FRINGE 2017 WORKSHOP

InSAR Time Series Analysis with PySAR

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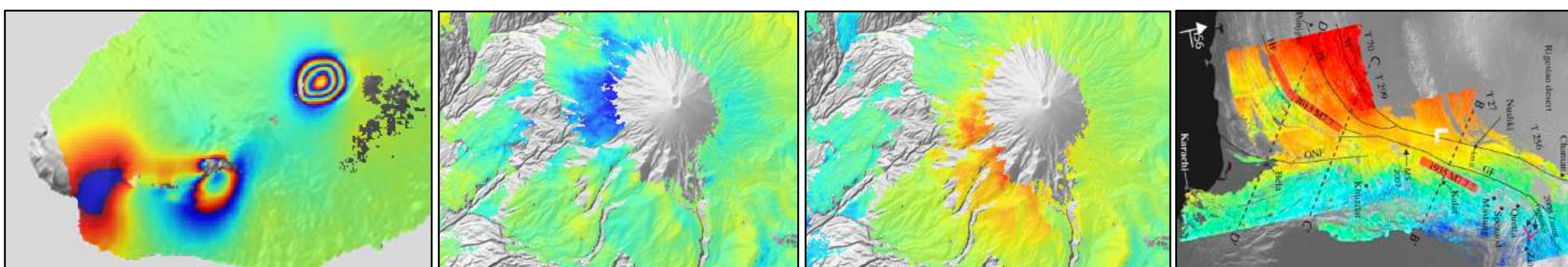
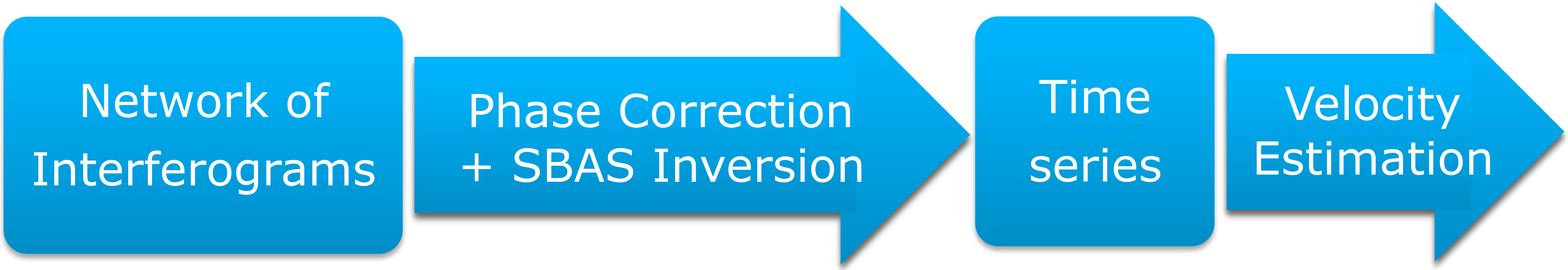
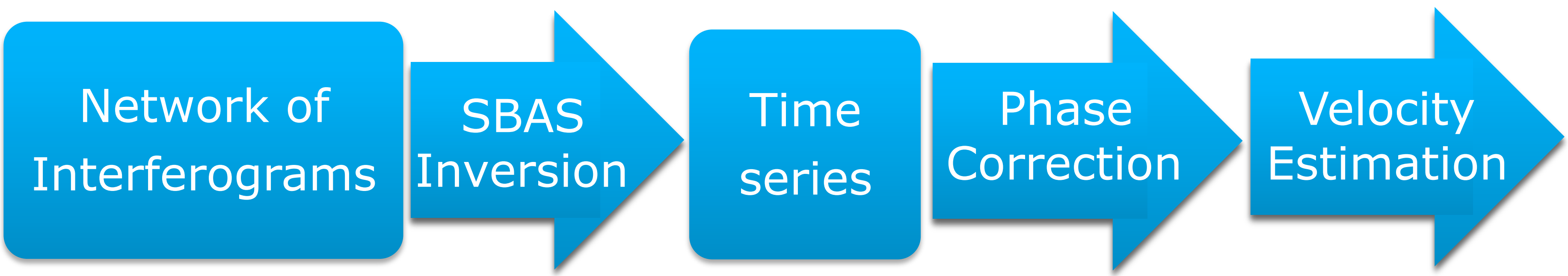


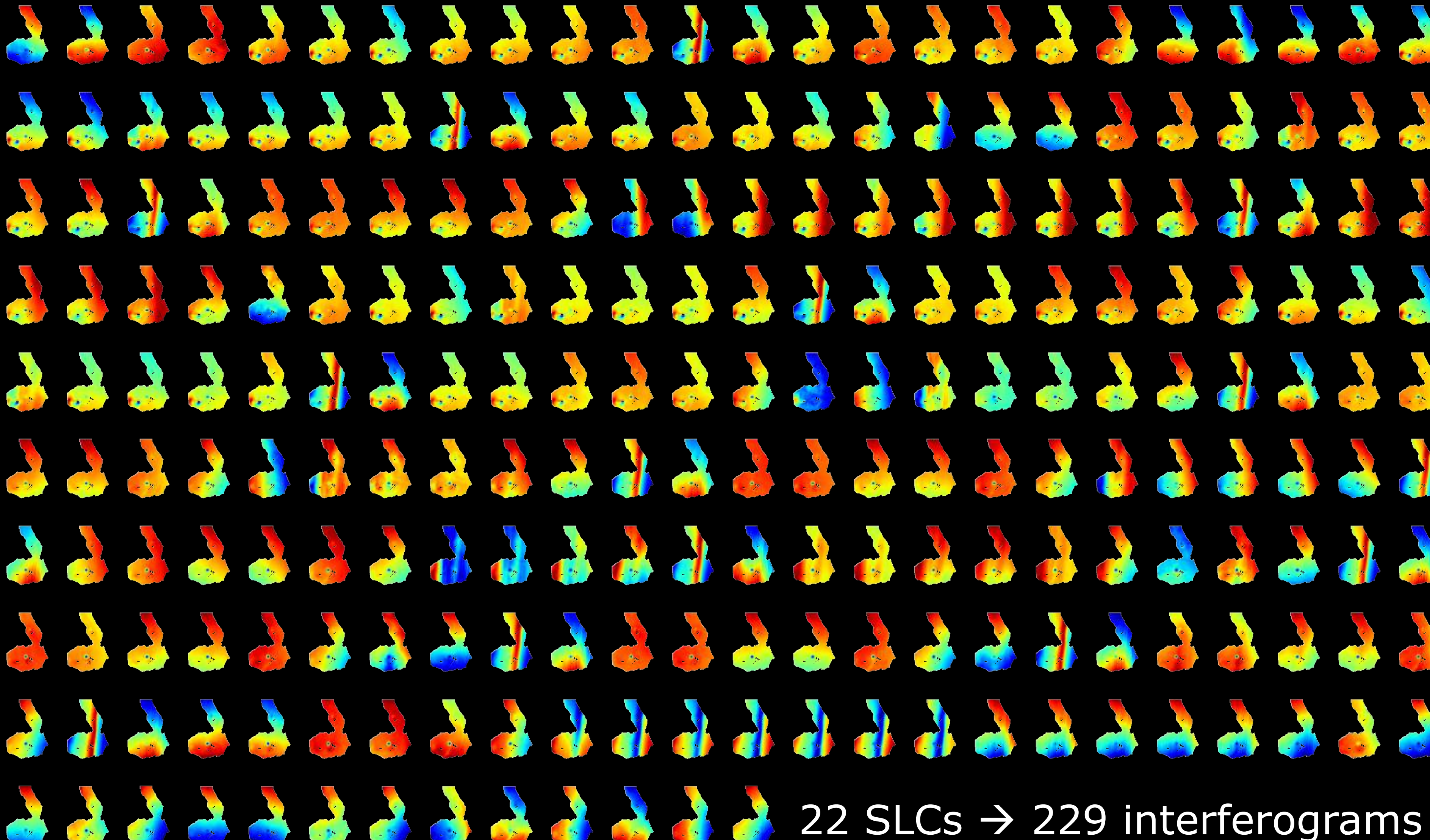
Motivation

Traditional SBAS :



Our approach: phase corrections in time domain





22 SLCs → 229 interferograms

Why phase correction in time series domain?

- Same result idealy but **less expensive in computation & storage**.
  - For N+1 images → up to $\frac{N(N+1)}{2}$ interferograms
  - i.e. 78 S1A/B desc SLCs in Mexico City → up to 3003 interferograms; and it's still growing.

- **Easy to check** each phase correction's effect/ **performance** on time series domain rather than on interferograms.

Network inversion into time series

- Considering *N*+1 SAR images at time $[t_0, t_1, \dots, t_N]$
- Generate *M* interferograms: $\delta\phi^T = [\delta\phi_1, \delta\phi_2, \dots, \delta\phi_M]$
- Network inversion:

$$\delta\phi = A\phi$$

A is the design matrix → **full rank matrix** A leads to unbiased network inversion.

$\phi^T = [\phi_0, \phi_1, \dots, \phi_N)]$ is inversed time series phase with respect to the first date t_0.

Time series phase analysis

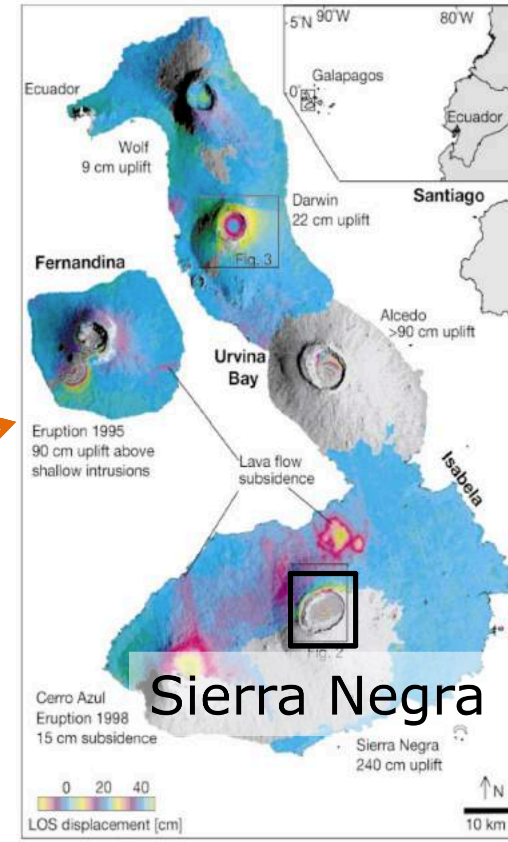
$$\phi_i = \phi_{def,i} + \phi_{atm,i} + \phi^{\varepsilon}_{topo,i} + \phi^{\varepsilon}_{orb,i} + \phi_{noise,i}, \quad i = 0, 1, \dots, N$$

- Cumulative ground deformation at t_i
- Atmospheric difference between t_i and t_1
  - Tropospheric phase delay
  - Ionospheric phase advance, frequency dependent
- Errors in imaging geometry between t_i and t_1
  - DEM error
  - Orbital error
  - Coregistration error and timing error (local oscilattor drift - Envisat)
- Phase noise due to geometric and temporal decorrelation, and thermal noise.

Outline

- Coherence-based network
- Phase corrections

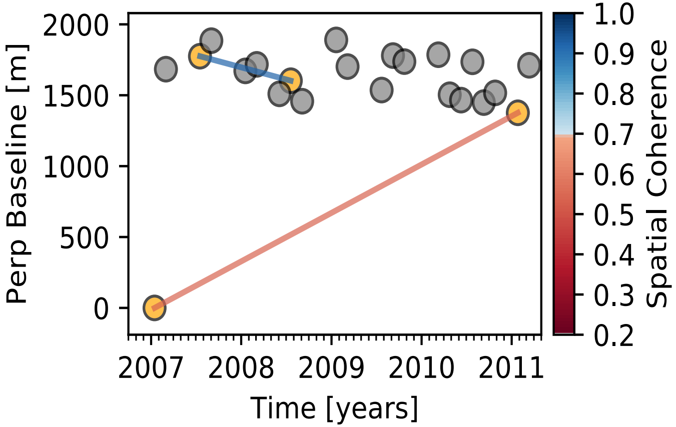
Data location @ Galápagos Island, Ecuador

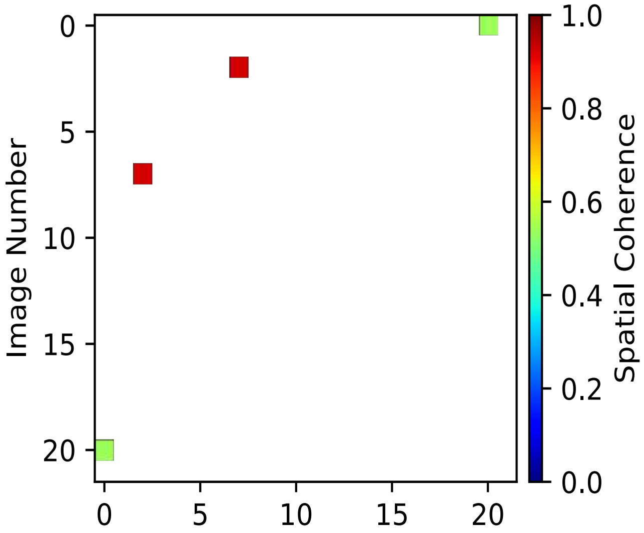


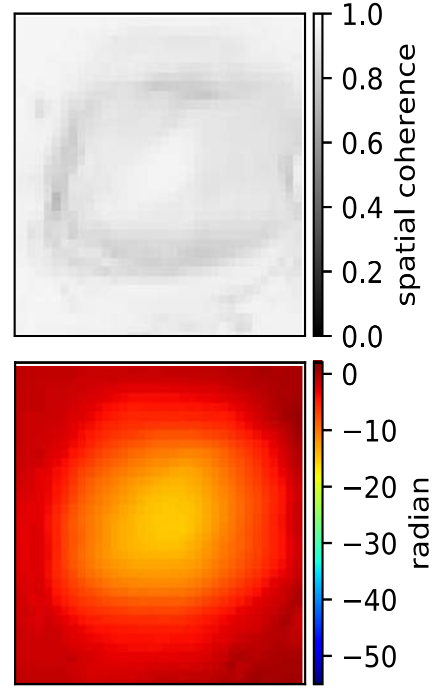
(Amelung et al., 2000)
ERS-1/2

- ALOS ascending track 133
- 2007.01 - 2011.03, 22 scenes

1. Network colored by spatial coherence



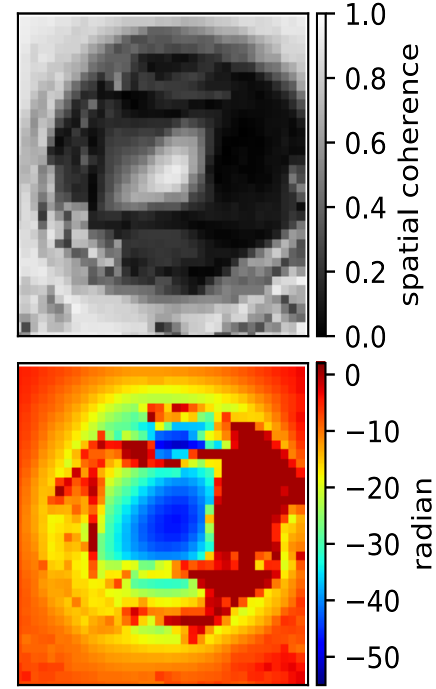




070718-080720

Bperp = 173 m

Btemp = 1 yr

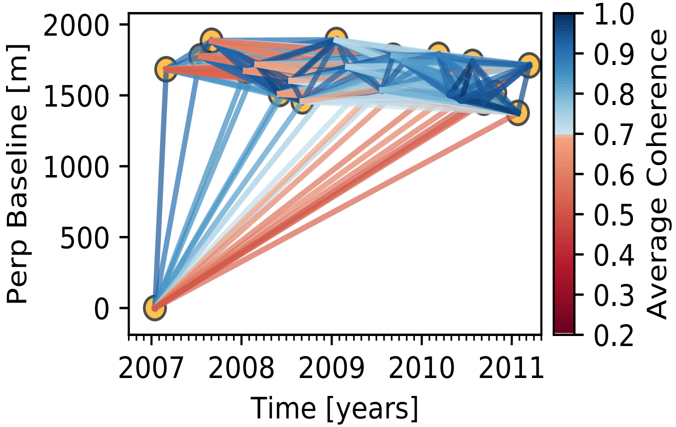


070115-110126

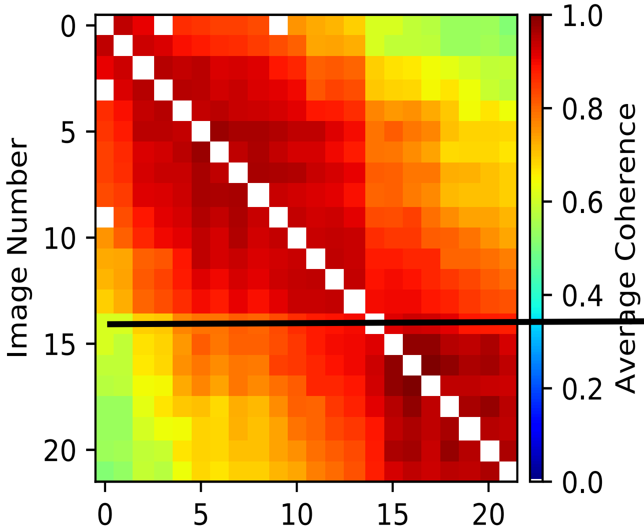
Bperp = 1376 m

Btemp = 4 yr

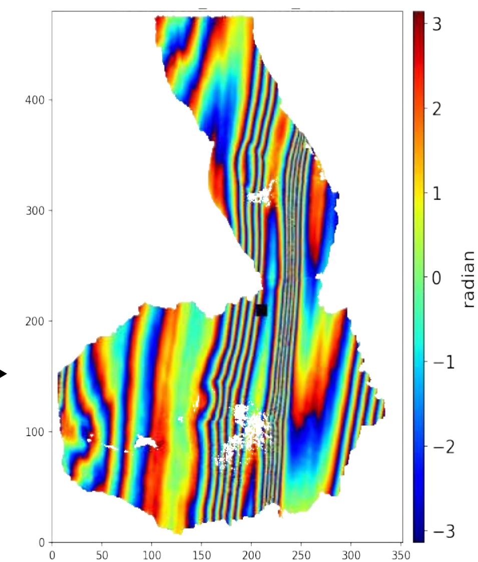
1. Network and coherence matrix



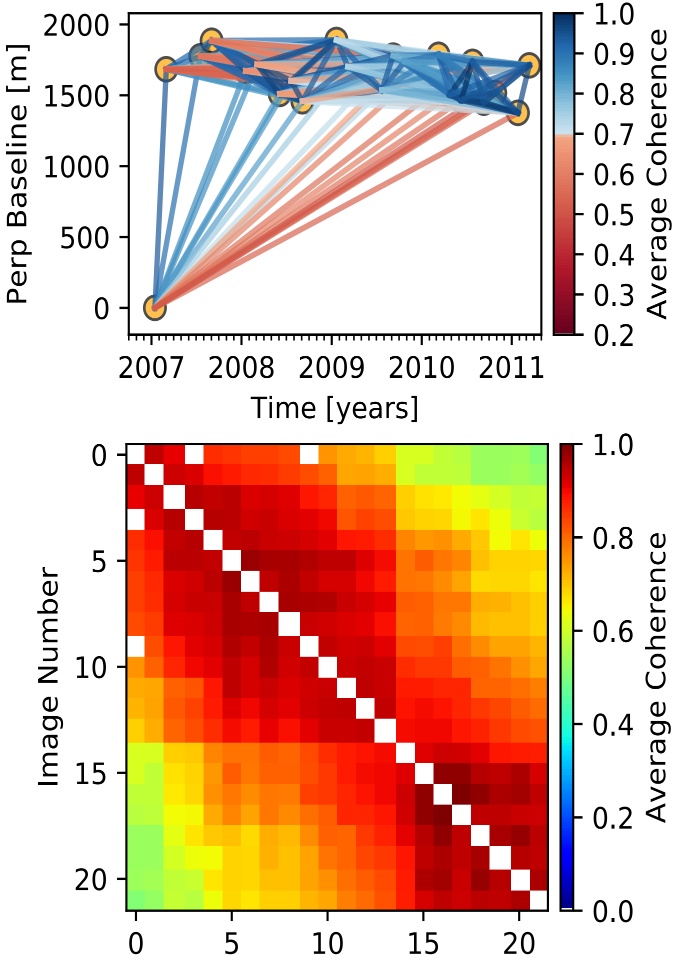
- Coherence decrease as temporal baseline increase



2010-03-10



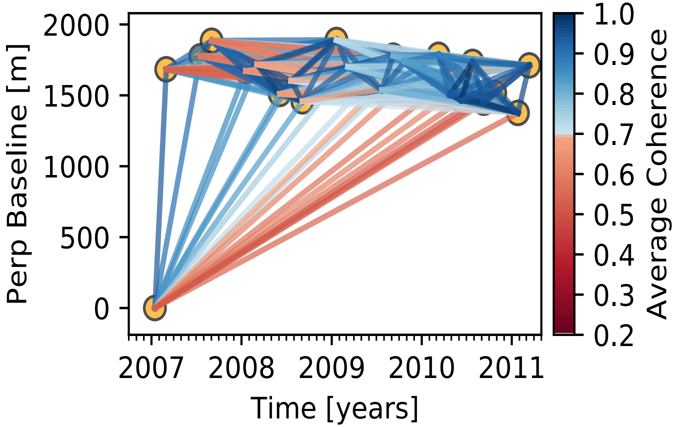
1. Network and coherence matrix

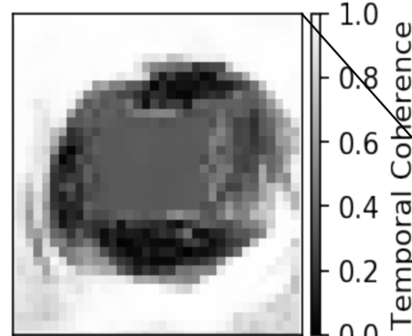


- Coherence decrease as temporal baseline increase
- Use **calculated total coherence** directly instead of **predicting coherence** from critical temporal and perpendicular baseline:

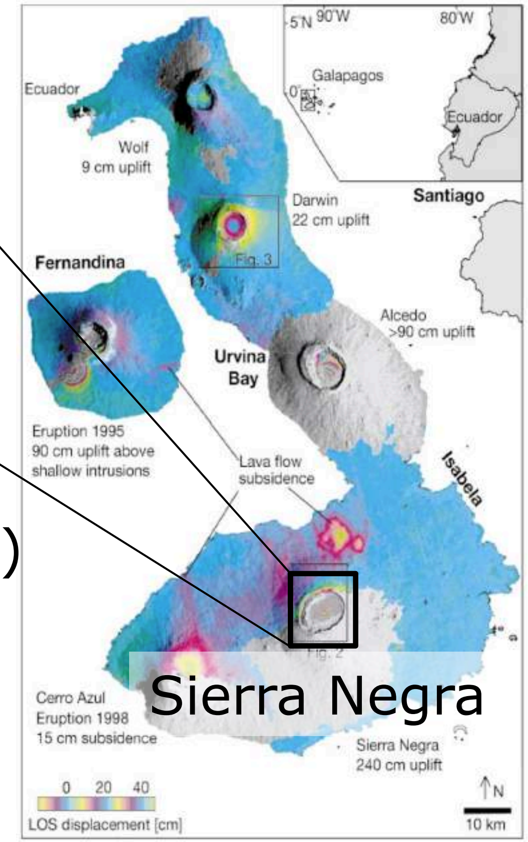
$$\rho_{\text{total}} = \rho_{\text{temporal}}\rho_{\text{spatial}}\rho_{\text{doppler}}\rho_{\text{thermal}}$$

1. Network: Small baselines





Υ



(Amelung et al., 2000)

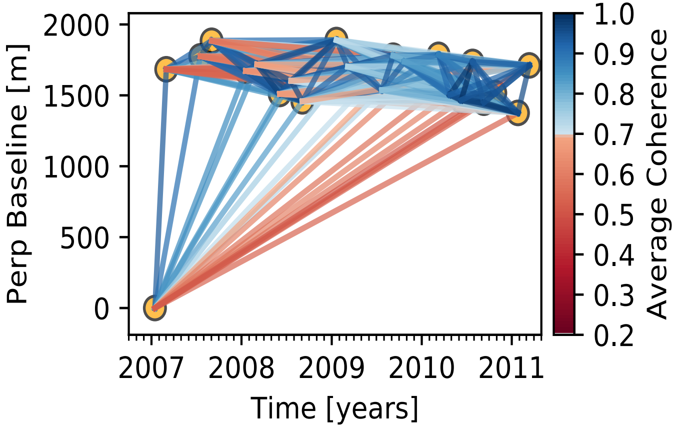
- mask based on Υ: $\Upsilon \geq 0.7$
- Temporal coherence Υ (Tizzani et al., 2007)
  - index of reliable network inversion

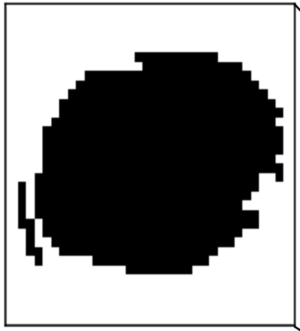
$$\gamma = \frac{\sum_{k=1}^{M} \exp\left[j(\delta\phi_k - \delta\bar{\phi}_k)\right]}{M}$$

where, M – number of interferograms

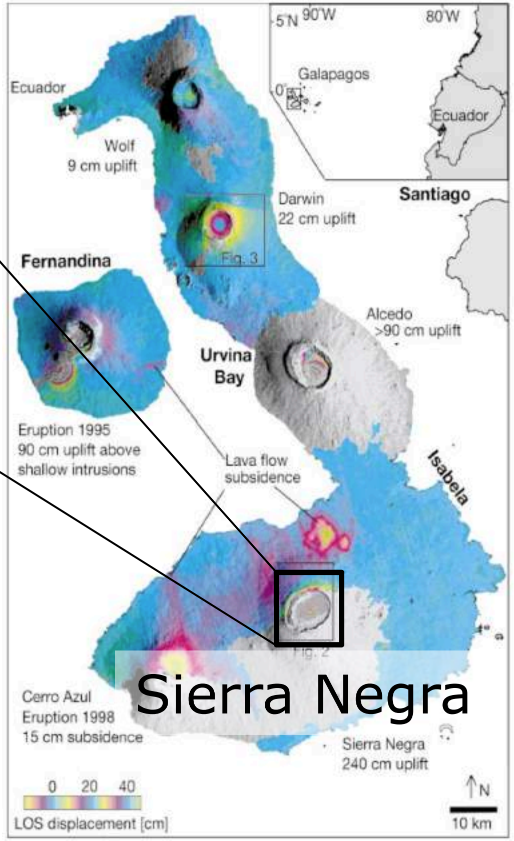
$\delta\phi_k$ and $\delta\bar{\phi}_k$ – original and "reconstructed" interferograms

1. Network: Small baselines





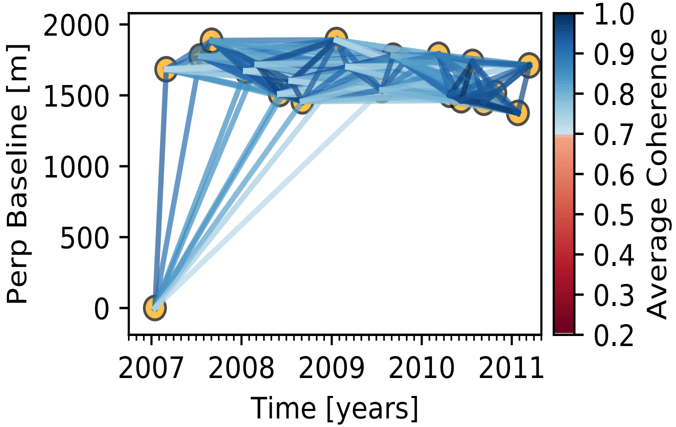
$\Upsilon \geq 0.7$

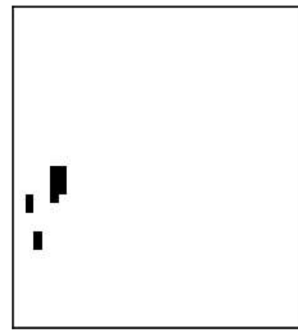


(Amelung et al., 2000)

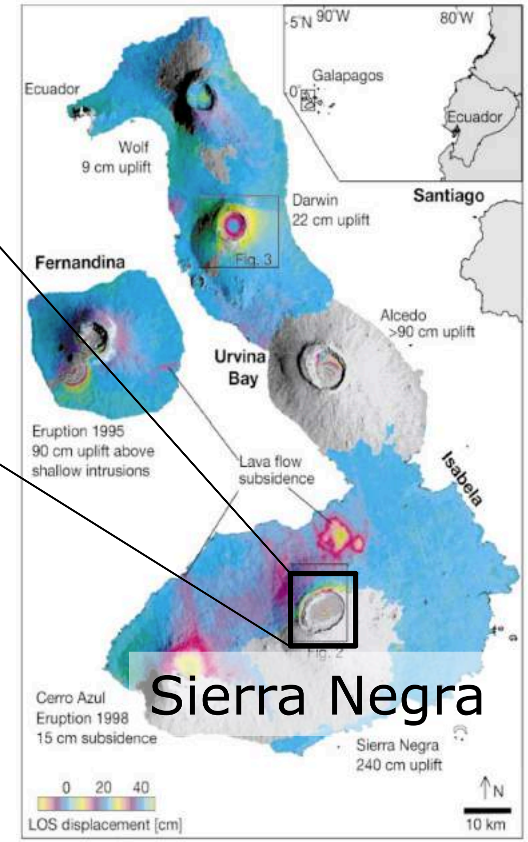
- mask based on Υ: $\Upsilon \geq 0.7$
- Temporal coherence Υ
  - index of reliable network inversion

1. Network: Coherence-based





$\Upsilon \geq 0.7$



(Amelung et al., 2000)

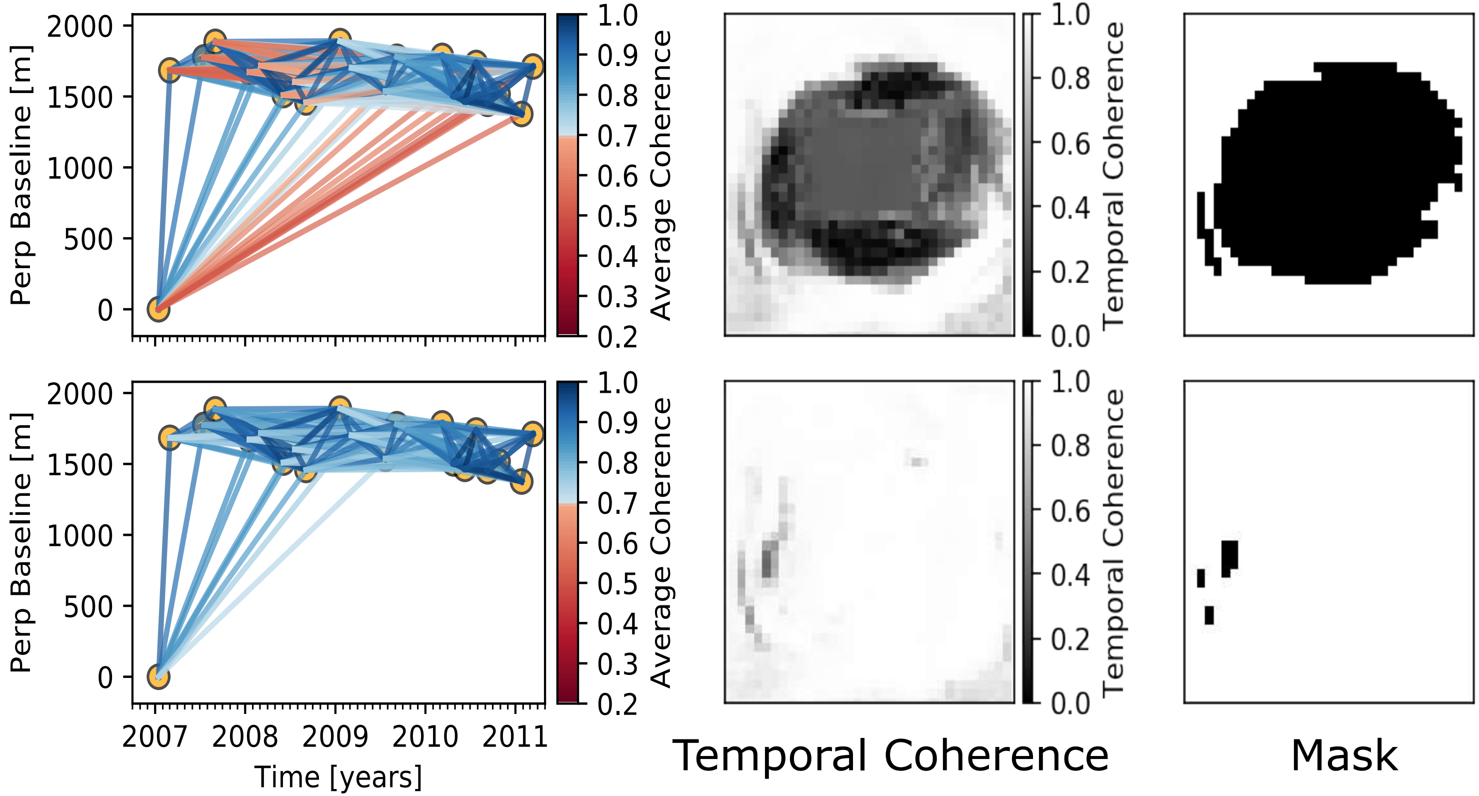
- mask based on Υ: $\Upsilon \geq 0.7$
- Temporal coherence Υ
  - index of reliable network inversion

1. Network: Comparison

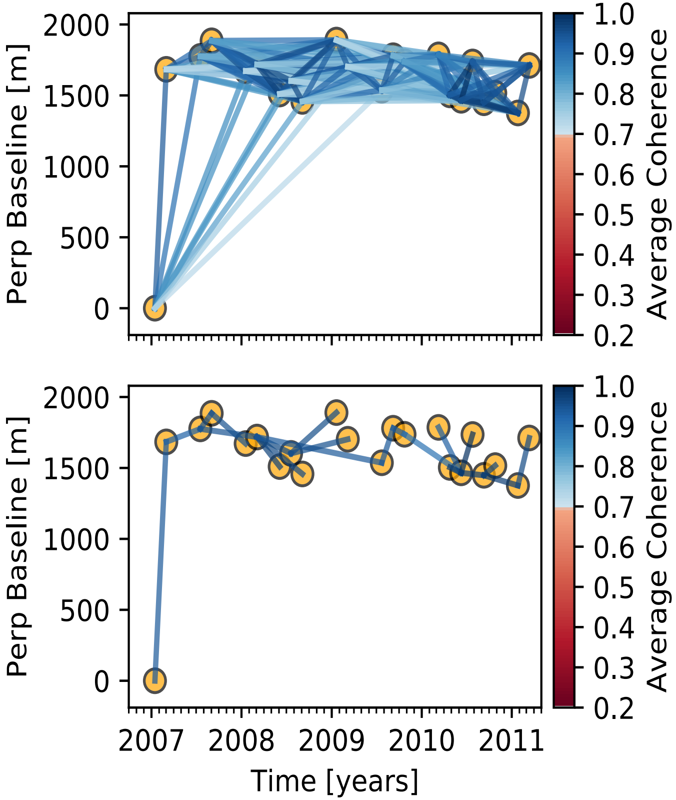
- Improved network inversion / temporal coherence
  → higher spatial coverage

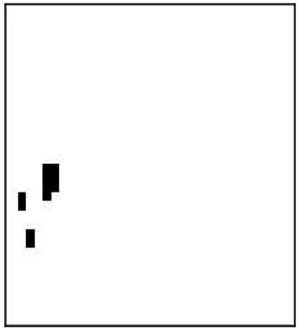
Pruning/ Small Baseline

Coherence -based



1. Network: Coherence-based + MST

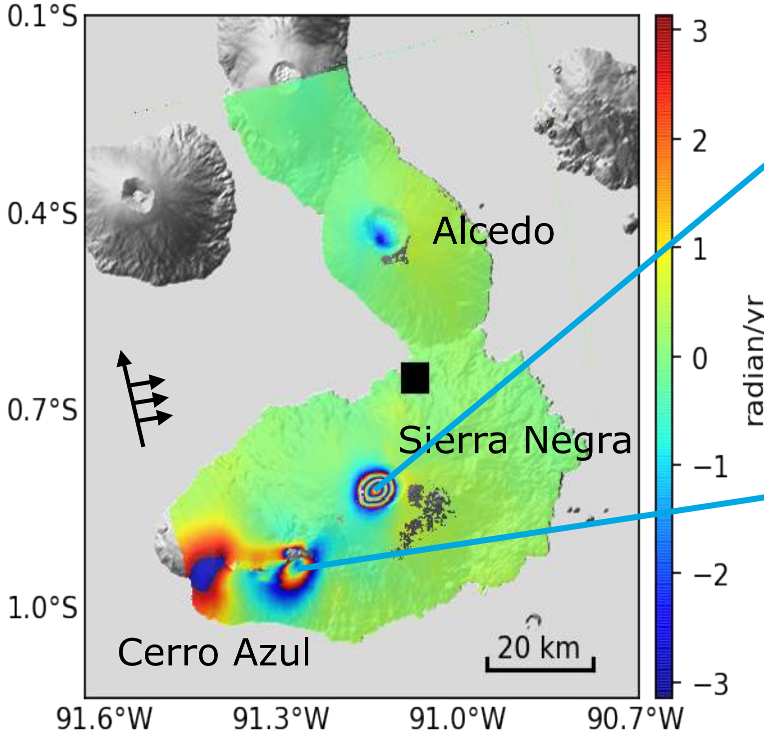




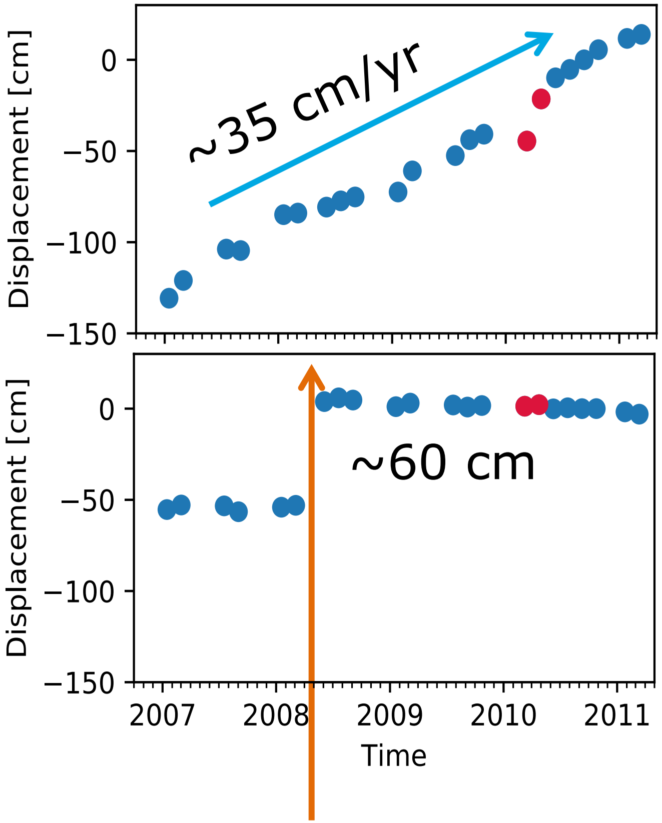
Minimum Spanning Tree
→ ensure fully connected network

→ Over-determined system
→ Un-biased network inversion

Galápagos: Time series result



Red dot: exclude dates



InSAR processor: ROI_PAC

2008 Dike Intrusion @ Cerro Azul

Outline

- Coherence-based network
- Phase corrections

2. Phase correction tools

$$\phi_i = \phi_{def,i} + \phi_{atm,i} + \phi^{\varepsilon}_{topo,i} + \phi^{\varepsilon}_{orb,i} + \phi_{noise,i}, \; i = 0, 1, \ldots, N$$

- Tropospheric delay correction:
  - Weather re-analysis models using PyAPS supporting ERA-Interim, MERRA, NARR datasets (Dee et al., 2011; Jolivet et al., 2011)
  - Height-correlation (Doin et al., 2009)
  - Joint inversion of baseline error and stratified tropospheric delay (Jo et al., 2010)
- Imaging geometric errors correction:
  - DEM error correction in time series domain (Fattahi and Amelung, 2013)
  - Local oscilattor drift correction for Envisat (Marinkovic and Larsen, 2013)
- Ramp removal for localized, short wavelength deformation
  - Optimal selection of reference date

2. Order of phase correction

- Based on the dependency & reliability of each method:

    - **ERA-Interim → DEM error (→ deramping)**

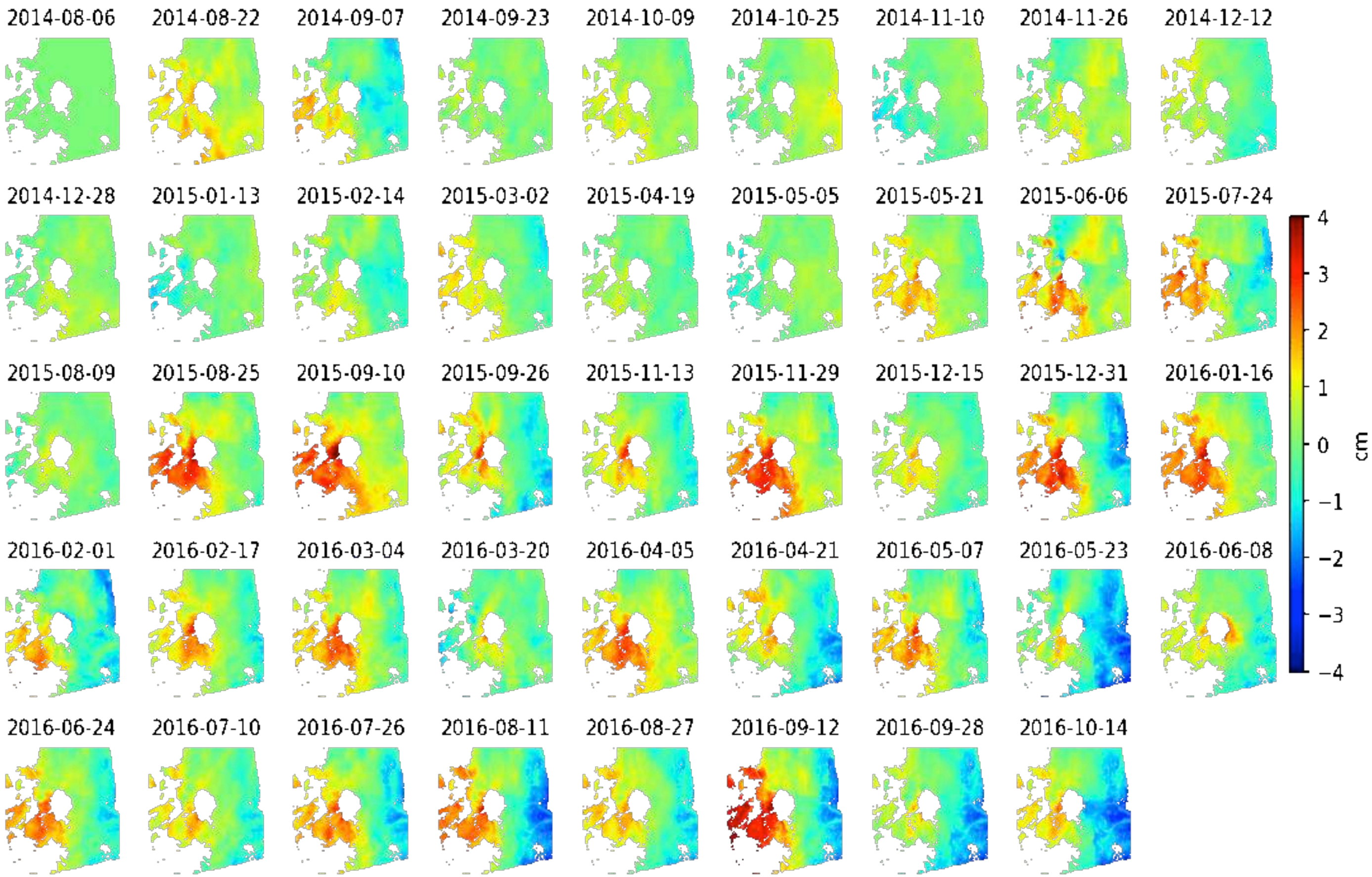
    - DEM error → height-correlated tropo (→ deramping)

Data location @ Cotopaxi Volcano, Ecuador

(Morales-Rivera et al., 2017, in Review)

- CSK ascending track 6
- 2014.08 - 2016.10, 44 scenes

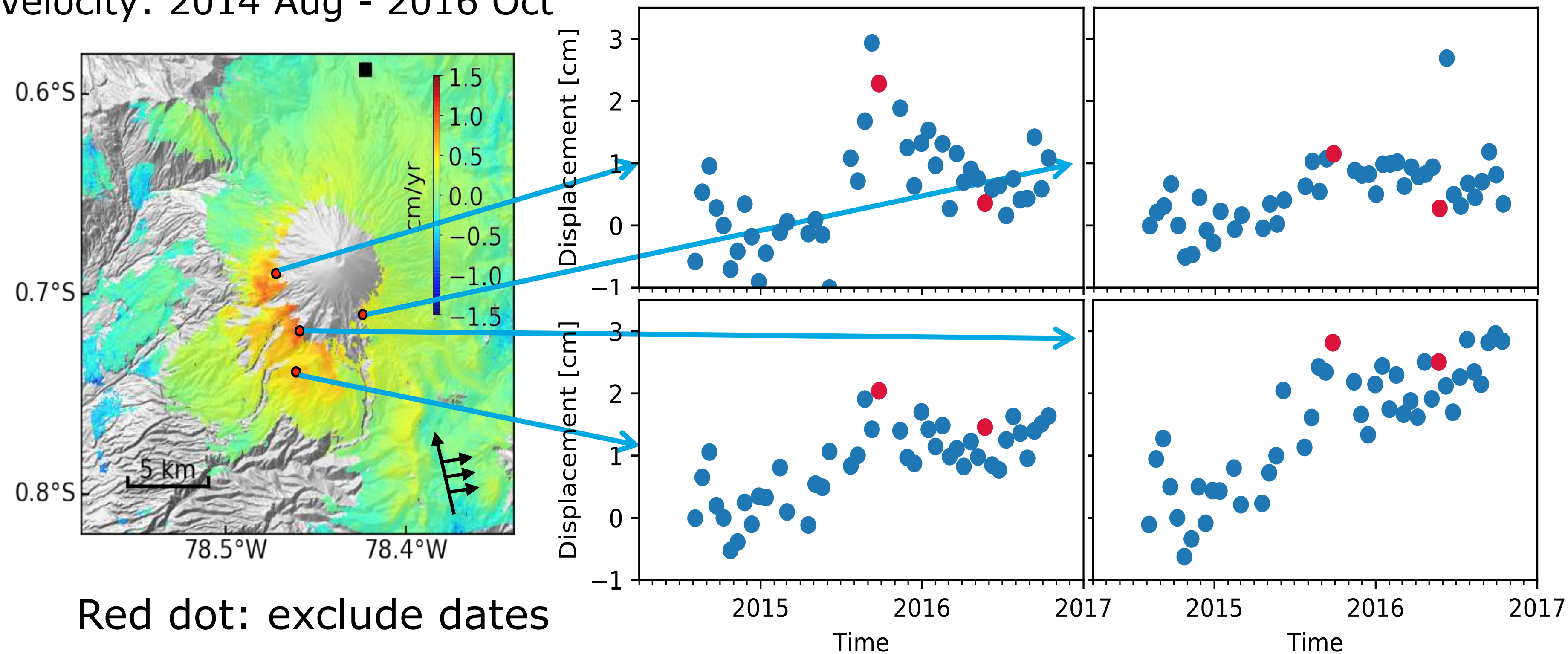
Raw



2014-08-06
2014-08-22
2014-09-07
2014-09-23
2014-10-09
2014-10-25
2014-11-10
2014-11-26
2014-12-12
2014-12-28
2015-01-13
2015-02-14
2015-03-02
2015-04-19
2015-05-05
2015-05-21
2015-06-06
2015-07-24
2015-08-09
2015-08-25
2015-09-10
2015-09-26
2015-11-13
2015-11-29
2015-12-15
2015-12-31
2016-01-16
2016-02-01
2016-02-17
2016-03-04
2016-03-20
2016-04-05
2016-04-21
2016-05-07
2016-05-23
2016-06-08
2016-06-24
2016-07-10
2016-07-26
2016-08-11
2016-08-27
2016-09-12
2016-09-28
2016-10-14
4
3
2
1
0
−1
−2
−3
−4
cm

Highly non-linear deformation @ Cotopaxi

Velocity: 2014 Aug - 2016 Oct

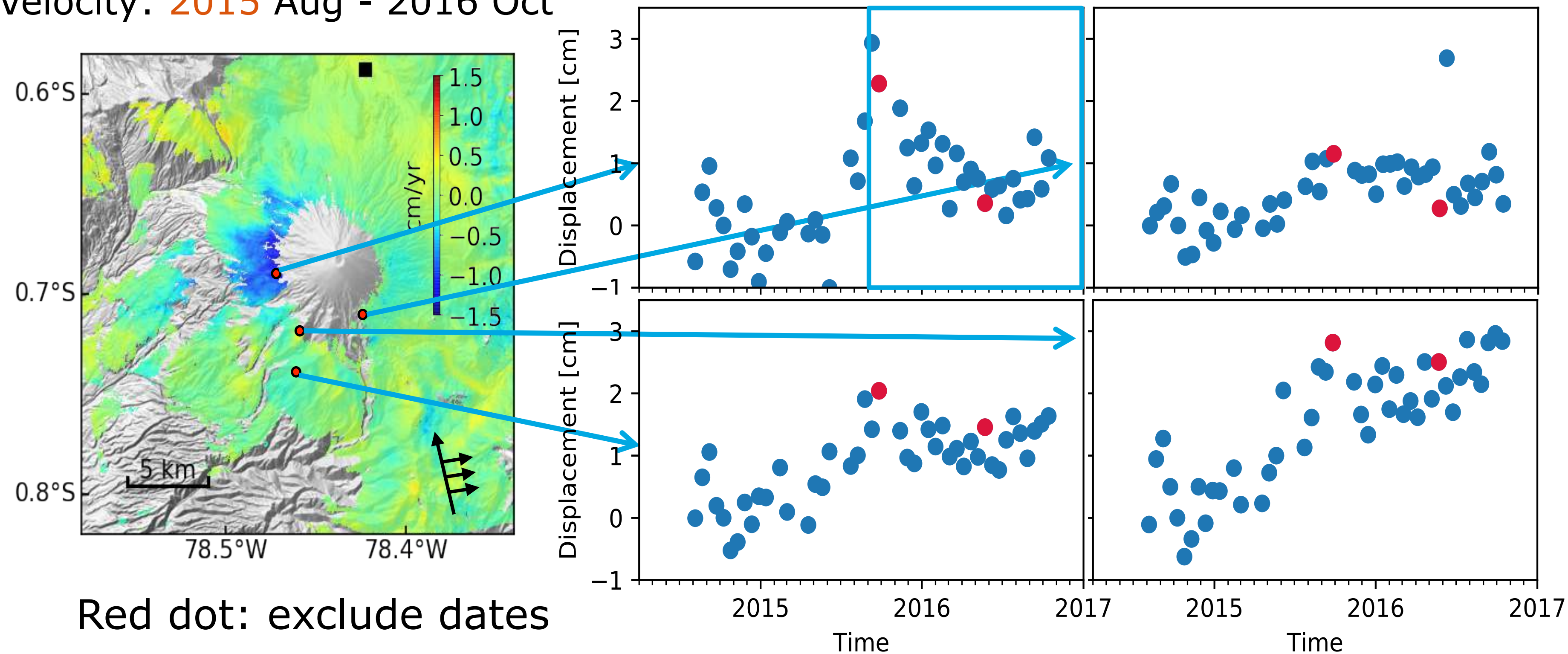


Red dot: exclude dates

No temporal model or temporal filtering applied → Reserve highly non-linear deformations are well reserved.

Highly non-linear deformation @ Cotopaxi

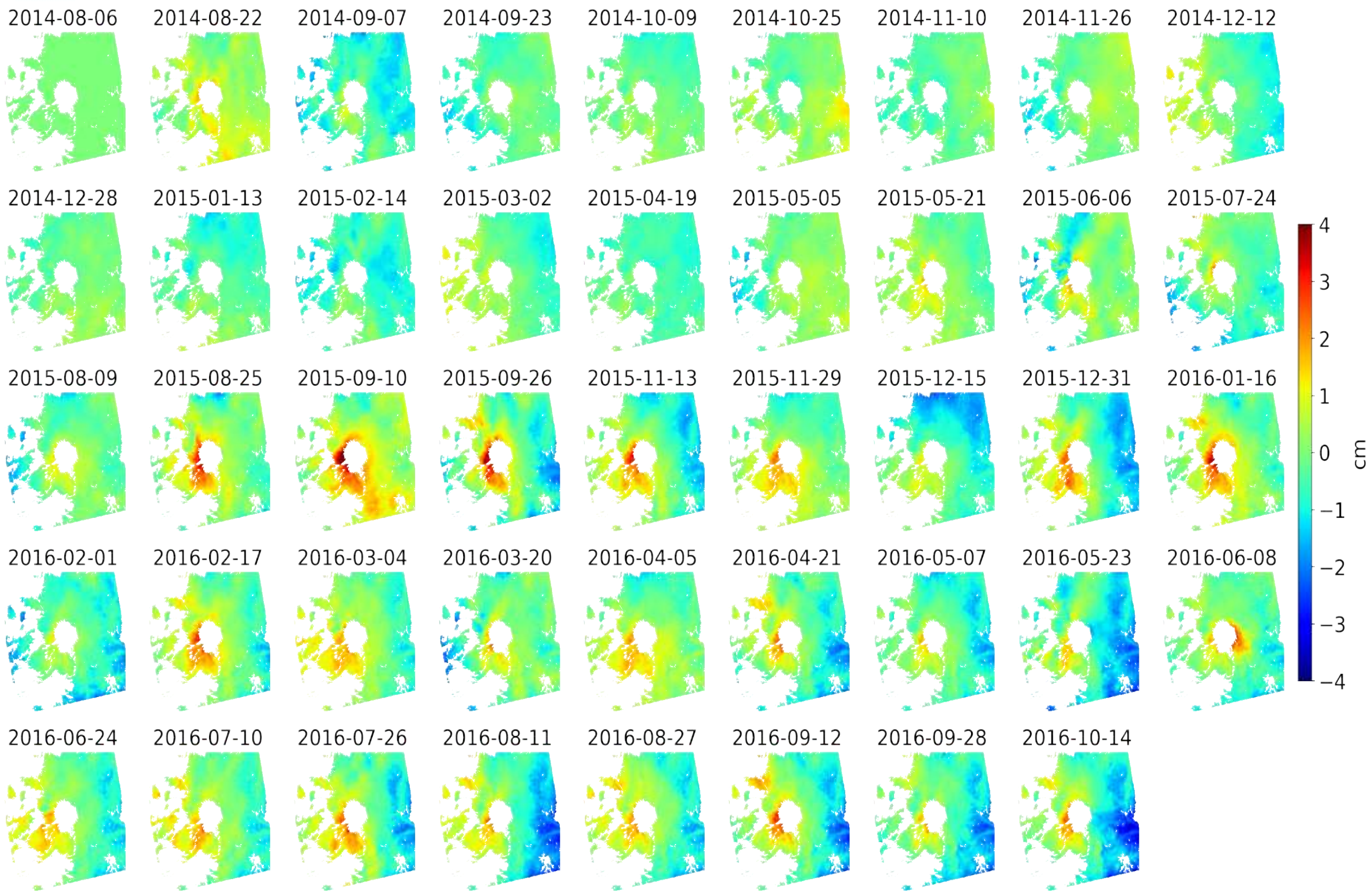
Velocity: 2015 Aug - 2016 Oct



Red dot: exclude dates

No temporal model or temporal filtering applied → Reserve highly non-linear deformations are well reserved.

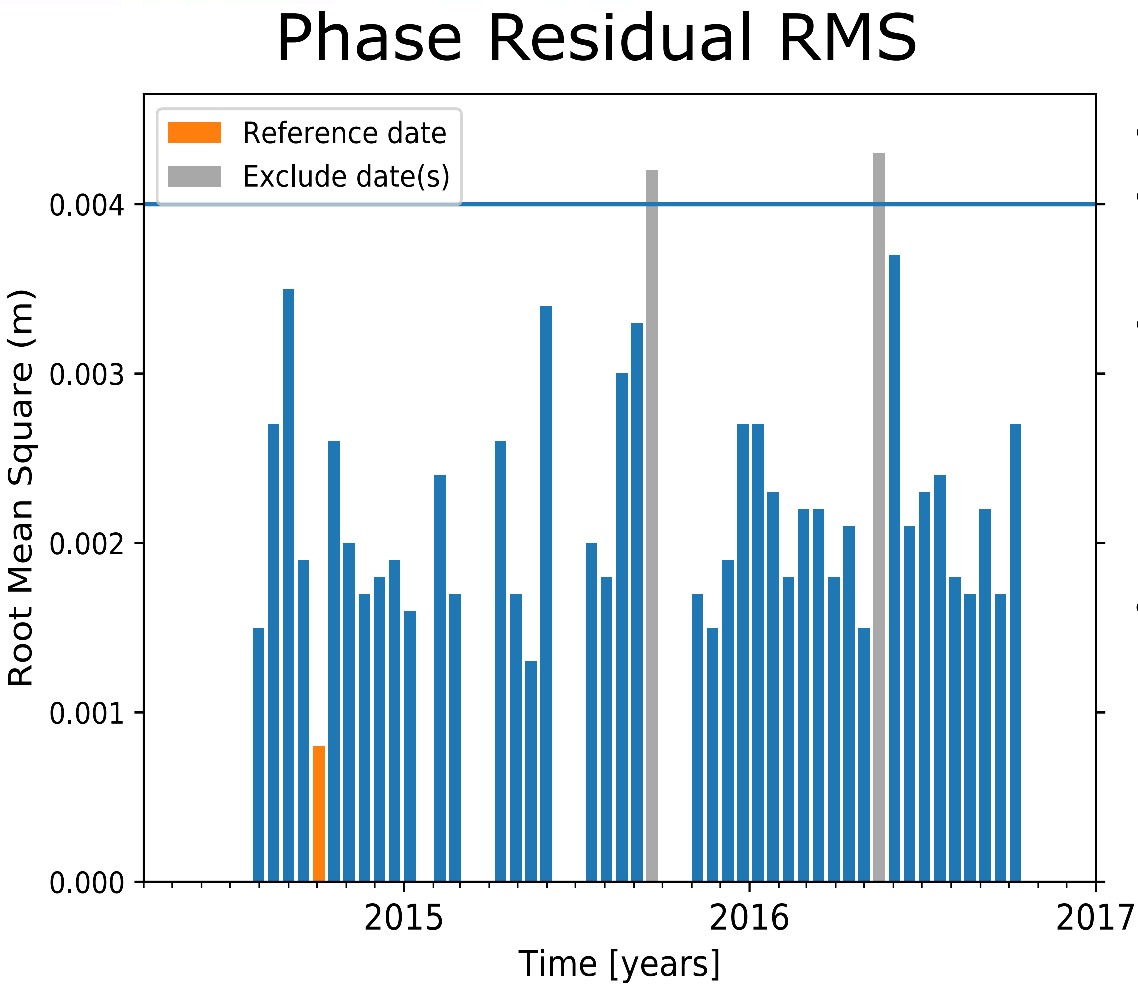
2.3 Optimal reference date: Tropo + Topo



2.3 Tropo + Topo - Def + Ramp

Phase residual

2.3 Optimal selection of reference date



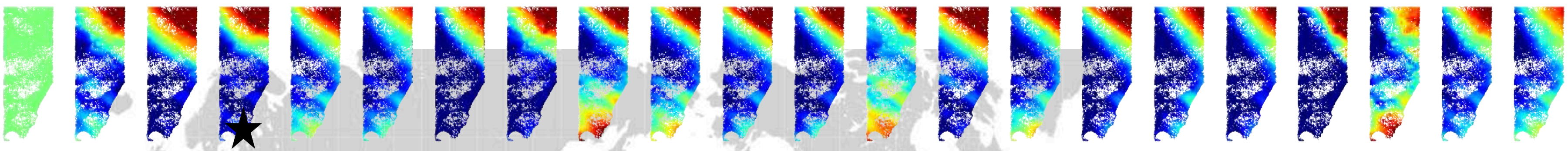
Unmodeled components:

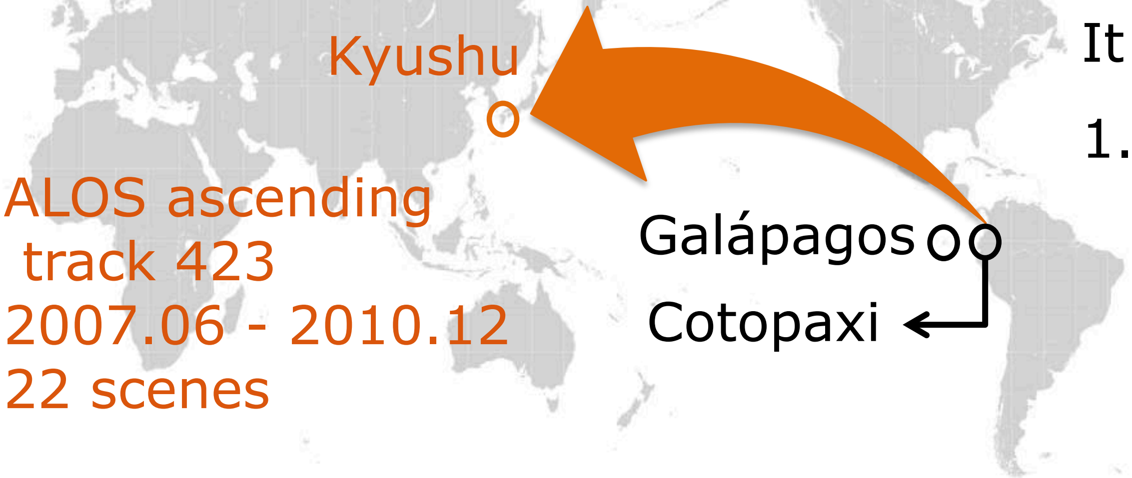
- tropospheric residual
- high frequency ionosphere
- unmodeled ground deformation

- Used only for **optimal reference date selection** and **outlier detection**.

2.3 Reference date sometimes matters!

- Default reference date - 1st date



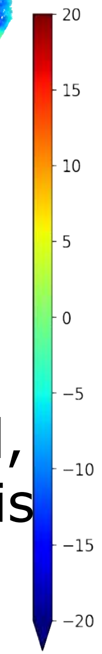


- ALOS ascending
- track 423
- 2007.06 - 2010.12
- 22 scenes

- It won't affect the linear velocity estimation

It helps when:

1. If interested in localized, short wavelength deformation signal, where deramping is needed
2. If first date is contaminated by severe atm turbulence



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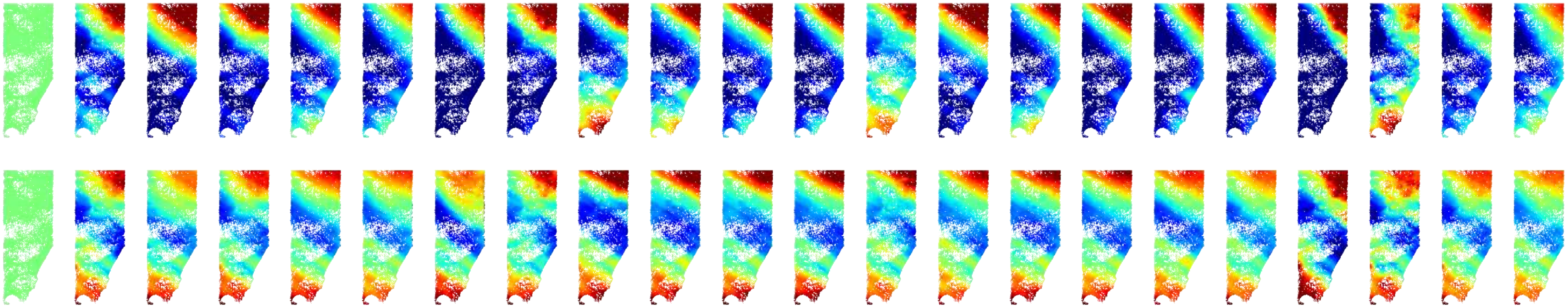
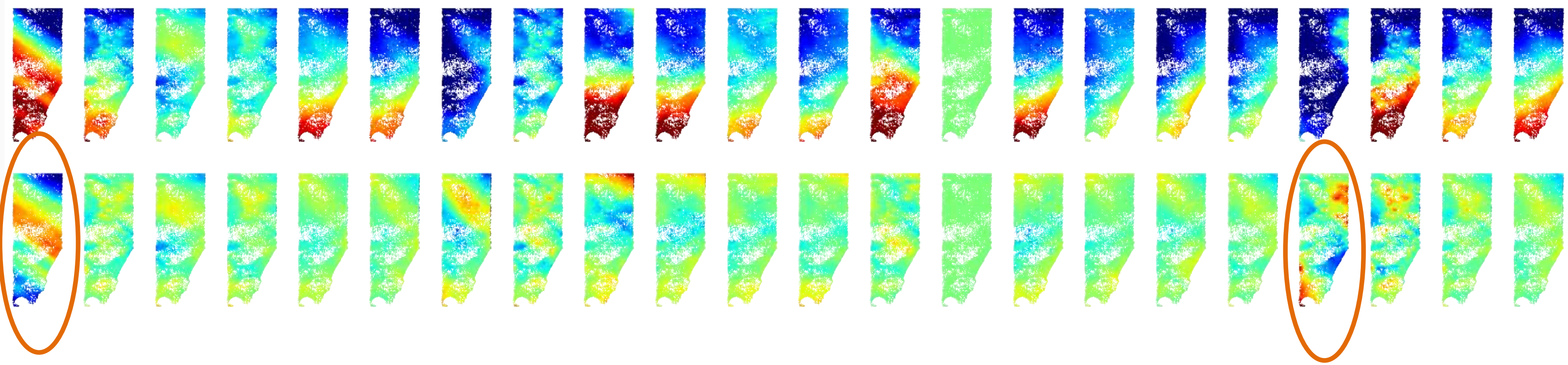
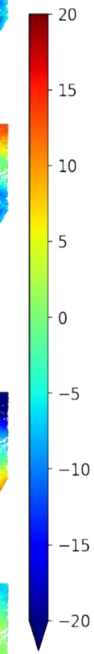


- Optimal reference date

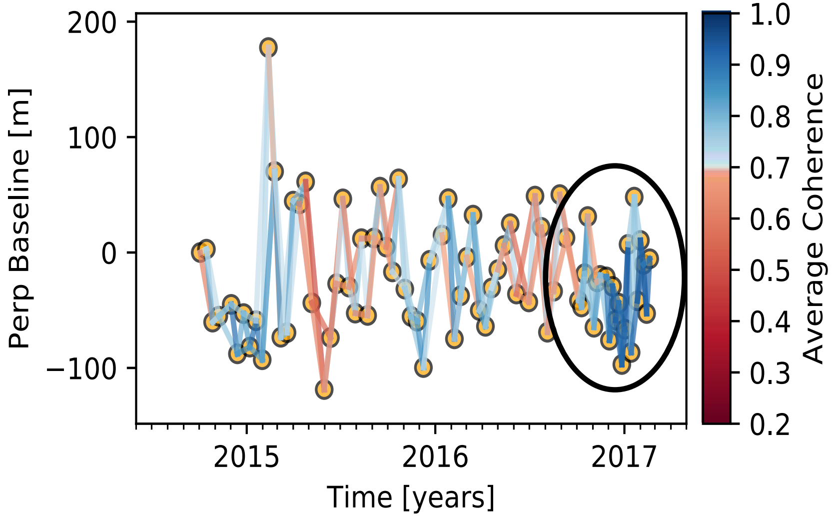


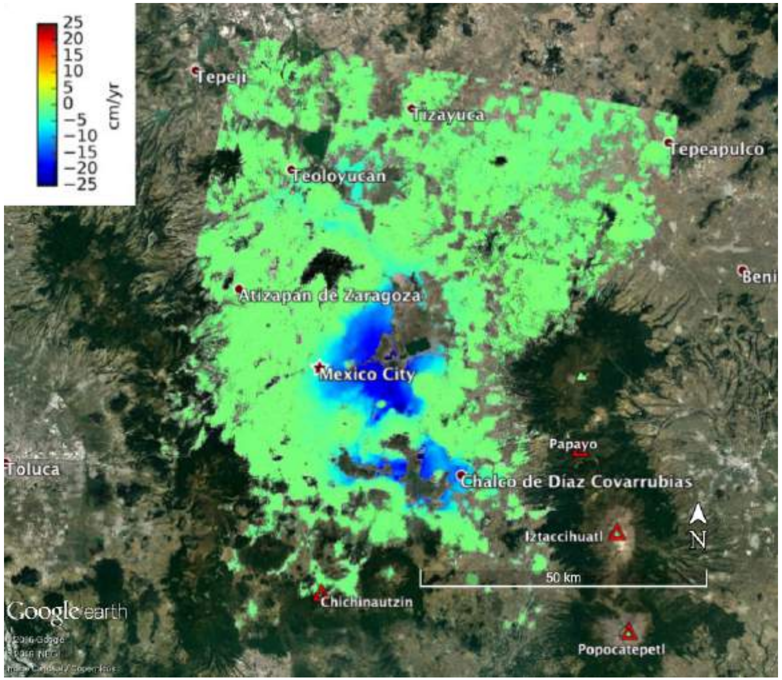


Code on Github, it's open-source!

https://yunjunz.github.io/PySAR/

PySAR reads ROI_PAC, ISCE and Gamma

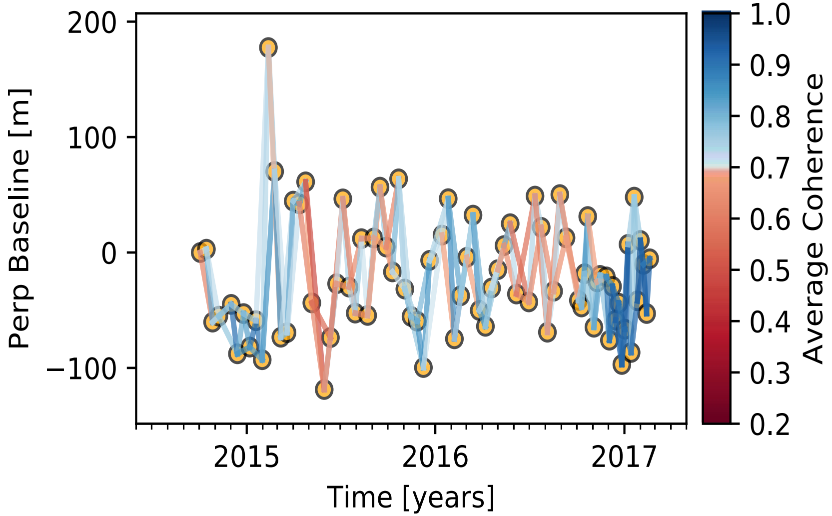




- Coherence increase since the end of 2016 - the 6 days S1A and S1B pairs.

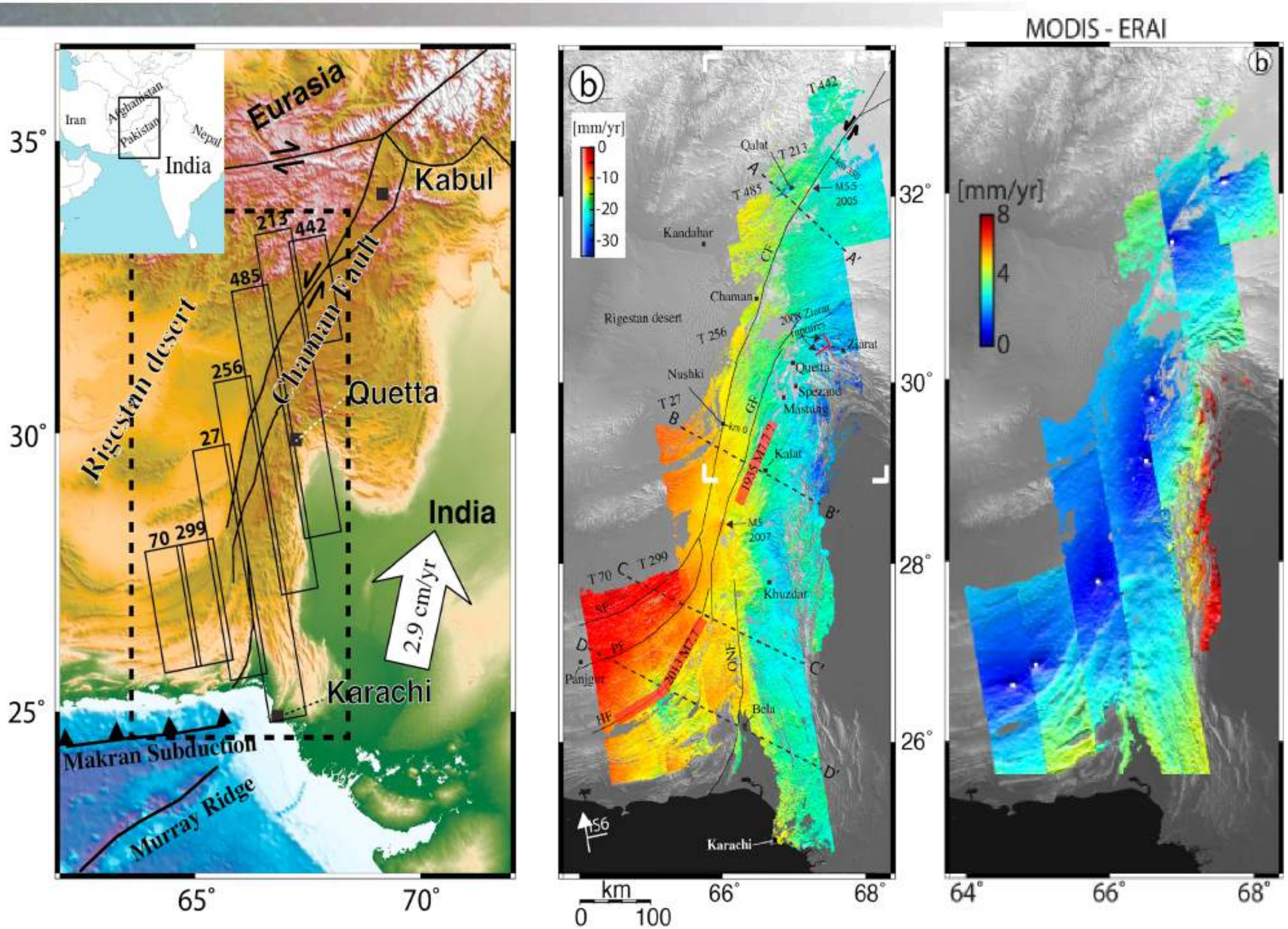
- InSAR processor: ISCE
- Sequential network
- Sentinel-1 A/B TOPS, descending track
- 2014 Oct - 2017 Feb, 78 scenes

Looking forward to S1 and future missions



- Well controlled small tubes and regular acquisitions
  → simple network like sequential works fine
- Less geometric error effect
- More effort should be put into the improvement of tropospheric and ionospheric correction.

Velocity uncertainty due to troposphere



(Fattahi & Amelung, 2015, 2016)

Conclusion

- Use coherence-based network to increase spatial coverage of InSAR measurement.
- Apply phase correction in time series domain rather than interferograms domain.
- Propose an optimal reference date selection methos, based on minimum phase residual RMS; and prelimenary outlier detection.
- Provide InSAR uncertainty due to stochastic tropospheric delay.