Persistent Scatterer InSAR time series

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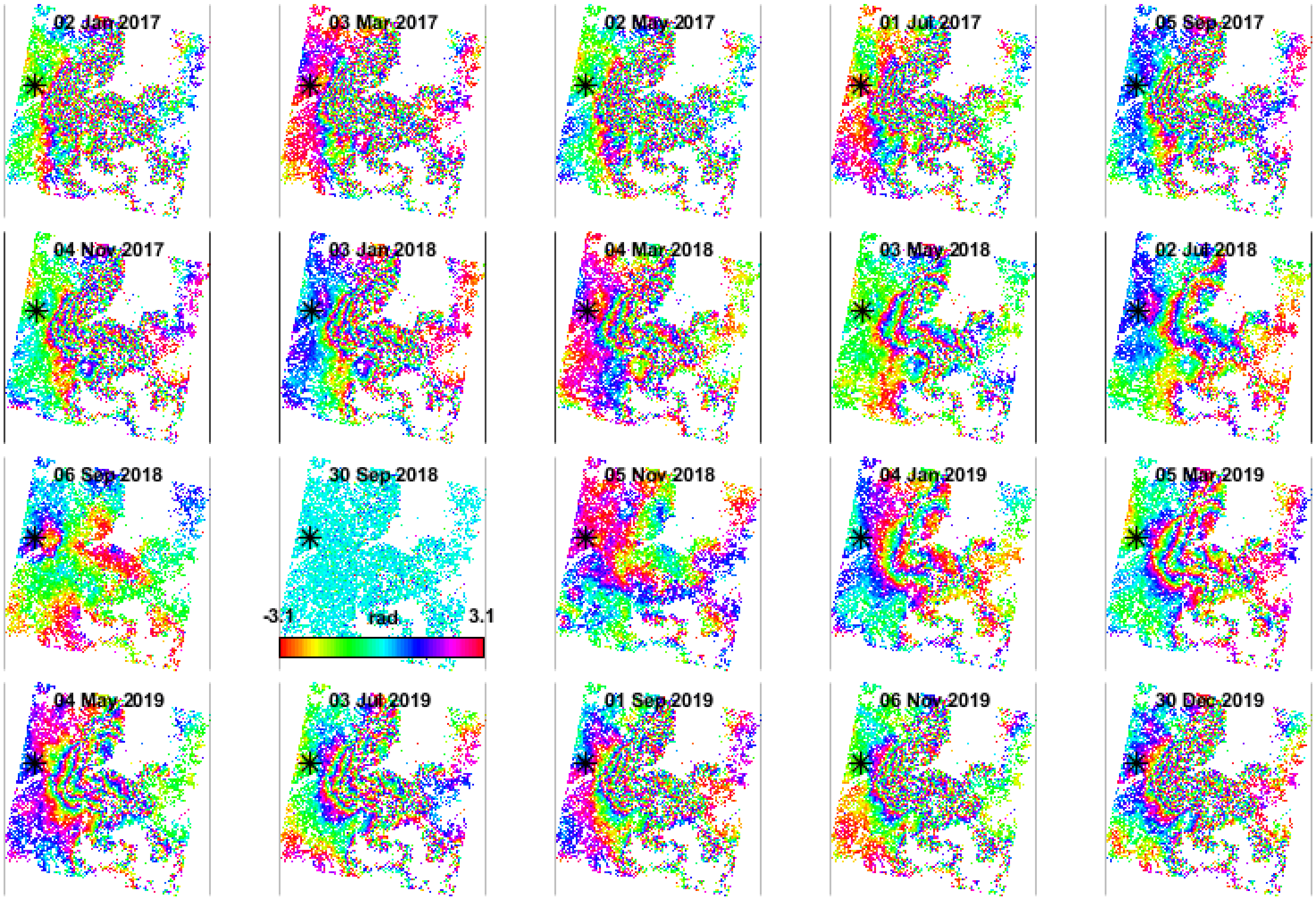
Motivation – Why do we need time series?

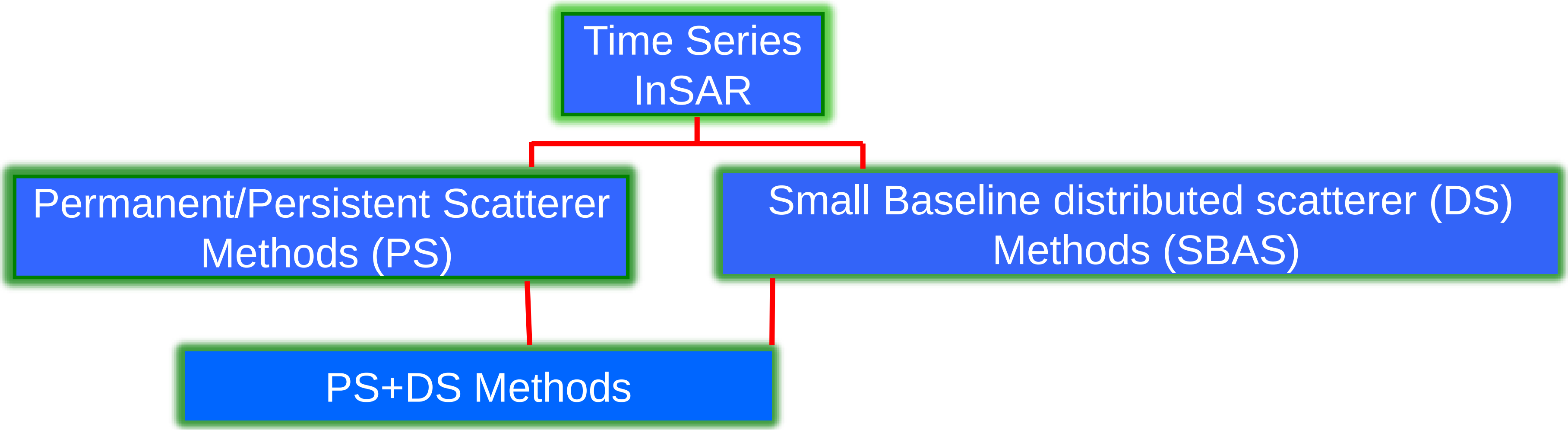
- **Science argument:**
  - Better inform scientists about the active geophysical phenomena over a given area
  - allow scientists to decompose contributions from different active phenomena
  - Enable better modelling of surface deformation
- **Technical argument:**
  - Allows measurements in slowly deforming areas
  - Reduces noise from atmospheric artifacts
  - Enables a better handle of unwrapping errors

What is InSAR time series?

A time series InSAR is simply the measurement of change through time with respect to a particular date.



Time series approaches



- Analysis wrapped phase and at high resolution – single look interferogram
- Computationally intensive
- PS limitation in rural environments – PS+DS is best for all

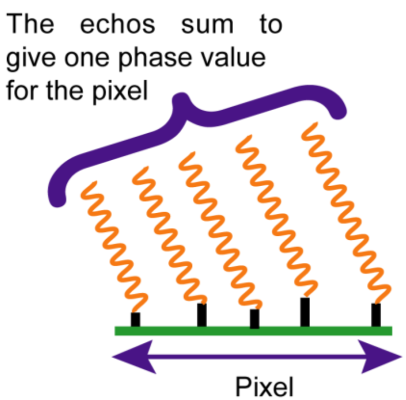
- Analysis unwrapped phase and at low resolution – multi look interferogram
- Computationally less intensive
- Works better in rural environments
- Phase unwrapping error
- Need external data for APS removal
- Lower performance

What are PS and DS?

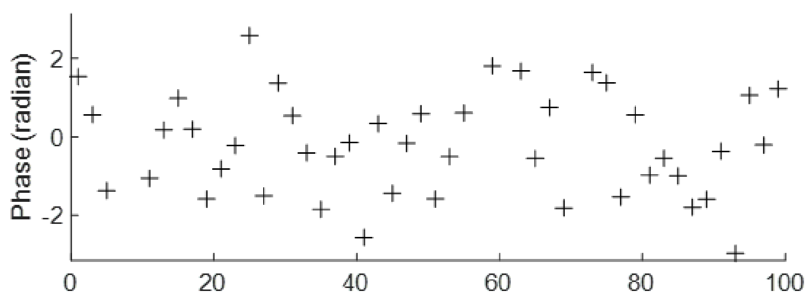
The radar return is a coherent sum of all the elements in a given pixel.

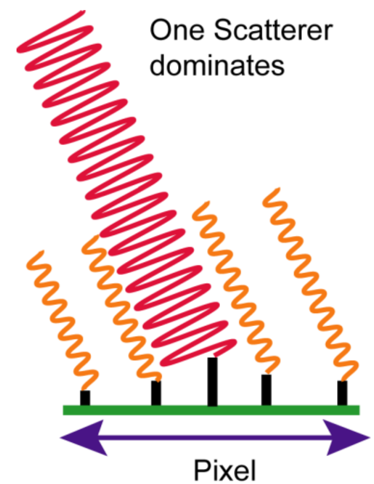
A distributed scatterer (DS) does not contain any dominant scatterer in the resolution element.

A persistent scatterer (PS) does contain a dominant scatterer in the resolution element.

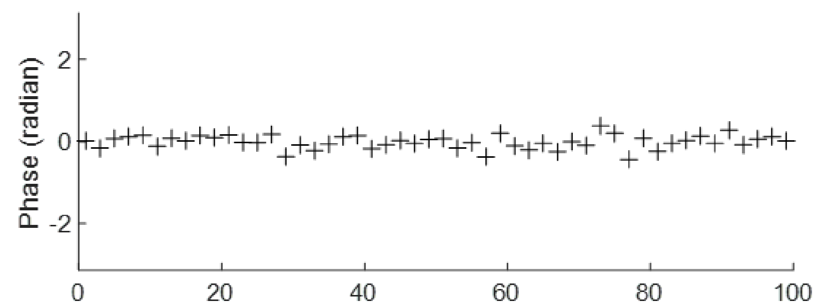


A DS pixel





A PS pixel



What are PS and DS?

Man-Made Structures

Buildings

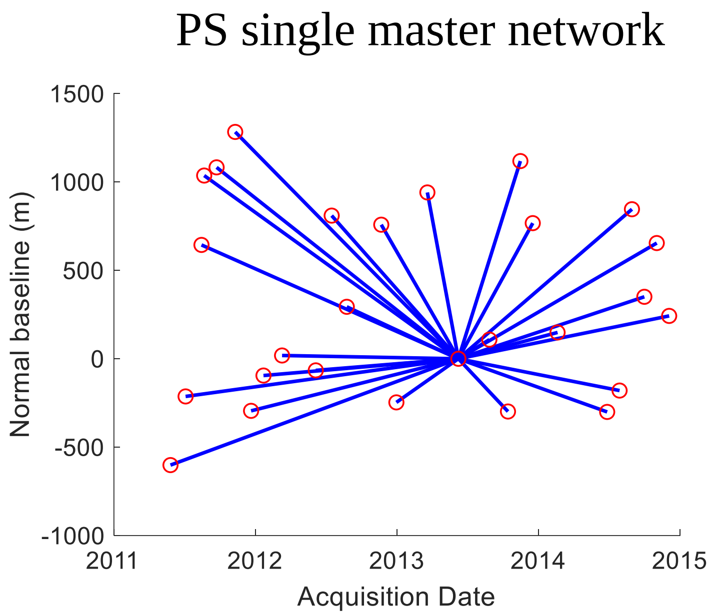
Rock Boulders

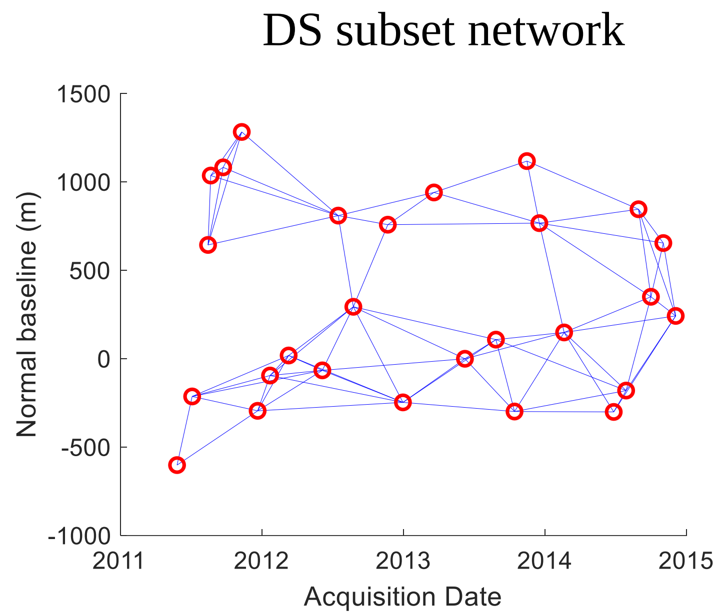
Short Vegetation

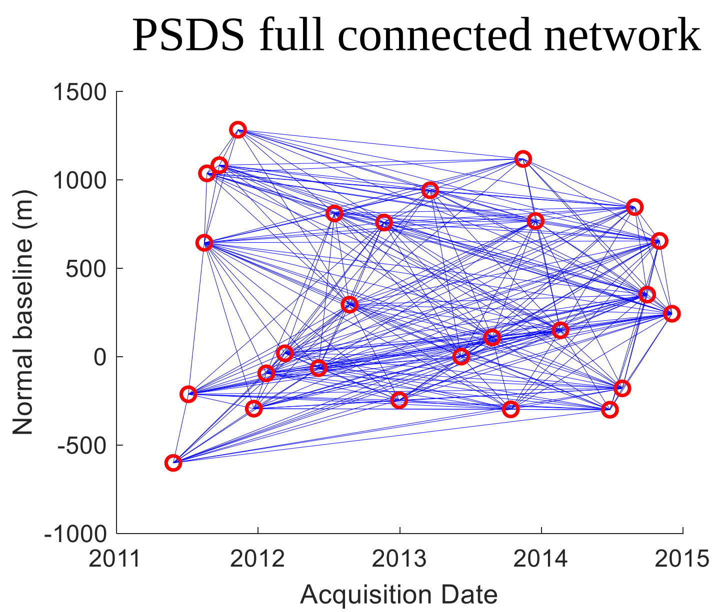
Scattered Outcrops

Homogeneous Ground

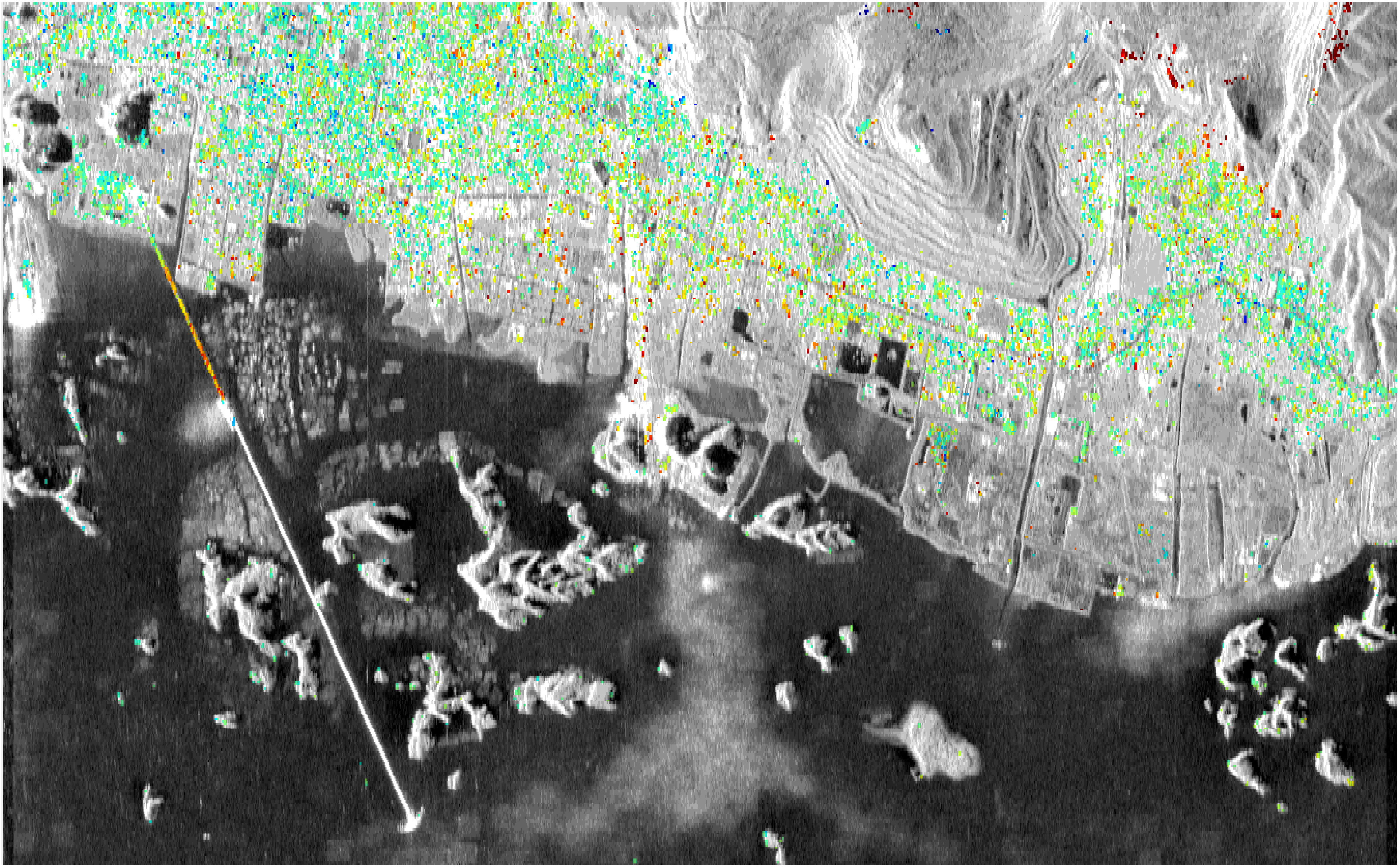
Possible interferometric sets



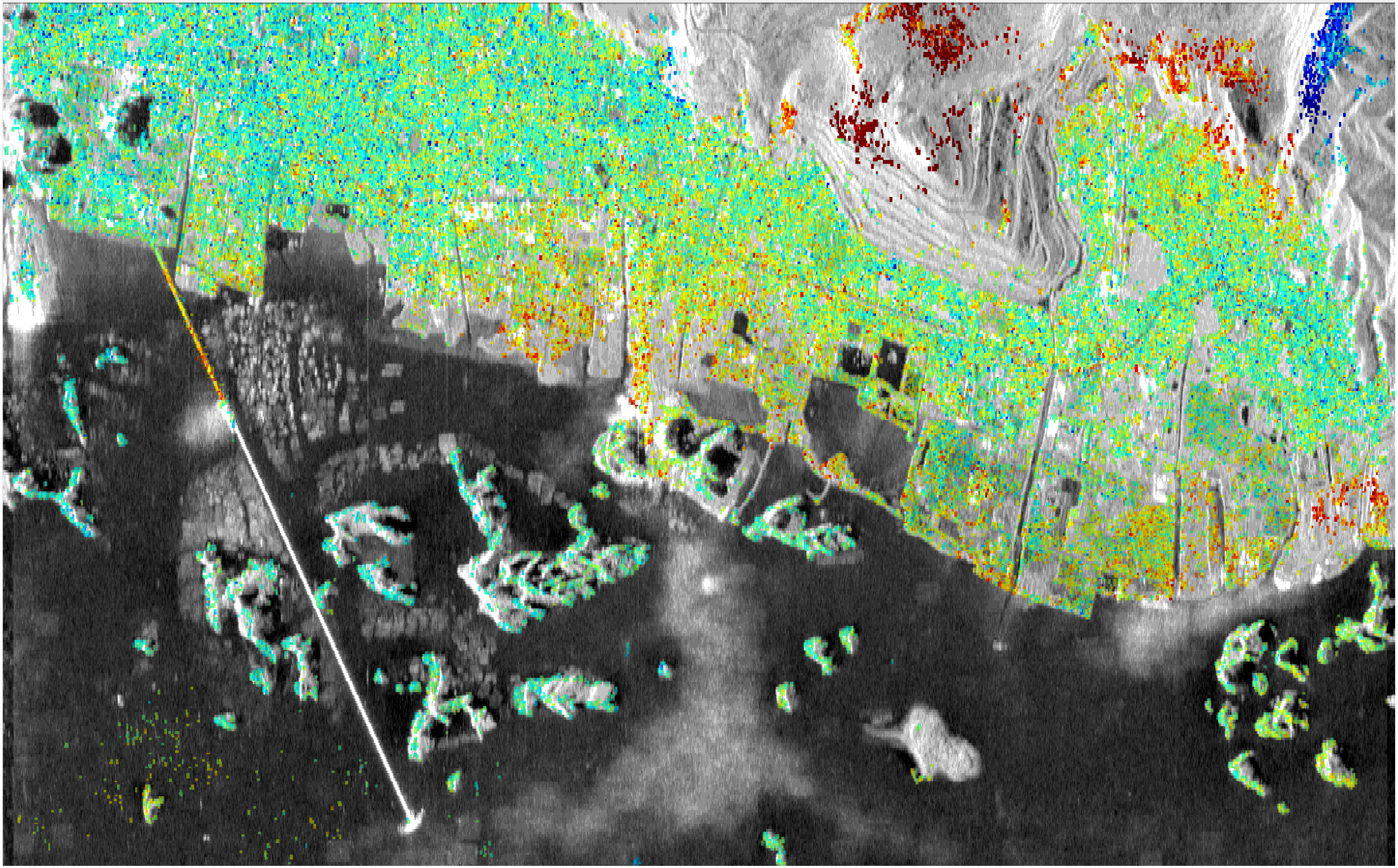




PSI technique : Stable targets



PSDS technique : Stable + DS targets



PS processing algorithms

<u>Summary of the SAR interferometric phase contributions</u>

PS pixels
small noises

$$\Delta\varphi = \Delta\varphi_{topo} + \Delta\varphi_{defo} + \Delta\varphi_{aps} + \Delta\varphi_{noise}$$

$$\boxed{\frac{\Delta h}{\sin\theta} \cdot \frac{B_n}{R_n} \cdot \frac{4\pi}{\lambda}}$$

$$\boxed{\frac{4\pi}{\lambda} d}$$

Key idea: Instead of analyzing the entire images, the analysis is based only on the selection of a number of highly coherent (PS), temporally stable, point-like targets within the imaged scene.

- <u>Systematic analysis</u> of InSAR data taking advantage of the available data set.

- <u>Estimation and removal</u> of the Atmospheric Phase Screen (APS).

- **<u>Extraction</u> of the phase contribution due to target motion with high accuracy**.

PS processing algorithms

Let us now consider the phase difference between two neighboring PS *i* and *0.*

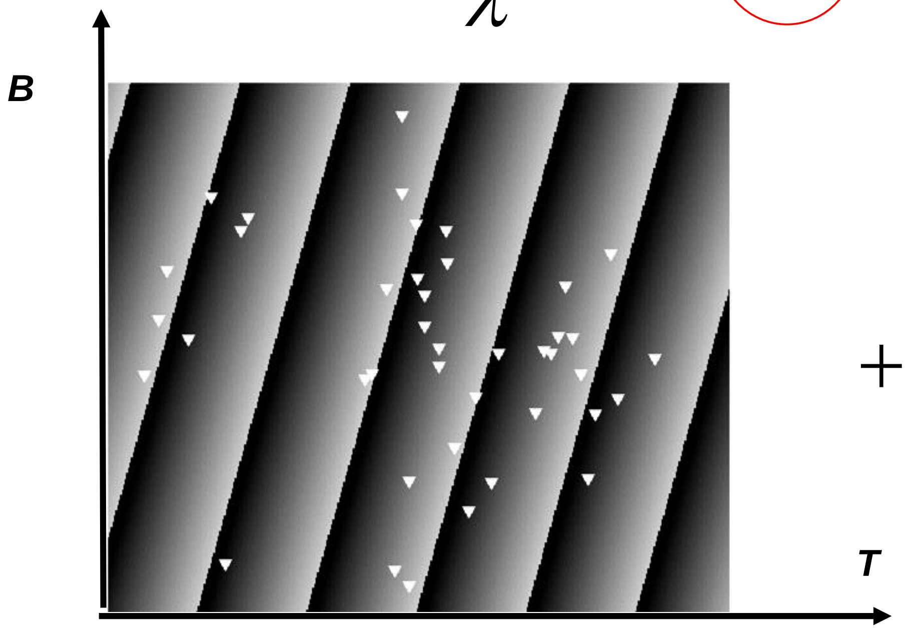
The phase component due to the relative displacement can be usefully split into two components:
1 - a constant deformation velocity (the phase varies linearly with time)
2 - a time-varying deformation velocity

Mean relative velocity

Non-Linear motion

$$\Delta\phi_{i0}^{k} = [C_b \cdot B^{(k)} \cdot \Delta\varepsilon_{i0} + \frac{4\pi}{\lambda} \cdot T^{(k)} \cdot \Delta v_{i0}] + (\mu_{NL}) + \alpha^{(k)} + n$$

$$\Delta\phi_{i0}^{k} =$$



$$+ (\mu_{NL}) + \alpha^{(k)} + n$$

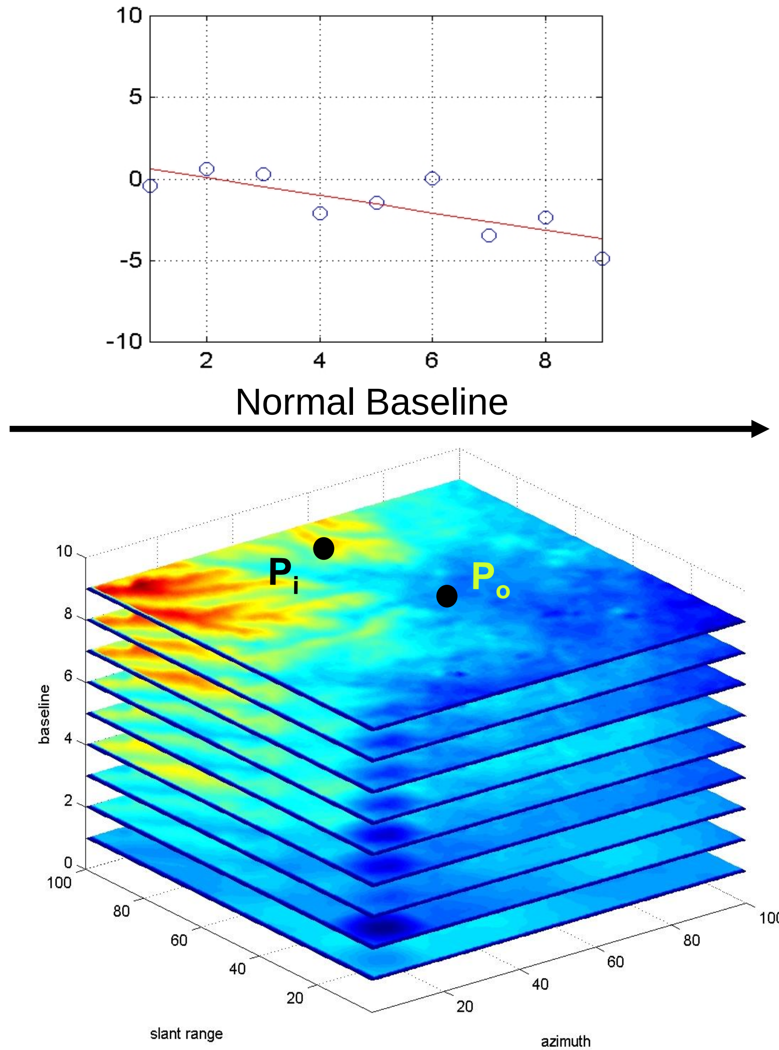
Phase Residues

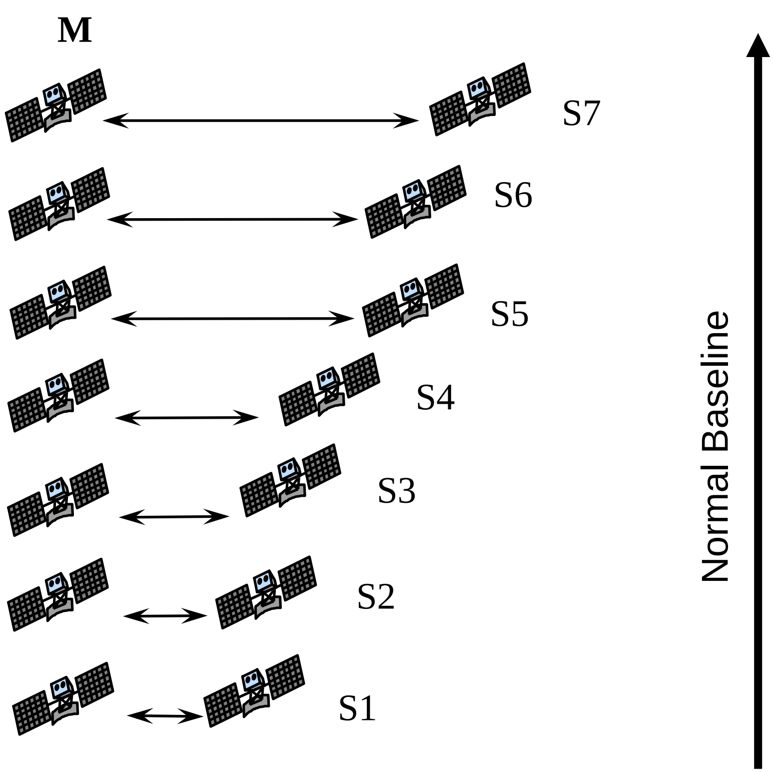
Phase difference between two PS

PS processing algorithms

Estimation of the relative elevation error

The relative elevation error $\Delta\varepsilon_{i0}$ is estimated as the slope of the line that best fits the differential phase as a function of baseline

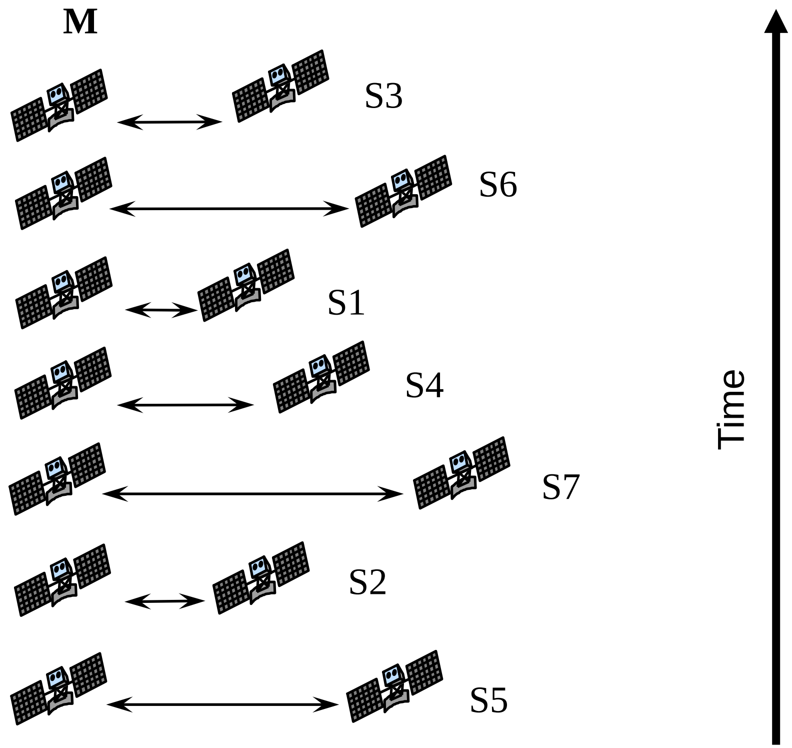


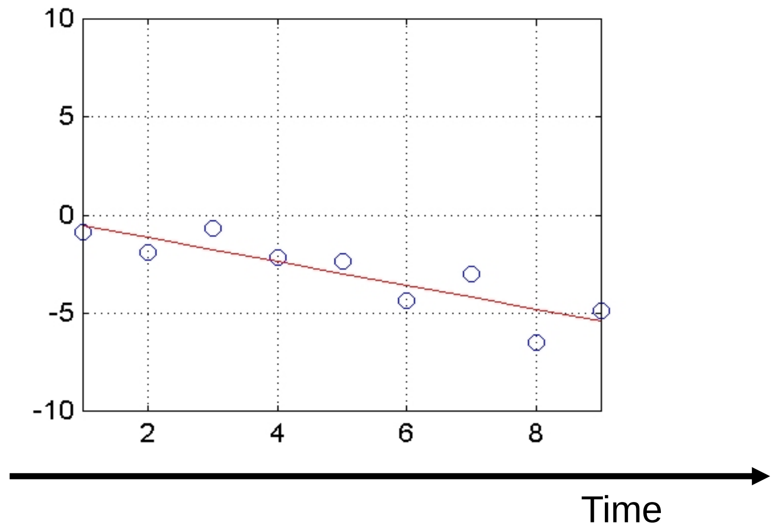


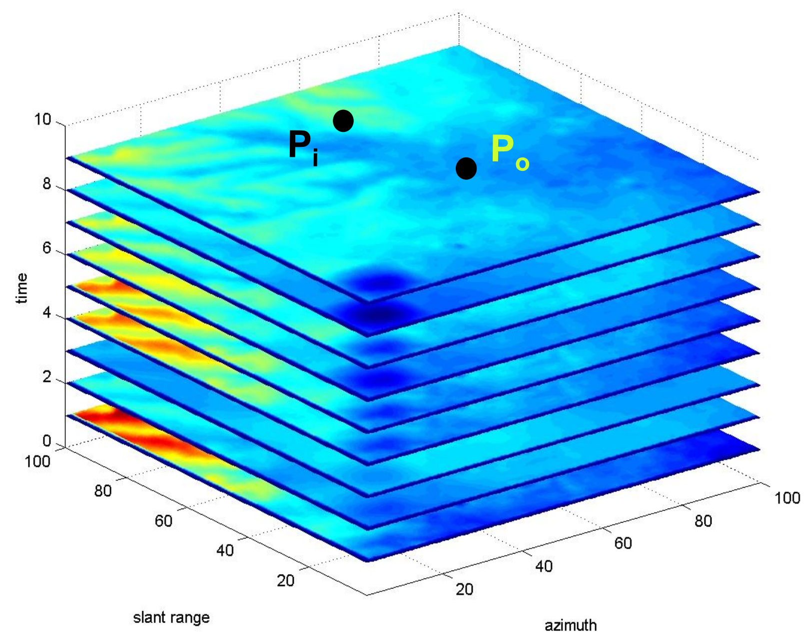
PS processing algorithms

Estimation of the relative constant velocity

The relative constant velocity Δv_{i0} is estimated as the slope of the line that best fits the differential phase as a function of time.





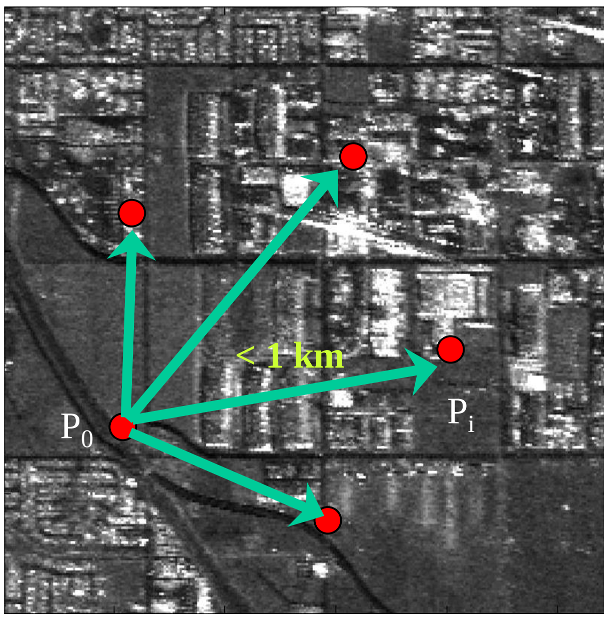


PS processing algorithms

In practice, the relative elevation error and the relative constant velocity are jointly estimated as the values of $\Delta\varepsilon_{i0}$ and Δv_{i0} that maximize the ensemble coherence defined as:

$$\boxed{\left|\gamma_{i0}\right| = \left|\frac{1}{N}\sum_{k=1}^{N}\exp\left(j\Delta w_{i0}^{k}\right)\right|}$$

$$\Delta w_{i0}^{k} = \Delta\phi_{i0}^{k} - [C_b \cdot B^{(k)} \cdot \Delta\varepsilon_{i0} + \frac{4\pi}{\lambda} \cdot T^{(k)} \cdot \Delta v_{i0}] = (\mu_{NL}) + \alpha^{(k)} + n$$

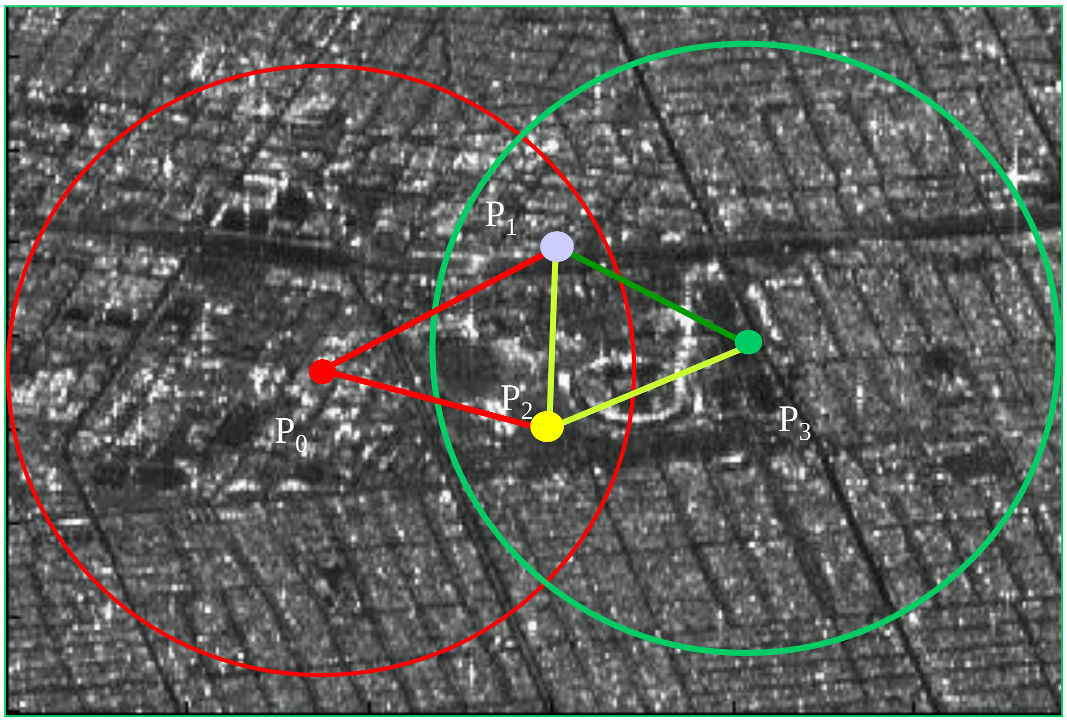


PS pairs with ensemble coherence lower than a given threshold are then discarded.

PS processing algorithms

The residual phase $\Delta w_{ij}^{k} = \mu_{ij}^{k} + \alpha_{ij}{}^{k} + n^{k}{}_{ij}$ as well as $\Delta\varepsilon_{i0}$ and Δv_{i0} can be computed for every PS pair. However, the largest distance of a PS pair should be kept shorter than the typical atmospheric decorrelation length (<1km) in order to guarantee that

$$\boxed{\left|\Delta w_{ij}^{k}\right| < \pi}$$

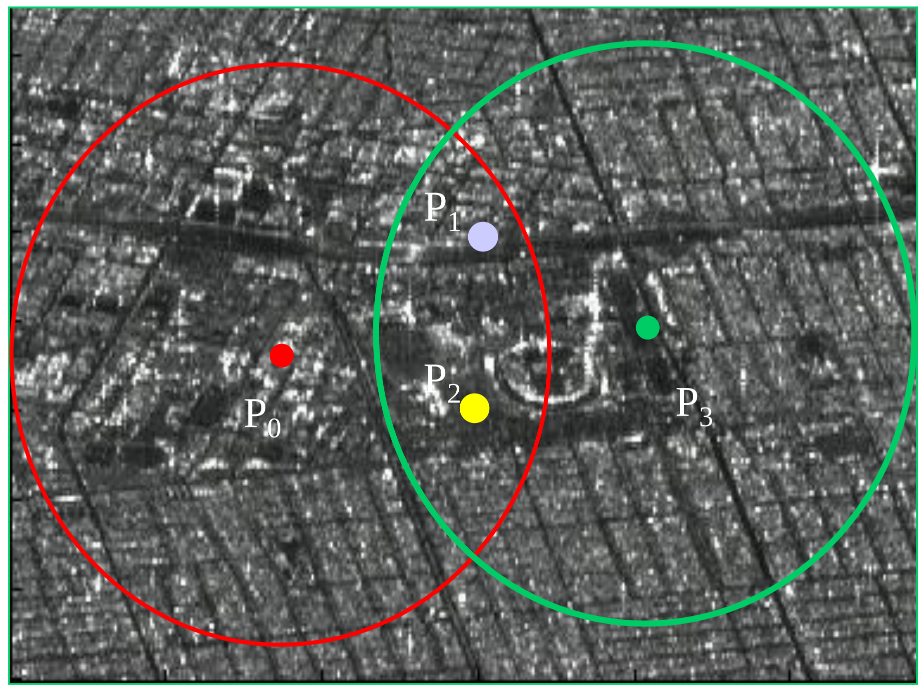


Phase Unwrapping on a Sparse Grid of Targets

Once the relative elevation error and the relative constant velocity have been estimated on the whole PS network, the phase differences (now unwrapped) can be LMS integrated starting from a reference point of known elevation and motion.

$$\begin{bmatrix} + & 0 & 0 & 0 \\ - & + & 0 & 0 \\ - & 0 & + & 0 \\ 0 & - & + & 0 \\ 0 & 0 & - & + \\ 0 & - & 0 & + \end{bmatrix} * \begin{bmatrix} \phi_0 \\ \phi_1 \\ \phi_2 \\ \phi_3 \end{bmatrix} = \begin{bmatrix} 0 \\ \Delta\phi_{10} \\ \Delta\phi_{20} \\ \Delta\phi_{21} \\ \Delta\phi_{32} \\ \Delta\phi_{31} \end{bmatrix}$$

The number of unknowns equals the number of PS.
The number of equations depends on the number of connections between PS pairs.



$$[G]*[\phi]=[\Delta\phi]$$

$$[\hat{\phi}]=\left[G^T G\right]^{-1} G^T \Delta\phi$$

Persistent Scatterer time series summary

- The technique is powerful. This allows us to monitor the study areas due to an unique reason: Satellites radar exist durably from 1993 and the Inteferometry technique is well matured.
- This method relies on pixels that exhibit low decorrelation with time and baseline.
- PS techniques work best in urban environments. With the advanced PS+DS, it is best for both urban and rural areas.

Recommend resources

Radar Interferometry: 20 Years of Development in Time Series Techniques and Future Perspectives

https://www.mdpi.com/2072-4292/12/9/1364