Small Baseline Time Series Method in InSAR

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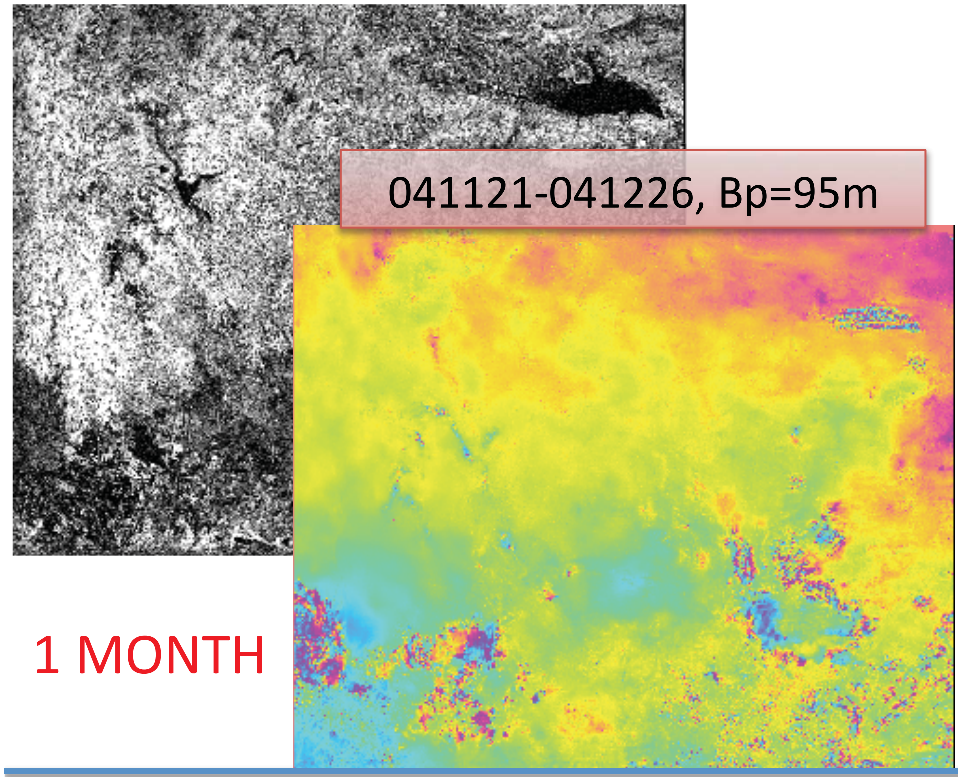
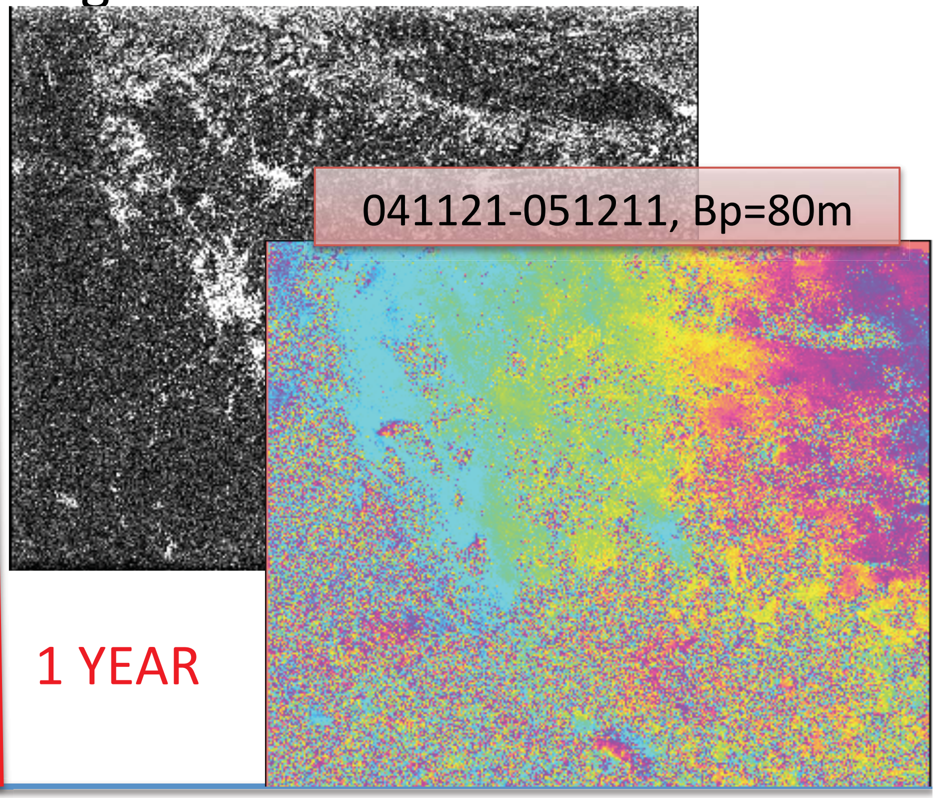
SBAS - Motivations

- Coherence is a key factor for InSAR
- Coherence mainly depends on temporal and perpendicular baselines given the same wavelength





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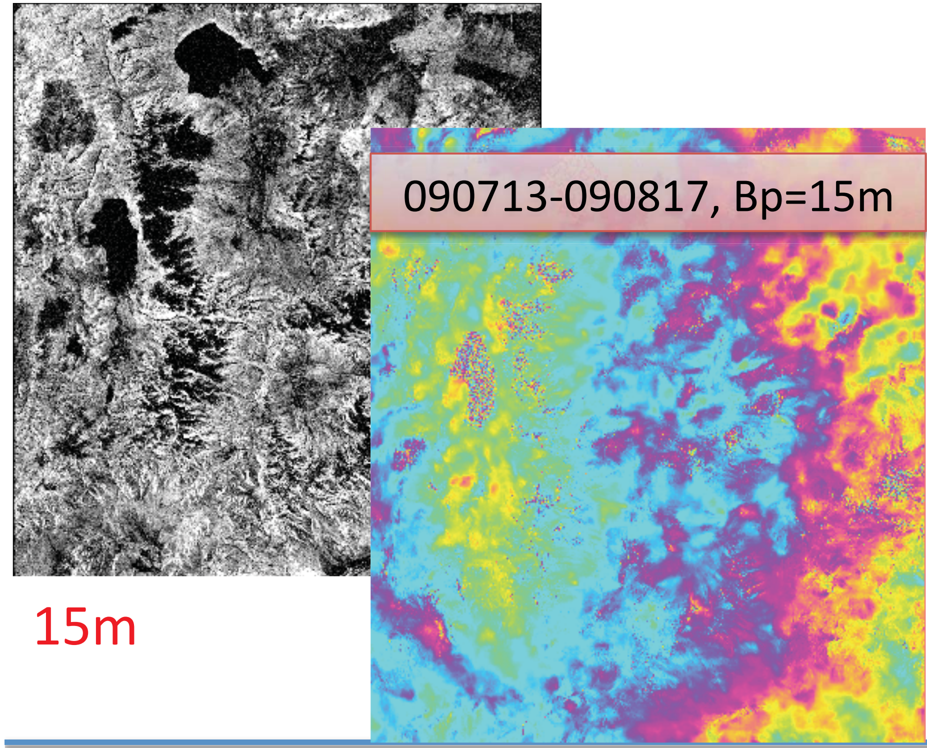
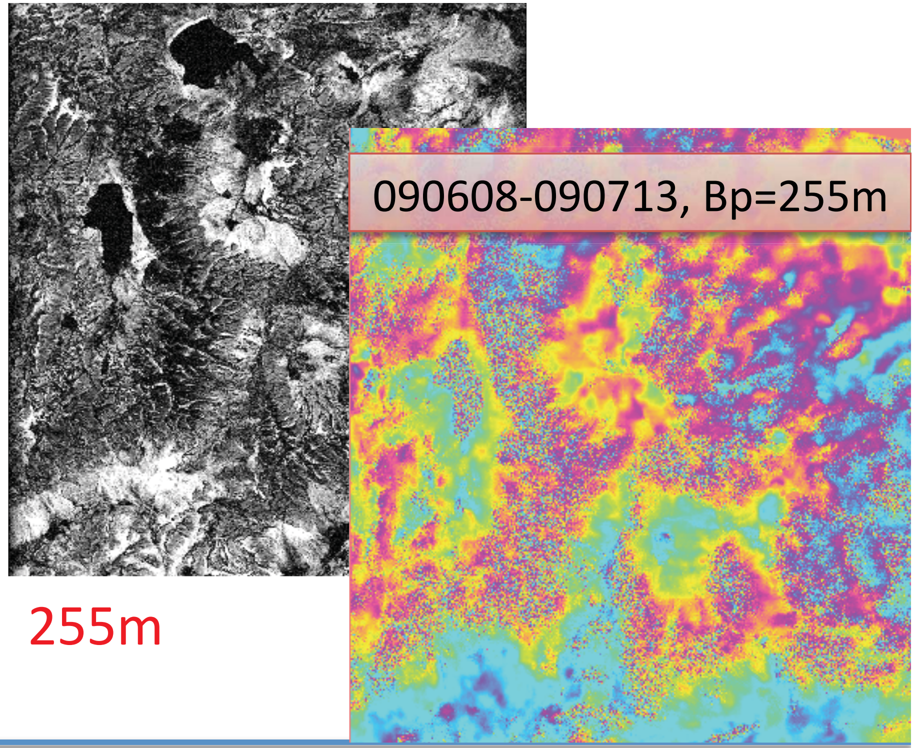
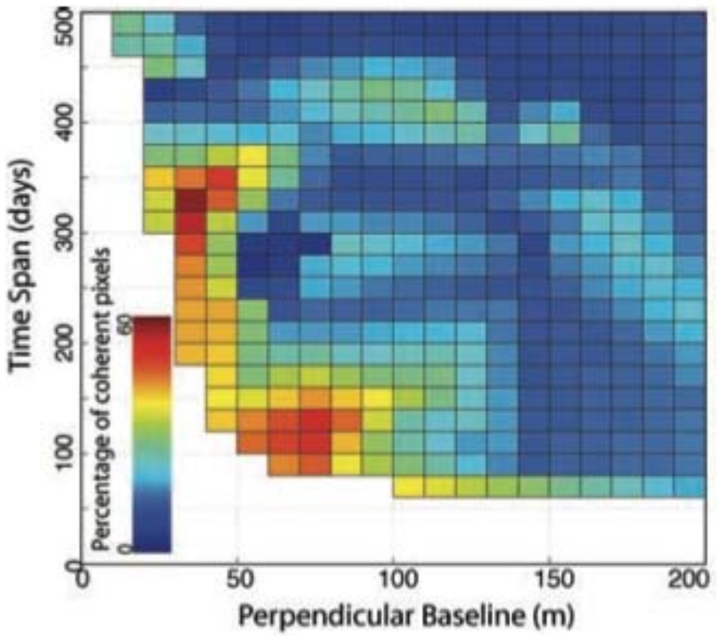


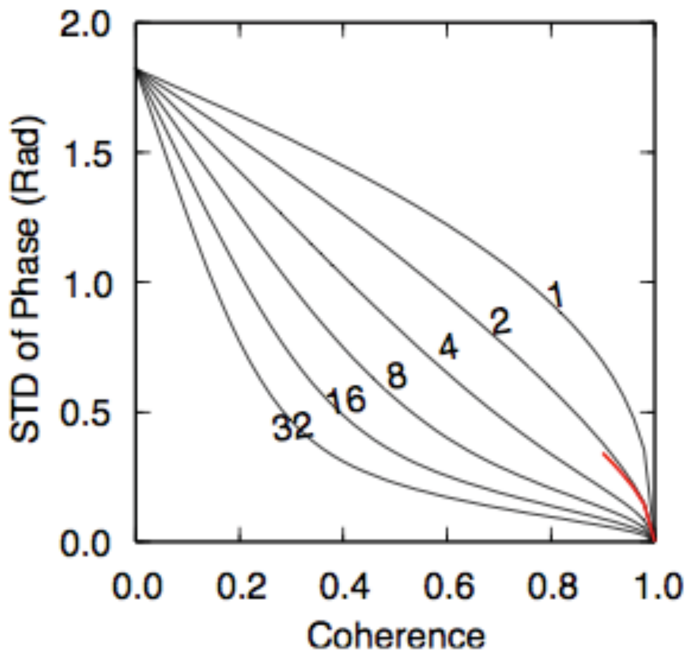


SBAS - Motivations

- Coherence is a key factor for InSAR
- Coherence mainly depends on temporal and perpendicular baselines given the same wavelength
- Smaller baseline gives higher coherence and more accurate phase



Biggs et al., 2007



$$\sigma_\phi^2 = \frac{1-\gamma^2}{2N\gamma^2}$$

Rodriguez and Martin (1992)

SBAS - Essentials

- Forming differential interferograms using small temporal and spatial baseline subsets
- Taking use of all coherent pixels (temporal vs persistent)
- Mitigating artifacts (e.g. atmosphere, orbit, DEM errors etc) by time series analysis (similar to PSInSAR)
- Usually starting from, but are not limited to, unwrapped interferograms

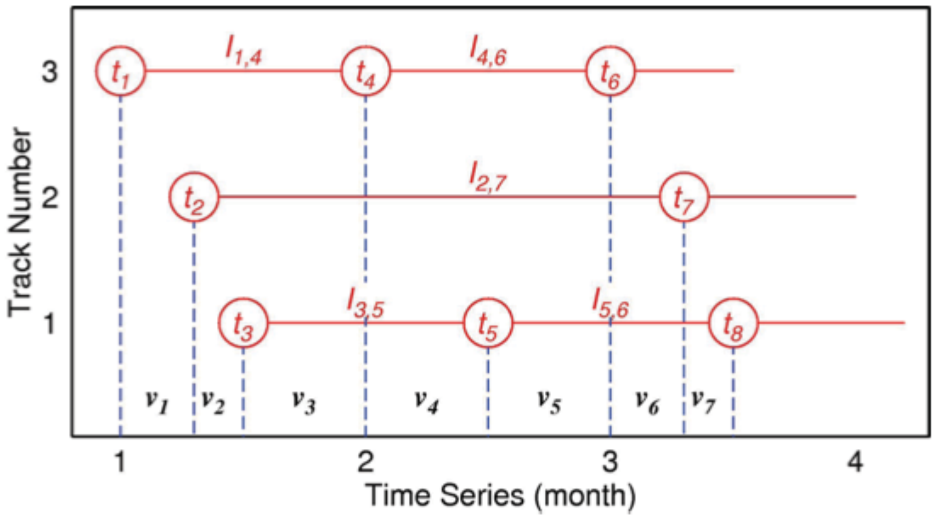
SBAS - Methodology

- System of equations

$$\mathbf{Gm} = \mathbf{d},$$

$$\mathbf{G}_{i,j} = [\underbrace{\mathbf{0}}_{i-1} \underbrace{\Delta t_i \cdots \Delta t_{j-1}}_{j-i} \underbrace{\mathbf{0}}_{n-j}],$$

$$\mathbf{m} = [v_1 \quad v_2 \quad \cdots \quad v_{n-1}]^T,$$



where $\Delta t_i = t_{i+1} - t_i$, t is the acquisition date, n is the total number of the acquisitions, $\mathbf{0}$ is a zero vector indicating acquisitions which are not covered by the interferogram $I_{i,j}$, v_i is the velocity of the ith time-span. Here, the acquisitions must be chronologically ordered

SBAS - Methodology

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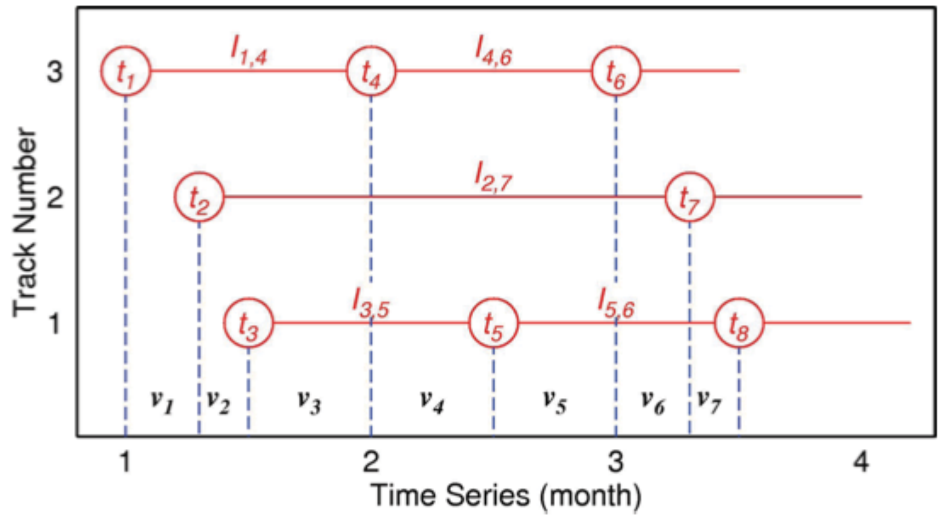

- Unknown parameters
    - Berardino et al. (2002): velocity of each epoch
    - Schmidt and Burgmann (2003): incremental displacement
    - Pi-RATE (above): velocity of each interval

SBAS - Methodology

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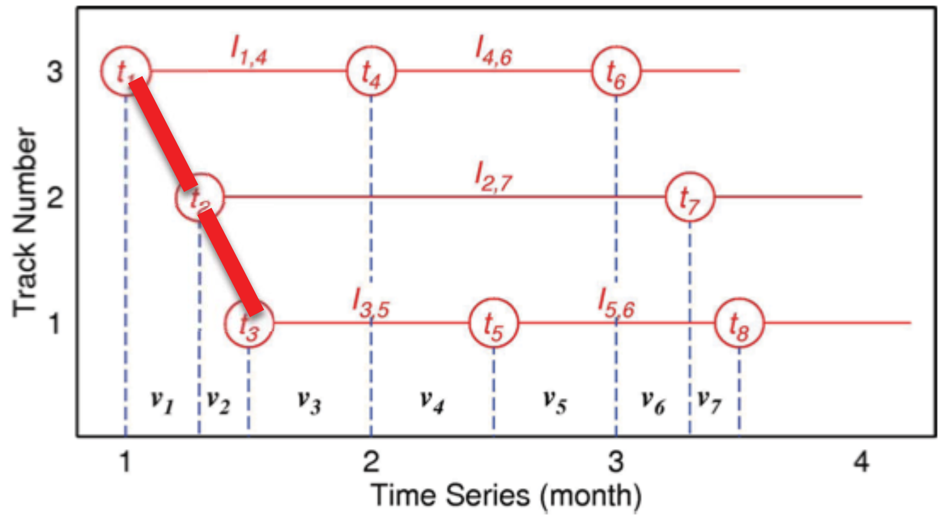


- Some isolated subsets exit, G is rank deficit
- All epochs are connected in a network, G is full rank
- Solution is not stable due to noise in d

SBAS - Methodology

- System of equations

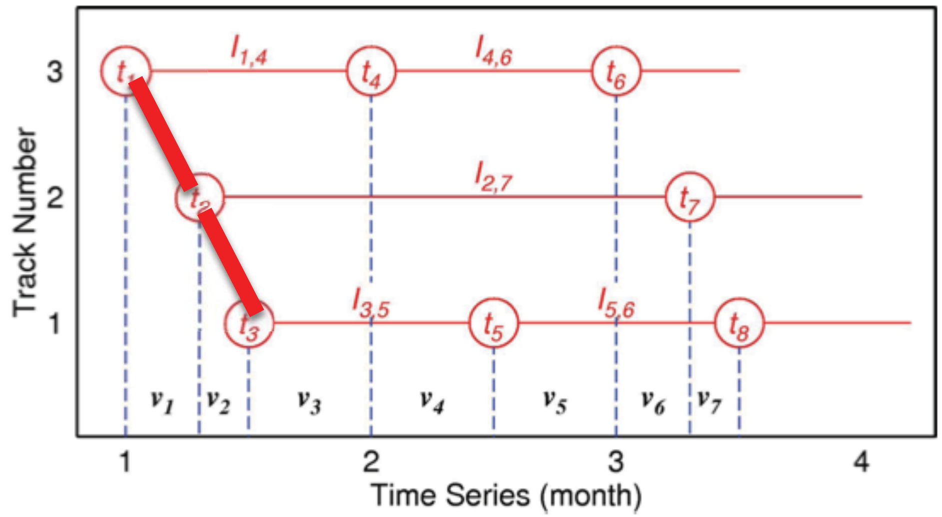
$$\mathbf{G}\mathbf{m} = \mathbf{d},$$

- Solution
  - SVD

$$\mathbf{m} = \mathbf{G}^{+}\mathbf{d}$$

  - Laplacian smoothing

$$\begin{bmatrix} \mathbf{G} \\ \kappa\nabla^2 \end{bmatrix} \mathbf{m} = \begin{bmatrix} \mathbf{d} \\ \mathbf{0} \end{bmatrix}$$



SBAS - Methodology

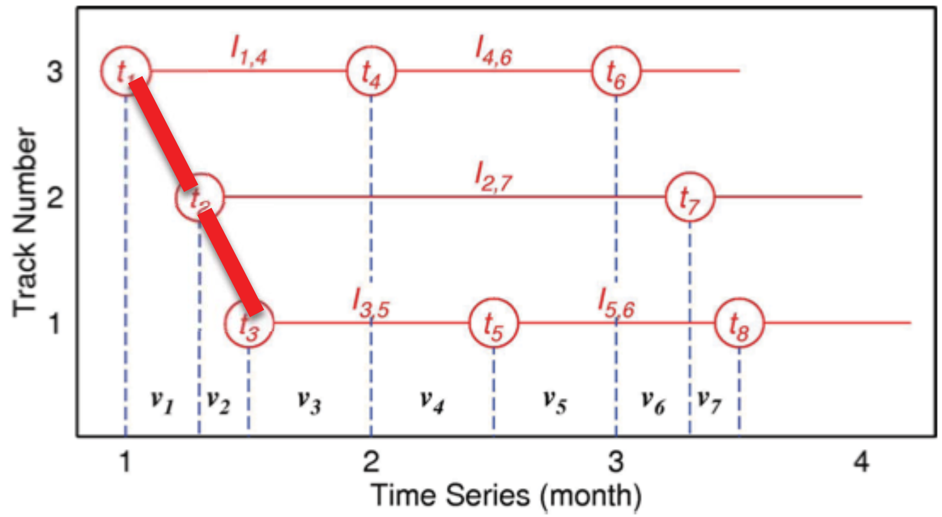
- System of equations

$$\mathbf{Gm} = \mathbf{d},$$

- Considering DEM errors

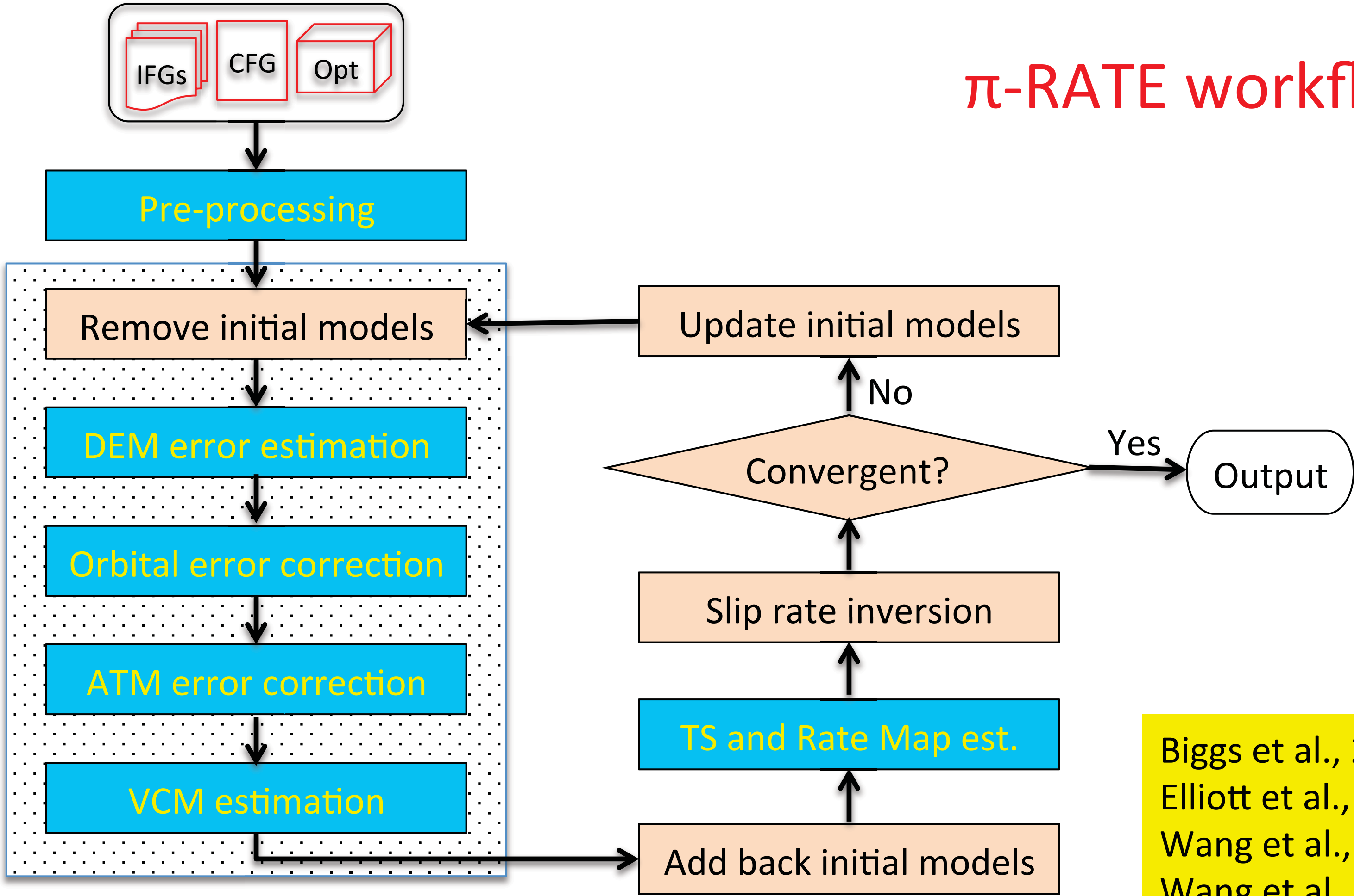
$$\begin{bmatrix} \mathbf{G} & \mathbf{B} \end{bmatrix} \begin{bmatrix} \mathbf{m} \\ \Delta h \end{bmatrix} = \mathbf{d}$$

$$\mathbf{B} = \begin{bmatrix} -\frac{B_\perp^1}{\rho \sin \vartheta} & & \\ & \ddots & \\ & & -\frac{B_\perp^m}{\rho \sin \vartheta} \end{bmatrix}$$



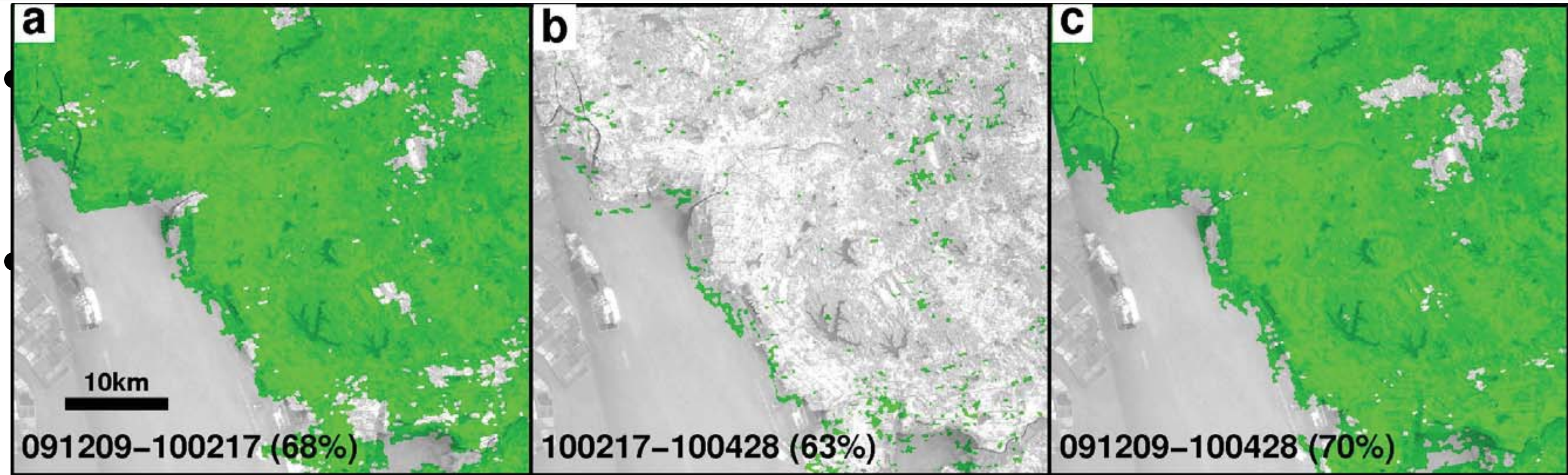
SBAS - Processing

π-RATE workflow

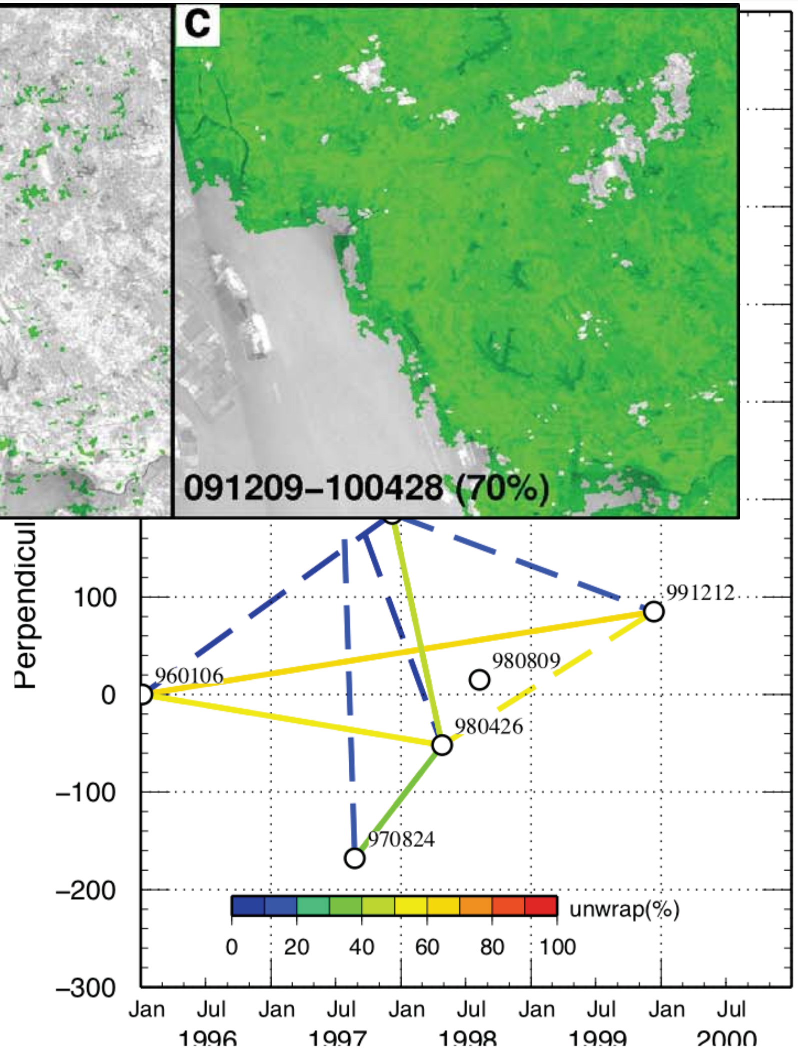


Biggs et al., 2007, GJI
Elliott et al., 2008, GRL
Wang et al., 2009, GRL
Wang et al., 2012, GJI

Interferogram Selection



- MST (select a chain for each pixel from a network)
  - Independent observations
  - Different subset of interferograms for each pixel



Components of interferometric phase

$$\Delta\phi = \Delta\phi_{def} + \Delta\phi_{orb} + \Delta\phi_{atm} + \Delta\phi_{dem} + \varepsilon$$

$\Delta\phi_{def}$:

- Spatial low frequency
- Temporal low frequency

$\Delta\phi_{orb}$:

- Spatial low frequency
- Temporal high frequency

$\Delta\phi_{atm}$:

- Spatial low frequency
- Temporal high frequency

$\Delta\phi_{dem}$:

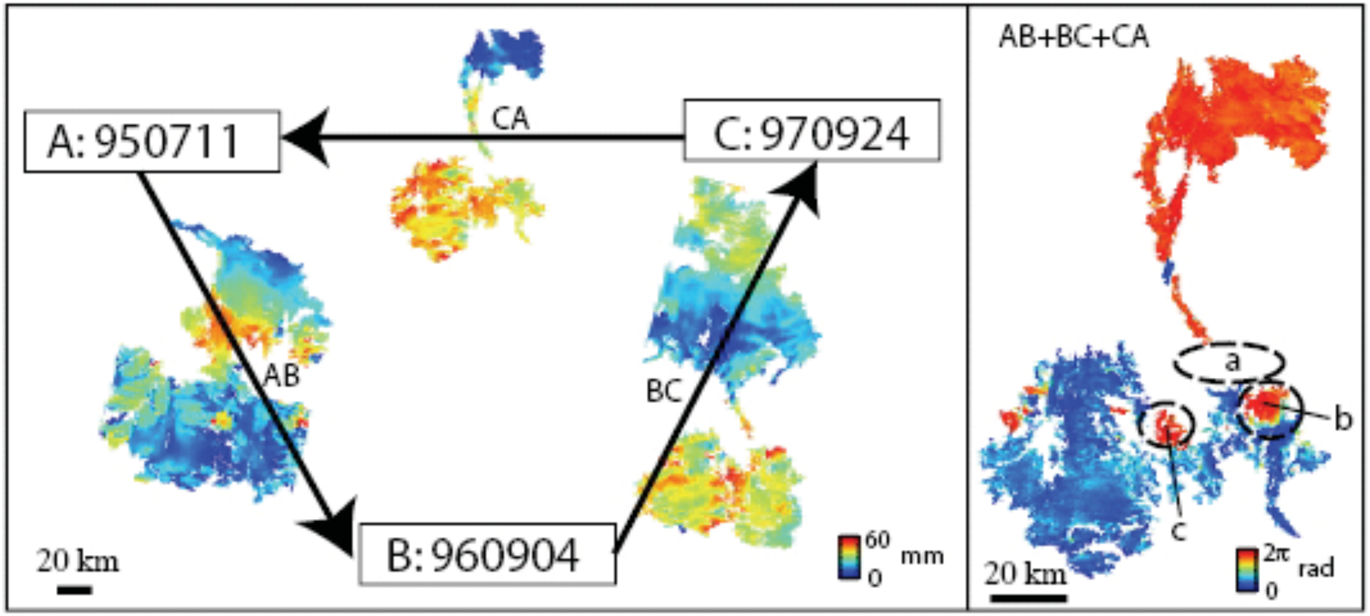
- Constant for a pixel in all the interferograms
- Proportional to perpendicular baseline

ε:

- Random noise
- unw errors

Phase unwrapping errors

- In theory, the sum of phase in a closure is zero.
- Jump exists once phase unwrapping is wrong.
- Mask or correct phase unwrapping errors after detection



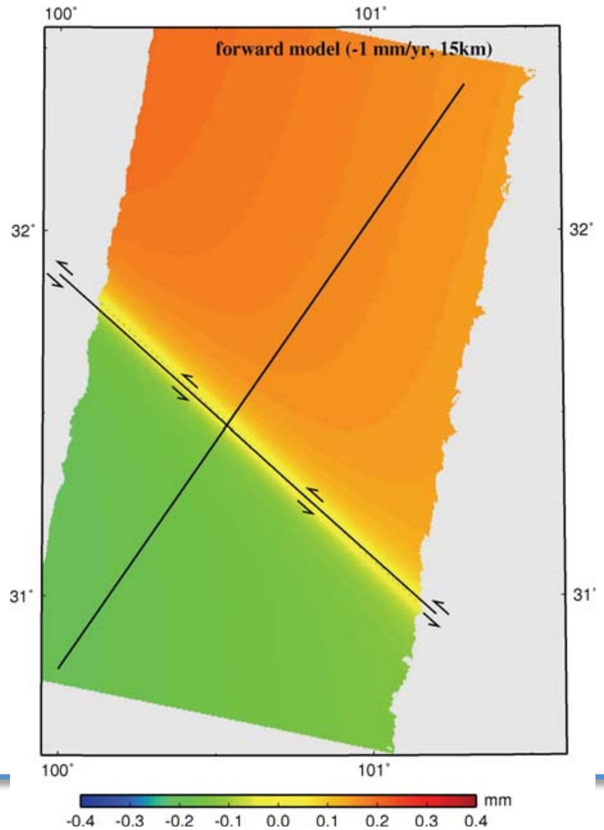
Biggs et al., 2007

Initial models

- Why do we use initial model?

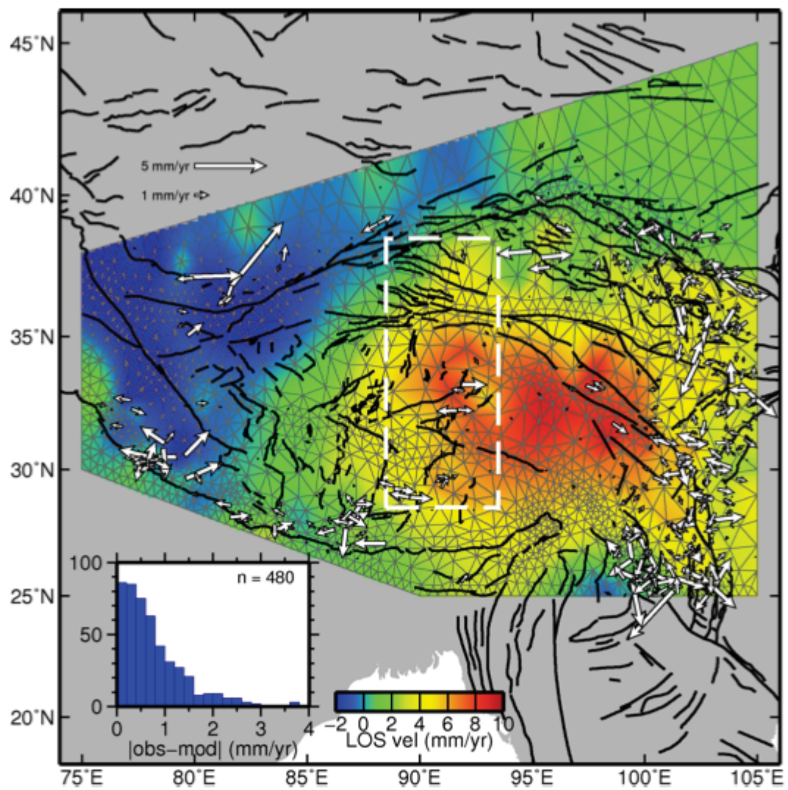
  spatial low frequency: deformation, atmosphere, orbit

Geophysical models



Wang, Wright, Biggs, 2009

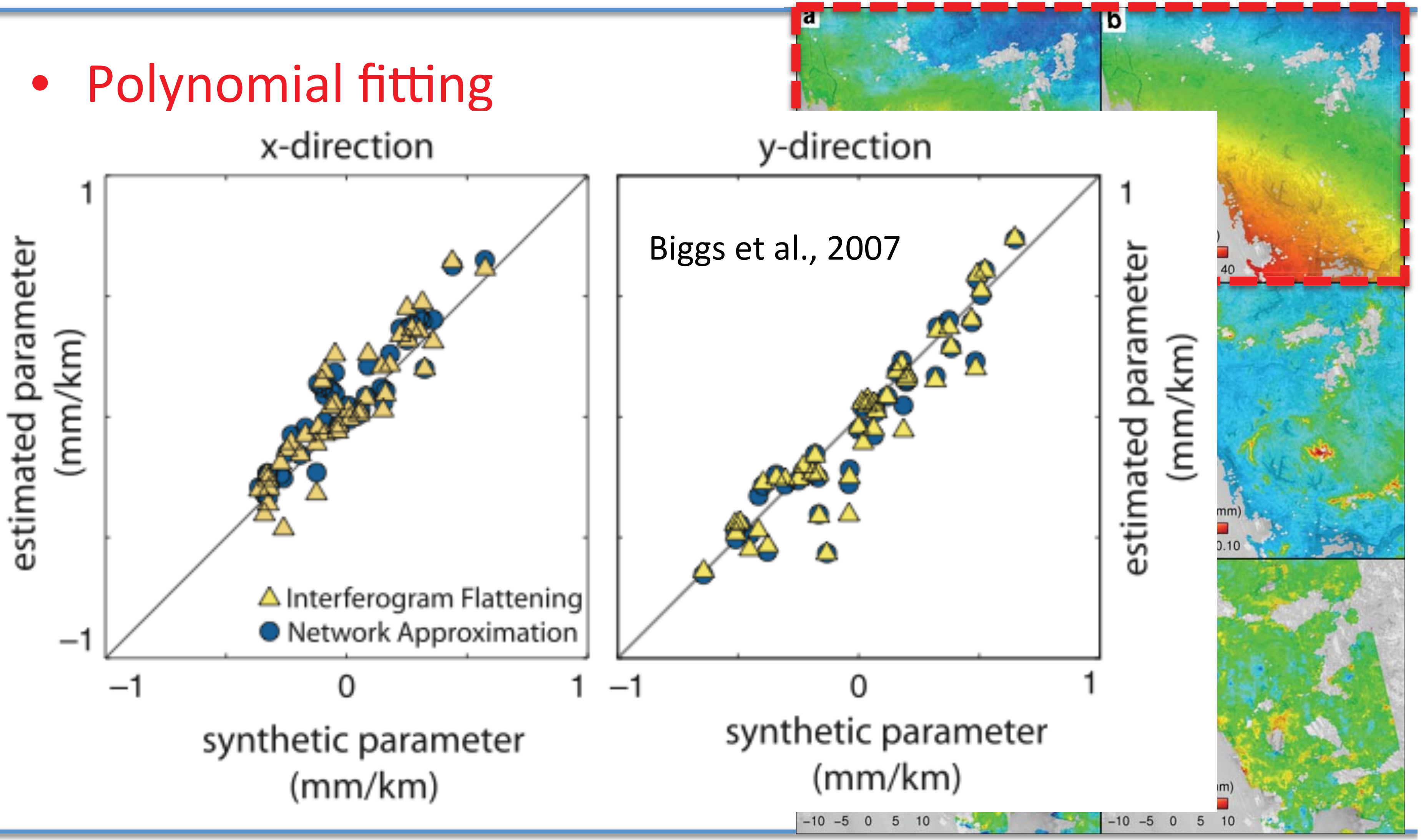
Velocity field



Garthwaite, Wang, Wright, 2013

Orbital error correction

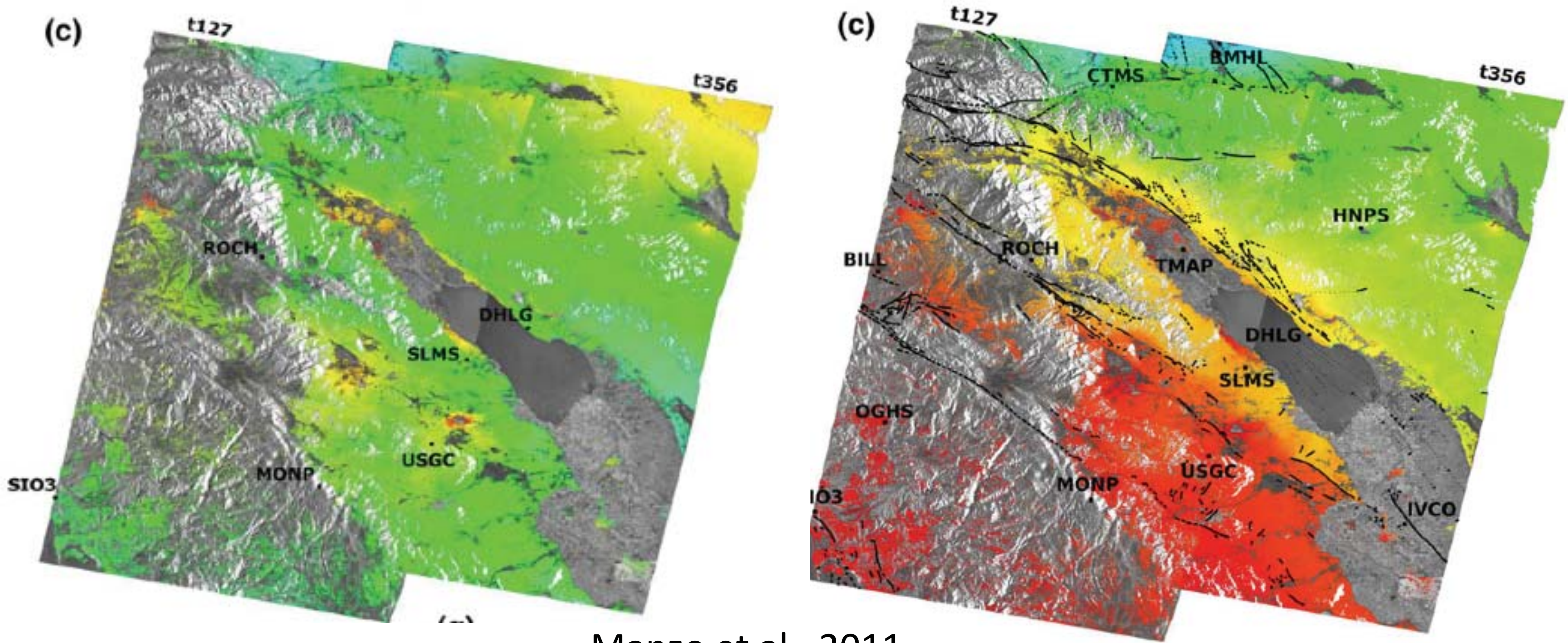
- Polynomial fitting



Wang et al., 2012

Orbital error correction

- Polynomial fitting
- GPS time series calibration



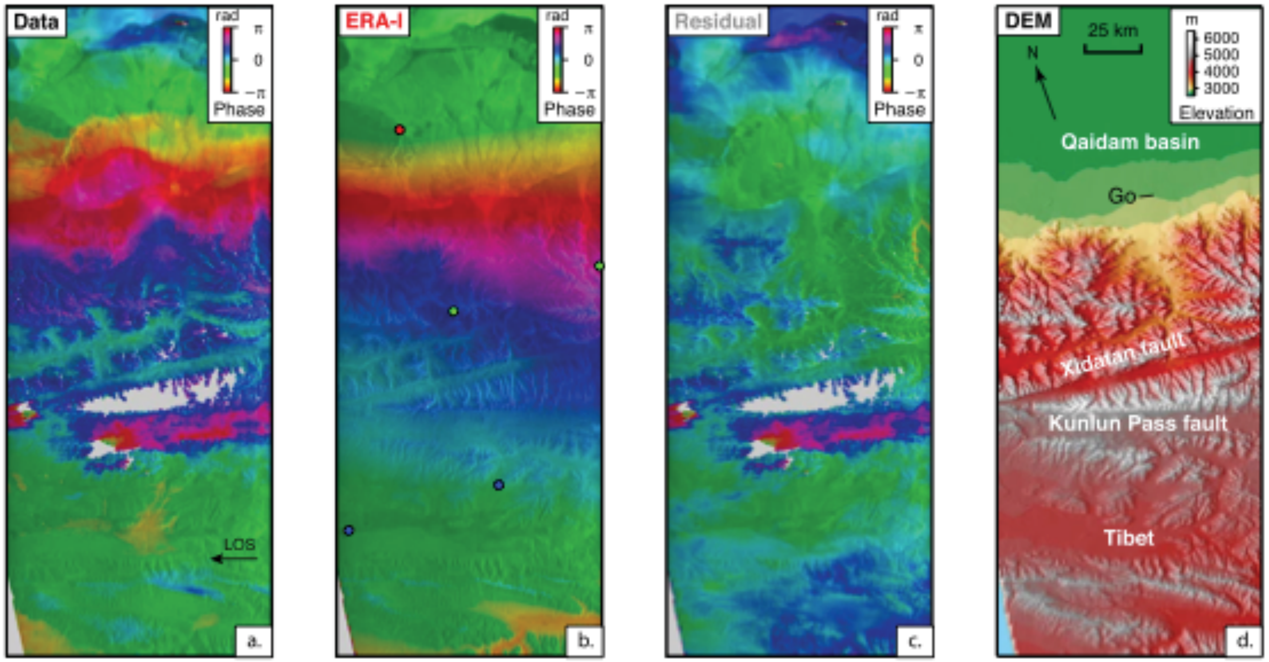
Manzo et al., 2011

Atmospheric delay errors

- External calibration (GPS, MODIS, MERIS, Metrological data)

❑ Advantage: independent of InSAR

❑ Disadvantage: spatial and temporal resolution discrepancies, GPS data availability



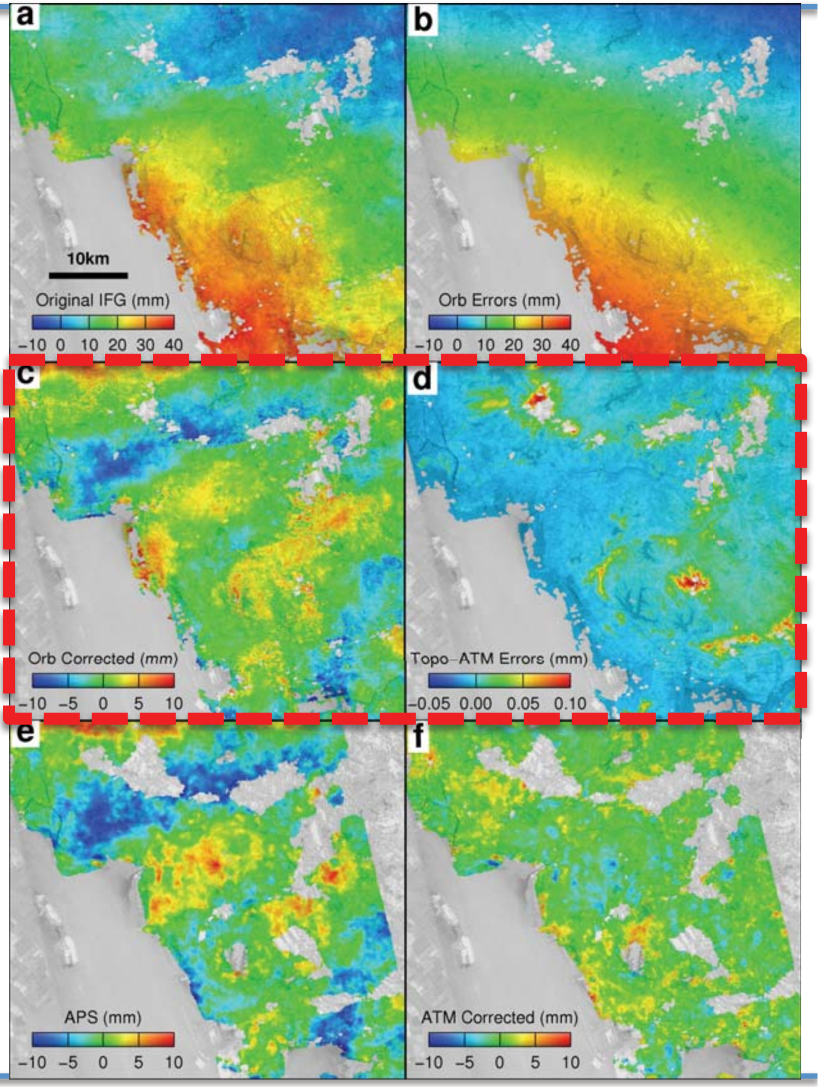
Jolivet et al., 2011

Atmospheric delay errors

- External calibration
- Empirical Estimation
  - Topo-correlated (stratified)

$$\Delta\phi = a \cdot (H - H_0) + b$$

  - APS estimation (turbulent)



Wang et al., 2012

Atmospheric delay errors

- External calibration
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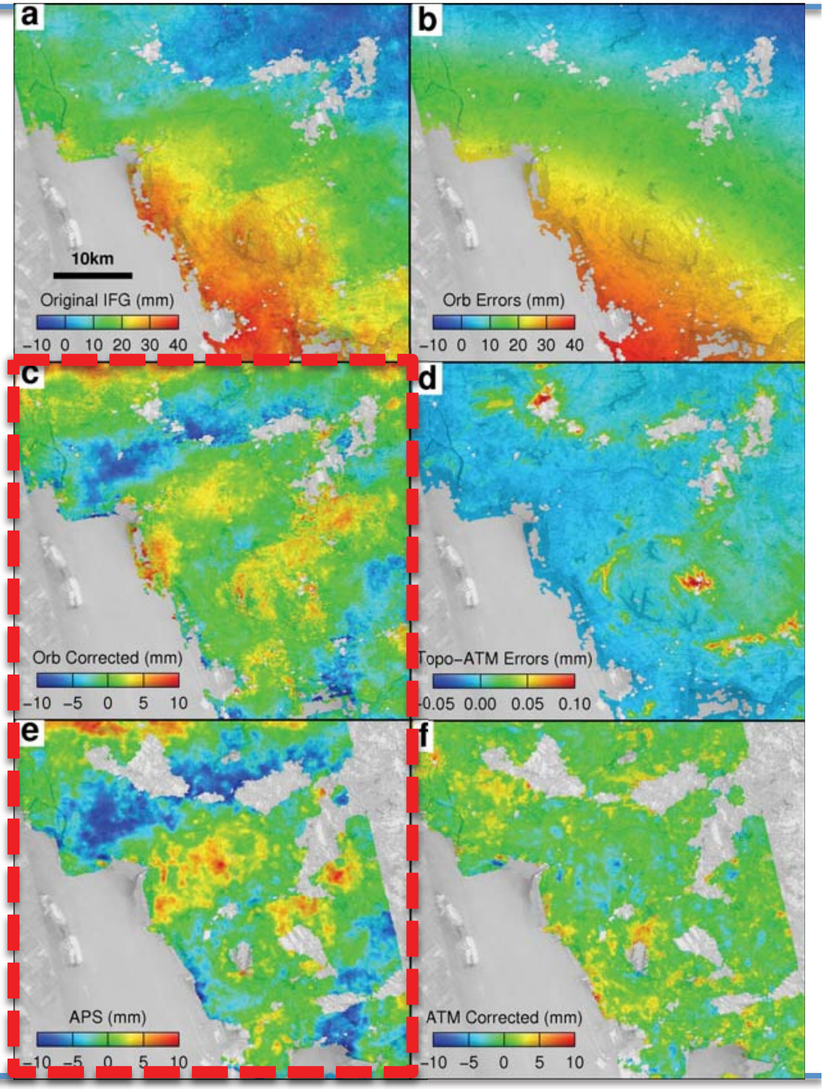
    - Raw time series inversion
    - Sudden deformation removal
    - Temporal low-pass filter
    - Spatial high-pass filter



Wang et al., 2012

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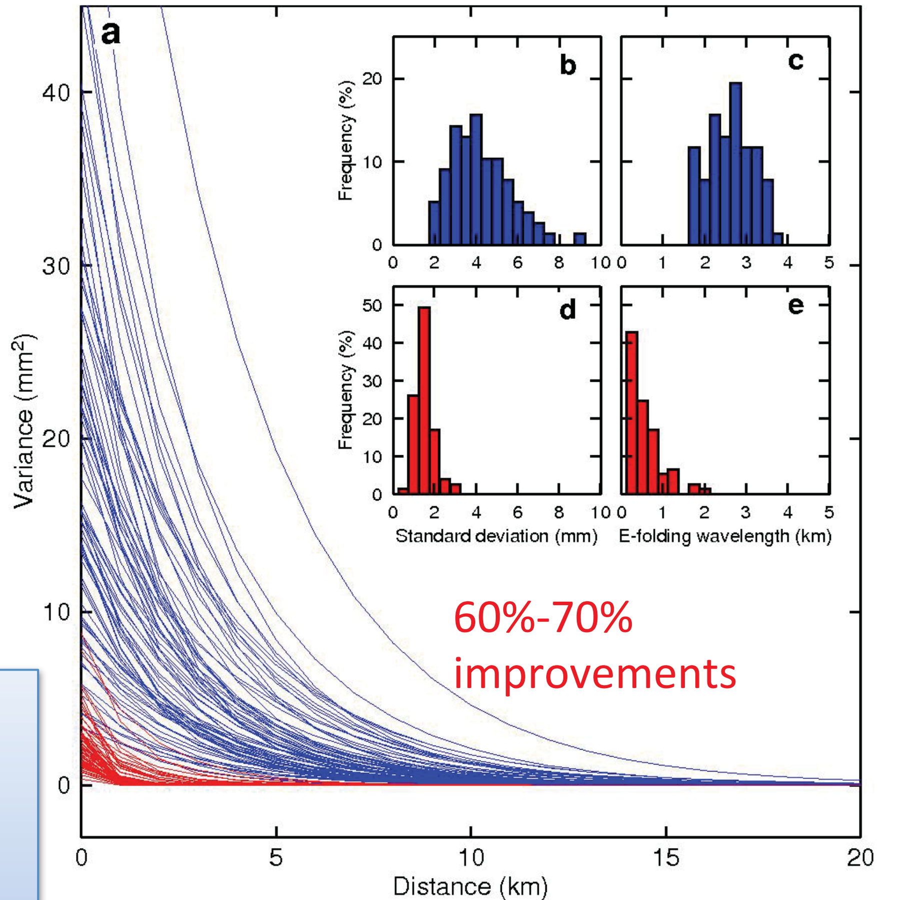
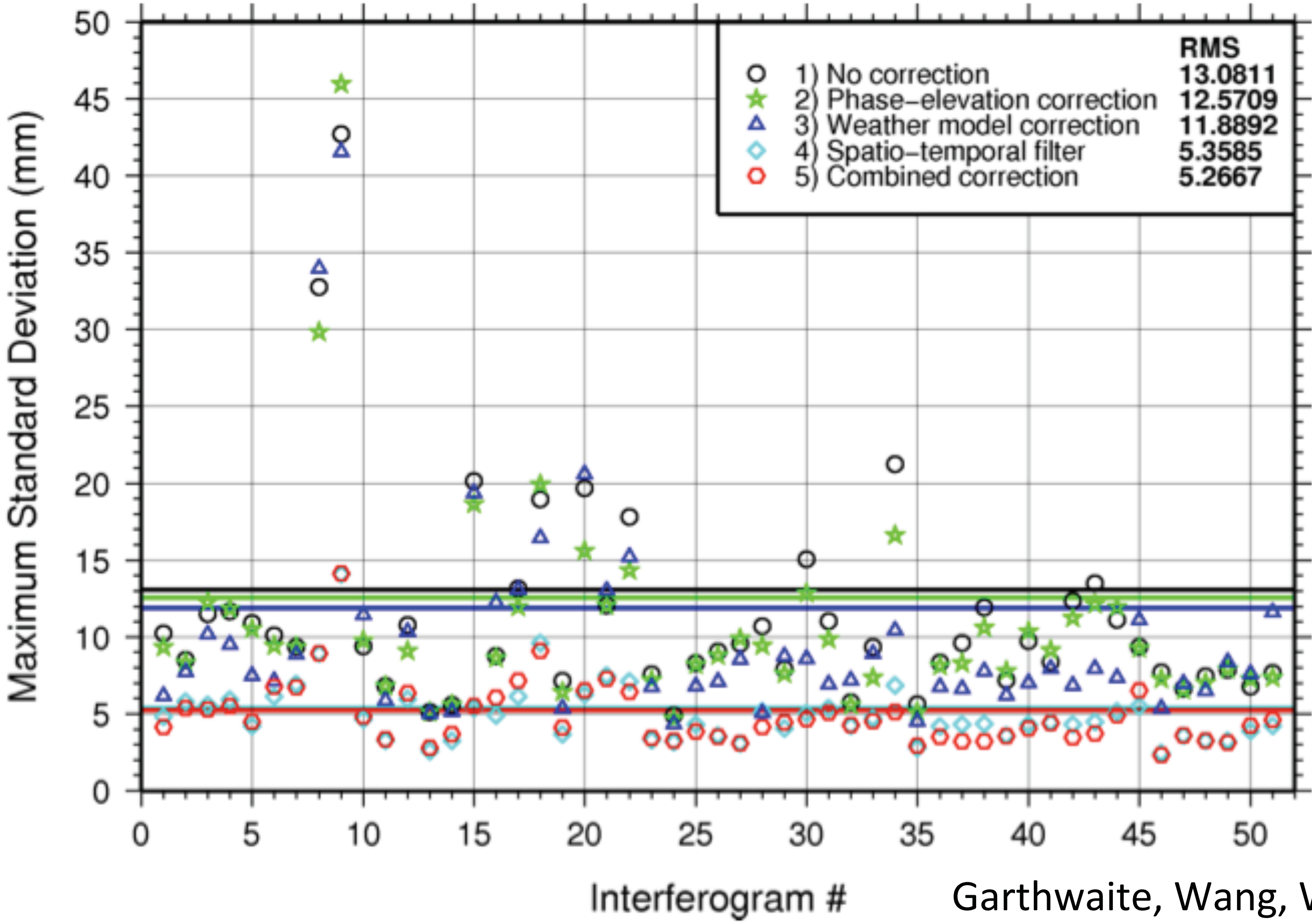
$$c_{jk} = \sigma^2 e^{-d_{jk}/\alpha}$$



Wang et al., 2012

- ❑ Advantage: only depends on InSAR data
- ❑ Disadvantages: (1) non-linear relationship exists between topography and delay; (2) how to determine smoothing windows for APS estimation

Atmospheric delay errors



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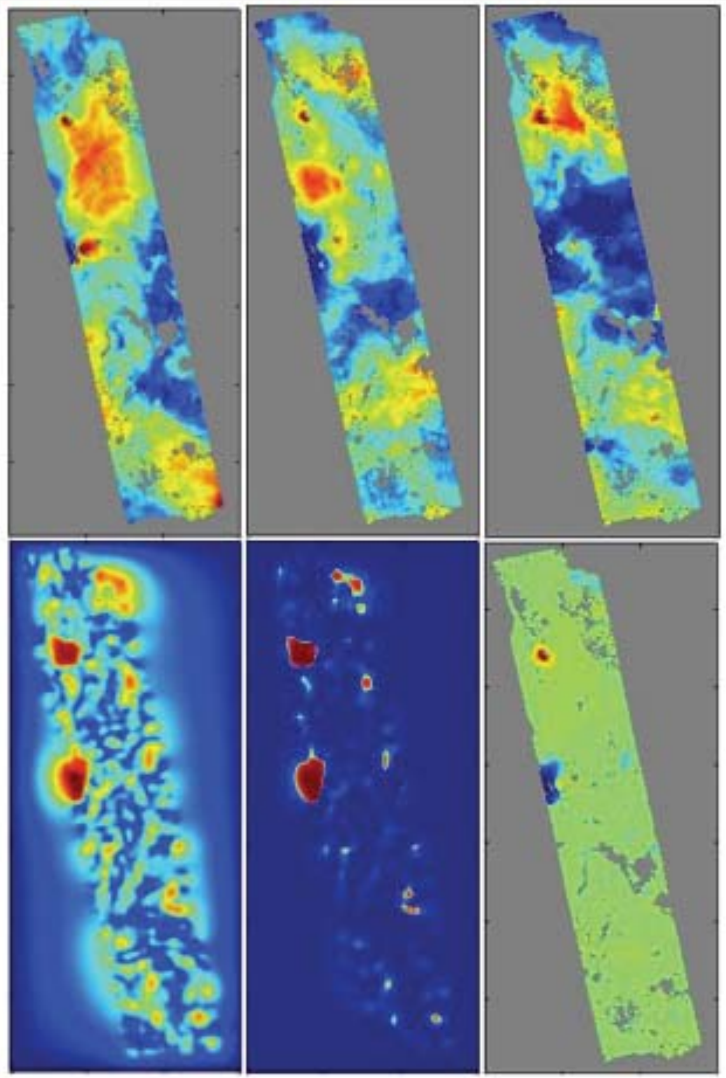

VCM estimation

- VCM in space (for initial model inversion)

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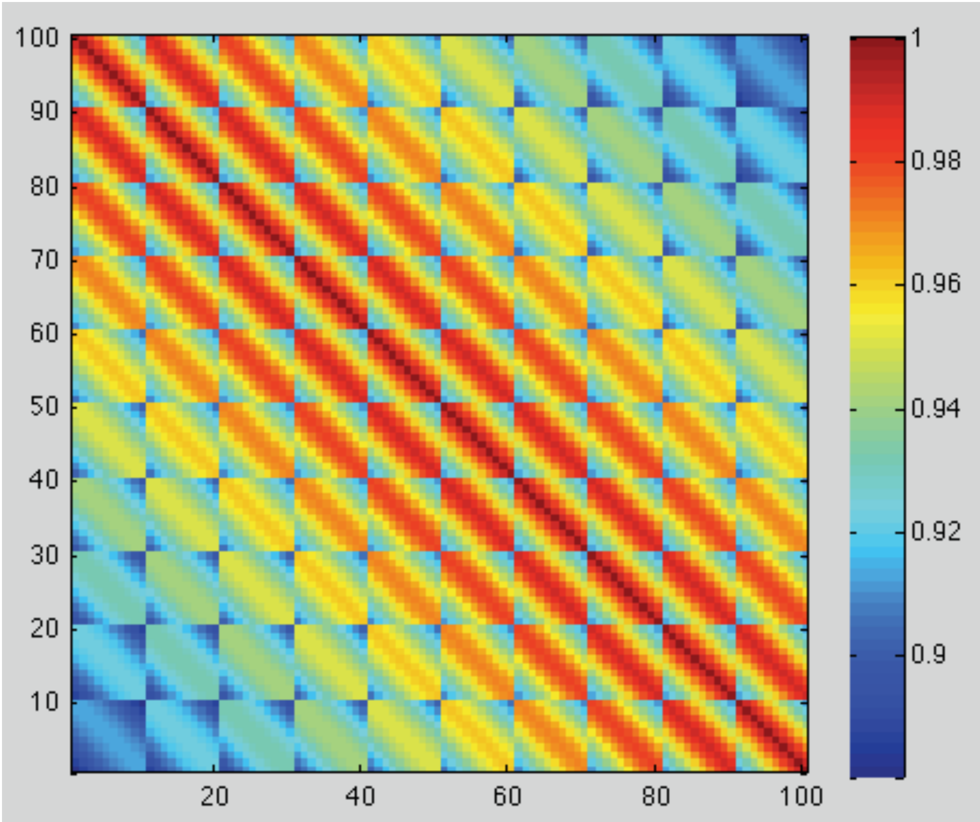

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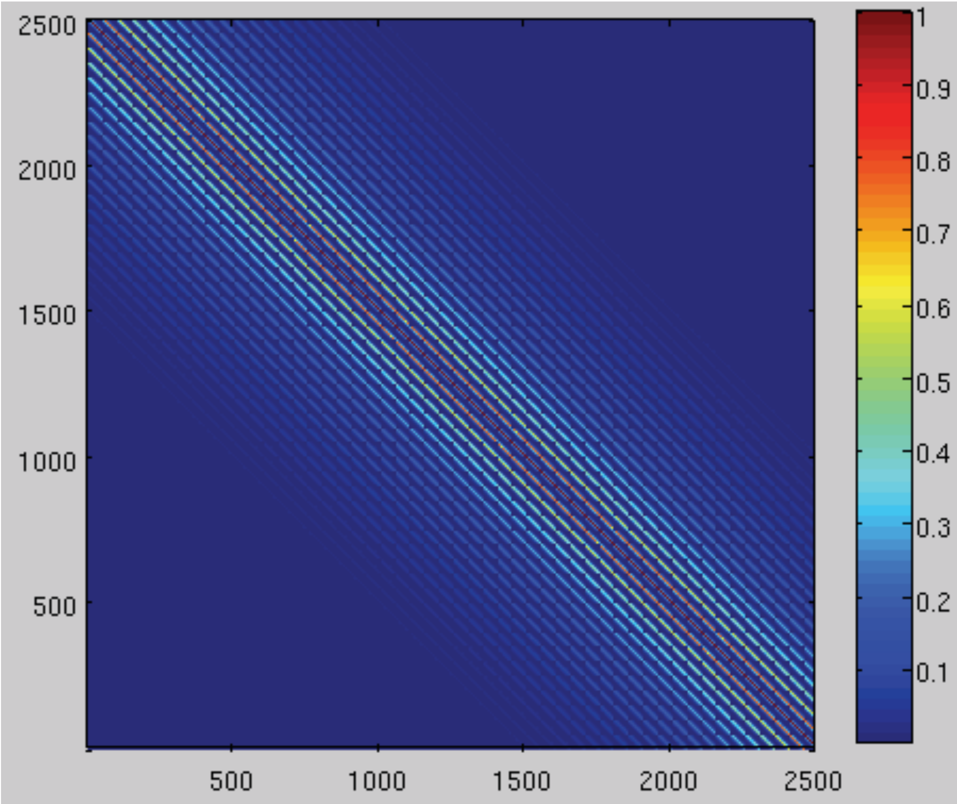
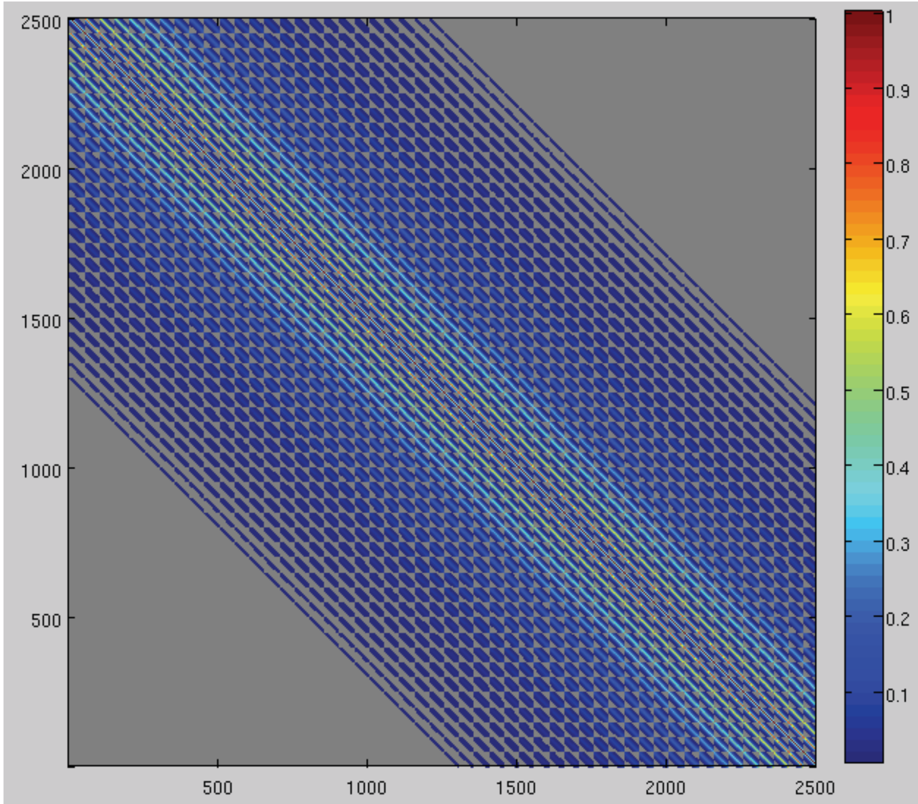


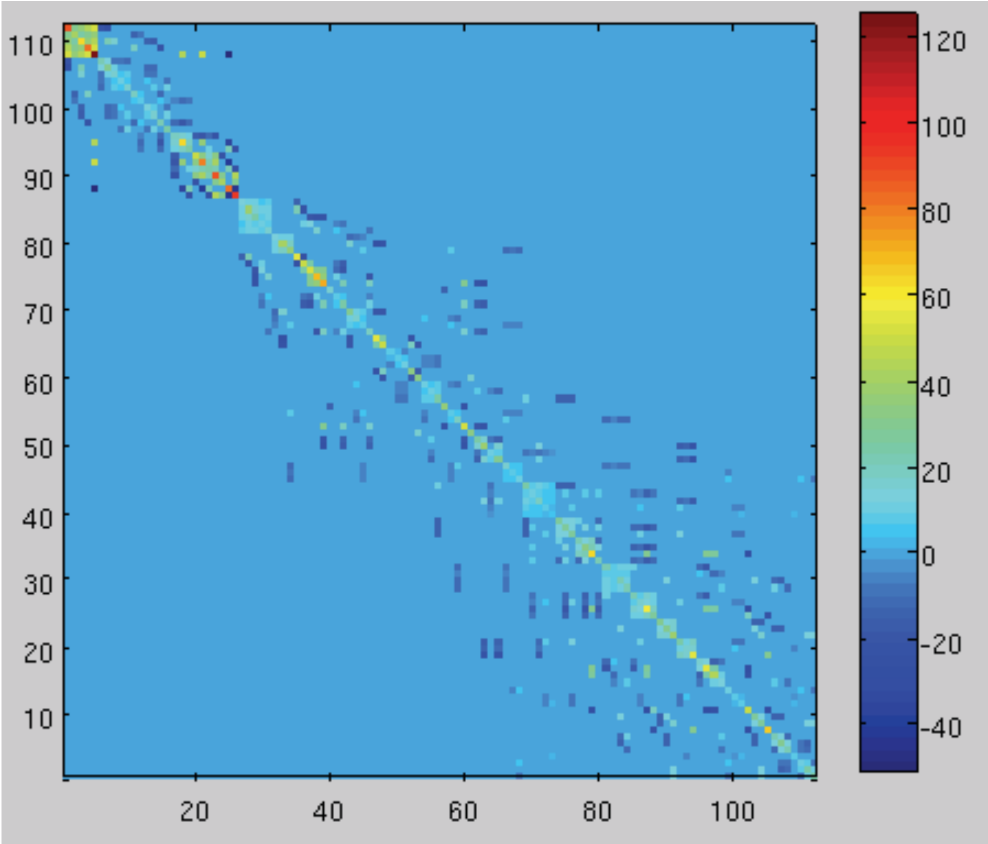


VCM estimation

- VCM in time (for time series and rate map inversion)

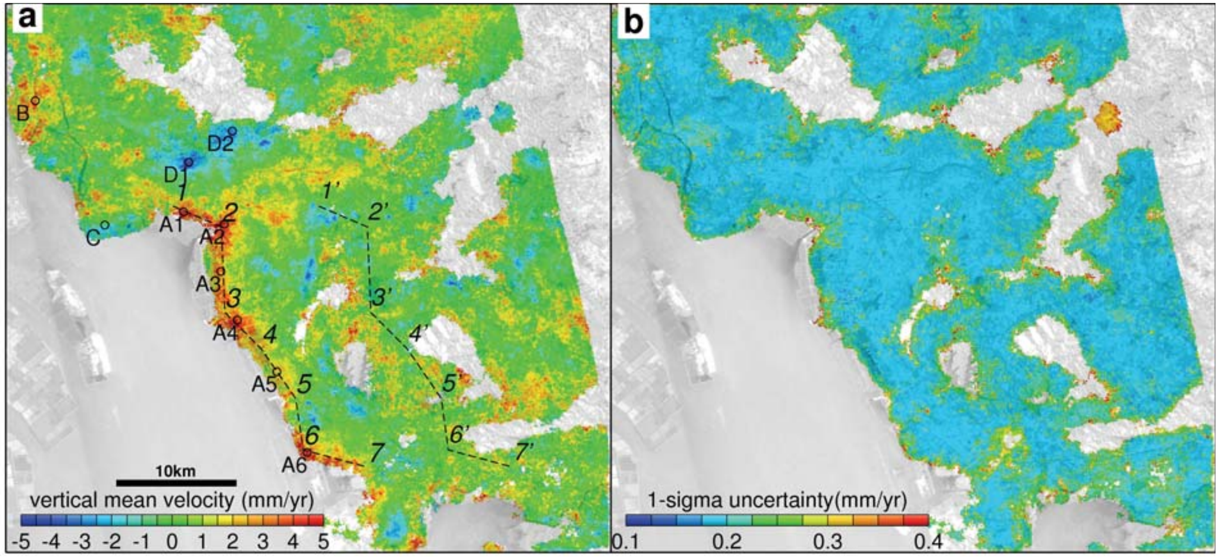
$$C_{lm,nq} = \begin{cases} 1 & (l = n, m = q) \\ -0.5 & (l = q \ or \ m = n) \\ 0.5 & (l = n \ or \ m = q) \\ 0 & (otherwise) \end{cases}$$

Biggs et al., 2007



Final products estimation

- Rate map
- Error map
- DEM errors
- Time series



Wang et al., 2012

$$\mathbf{Gm} = \mathbf{d}$$

$$\mathbf{m} = (\mathbf{G}^T\mathbf{C}^{-1}\mathbf{G})^{-1}\mathbf{G}^T\mathbf{C}^{-1}\mathbf{d}$$

$$\mathbf{C_m} = (\mathbf{G}^T\mathbf{C}^{-1}\mathbf{G})^{-1}$$

Final products estimation

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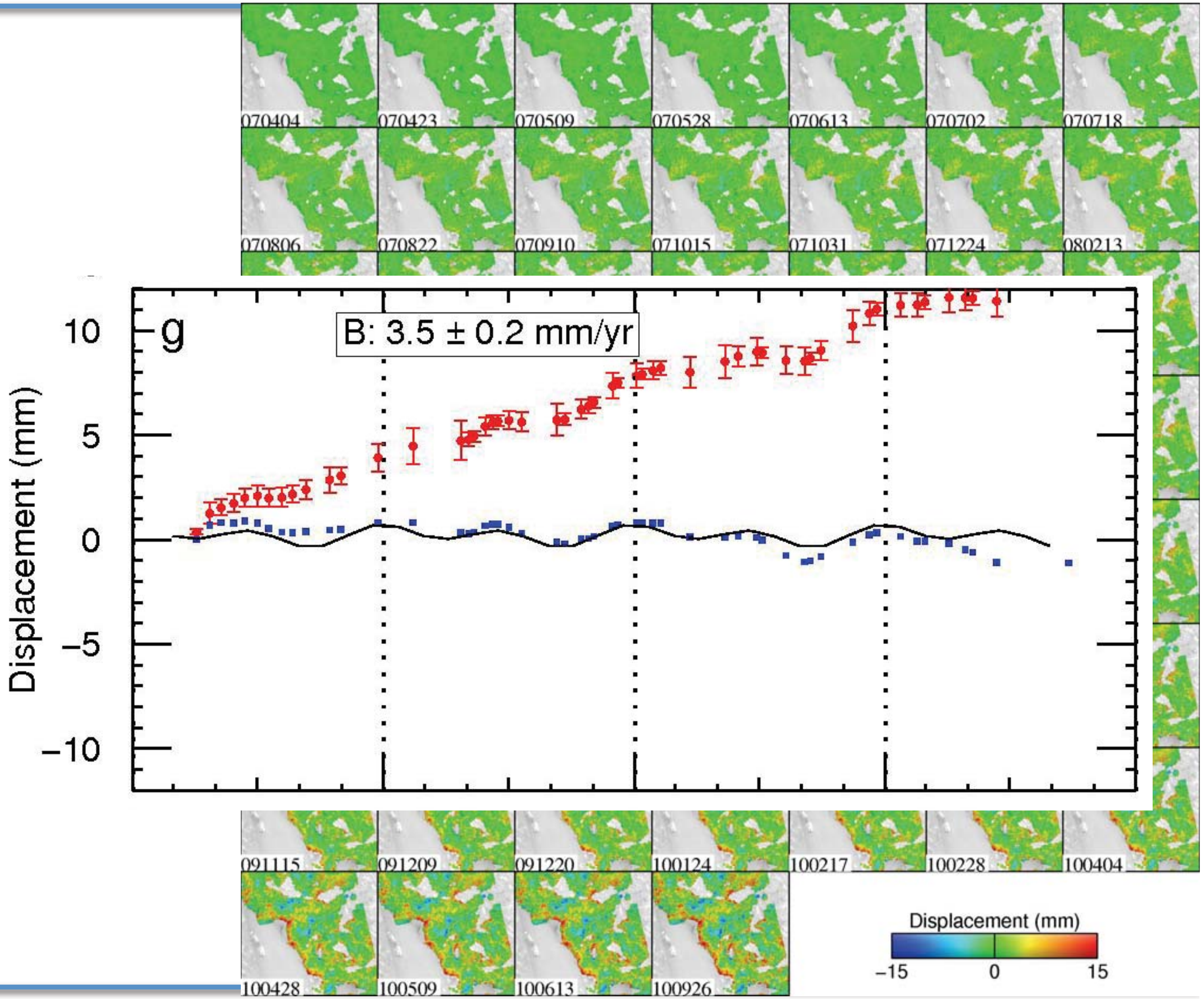
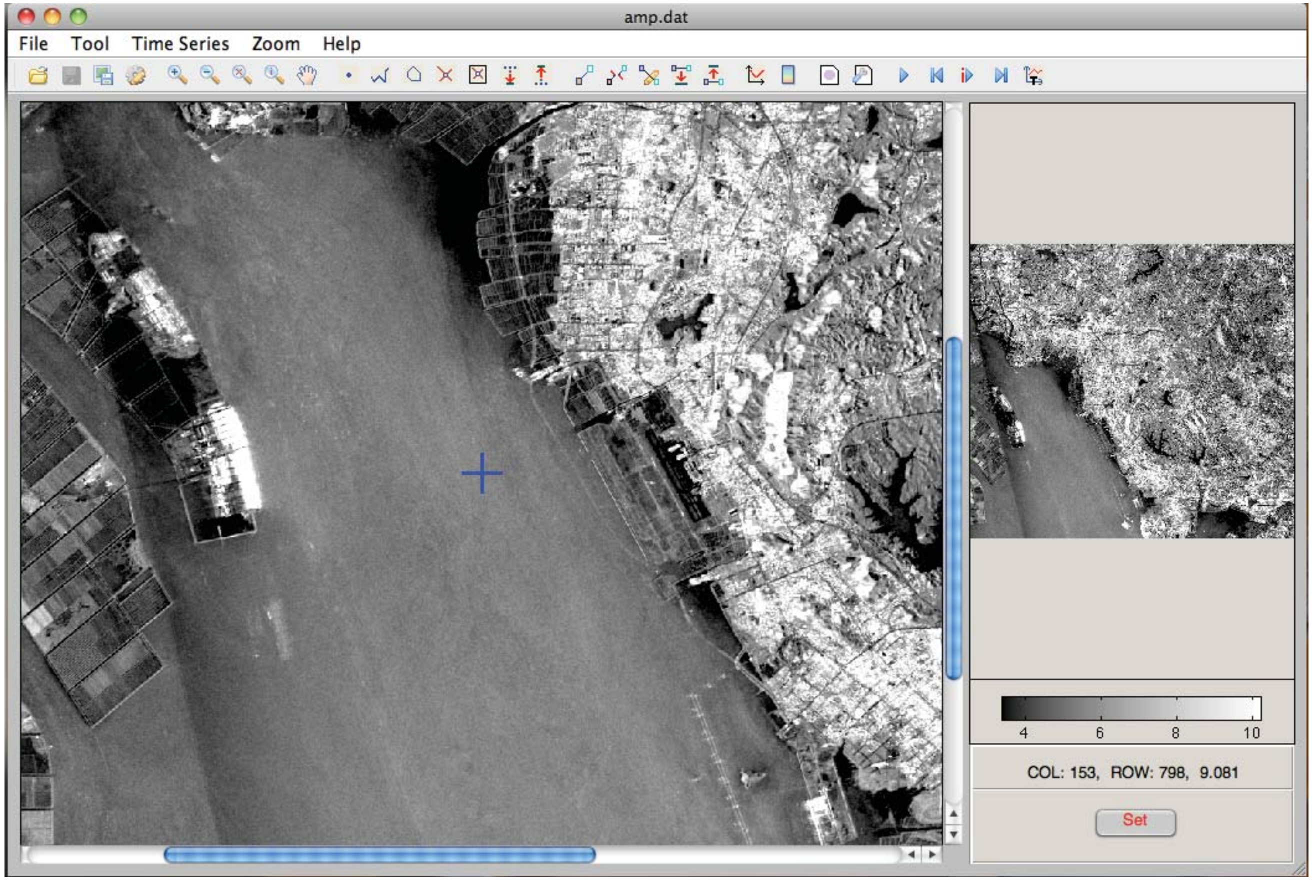


Wang et al., 2012

By-products

- Amplitude
- Coherence
- …



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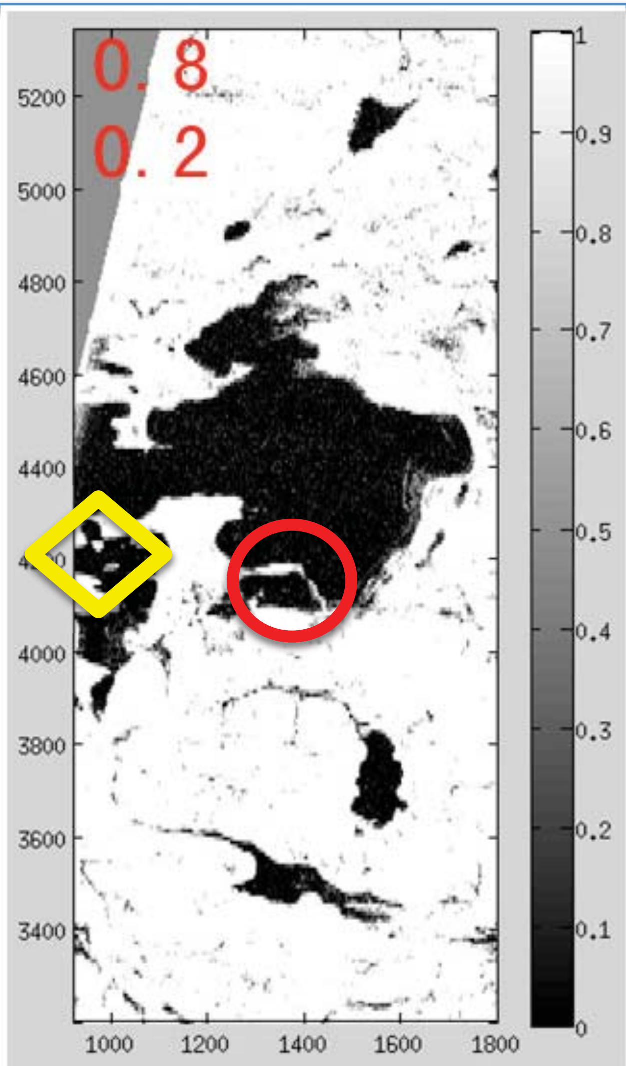
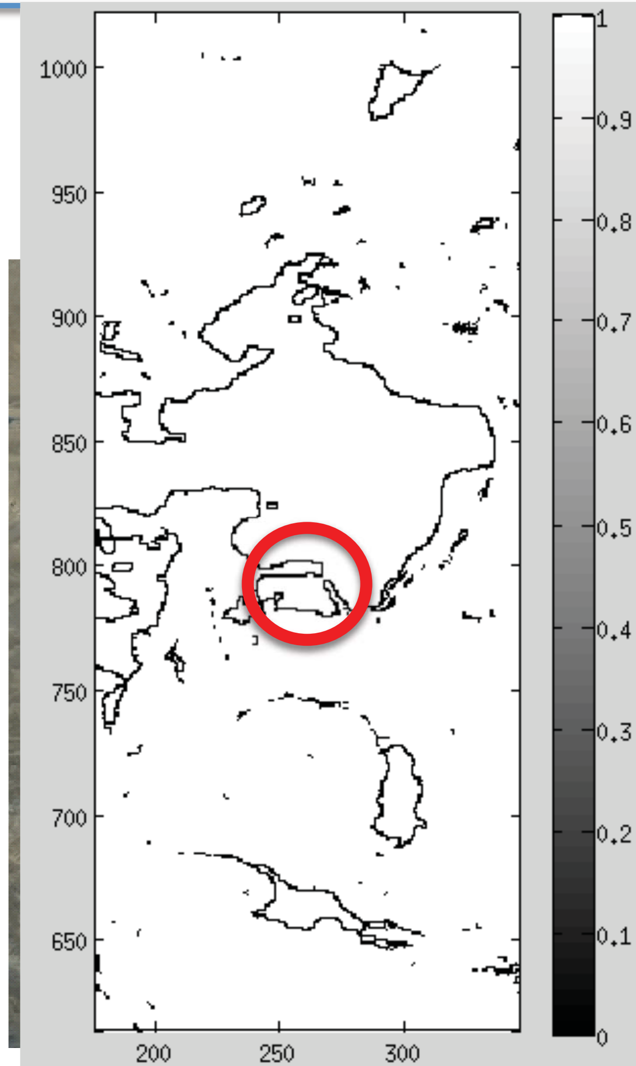
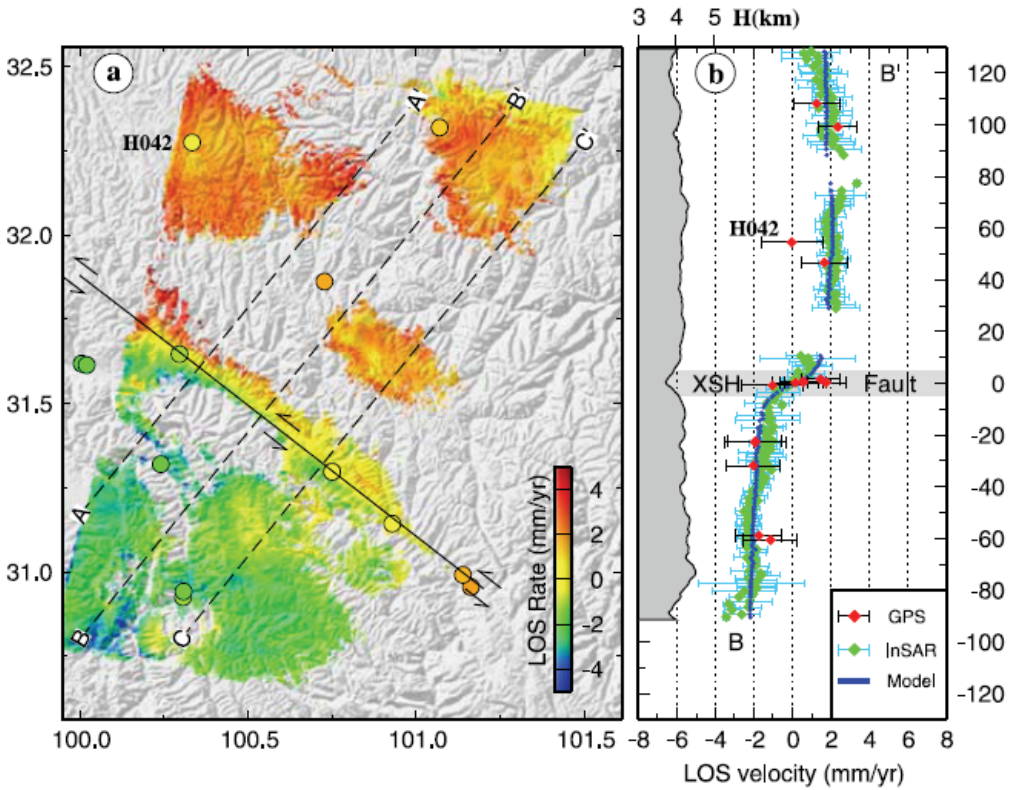
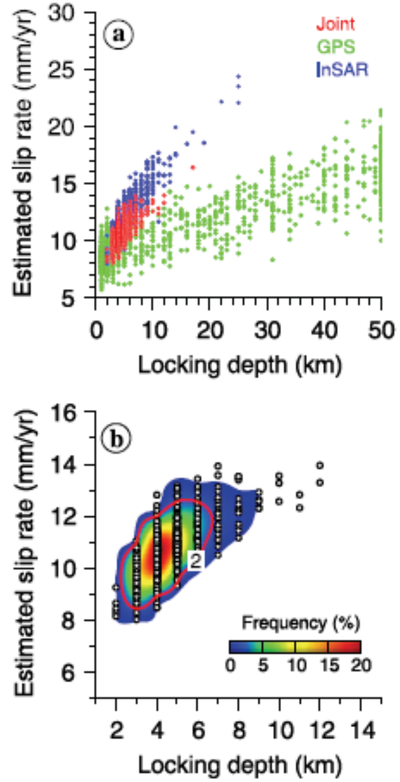




Examples: Eastern Tibet (XSH)

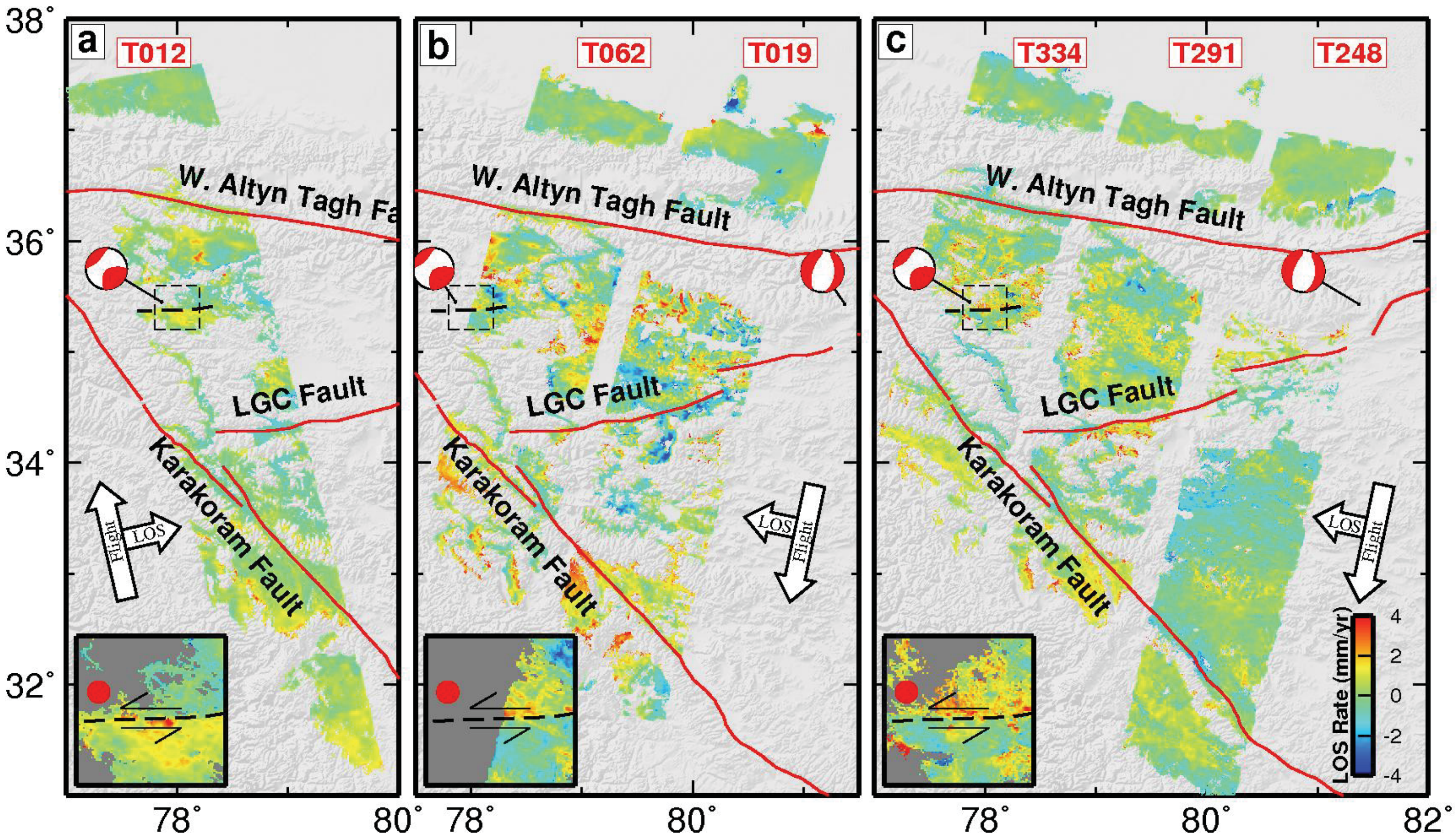




- Consistent interseismic deformation measured by InSAR and GPS
- Improvement on the constraint of locking depth using InSAR and GPS
- Slip rate: 9-12 mm/yr; locking depth: 3-6 km.

Wang, Wright, Biggs, 2009, GRL

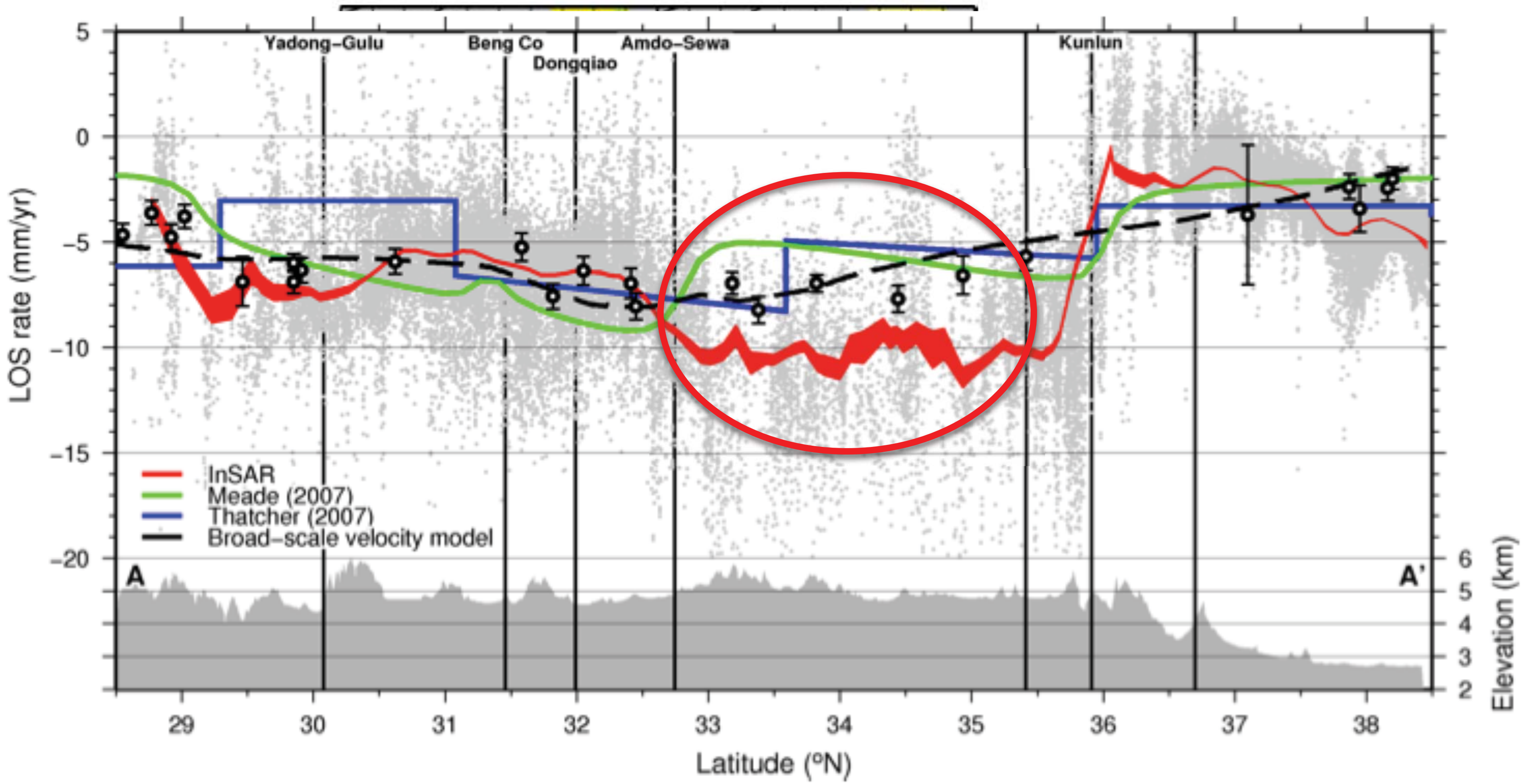
Examples: Western Tibet



- InSAR reveals internal deformation in western Tibet

Wang and Wright, 2012, GRL

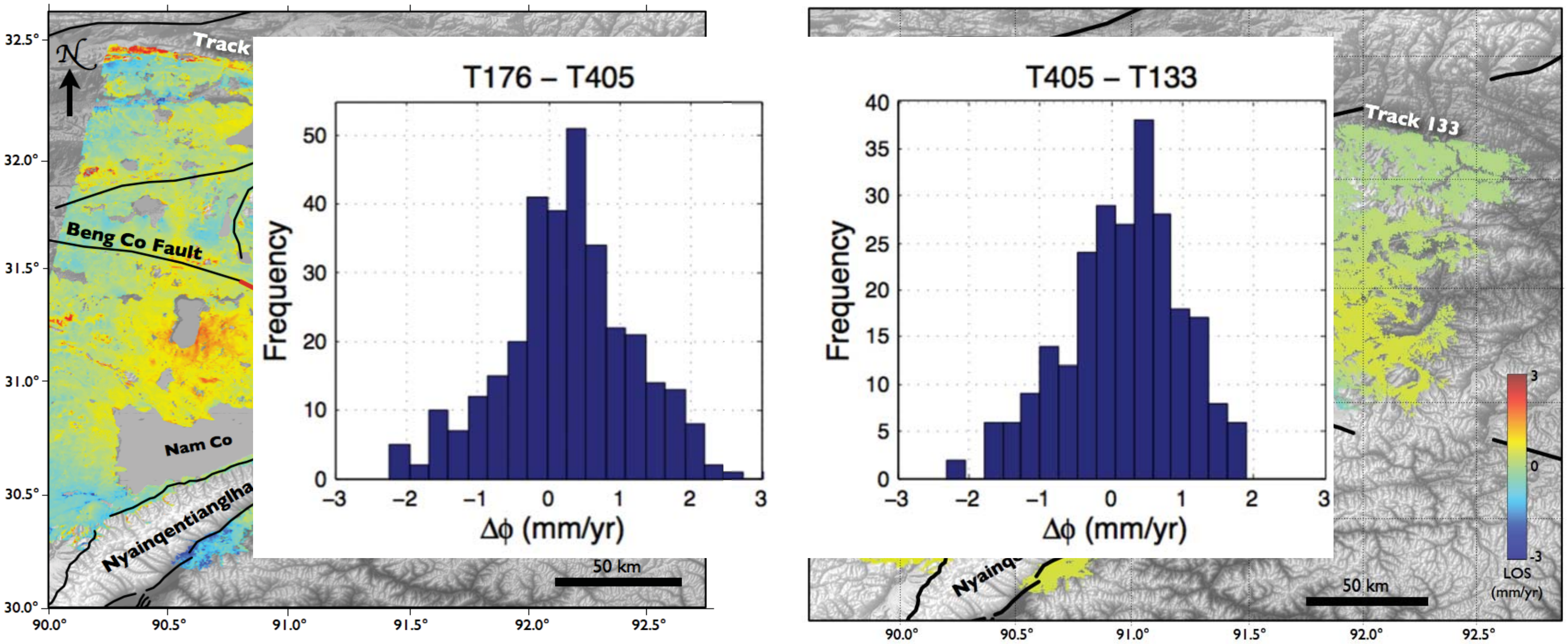
Examples: Central Tibet



- InSAR reveals vertical deformation in central Tibet

Garthwaite, Wang and Wright, 2013

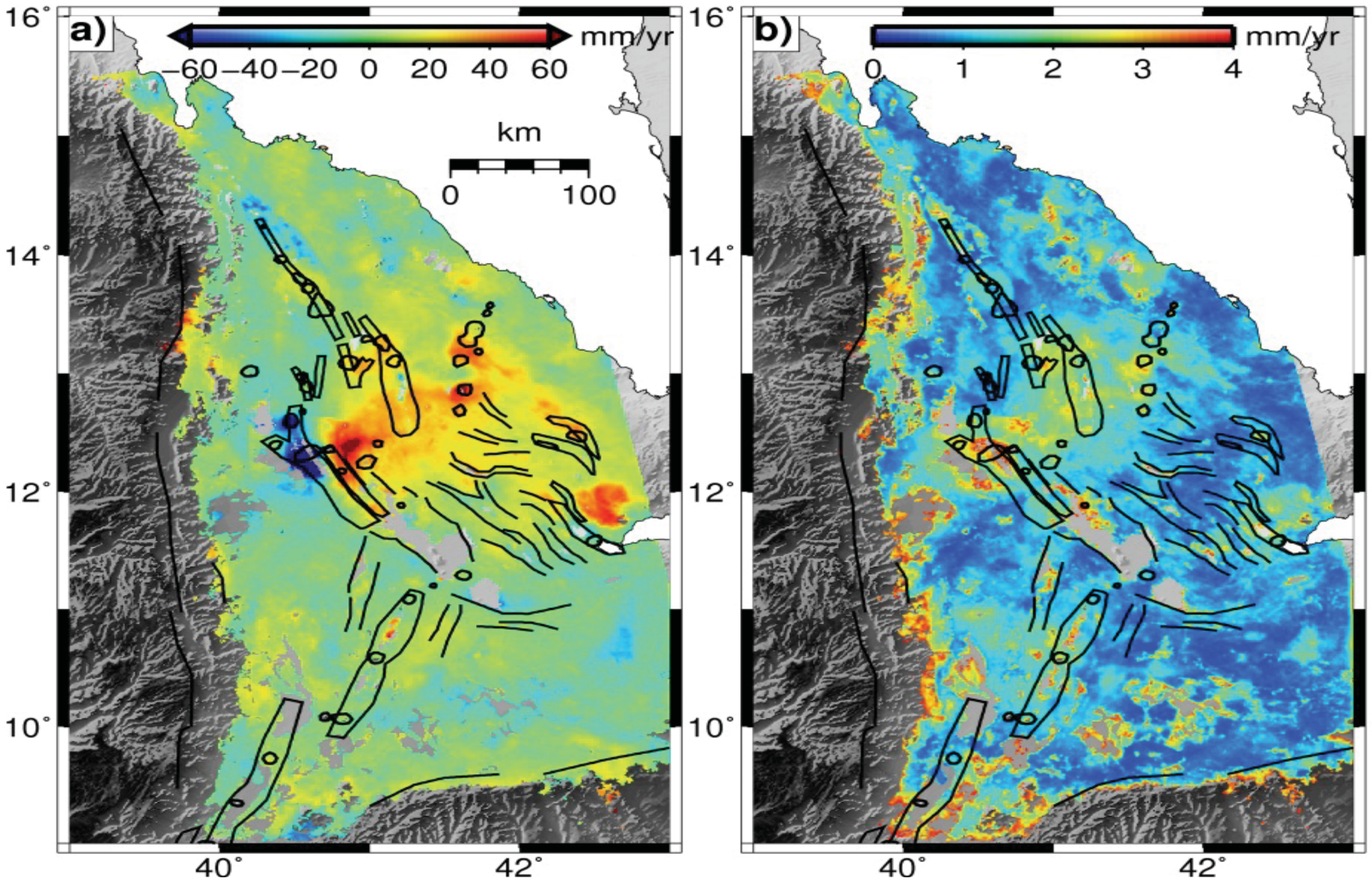
Beng Co and Yadong-Gulu Rift



- Postseismic deformation following the 1951/1952 earthquakes
- Viscoelastic stress relaxation in the lower crust (viscosity = 3e19)

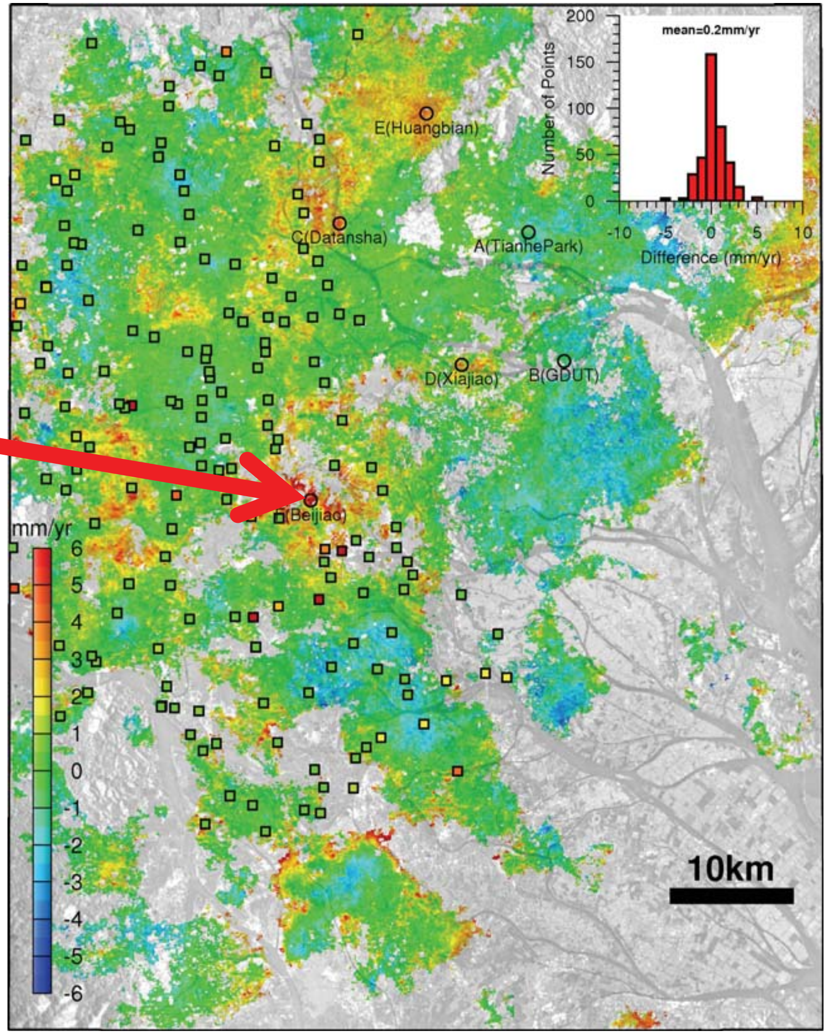
Ryder et al., in prep

Examples: Afar-wide swath rate map



Pagli et al., in prep

Examples: PRD subsidence

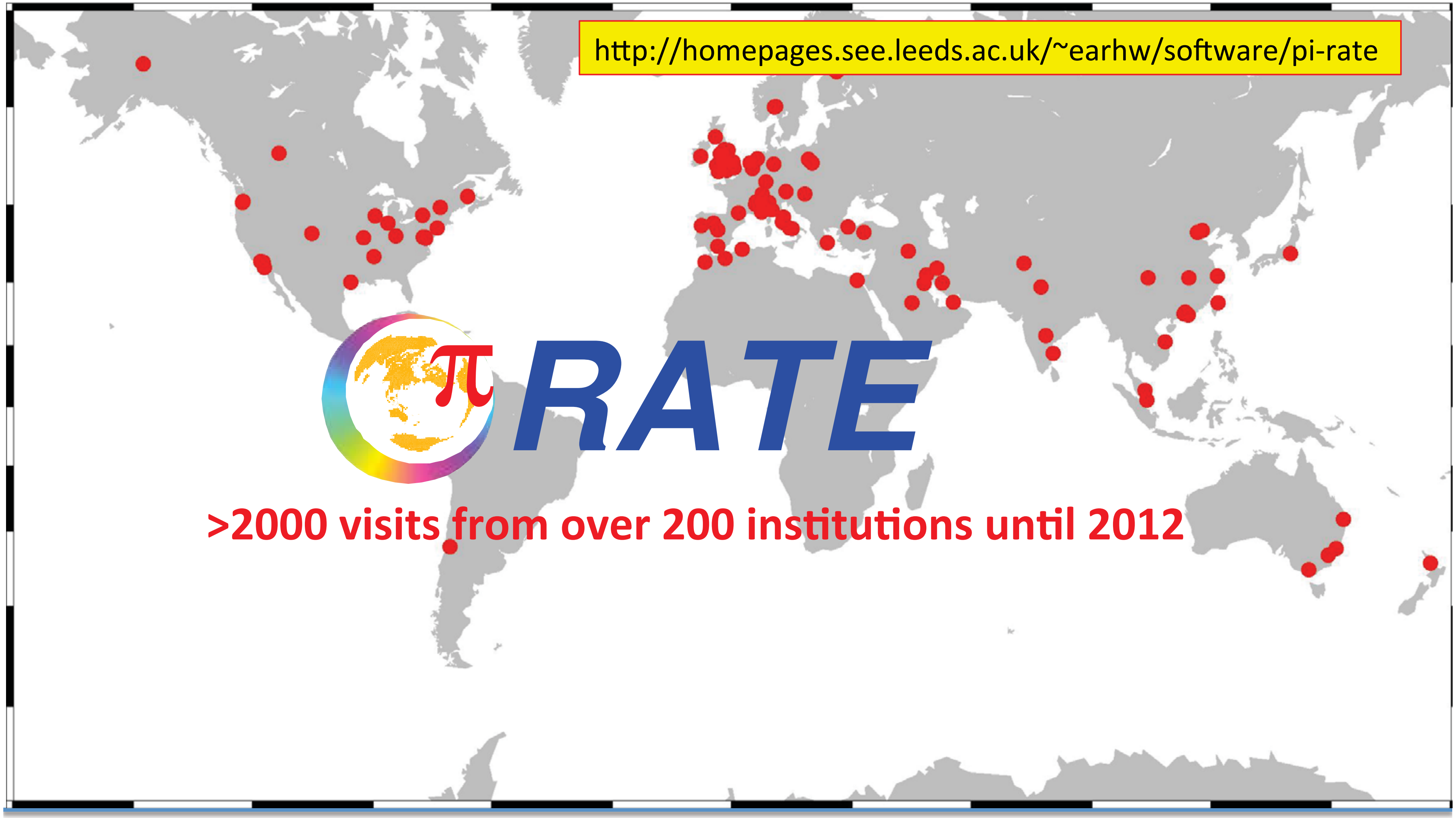


InSAR - Leveling: 0.2 mm/yr

Conclusions and future work

- SBAS method has been widely used for measuring deformation due to its easy realization.
- No general method can reliably correct atmospheric delay errors.
- Phase unwrapping is challenging and time consuming in SBAS.
- Spatial resolution is usually limited due to multi-look processing for phase unwrapping.
- Extraction of different components in InSAR time series.
- New satellites with shorter revisit time will increase coherence, thus make phase unwrapping much easier.

Thank You!


http://homepages.see.leeds.ac.uk/~earhw/software/pi-rate
πRATE
>2000 visits from over 200 institutions until 2012