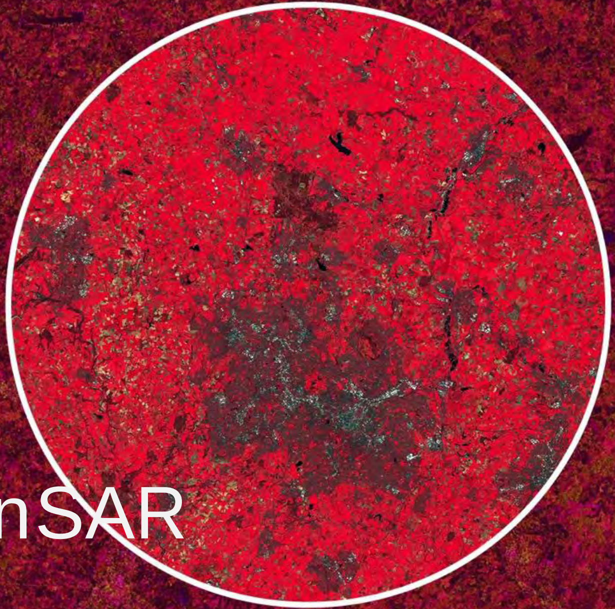
National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LEICESTER

esa

→ 8th ADVANCED TRAINING COURSE ON LAND REMOTE SENSING

10–14 September 2018
University of Leicester | United Kingdom



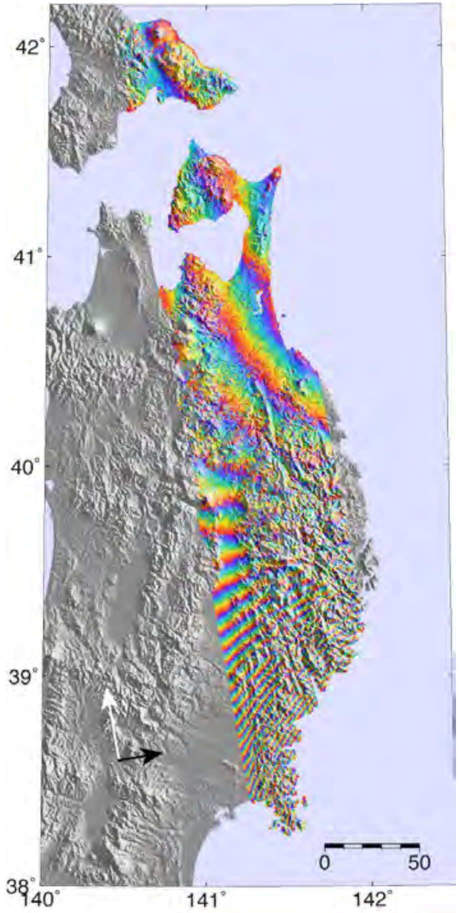
Surface deformation with PSInSAR

Andy Hooper

12/09/2018

Motivation for PSInSAR

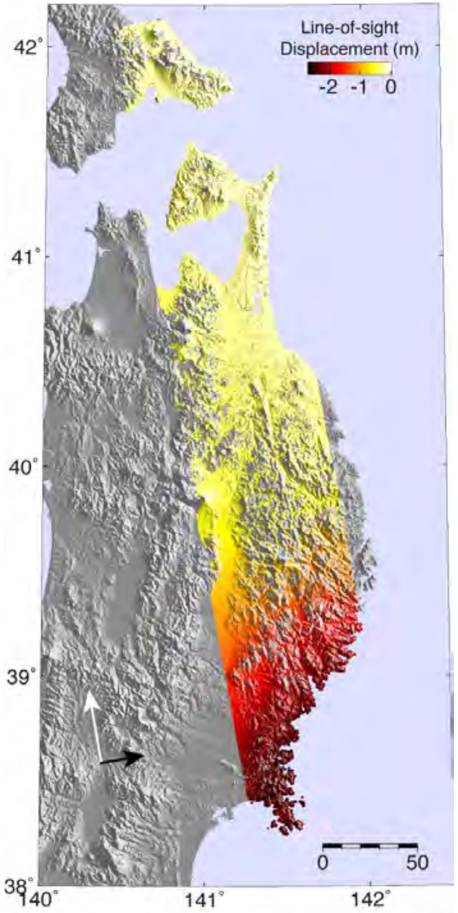
A “good” interferogram



- Good correlation (low noise)
- Signal is dominated by deformation

2011 Tohoku earthquake

ALOS data supplied by JAXA: each colour fringe represents 11.6 cm of displacement away from satellite



Motivation for PSInSAR

Unwrapped good interferogram

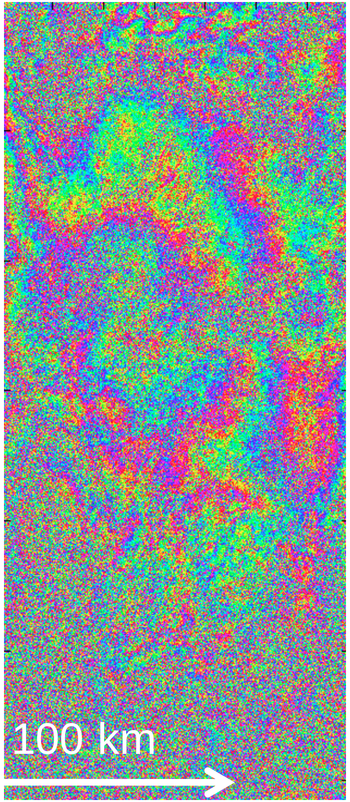
- Can be easily unwrapped
- Deformation dominates

Integrated phase cycles giving 2.5 m relative displacement

More typical interferograms

Signal dominated by atmosphere, orbit and DEM errors

(larger than deformation for low strains and short intervals)



More typical interferograms

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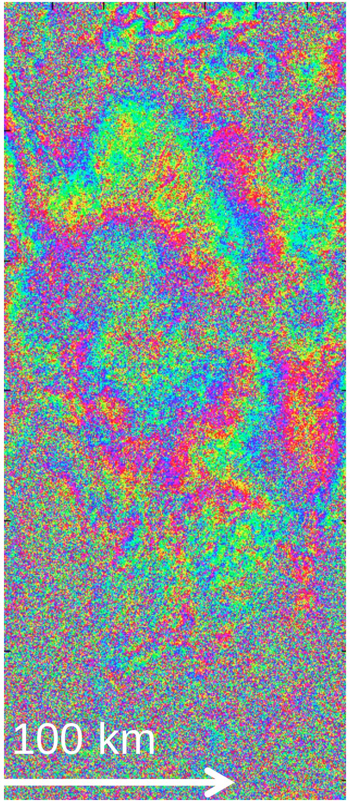
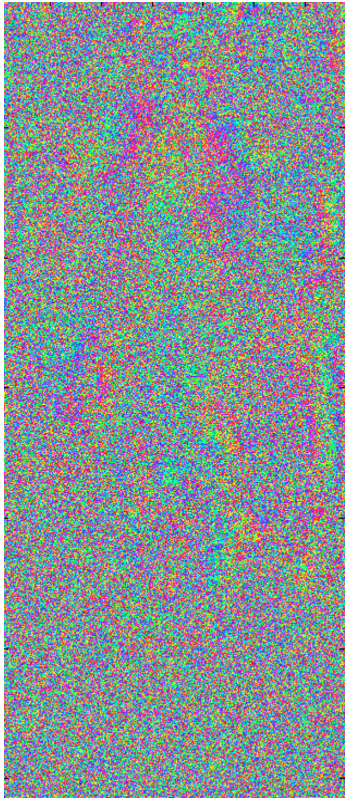




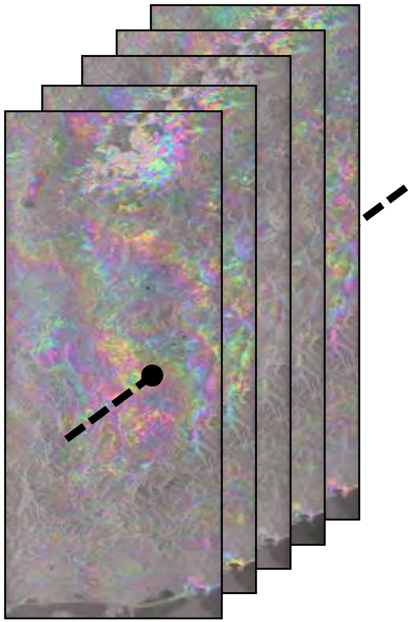
High Decorrelation

(especially for long intervals)

Persistent Scatter (PS) InSAR

Motivation

- Allows better selection of coherent pixels
- DEM error estimation possible
- More reliable phase unwrapping possible (3-D)
- Other errors can be reduced by filtering in space and time
- Additionally, deformation can be attributed to specific structures

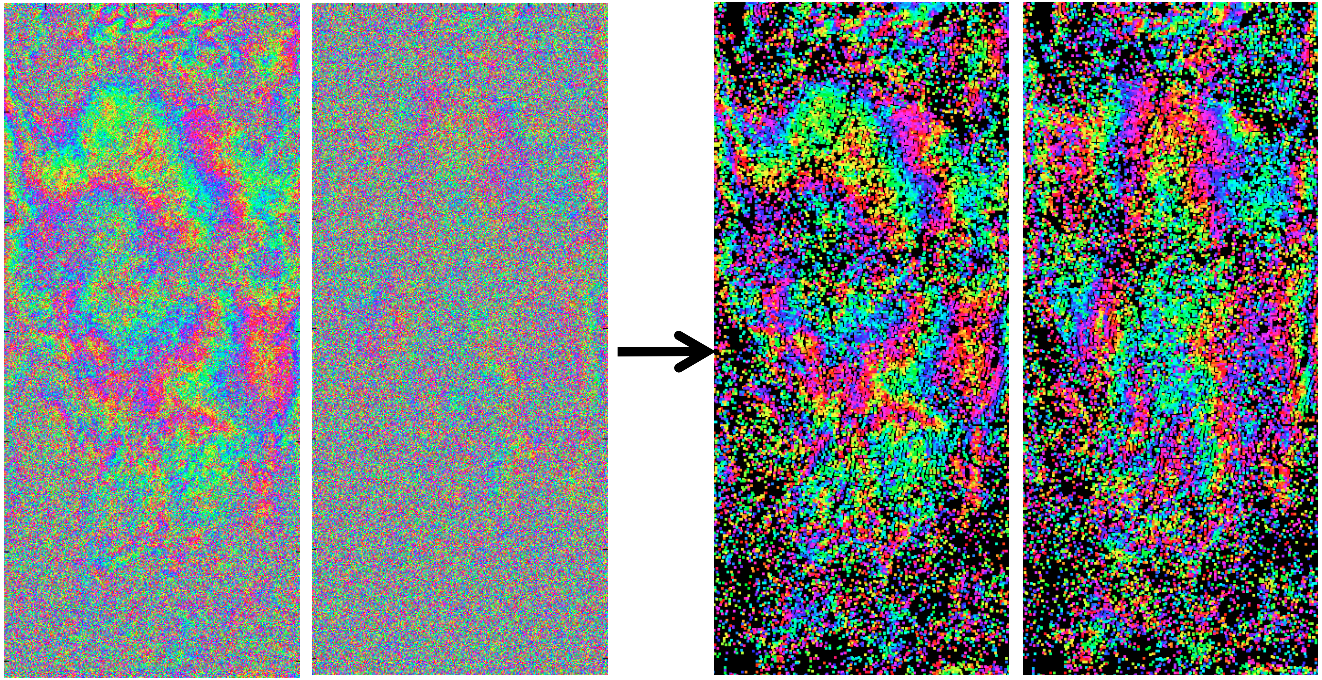


A time series analysis approach

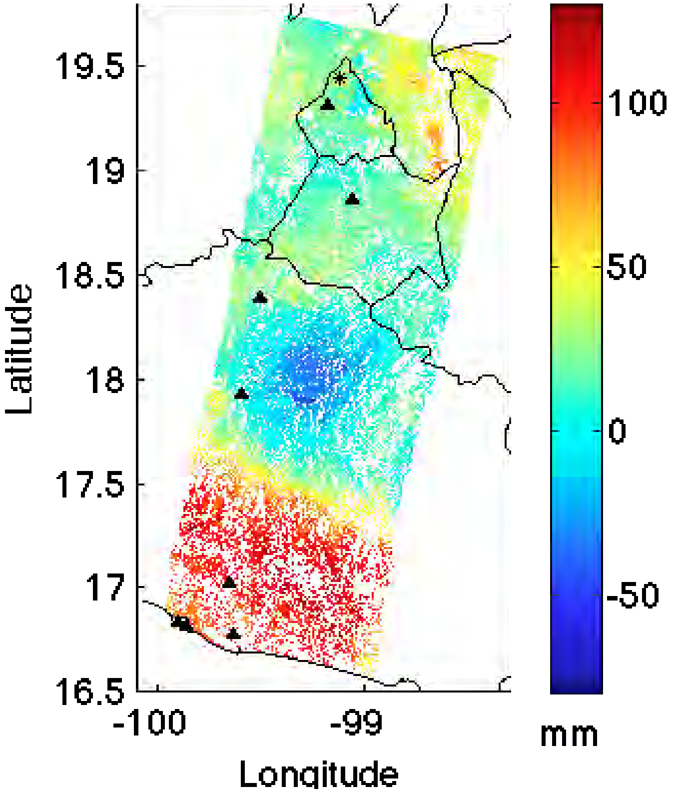
Improvement of coherence

InSAR (80 looks)

Persistent Scatterer InSAR



Reduction of non-deformation signals



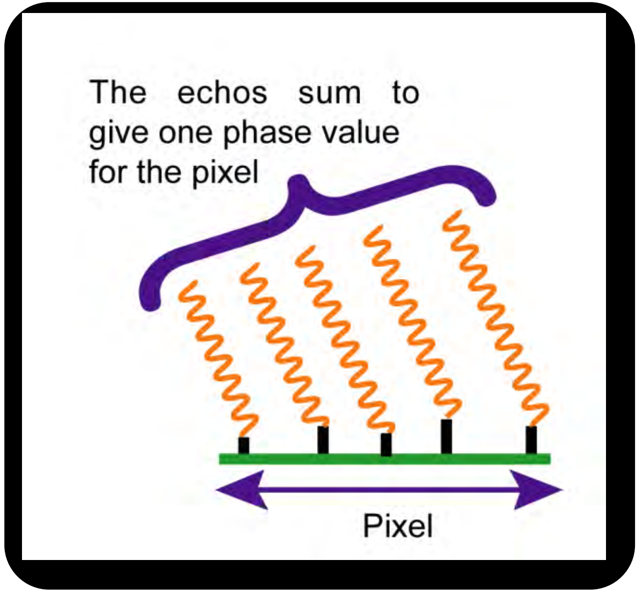
Mean velocity from 25 interferograms

High resolution PS Processing

Barcelona Olympic Port (Institut de Geomatica)

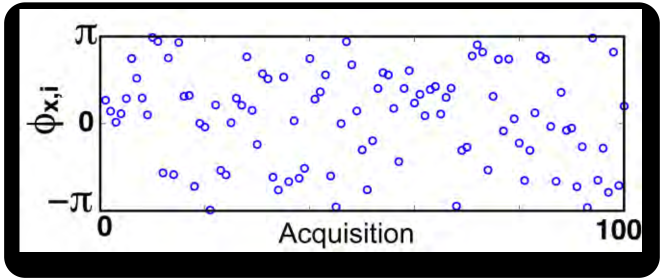
Deformation can be attributed to specific structures

Cause of Decorrelation



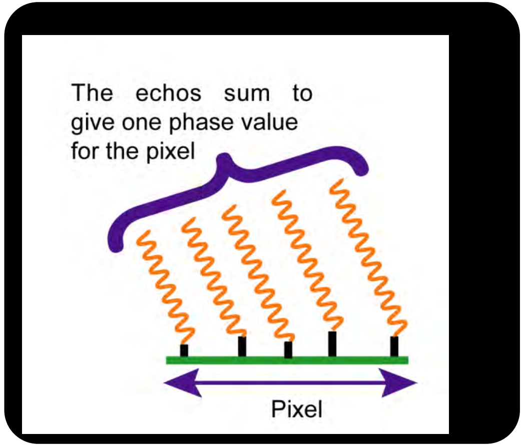
Distributed scatterer pixel (typical)

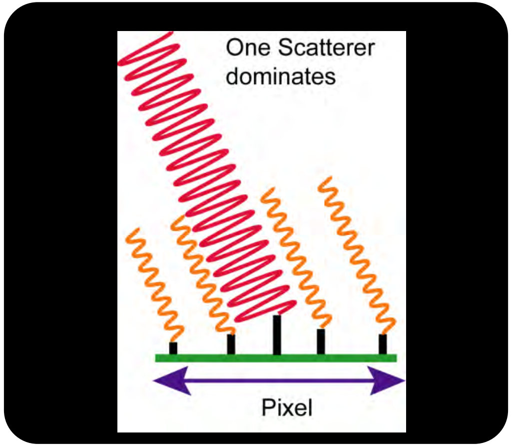
If scatterers move with respect to each other, the phase sum changes

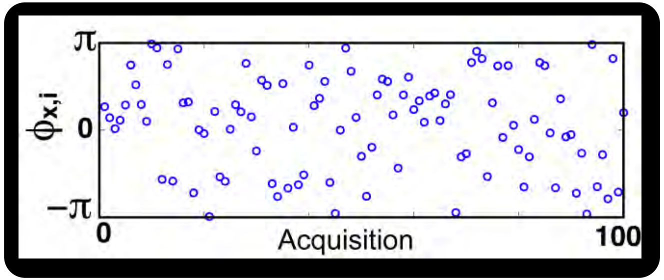


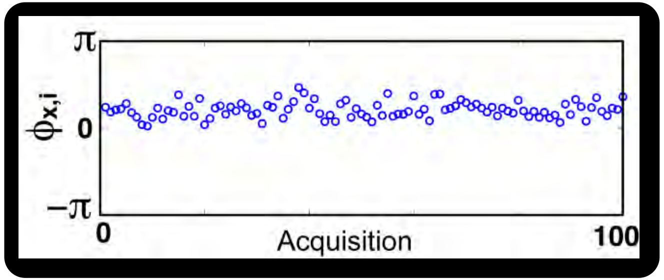
(similar effect if incidence angle changes)

How to reduce decorrelation?









Distributed scatterer pixel

"Persistent scatterer" (PS) pixel

PS Interferogram Processing

All interferograms are formed with respect to the same “master” image

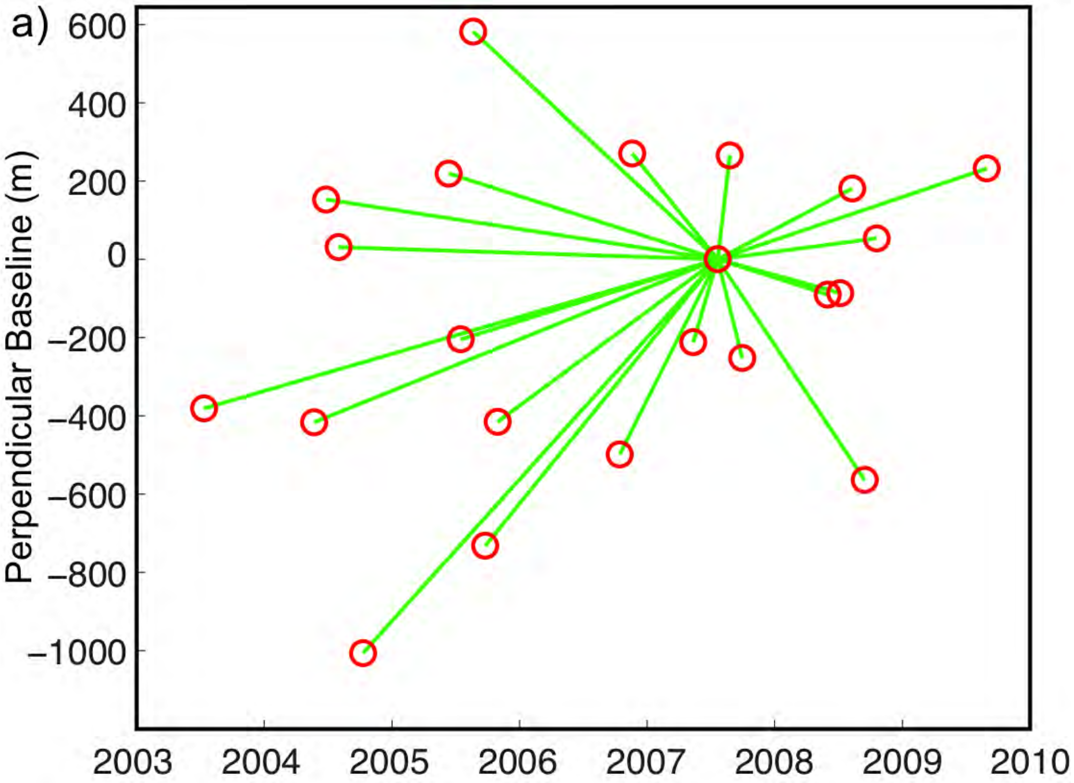
No spectral filtering applied (to maximise resolution)

Oversampling is preferred to avoid PS being at edge of resolution cell

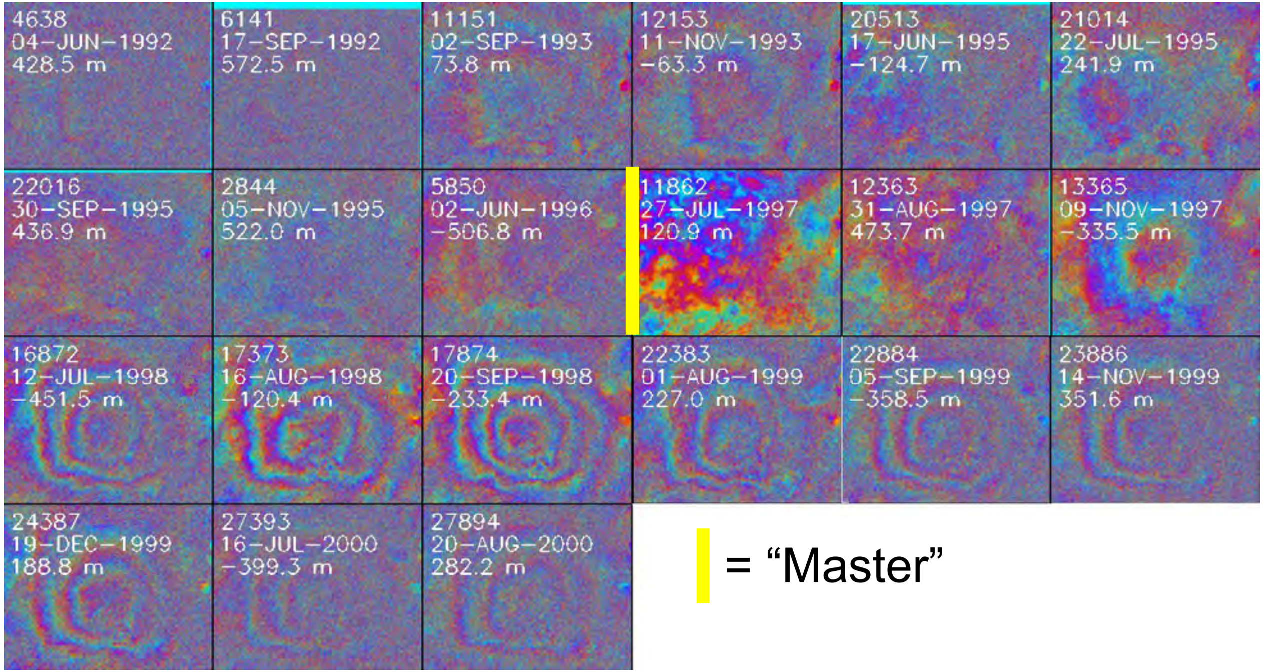
Coregistration can be difficult - use DEM/orbits or slave-slave coregistration

Reduction of interferometric phase using *a priori* DEM to minimize ambiguities

Interferograms formed



Example: single-master interferograms



= "Master"

How to identify PS pixels?

For each pixel in each interferogram:

$$\phi_{int} = W\{\phi_{defo} + \phi_{atmos} + \Delta\phi_{orbit} + \Delta\phi_{topo} + \phi_{noise}\}$$

Deformation in LOS

Atmospheric Delay

Orbit Error

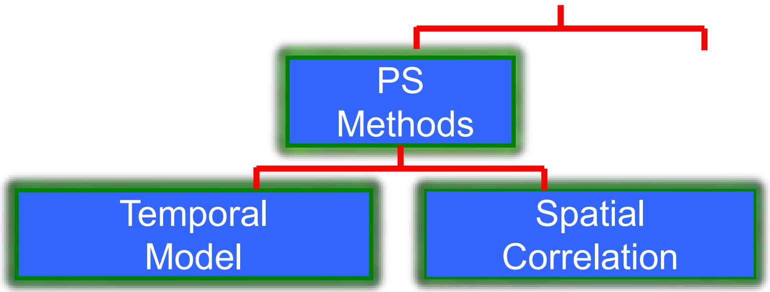
DEM Error

“Noise”

Low noise indicates PS pixel

$W\{\bullet\}$ = wrapping operator

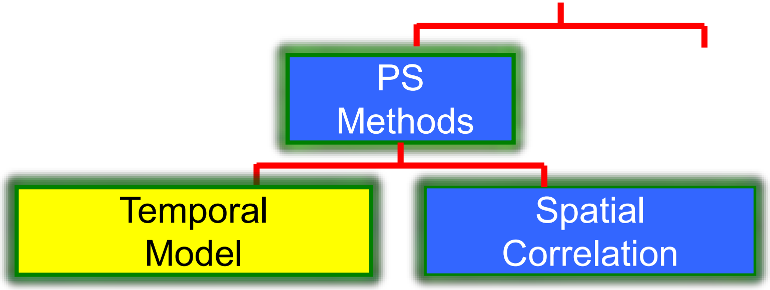
PS Processing Algorithms



Relying on model of deformation in time: e.g. “Permanent Scatterers” (Ferretti et al. 2001), Delft approach (Kampes et al., 2005)

Relying on correlation in space: StaMPS (Hooper et al. 2004)

PS Processing Algorithms



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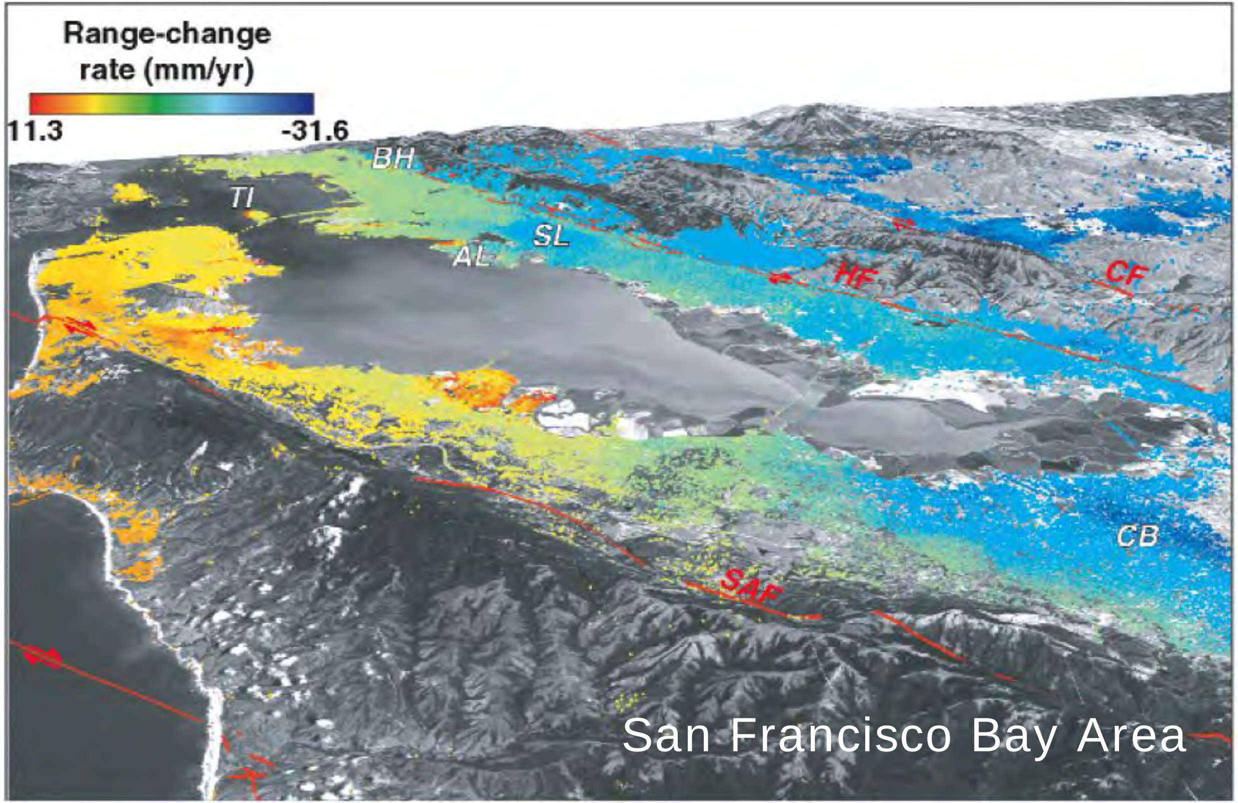
"Permanent Scatterer" Technique



Ferretti et al, 2004

Double-difference phase

For each pair of pixels in each interferogram:

$$\delta\phi_{int} = \delta\phi_{defo} + \delta\phi_{atmos} + \Delta\phi_{orbit} + \delta\Delta\phi_{topo} + \delta\phi_{noise}$$

Deformation in LOS

Atmospheric Delay

Orbit Error

DEM Error

"Noise"

Double-difference phase

If pixel pairs are nearby:

$$\delta\phi_{int} = \delta\phi_{defo} + \cancel{\delta\phi_{atmos}} + \cancel{\Delta\phi_{orbit}} + \delta\Delta\phi_{topo} + \delta\phi_{noise}$$

Deformation in LOS

Atmospheric Delay

Orbit Error

DEM Error

“Noise”

Double-difference phase

If pixel pairs are nearby:

$$\delta\phi_{int} = \delta\phi_{defo} + \delta\Delta\phi_{topo} + \delta\phi_{noise}$$

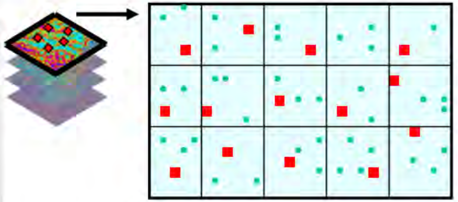
- model these two terms

Deformation in LOS

DEM Error

"Noise"

Preliminary Network



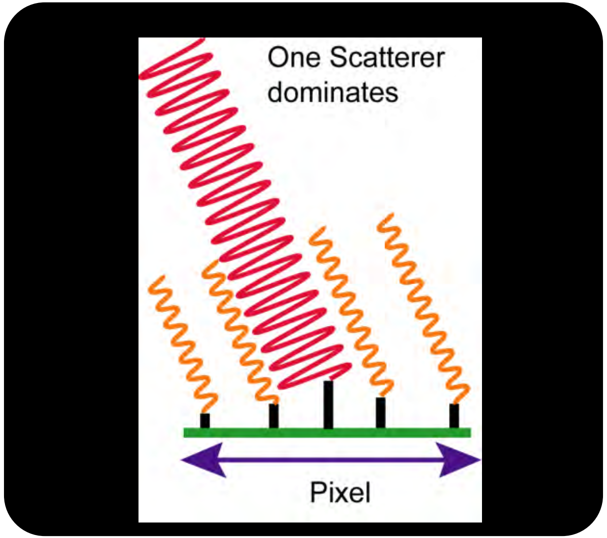
1: SELECTION

Only consider point (-like) scatterers.
Select the ***best points*** (▪) in each grid cell (ca. 250x250 m).

Remote Sensing Technology Institute

Initial selection

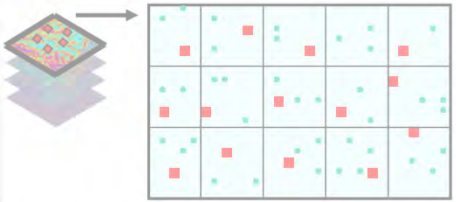
Initial selection based on amplitude dispersion (Ferretti et al., 2001)



If pixel dominated by a bright scatterer, the amplitude will vary less with time and look angle

Only a reasonable proxy for phase noise when small (<0.25 rad)

Preliminary Network



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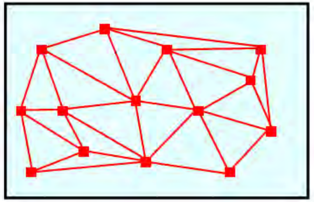
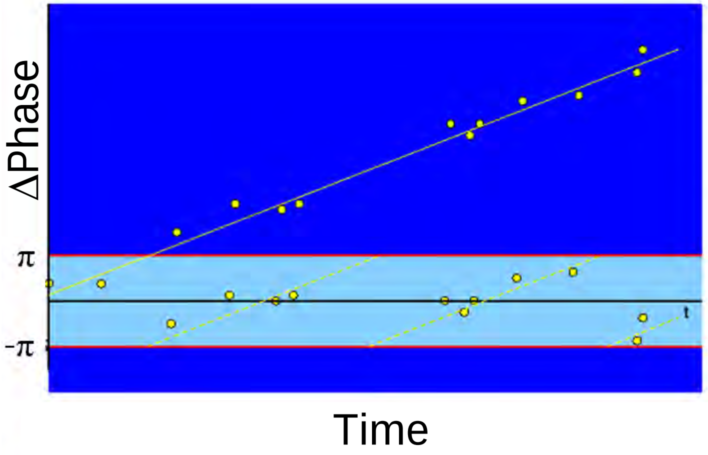


2: ESTIMATION

Construct a "network" to estimate displacement parameters and DEM error differences ***between nearby points*** in order to reduce atmospheric signal.

Remote Sensing Technology Institute

Estimation in Time



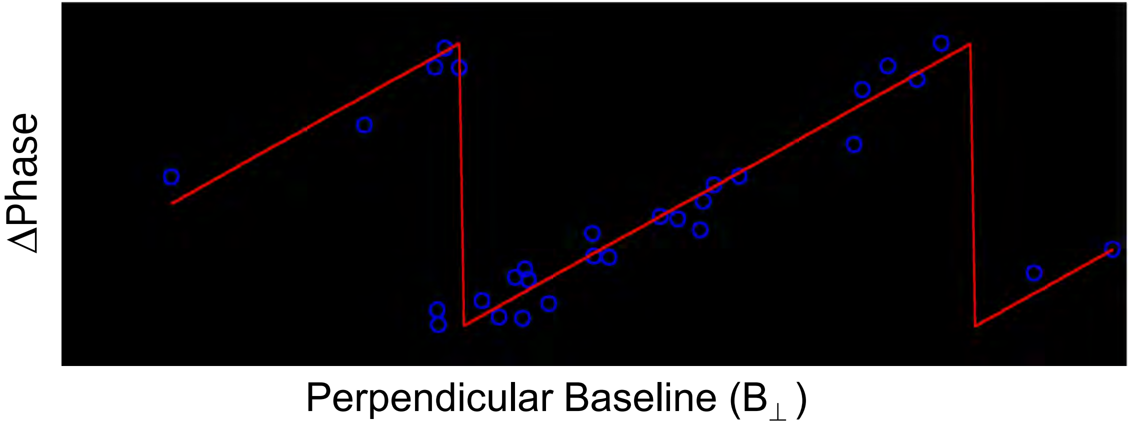
(for each "arc" between 2 points)

- Linear deformation model
- Phase is function of time
  $d(t) = a * t$
- Observed is wrapped phase
  $-\pi < phase < \pi$
- Goal is to unwrap the phase time series, supported by the model

- There are many possibilities.

- A norm must be used to decide which solution best.

Simultaneous Estimation of DEM Errors

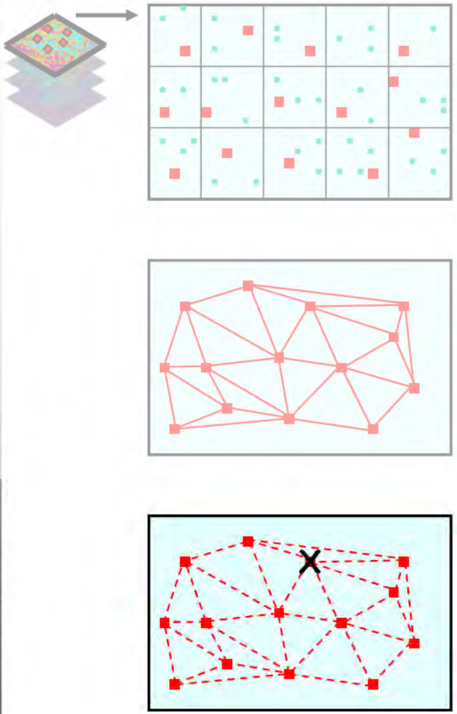


Constant for each interferogram

$$\Delta\varphi = \frac{4\pi B_{perp} \sin(\theta) \Delta h}{\lambda}$$

θ is incidence angle, Δh is DEM error,

Preliminary Network



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Select the ***best points*** (▪) in each grid cell (ca. 250x250 m).

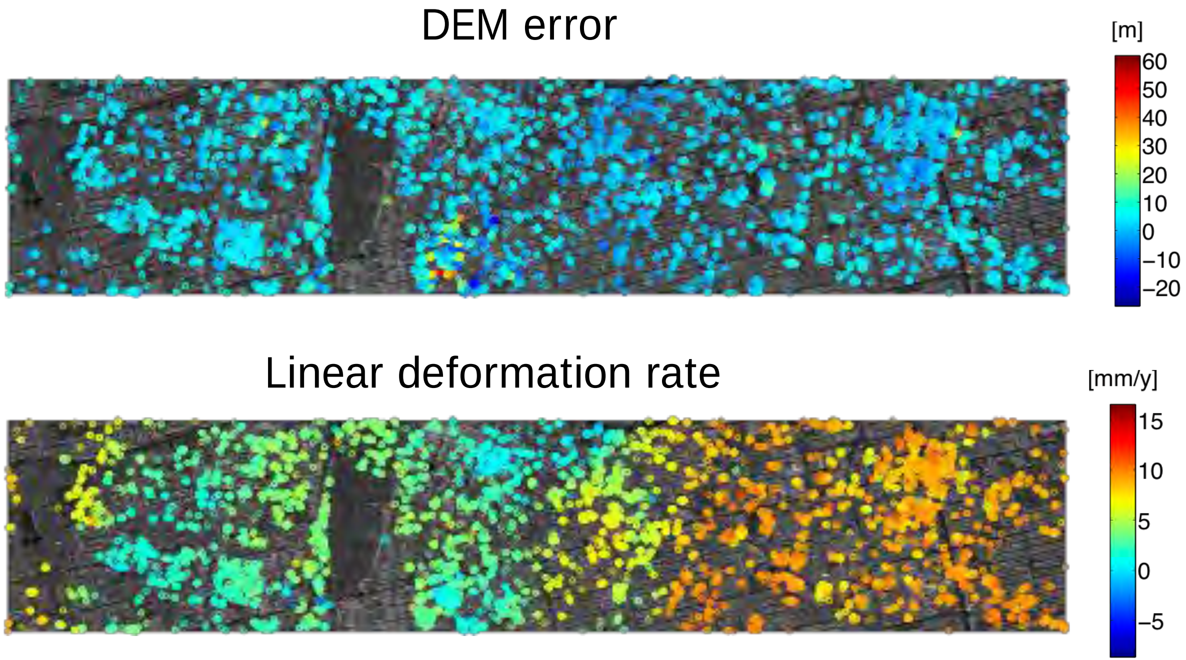
2: ESTIMATION

Construct a "network" to estimate displacement parameters and DEM error differences ***between nearby points*** in order to reduce atmospheric signal.

3: INTEGRATION

Obtain the ***parameters at the points*** by LS integration w.r.t. a reference point (**X**).
Identify incorrect estimates and/or incoherent points using alternative hypothesis tests.

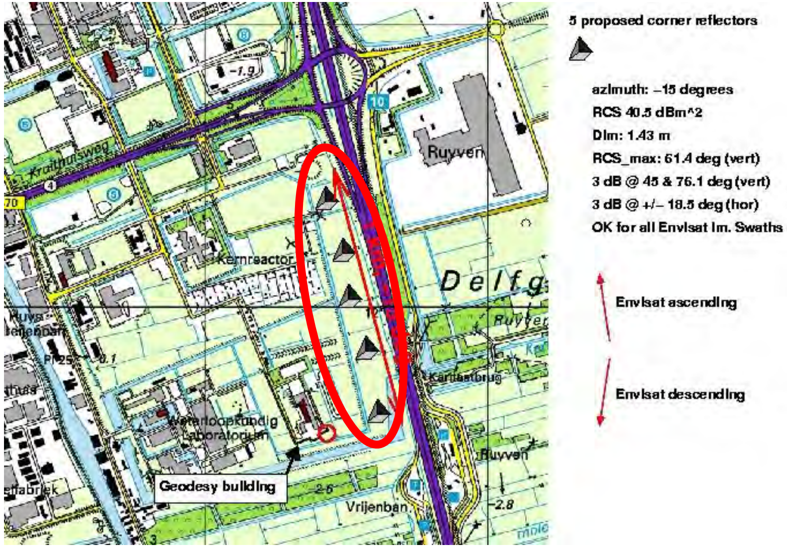
Integrated results (Las Vegas)

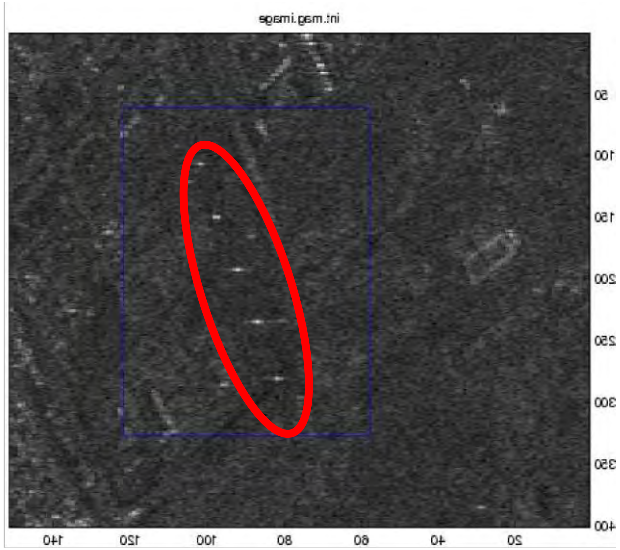


Next steps…

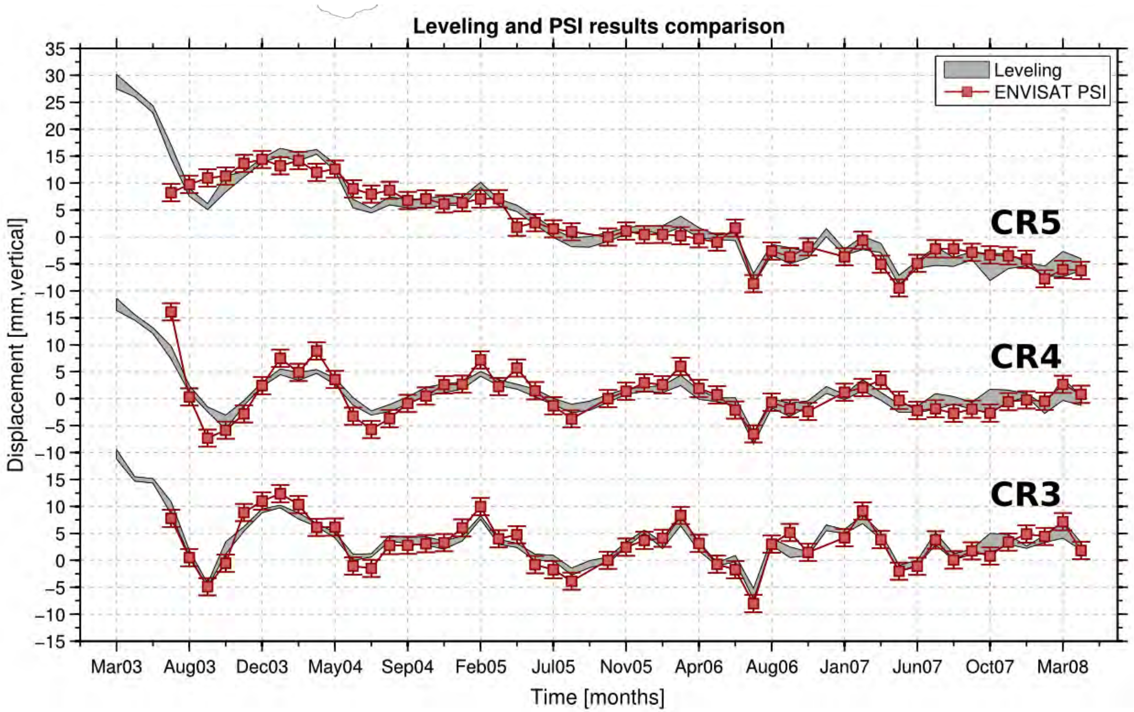
- Estimation and interpolation of signal not explained by deformation and DEM error model (assumed atmosphere). This is then subtracted from all pixels
- Testing of all other pixels by forming arcs to initial network
- Filtering in time and space to try and separate unmodelled deformation from atmosphere

Corner Reflector Experiment



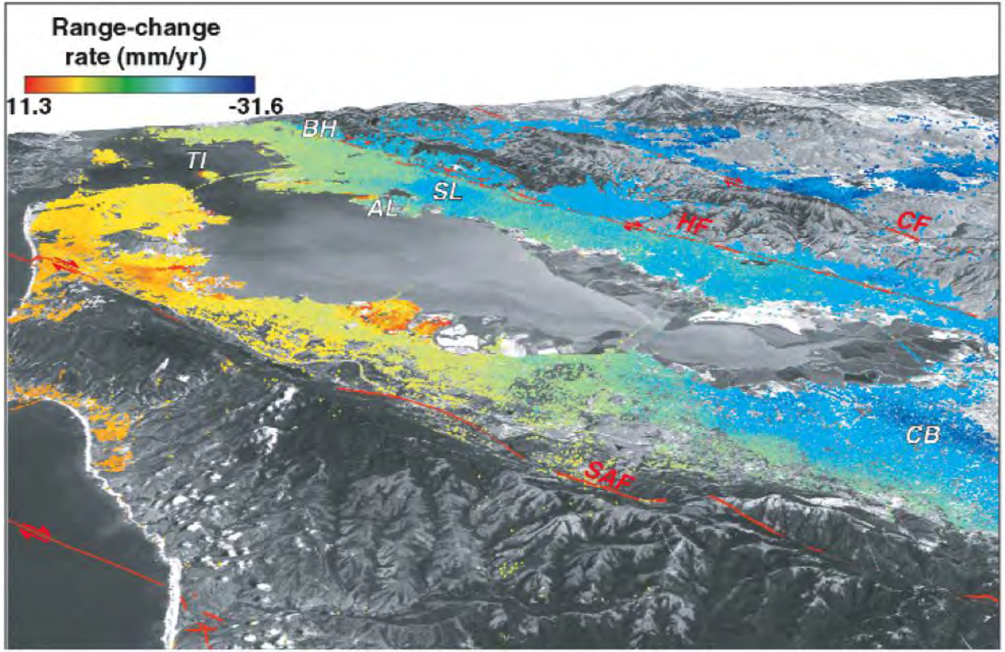


Corner Reflector InSAR vs Leveling



Marinkovic et al, CEOS SAR workshop, 2004

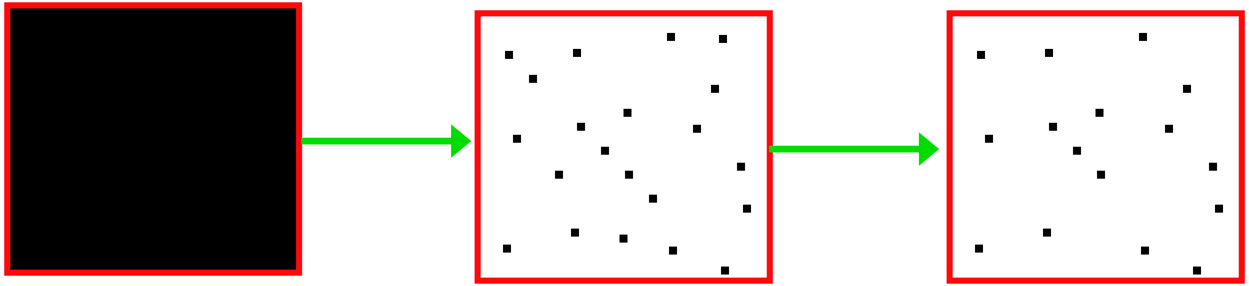
Results: Bay Area, California



San Francisco Bay Area (Ferretti et al., 2004)

- Works well in urban areas, but not so well in areas without man-made structures. Why?

Initial Selection

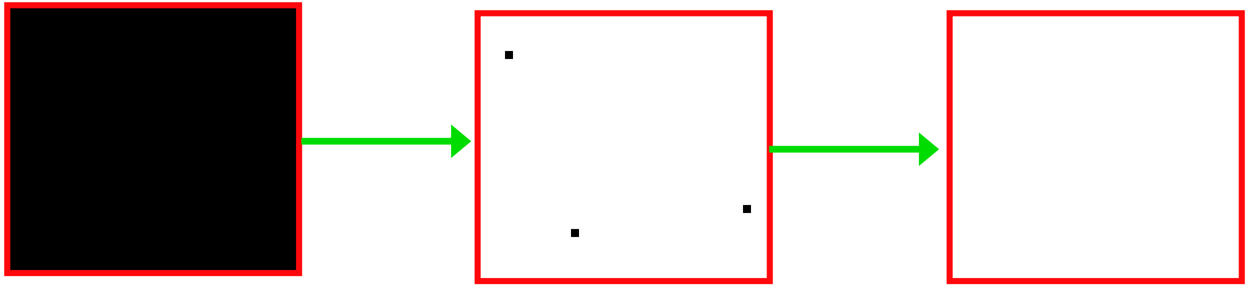


All pixels

Best candidates picked e.g. Amplitude

Bad candidates rejected using phase model for pixel pairs

Why few pixels picked in rural areas



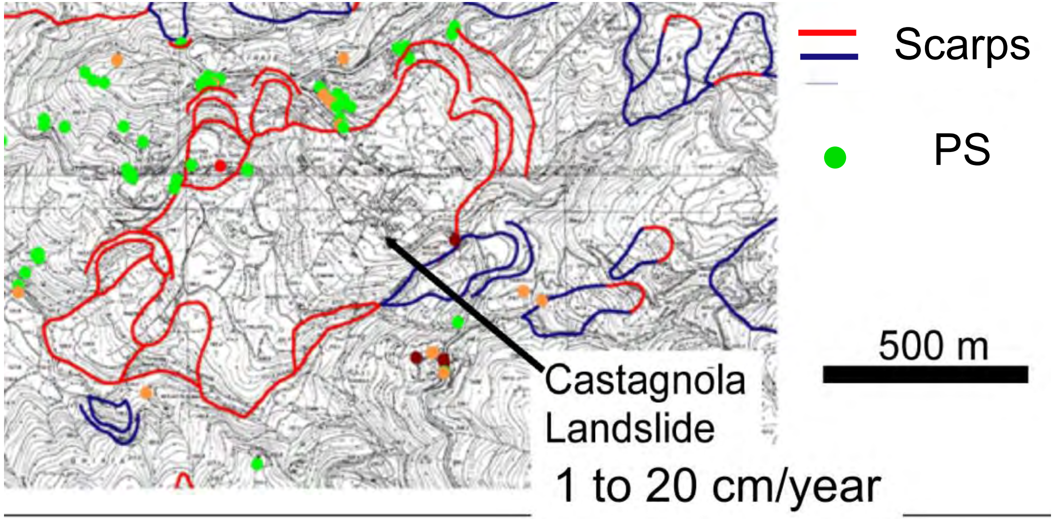
All pixels

Too few "best" candidates

Difference in atmospheric noise between pixels is large, so unable to reliably estimate velocity and DEM error: All pixels rejected

- Lowering the bar for candidate pixels also leads to failure: too many "bad" pixels for network approach.

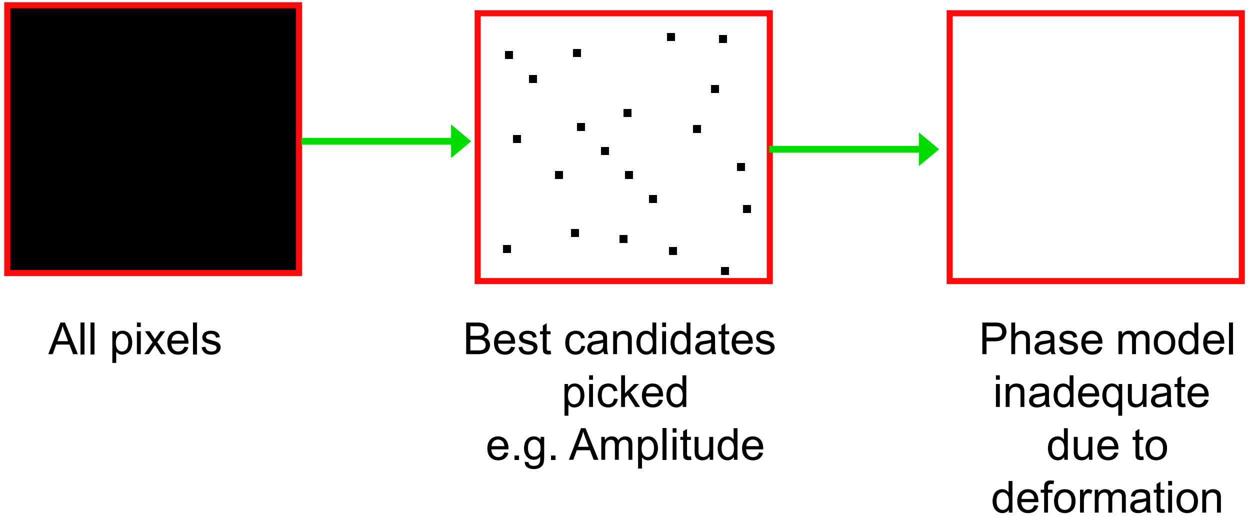
Loss of PS due to non-steady motion



Castagnola, Northern Italy (from Paolo Farina)

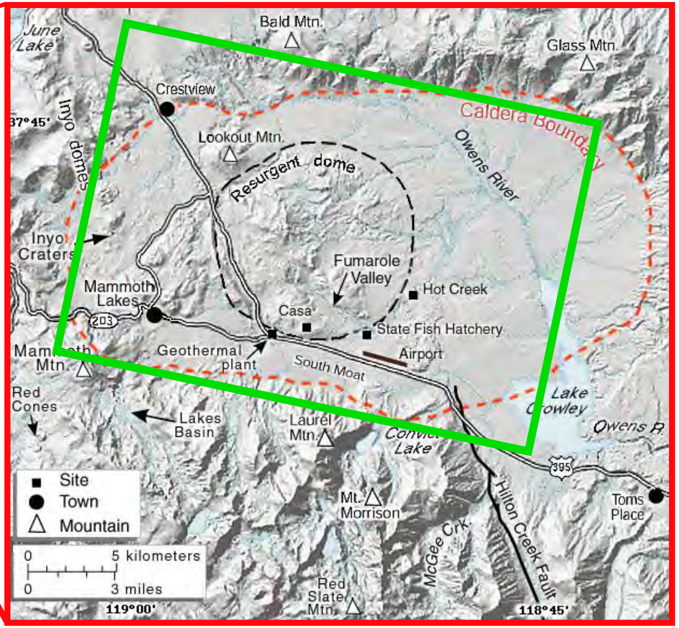
- Algorithm rejects pixels whose phase histories deviate too much from a predetermined model for how deformation varies with time

Why few pixels picked when deformation rate is irregular



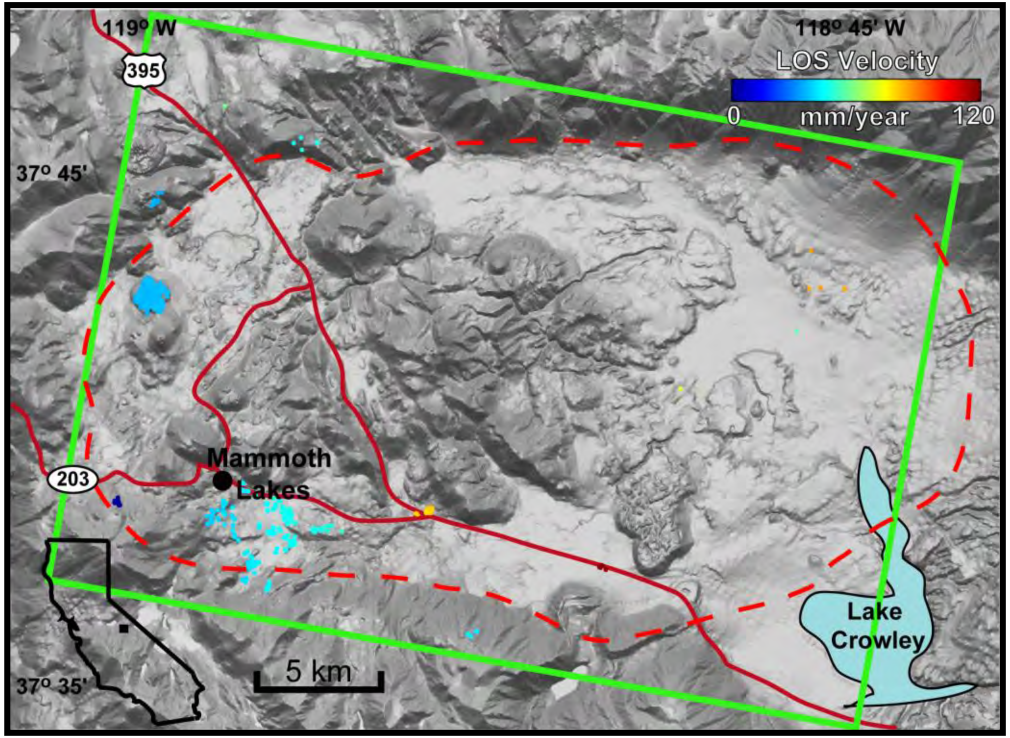
Example of rural area with irregular deformation

Long Valley Volcanic Caldera



5km

Using Temporal Model Algorithm



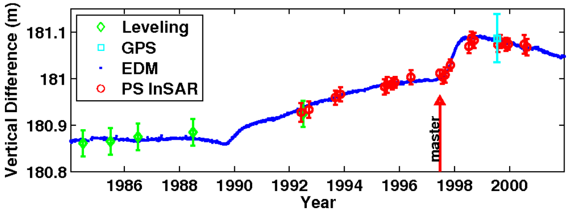
- 300 high-amplitude persistent scatterers

StaMPS PS Approach

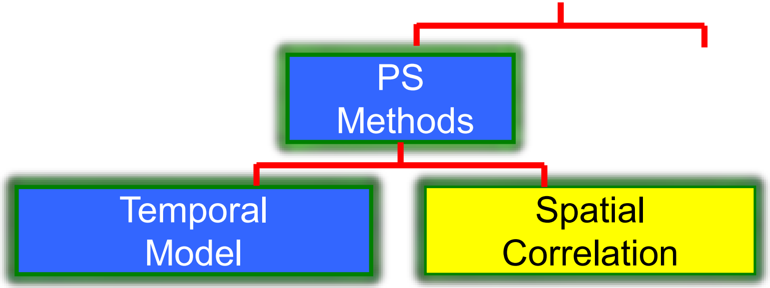
Developed for more general applications, to work:

a) in rural areas without buildings (low amplitude)

b) when the deformation rate is very irregular



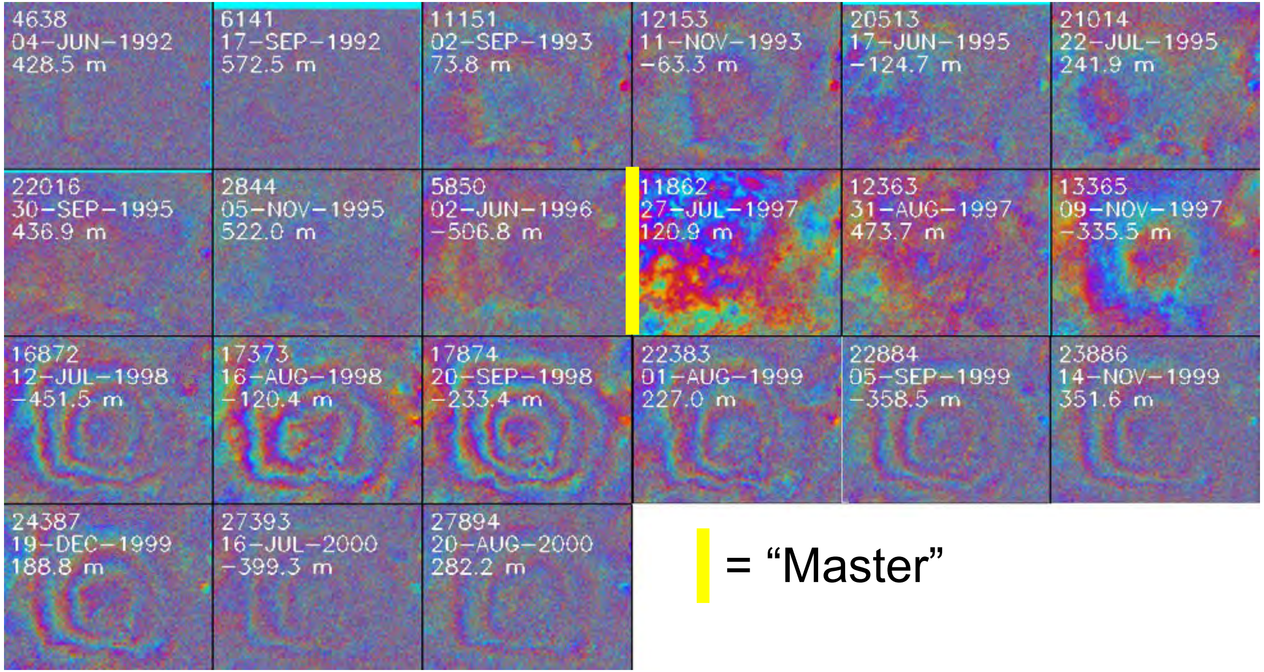
PS Processing Algorithms



Relying on correlation in space: StaMPS Hooper et al. (2004, 2007, 2012)

Series of single-master interferograms

- Pre-Processing as for Temporal Model Algorothm



Spatial Correlation PS Algorithm

Exploits spatial correlation of the deformation signal.

Interferometric phase terms as before:

$$\phi_{int} = \phi_{defo} + \phi_{atmos} + \Delta\phi_{orbit} + \Delta\phi_{topo} + \phi_{noise}$$

- ϕ_{defo}: Deformation in LOS
- ϕ_{atmos}: Atmospheric Delay
- $\Delta\phi_{orbit}$: Orbit Error
- $\Delta\phi_{topo}$: DEM Error
- ϕ_{noise}: “Noise”

Spatial Correlation PS Algorithm

Exploits spatial correlation of the deformation signal.

Interferometric phase terms as before:

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Spatial Correlation PS Algorithm

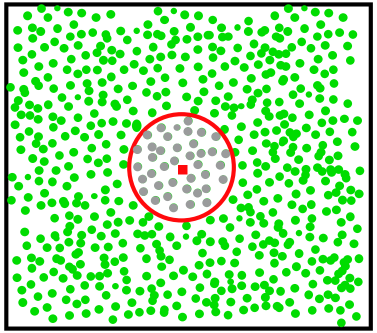
Exploits spatial correlation of the deformation signal.

Interferometric phase terms as before:

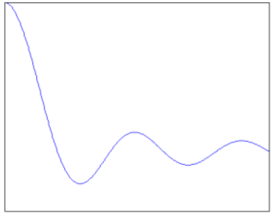
$$\phi_{int} = \phi_{defo} + \phi_{atmos} + \Delta\phi_{orbit} \begin{matrix} + \Delta\phi_{topo}^{uncorr} \\ + \Delta\phi_{topo}^{corr} \end{matrix} + \phi_{noise}$$

- Correlated spatially - estimate by iterative spatial bandpass filtering

Estimation of Spatially Correlated Terms



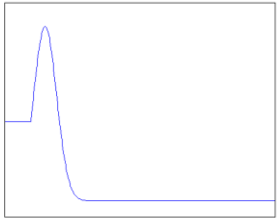
E.g. Average of surrounding pixels crude (Hooper et al., 2004)



Frequency response

Better (Hooper et al., 2007)

- Low frequencies plus dominant frequencies in surrounding patch are kept.



Example frequency response

e.g., low-pass + adaptive “Goldstein” filter (Goldstein and Werner, 1998)

Spatial Correlation PS Algorithm

$$\phi_{int} = \phi_{defo} + \phi_{atmos} + \Delta\phi_{orbit} \begin{matrix} + \Delta\phi_{topo}^{uncorr} \\ + \Delta\phi_{topo}^{corr} \end{matrix} + \phi_{noise}$$

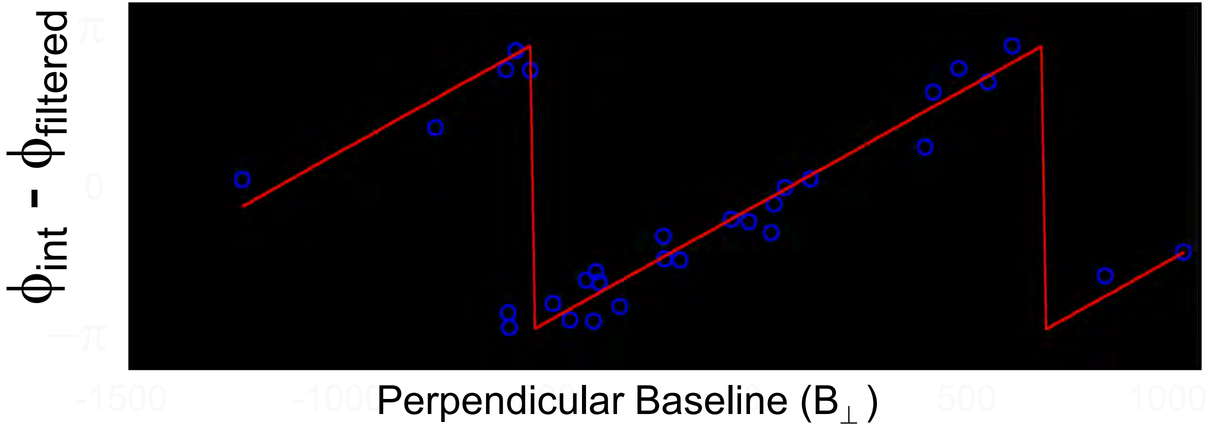
- Correlated spatially - estimate by iterative spatial bandpass filtering

Spatial Correlation PS Algorithm

$$\phi_{int} = \phi_{defo} + \phi_{atmos} + \Delta\phi_{orbit} \begin{matrix} + \Delta\phi_{topo}^{uncorr} \\ + \Delta\phi_{topo}^{corr} \end{matrix} + \phi_{noise}$$

- Correlated spatially - estimate by iterative spatial bandpass filtering
- Correlated with perpendicular baseline - estimate by inversion

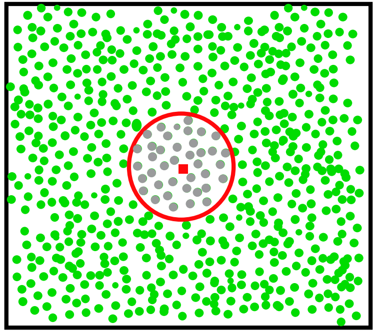
Spatial Correlation PS Algorithm



- 1-D problem (as opposed to 2-D with temporal model approach)

Temporal coherence is then estimated from residuals
(residuals of zero -> coherence of 1)

Re-estimation of Spatially Correlated Terms

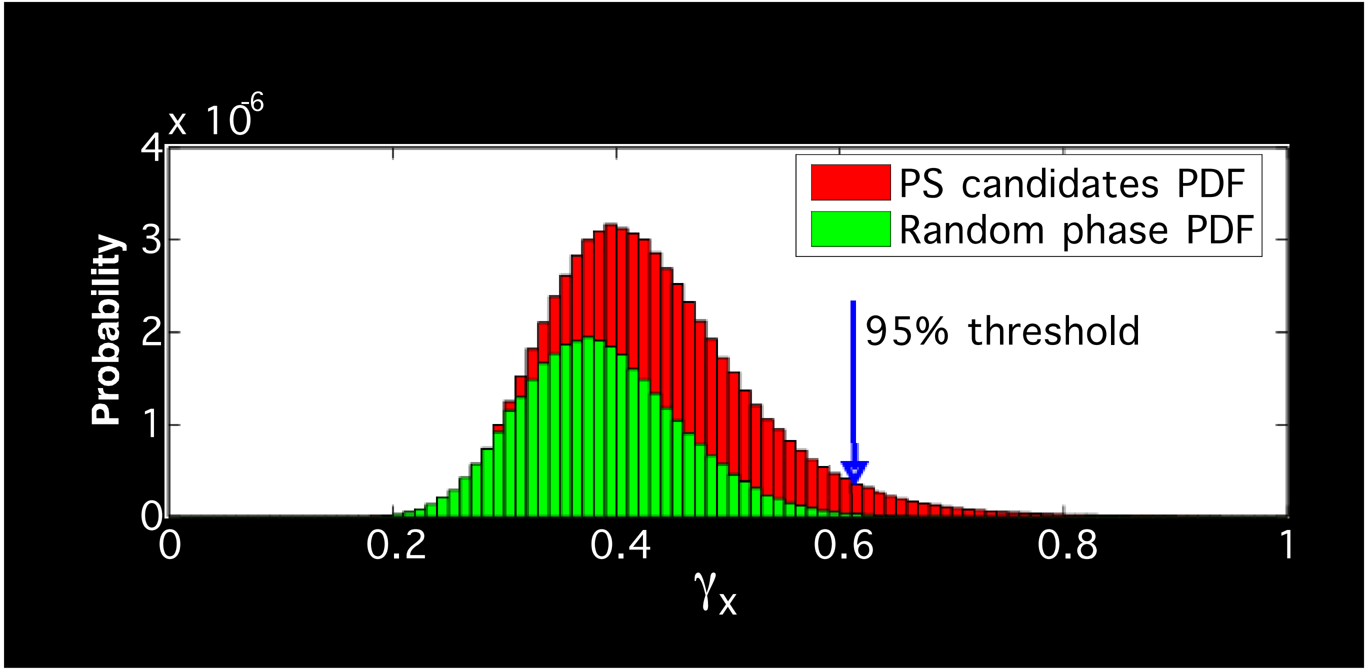


Spatially-correlated terms re-estimated with contribution of each pixel weighted based on its estimated temporal coherence

- Followed by restimation of DEM error and temporal coherence

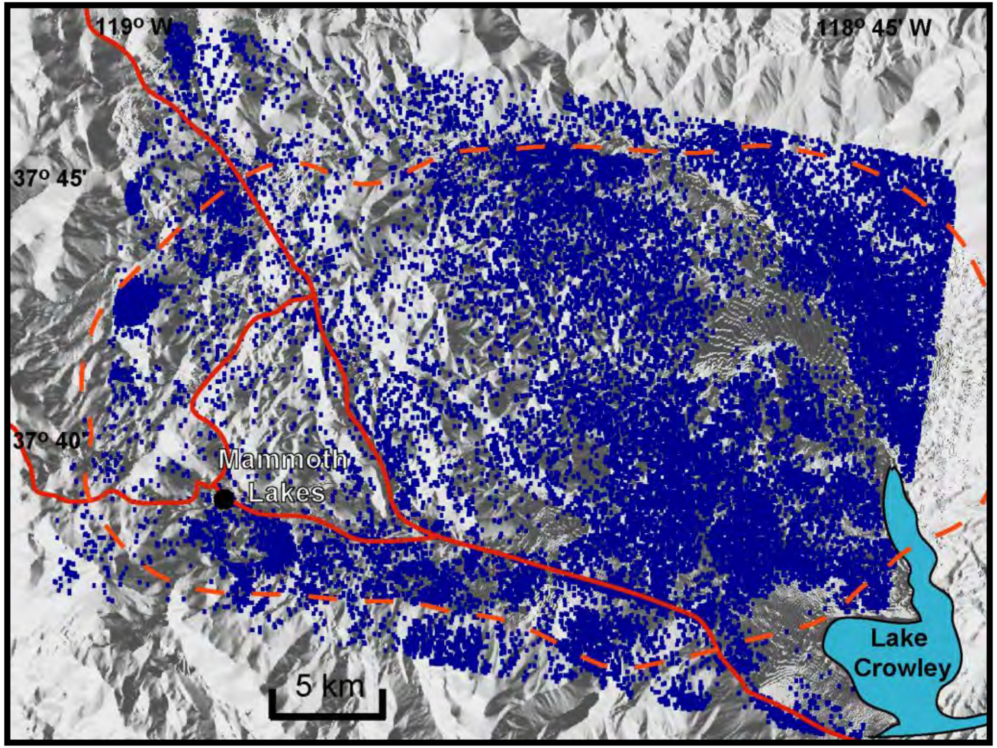
- Iterated several times

Selecting PS



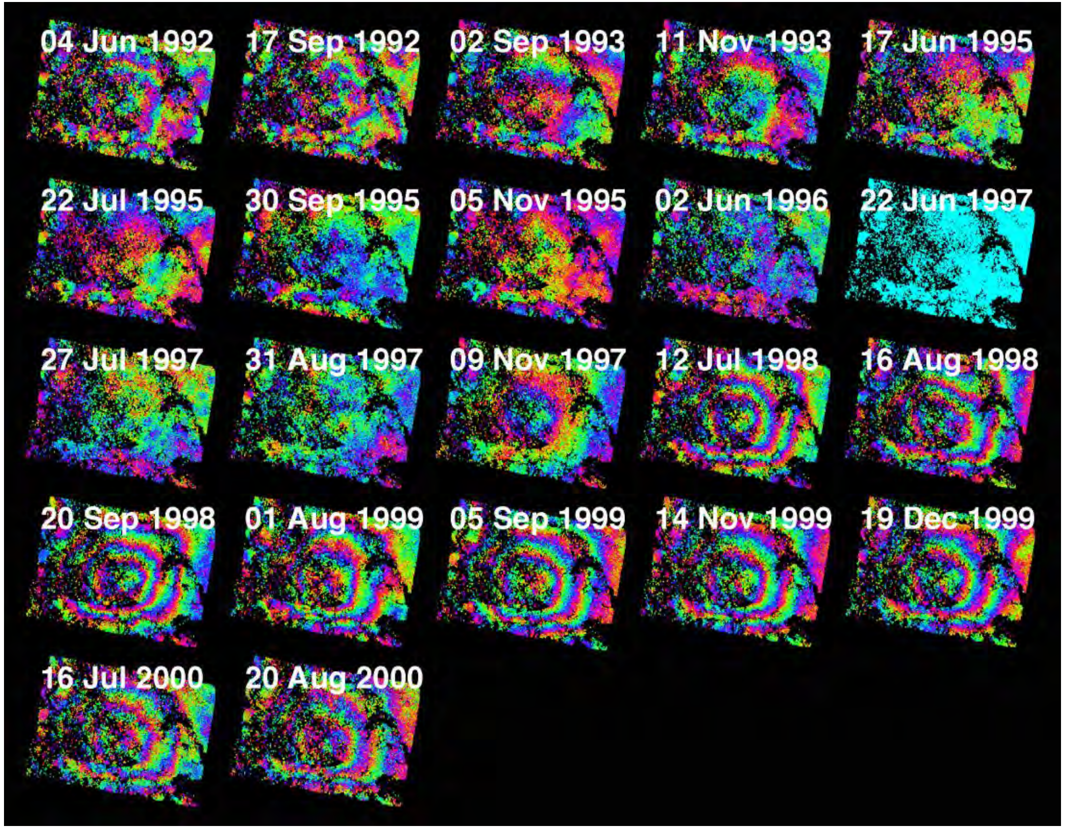
Where γ_x is the temporal coherence

Results in Long Valley



- 29,000 persistent scatterers

Wrapped PS Phase



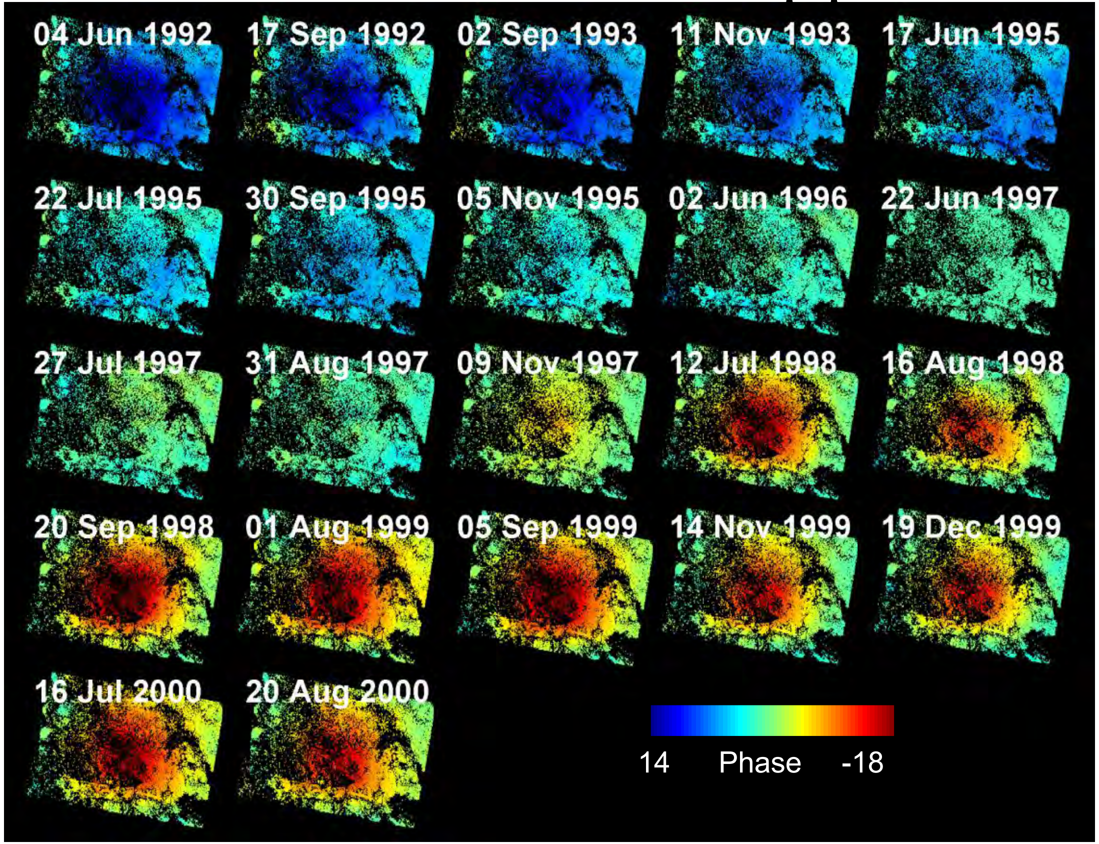
- Interferogram phase, corrected for topographic error

Phase unwrapping

With temporal model, phase is unwrapped by finding model parameters that minimise the wrapped residuals between double difference phase and the model

In the spatial correlation approach, a 3-D phase unwrapping algorithm is used instead

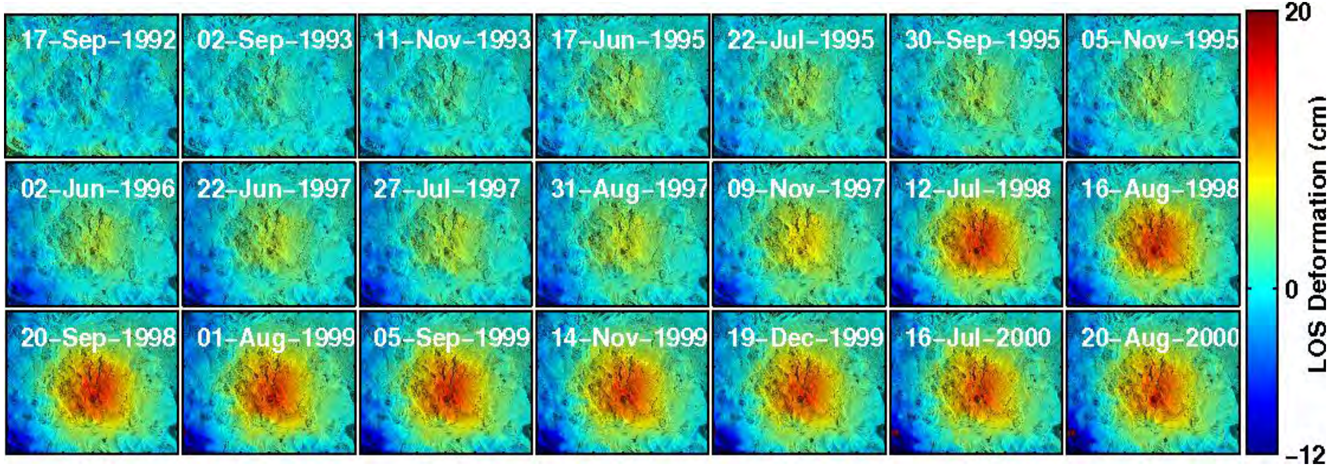
Unwrapped PS Phase



- Not linear in time

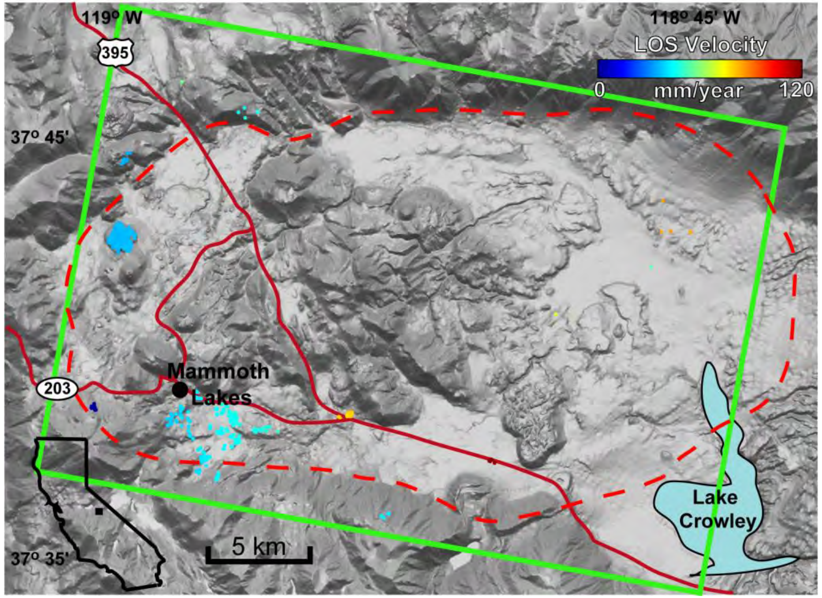
Estimation of Atmospheric Signal And Orbit Errors

- ➢ Filtering in time and space, as for temporal model approach

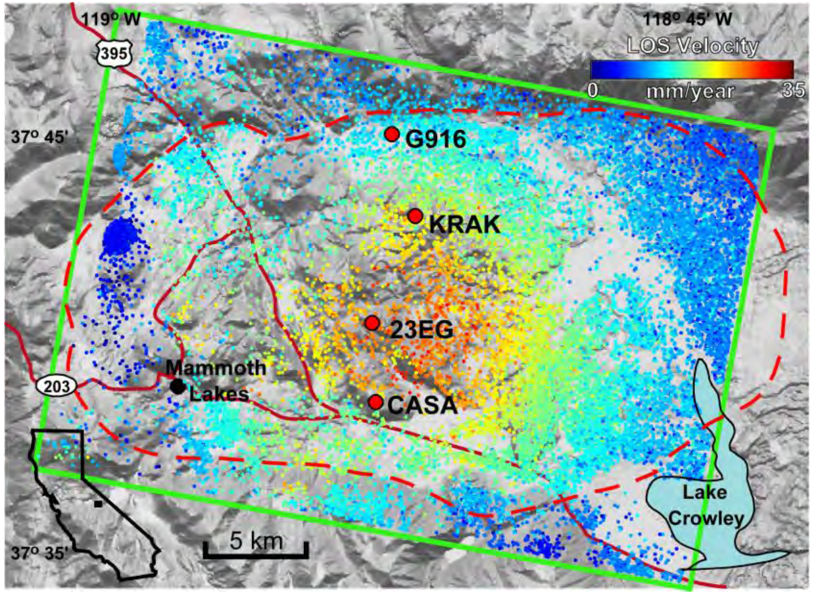


Estimate of atmospheric and orbit errors subtracted, leaving deformation estimate (not necessarily linear).

Comparison of approaches

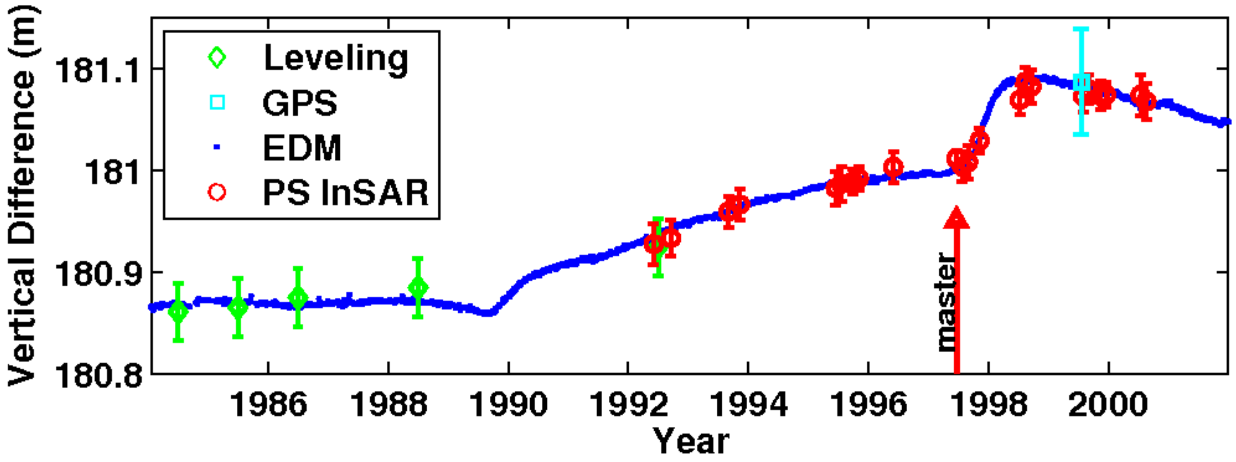


Temporal model approach



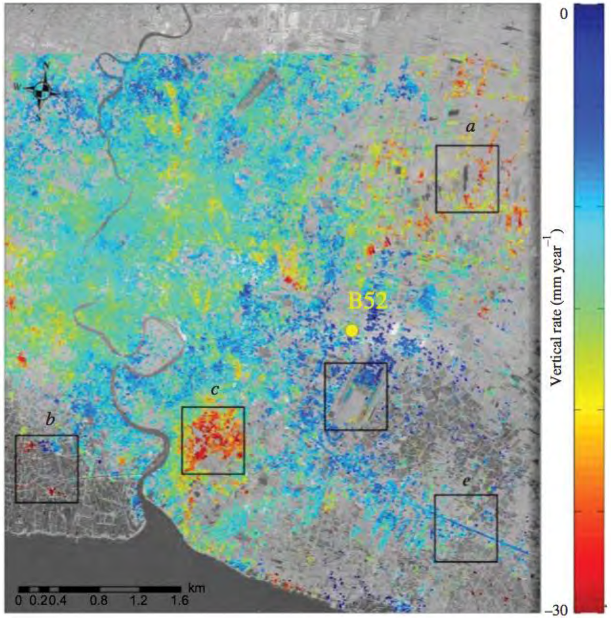
Spatial correlation approach

Validation with Ground Truth

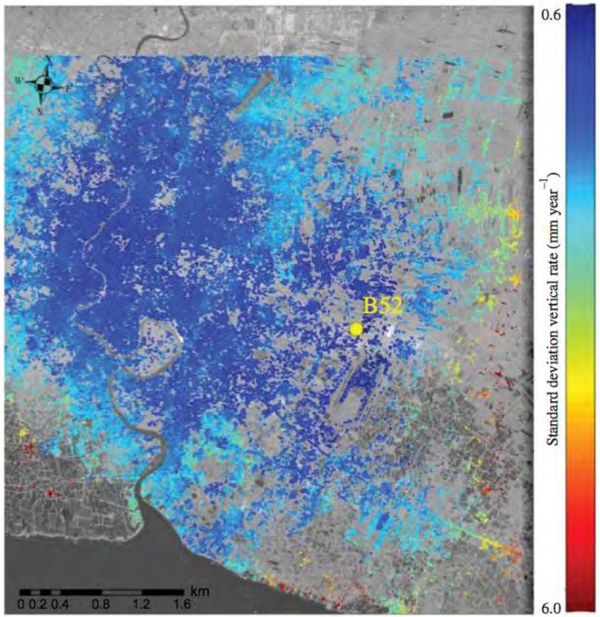


- ➢ PS show good agreement

Error estimation



Subsidence rates in Bangkok

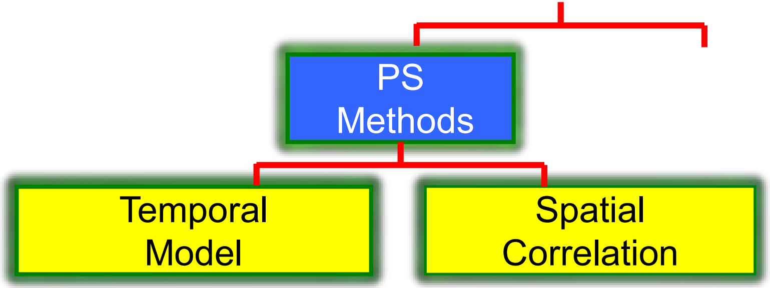


Standard deviations of rates

(Errors grow with distance from reference, B52)

Because no temporal model was assumed, probability density functions can be estimated by repeatedly fitting a temporal model using the percentile bootstrapping method.

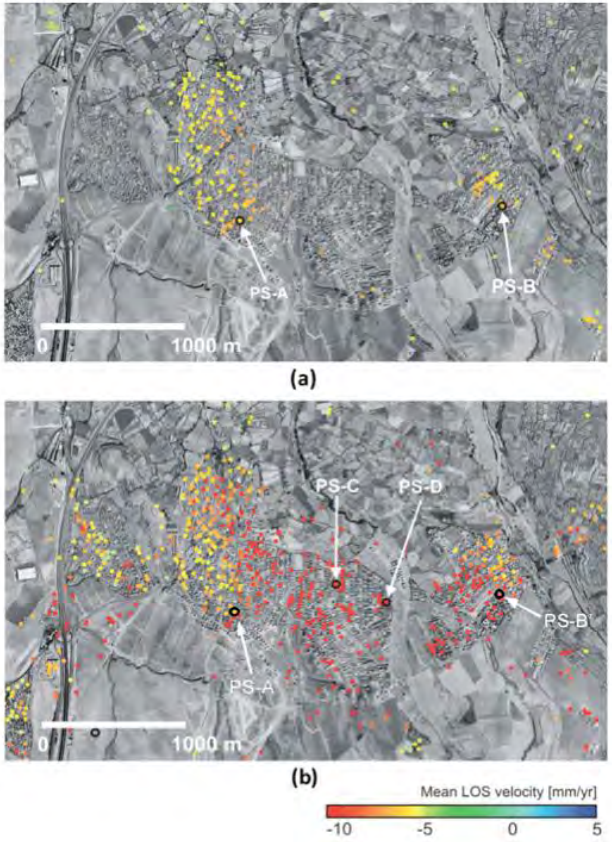
Comparison PS Algorithms



- Spatial correlation algorithm works in more general case, but may miss PS with non-spatially correlated deformation
- Temporal model algorithm more rigorous in terms of PS reliability evaluation, but may not work in rural areas, or where deformation is irregular in time.

Comparison PS Algorithms

(Sousa et al, 2010)



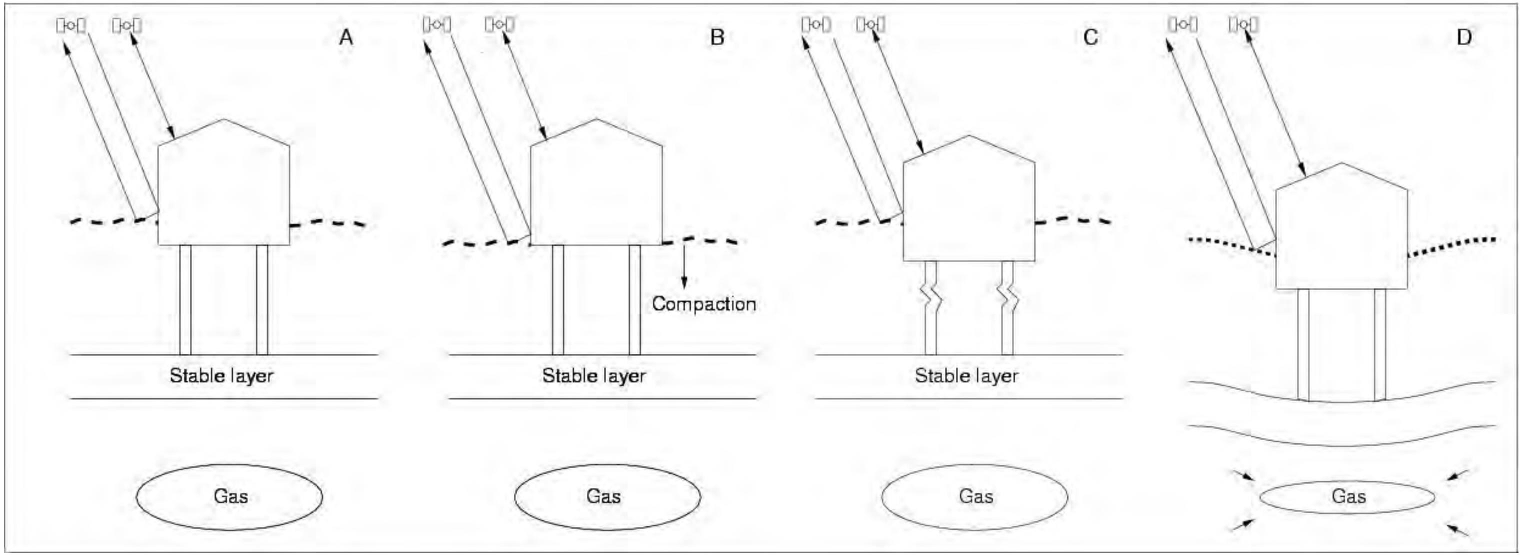
Temporal model approach
(DePSI, Ketelaar thesis, 2008)

Spatial coherence approach
(StaMPS, Hooper et al, JGR 2007)

Housing development near Granada, Spain

Interpretation of PS observations

Consider what is actually moving



- Consideration of single vs double bounce can differentiate

Persistent Scatterer (PS) InSAR

Summary

- PSInSAR Relies on pixels that exhibit low decorrelation with time and baseline
- Non-deformation signals are reduced by modelling and filtering
- PS techniques work best in urban environments, but can also be applied in rural environments

snap2stamps software package

(slide from Michael Foumelis)

Open and available at:

https://github.com/mdelgadoblasco/snap2stamps

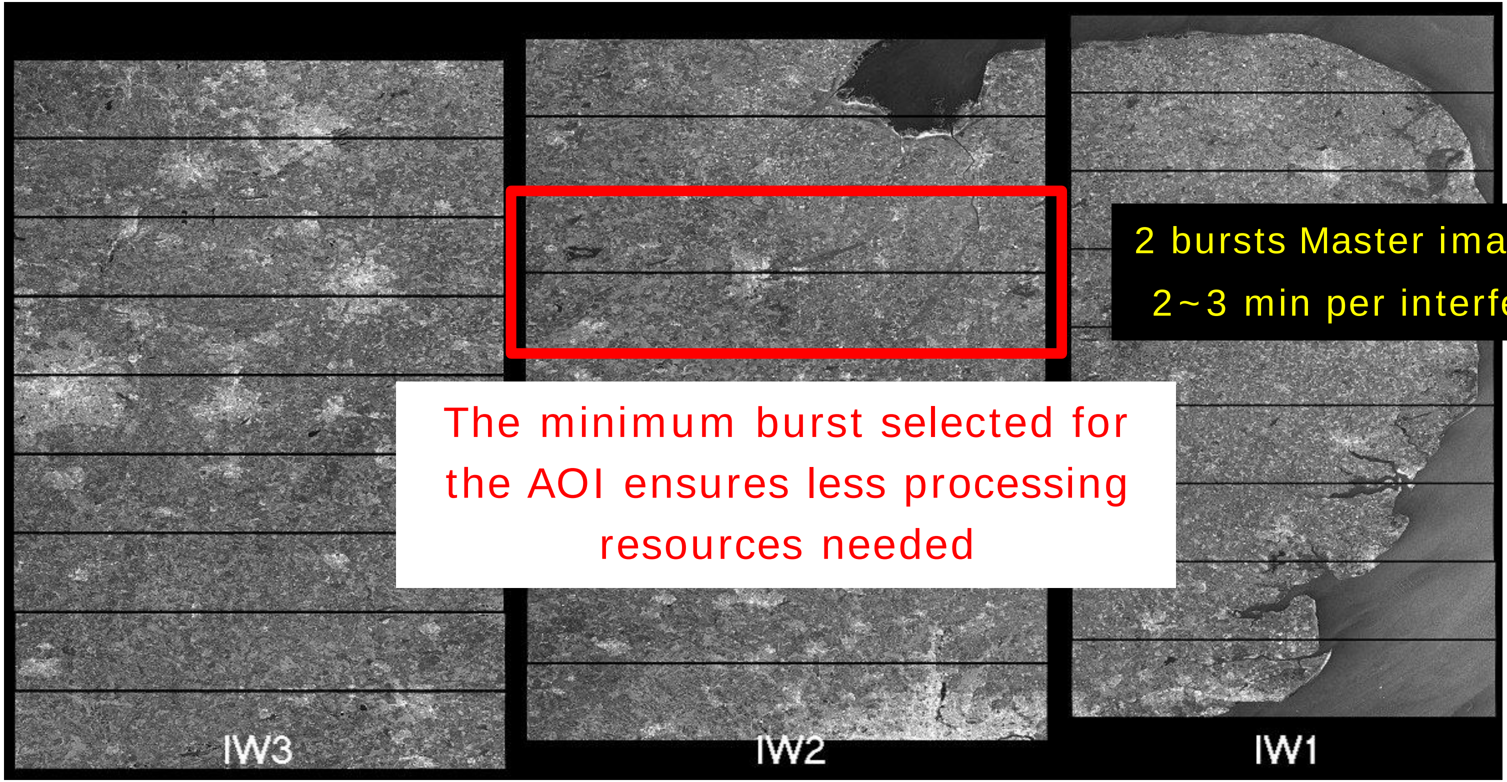
DOI 10.5281/zenodo.1308835

This software uses a configuration file which needs some parameters setting such as:

- Project folder
- CPU and Cache memory specification
- Path to the SNAP Graph Processing Tool (GPT) to use SNAP in command line mode
- Subswath(s) to process
- Pre-processed master image (orbit refinement and splitted)

We suggest to do the Master selection and subsetting using SNAP GUI

Master subsetting



2 bursts Master image needs
2~3 min per interferogram

The minimum burst selected for the AOI ensures less processing resources needed