Results of UAVSAR Airborne SAR Repeat-Pass Multi-Aperture Interferometry

Bryan Riel, Ron Muellerschoen

Jet Propulsion Laboratory, California Institute of Technology

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CEOS SAR Cal/Val Workshop

Outline

- **References of Multi Aperture Interferometry**
- **Repeat Pass Interferomery Overview**
- **Baseline Estimation**
  - **Range Offsets**
  - **Azimuth Offsets**
- **Multi Aperture Technique**
- **Finite Impulse Response Filter Implementation**
- **Controlled Example**
- **UAVSAR Results**
- **Summary**

References

- **P. Prats, J.J. Mallorqui, "Estimation of Azimuth Phase Undulations with Multisquint Processing in Airborne Interferometric SAR Images," IEEE Transactions on Geoscience and Remote Sensing, Vol. 41, no. 6, pp. 1530 - 1533, June 2003.**

- **A. Reigber, "Correction of residual motion errors in airborne SAR interferometry," IEE Electron. Lett., vol. 37, no. 17, pp. 1083-1084, Aug. 2001.**

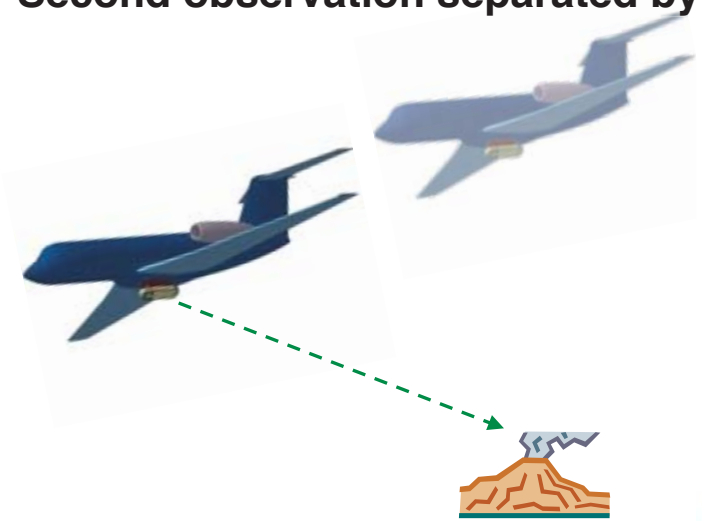
- **A. Reigber, P. Prats, J.J. Mallorqui, "*Refined estimation of time-varying baseline errors in airborne SAR interferometry,"* IEEE Geosci. Remote Sensing Lett., 3 (1), Jan. 2006.**

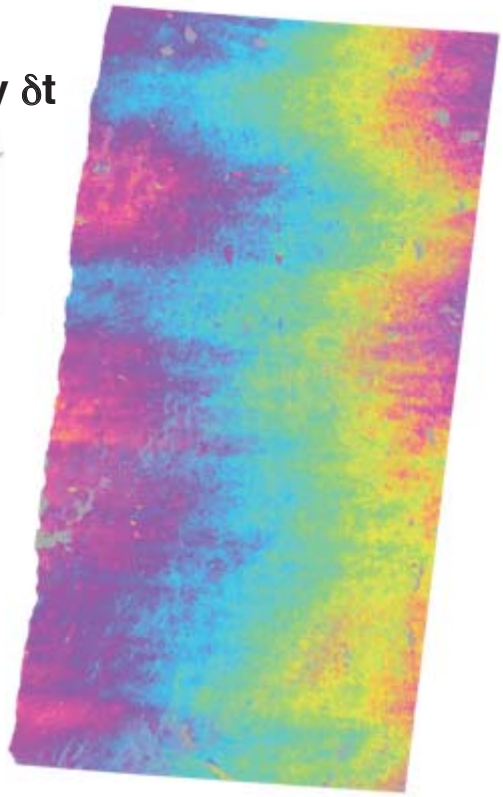
Repeat Pass Interferometry Overview

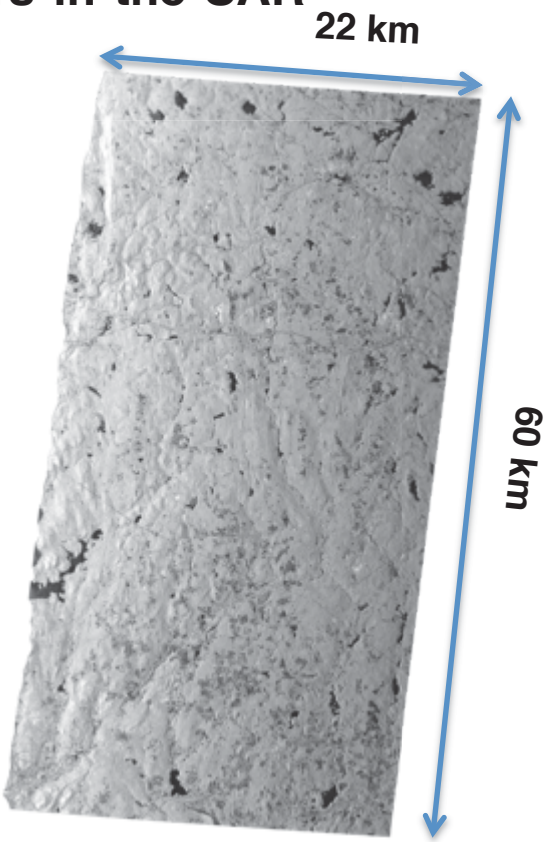
Measuring deformation using radar interferometry uses two passes separated by time intervals ranging from minutes to years to access motion along the radar line-of-sight between observations.

State-of-the-art data fusion of precise GPS positions and aircraft INU data still leaves residual phase errors in the SAR interferogram.

Second observation separated by δt







Baseline Estimation – Range Estimates

- **Range and azimuth displacements between the images of the two passes can be used to obtain baseline correction.**
  - **Two methods of displacement construction will be discussed**
    - **ampcor – Amplitude Correlation**
    - **MAI – Multi-Aperture Interferometry**
  - **Components of the baseline offsets in the cross-track (B_C) and vertical (B_H) direction can be obtained by minimizing the performance functional J_R**

$$J_R(B_C(k), B_H(k)) = \sum_{i \in k} \left\| \frac{\lambda}{4\pi} \phi_r(i) - B_C(k) L_C - B_H(k) L_H \right\|^2$$

where L_C and L_H are the components of the look vector at instance i

Baseline Estimation – Azimuth Estimates

- **Range and azimuth displacements between the images of the two passes can be used to obtain baseline convergence angles.**
  - **Baseline convergence angles tan γ and tan δ can be obtained by minimizing the performance function J_A**

$$J_A\left(\frac{dB_C(k)}{dS},\frac{dB_H(k)}{dS}\right)=\sum_{i\in k}\left\|\sin\alpha-\frac{\left\langle \overline{T}-\overline{P_1}-\overline{B(k)},M(k)\bullet\hat{n}\right\rangle}{\left|\overline{T}-\overline{P_1}-\overline{B(k)}\right|}\right\|^2$$

where α is the electronic steering angle, $\hat{n}$ is the imaging plane normal,

T and P_1 are the target and platform locations and

$$\overline{\mathrm{B(k)}}=\left(\frac{\text{azimuth spacing}}{4\pi}\phi_a(i),B_C(k),B_H(k)\right)$$

$$M(k)=\begin{pmatrix}1 & -\gamma(k) & \delta(k)\\ \gamma(k) & 1 & 0\\ -\delta(k) & 0 & 1\end{pmatrix}$$

$$\tan\gamma(k)=\frac{dB_C(k)}{dS}$$

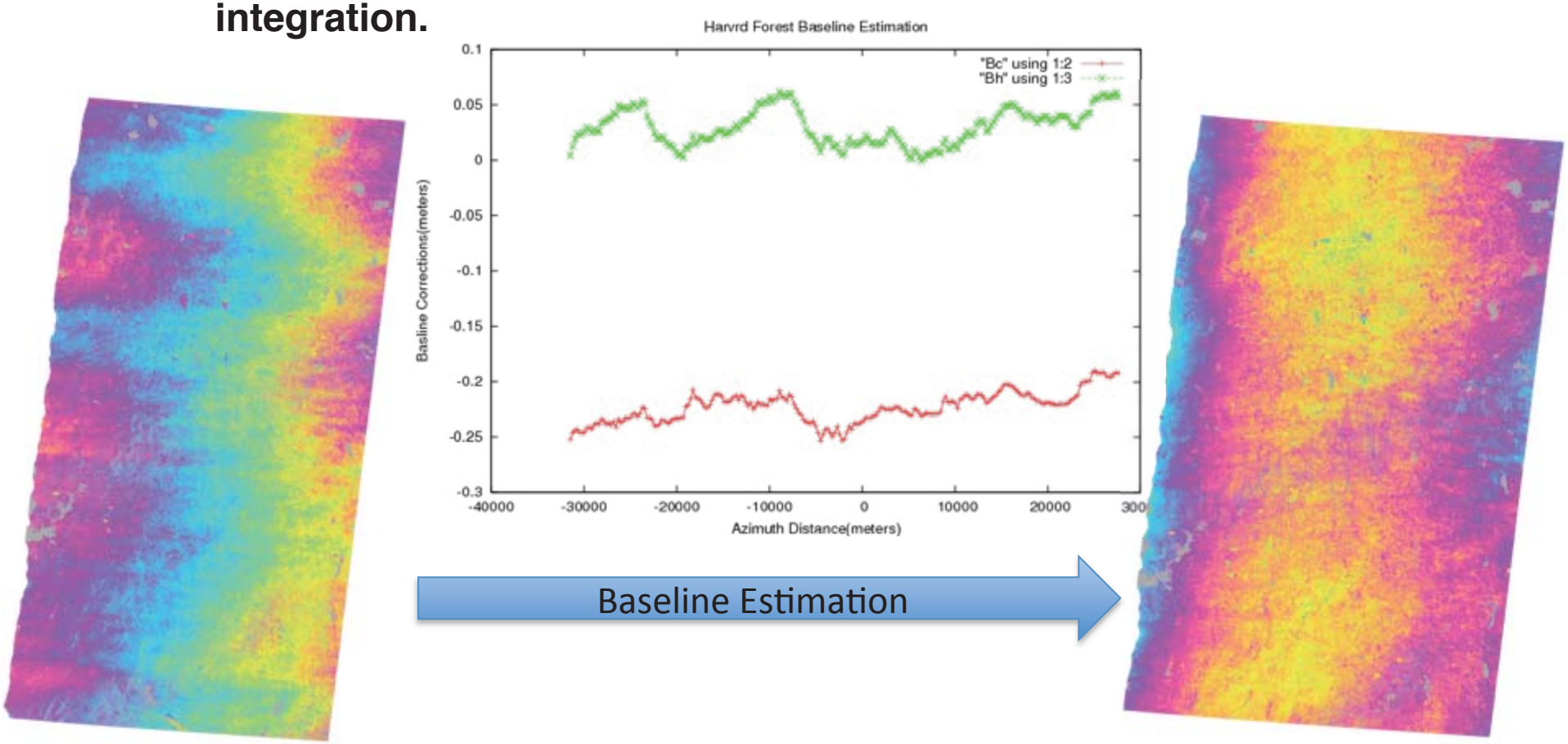
$$\tan\delta(k)=\frac{dB_H(k)}{dS}$$

NB: scaling by (azimuth spacing / 4 / π) to be explained

Ref: Hensley S., et al., "Residual Motion Estimation for UAVSAR: Implications of An Electronically Scanned Array", Radar Conference 2009, IEEE

Baseline Estimation Process

- **Integrating the baseline convergence angles tan γ and tan δ produces estimates of the baseline offsets.**
  - **Estimates of cross-track baseline offsets (B_C) and vertical baseline offsets(B_H) as determined from J_R are used as the constants of integration.**



Multi-aperture Interferometry Overview

- **Range and azimuth displacements can be generated from cross-correlation of <u>amplitude</u> images.**
  - **Sub-pixel precision can be obtained by oversampling the data during cross-correlation.**
  - **Computation is performed on small patches of the images resulting in offset measurements in both Range and Azimuth directions.**
    - **Range estimates and Azimuth estimates are correlated.**
  - **Method depends on speckle correlation--not image correlation.**
  - **"ampcor"**
- **Range and azimuth displacements can also be generated from <u>phase differences</u> in the images.**
  - **Generate forward and backward SLC's which correspond to positive and negative Doppler frequencies.**
  - **Computation is performed on large patches of data resulting in offset displacements in Azimuth direction.**
    - **Additionally requires phase unwrapping.**
    - **Range offsets derived directly from the interferogram of the scene and therefore uncorrelated with the azimuth estimates.**
      - **But also requires phase unwrapping.**
  - **Proves to work well with scenes of low contrast such as ice.**
  - **Multi-Aperture Interferometry or MAI**

MAI Technique – Geometry

Sub-aperture processing produces forward and backward looking interferograms:

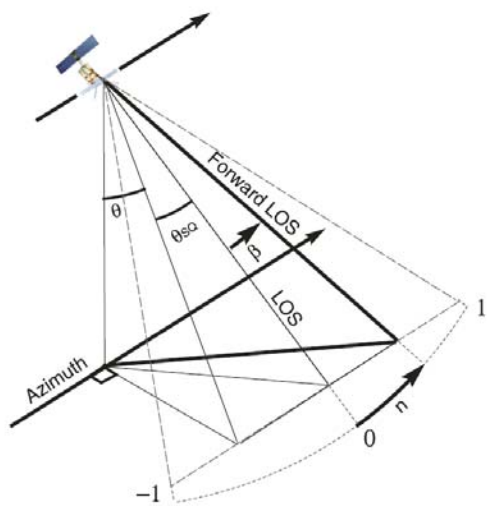


Figure: MAI imaging geometry. Bechor, 2006

$$\Phi_{forward} = -\frac{4\pi}{\lambda}\Delta S \sin(\theta_{sq} + \beta)$$

$$\Phi_{backward} = -\frac{4\pi}{\lambda}\Delta S \sin(\theta_{sq} - \beta)$$

$$\Phi_{MAI} = \Phi_{forward} - \Phi_{backward} = -\frac{8\pi}{\lambda}\Delta S \cos\theta_{sq} \sin\beta$$

where β is the fraction of the full beamwidth α and ΔS is a displacement in the along track

For N subapertures:

$\beta = \frac{\alpha}{2N}$ and $\alpha = \frac{\lambda}{L_a}$ and L_a is the effective antenna length

$\therefore \quad \Delta S = -\Phi_{MAI}\frac{2NL_a}{8\pi}$ for small θ_{sq} and small β

For a azimuth resolution of 3 meters, L_a is 6 meters, and with 2 sub-apertures:

$\Delta S = -\Phi_{MAI} * (3 / \pi)$ meters

$\phi_a(i) = (4*\pi\, \Delta S) / (\text{azimuth spacing})$

Ref: Bechor and Zebker, "Measuring two-dimensional movements using a single InSAR pair", GRL, Vol. 33, 2006

MAI Technique – Two Possible Approaches

- **4 additional images are required**
  - **1.) forward looking image of pass 1, call it S_1^f**
  - **2.) backward looking image of pass 1, call it S_1^b**
  - **3.) forward looking image of pass 2, call it S_2^f**
  - **4.) backward looking image of pass 2, call it S_2^b**

$$\Phi_{MAI} = \arg\left\{\left(S_1^f S_2^{f*}\right)\left(S_1^b S_2^{b*}\right)^*\right\}$$

- **Instead, filter the focused images in the azimuth direction**
  - **Construct a FIR filter with pass band equal to the width of a single sub-aperture (α/N)**
  - **Shift in the frequency domain to pass either the positive or negative frequencies associated with the Doppler centroid**
  - **NB: Each filter will be range dependent due to look angle variation over the range swath**

MAI Technique – convolve SLC with FIR filter

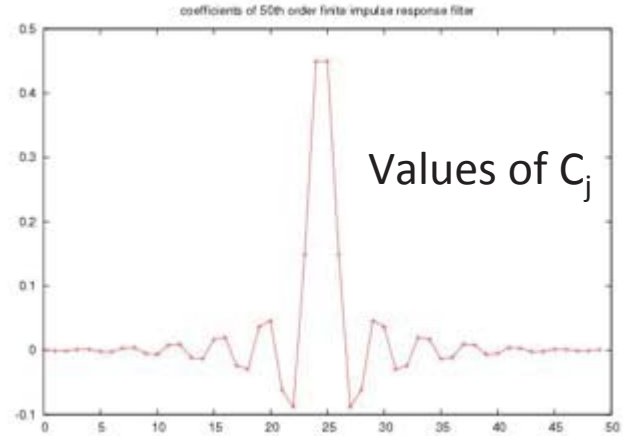
- **In time domain, construct forward looking filter h^f and backward looking filter h^b**

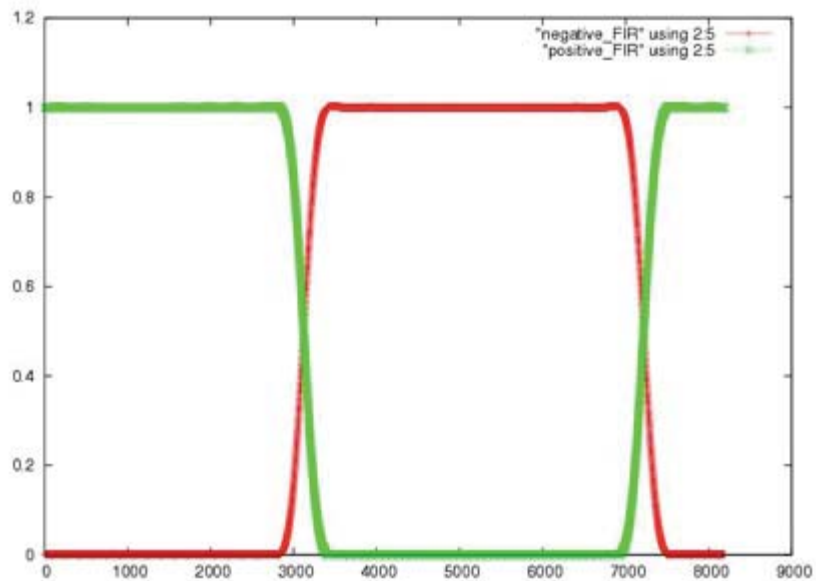
$$h^f(j;r) = C_j e^{i4\pi j(+0.25)} e^{i4\pi j f_0}$$

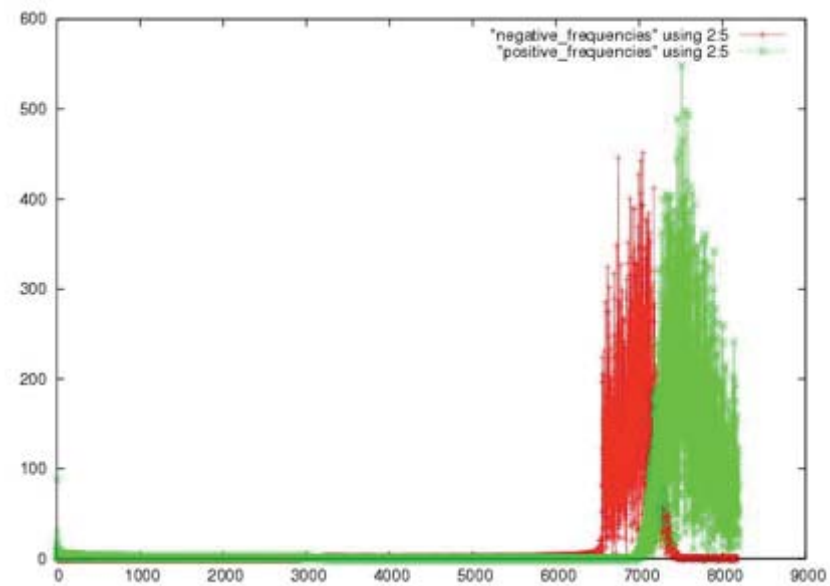
$$h^b(j;r) = C_j e^{i4\pi j(-0.25)} e^{i4\pi j f_0}$$

$$\text{where } f_0(r) = \frac{2(\text{azimuth spacing})\mathrm{L}_S(r)}{\lambda}$$

and $L_S(r)$ is the component of the look vector in the along track direction

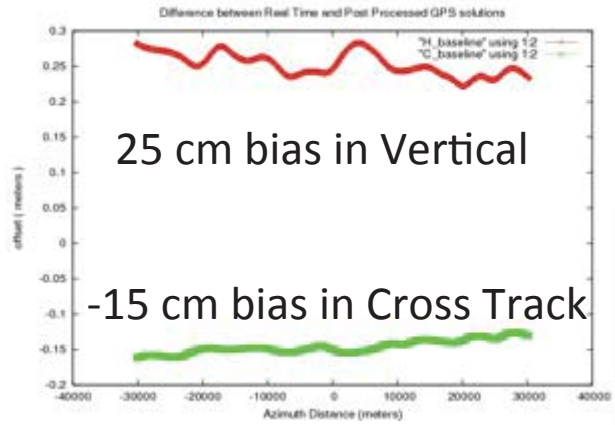




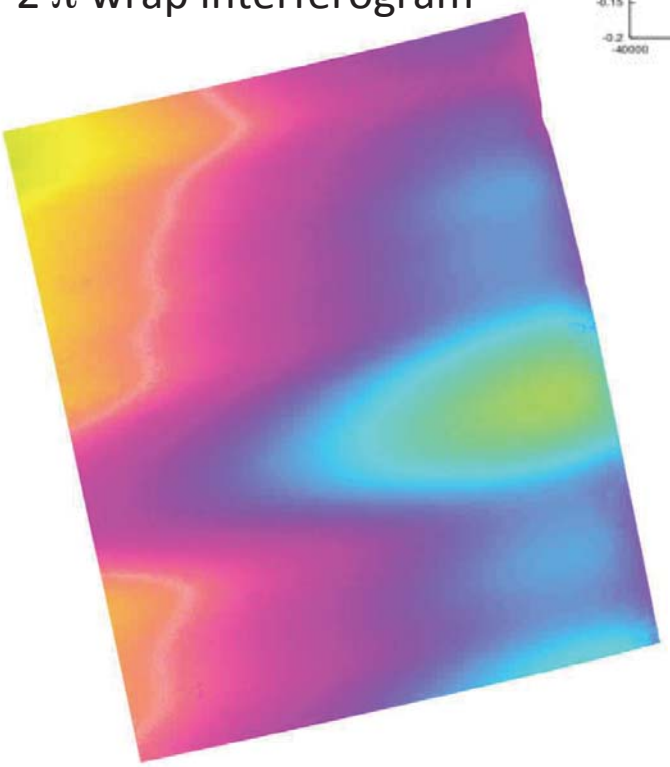


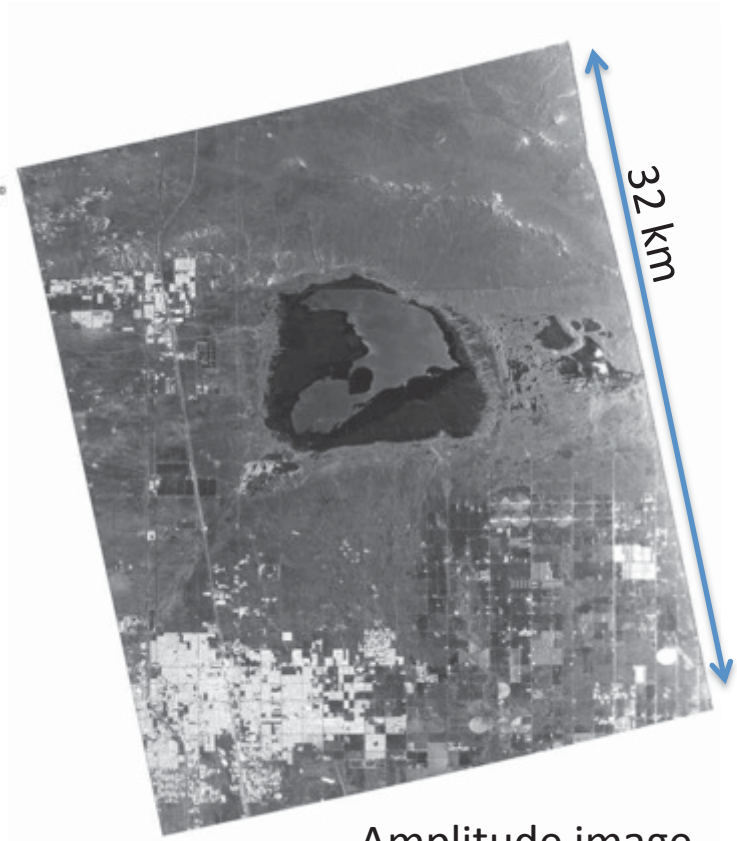
Controlled Example

- **Use same data in repeat pass mode –but perturb platform motion.**
  use real-time vs. post-processed GPS data



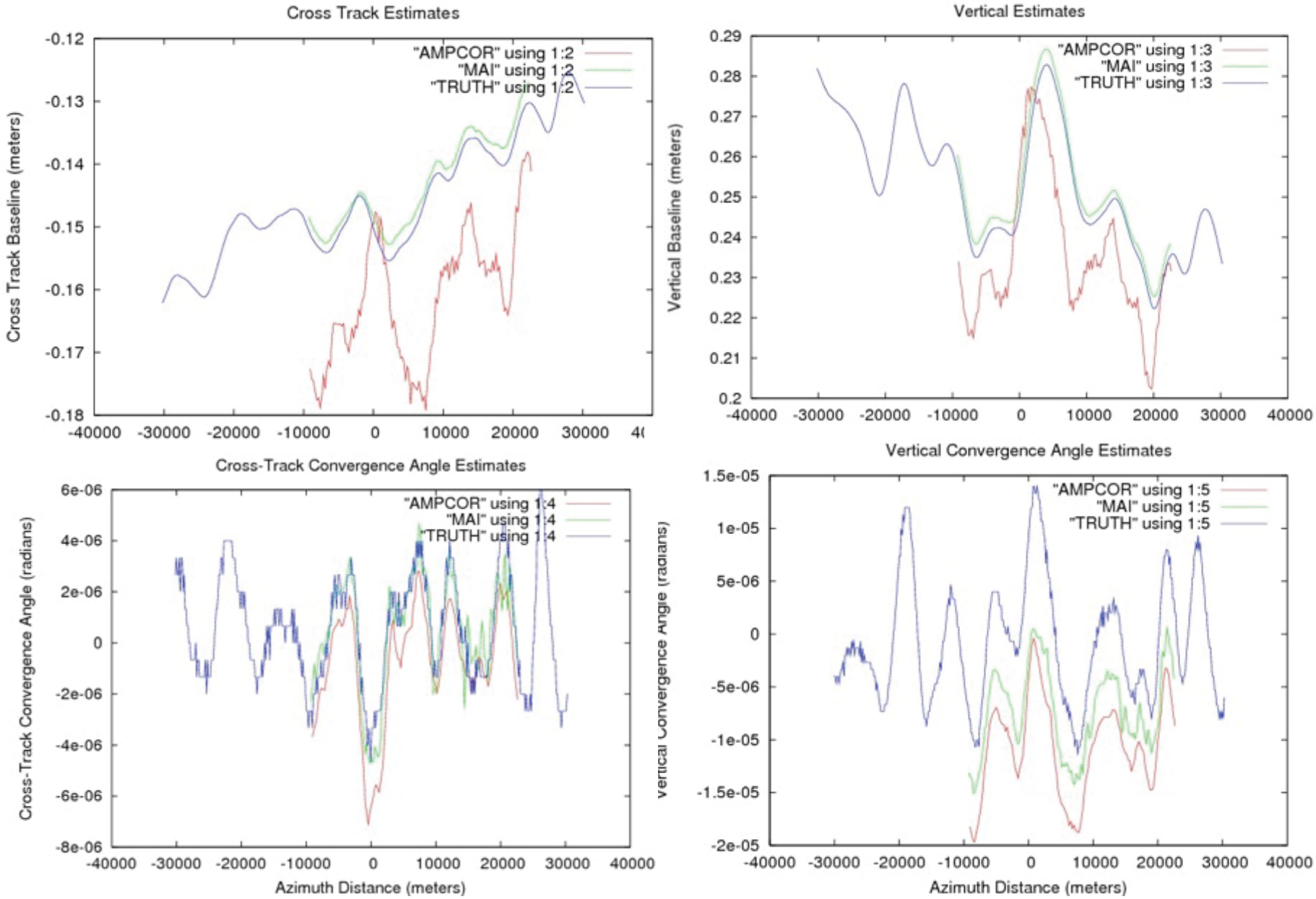
2 π wrap interferogram





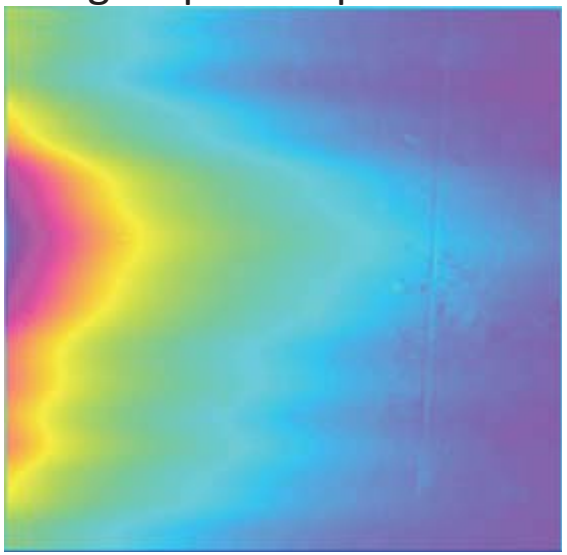
Amplitude image

Baseline Estimates from Minimizing J_R and J_A

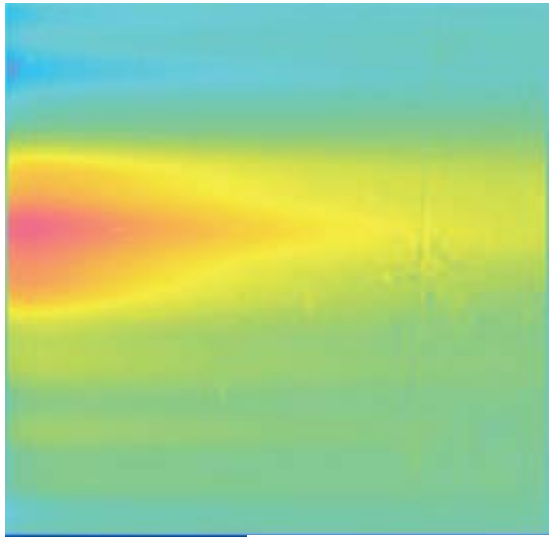


Interferograms from Baseline Estimates…

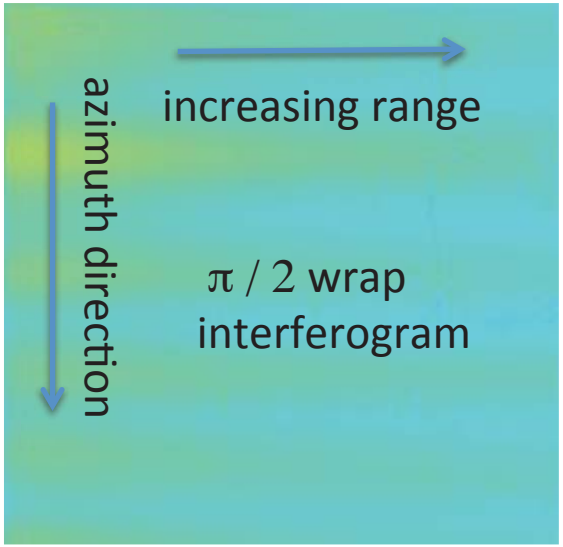
using ampcor displacements

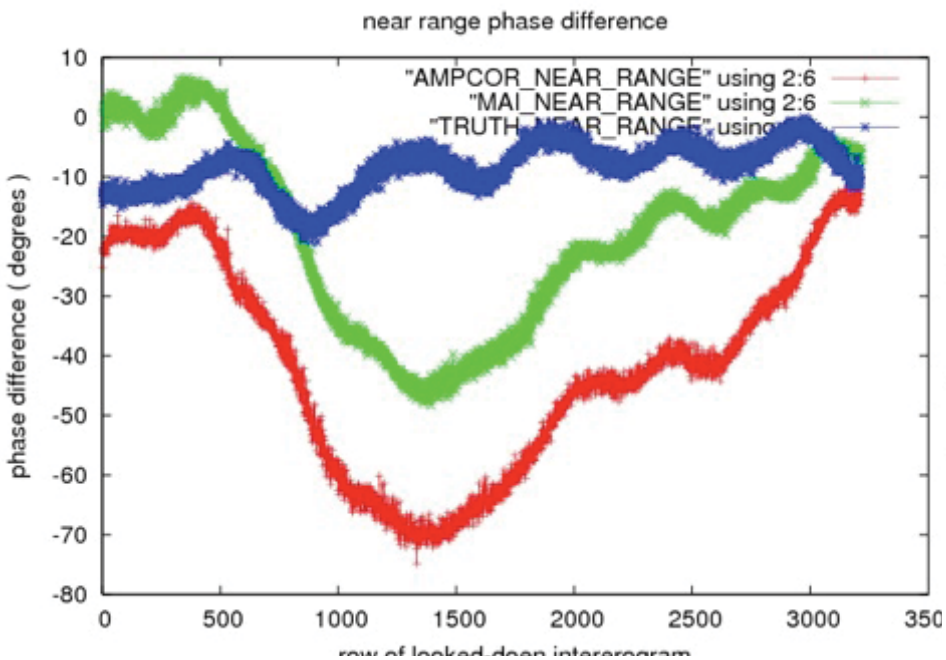


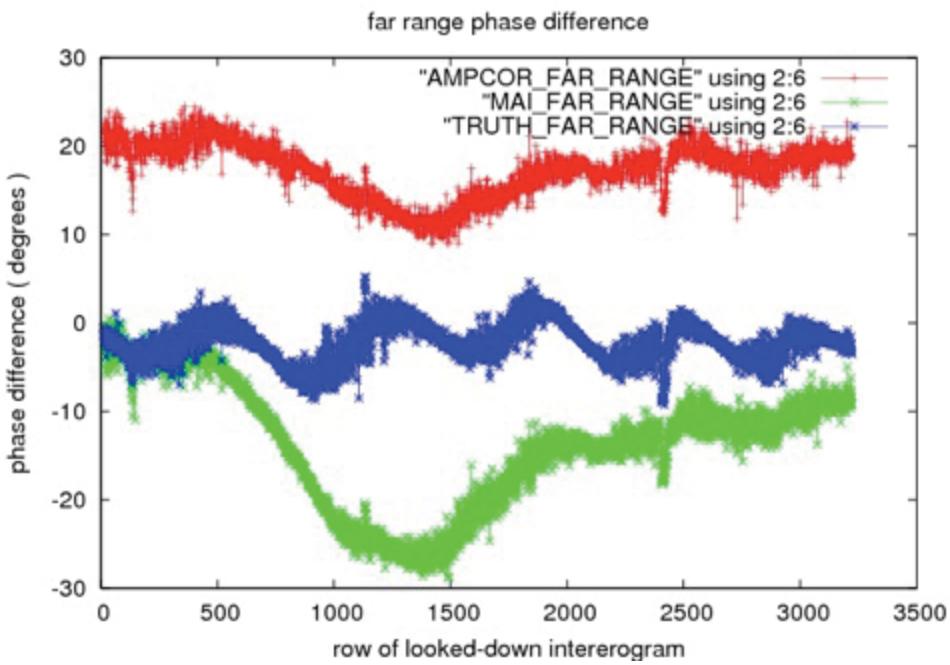
using MAI displacements



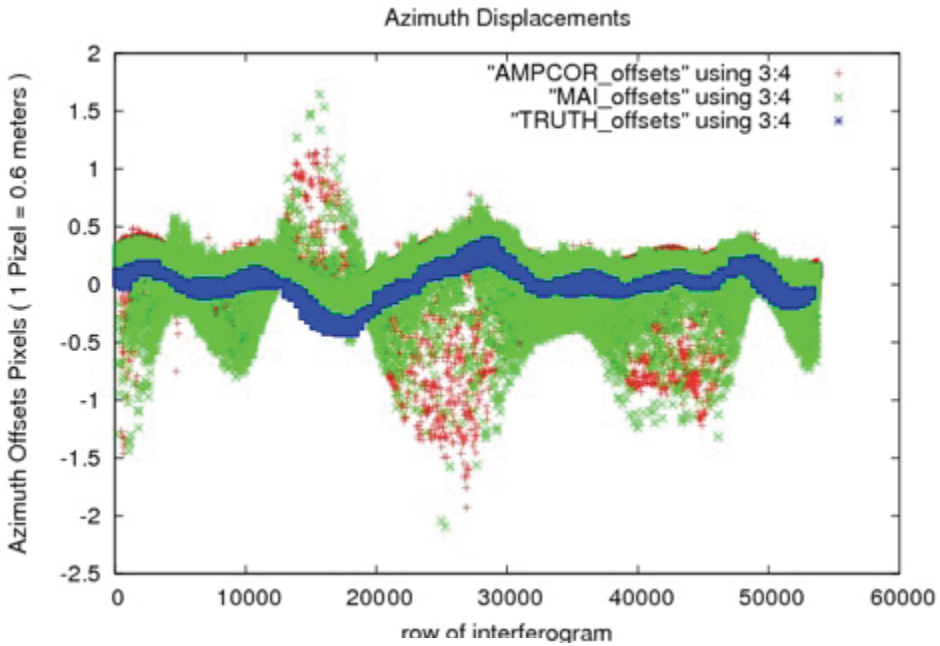
using truth displacements

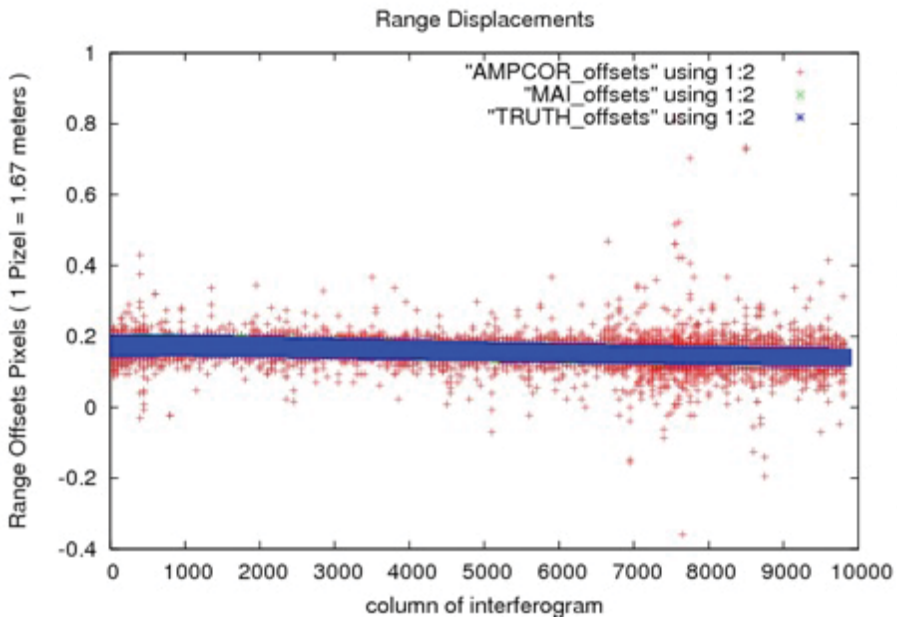


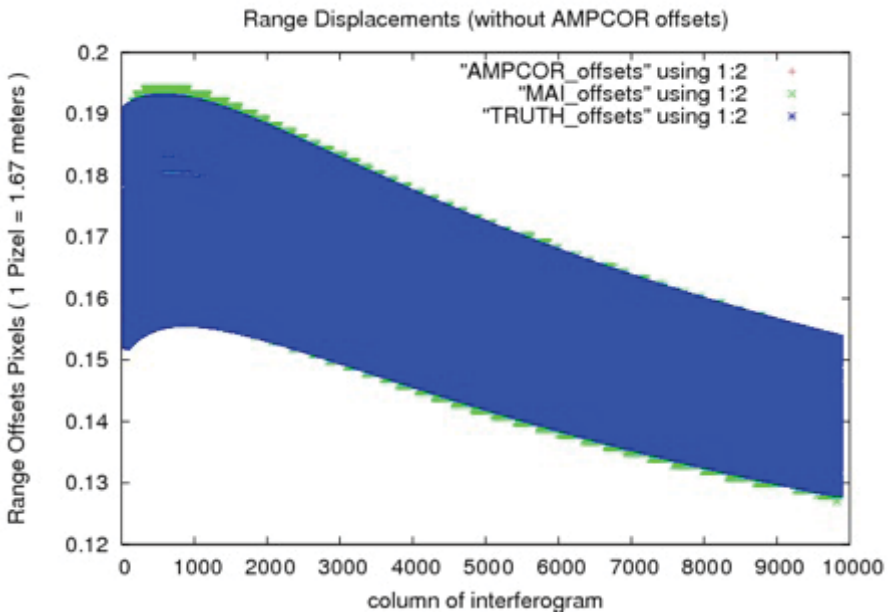




Range and Azimuth Displacements



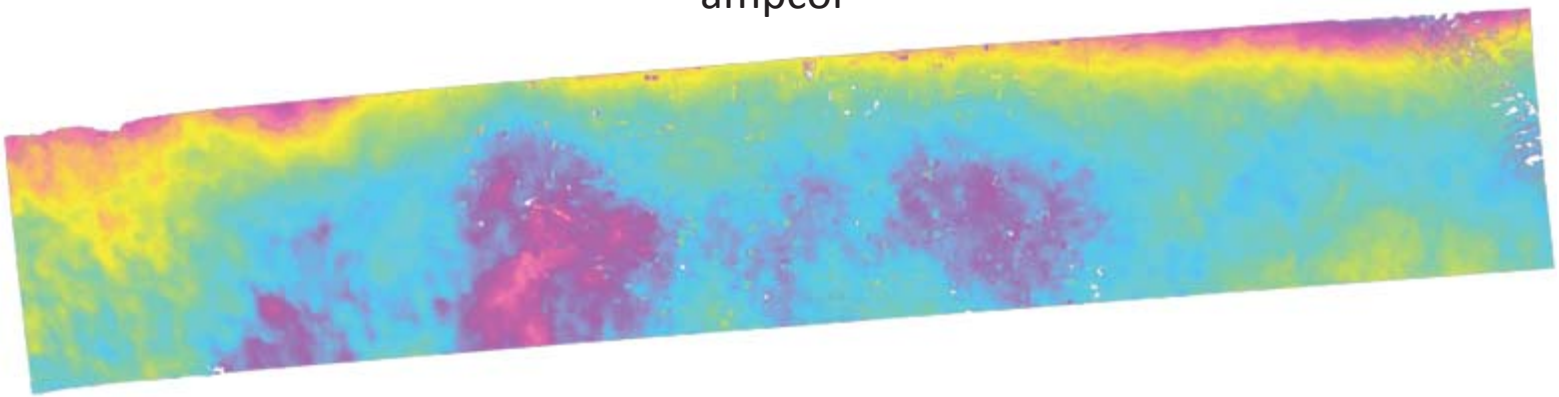




Examples—processing sample RPI cases with MAI

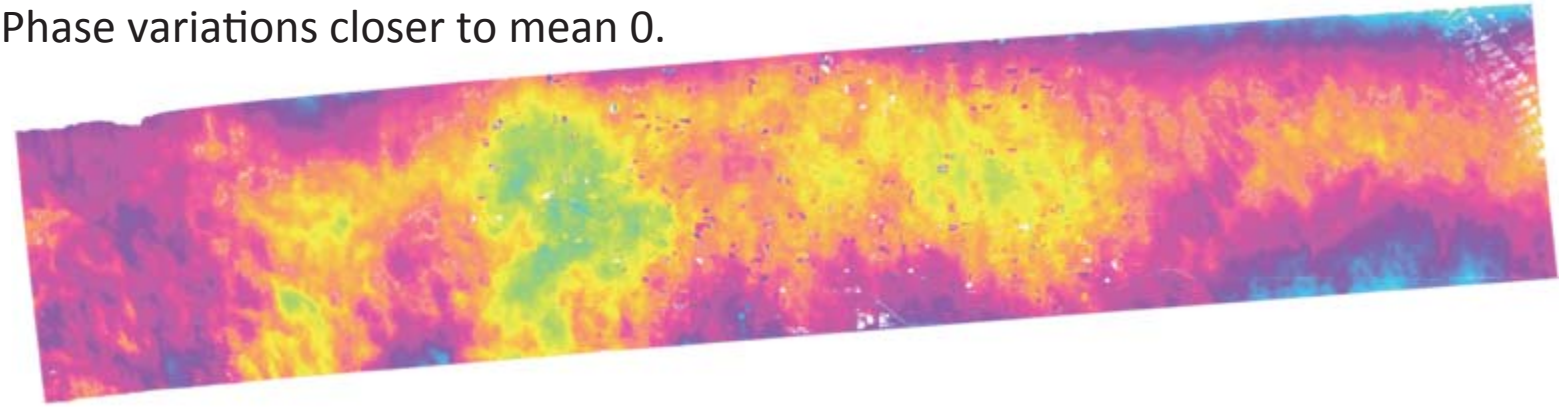
SanAnd_26501_10027-001_10028-000_0001d_s01_L090HH_02
(10027: 2 deg avg yaw, 10028: 4 deg avg yaw)

ampcor



MAI

Near range fringing appears to be reduced.
Phase variations closer to mean 0.

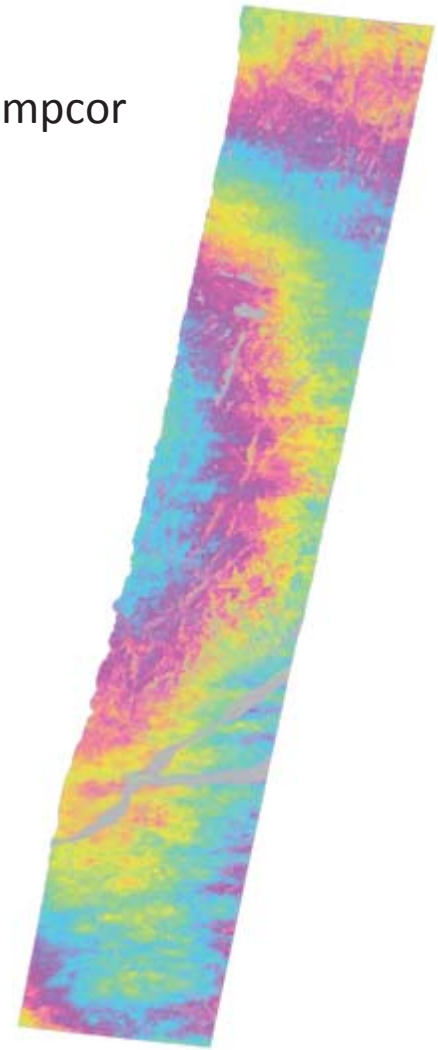


Examples—processing sample RPI cases with MAI

Laurnt_18801_09054-005_09056-005_0002d_s01_L090HH_01

(09054: 7 deg avg yaw, 09056: 4 deg avg yaw)

ampcor



MAI

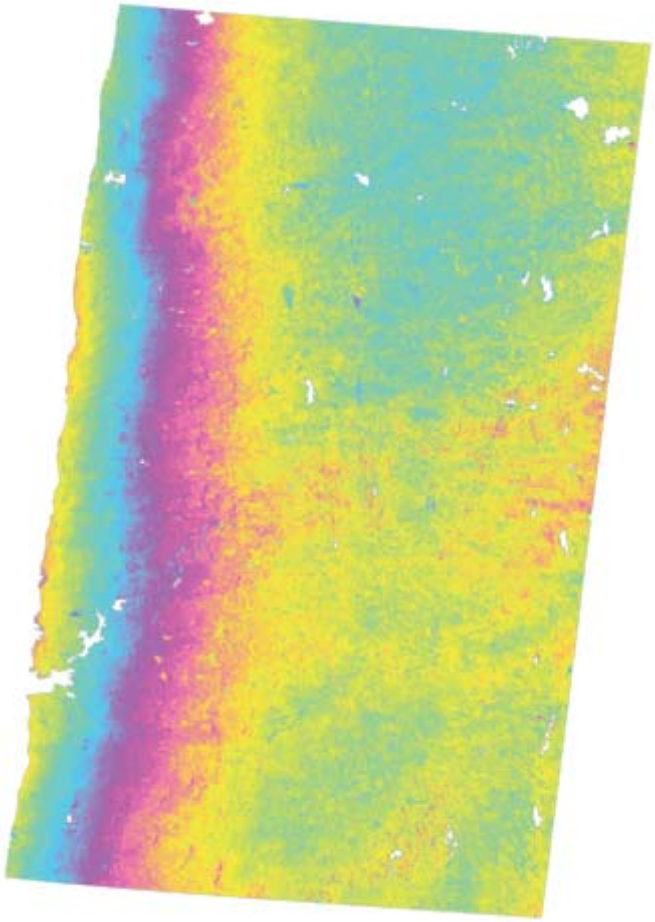
Smaller Residual Phase

Examples—processing sample RPI cases with MAI

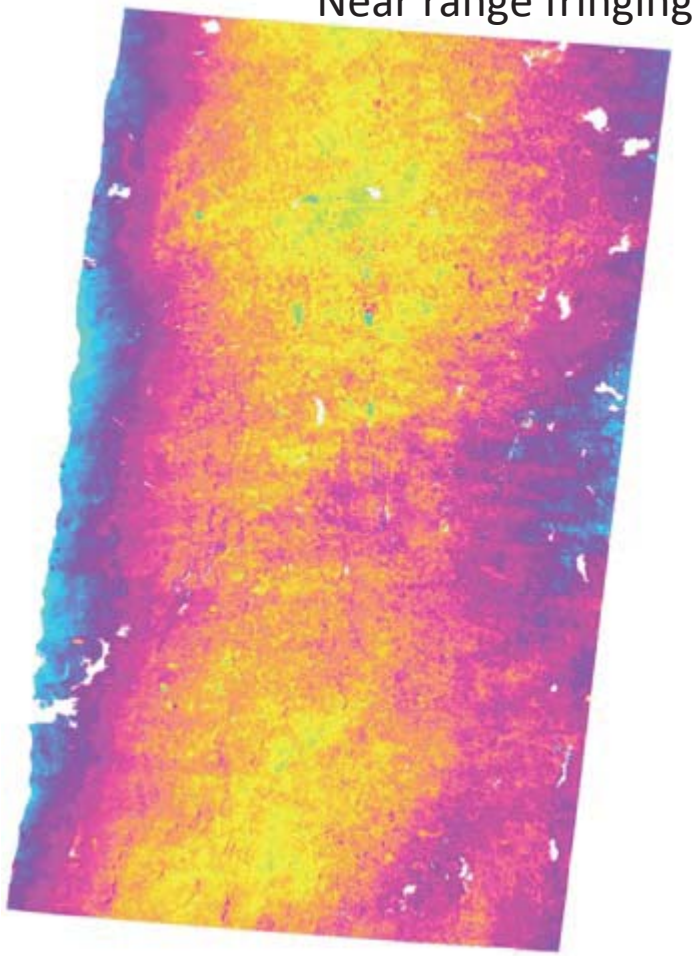
harvrd_18505_09060-005_09065-004_0004d_s01_L090HH_01

(09060: avg -1deg yaw, 09065: avg 9deg high yaw)

ampcor



MAI
Near range fringing reduced



Examples—processing sample RPI cases with MAI

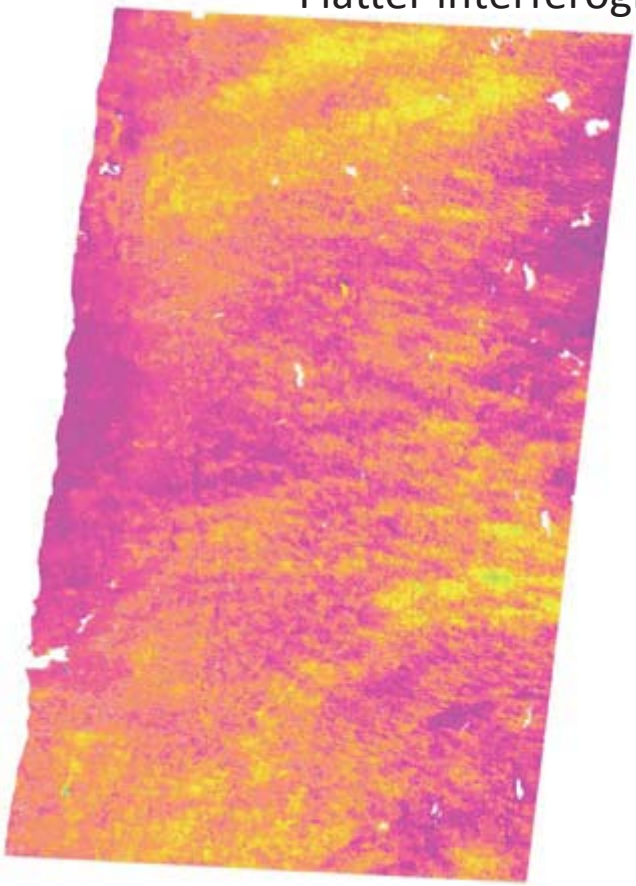
harvrd_18501_09063-002_09065-006_0001d_s01_L090HH_01

(09063: -0.6 avg yaw, 09065: -0.5 avg yaw)

ampcor

MAI

Flatter interferogram



Summary

- **Demonstrated that Multi-Aperture Interferometry can produce azimuth displacements comparable to amplitude correlation displacements.**
  - **Method has not been adopted for production of repeat-pass interferometry at JPL.**

- **Possible advantage of MAI is that the range displacements are uncorrelated from the azimuth estimates.**
  - **Range offsets come directly from unwrapped interferogram.**

- **Additional sub-banding techniques are also being investigated for improved residual motion recovery.**