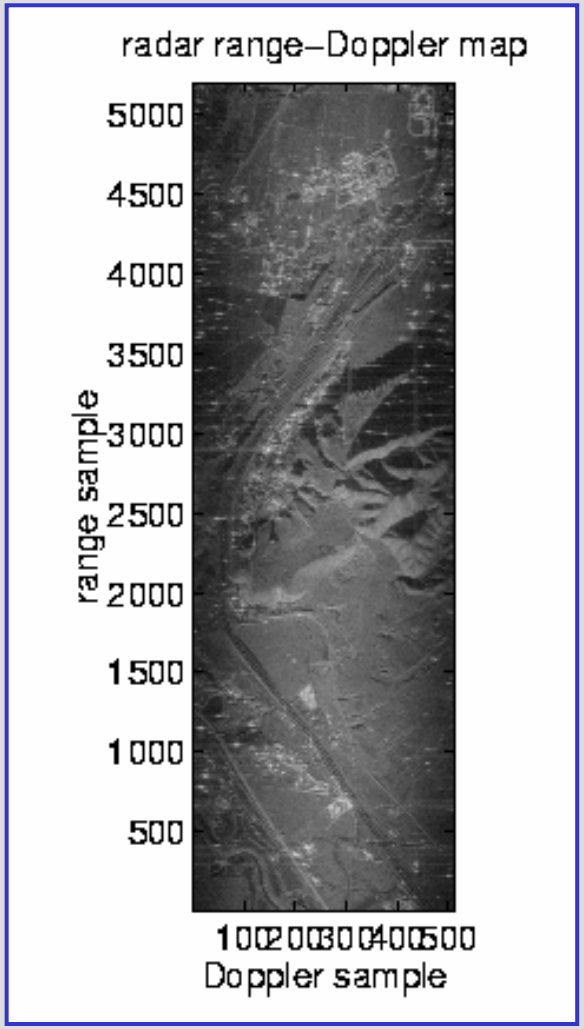
- If data errors have structure, then using that structure is useful
  - Smoothes out the effects of noise, moving objects and ambiguous energy
  - Mitigates problems with non-stationary clutter statistics
  - Tends to avoid introducing egregious errors
- Why emphasis on canceling clutter?
  - Clutter has highly variable statistics
  - Generally very non-gaussian with heavy tails
  - Experience has shown that the “back end” processing gets overwhelmed by false alarms if clutter cancellation is not working well

Tuxedo Antenna Configuration



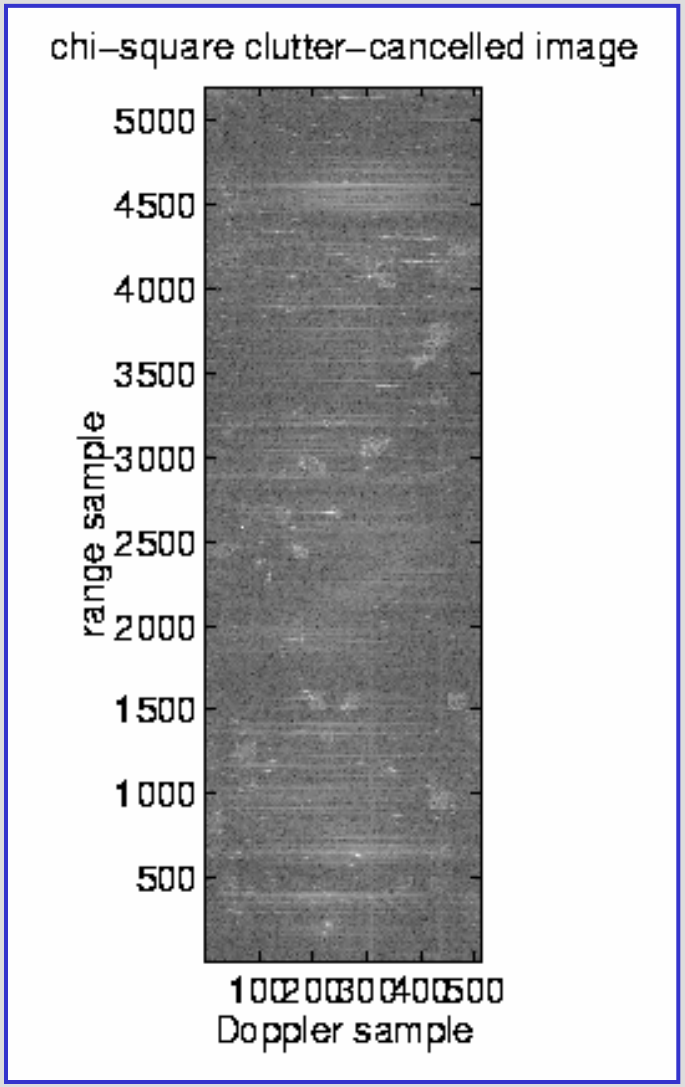
Pure STAP Problem Illustration

- Divide 3 complex channel images up into 100x32 patches
- Form 3x3 complex covariance matrices for each patch



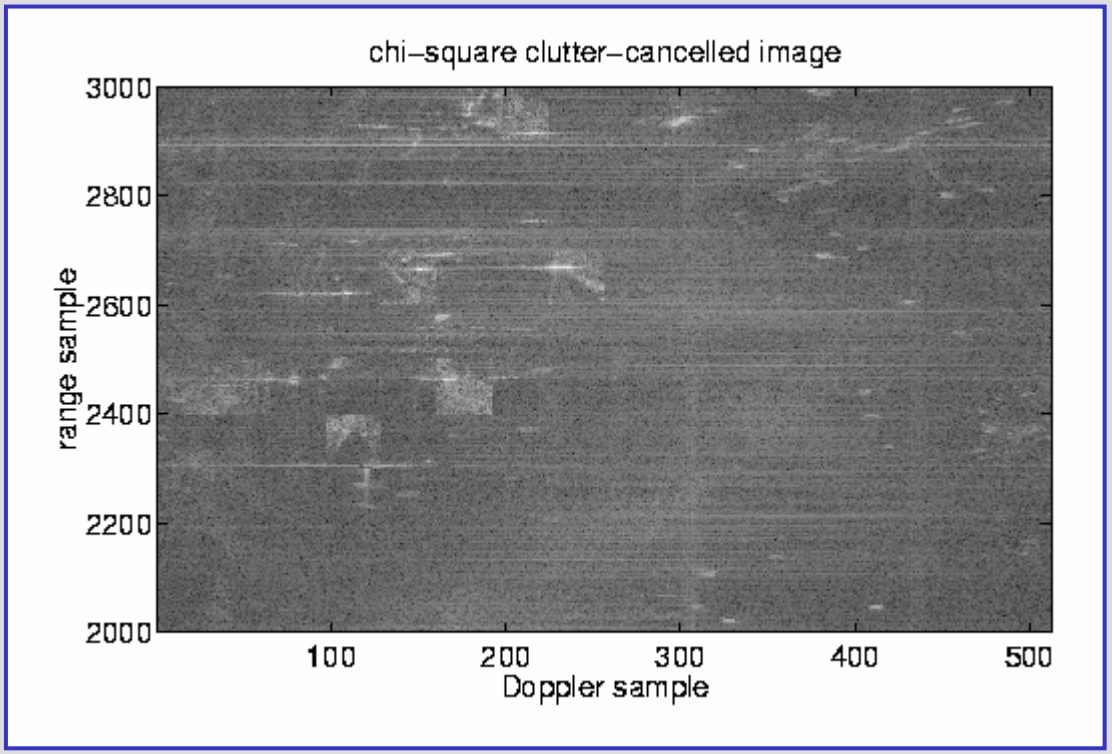
Pure STAP Problem Illustration (2)

- Patch by patch chi-square image
- Simple form of Sample Matrix Inverse processing
- Visible patch boundaries from non-stationary clutter
- Easily fooled by bright moving targets



Pure STAP Problem Illustration (3)

- Patch by patch chi-square image
- Magnified view



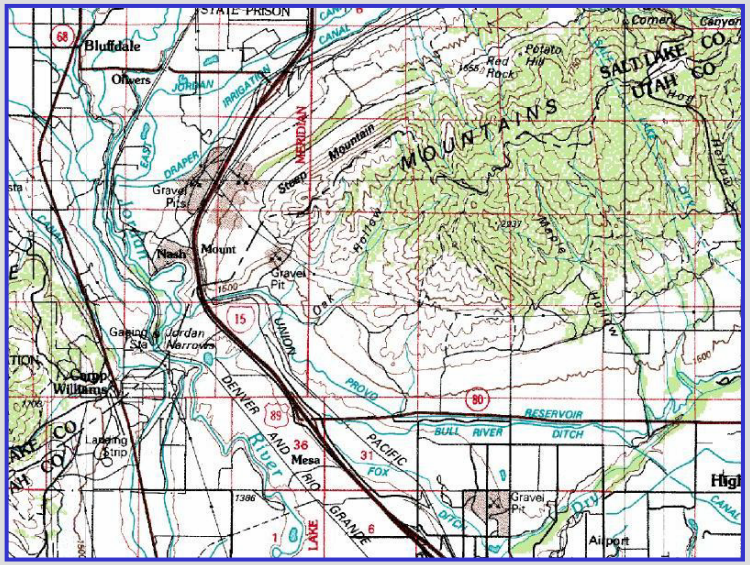
Incorporation of DEM into Processing

Use DEM data at two different points in the processing

- Make deterministic adjustments to channel phases based upon DEM geometry
- Avoid using shadow areas to measure statistics (balance channels)
  - Mostly noise
  - Moving targets dominate, potentially causing bad measurements

Map Area for Model-Based STAP Demo

Point of Mountain, Orem, Utah



Map

Aerial Photo

Radar Data

- Tuxedo platform collected LIDAR data under contract to a third party for DEM production
- Radar data (Tuxedo pass 3660) for area was collected for possible future use in a project such as this
- Data is ideal for stressing MTI algorithms
  - Many moving targets
  - Large terrain variation
  - Large clutter variation

Radar Data Properties

Center frequency: 9.6GHz

Transmit pulse envelope: 100 MHz chirp

Pulse length: 35 microseconds

PRF: 1114.8 Hz

Nominal channel spacing: 2 ft physical

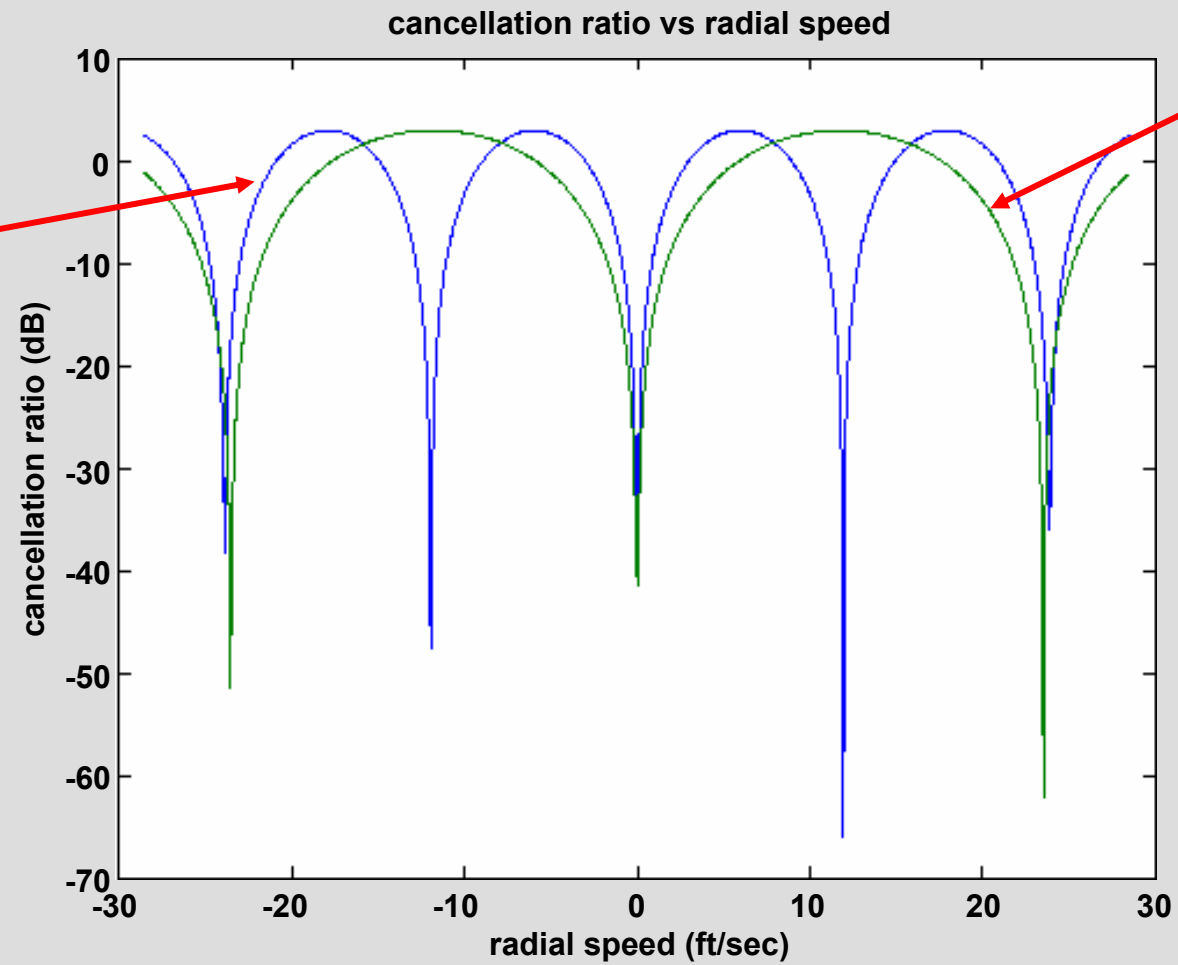
Inter-pulse distance: 0.408 ft

Range = 11.18 nmi

Grazing angle: 18.5°

Processed pulses: 512

Target Cancellation



Channel 0-2 difference

Channel 1-2 difference

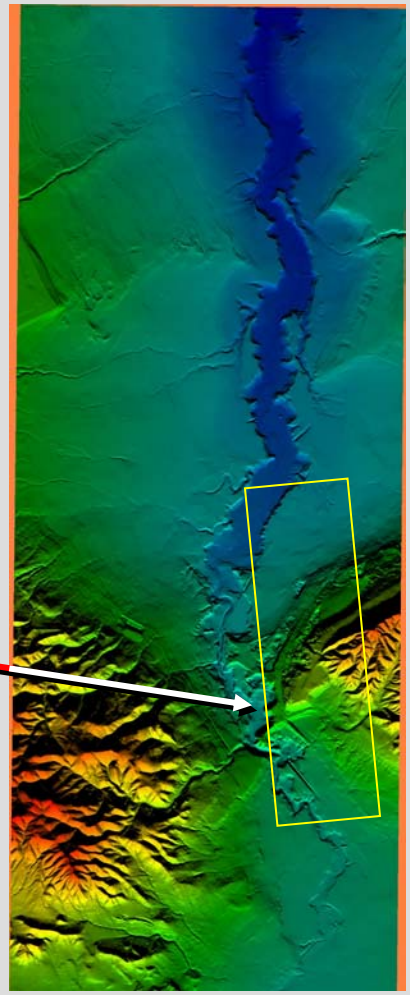
DEM Data

- Original intent: use DEM data collected by Tuxedo platform
  - Raw data looked OK but had not been checked for quality
  - Did not cover entire radar image area
- Actually used USGS DEM data
  - Data is available on-line for free in Spatial Data Transfer Standard (SDTS) format
  - Read and exported to ASCII file using the almost free ($129) Global Mapper PC-based utility (produced by Global Mapper Software)
  - Particular DEM has nominal 10 meter posts

DEM Data *continued*

- Image output from Global Mapper utility
- Two SDTS data products

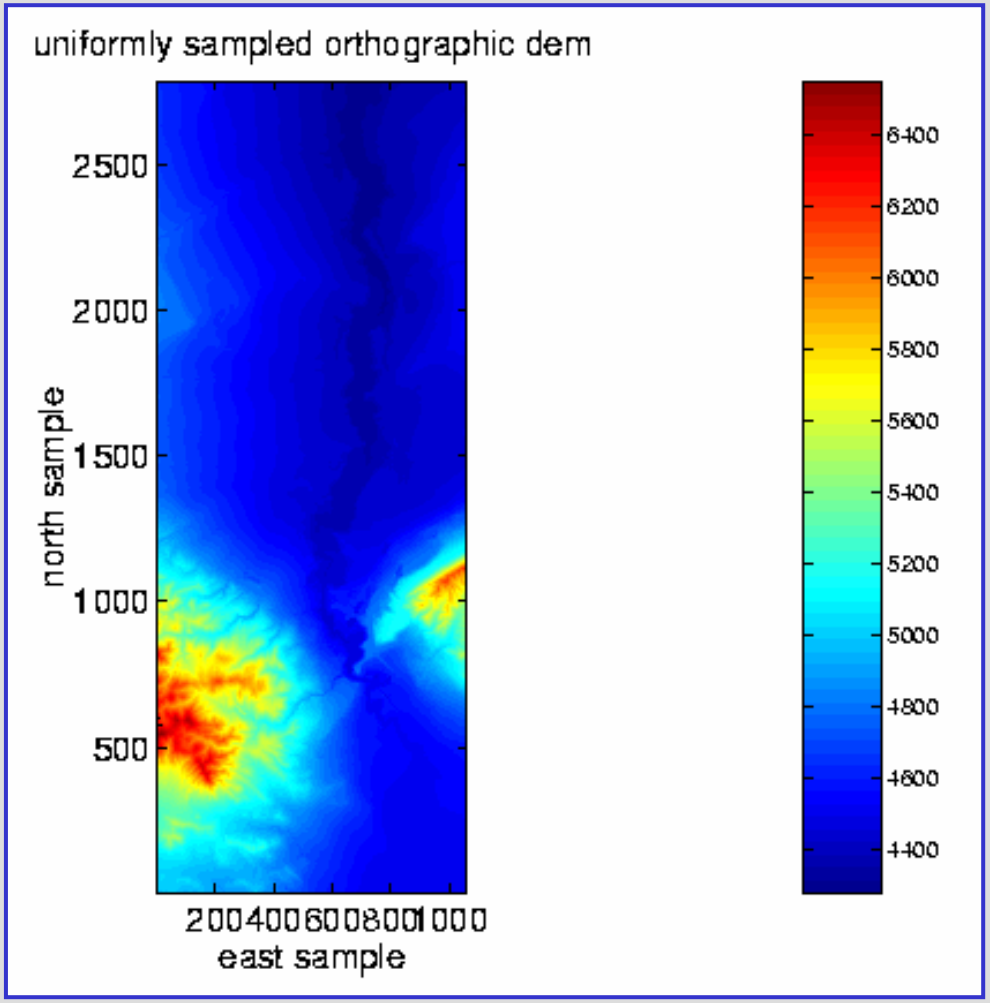
Approximate area
of radar image



Processed DEM: uniform samples

Raw DEM data is not quite uniformly spaced and has small holes

10 meter north/east sample spacing



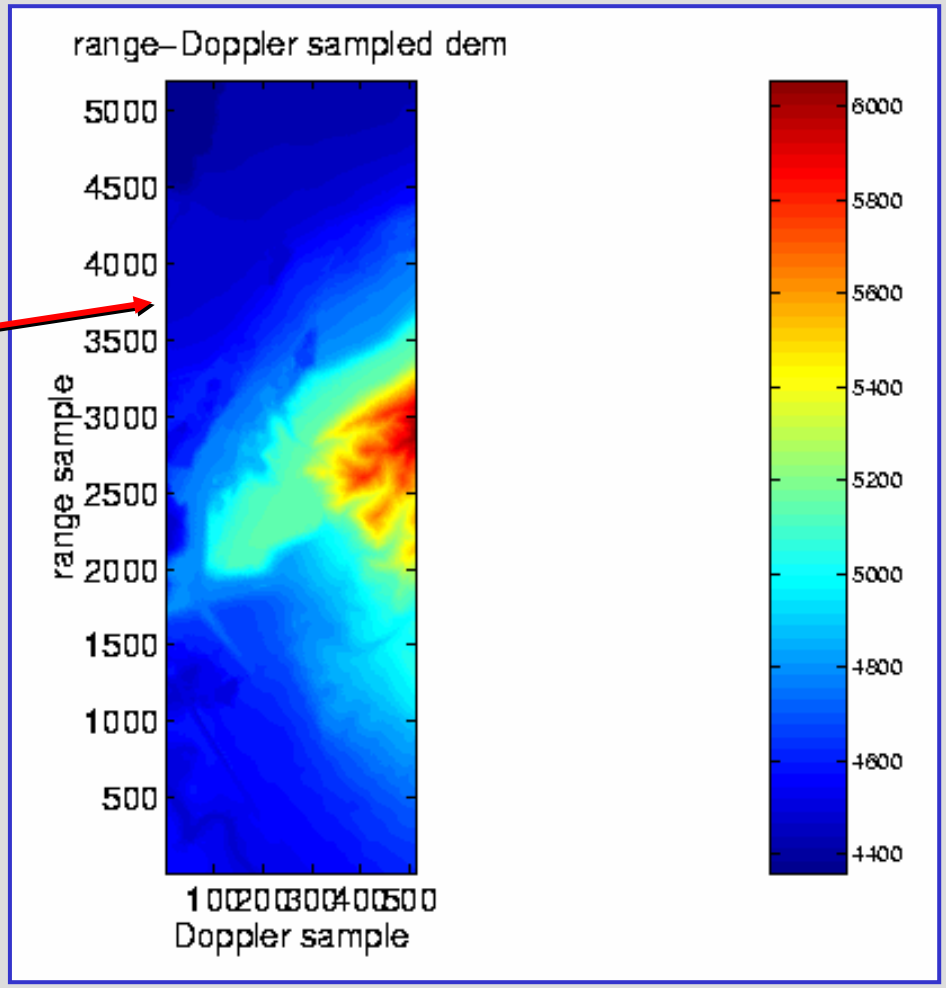
Processed DEM: radar cell samples

center image sample spacings:

4.9371 range
16.6653 azimuth

z-component of xyz triples at radar image points

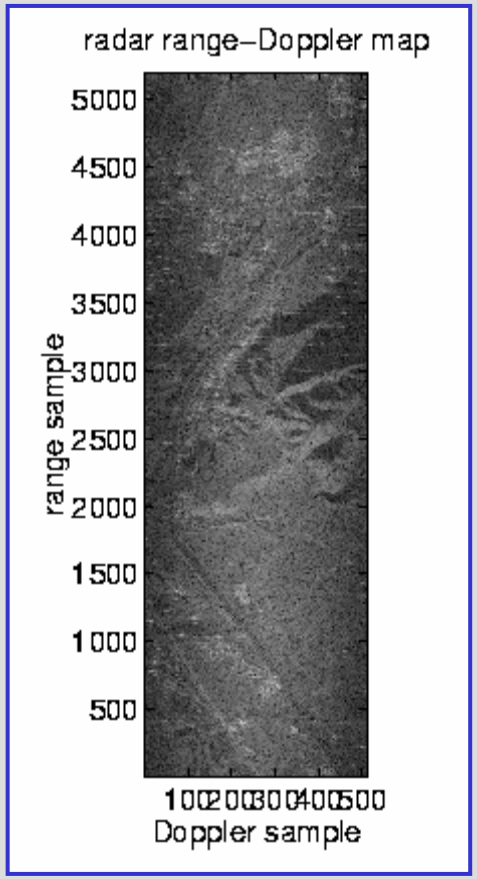
XYZ points computed by following range-Doppler circles to the DEM

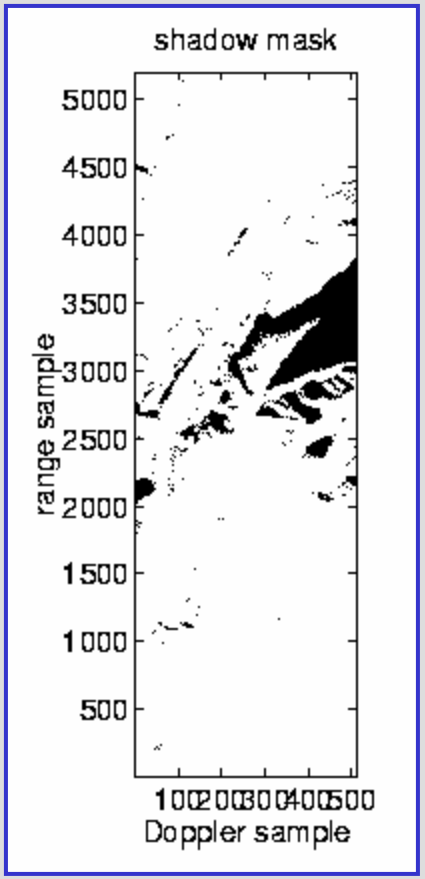


Processed DEM: shadow mask

The shadow mask is in good agreement with the image

Covariance data for patches having shadowed centers were ignored

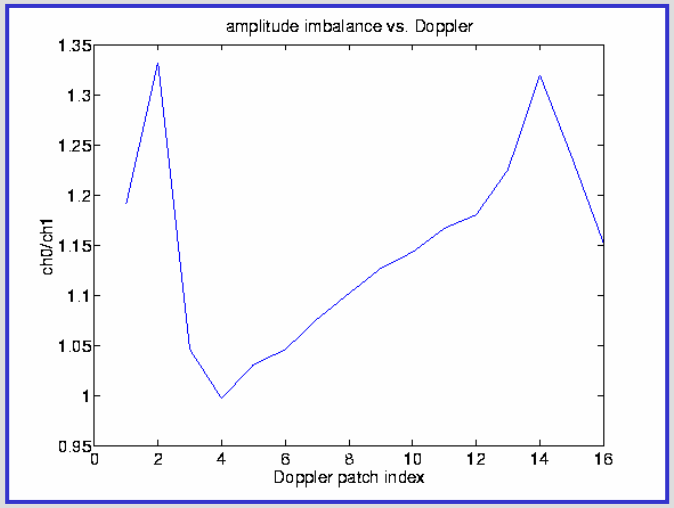


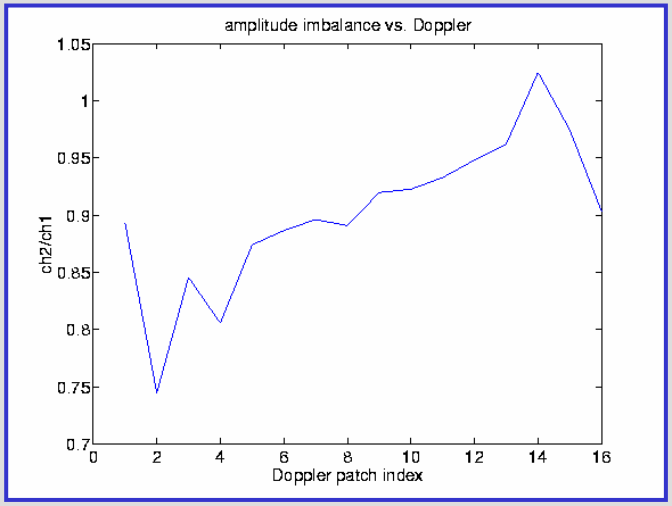


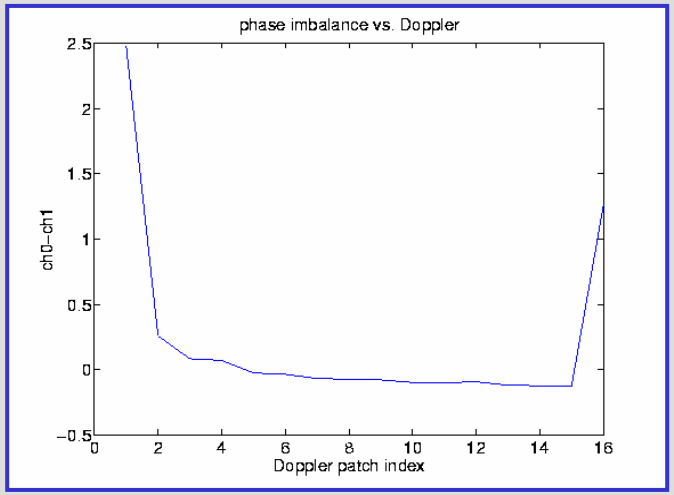
Doppler Variation of Imbalances

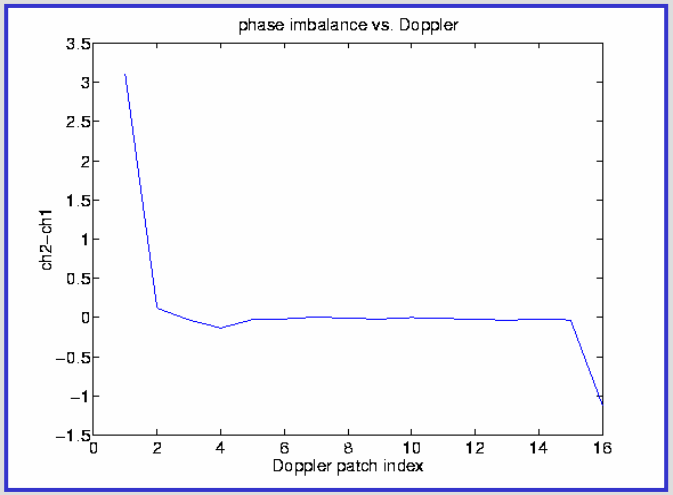
Cuts through center range

Phases in radians

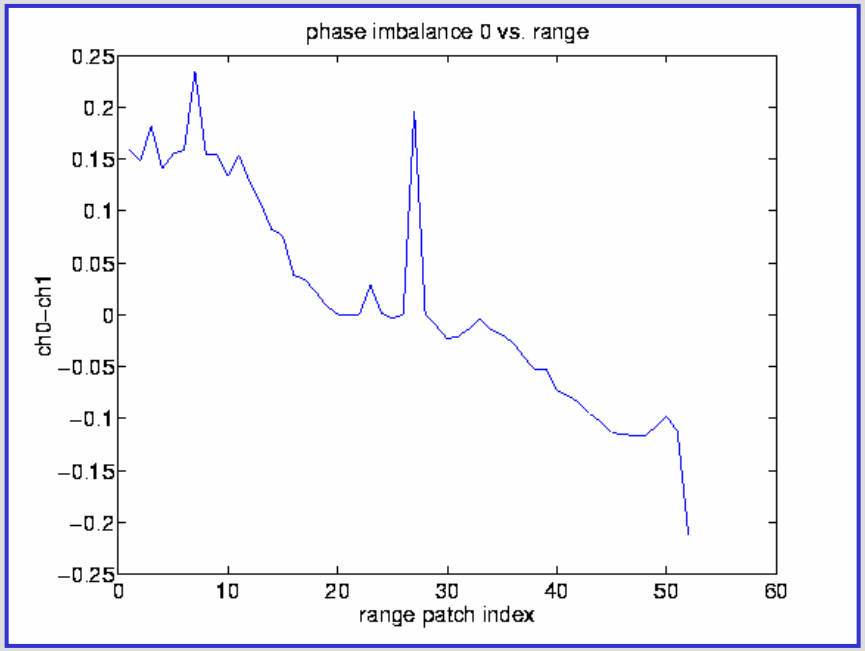


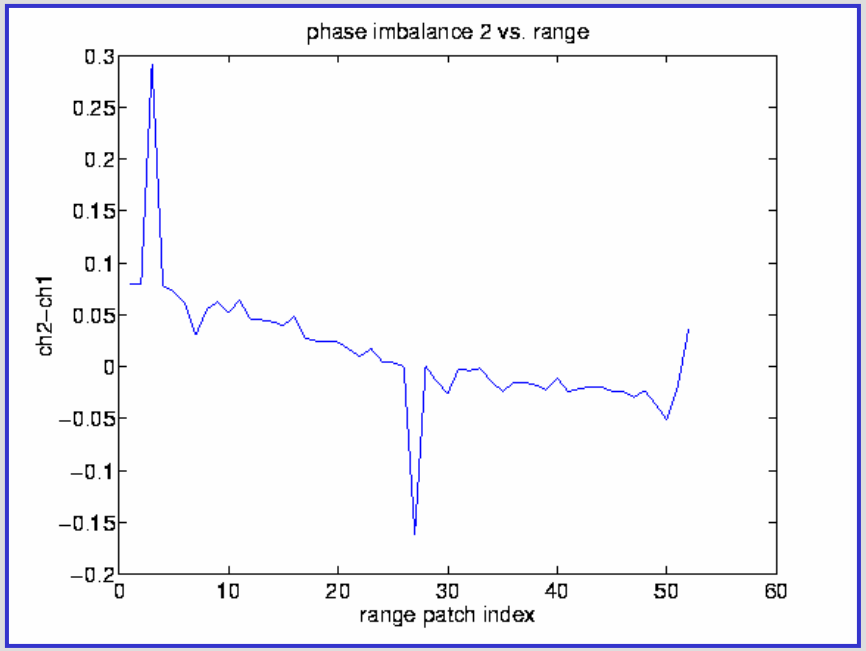






Range Variation of Phase Imbalances with DEM correction

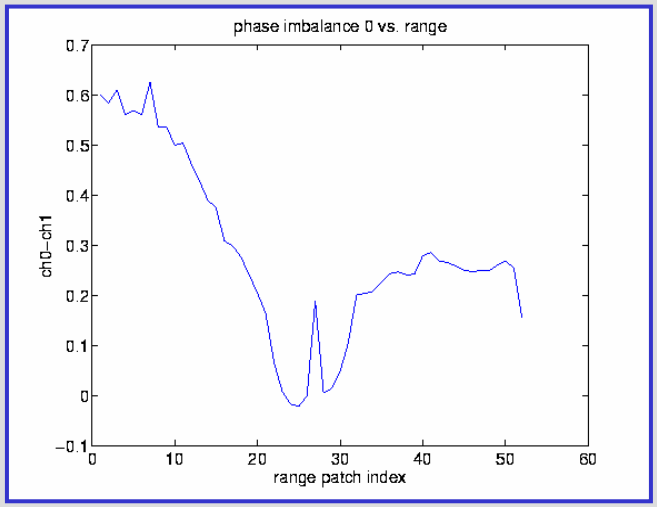


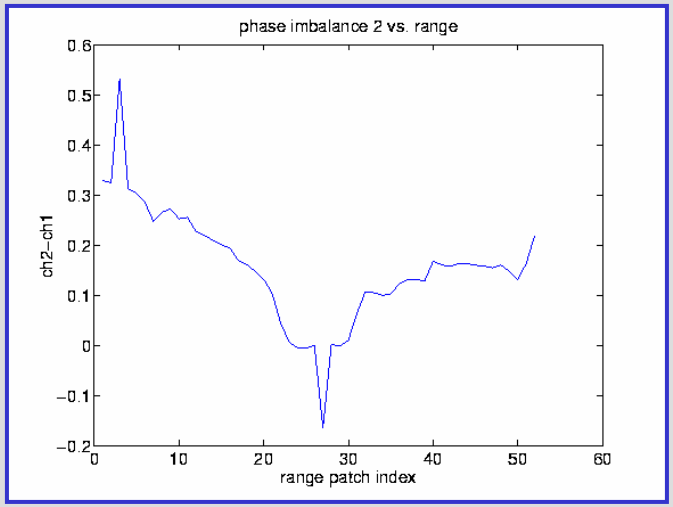


Cuts through center Doppler

Phases in radians

Range Variation of Phase Imbalances without DEM correction

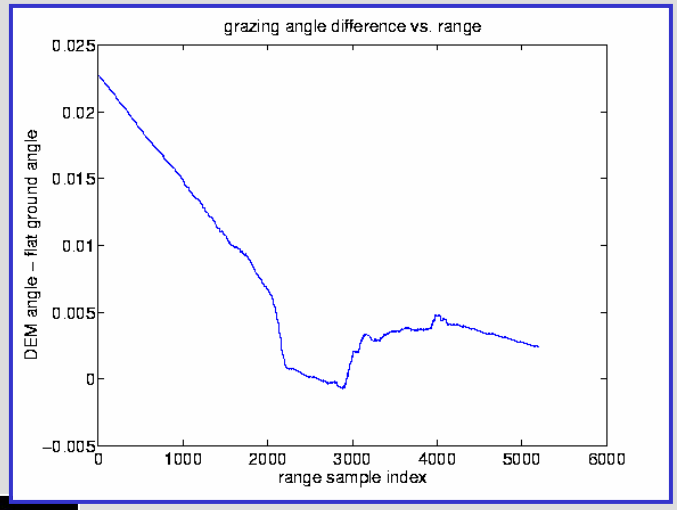




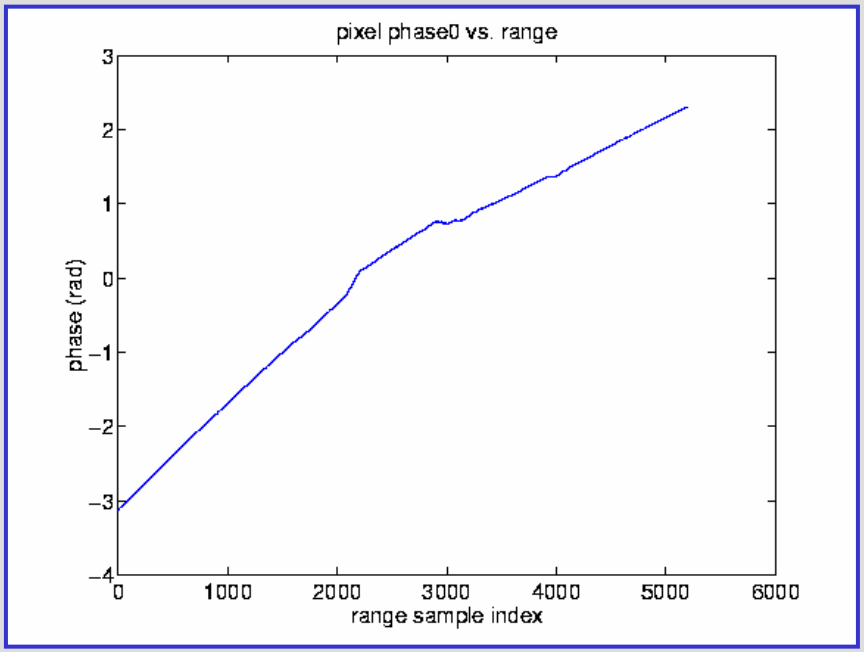
Cuts through center Doppler

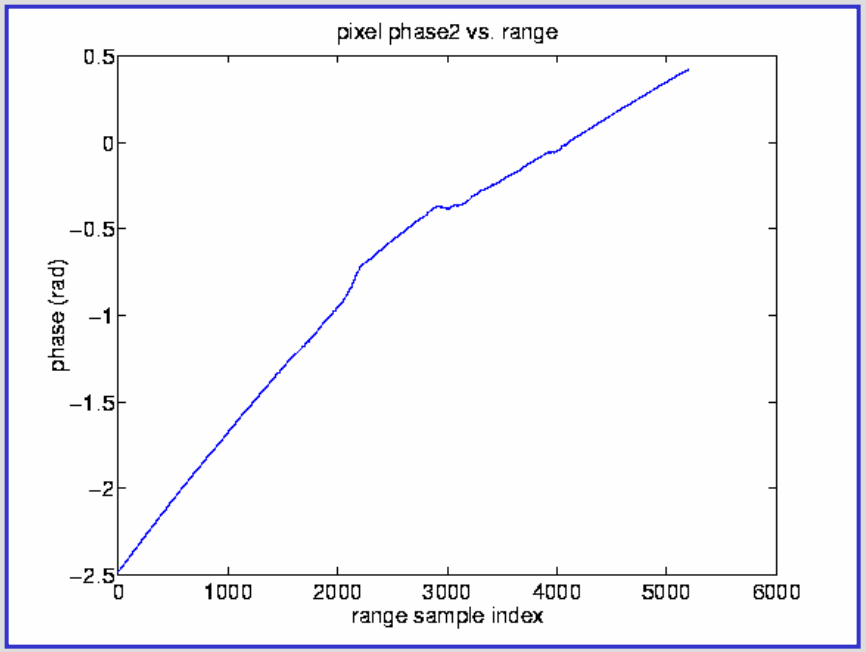
Phases and angles in radians

Change in grazing angle using DEM



Range Variation of Phase Corrections Image Domain

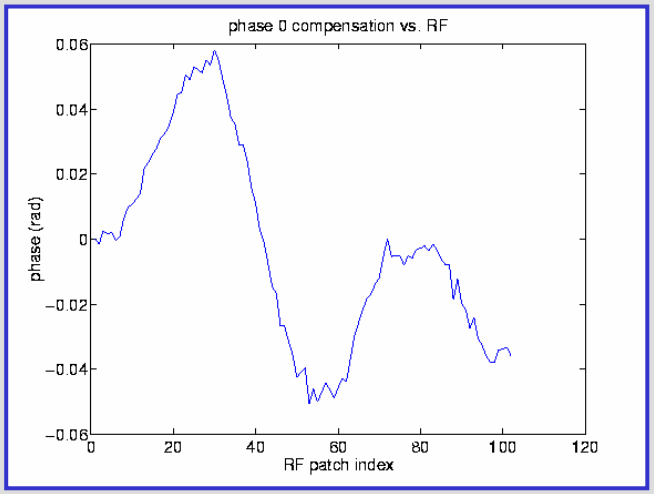


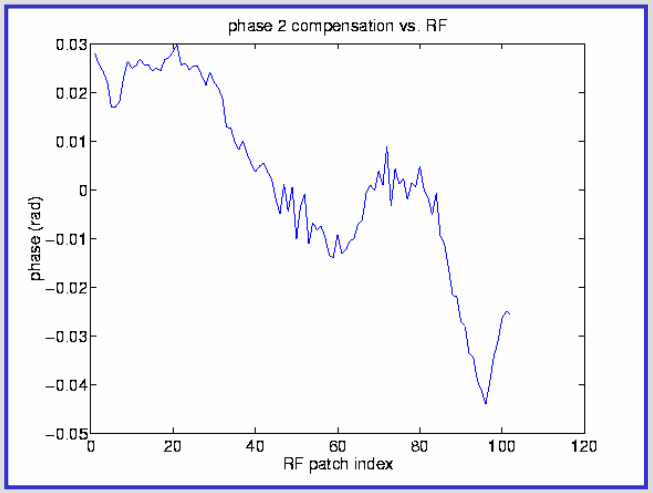


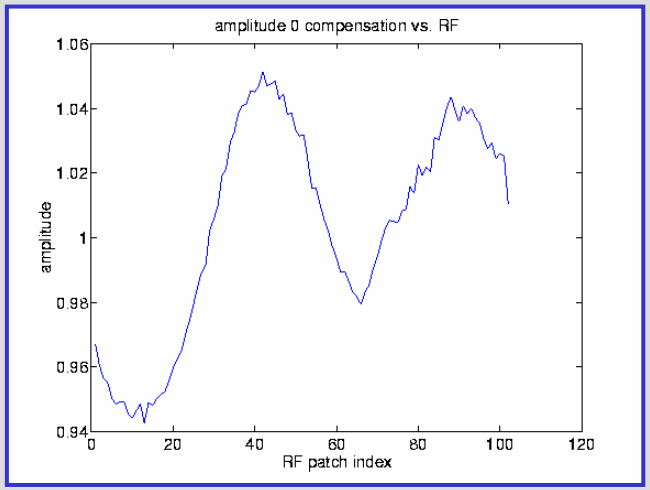
Cuts through center Doppler

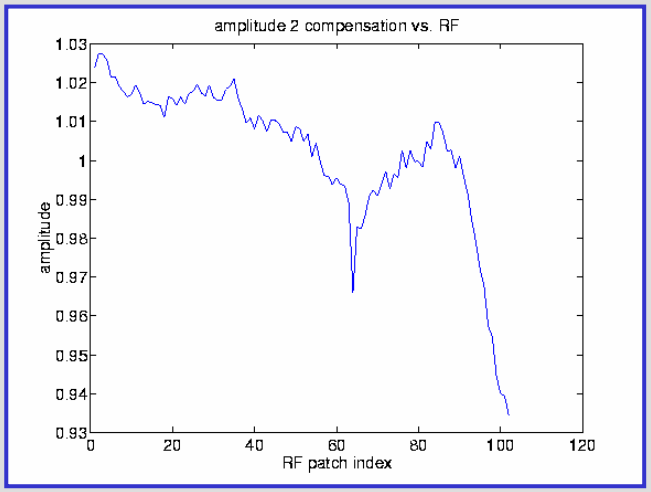
Phases in radians

Variation of Corrections RF Domain

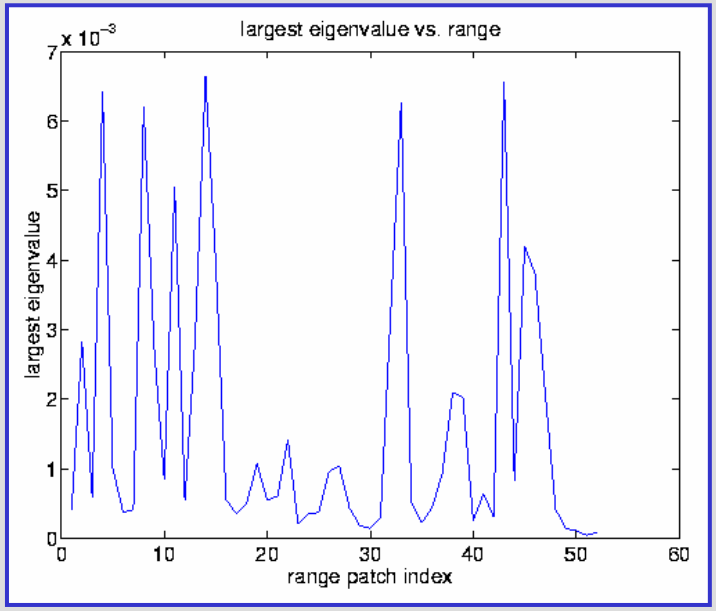


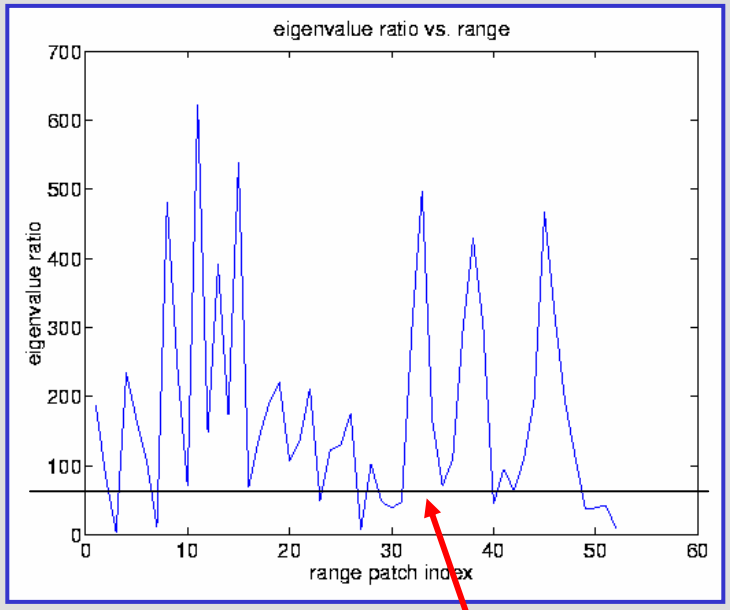






Patch Metrics



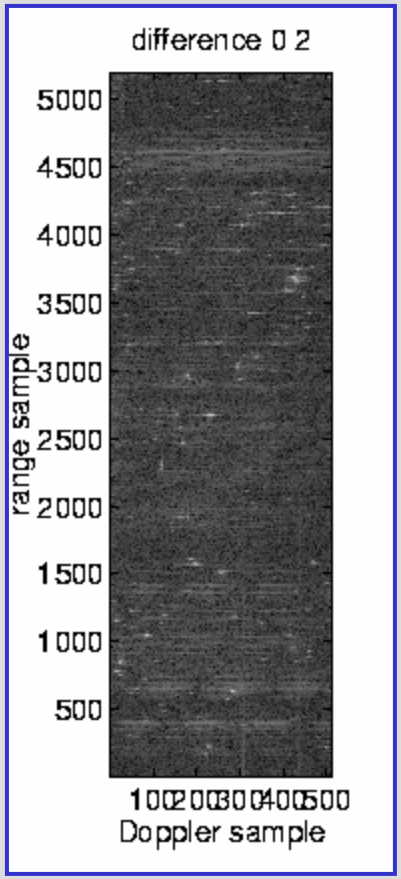


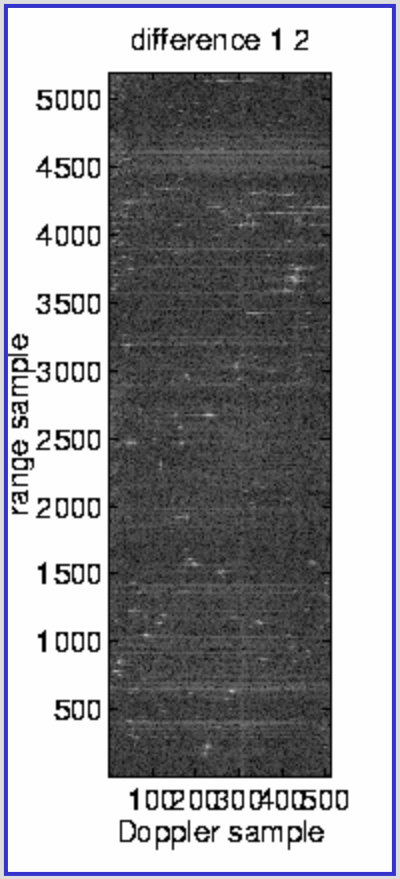
Cuts through center Doppler

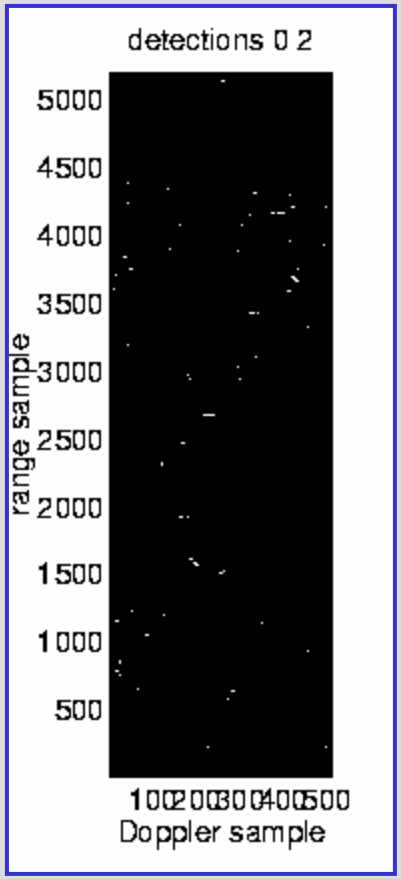
Square root of largest eigenvalues used as surface-fit weights

Rejection level = 60

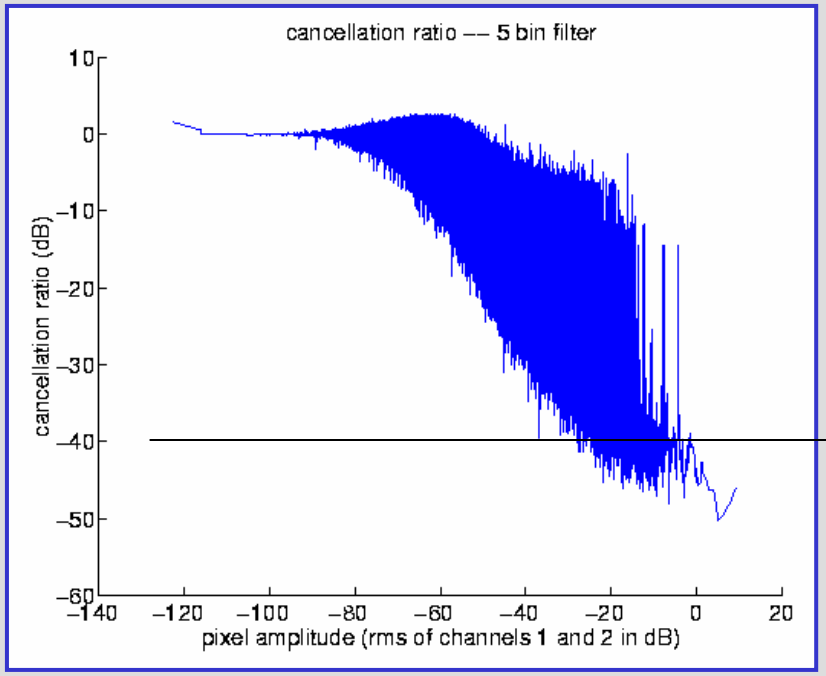
Difference and Detection Maps

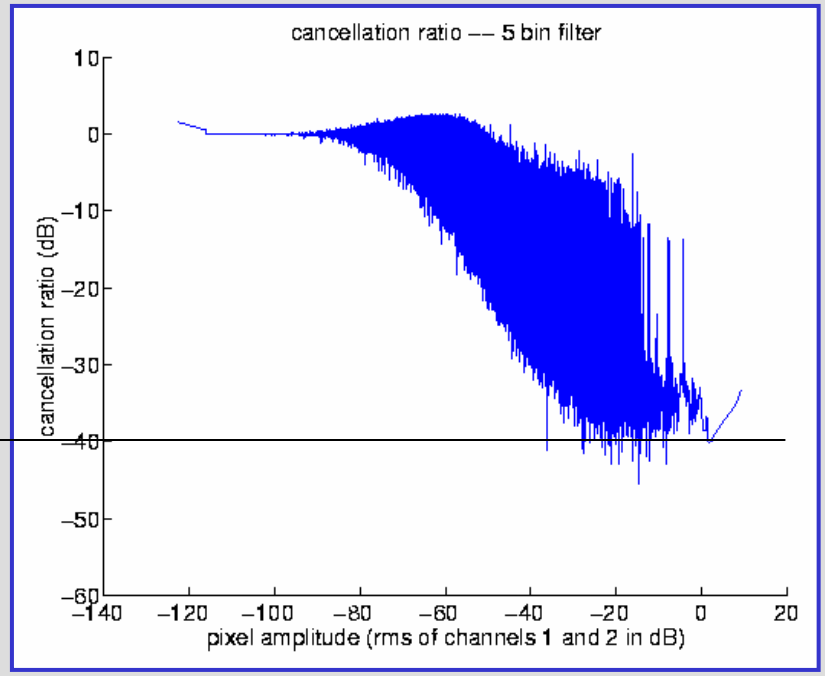






Performance Comparison
Cancellation ratio with 5-bin averaging

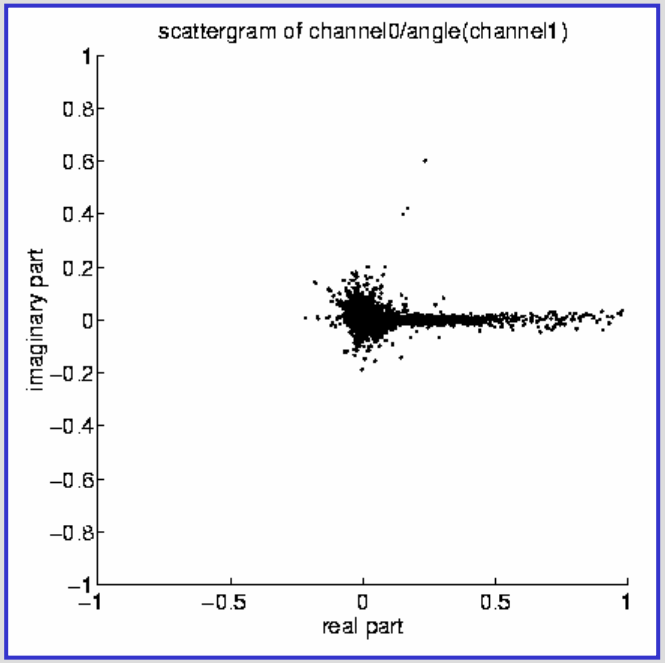




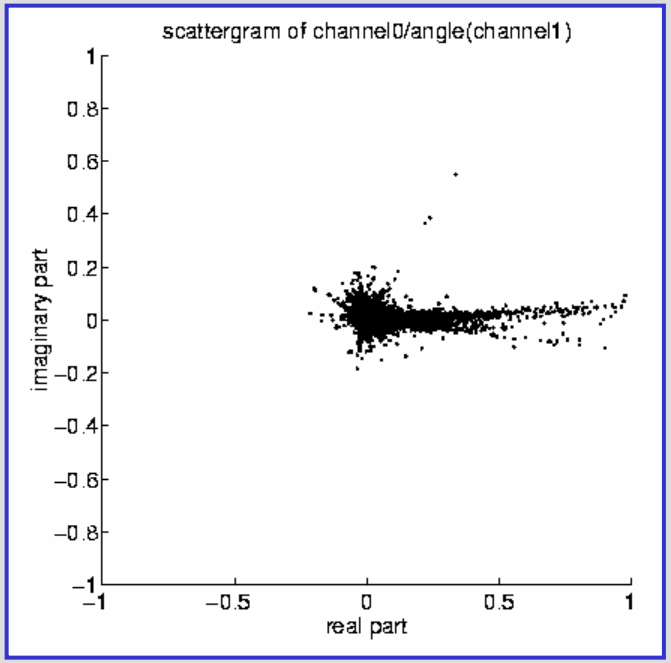
With DEM information

Without DEM information

Performance Comparison
Scattergrams of Uncancelled Data



With DEM information



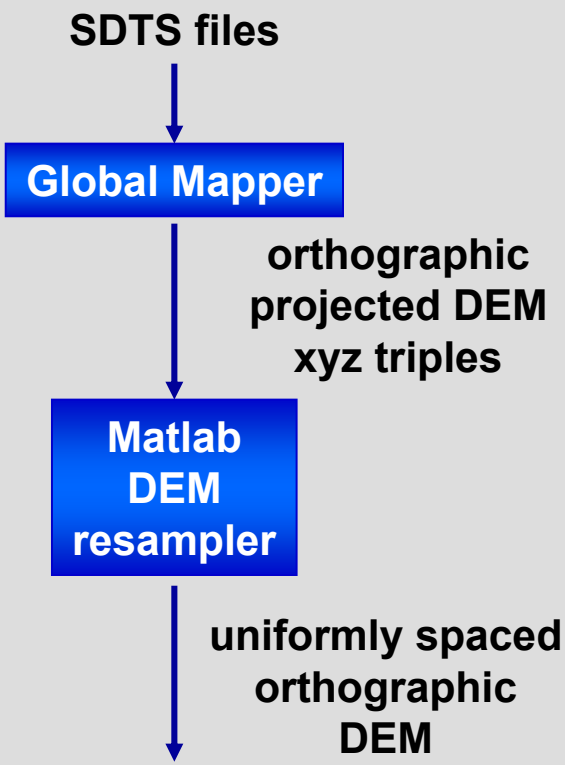
Without DEM information

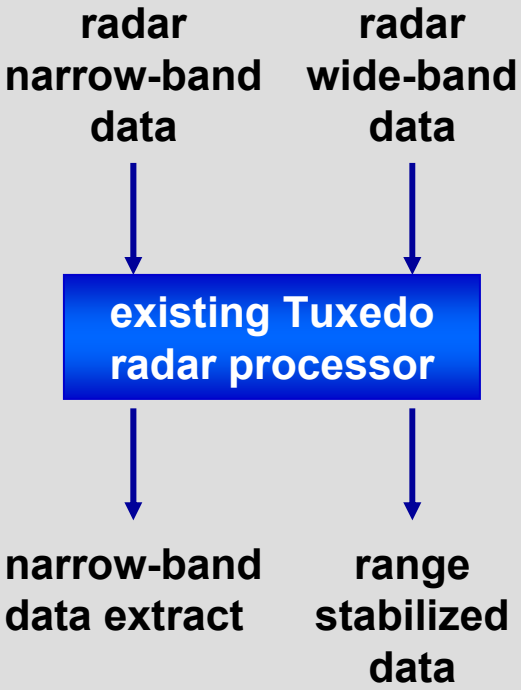
Conclusions

- Use of DEM data can improve the performance of a GMTI system
- DEM data was incorporated into processing at two different points
  - Deterministic phase compensation
  - Remove shadows from statistical analysis
- Deterministic phase compensation helped more than shadow rejection
  - Not apparent from these slides
  - Leaving out shadow rejection caused no significant change in results (rejected additional 5 out of 832 patches)
  - Shadow rejection is probably good for increasing the robustness of the process

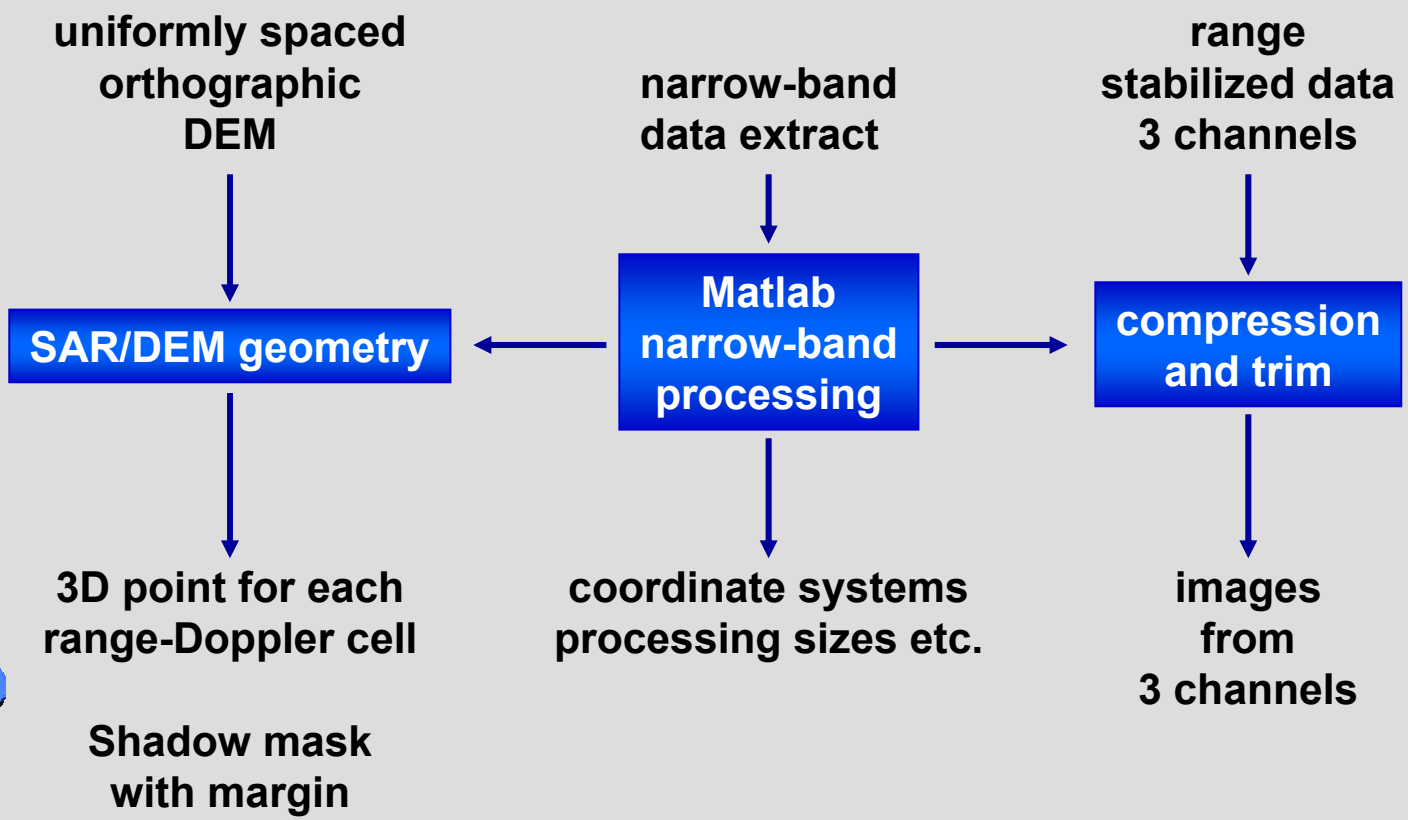
Backup Slides

Processing Steps

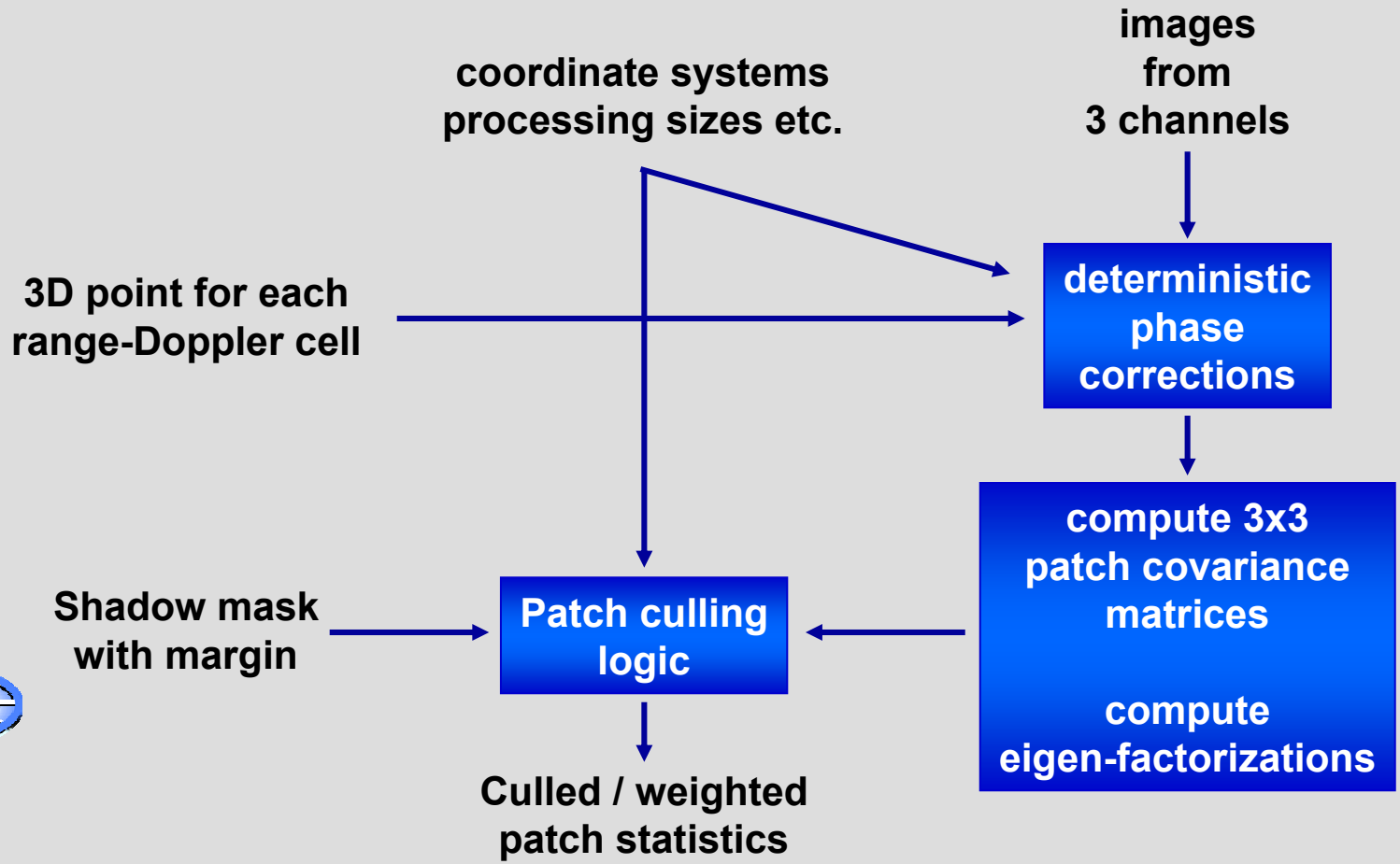




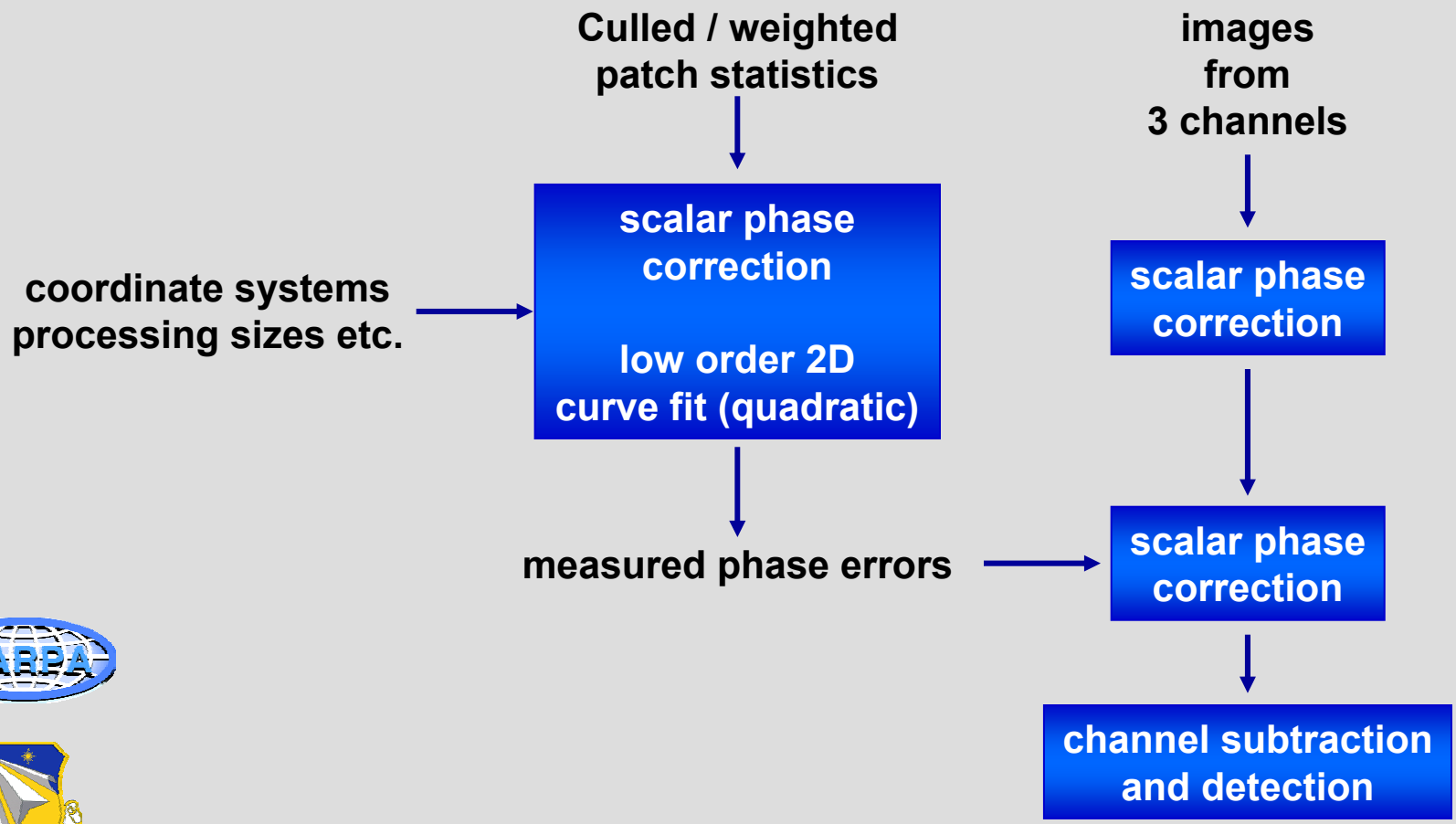
Processing Steps (2)



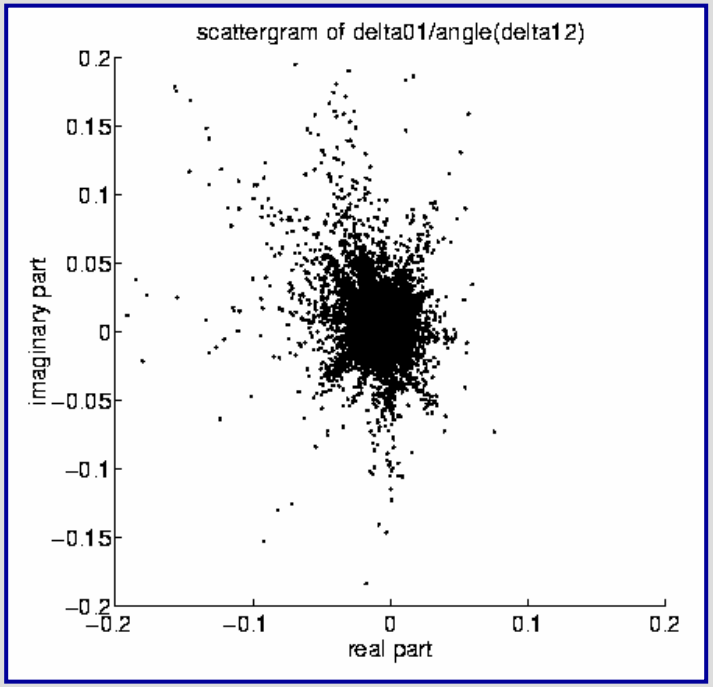
Processing Steps (3)



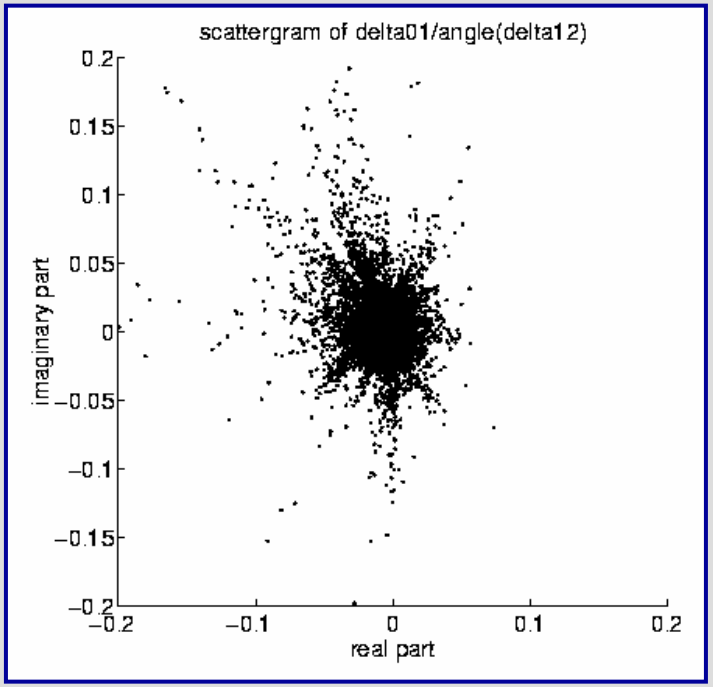
Processing Steps (4)



Performance Comparison
Scattergrams of Cancelled Data

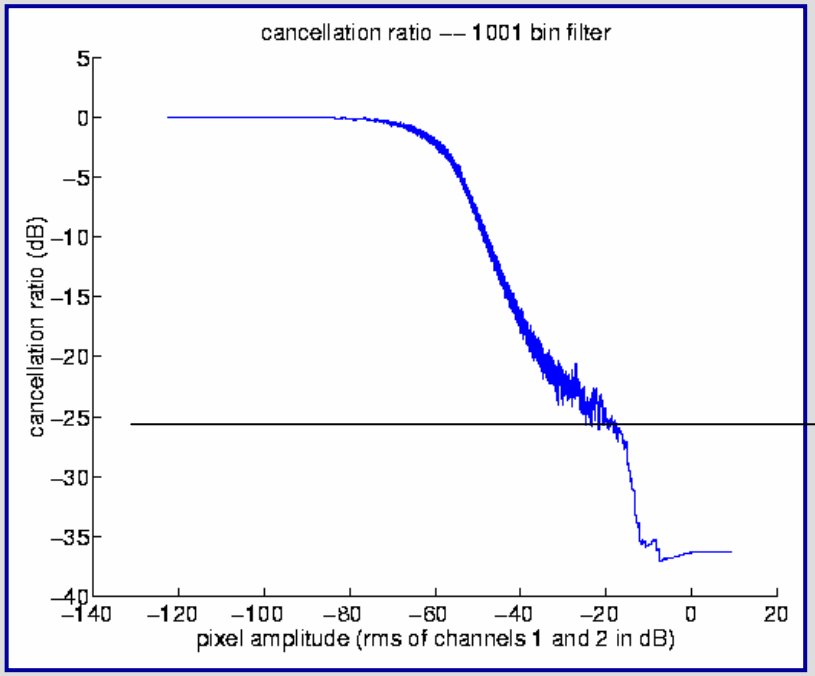


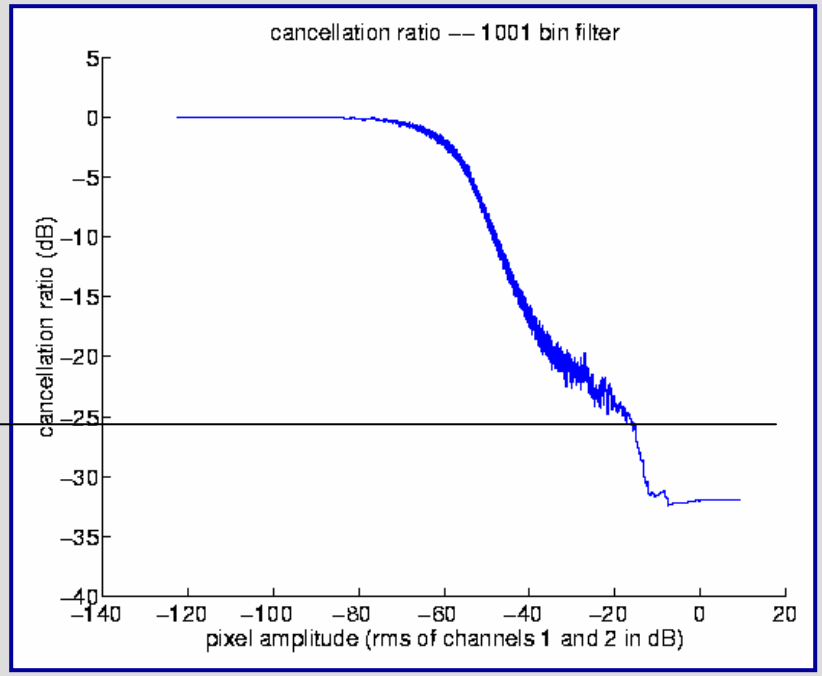
With DEM information



Without DEM information

Performance Comparison
Cancellation ratio with 1001-bin averaging





With DEM information

Without DEM information