GTC | Geo-intelligence, Building Multi-dimensional Foundation

PSInSAR and Alternatives for Surface Motion Estimation

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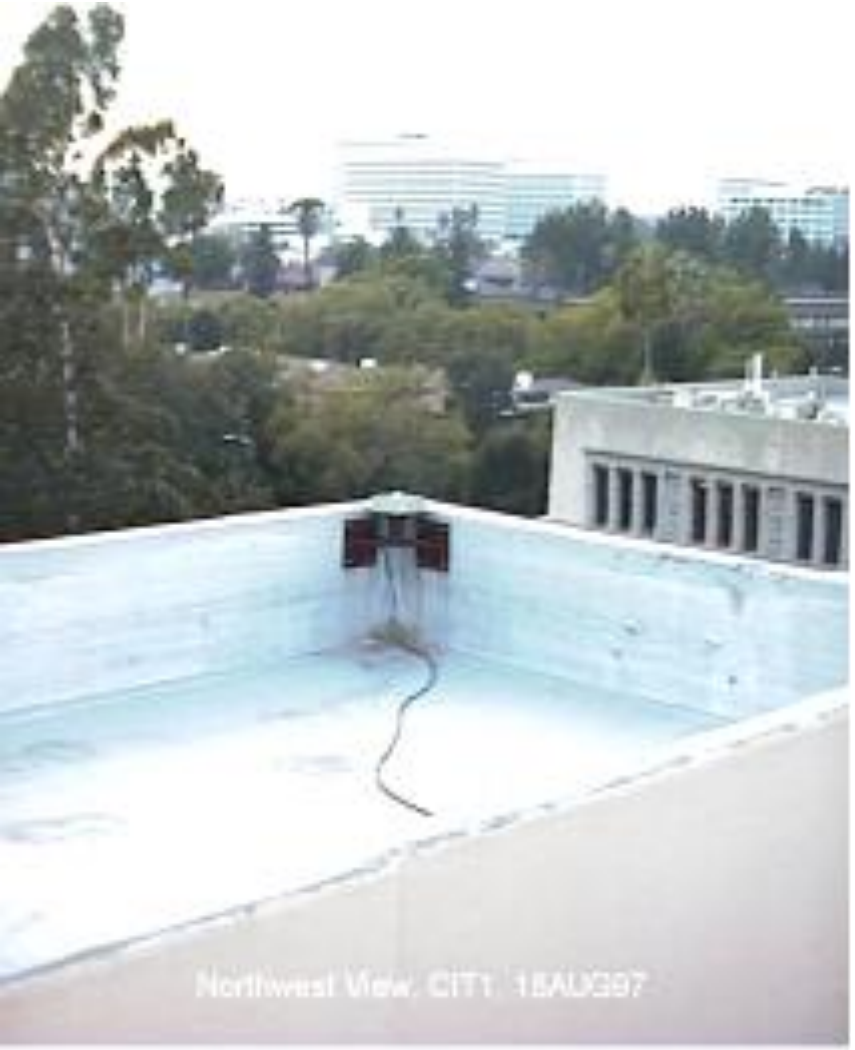
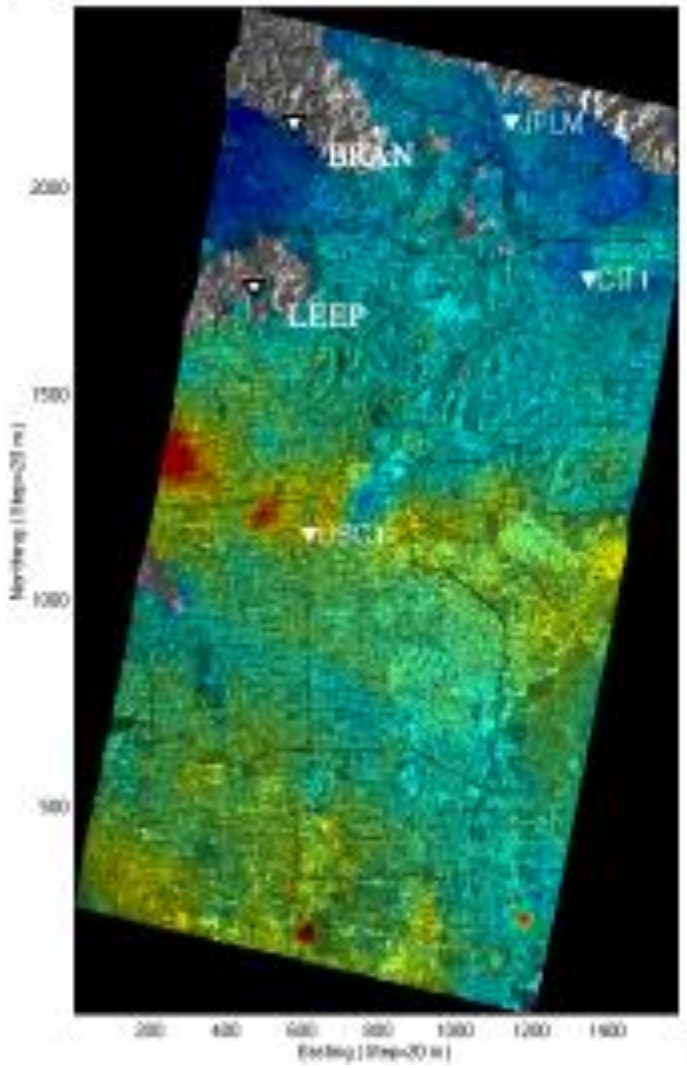
5th GIS Software Technology Conference (GTC 2022)

GPS vs SAR



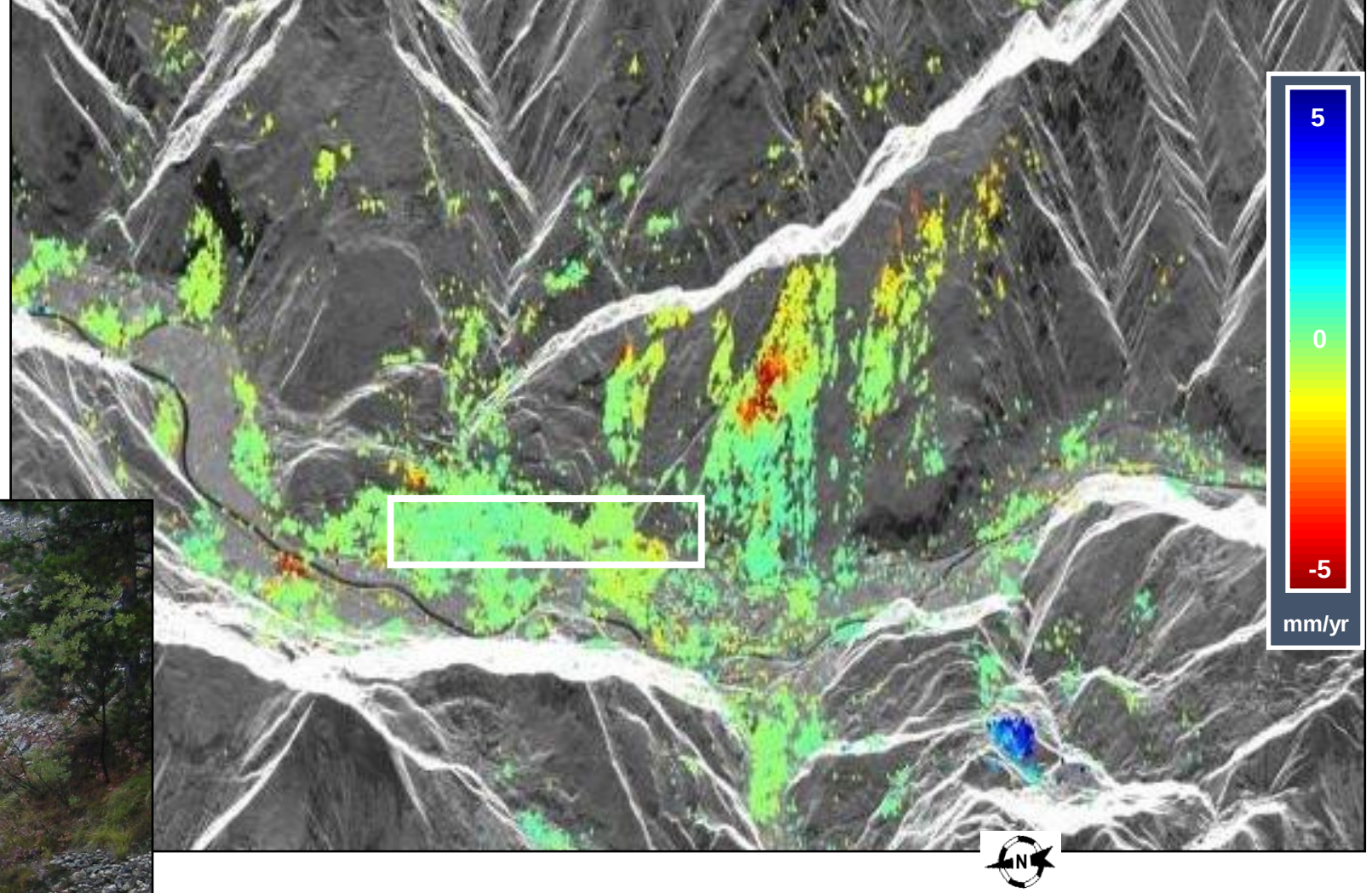
	GPS [mm/yr]	SAR [mm/yr]
JPLM*	-2.7±0.3	-2.7±0.2
CIT1	-2.3±0.3	-2.3±0.2
USC1	-7.9±0.3	-7.9±0.1
LEEP	-3.1±0.3	-3±0.2
BRAN	-7.5±0.4	-2.3±0.4



(source: Fabio Rocca)

PS-InSAR

Frana dei Lavini di Marco (TN)



(source: Fabio Rocca)

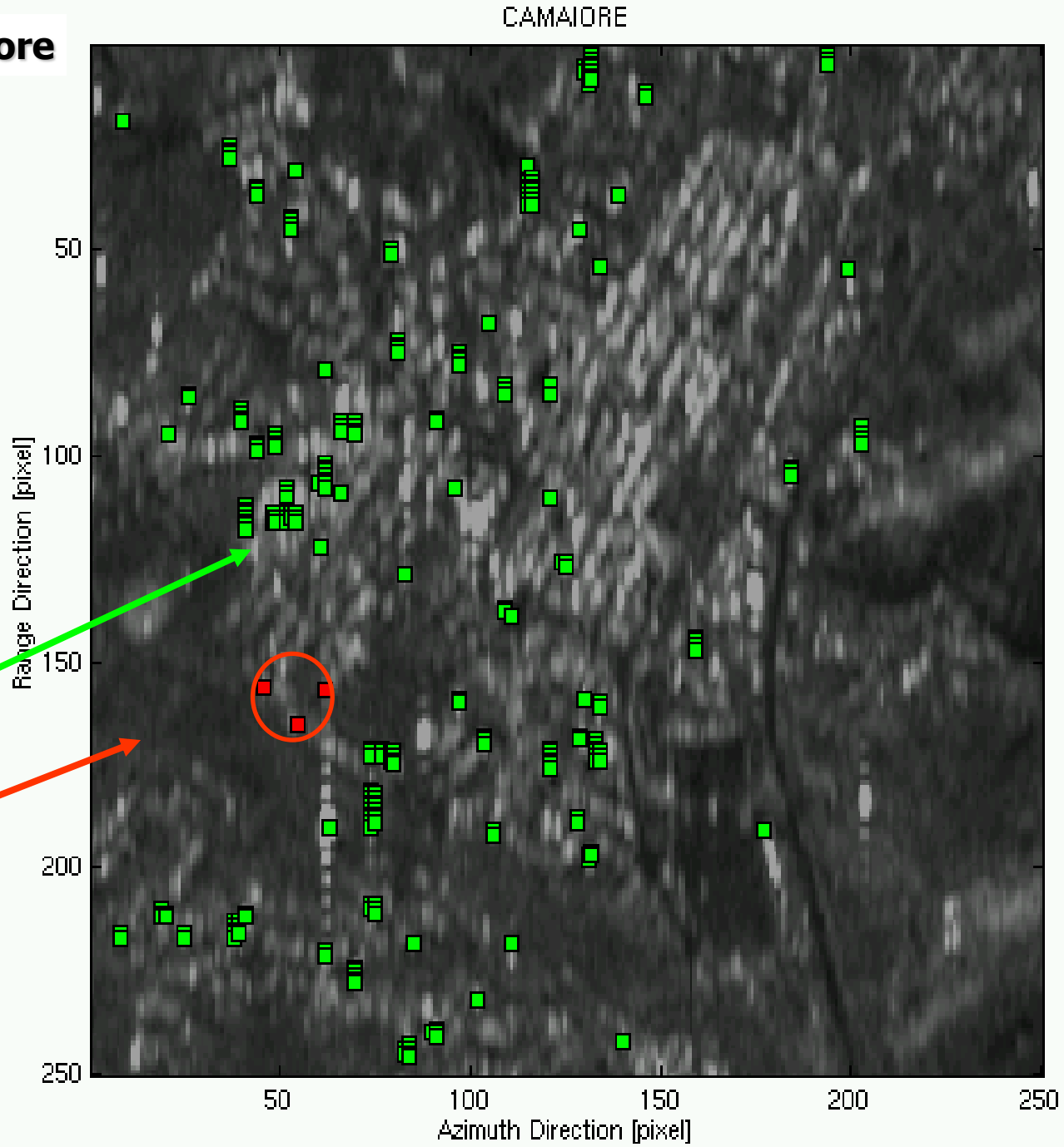
PS-InSAR

October 15th, 1995: Building Collapse in Camaiore (Tuscany) due to subsurface phenomena

(source: Fabio Rocca)

PS-InSAR

The case of Camaiore

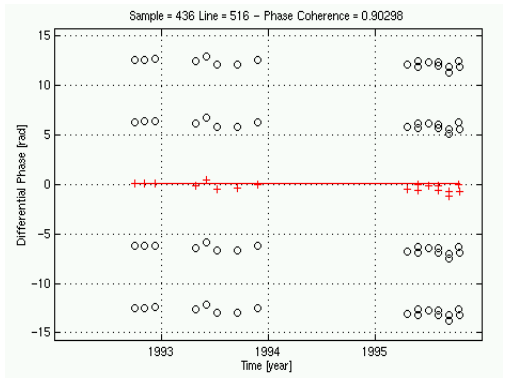


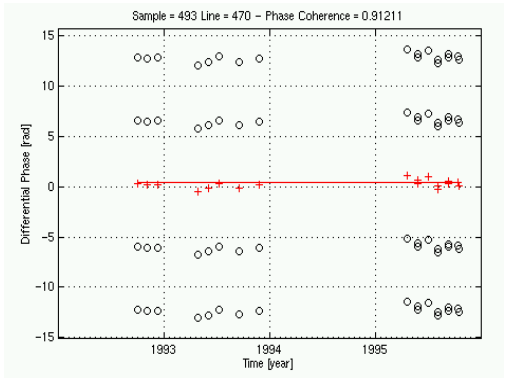
Stable targets

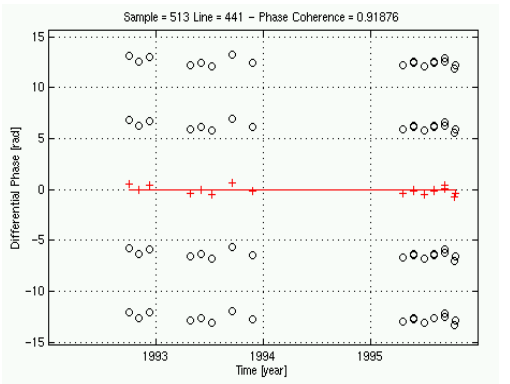
Targets showing Oct. 95 collapse precursors

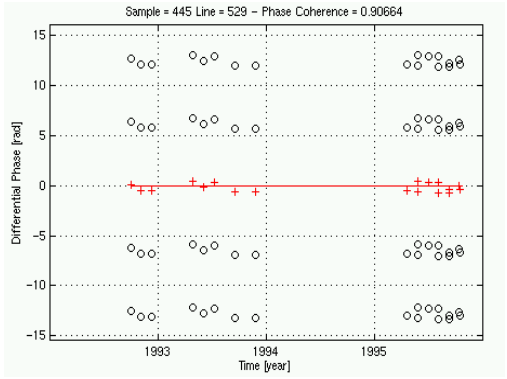
(source: Fabio Rocca)

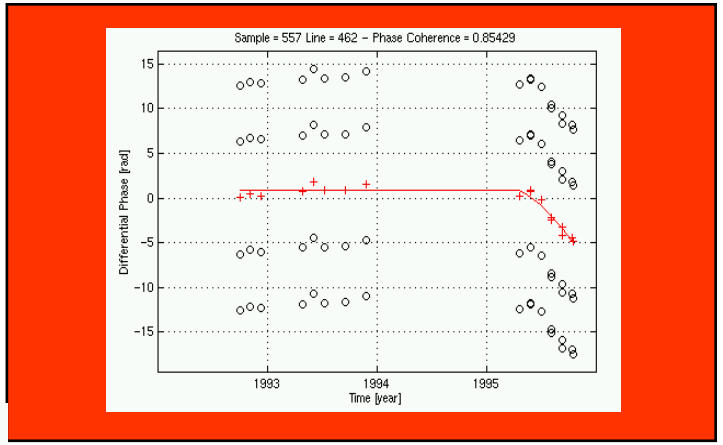
Time series before collapse

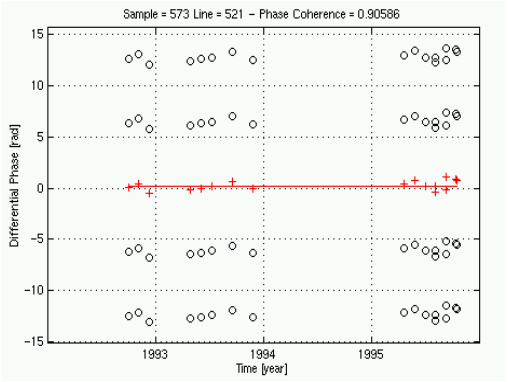


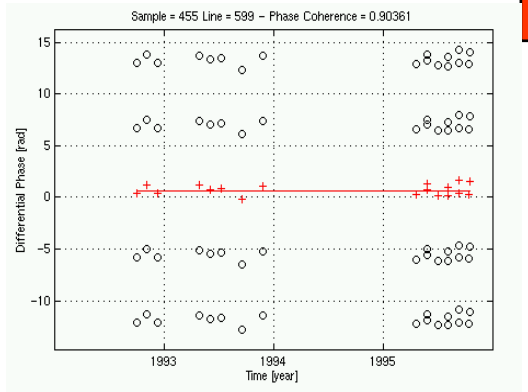


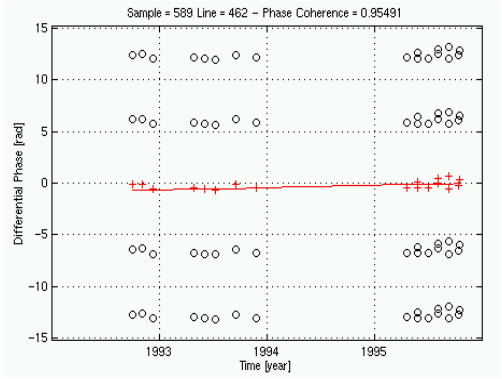


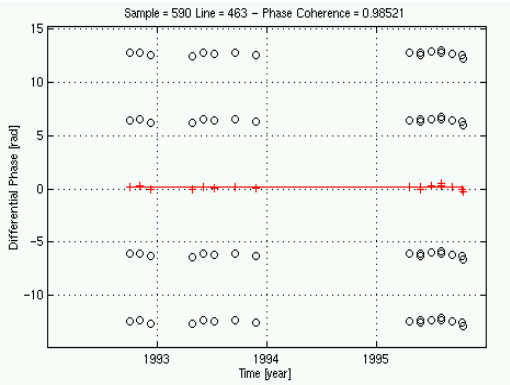












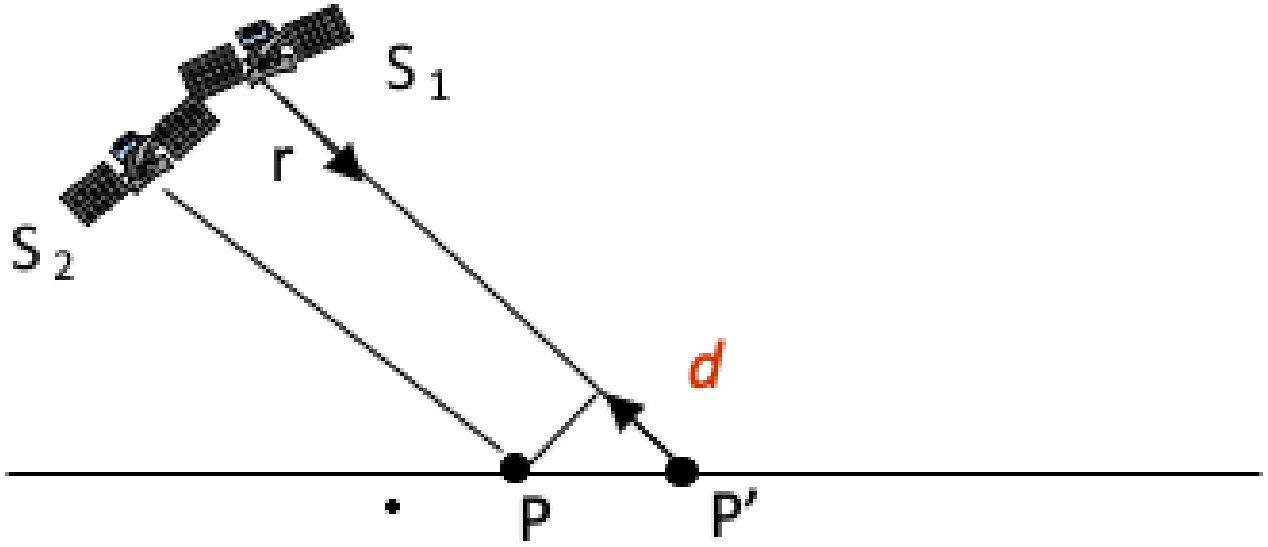

Users/Industry
Science

Reasons for The Gap

- PSInSAR is an opportunistic technology
  - Great results under favourable circumstances
- PSInSAR is complicated
- Various methods address and improve different issues of the original method
- No solution fits to all problems
- Commercial Software / Commercial Services / Open-Source Software
  - Limited Availability and accessibility hinder transparency

surface motion contribution

If a scatterer on the ground slightly changes its relative position in the time interval between two SAR acquisitions (e.g. subsidence, landslide, earthquake …), an additive phase term, independent of the baseline, appears.



$$\Delta\varphi_{displacement} = \frac{4\pi}{\lambda} d$$

Here, *d* is the relative scatterer displacement projected on the slant-range direction

(source: Fabio Rocca)

D-InSAR problems

- Phase Wrapping / Ambiguity
- Speckle
- Temporal Decorrelation
- Atmospheric Effects

Speckle

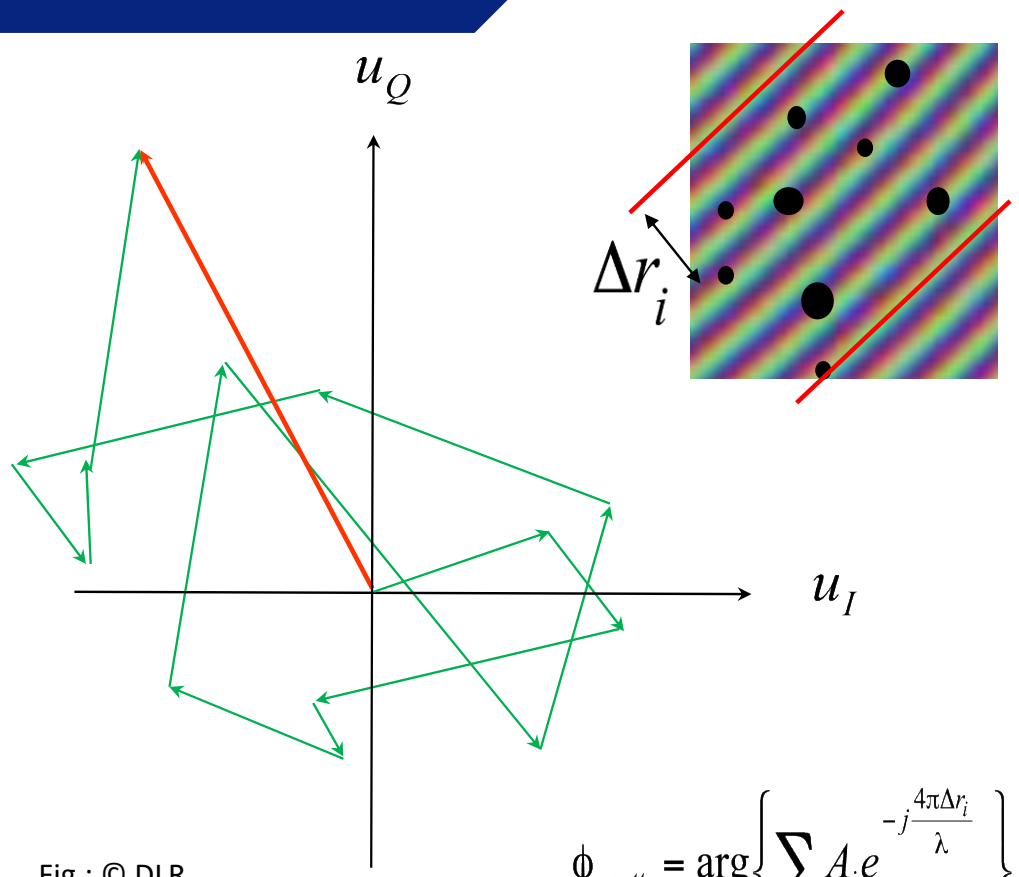
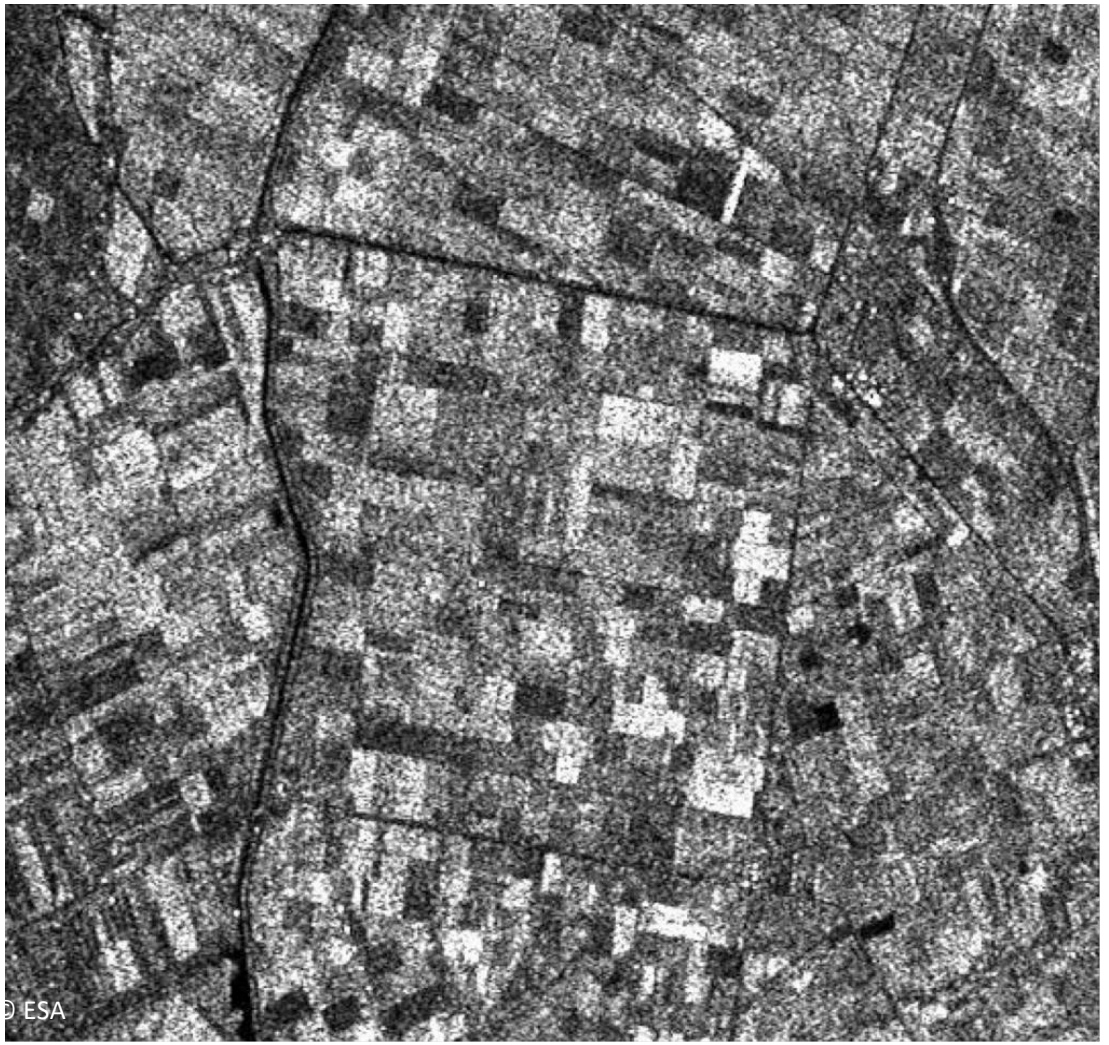


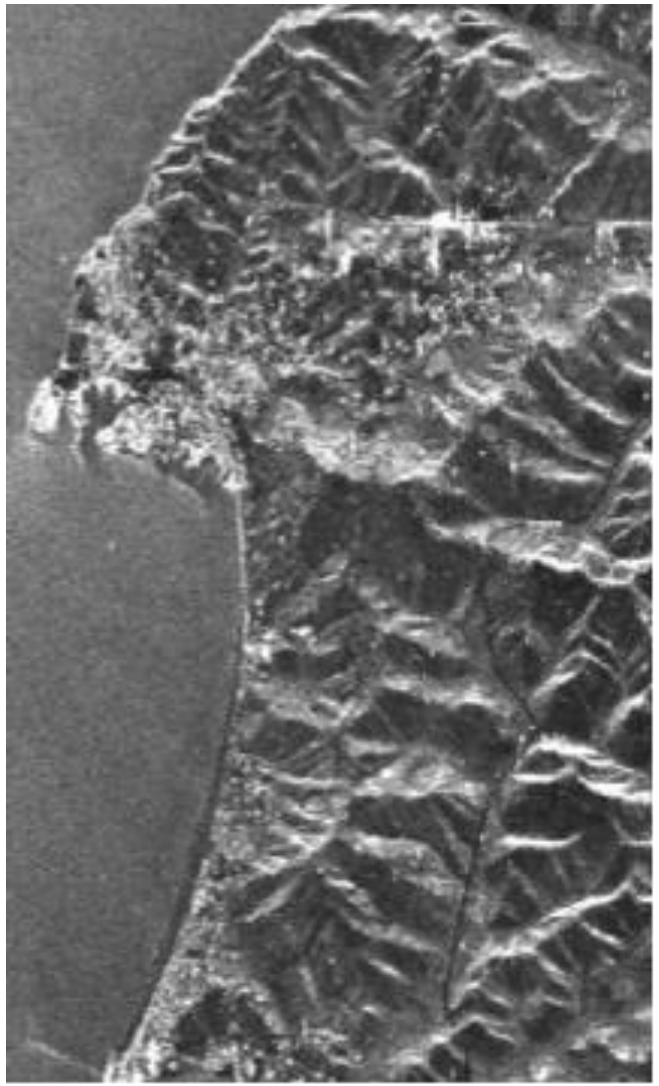
Fig.: © DLR

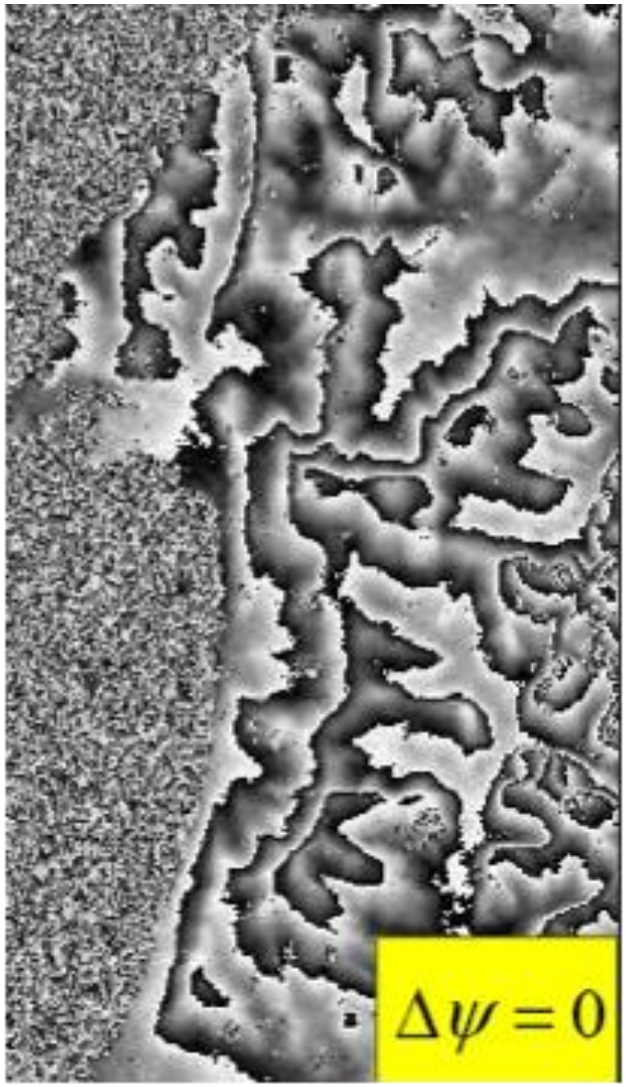
$$\phi_{scatt} = \arg\left\{\sum A_i e^{-j\frac{4\pi\Delta r_i}{\lambda}}\right\}$$



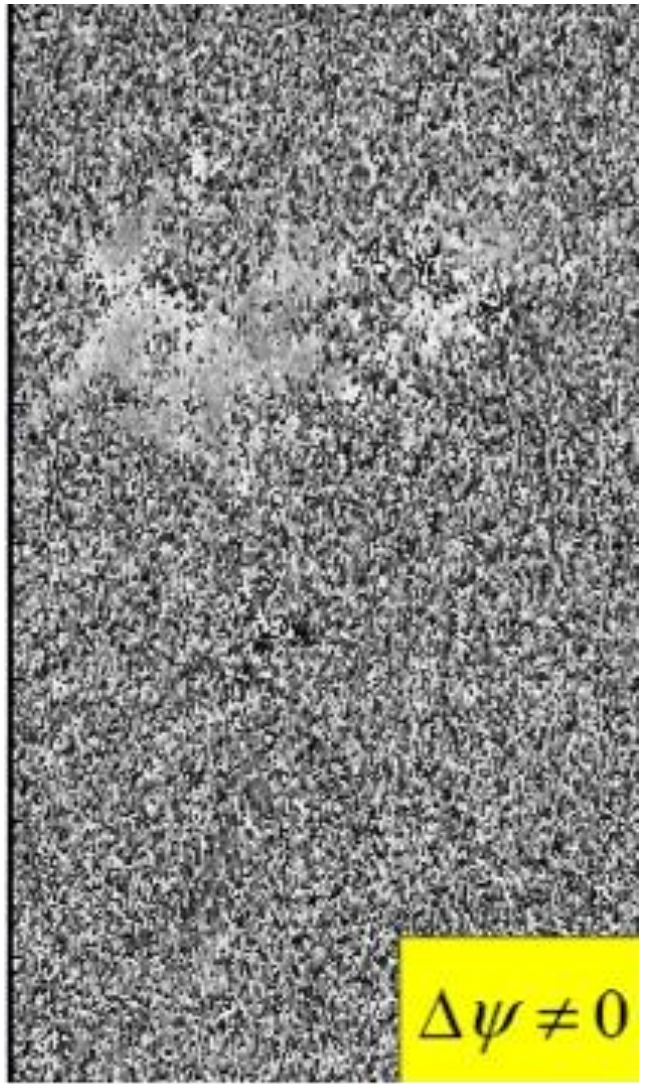
- Random positive and negative interference of wave contributions from the many individual scatterers within one resolution cell
  - Varying brightness from pixel to pixel even for constant σ_0
  - Granular appearance even of homogenous surfaces

Temporal Decorrelation





1-day (Tandem) Interferogram



15 months Interferogram

(source: Fabio Rocca)

Atmosphere

SAR signal propagation through atmosphere

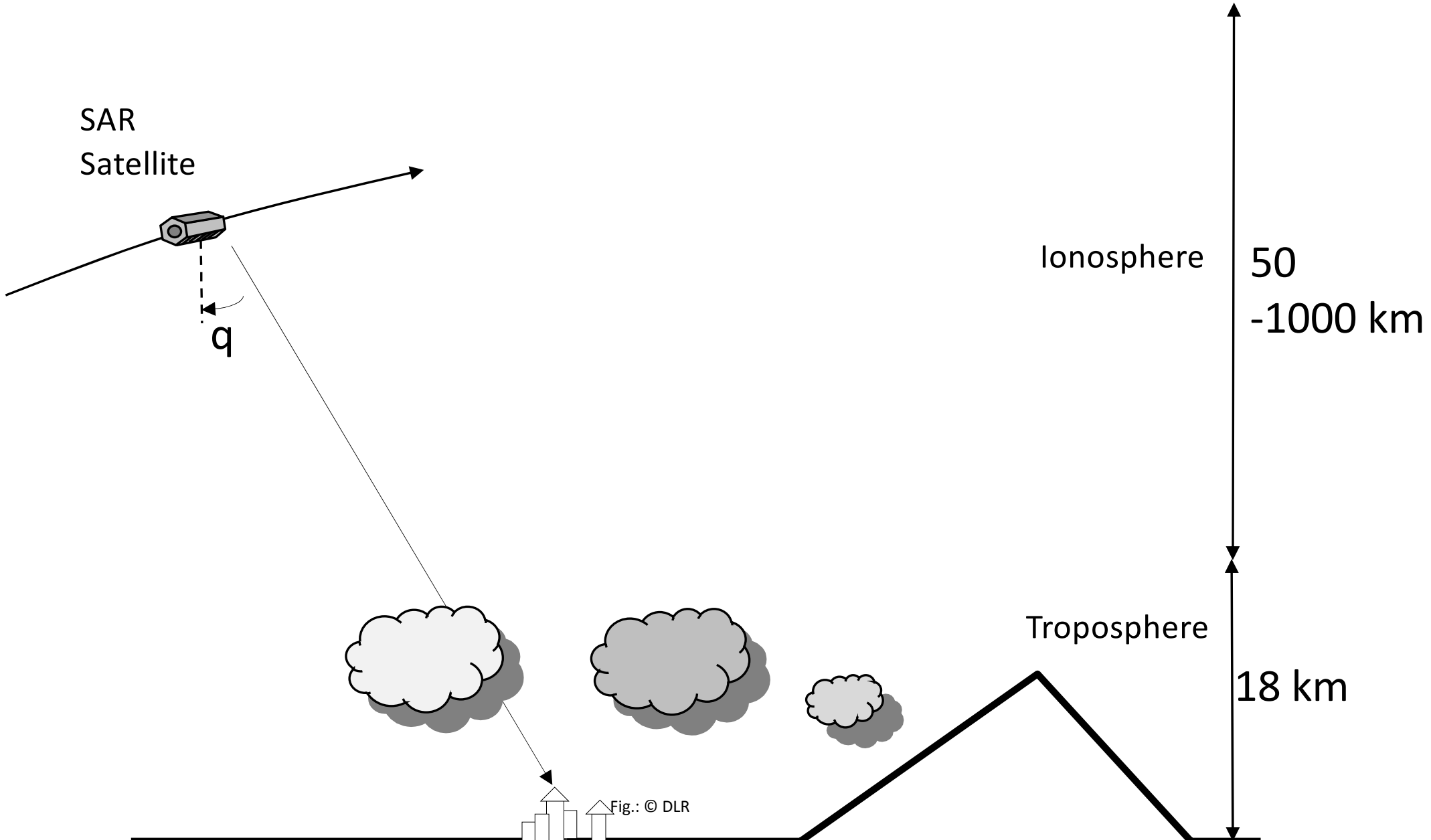
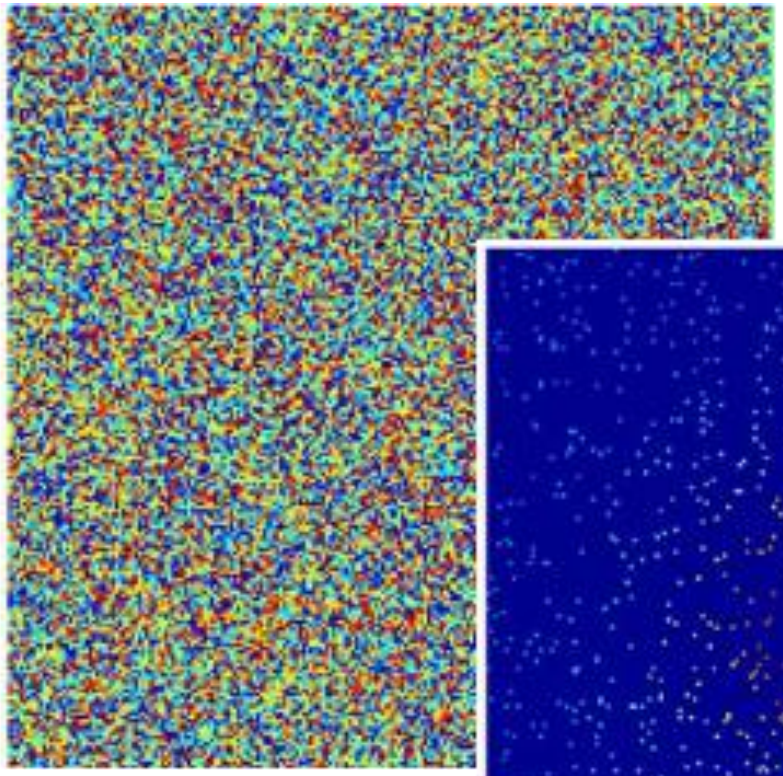


Fig.: © DLR

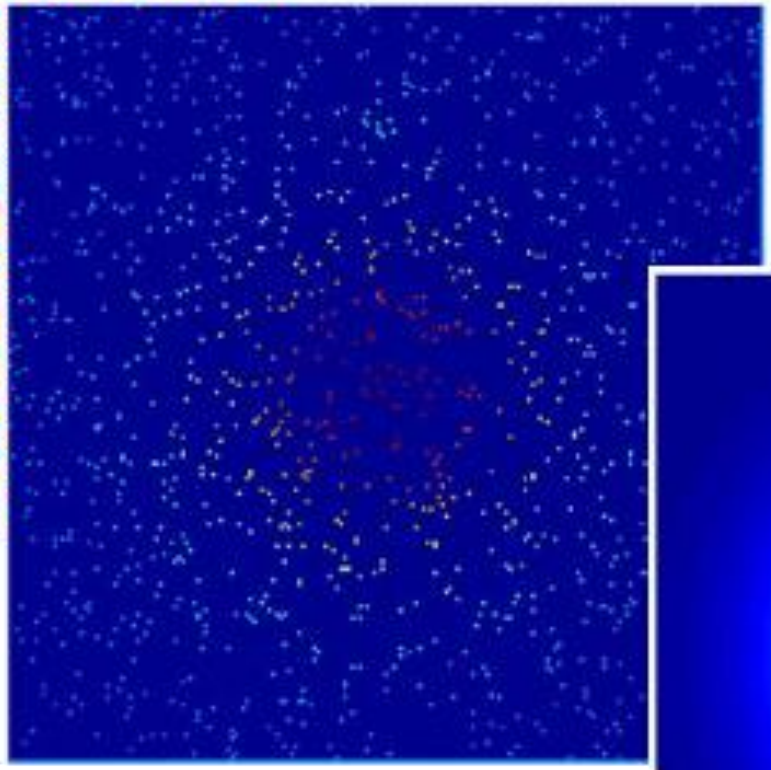
How does PSInSAR solve these issues?

Spoiler: Some issues are avoided not solved….

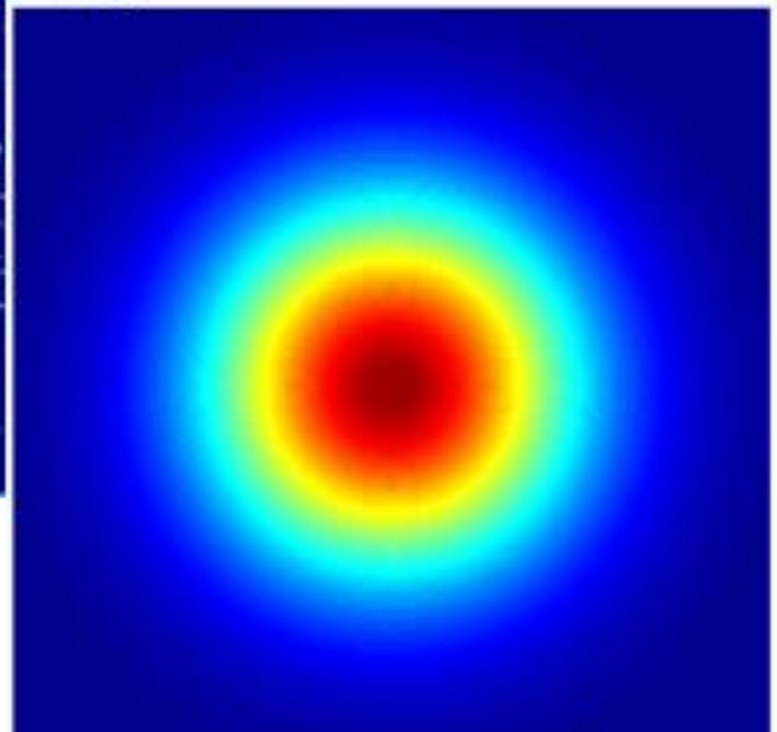
PS Technique



Interferometric fringes



Interferometric fringes punctured at the PS locations



(source: Fabio Rocca)

What is a PS?

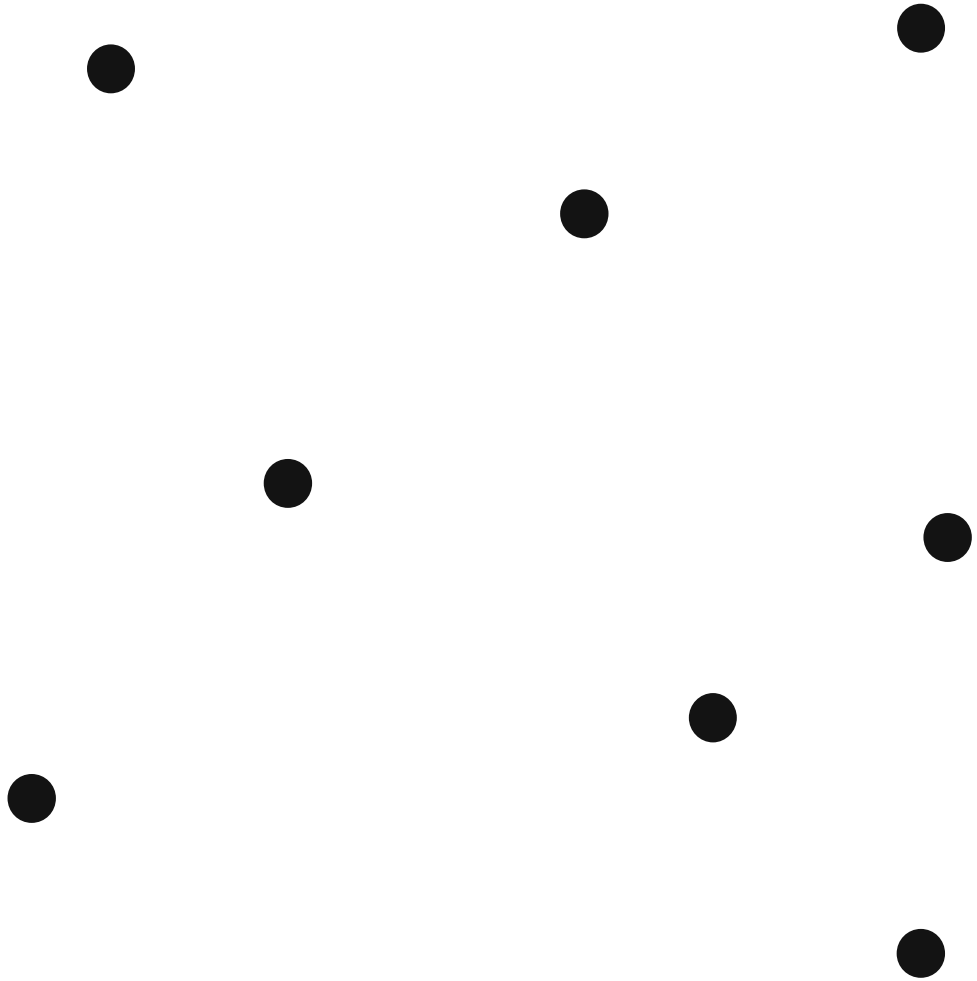
PS are radar targets exhibiting stable radar returns:
man-made objects, pipelines, poles, outcrops, rocky areas,...

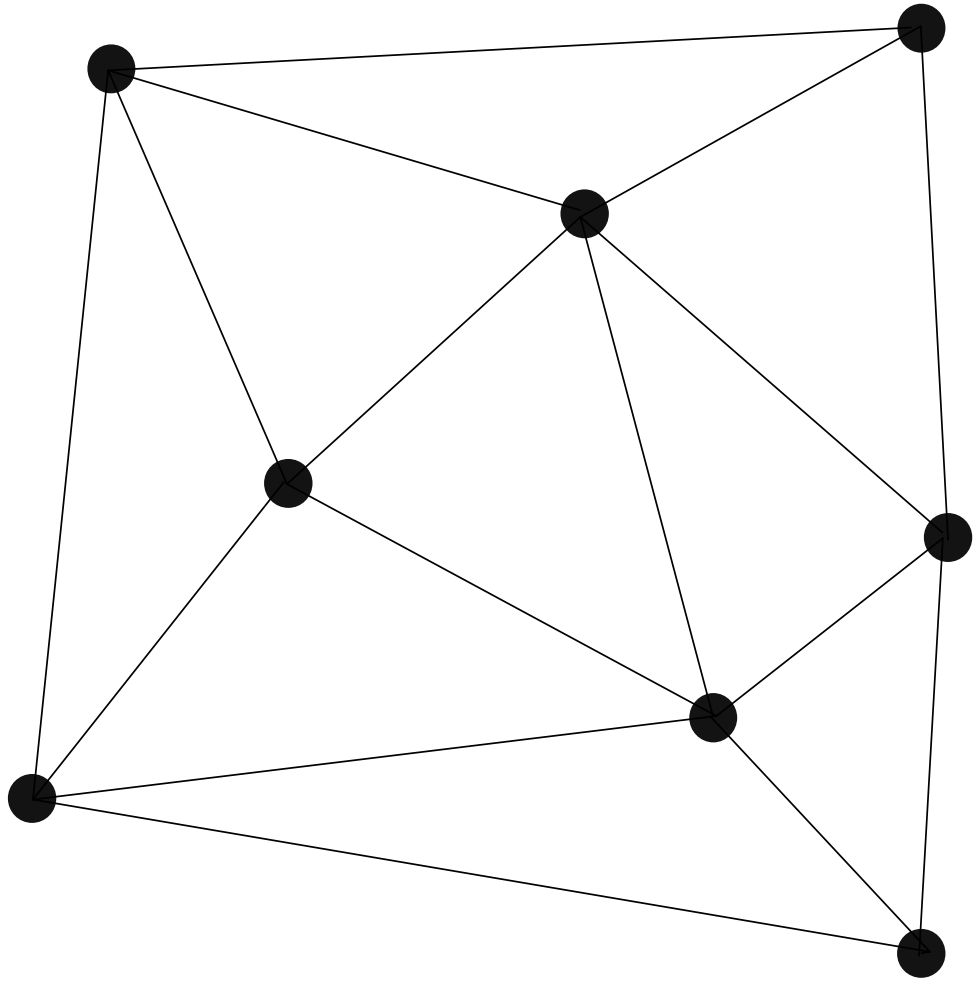
(source: Fabio Rocca)

Permanent Scatterer

- A Permanent Scatterer has by definition
  - No Speckling
    - Speckling occurs when there are several backscatterers in one resolution cell
    - PS is defined as one dominant scatterer in a resolution cell
    - Therefore, PS is not affected by speckling
  - No Temporal Decorrelation
    - PS is defined as being stable in time
    - Therefore, PS is not affected by temporal decorrelation

PS processing





Value estimation

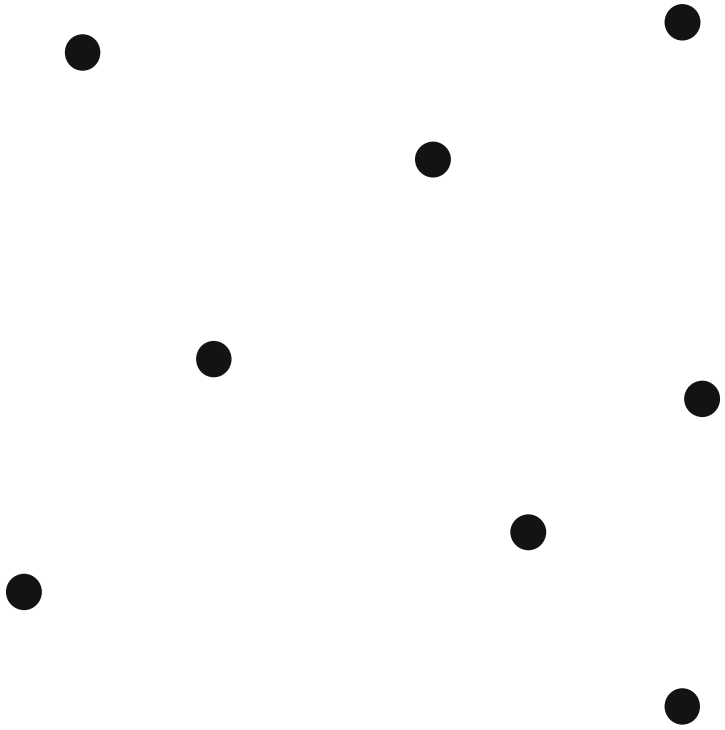
$$\varphi = W\{\phi_{topo} + \phi_{motion} + \phi_{atmo} + \phi_{orbit} + \phi_{noise}\}$$

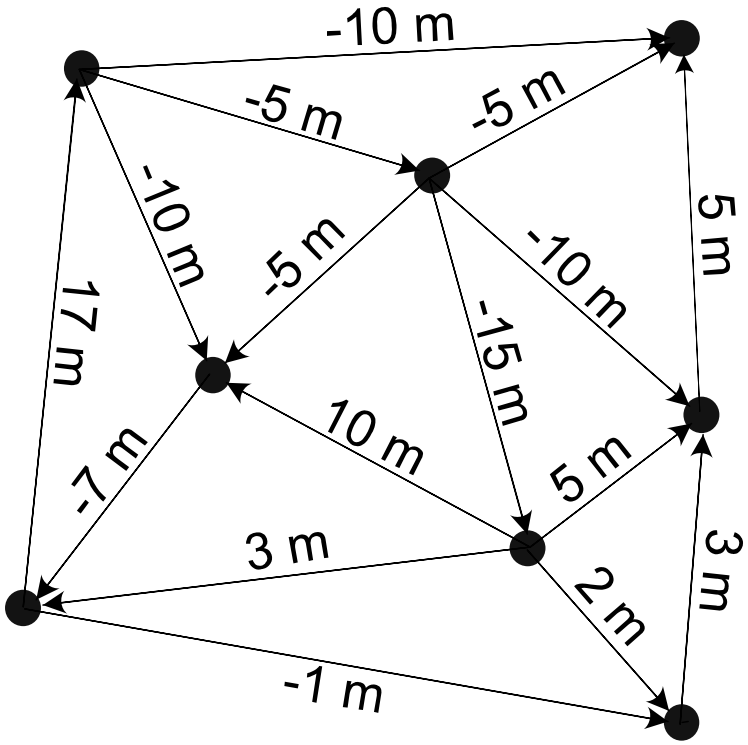
$$\Delta h = \frac{\lambda \Delta \phi_{topo}}{4\pi} \frac{r \cdot \sin\theta}{B_{\perp}}$$

$$\Delta v_{linear} = \frac{\phi_{motion} \cdot \lambda}{4\pi \cdot \Delta t}$$

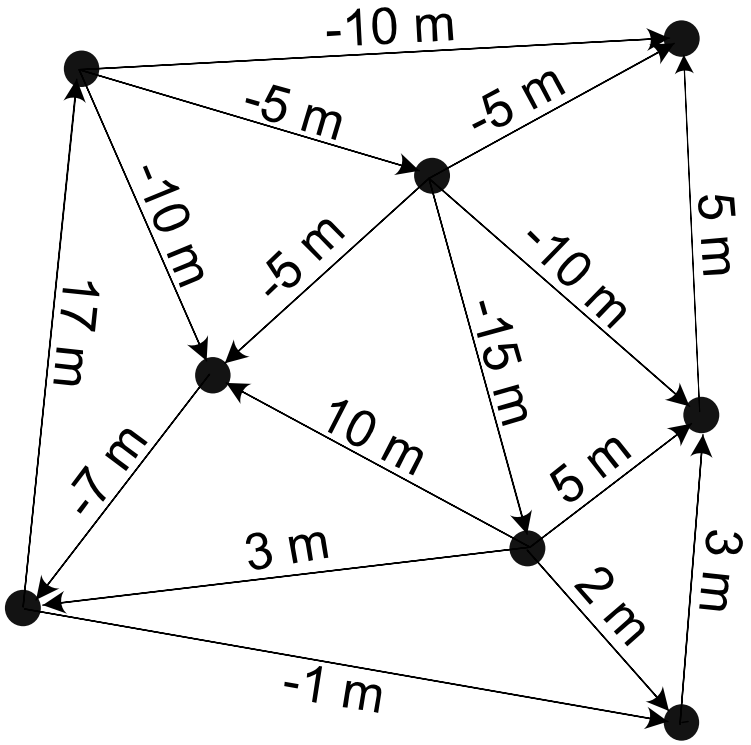
$$\begin{bmatrix} \phi_1 \\ \vdots \\ \phi_n \end{bmatrix} = \begin{bmatrix} a_1 \cdot 2\pi + \phi_{topo,1} + b_1 \cdot 2\pi + \phi_{motion,1} + \phi_{res,1} \\ \vdots \\ a_n \cdot 2\pi + \phi_{topo,n} + b_n \cdot 2\pi + \phi_{motion,n} + \phi_{res,n} \end{bmatrix}$$

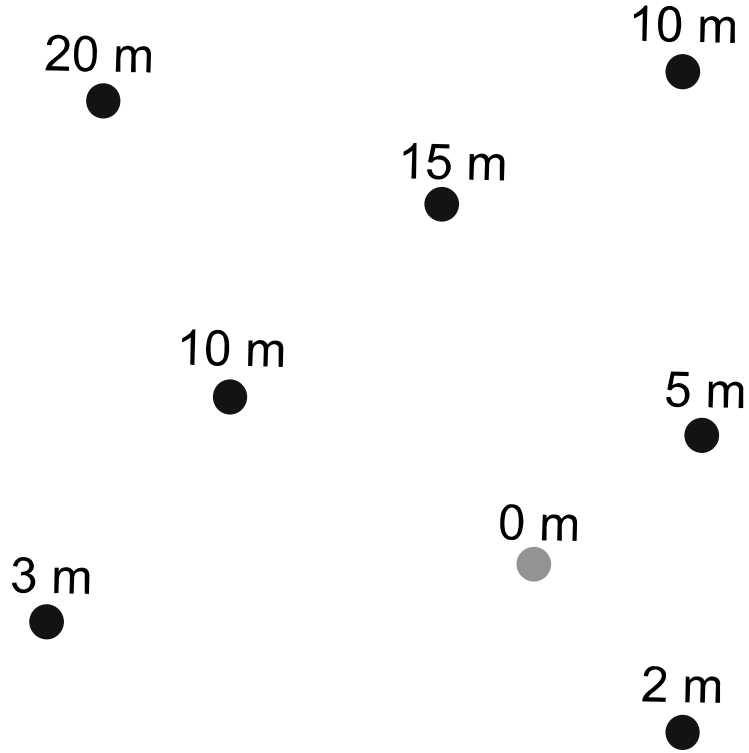
APS estimation



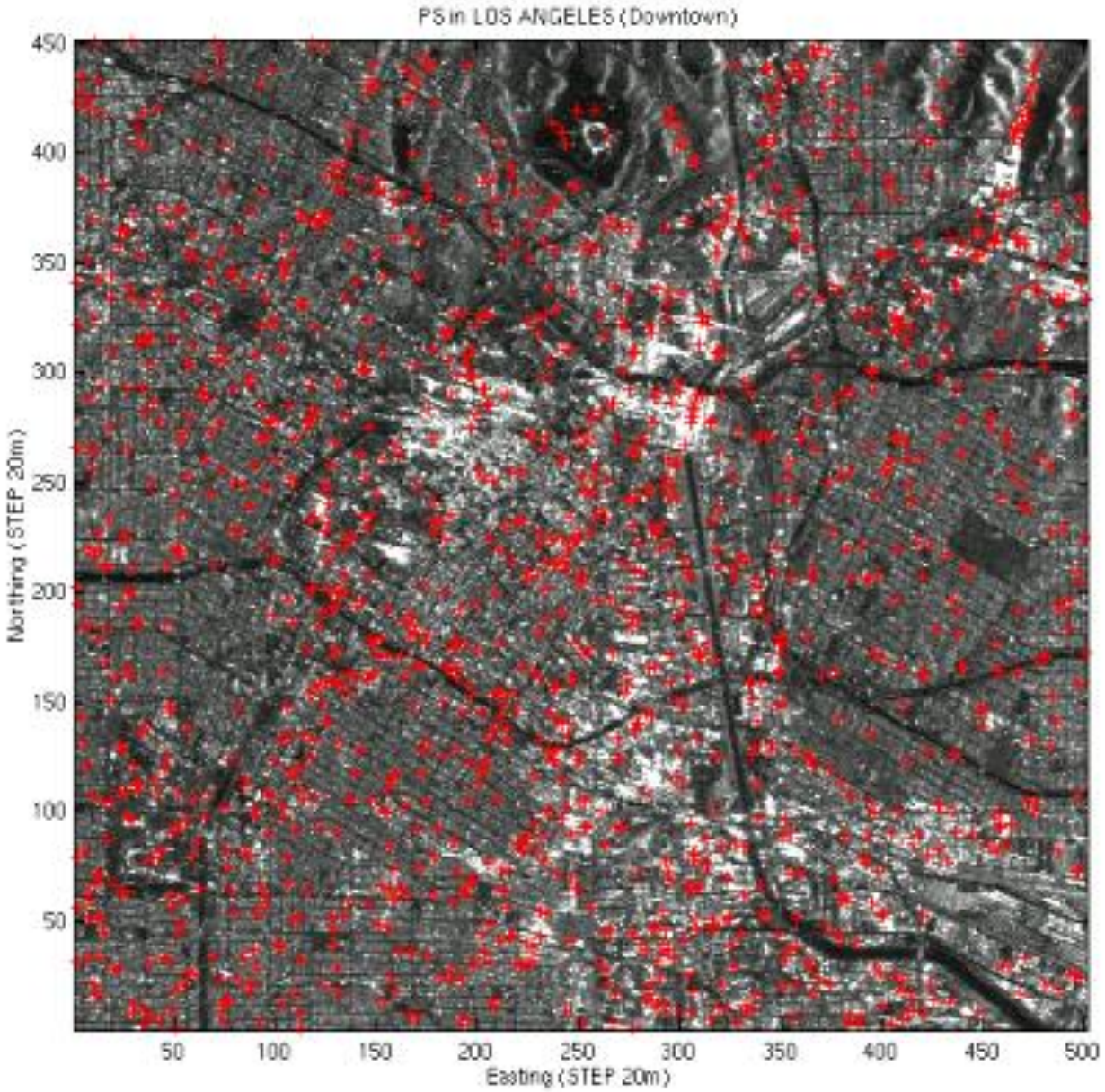


APS estimation





PS density



More than 10 PS/km² detected (σ_ϕ < 0.35 rad with respect to the linear model)

(source: Fabio Rocca)

PSInSAR shortcomings

- PSInSAR needs a high density of PS points
  - Can be found in urban areas
  - What about non-urban areas?
- PSInSAR estimates a linear motion
  - What about non-linear motion?

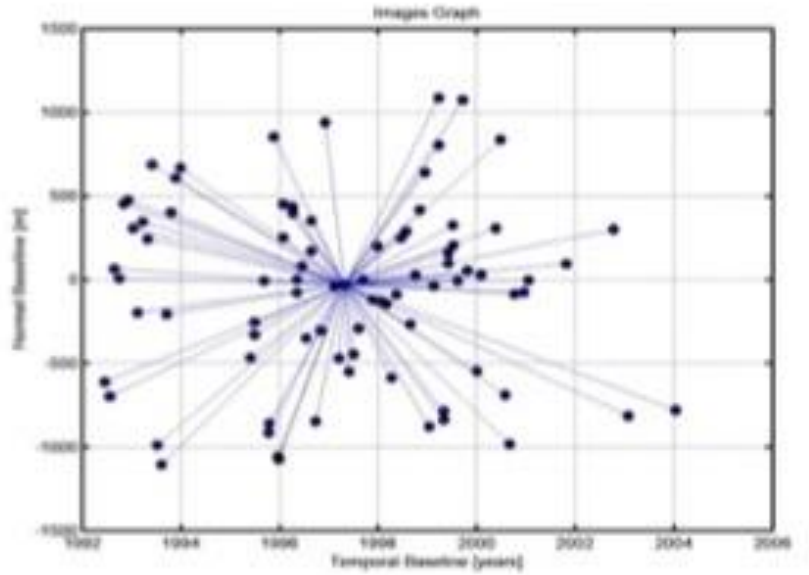
Two basic approaches

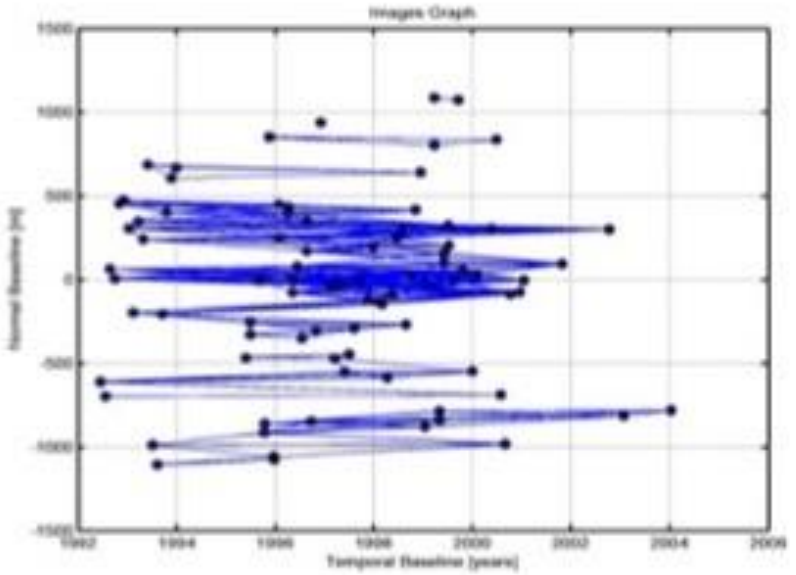
- PS based methods
  - Still based on PS points
  - Alternatives to find more or better PS
  - Alternative processing
- DS based methods
  - DS = distributed scattering
  - Works in non-urban areas
  - Requires limiting temporal and spatial baselines
  - Requires dealing with speckle

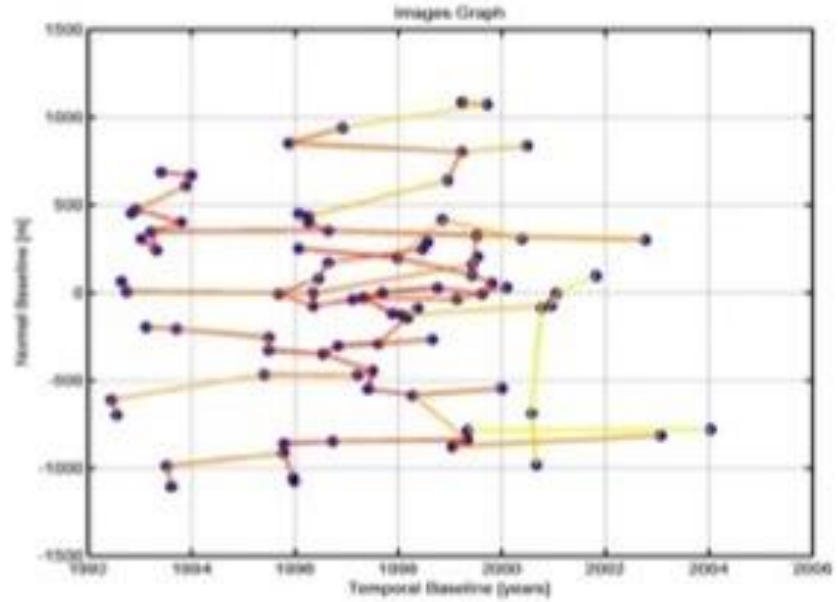
DS based methods

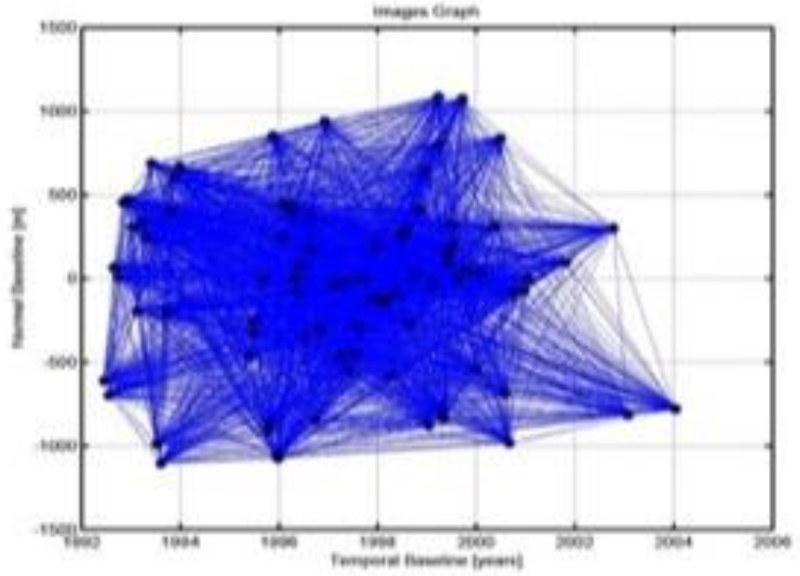
- SBAS
- QPS
- SqueeSAR

Interferogram Connections









from PS to PS+DS

Man-Made Structures

Buildings

Rock Boulders

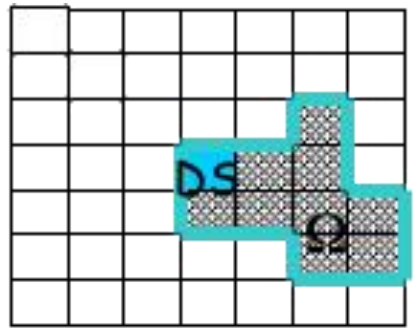
Short Vegetation

Scattered Outcrops

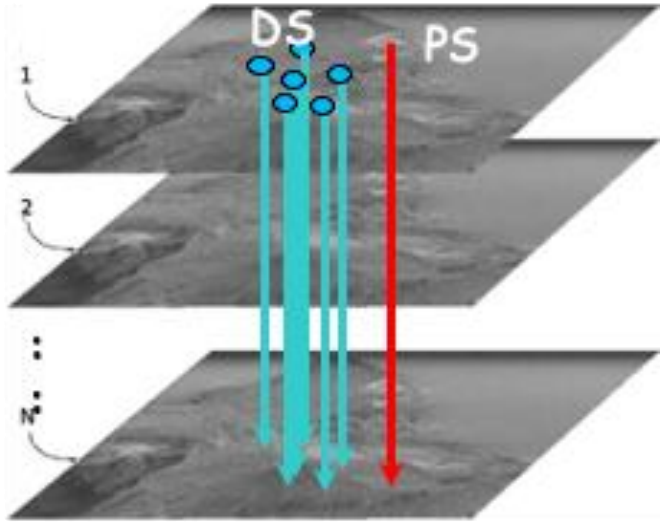
Homogeneous Ground

Basic Ideas

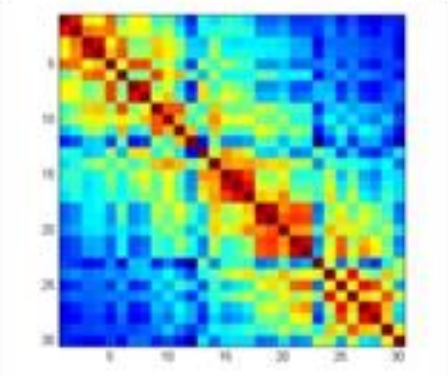
- We want to use both deterministic (point-wise) and stochastic (distributed) targets.



- To detect DS, we adopt a statistical test to identify Statistically Homogeneous Pixels (SHP) in the neighbourhood of each pixel (DespecKS algorithm)



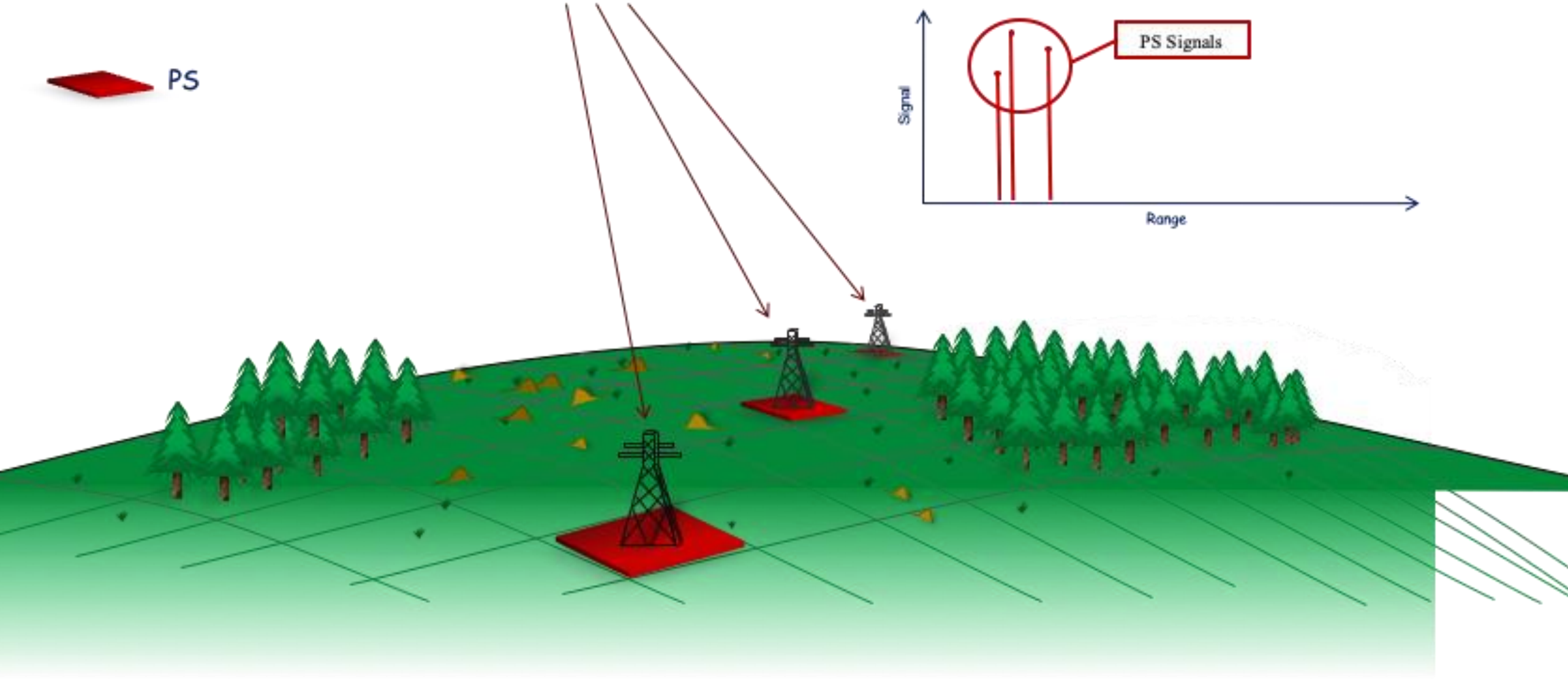
- Whenever the number of SHP is high enough we have a DS and we can compute the sample coherence matrix, Γ.



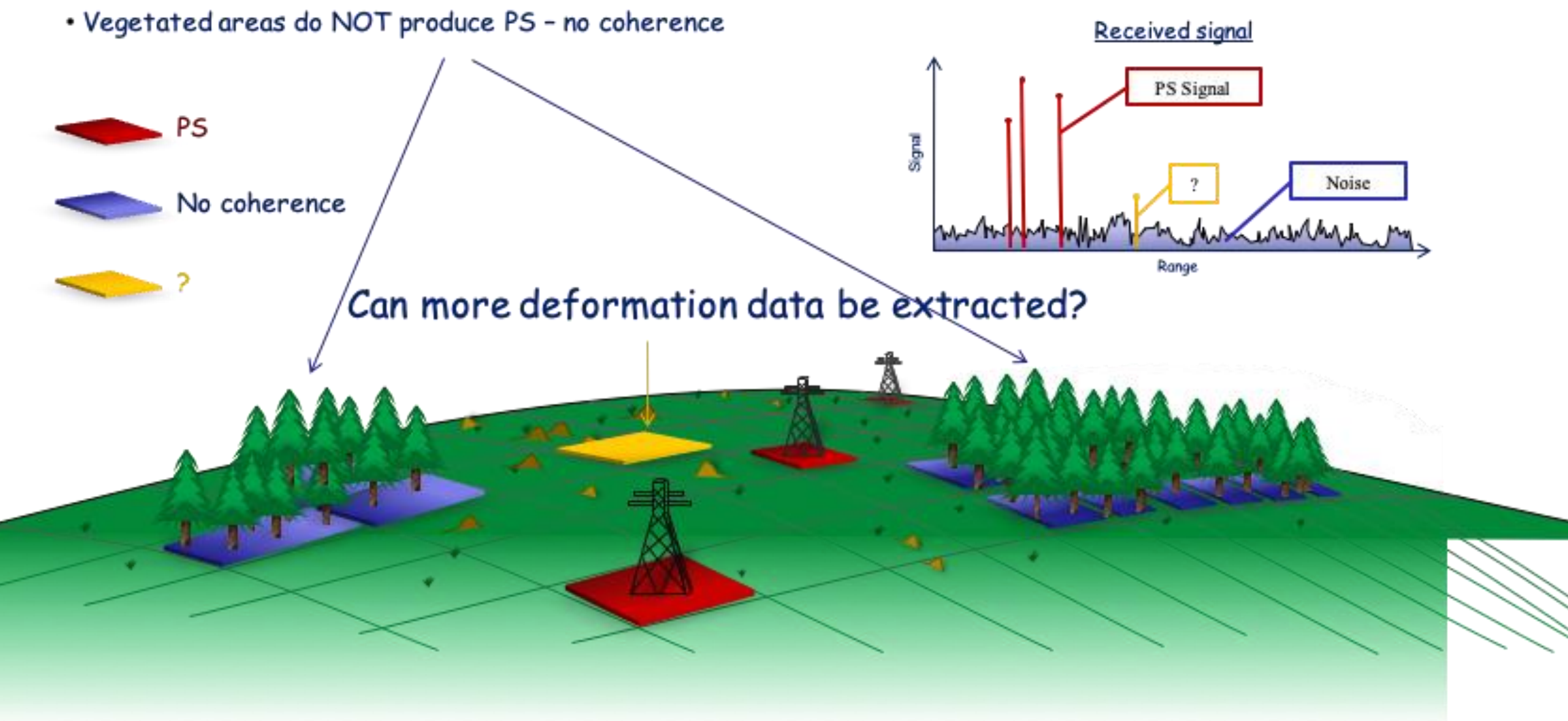
- The coherence matrix Γ can fully characterise the target (CG variables)

Framework

- High reflectivity, phase-stable radar targets are identified as PS



Framework


• Vegetated areas do NOT produce PS – no coherence
PS
No coherence
?
Received signal
PS Signal
?
Noise
Signal
Range
Can more deformation data be extracted?

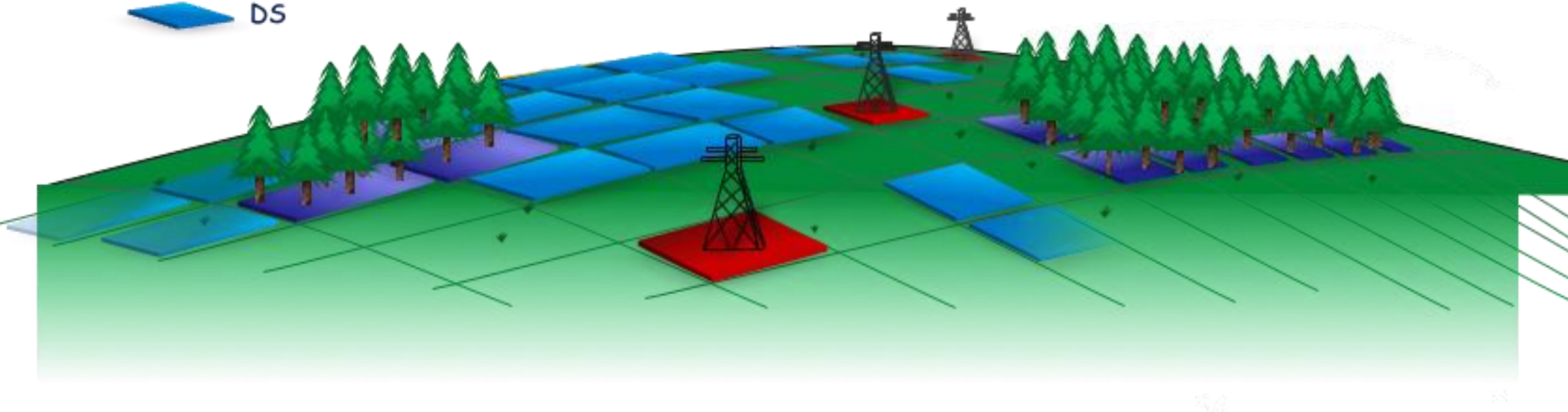
DS Identification

- The process is continued for every pixel

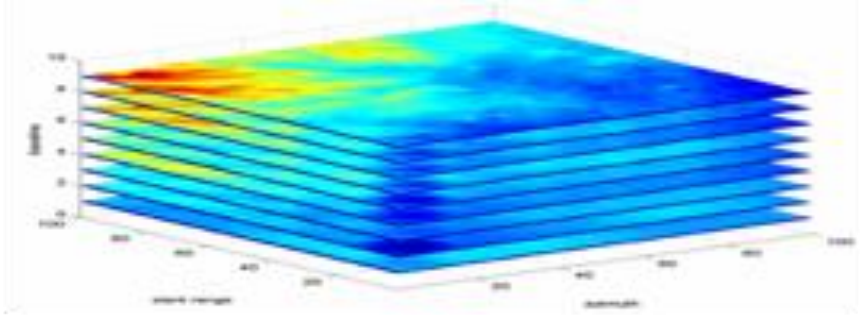
PS

No coherence

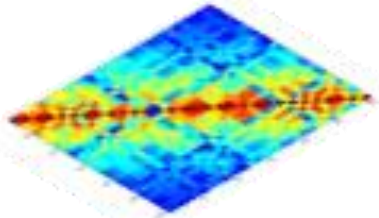
DS



SqueeSAR



DespecKS algo
➔ for each DS…



From N/(N-1)/2 itfgs…

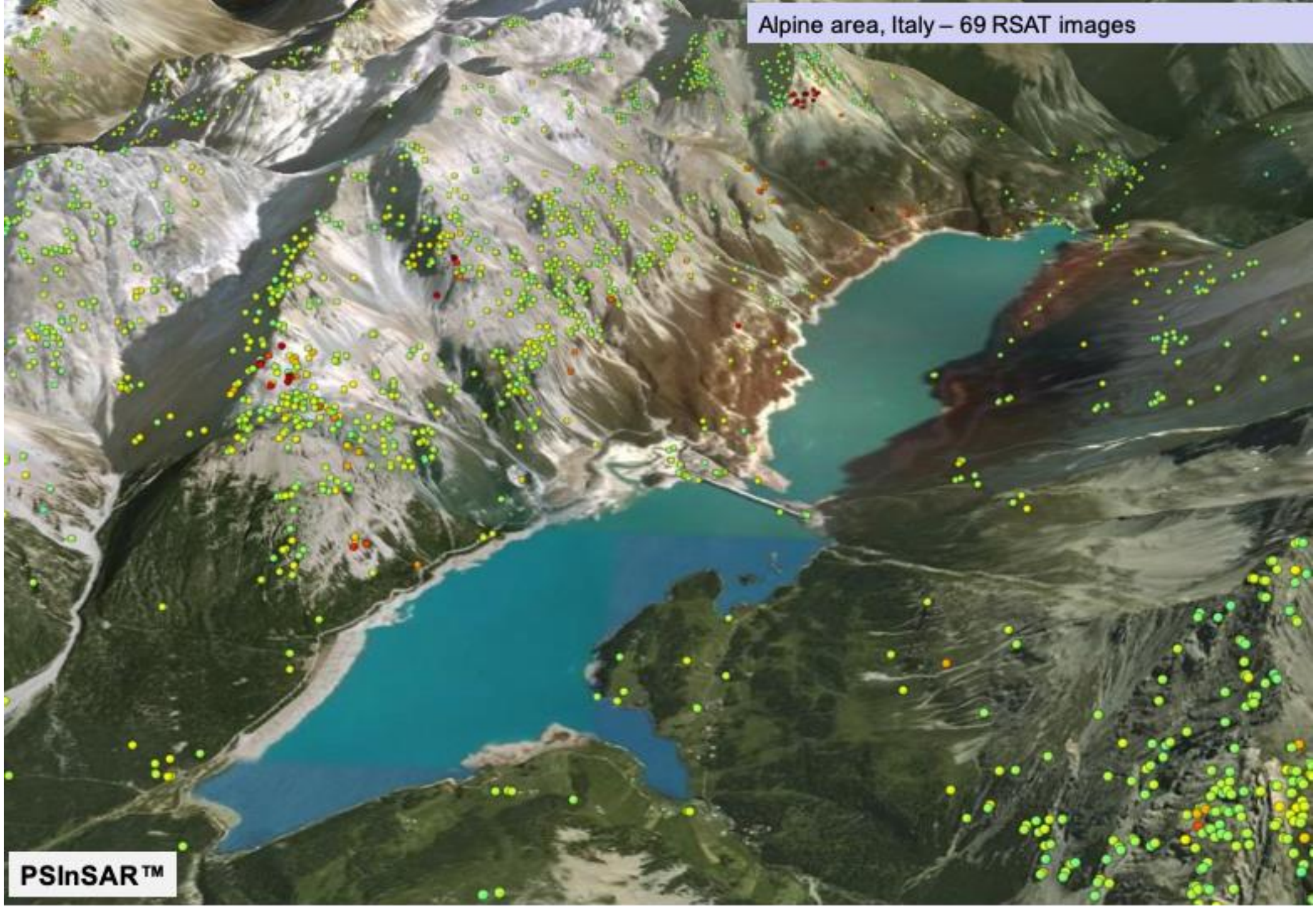
Displacement Estimation

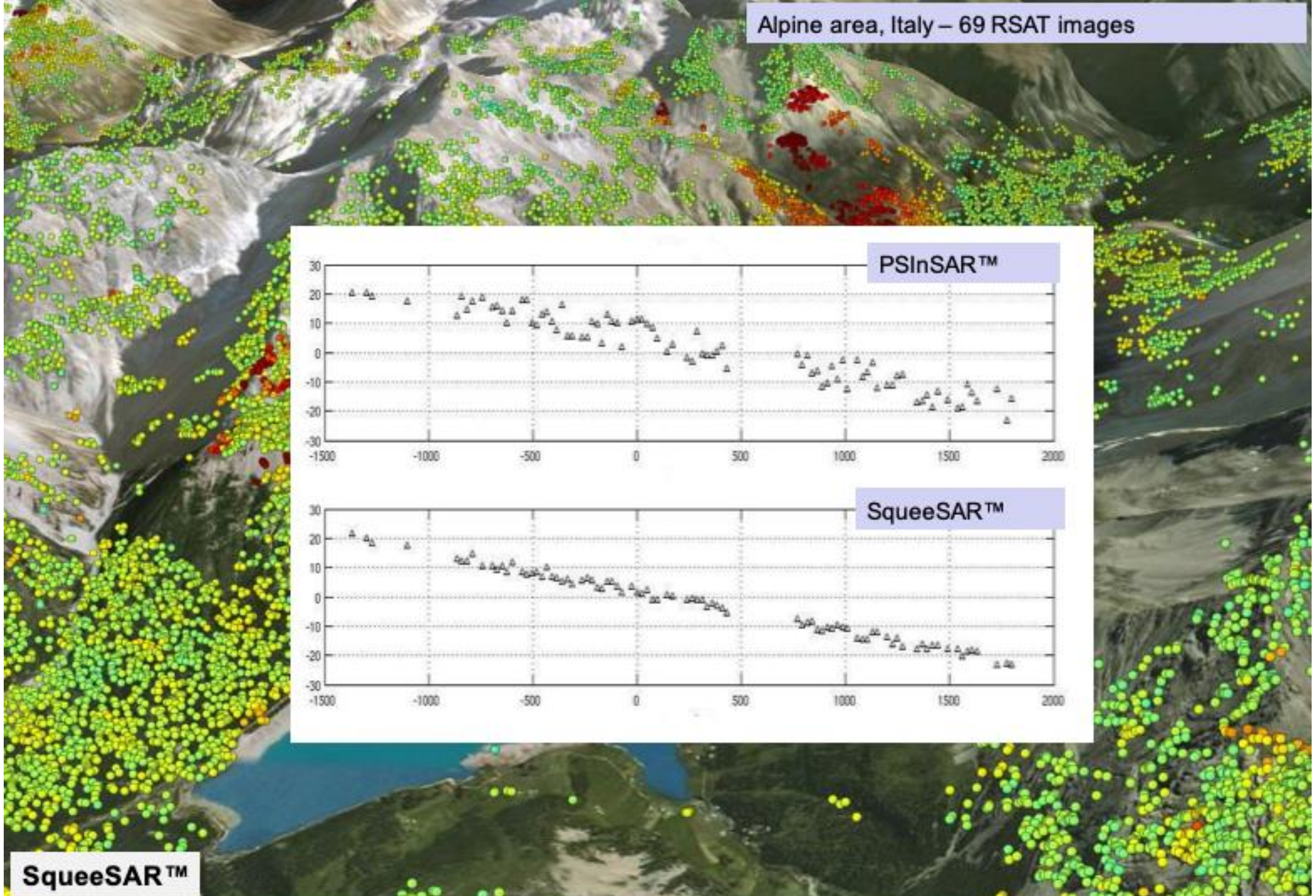
3D Phase Unwrapping

$[\Phi_0\ \Phi_1\ \Phi_2\ \Phi_3\ ....\ \Phi_{N-1}]$

..to N optimum phase values..

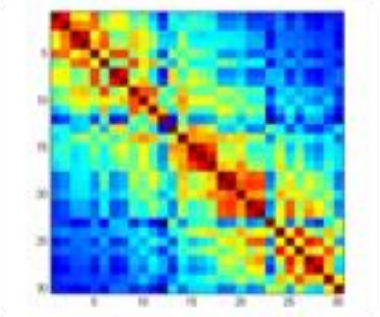
Ferretti et al. "*A New Algorithm for Processing Interferometric Data-Stacks: SqueeSAR*"

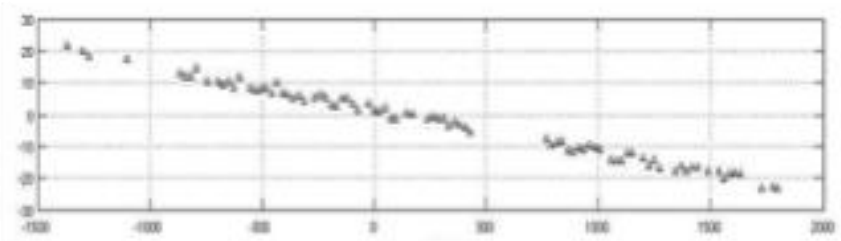

Alpine area, Italy – 69 RSAT images
PSInSAR™


Alpine area, Italy – 69 RSAT images
PSInSAR™
SqueeSAR™
30
20
10
0
-10
-20
-30
-1500
-1000
-500
0
500
1000
1500
2000
SqueeSAR™

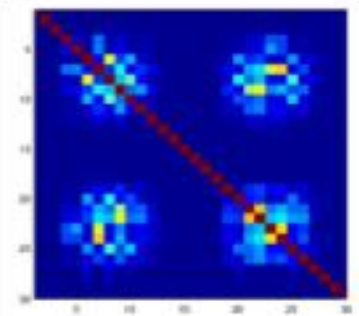
Limits

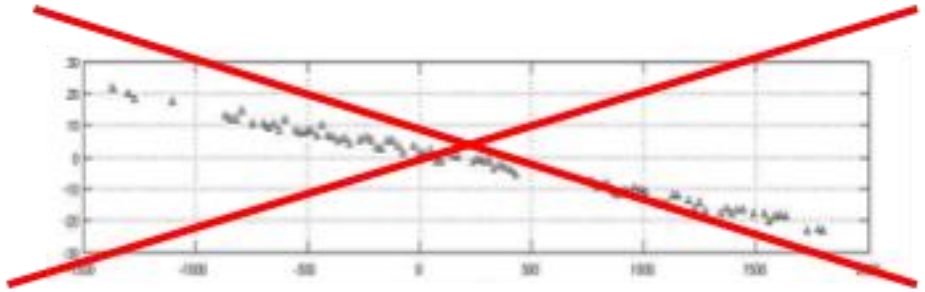
➢ In SqueeSAR, we require for each DS a good phase stability in all SAR images, in order to retrieve a full time-series of displacement values for each measurement point.





➢**Temporary Coherent Scatterers** (TCS), i.e. targets whose SNR values can vary dramatically over time, are typically discarded.





Conclusions

- Various methods for surface motion estimation exist
- They have different assumptions of the deformation patterns and atmospheric patterns
- PS vs DS
- Not all methods are available for every user
- Know the differences and accept that some areas may be difficult to process

International Academy of GeoInformation

- Wuhan University is the best university for remote sensing in the world
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Thank You !

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