Synthetic Aperture Radar Persistent Scatterer Interferometry (PSInSAR)

(*Lecture III- Thursday 13 May 2010*)

ISNET/CRTEAN Training Course on Synthetic Aperture Radar (SAR) Imagery: Processing, Interpretation and Applications
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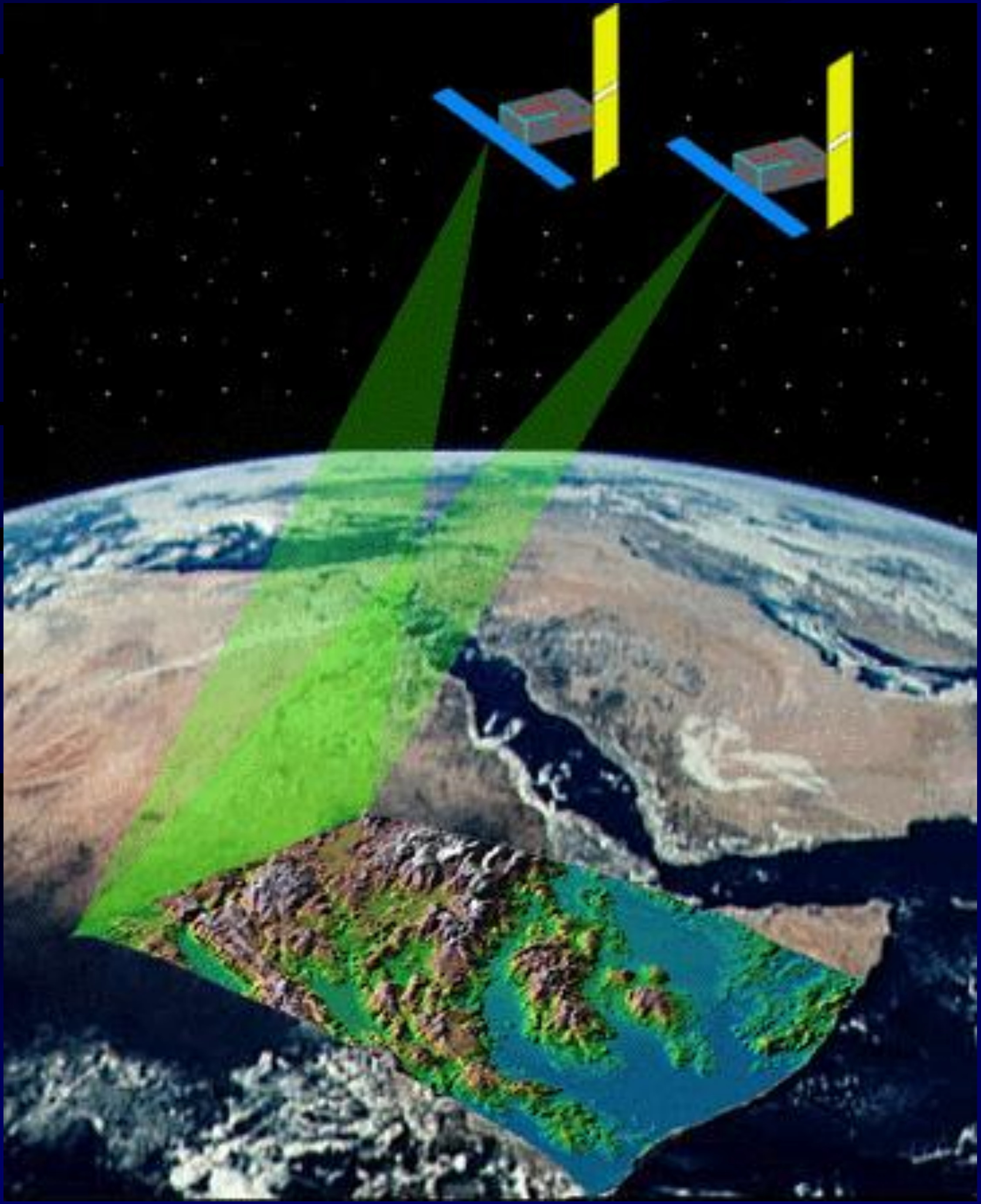
OUTLINE

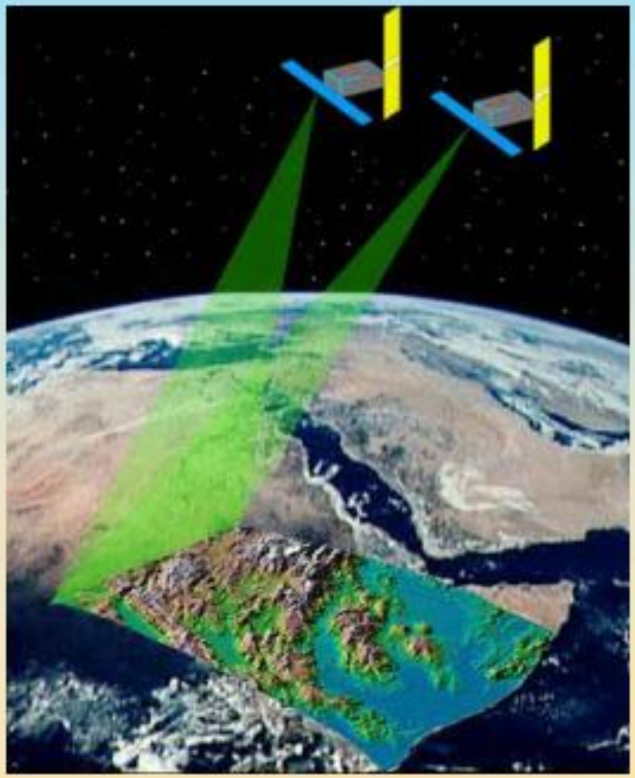
- INTRODUCTION
- BACKGROUND AND CONCEPTS
- PSINSAR PRINCIPLES
- APPLICATIONS AND SAMPLES
- ANALYSIS
- RESULTS



PSInSAR

- **InSAR** is a remote sensing technique that can be used to accurately measure ground displacement.
- InSAR in recent years proves to be a strong method for change detection, DEM generation, classification and…
- For SAR interferometry, two radar images of the same area with slightly different imaging angles is required.

Interferometric Synthetic Aperture Radar (InSAR)

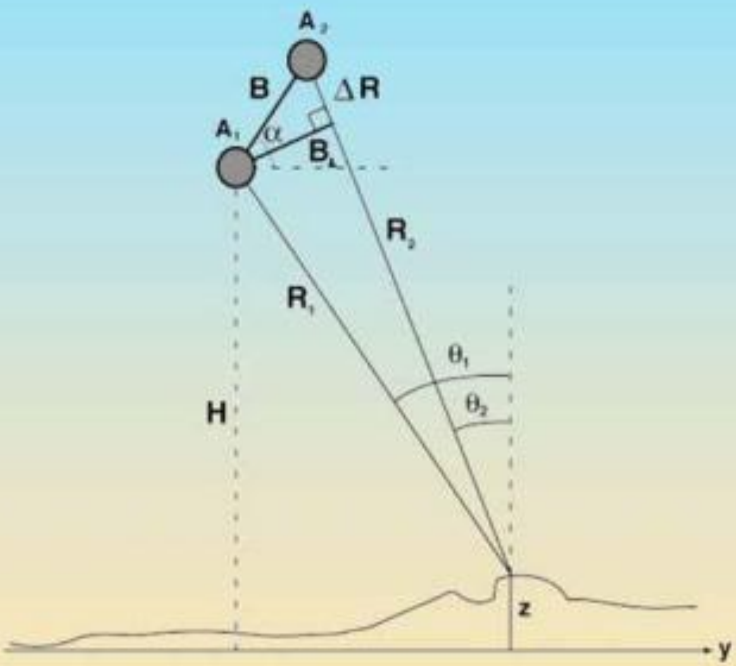


Spaceborne radar satellites

Multiple observations of surface
- Simultaneously
- Spaced in time

Applications
- Hi-res topography
- Motions
- Crustal deformation

InSAR method



Imaging geometry

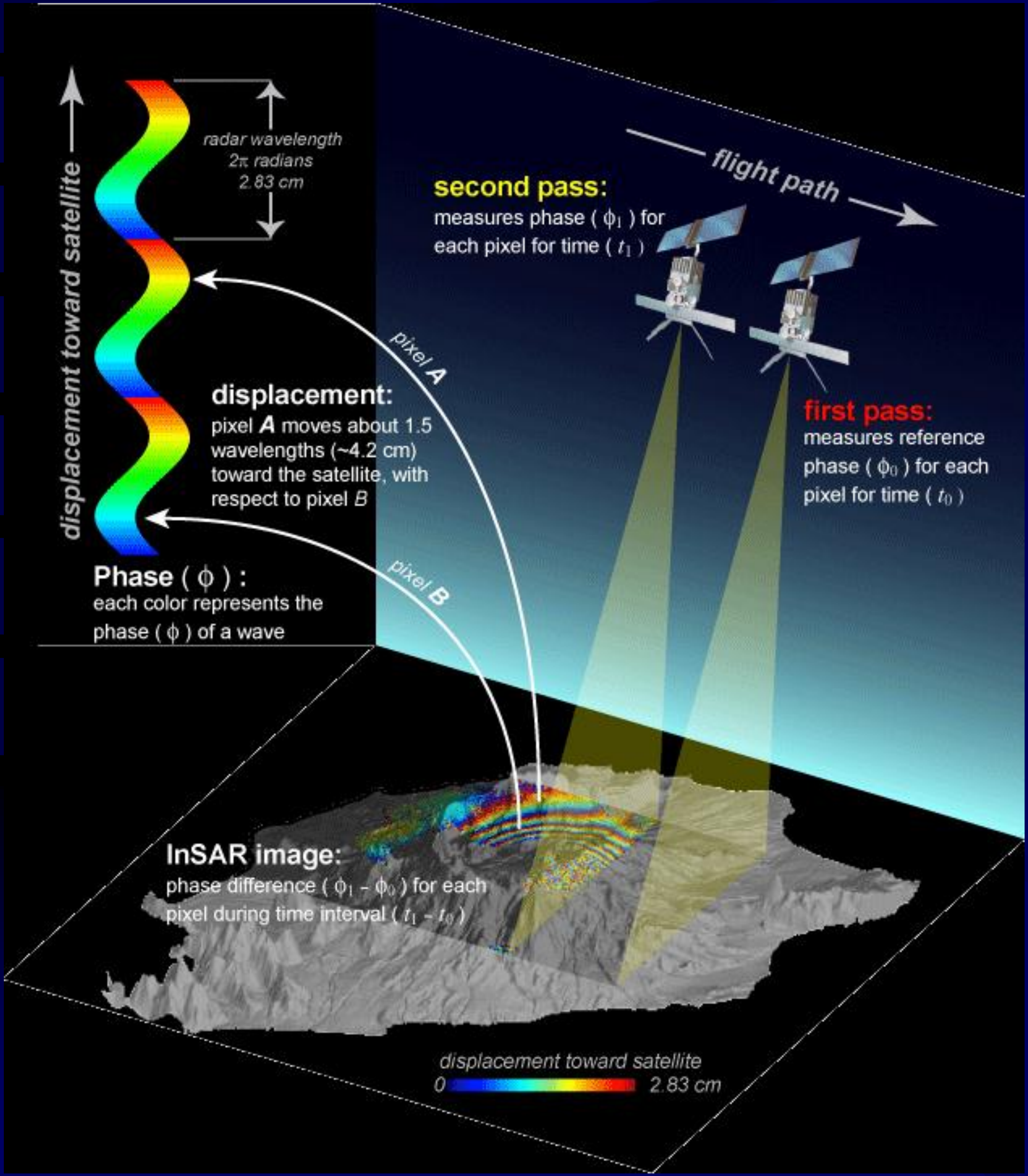
Phase changes from
- Parallax
- Motion of points between observations

Measure changes to $\lambda/100$
- m-scale topography
- cm-scale motions

PSInSAR

- Radar sensors mounted on satellites transmit microwave signals toward a target area; some are reflected back to the satellite.
- These ‘back scattered’ signals are read and stored by the satellite sensor to form radar images of the target area.
- Sophisticated software compares pairs of images of the same target to detect changes in the ground surface, such as displacement, that have occurred in the time span between the two acquisitions.

DInSAR

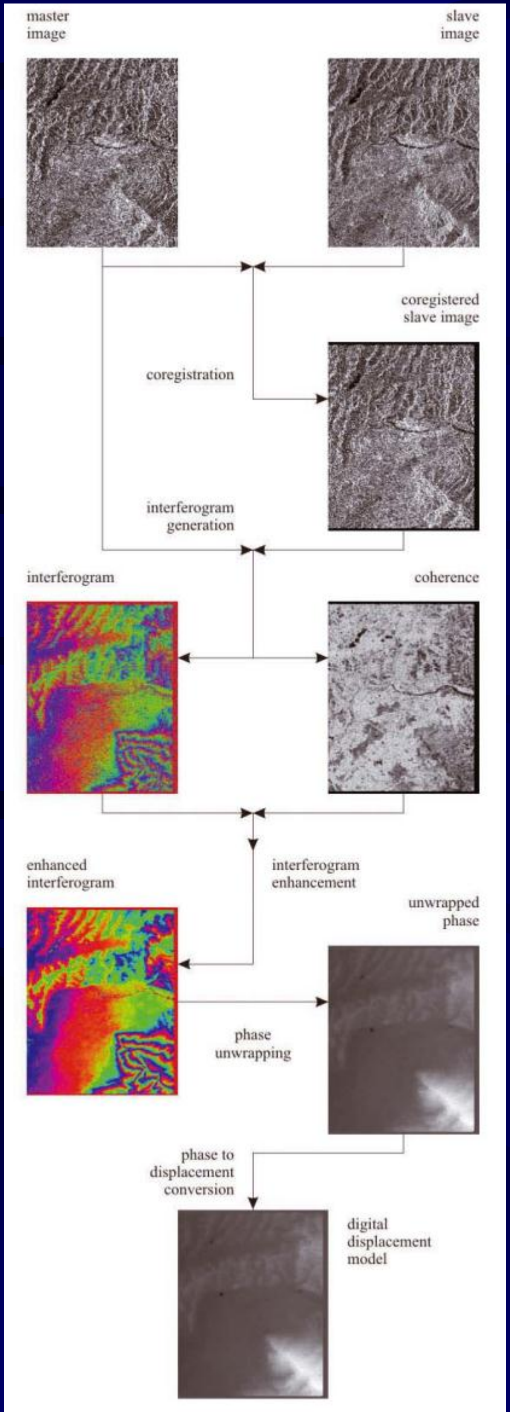


InSAR Method

InSAR processing procedure

- selection of image pairs,
- co-registration of images,
- preparation of the external digital elevation model,
- interferogram generation,
- interferogram enhancement,
- phase unwrapping,
- production of a digital elevation and movement model,
- geocoding

DInSAR Method



PSInSAR

- InSAR is a non-intrusive, non-destructive technology that measures relative displacement over time, with sub-centimeter accuracy.
- InSAR is however limited by the impossibility of removing errors introduced by

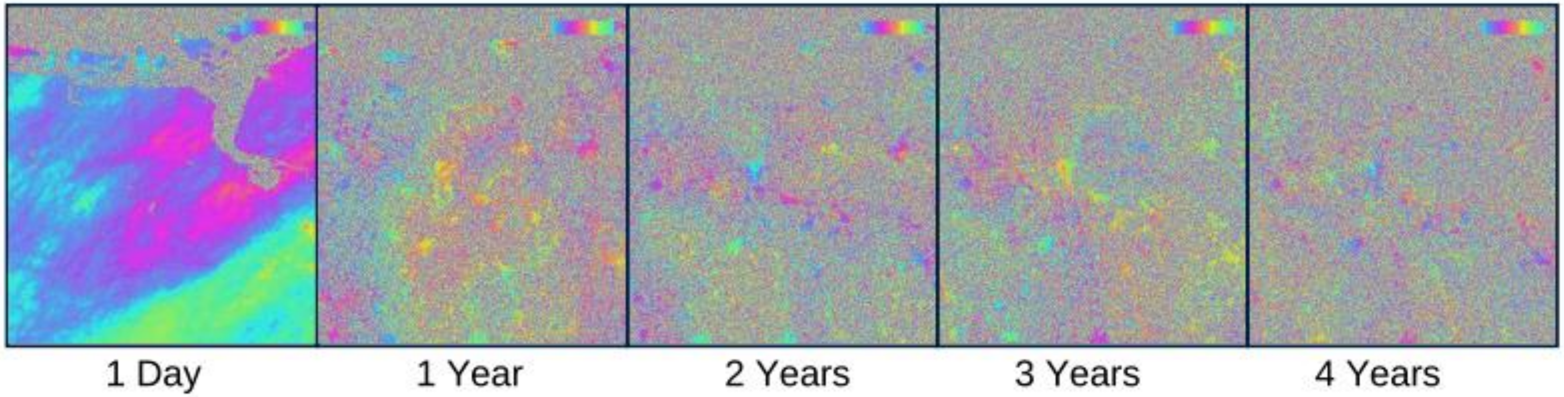
  atmospheric effects,

  orbital errors,

  thermal and other noises

  and is only able to measure total displacement and average displacement rates; it cannot distinguish between linear and non-linear movement.

Results of conventional InSAR



Error sources:

- Temporal decorrelation,
- Geometric decorrelation,
- Atmospheric disturbances.

Consider:

- Magnitude of signal of interest,
- Spatial cover versus signal coherence.

Conventional InSAR application is limited in semi-urban/non-urban areas:

- Area sensible to error sources (vegetation changes, atmosphere).
- Subsidence due to gas extraction is low: <1 cm/year.

InSAR; advantages & disadvantages

InSAR -
Interferometric Synthetic Aperture Radar

pros:

Spatial Resolution (4x20m)

Accuracy (mm-cm scale)

Spatial coverage

cons:

LOS ambiguity (1D measurement)

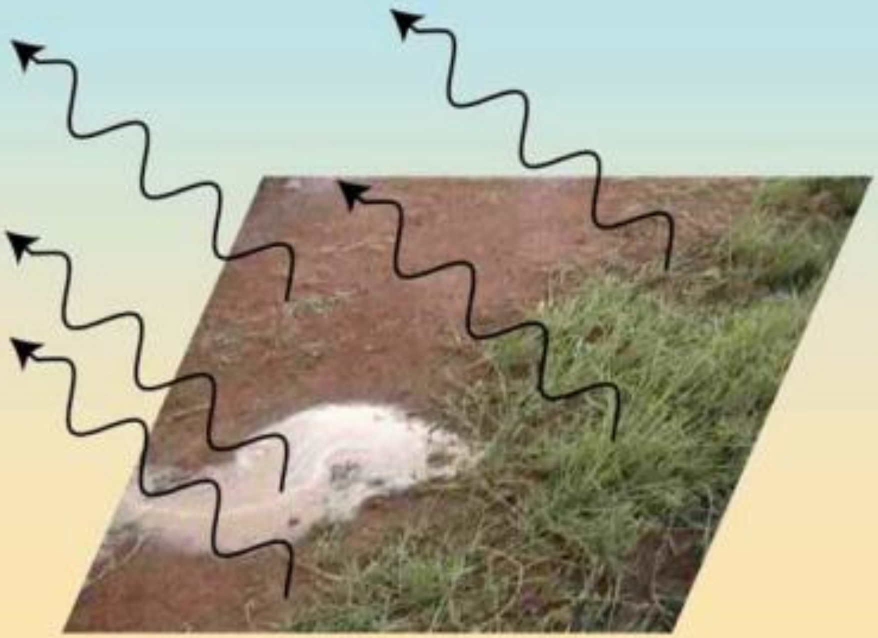
Decorrelation (slopes, vegetation, unstable ground, large deformation gradients, etc)

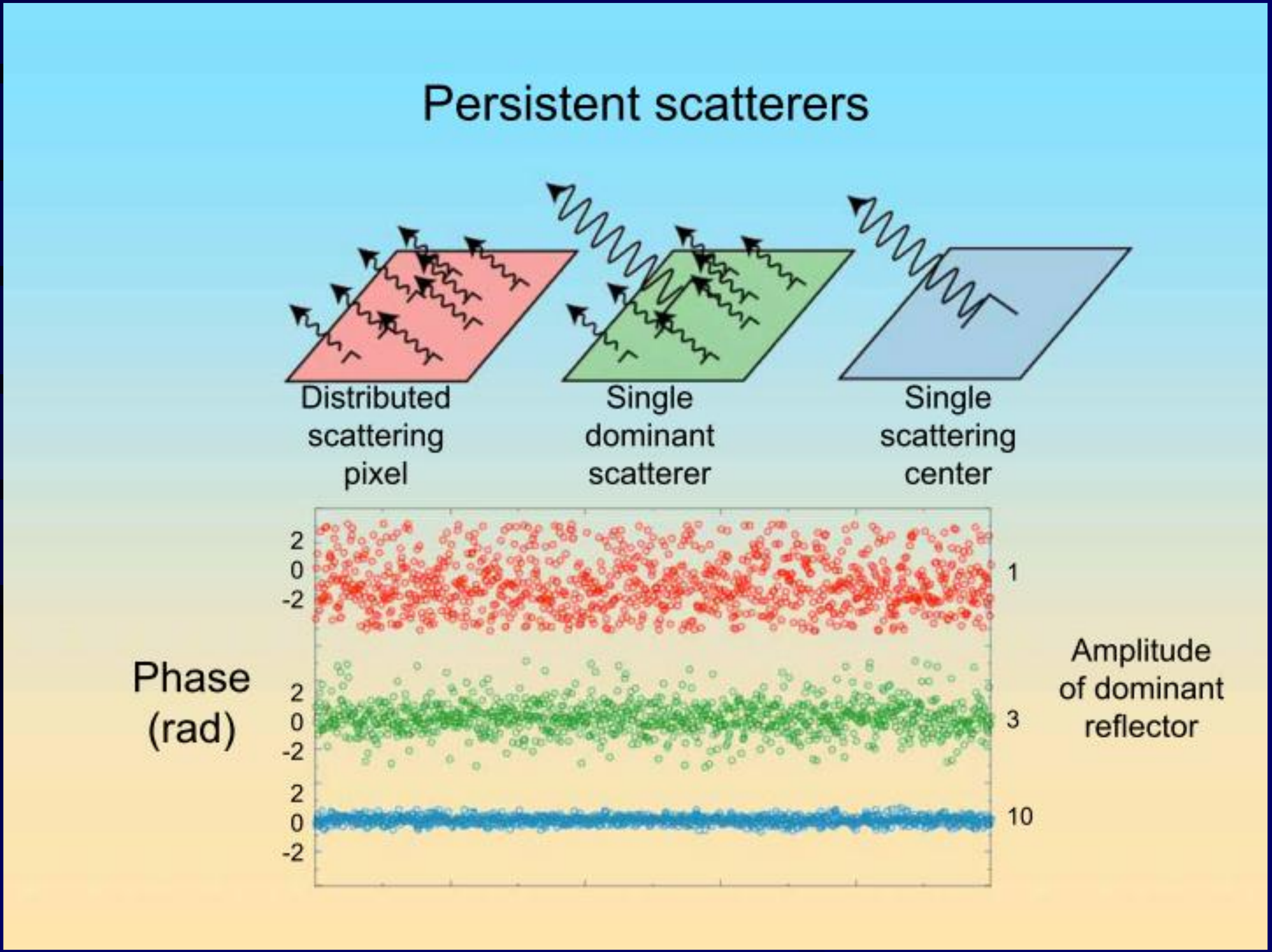
Low sensitivity to horizontal displacement parallel to trajectory

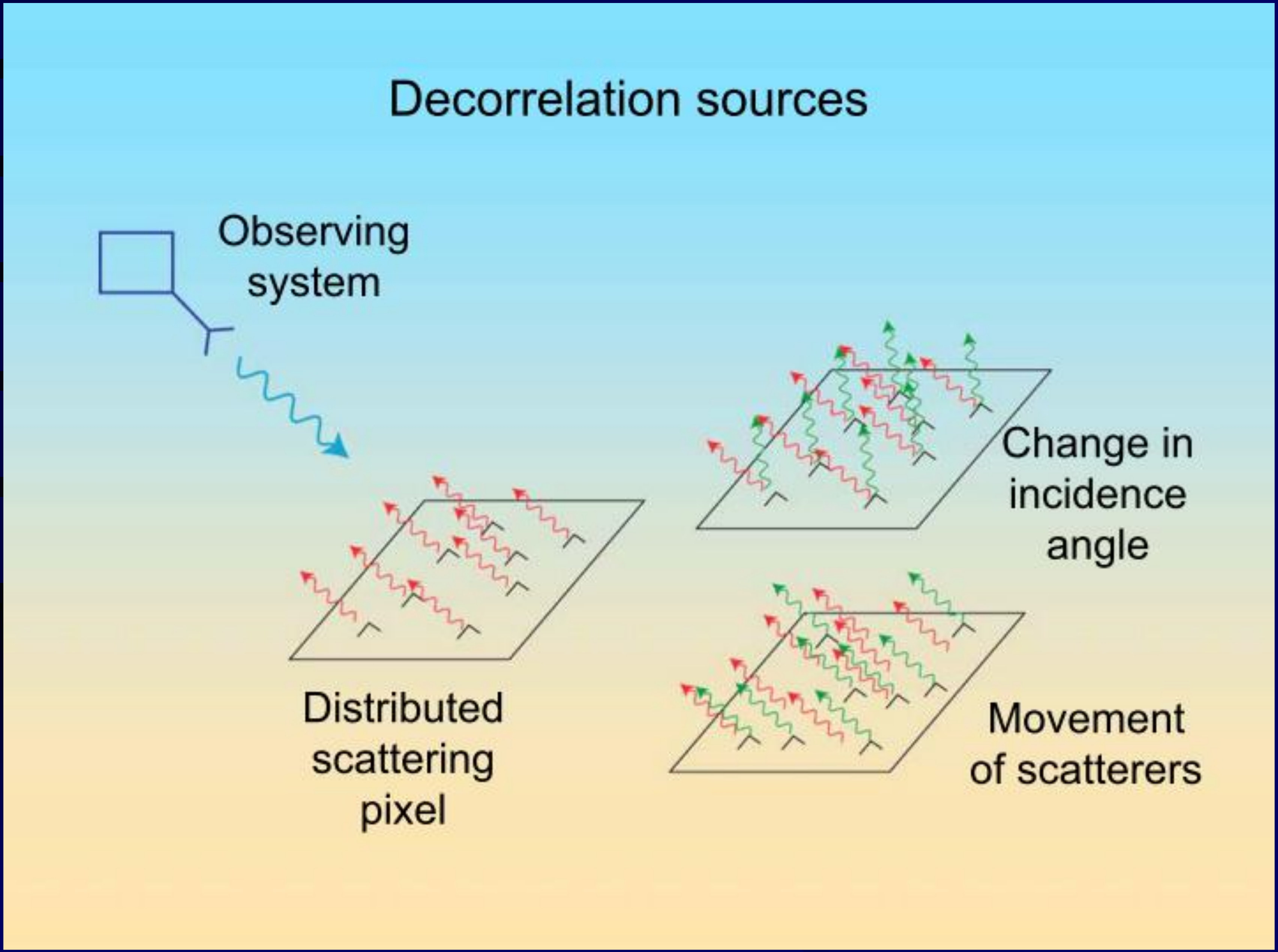
Scattering model:

Decorrelation arises from speckle

- Received signal is sum of echoes from many discrete scatterers




Persistent scatterers
Distributed scattering pixel
Single dominant scatterer
Single scattering center
Phase (rad)
2
0
-2
2
0
-2
2
0
-2
1
3
10
Amplitude of dominant reflector


Decorrelation sources
Observing
system
Change in
incidence
angle
Distributed
scattering
pixel
Movement
of scatterers

PSInSAR

- **Persistent or Permanent Scatterer** techniques are the recent development from conventional InSAR. It relies on studying pixels which remain coherent over a sequence of interferograms.
- It was first emerged in **1999,** when the Polytechnic University of Milan (POLIMI) in Italy, produced and patented its **PSInSAR algorithm**. It was a new multi-image approach in which the stack of images are inspected for objects on the ground providing consistent and stable radar reflections back to the satellite.
- The objects could be the size of a pixel or sub-pixel, and are present in every image in the stack.
- These techniques are collectively referred to as Persistent Scatterer Interferometry or PSI techniques.
- The term Persistent Scatterer Interferometry (PSI) created by ESA to define the second generation of radar interferometry techniques.

How Persistent Scatterers *works?*

- PSI makes measurements of ground movement on naturally occurring permanent scattering points.
- Persistent Scatterers are features such as the roofs of buildings, metallic structures and prominent natural features.
- In urban areas, there can be as many as 600 persistent scatterers per square kilometers.
- Uniquely, this technique provides the motion history for each individual persistent scatterer.

Data Used

- PSI uses radar satellite data acquired by the ERS-1, ERS-2, Radarsat and Envisat satellites.
- All of the UK, most of mainland Europe and much of the US and Japan have sufficient data to allow PSI processing, with new data being acquired regularly.
- Due to the large volume of data the maximum area processable in one block is currently 50 x 50km.

Removal of atmospheric and topographic influence

- PSI overcomes atmospheric and topographic induced errors (related to certain weather conditions and DEM accuracy) by utilizing 30 or more scenes to calculate:

An ***atmospheric correction***, which is calculated from the 30 scene archive that removes atmospheric artifacts from the interferograms.

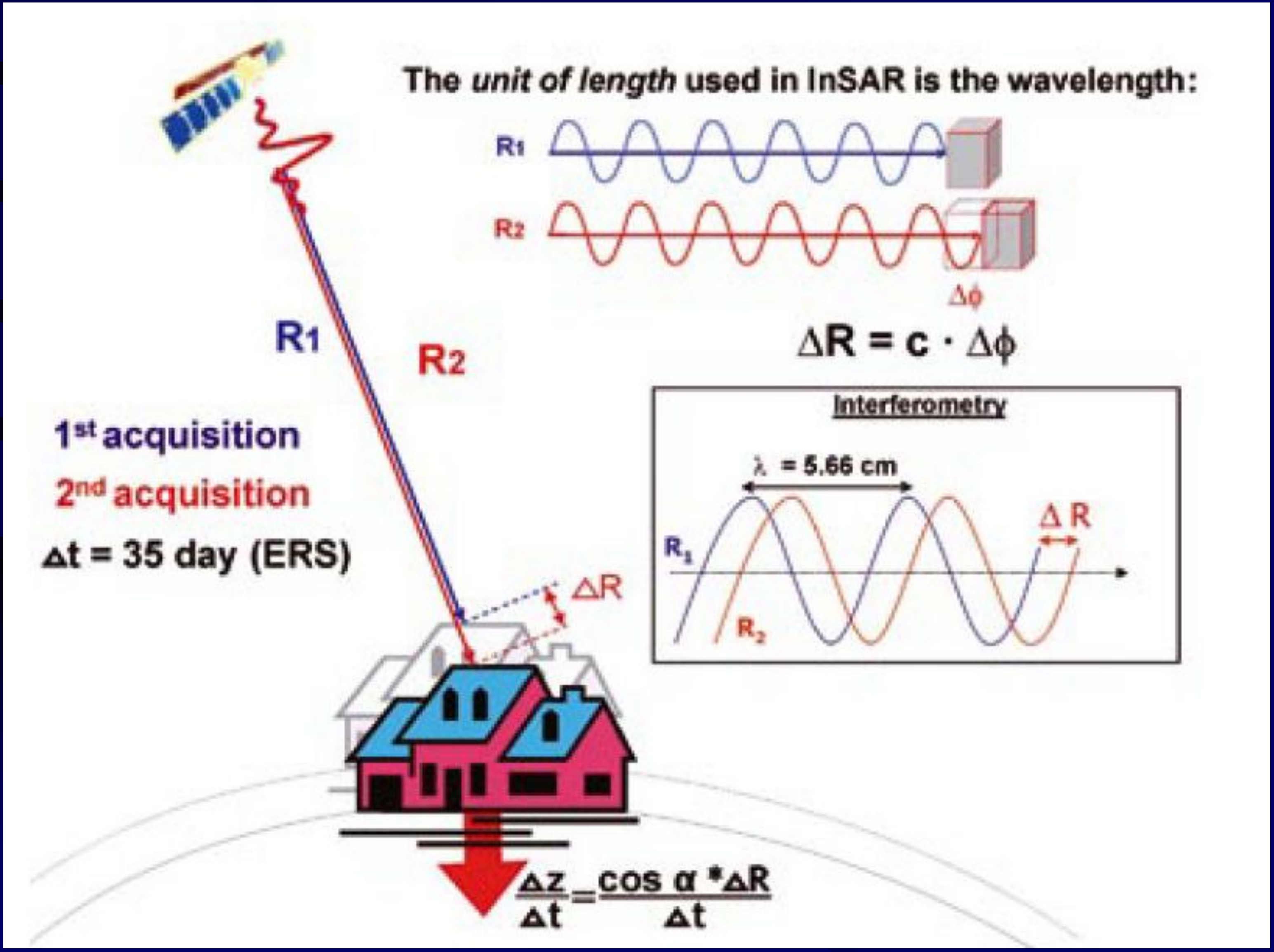
An ***accurate DEM*** for the measurement points.

PSI is a significant evolution of conventional InSAR whereby:

- A multi-image data set is used
- Atmospheric and orbital errors are essentially removed
- Sub-pixel radar reflections are analyzed
- Linear and non-linear deformation patterns are identified
- Time histories of movement are generated for every radar target

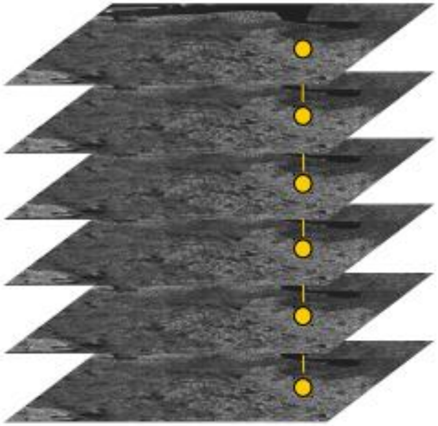
- ***Persistent Scatterer Interferometry (PSI) is a revolutionary new technique for measuring ground displacements to a degree of accuracy and over time periods previously unachievable using conventional interferometry methods.***

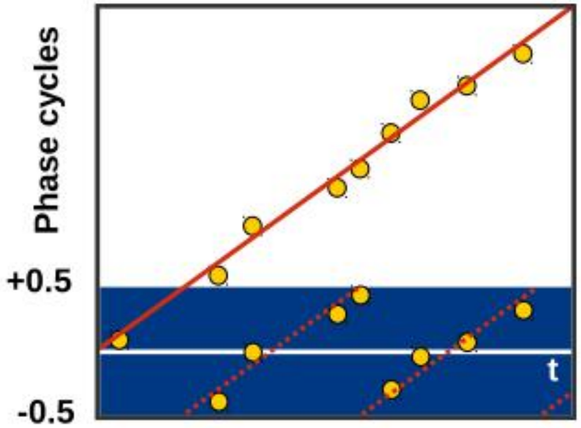
Basic principle of PSInSAR

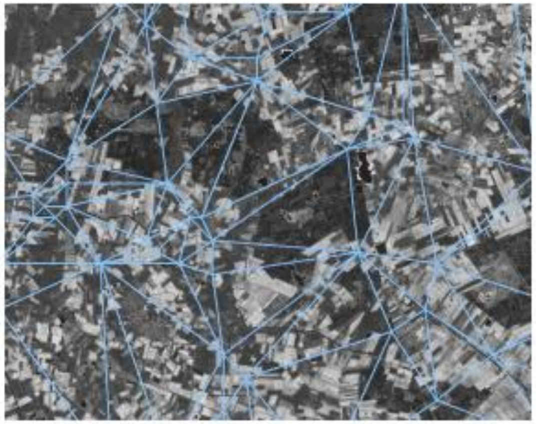


PSInSAR

- Multi-pass InSAR time series,
- Select scatterers with high and consistent reflections in time,
- Estimation of deformation and error sources in network of potentially reliable "measurement points"



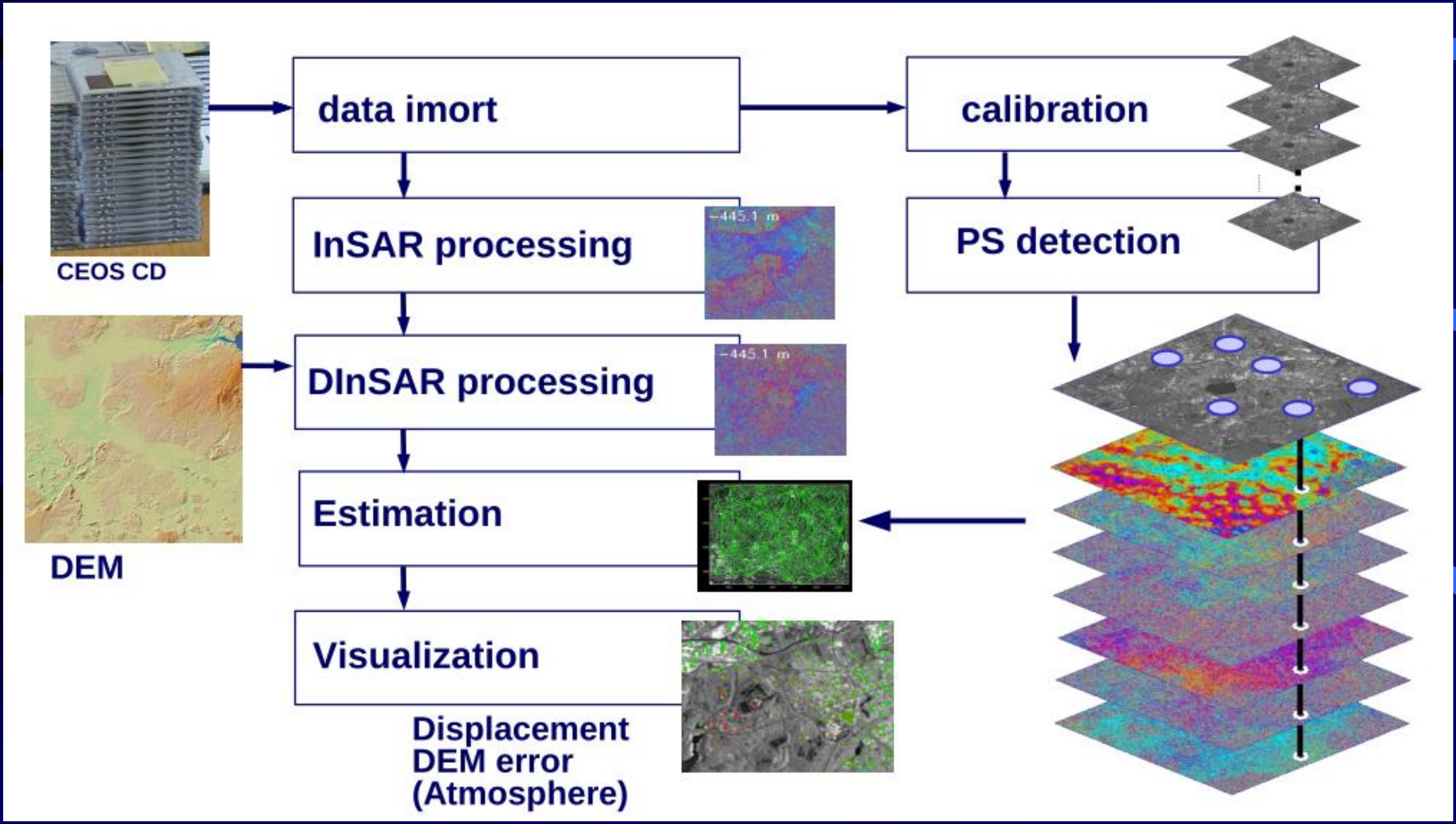




Detect point targets even in largely decorrelated areas:

Persistent Scatterers (PS)

PSInSAR processing flowchart



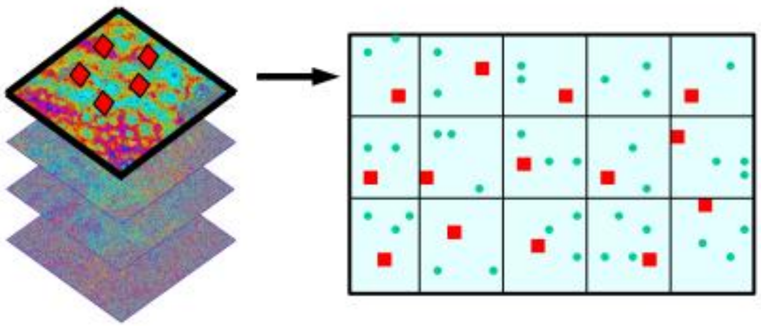
PSInSAR processing steps

- **InSAR processing [block 1]:**
  - formation of N interferograms on a common master using all N+1 available images
- **DinSAR processing [block 2]:**
  - remove known topographic phase using DEM
- **Preliminary estimation [block 3]:**
  - identify a coarse grid of the best point and estimate DEM error and displacement
- **Final estimation [block 4]:**
  - estimate parameters on more points using the preliminary estimates

PSInSAR stack generation, steps 1 &2

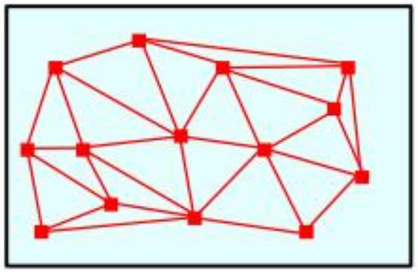
- All interferograms are formed w.r.t. the same master image
  - oversampling of the images with factor two to avoid aliasing of the interferometric phase.
- Absolute calibration accounting for range spreading loss, antenna pattern, processor gain.
  - optional step
  - pixels with large amplitude in most images are likely to be point scatterers; a threshold is used to identify a set of pixels for further analysis.
- Coregistration
  - correlation optimization, or
  - geometric co-registration based on precise DEM and orbits ars used if expected coherence is low.
- SRTM data used for topographic correction.

PSInSAR preliminary estimation, step 3



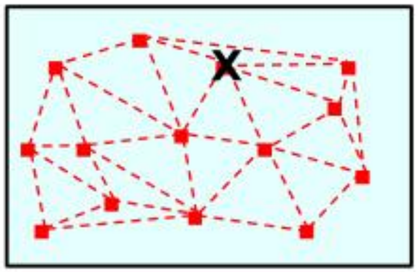
1. SELECTION:

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



2. ESTIMATION

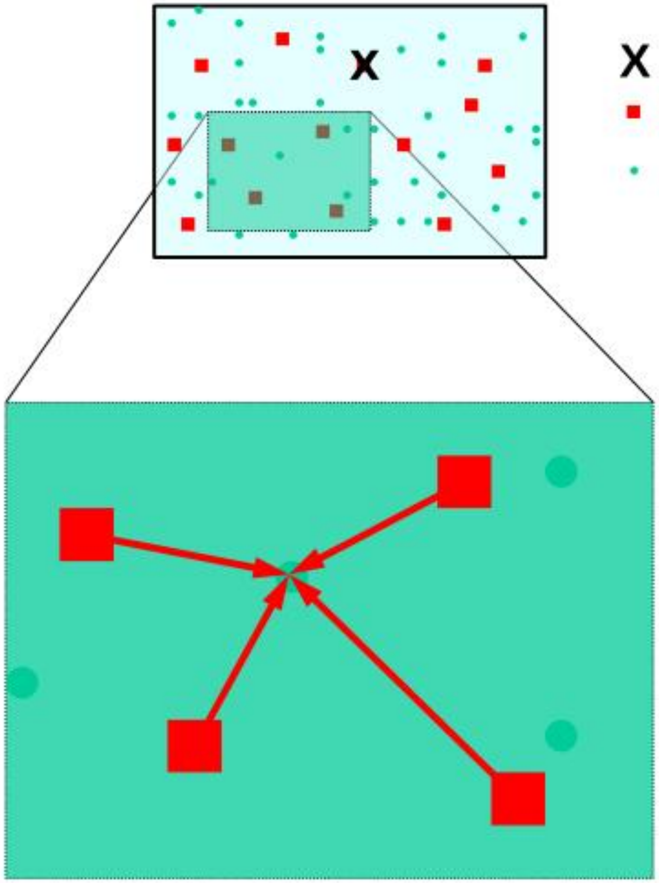
Construct a "network" to estimate displacement parameters and DEM error differences ***between nearby points*** in order to reduce atmospheric signal.



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.

PSInSAR final estimation (densification), step 4

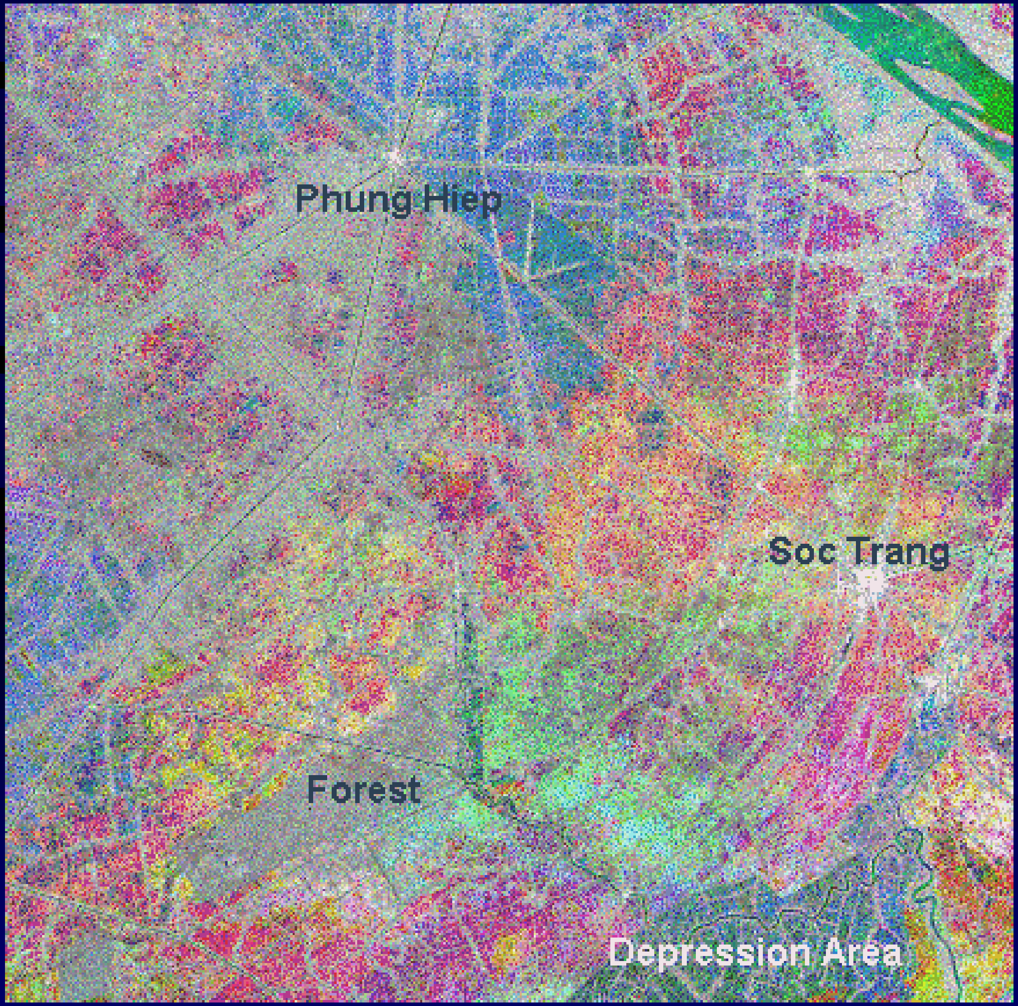


X reference point
■ point in reference network (already estimated)
• *new* point

1. ESTIMATION:
Estimate displacement parameters and DEM error differences w.r.t. the nearest known points.

2. TESTING:
Compute test-statistics to identify incorrect estimation at a single arc. If test not accepted, remove the arc.

- Using multi-image datasets allows identifying stable reflectors, referred to as permanent scatterers, or **PS**, which **are points on the ground that consistently return stable signals to the satellite sensor**.



An example of a multi-temporal color composite SAR image.
The area is part of the rice growing areas in the Mekong River delta, Vietnam, near the towns of Soc Trang and Phung Hiep. Three SAR images acquired by the ERS satellite during 5 May, 9 June and 14 July in 1996 are assigned to the red, green and blue channels respectively for display. The colorful areas are the rice growing areas, where the land-covers change rapidly during the rice season. The grayish linear features are the more permanent trees lining the canals. The gray patch near the bottom of the image is wetland forest. The two towns appear as bright white spots in this image. An area of depression flooded with water during this season is visible as a dark region.

- These PS allow ground displacement velocities to be measured with millimeter accuracy.
- PS typically correspond to objects on man-made structures such as buildings, bridges, dams, water-pipelines, antennae, as well as to stable natural reflectors (e.g. exposed rocks).
- The **PSInSAR™** algorithm was **licensed exclusively to TRE** (Tele-Rilevamento Europa) for world-wide application.

PSInSAR applications

Applications

- Such techniques are most useful in urban areas with lots of permanent structures, for example the PSI studies of European cities undertaken by the Terrafirma project.
- The Terrafirma project (led by Fugro NPA) provides a ground motion hazard information service, distributed throughout Europe via national geological surveys and institutions.
- The objective of this service is to help save lives, improve safety, and reduce economic loss through the use of state-of-the-art PSI information.
- Over the last years this service has supplied information relating to urban subsidence and uplift, slope stability and landslides, seismic and volcanic deformation, coastlines and flood plains.

- ***Measurements of customer specified points using artificial reflectors*** **Corner Reflectors (CRInSAR)**
- For measurements at specific, predetermined points, inexpensive radar corner reflectors can be deployed, acting as purpose-built persistent scatterers.
- Development of Corner Reflector InSAR as an ideal tool for monitoring the displacement of engineered developments such as reservoirs, dams, bridges, pipelines, buildings, or even areas of slope instability.

PSInSAR

PSInSAR Applications :

- **Subsidence or uplift**

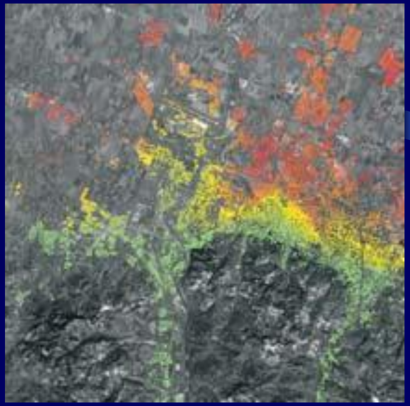
Whether by natural failure (e.g. karst limestone cavity collapses) or from manmade activities (e.g. extraction of water/gas/oil), the PS Technique provides monthly updates on displacement patterns. It is particularly suited to monitoring urban subsidence where conventional methods of survey cannot match the information density, at similar cost.

- **Seismic faults and volcanic areas**

The ease with which PS data can be updated suits the improvement of early warning systems in matters of Civil Protection. TRE's substantial data processing center can respond quickly in providing urgently needed data in emergency situations.

- **Managing land use**

The PS Technique facilitates the planning of major capital works such as pipelines, transmission lines, highways and railways by identifying stable corridors for these facilities. Similarly, updates of town planning schemes can benefit from PS data which, in urban areas, have a high density of scatterers.



PSInSAR Applications :

- **Assessing a claim**

An historical archive of radar data can contribute to verifying the cause-effect connection between, for example, the construction of a new tunnel and damage occurring to facilities in the neighborhood of the excavation area. PS data have already been used as evidence in lawsuits. Insurance companies are showing interest in the technology as a risk allocation tool.

- **Checking the stability of buildings**

While PS data cannot substitute for site surveys, they are nevertheless becoming a powerful monitoring tool for large urban areas, where a regular check of all of the buildings would not be feasible. PS data can be used in the design of mitigative measures to offset the effects of a potential geohazard.

- **Slow landslides and instability phenomena**

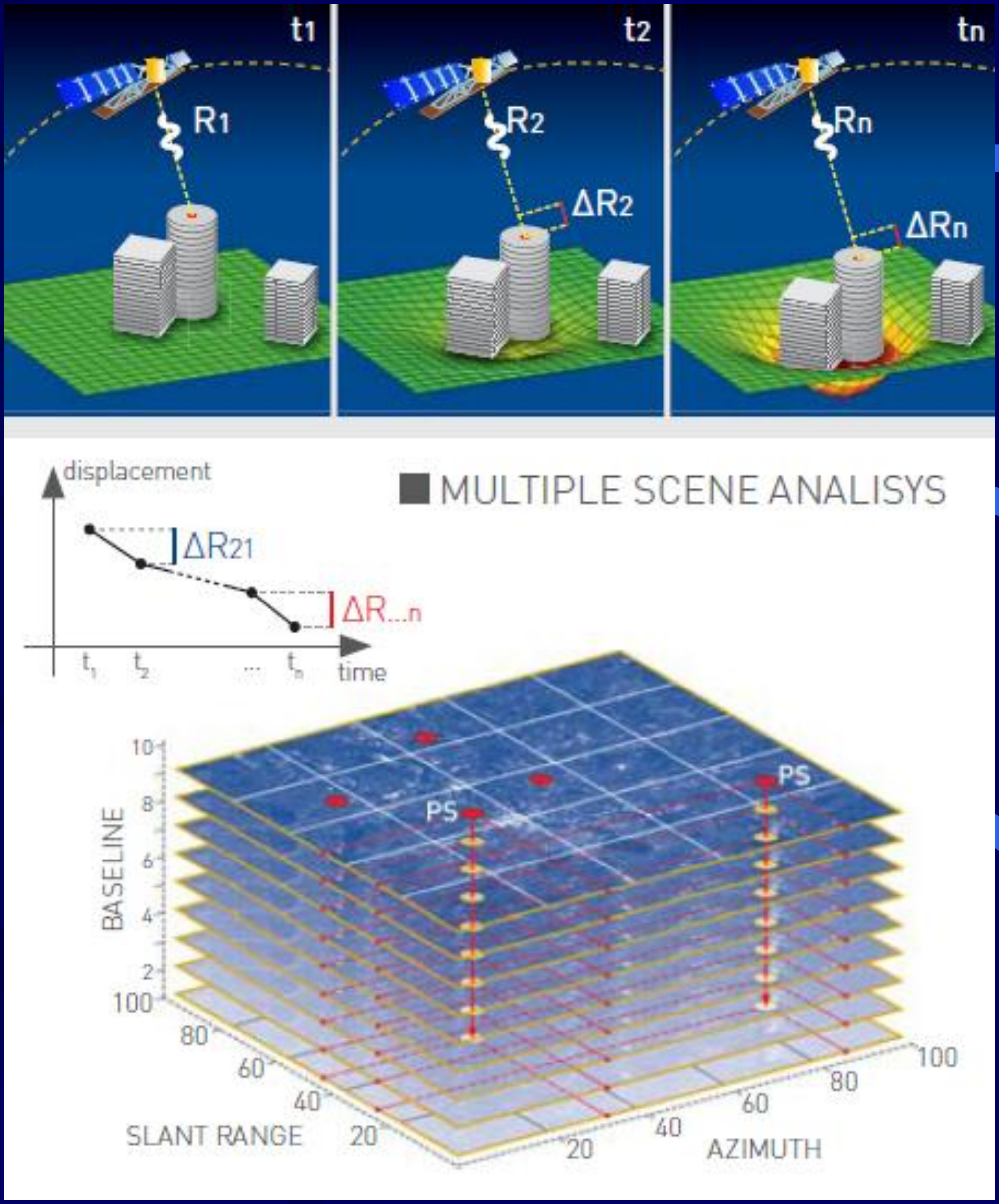
The PS Technique identifies the extent of unstable land and the corresponding rate of movement, when slow movements occur. The integration of PS data within a GIS and regular updating of PS data have significantly increased the potential of radar remote sensing for landslide investigations.

PSInSAR Applications examples:

- **Surface deformation measurement**
- **Slope instability**
- **Landslide inventory**
- **Flood protection**
- **Oil field monitoring**
- **Co2 Sequestration**
- **Seismic faults**

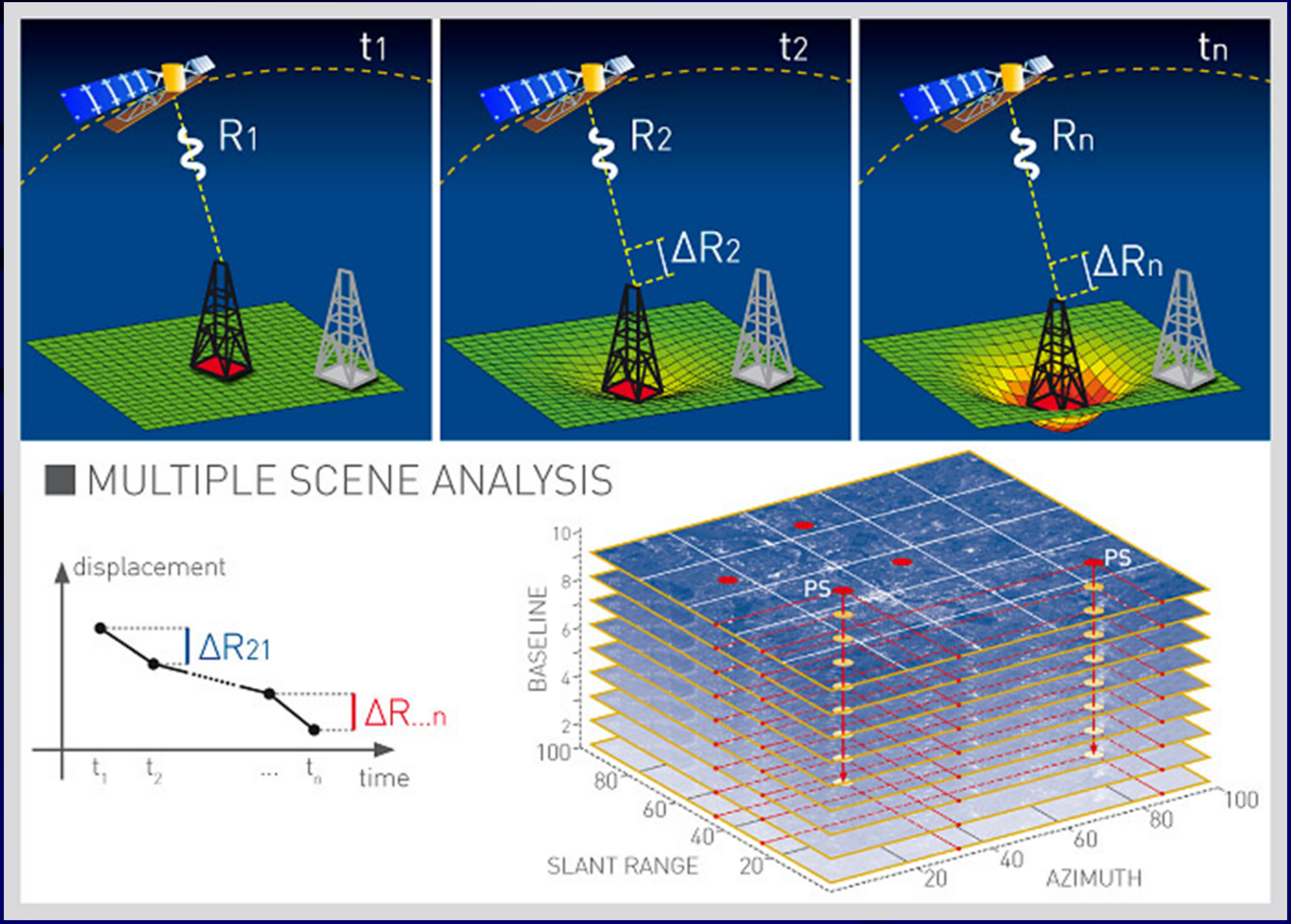
PSInSAR Applications :

Surface deformation measurement

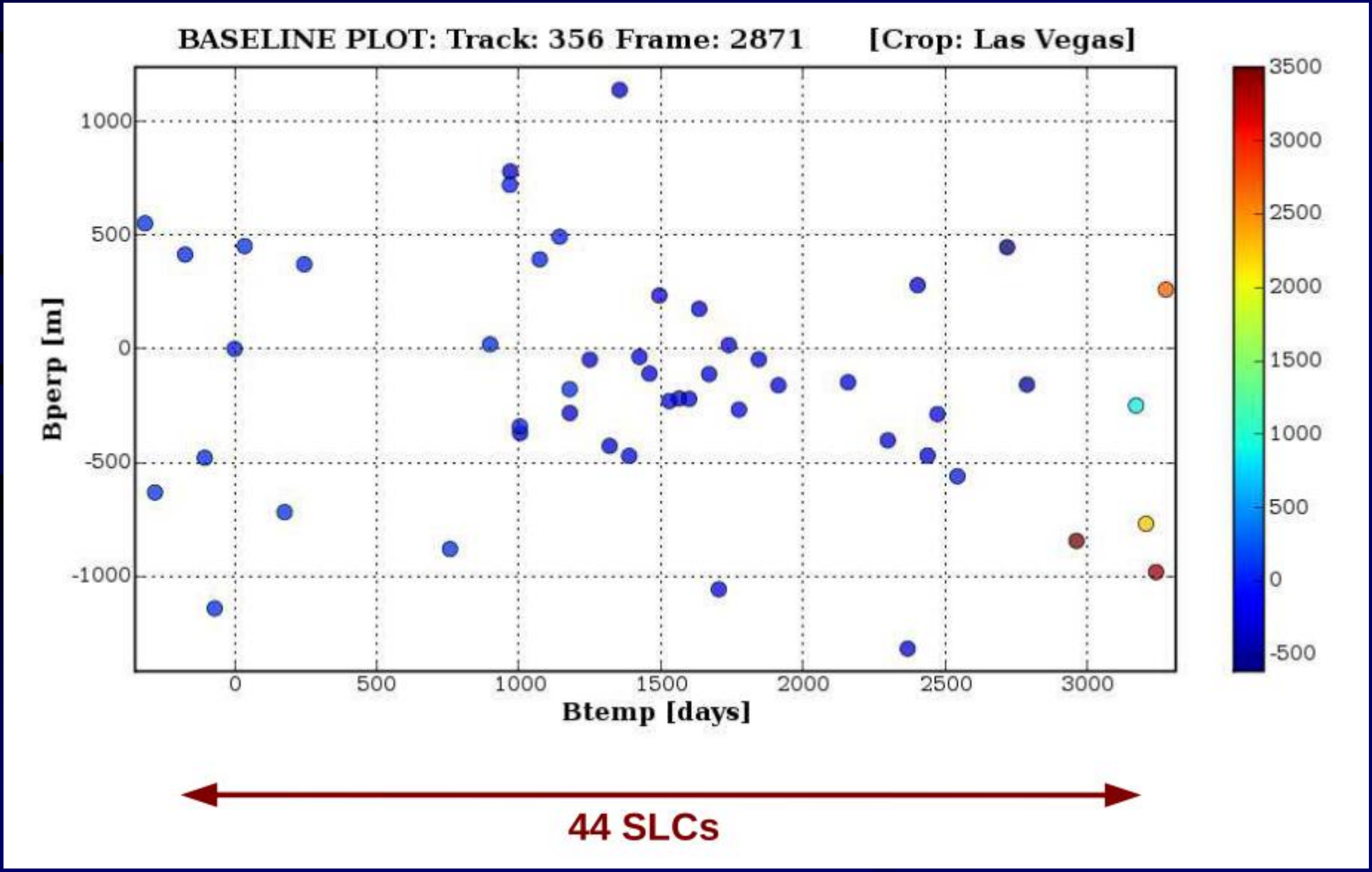


PSInSAR Applications :

Surface deformation measurement

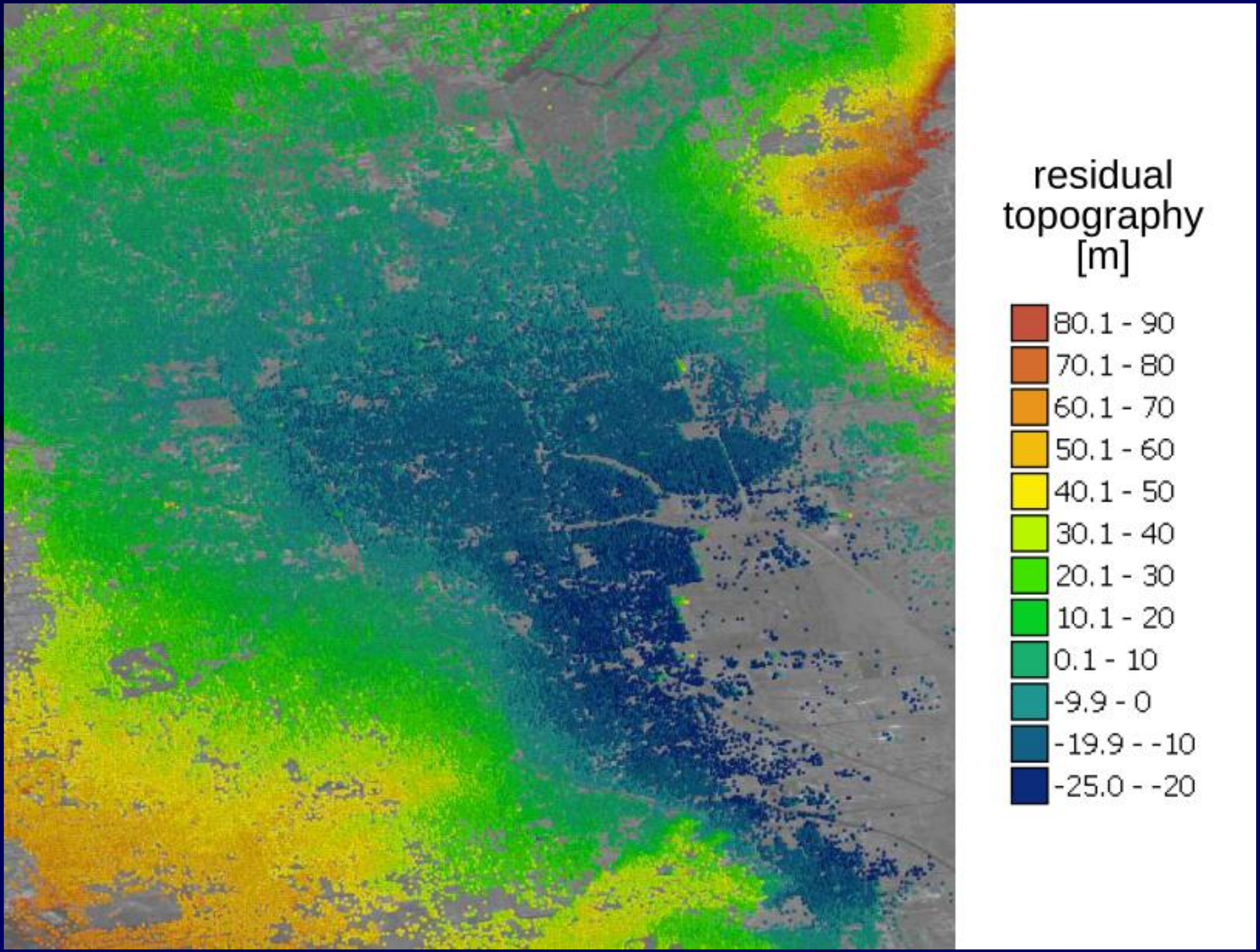


PSInSAR example: Las Vegas

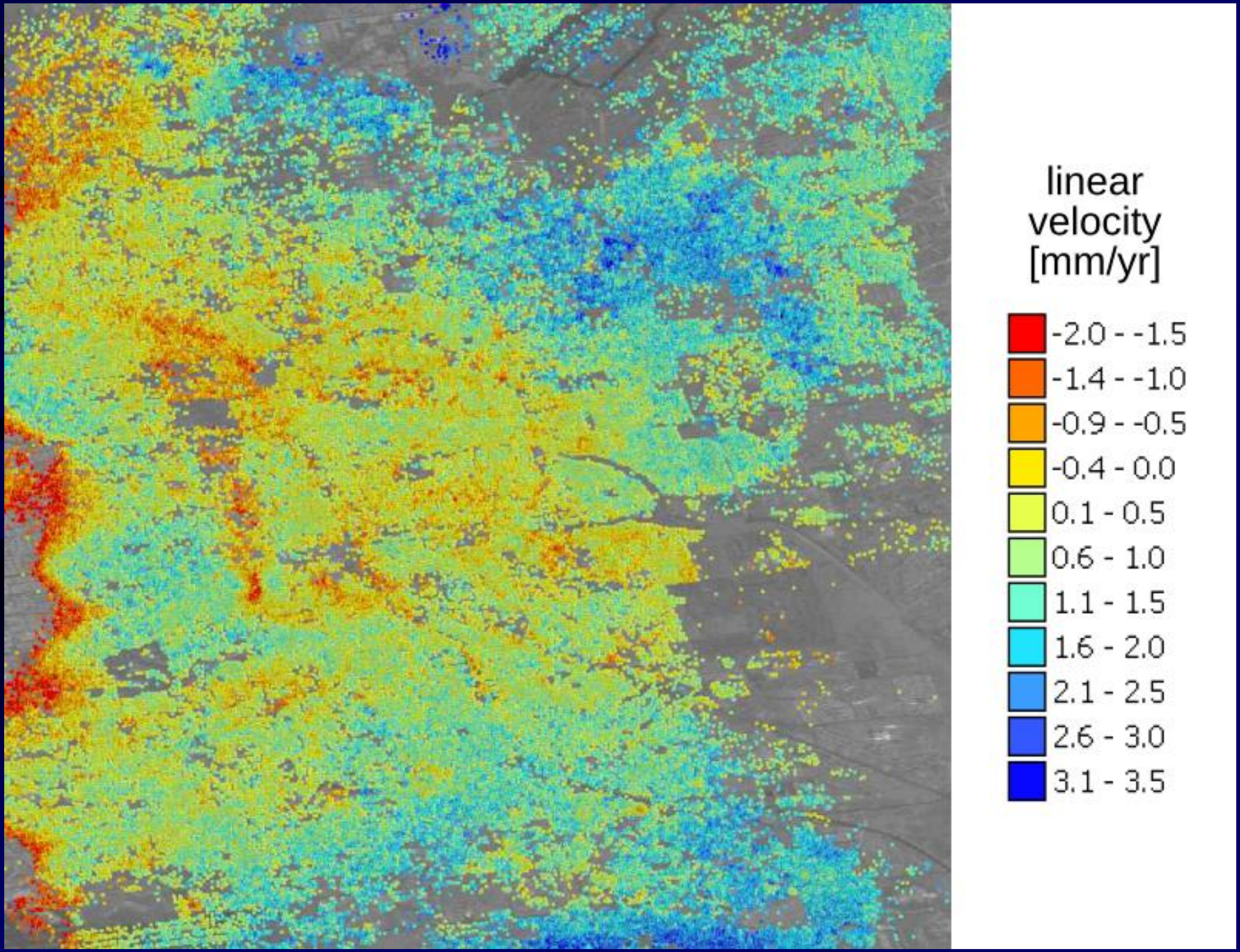


PSInSAR example: Las Vegas

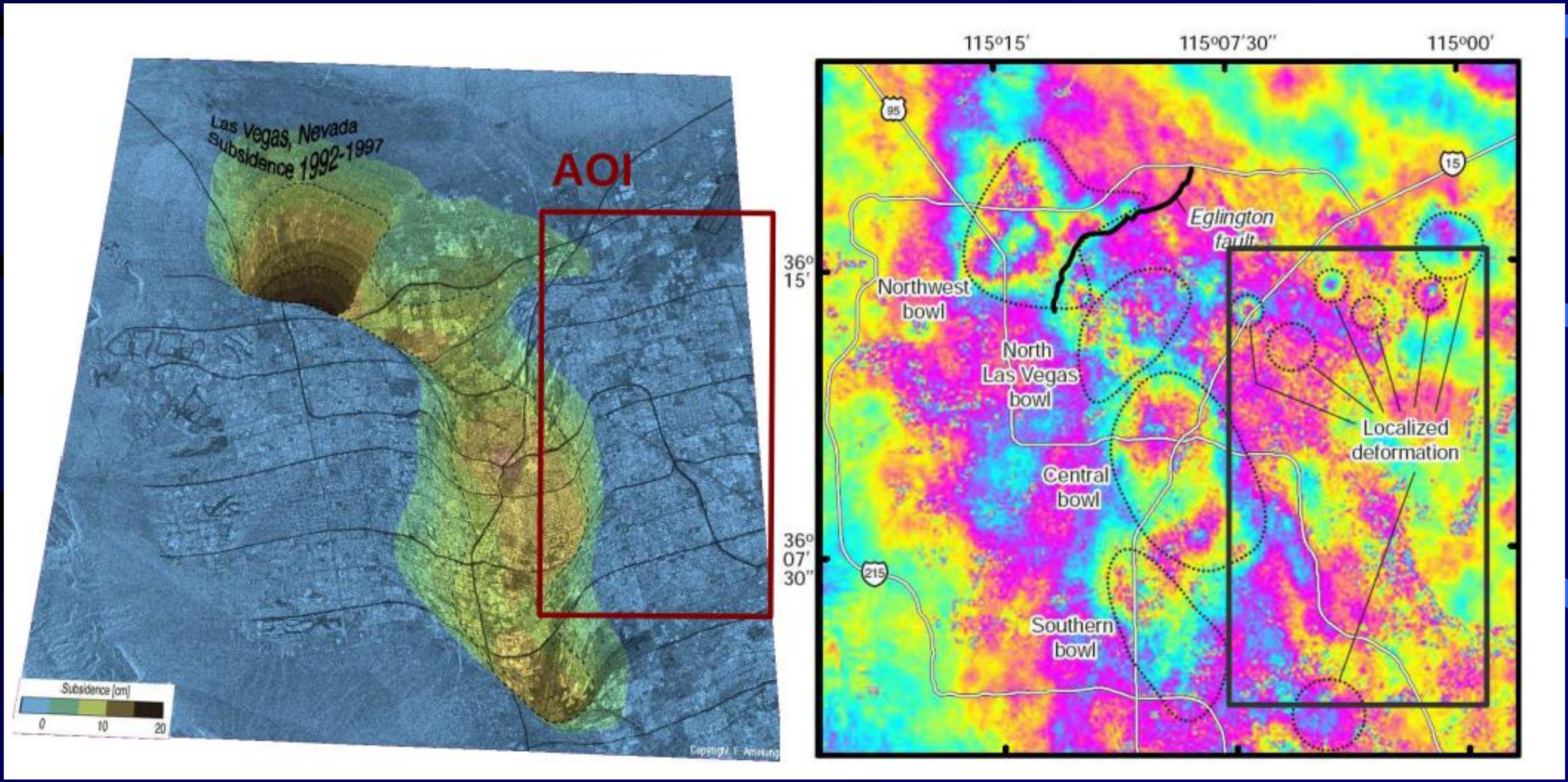
PSInSAR example: Las Vegas topography



PSInSAR example: Las Vegas displacement



PSInSAR example: Las Vegas, validation

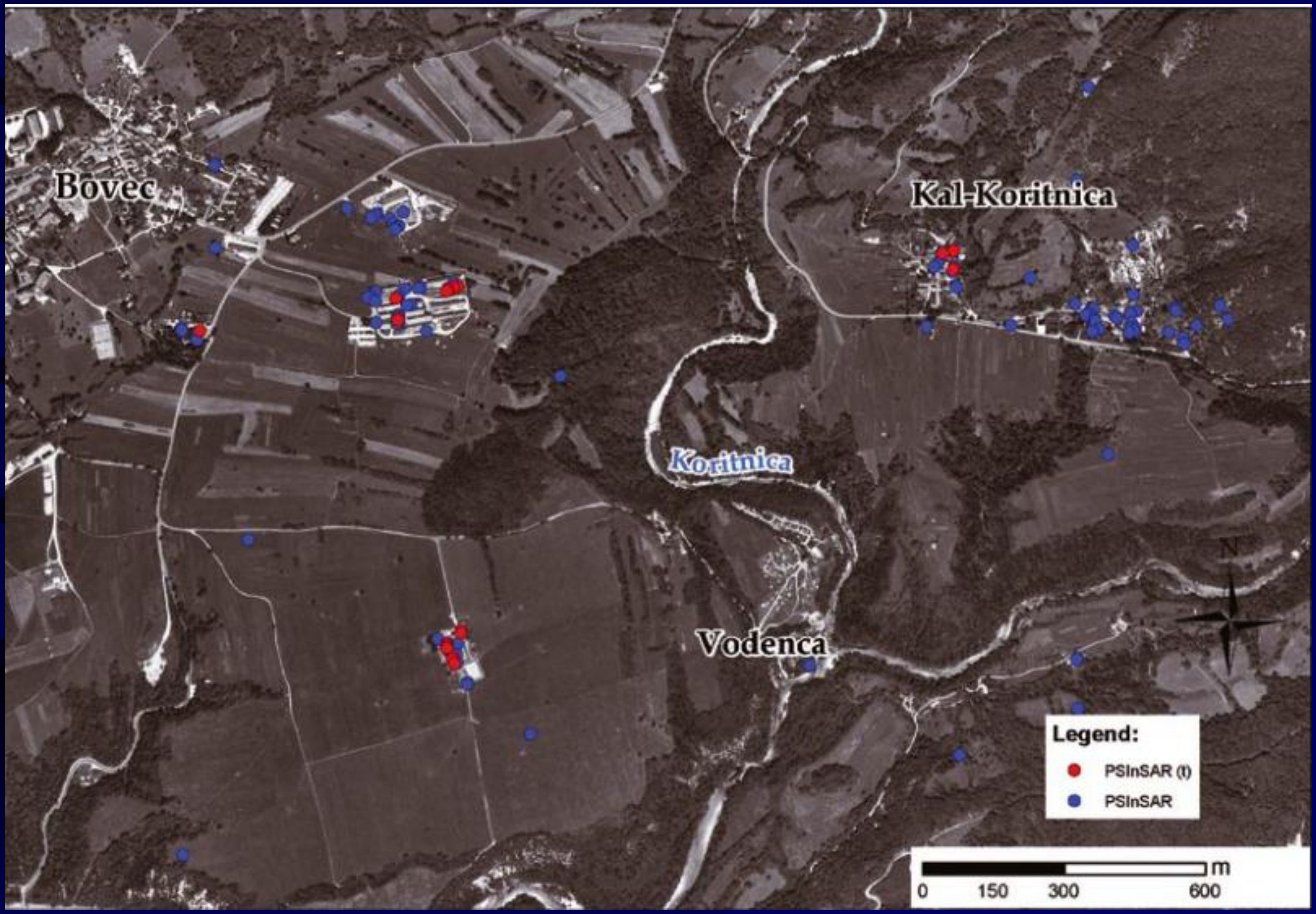


Summary

- InSAR measures fine-scale motions precisely
- Persistent scatterer method permits use in vegetated regions
- Maximum likelihood estimation yields dense network
- Can now identify/monitor crustal change worldwide from space

Subsidence in Las Vegas Valley, 1992-97

PSInSAR example: **surface deformations, NW Slovenia**

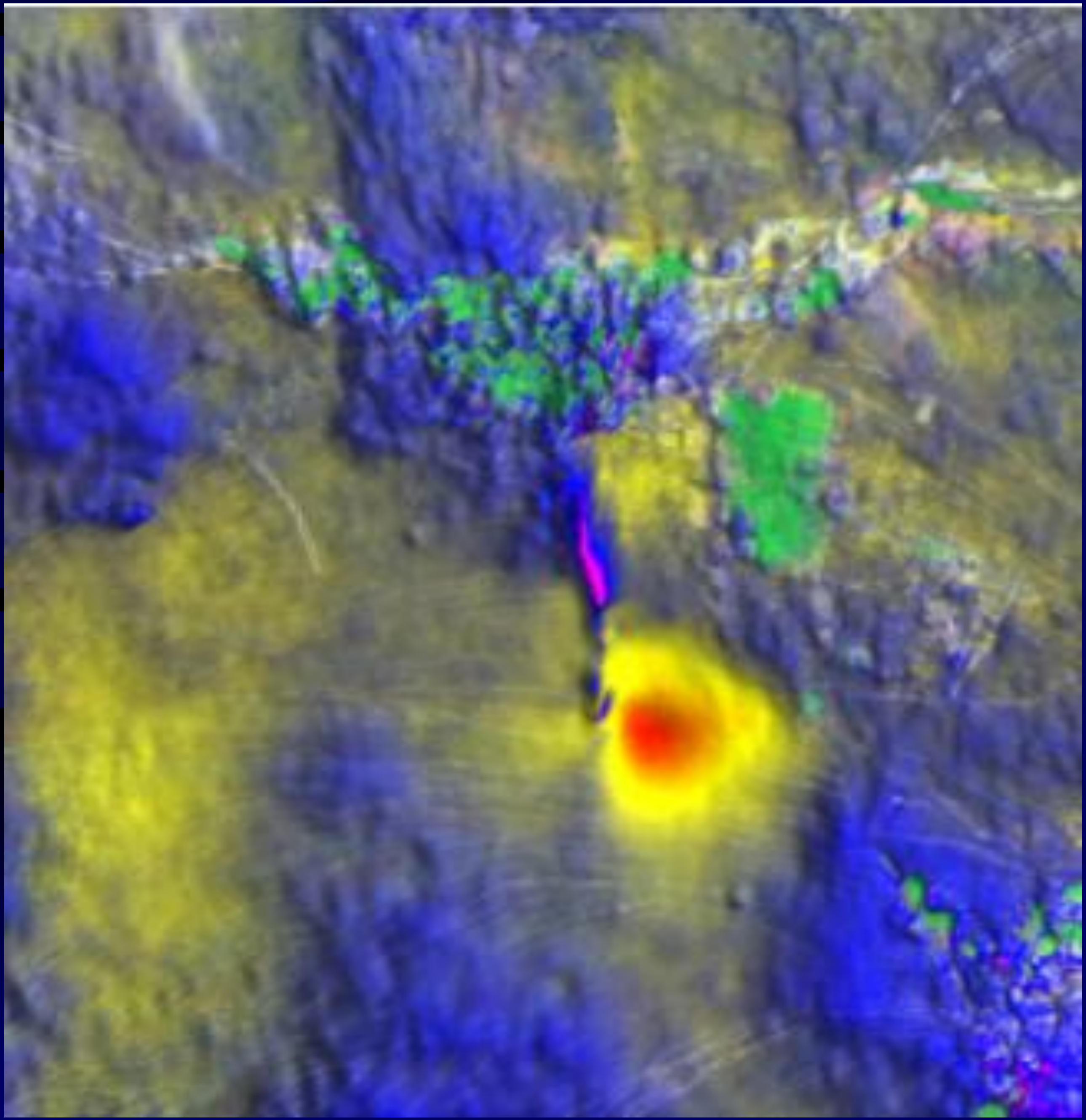


Red points represent PS where temporal displacements are available

Blue points represent all PS in the area

Bovec basin, 2007

PSInSAR



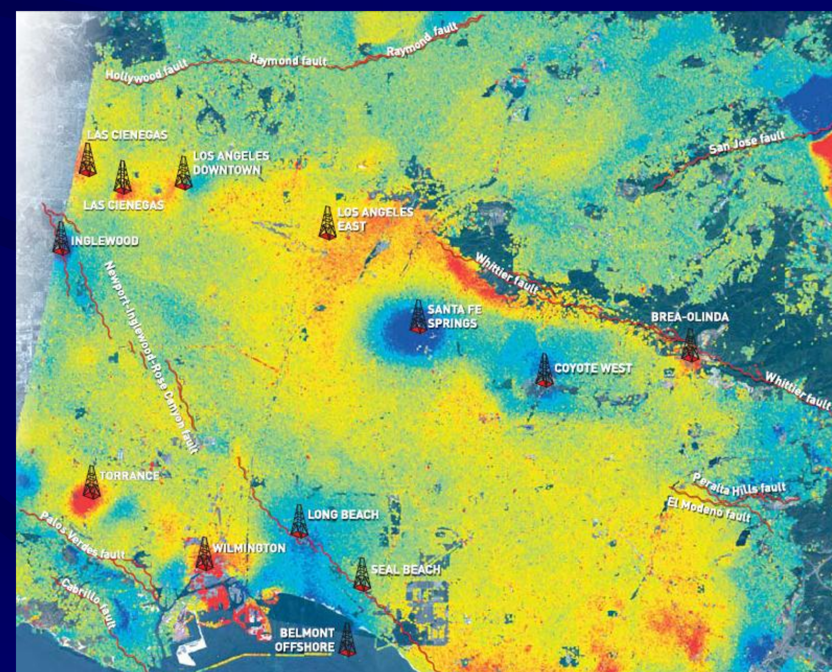
PSInSAR example:

Bam displacement Iran

(the quake of 26 Dec. 2003)

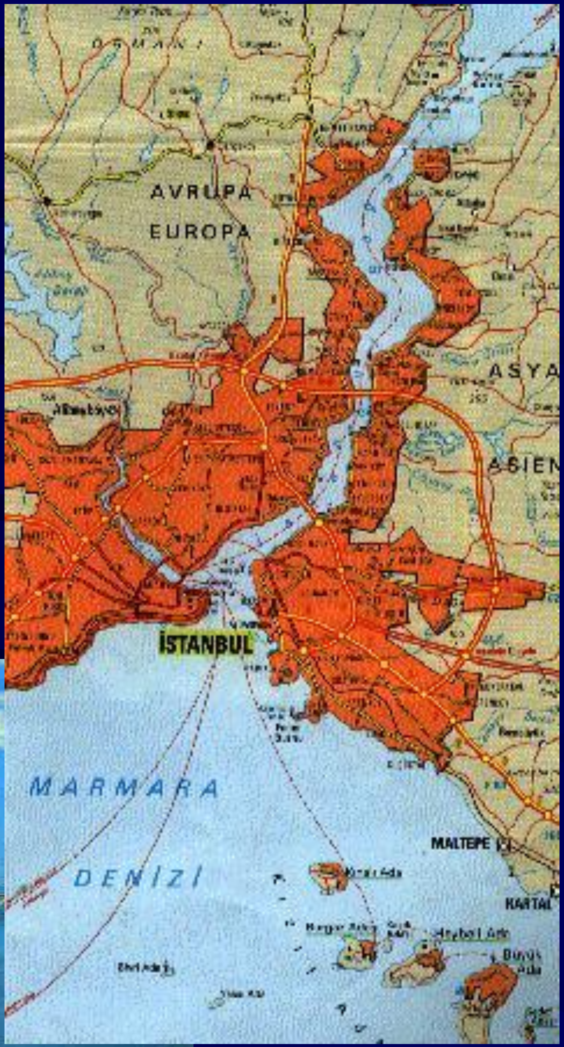
PSInSAR Applications :

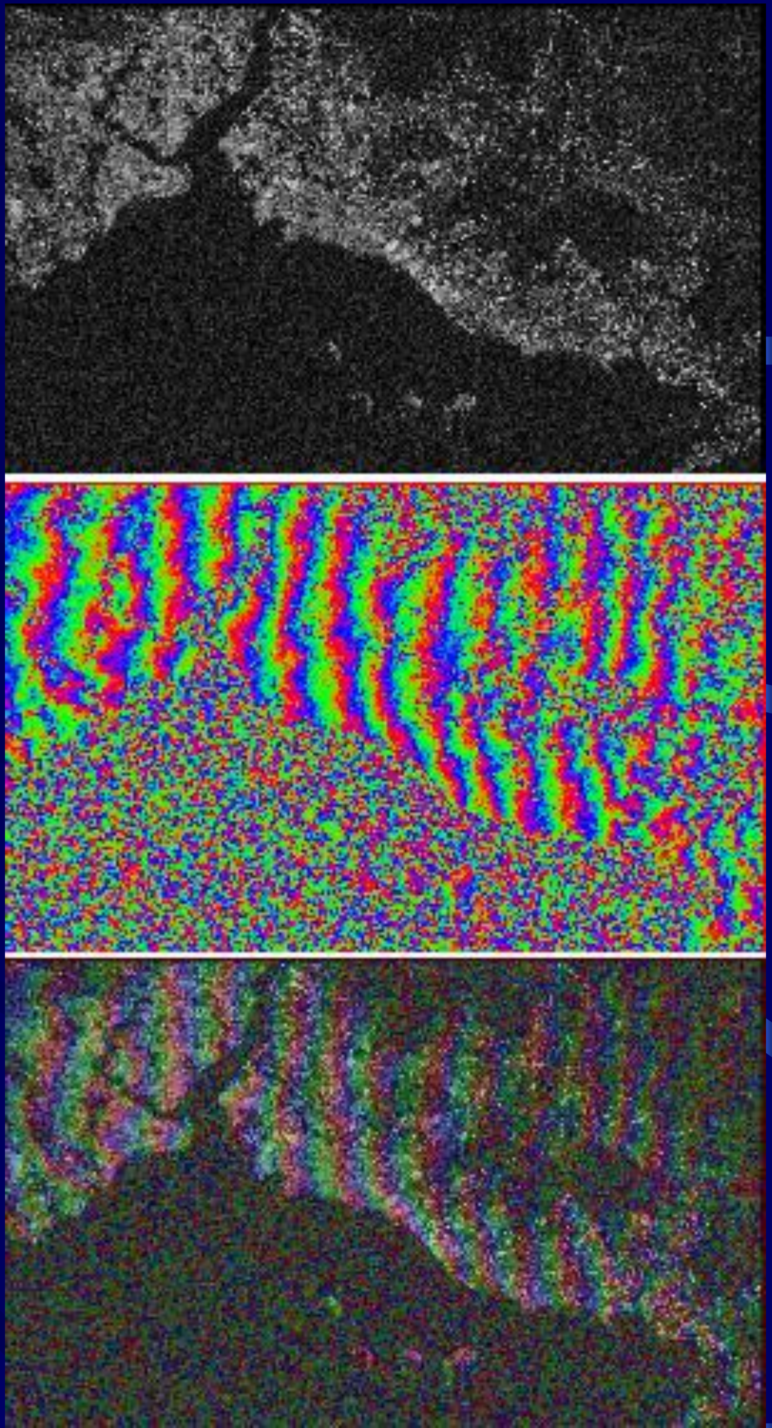
Surface Deformation Fields, Los Angeles Basin



New Technologies in monitoring and management of calamities and dynamic changes

Bosporus Strait

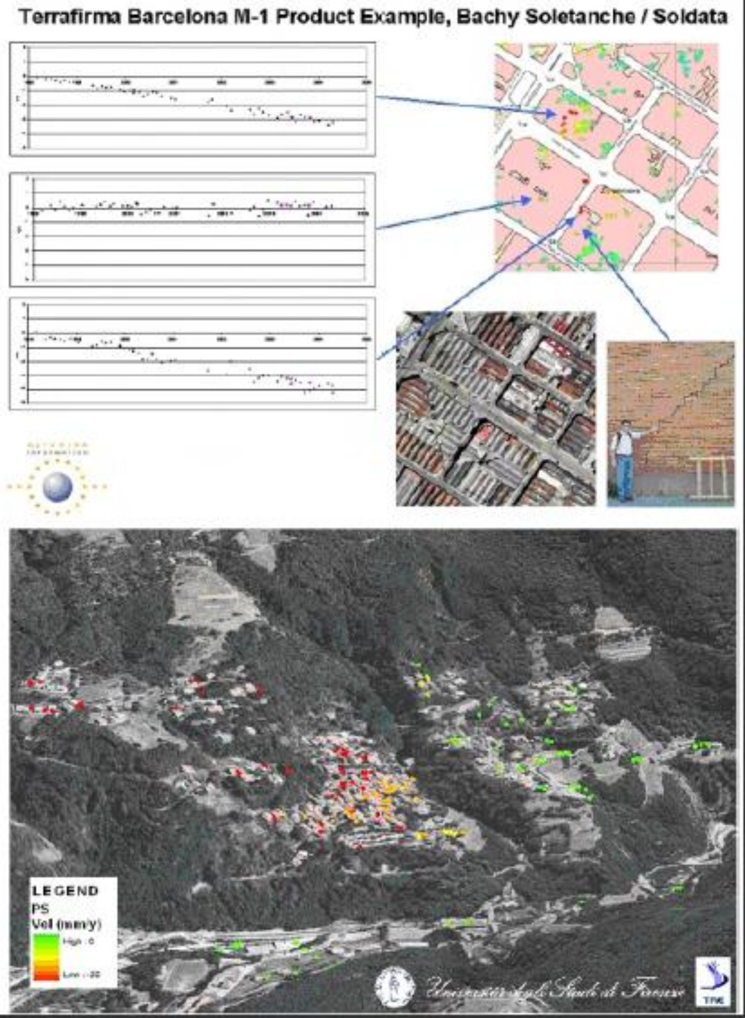




PSInSAR method and applications

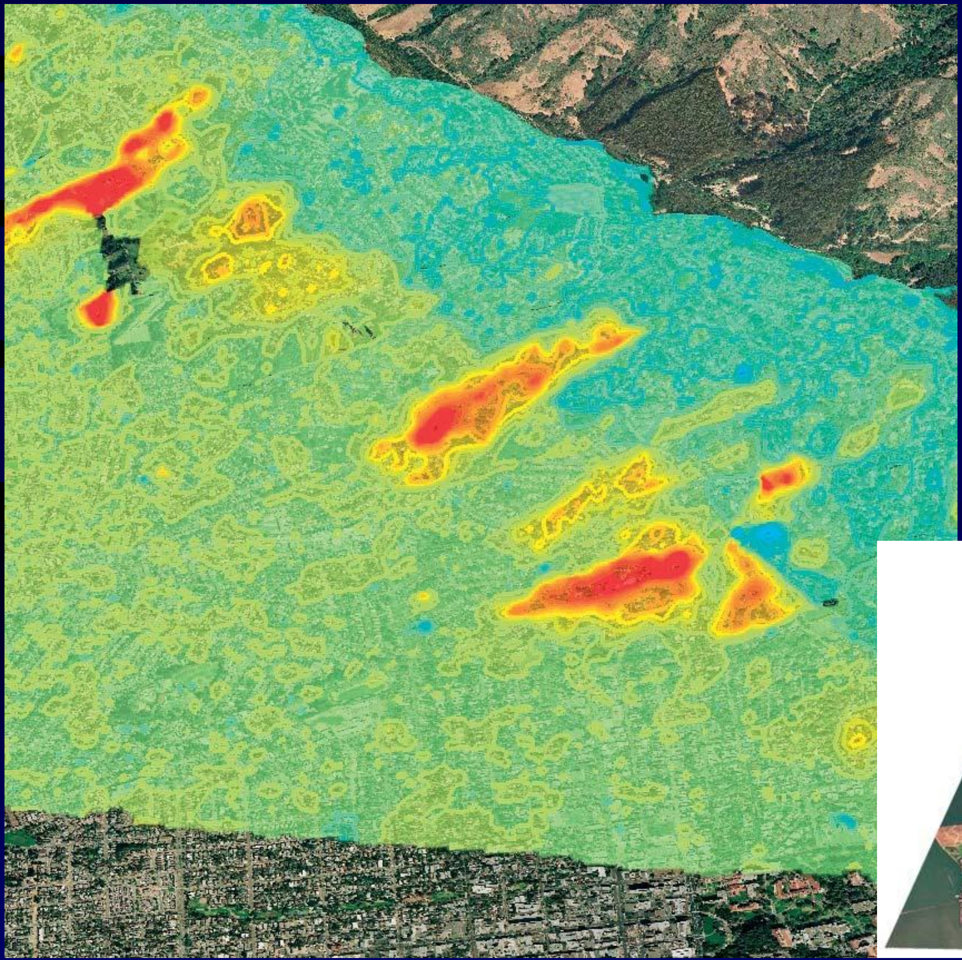
1. Monitoring buildings and facilities:
Detecting deterioration / instabilities
Real-time alert and on-site validation

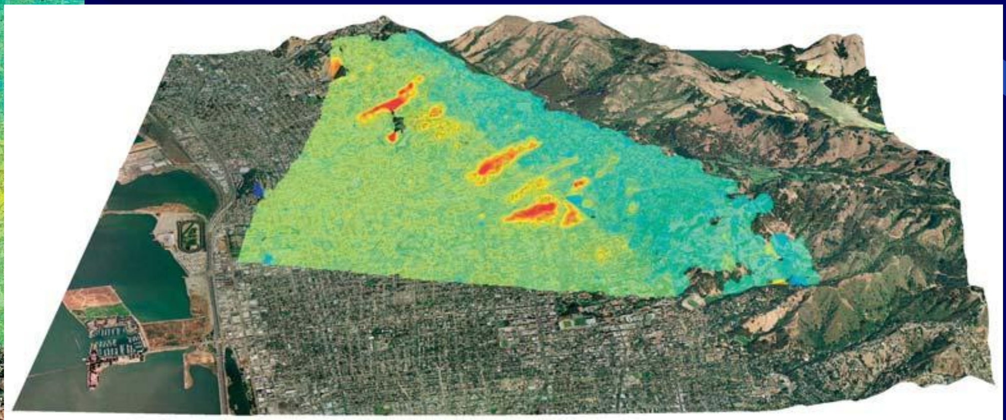
2. Slope stability:
Detecting accelerations (instabilities)
Evaluating volume of future slides



PSInSAR Applications :

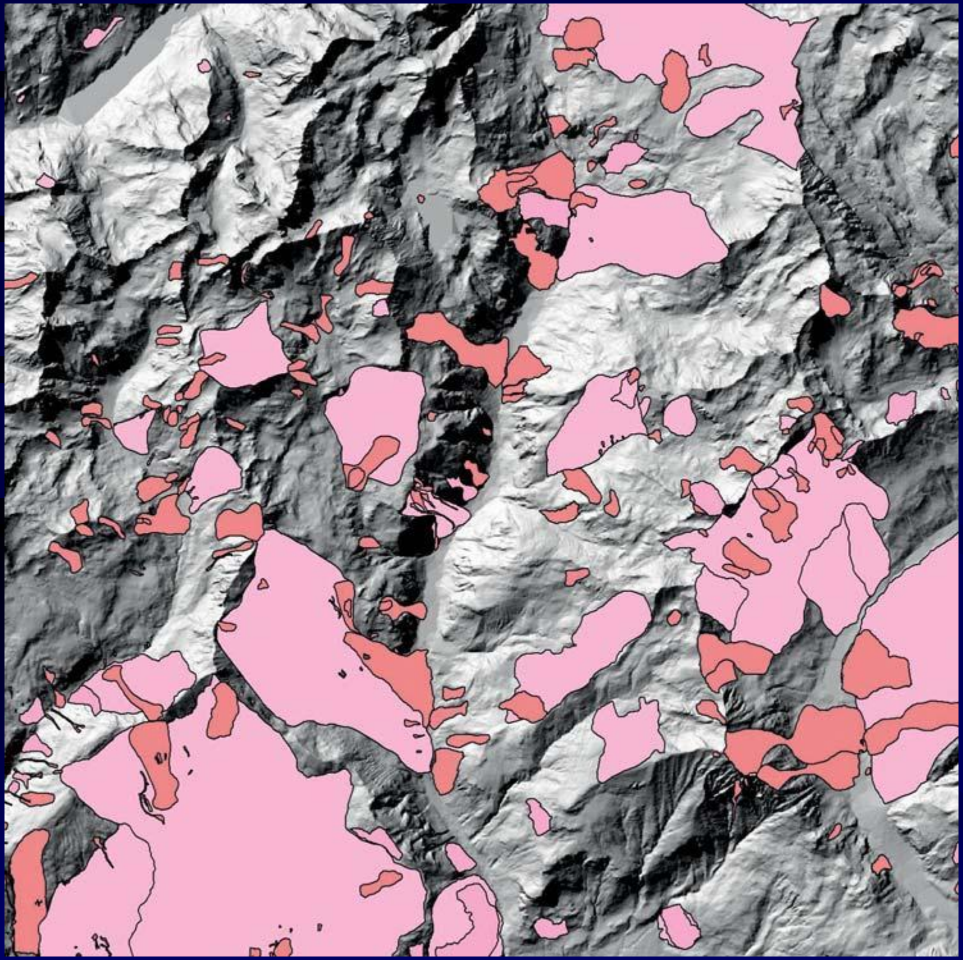
Slope instability, Berkley

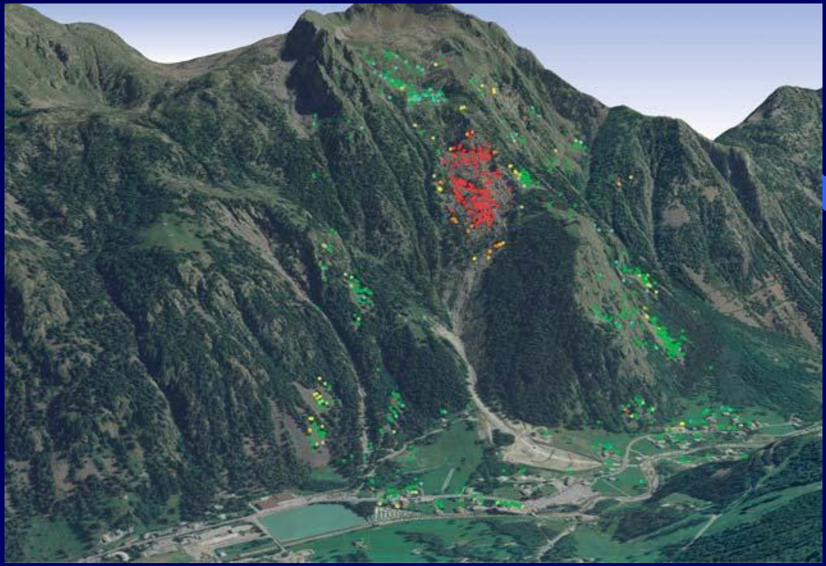




PSInSAR Applications :

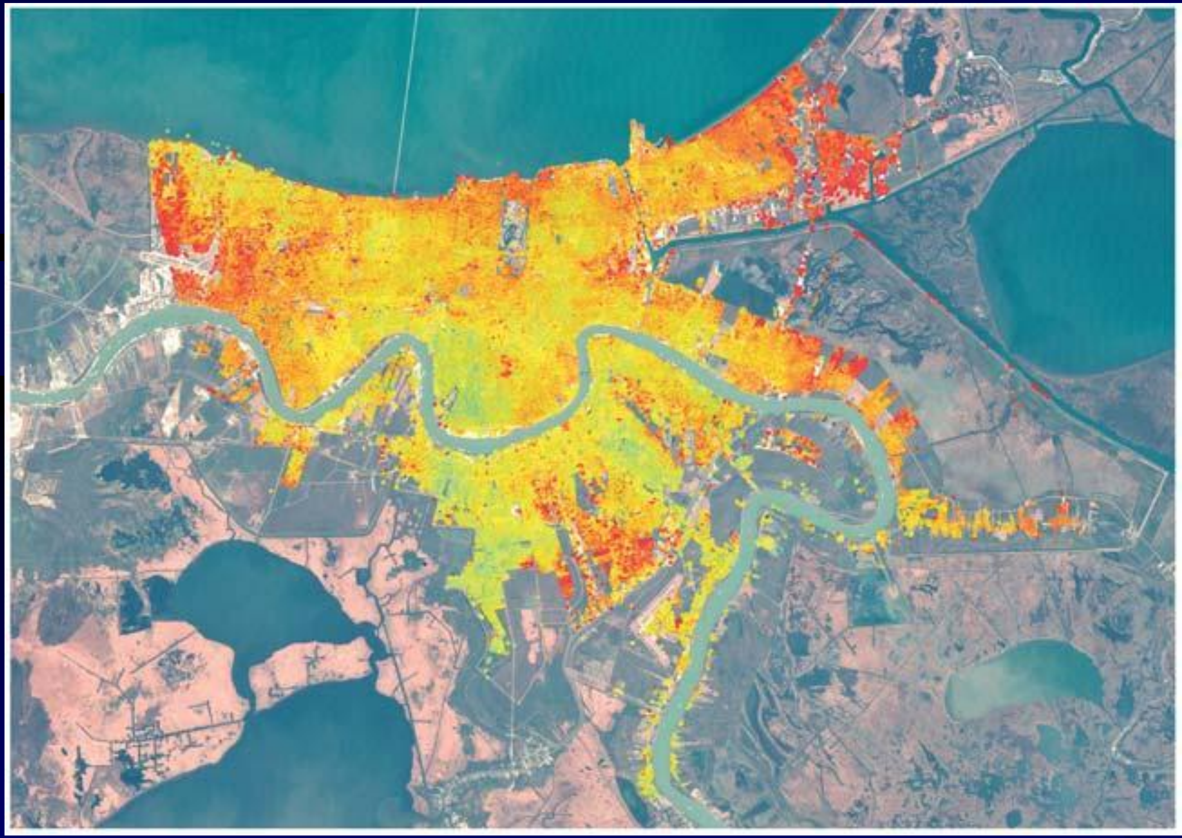
Landslide inventory, The Italian Alps

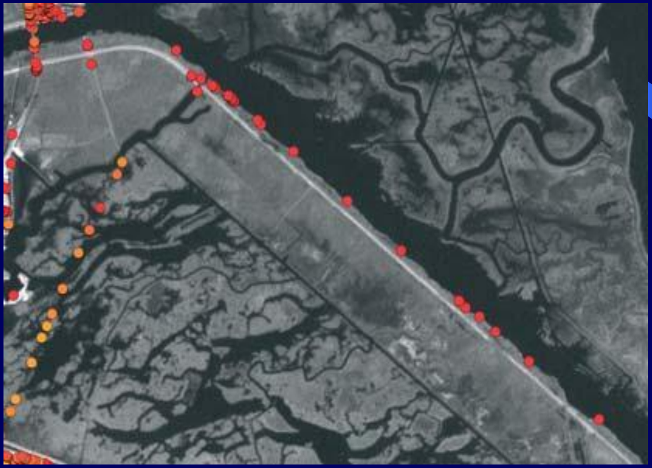




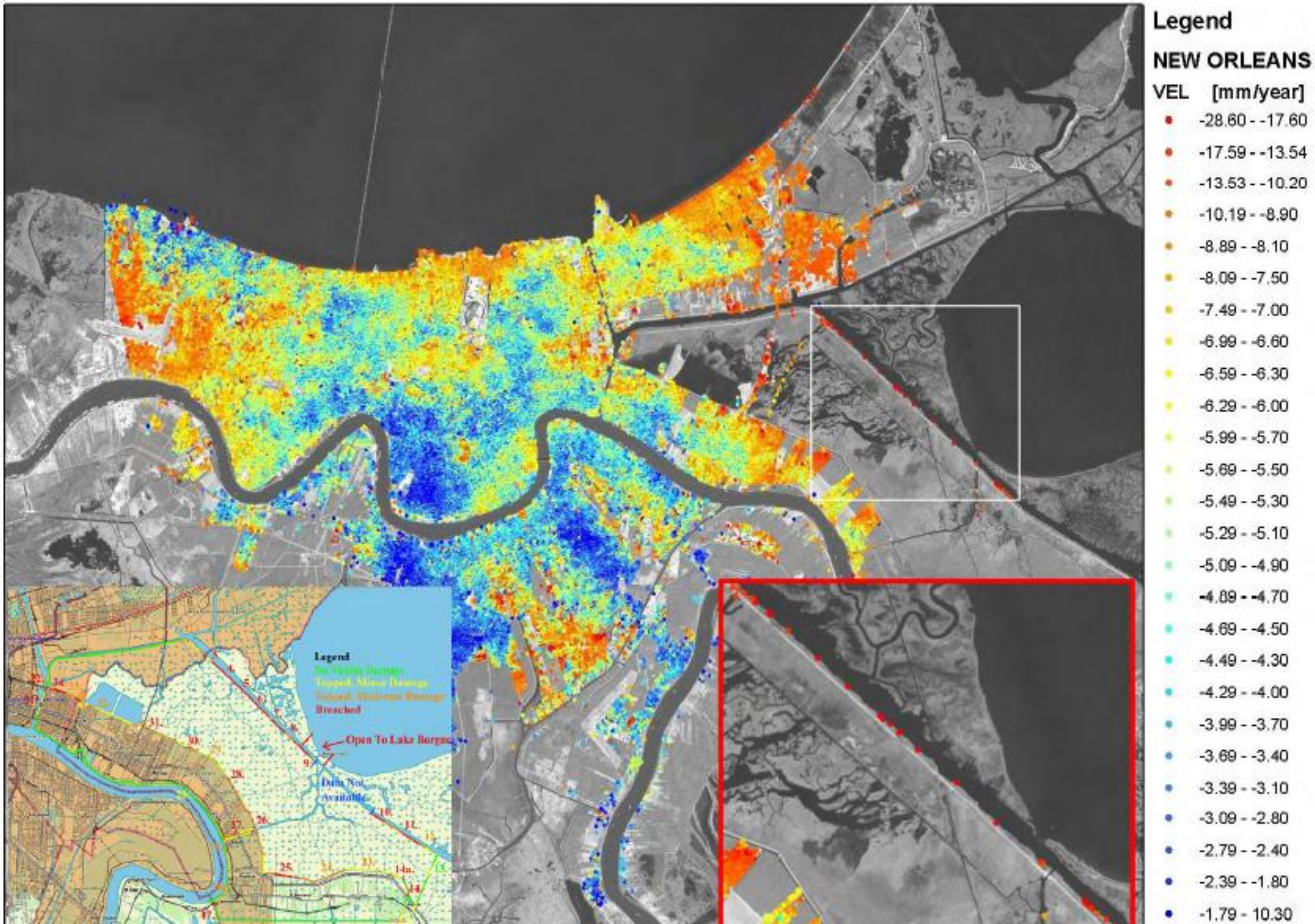
PSInSAR Applications :

Flood protection, New Orleans



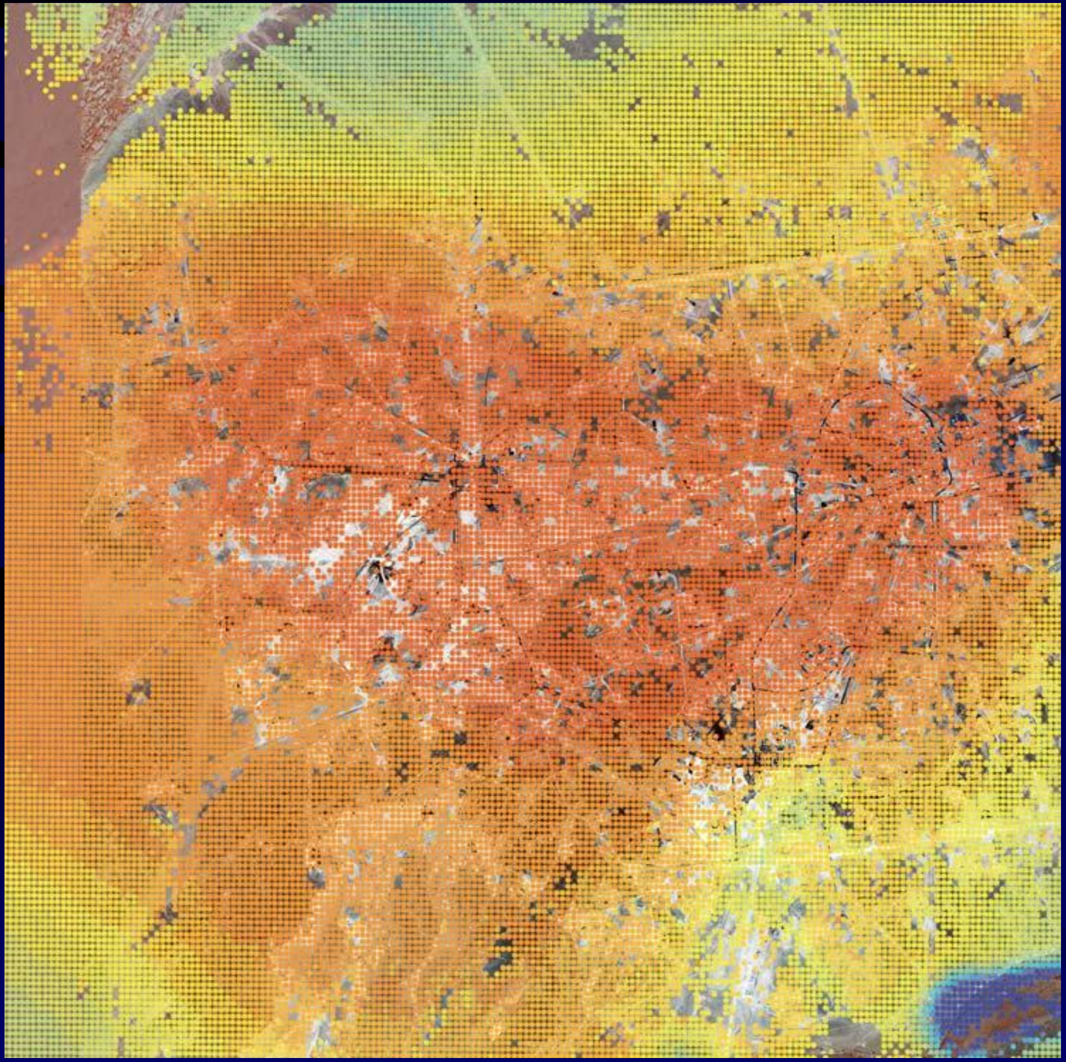


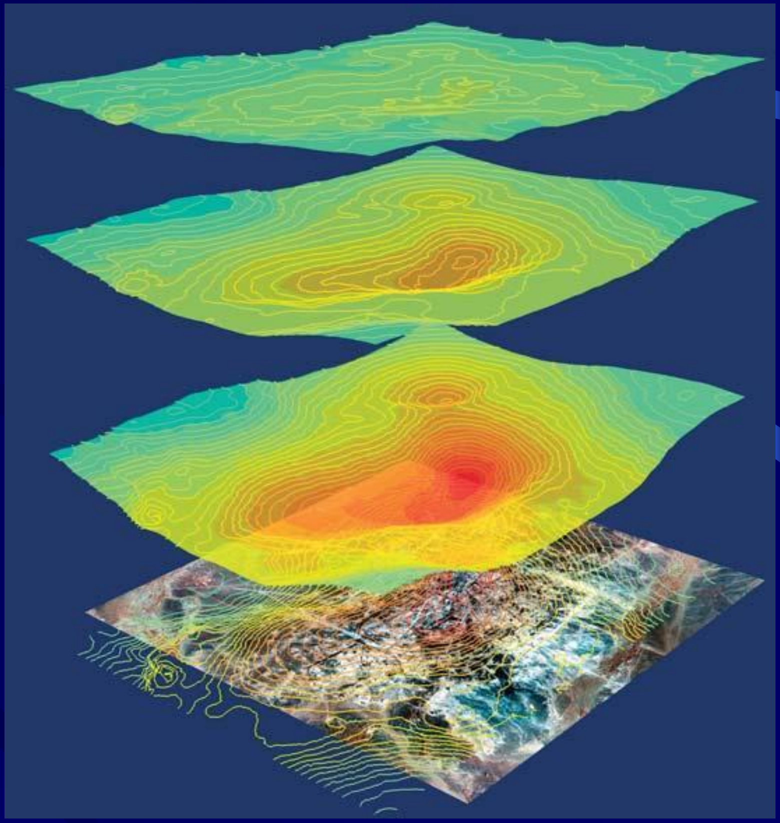
Advanced PSInSAR method and applications:



PSInSAR Applications :

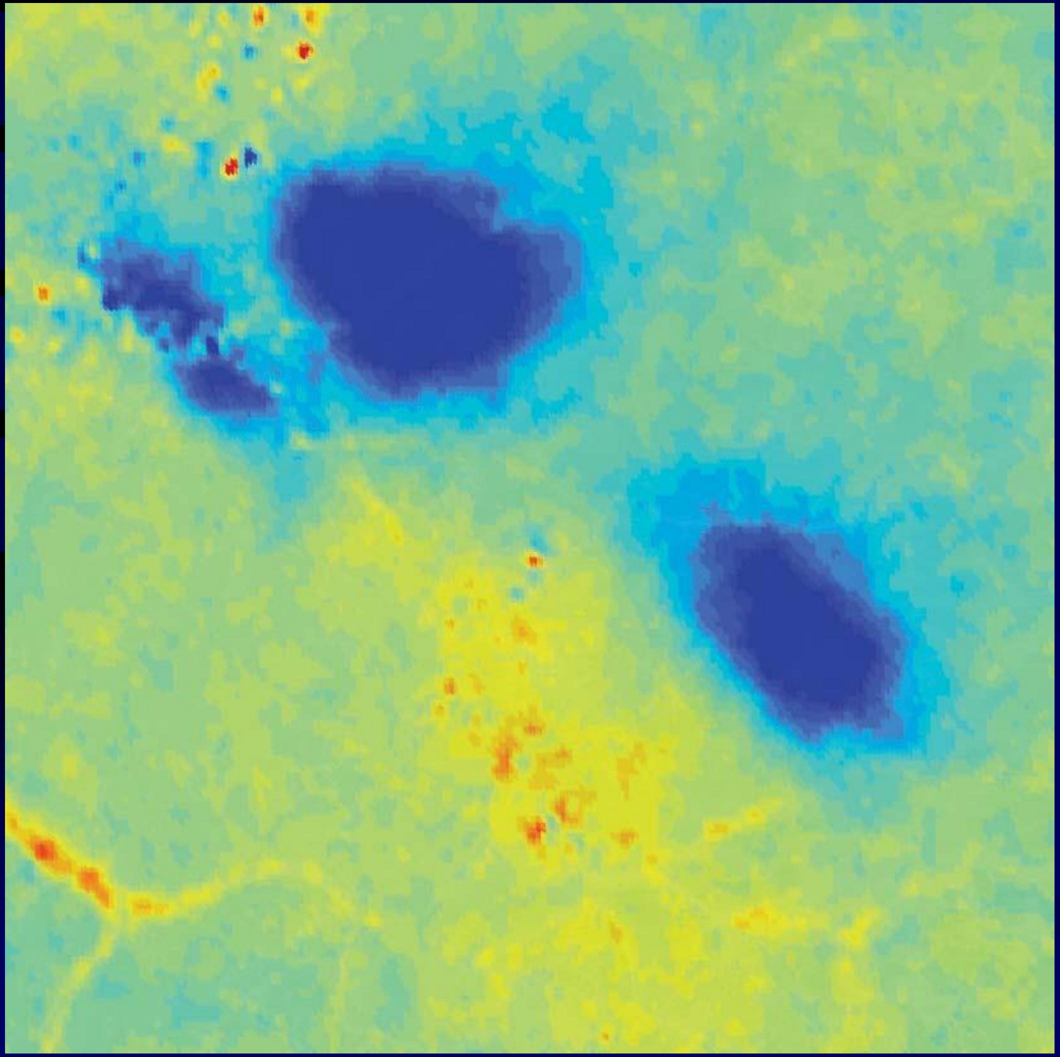
Oil field monitoring, Middle East

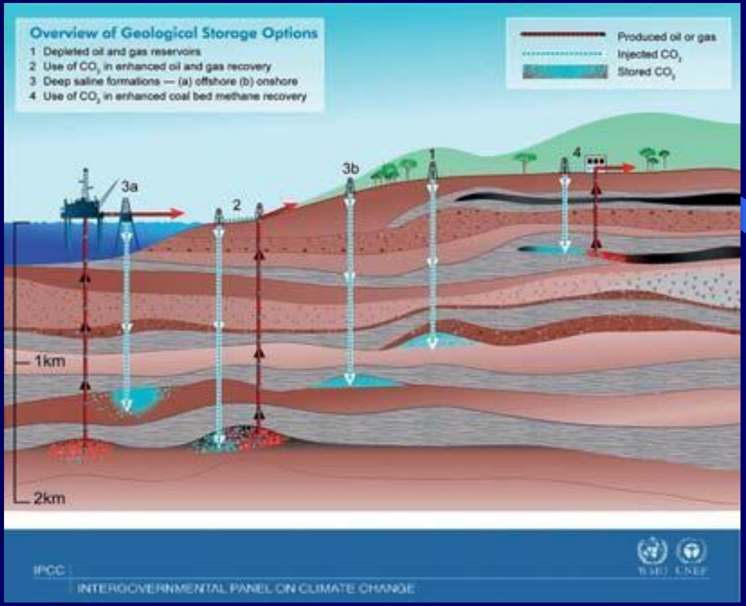




PSInSAR Applications :

Co2 Sequestration, North Africa



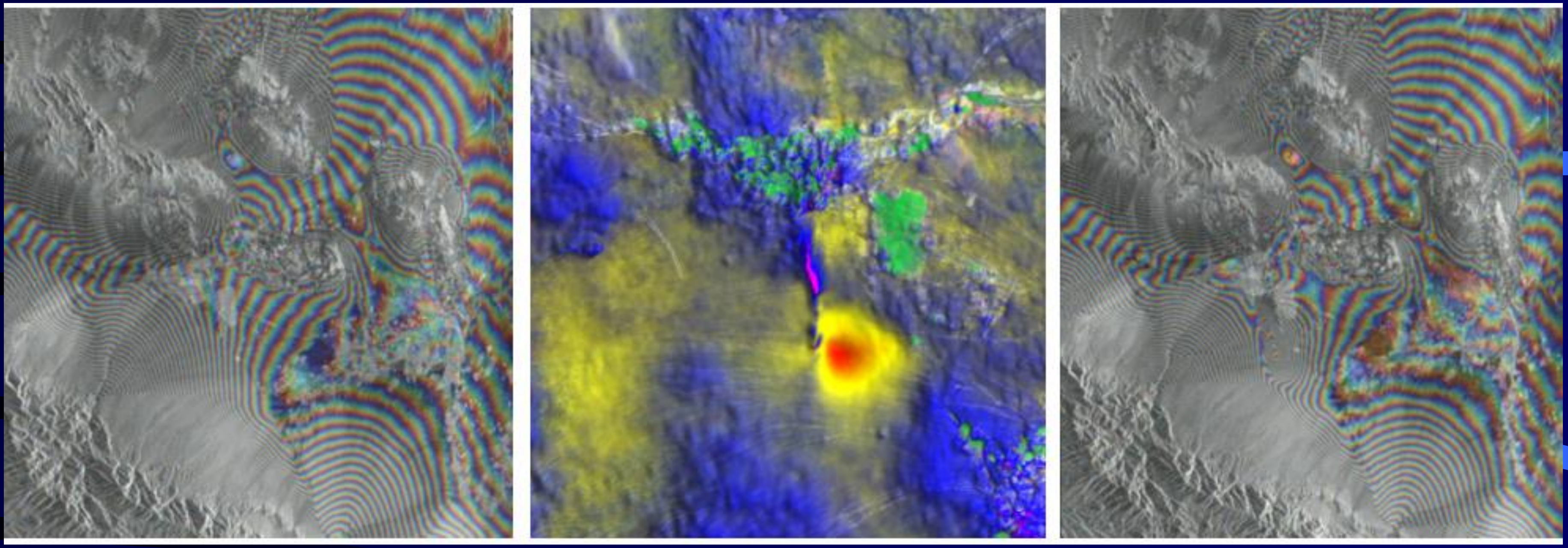


PSInSAR Applications :

Seismic faults, San Francisco Bay Area

Bam Quake, 26th December 2003

SAR Interferometry



Left image: topo-DInSAR product of Envisat-ASAR data of 11 Jun and 3 Dec 2003 (nbsl. 476.9m, pbsl. 141.6m)
Right image: topo-DInSAR product of the 3 Dec 2003 and 7 Jan 2004 (nbsl. 521.9 m, pbsl. 268.3 m).
Middle image: 3-D perspective view of vertical displacement of south of Bam (during the 3.5 years after the 6.6 earthquake)
Displacements along the radar line-of-sight direction: 30 cm and 16 cm at south-east and north-east lobes of the interferogram
Displacement to the western part of the area, about 5cm along the radar line-of-sight direction

Advantages and limitations of PSInSAR

Advantages	Limitations
Regular and financially acceptable measurements of larger areas	Vegetated areas disable the use of PSInSAR
High density of PS (up to 1.000 PS/km^2)	Inapplicability on continous surfaces
Fast data processing / little need for inclusion of end user	Time measurements are limited with the satellites' orbiting intervals
High accuracy	Detection of slow deformations (< 10 cm/year in the LOS direction)
Simple export into GIS	

(Ferretti & Crespa, 2006)

SqueeSAR

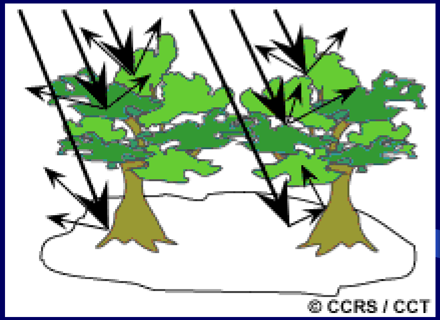
the next step in development of **InSAR**

following

PSInSAR

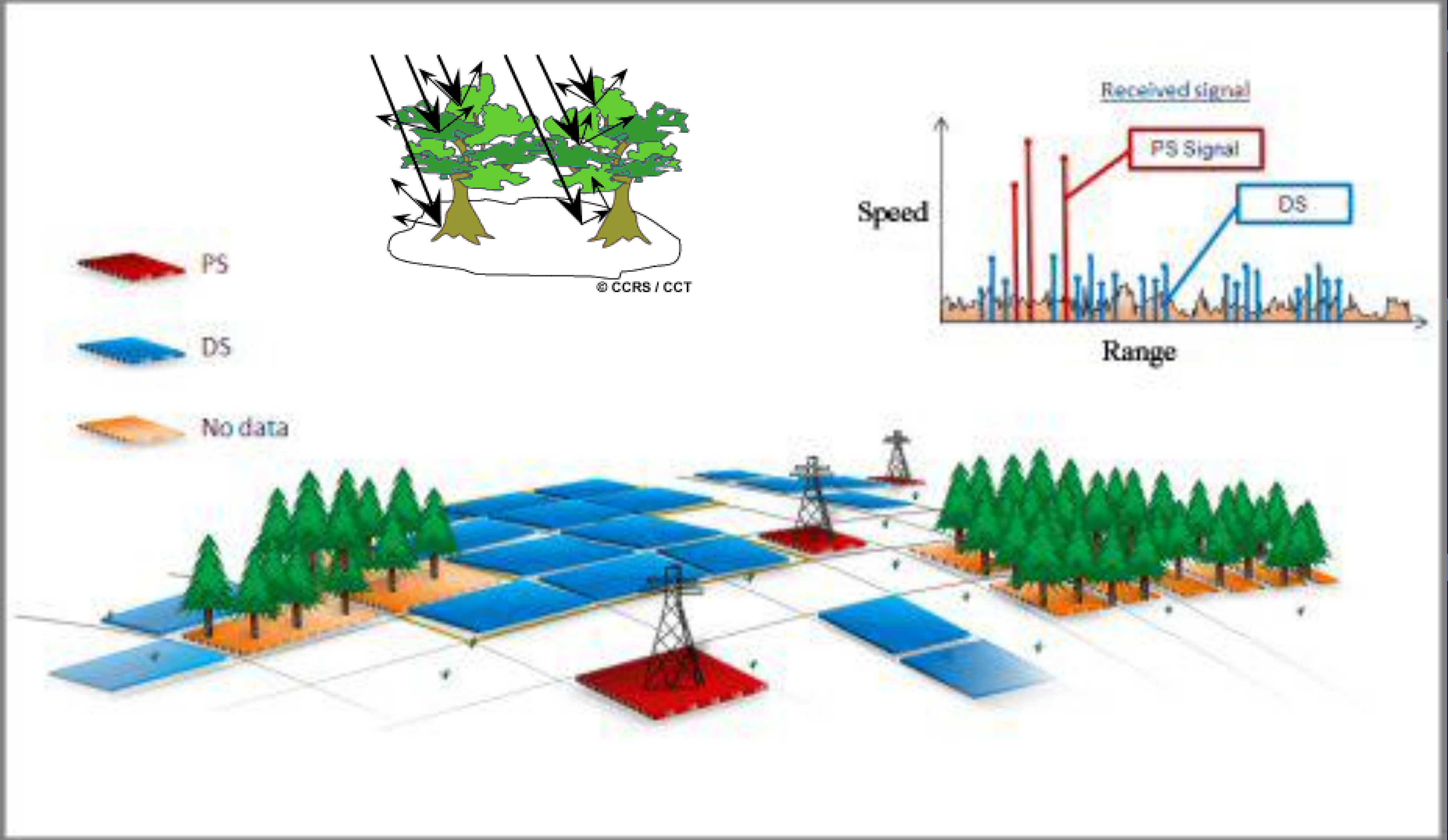
- Ten years after PSInSAR, in 2009 TRE has developed a new algorithm, namely **SqueeSAR**, which represents a further advancement for satellite data analysis and a breakthrough in Earth observation capabilities.
- Beyond PS, it is noticeable that distributed scatterers also exist and that they too can be used for monitoring ground displacement.
- Distributed scatterers or **DS consist of an extensive area where the back-scattered energy is less strong in some way, but statistically homogeneous within the area**.

- Using the SqueeSAR algorithm, it is also possible to ’process’ this energy and detect the movement of areas namely dominated by DS, with the same accuracy as analysis with PS.
- DS displacement time series are indeed less noisy too. DS typically correspond to debris areas, non-cultivated lands and desert areas.



- It is also important to highlight that the PSInSAR processing chain is maintained and used within the SqueeSAR algorithm: the result is an enhancement of the information output capacity, meaning PS plus DS, to gain an enhanced insight into ground deformation and associated surface movements.

SqueeSAR Method



SqueeSAR Method

SqueeSAR algorithm in summary:

- Ground points identified: **PS** and **DS**
- **High density** of ground measurement points identified in **urban areas** (PS)
- **High density** of ground measurement points identified in **non-urban areas** (PS and DS)
- **Time series** provided for each ground point (PS and DS)
- **Millimetre accuracy** on ground displacement values
- Time series **standard deviation reduces** – i.e. coherence increases and noise decreases
- **Increased confidence on ground behaviour** due to increased coverage of points – especially significant for landslides, outcrops and generic areas with low reflectivity

SqueeSAR Applications

Areas subject to slow landslides or slope instability

Monitoring E&P activities

Areas subject to subsidence and uplift

Monitoring of major capital works

Seismic faults and volcanic areas

Checking the stability of buildings

SqueeSAR Applications

The fast analysis of large areas of land, the high density of measurement points, the precision of measurements and the ability to access an historic database make our technology a powerful tool for identifying and monitoring:

Areas subject to slow landslides or slope instability

The extent of unstable land and the corresponding rate of movement, when slow movements occur is defined.

Monitoring E&P activities

The measurements are used to support exploration and production activities, to monitor oil & gas fields and storage areas and to assess environmental impact for risk prevention.

SqueeSAR Applications (continued)

Areas subject to subsidence and uplift

Subsidence or uplift, whether by natural failure or from man-made activities is monitored.

Monitoring of major capital works

The measurements can contribute to the planning of major capital works, such as pipelines, transmission lines, highways and railways, by identifying stable corridors for these facilities.

Seismic faults and volcanic areas

From a satellite it is possible to investigate large areas measuring up to several thousands of square kilometers.

Checking the stability of buildings

Thank you!

KNOWLEDGE SHOULD BE SHARED, OTHERWISE IT IS USELESS.

ISNET can play a key role!