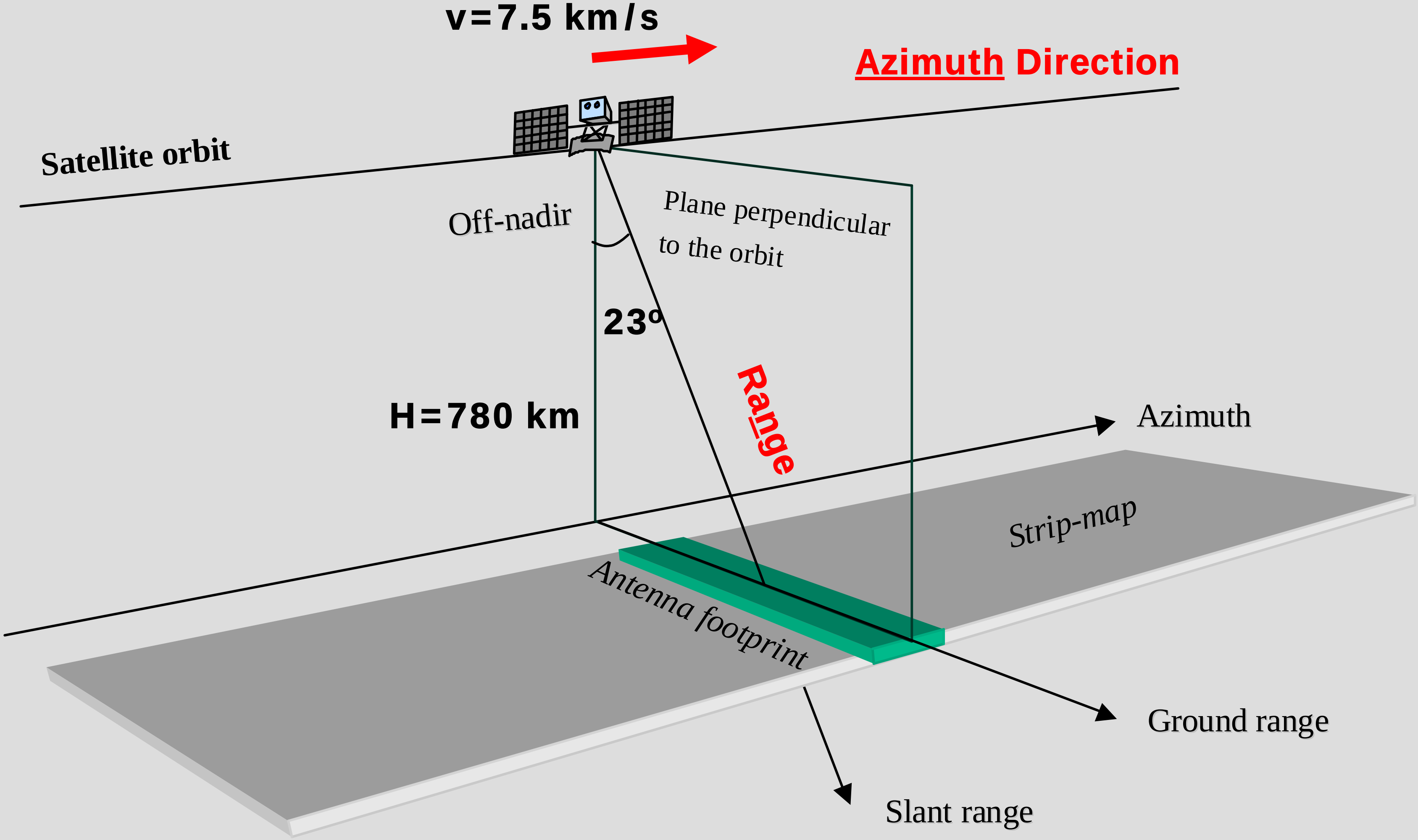
Detecting and Monitoring Ground Movement using Satellite Borne Radar - InSAR

What is InSAR?

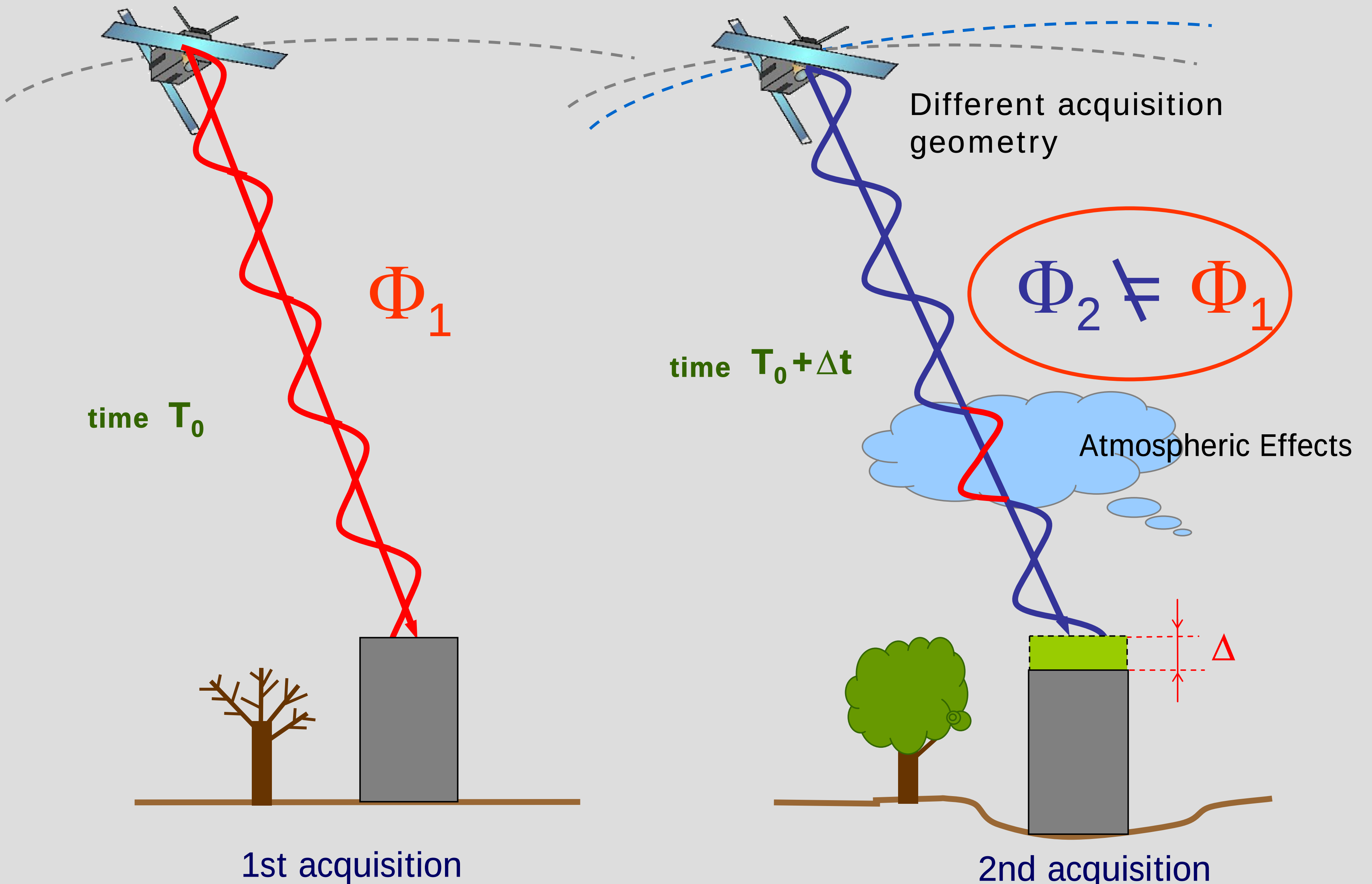
- Interferometry
- Synthetic Aperture Radar

How does InSAR work?



Antenna dimensions: 1 m (cross range) x 10 m (azimuth)

How Does InSAR Work?



How Does InSAR Work?

Signal Phase contribution of a single SAR acquisition can be expressed as:

$$\phi = \psi + \frac{4\pi r}{\lambda} + \alpha + \text{noise}$$

ψ = reflectivity of the target

$\frac{4\pi r}{\lambda}$ = distance between sensor and target

α = atmospheric phase contribution

How Does InSAR Work?

- Using the previous phase contribution formula, signal phase of a SAR Interferogram can be expressed as

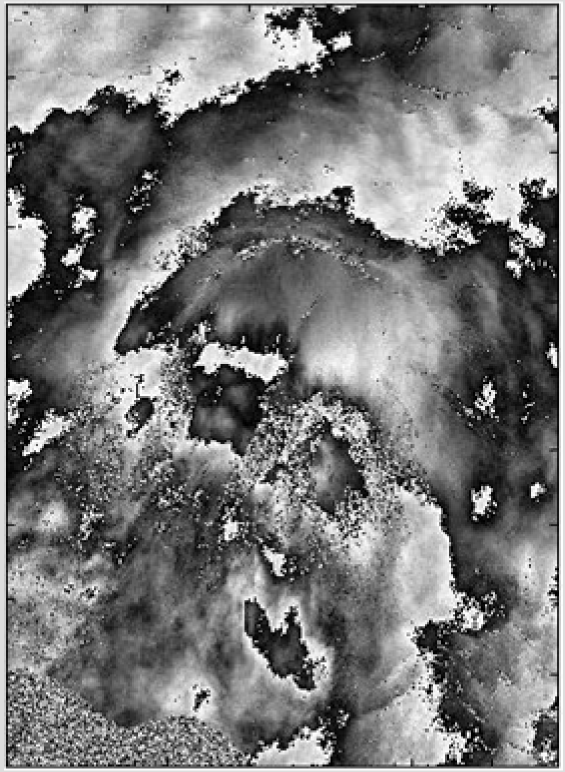
$$\Delta\phi = \Delta\psi + \frac{4\pi}{\lambda}\Delta r + \Delta\alpha + noise$$

- IF we can eliminate the non-range components then:

$$\Delta\phi = \frac{4\pi}{\lambda}\Delta r$$

Differential Interferogram Generation

Interferogram - Synthetic Interferogram generated from a DEM = Differential Interferogram



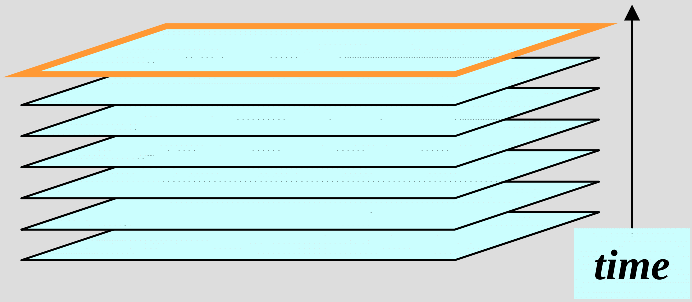
$$\phi = \phi_{topography} + \phi_{displacement} + \phi_{atmosphere} + \phi_{noise}$$

DInSAR

- Applies to 2 time-separated images
- Works at the pixel level
- Yields the footprint of movement and the degree of movement within the footprint
- Problem: Accuracy is impaired by atmospheric effects and, to a lesser extent, by phase decorrelation

DInSAR vs. PSInSAR

- Despite its remarkable potential, the challenges facing DInSAR lead to consideration of a multi-interferogram approach.



- PSInSAR™, IPTA, CTM are current multi-interferogram InSAR tools. CNES has been researching a similar tool.

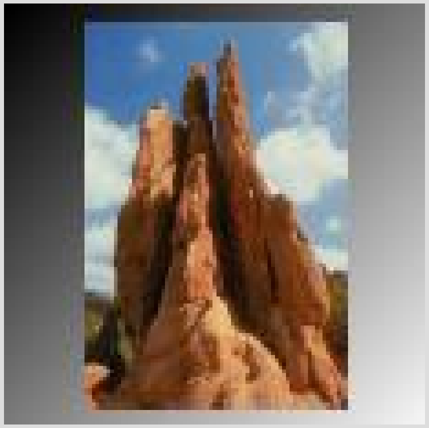
PSInSAR

- In multiple interferograms, we are looking for stable “targets” that:
  - Are not affected by acquisition geometry
  - Are not affected by temporal decorrelation
  - Display reliable phase information
- Such points are referred to as Permanent Scatterers and are nearly always found within the pixel.

What is a Permanent Scatterer?

- What does a PS look like?

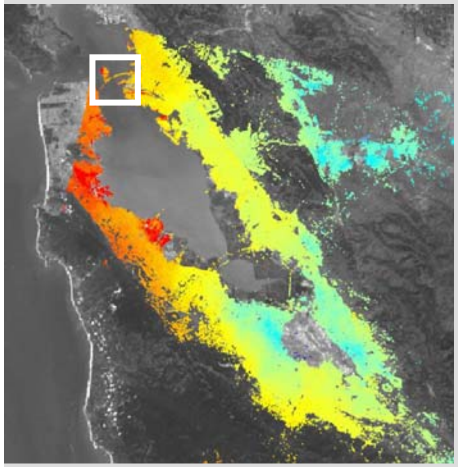
Natural Feature

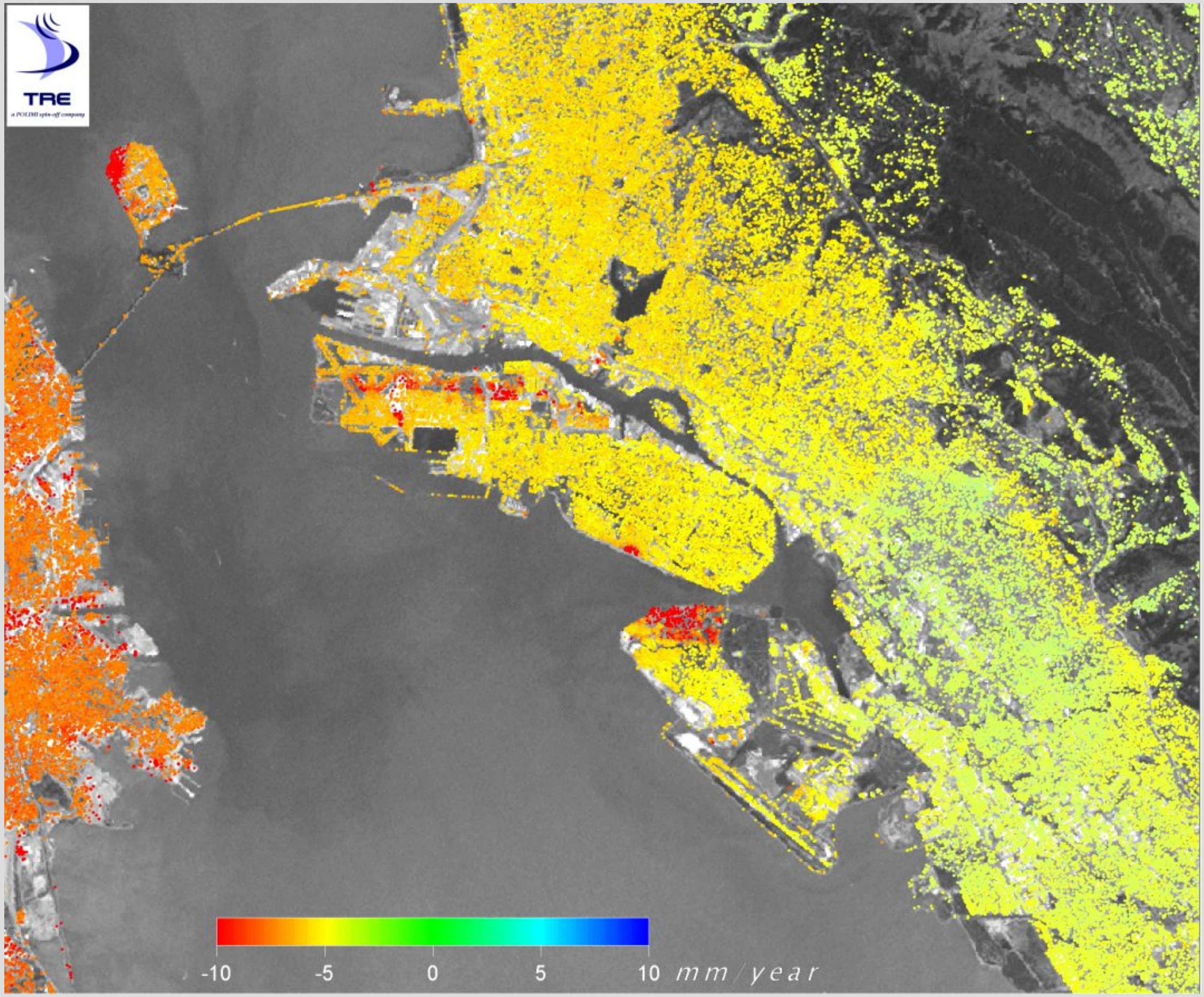


Man-made Feature

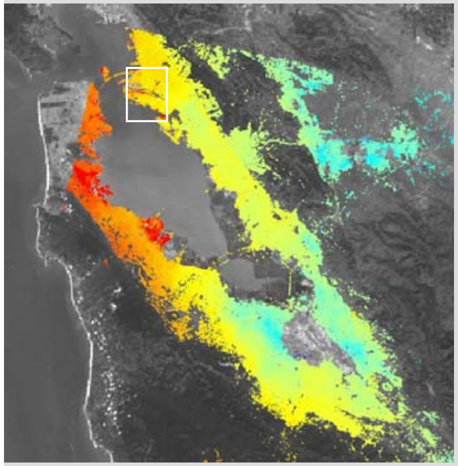
Fabricated Feature

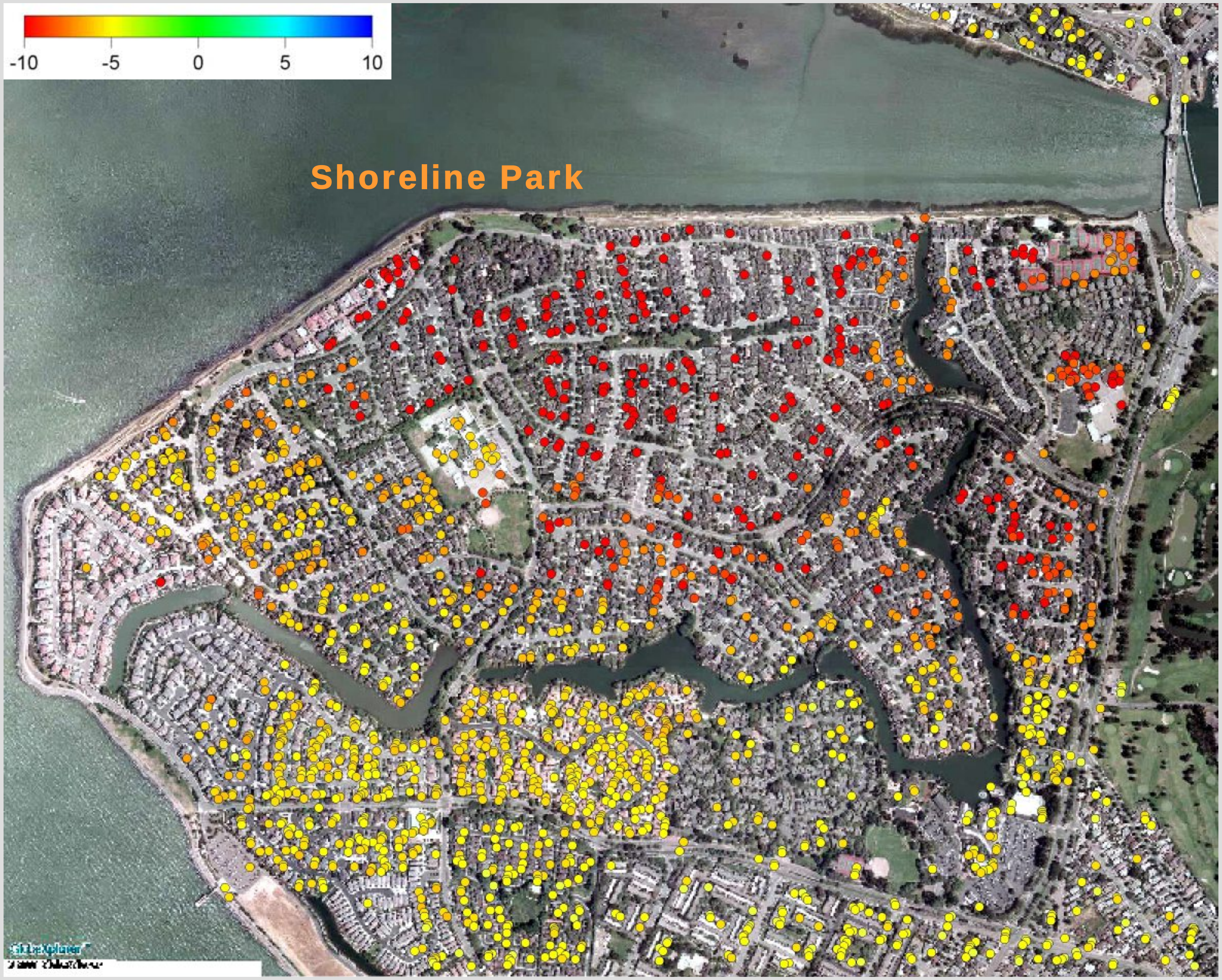
PSInSAR™ - SPSA





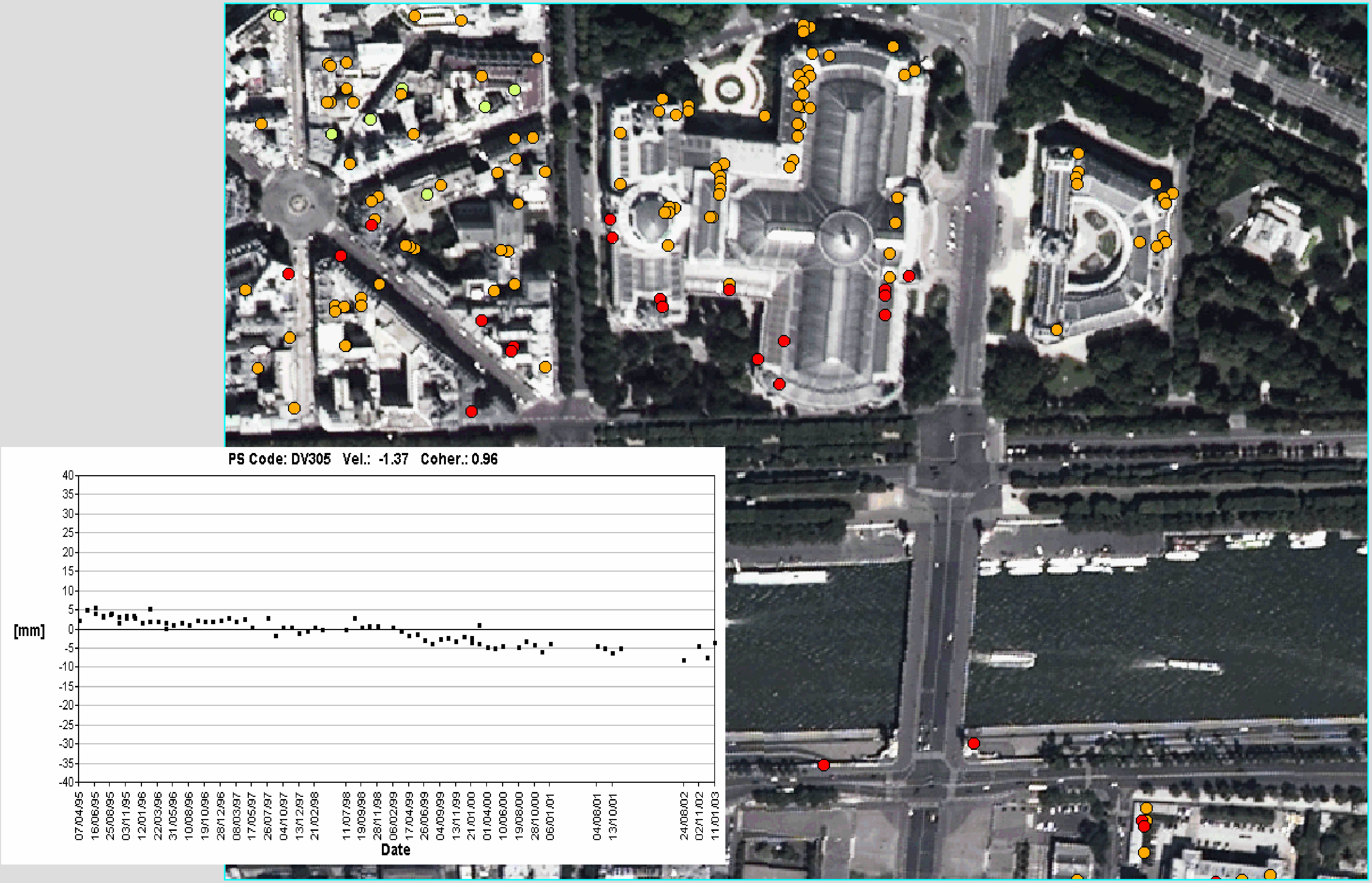
PSInSAR™ - APSA



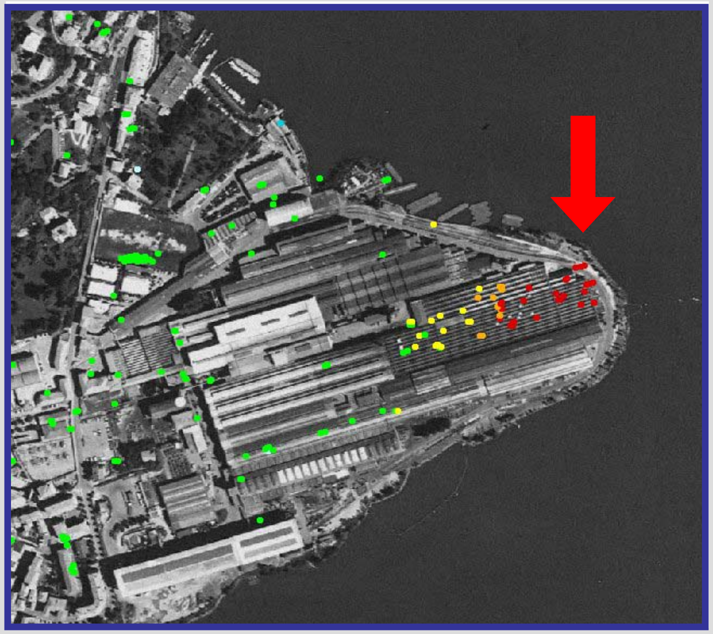


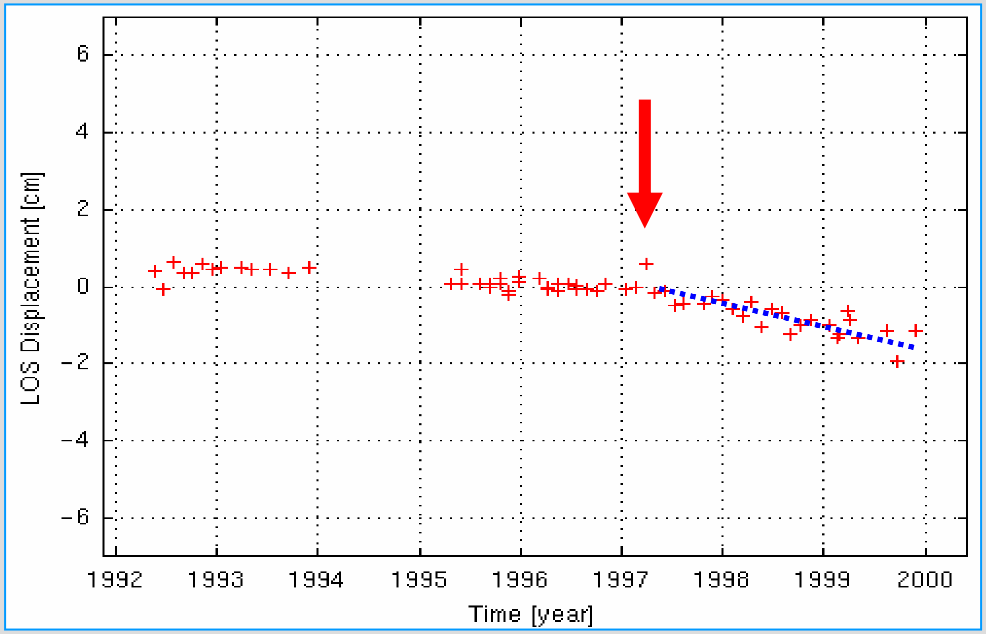
See demo:
www.treuropa.com

PSInSAR™ - APSA



PSInSAR™ - APSA



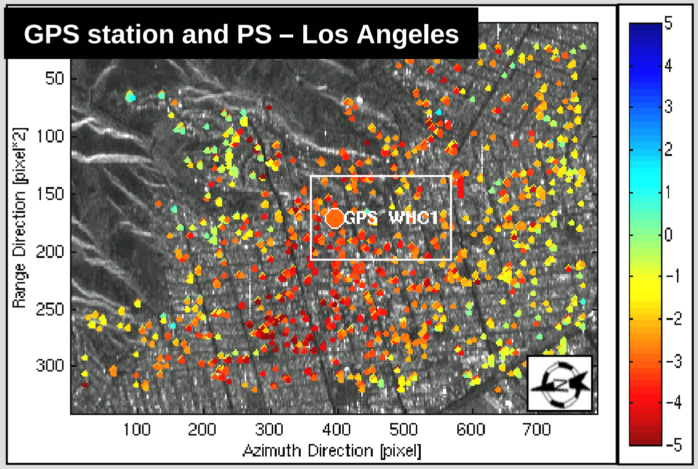


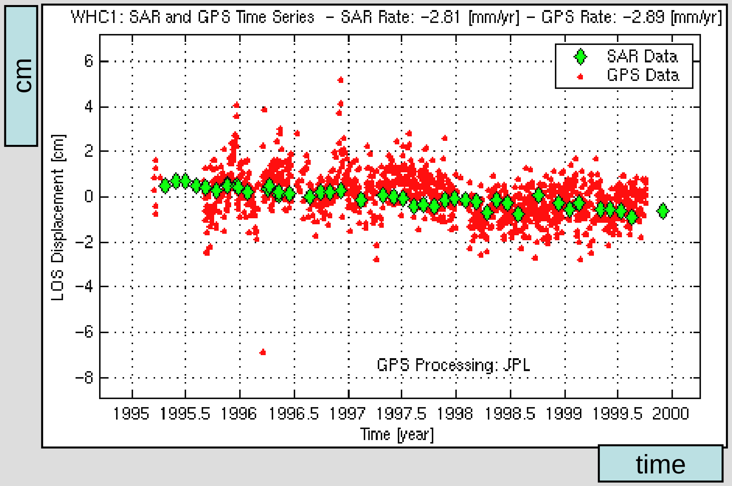
PS Data Validation

- How does PS InSAR compare with:
  - GPS
  - Optical methods
  - Thermal Dilation models (for buildings)

PS Data Validation

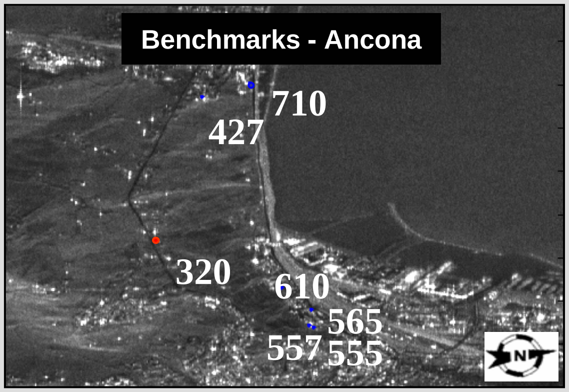
- PS InSAR vs. GPS

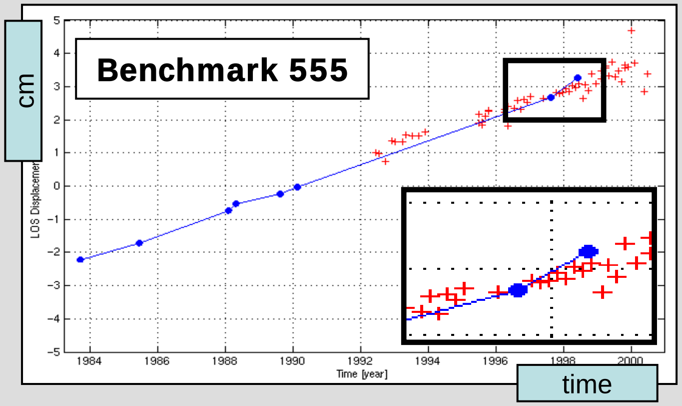




PS Data Validation

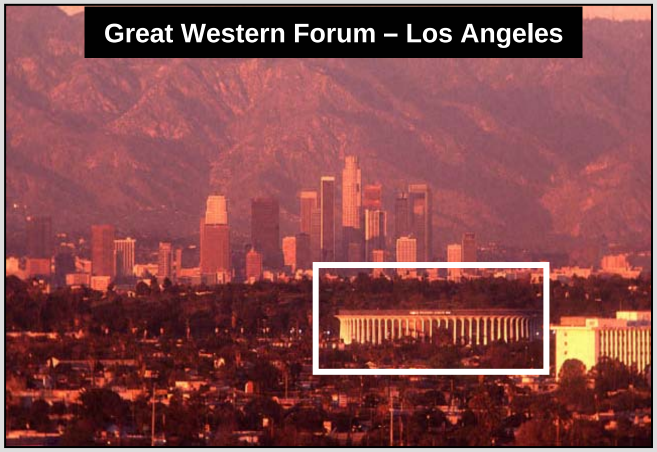
- PS InSAR vs. Optical Levelling

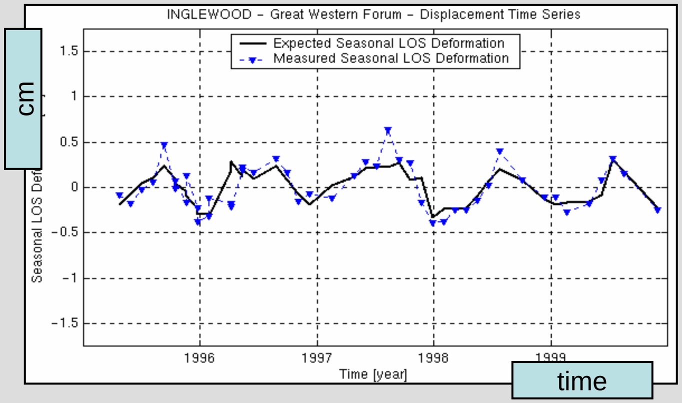




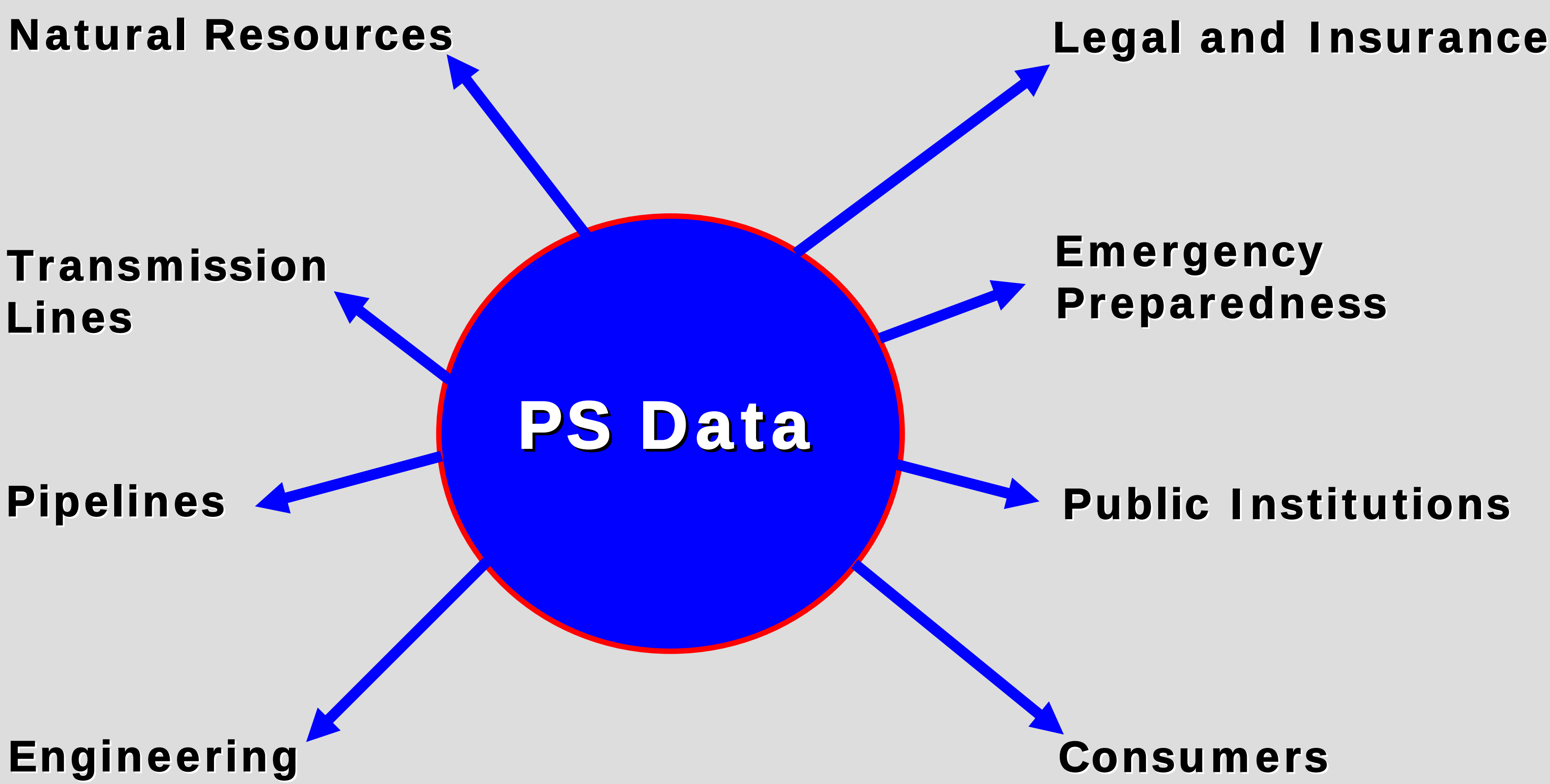
PS Data Validation

- PS InSAR vs. Thermal Dilation Models





Where can this Technology be used?



Applications

- Plate Tectonics & Volcanology

Applications – Plate Tectonics

Seismic Faults in Los Angeles Basin:

1. San Jose Fault
2. Raymond Fault
3. Whittier Fault
4. El Modeno and Peralta Hills Faults
5. Los Alamitos Fault
6. Newport - Inglewood Fault
7. Palos Verdes and Cabrillo Faults

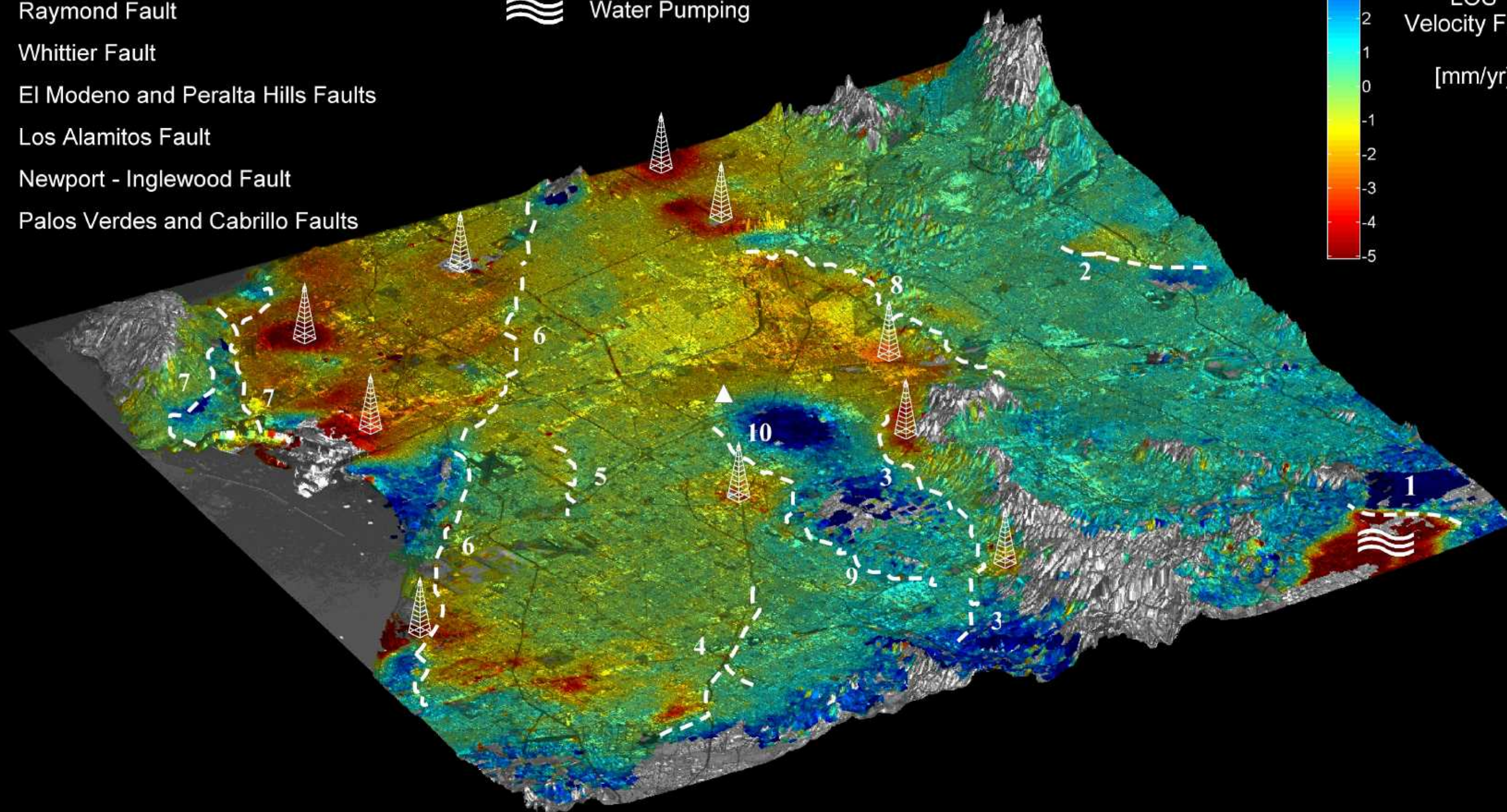
Subsidence Phenomena:

Oil & Gas Fields

Water Pumping

LOS Velocity Field [mm/yr]

5 4 3 2 1 0 -1 -2 -3 -4 -5



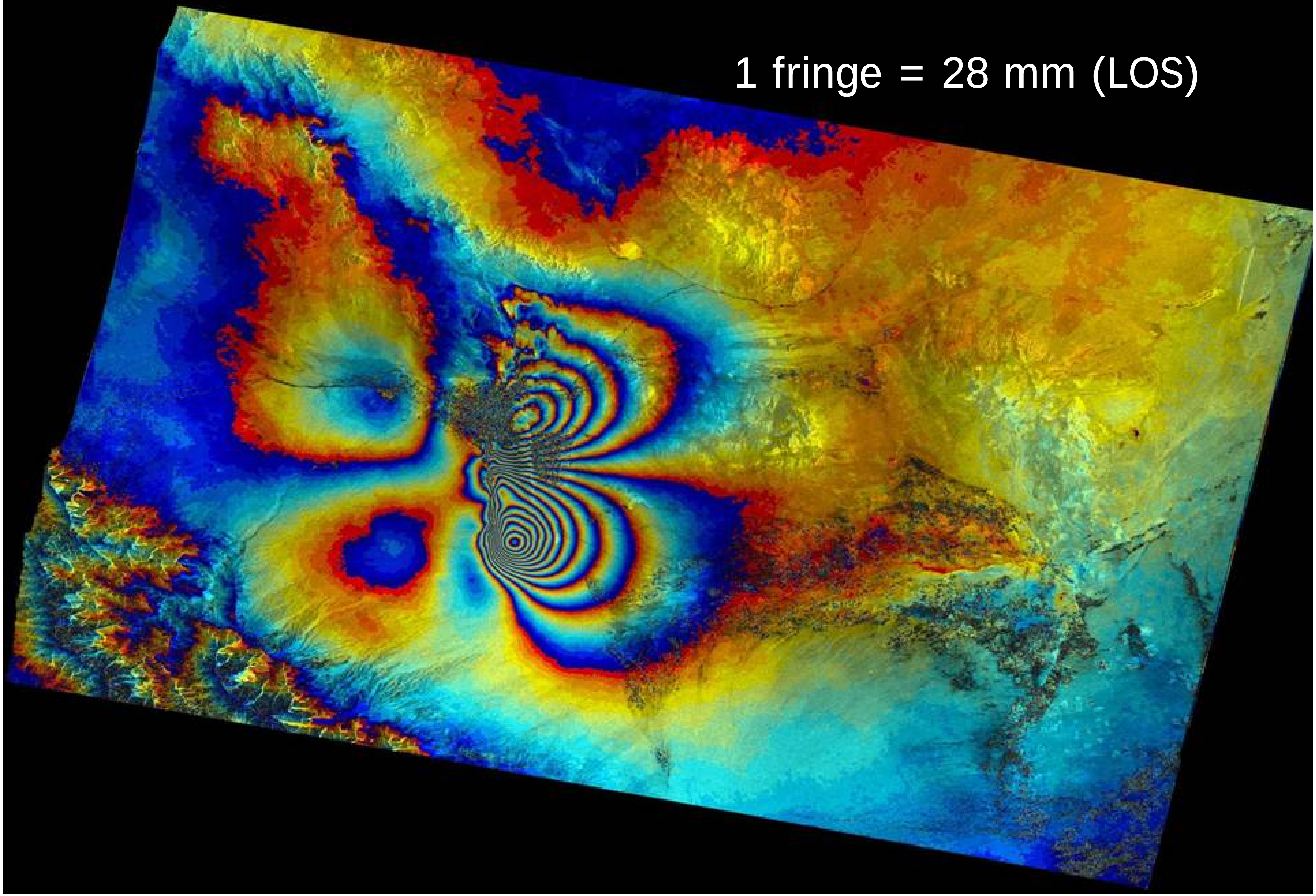
8. Elysian Park Blind Thrust (?)
9. Coyote Hills Blind Thrust (?)
10. Santa Fe Spring Blind Thrust (?)

Puente Hills Blind Thrust (?) (items 9–10)

Applications

- Earthquakes

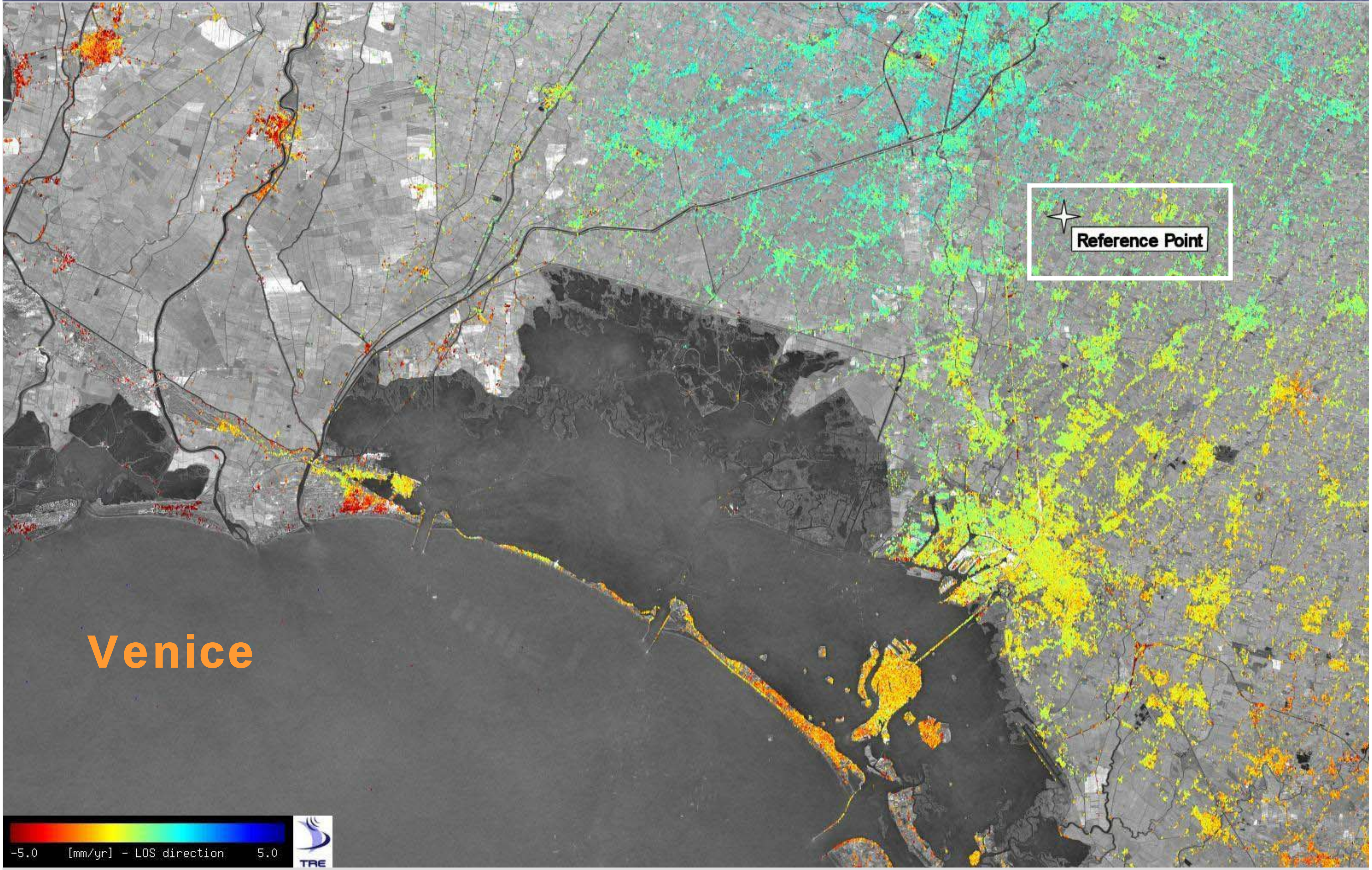
Applications – Earthquakes (BAM earthquake 2003)



Applications

- Subsidence

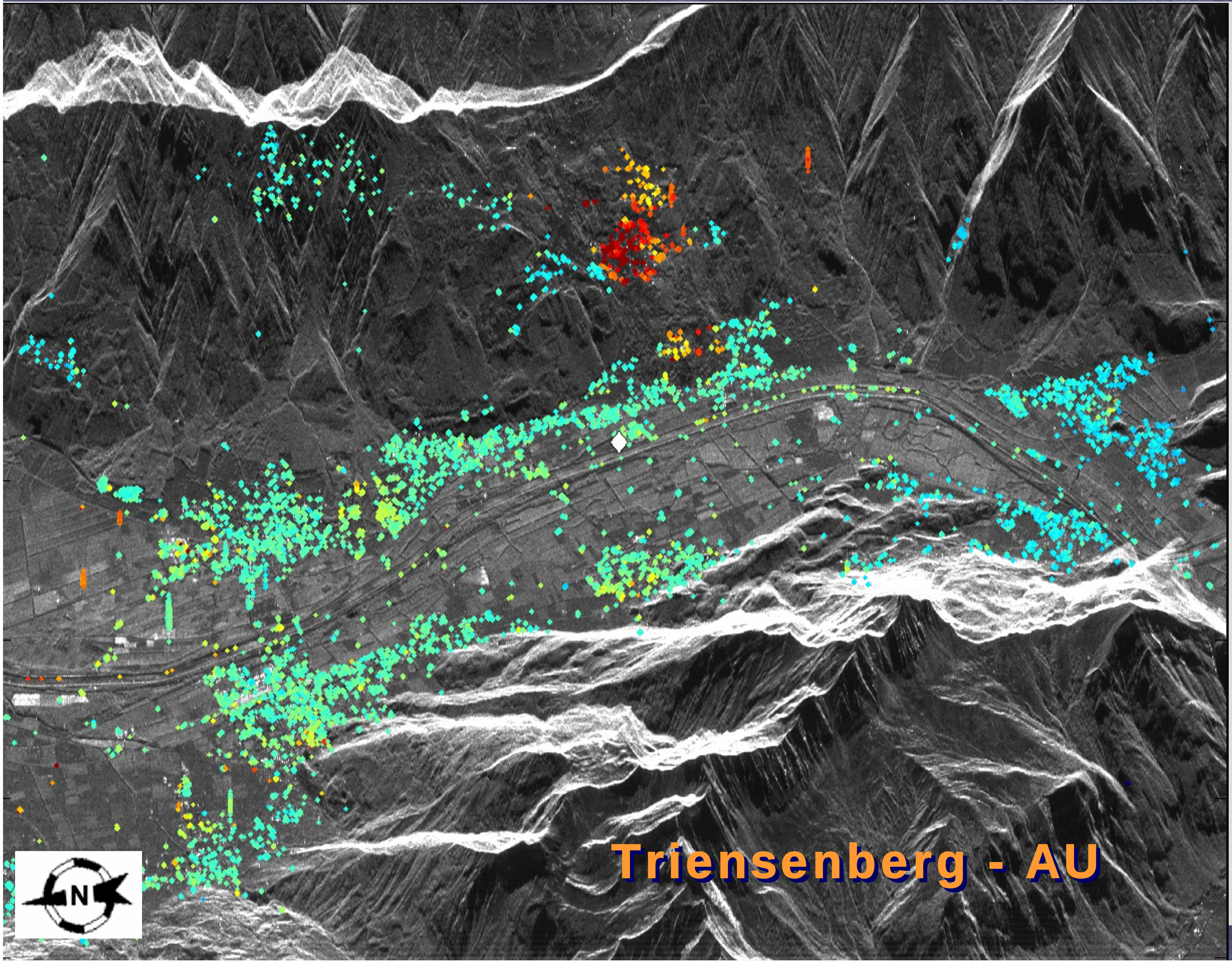
Applications - Subsidence



Applications

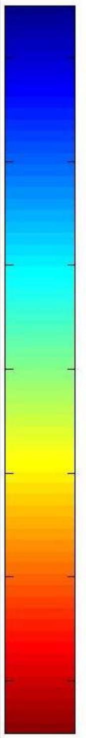
- Landslides

Applications - Landslides



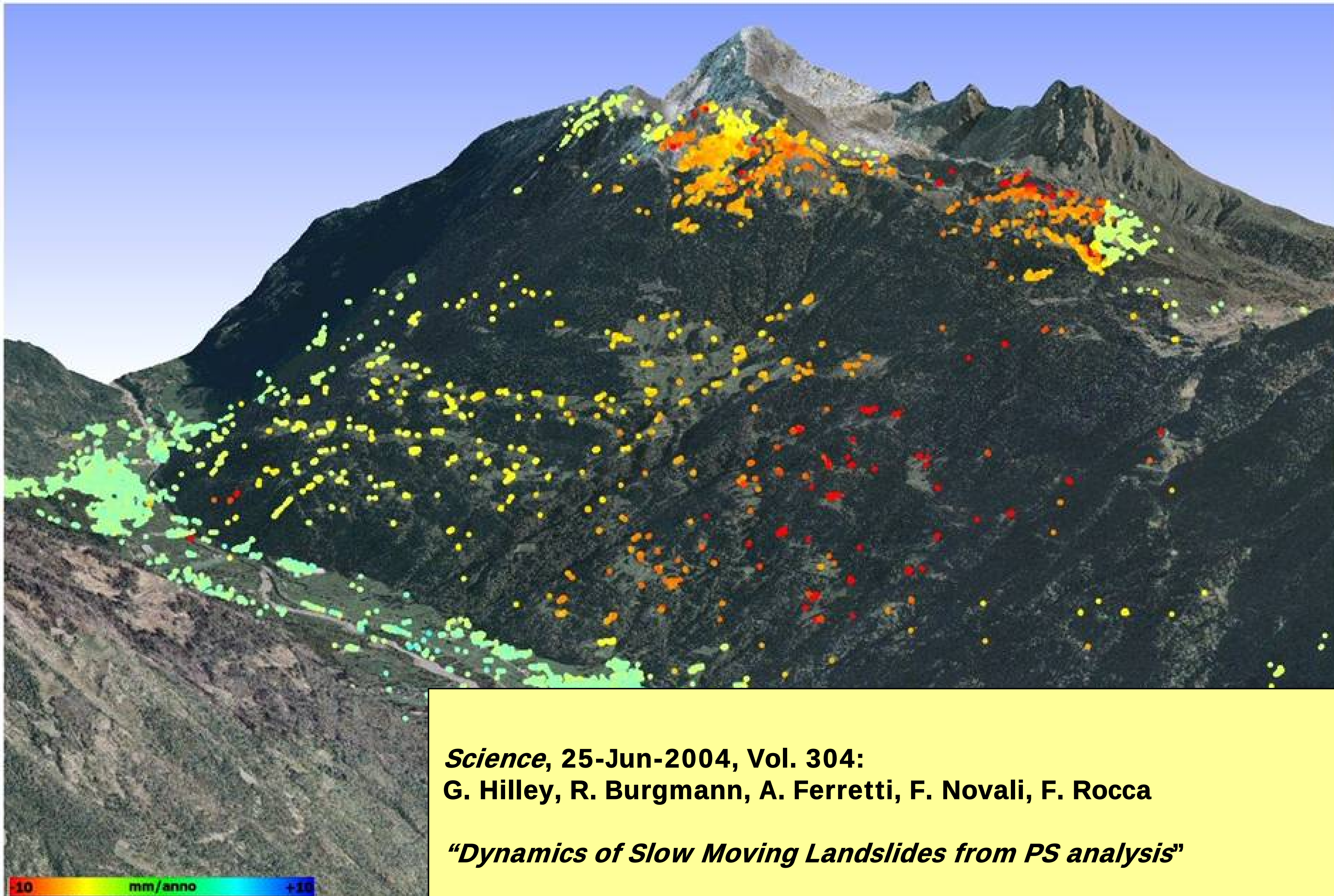
Average LOS velocity [mm/yr]

+7 [mm/yr]



-7 [mm/yr]

Applications – Landslides (Grosio, Italy)



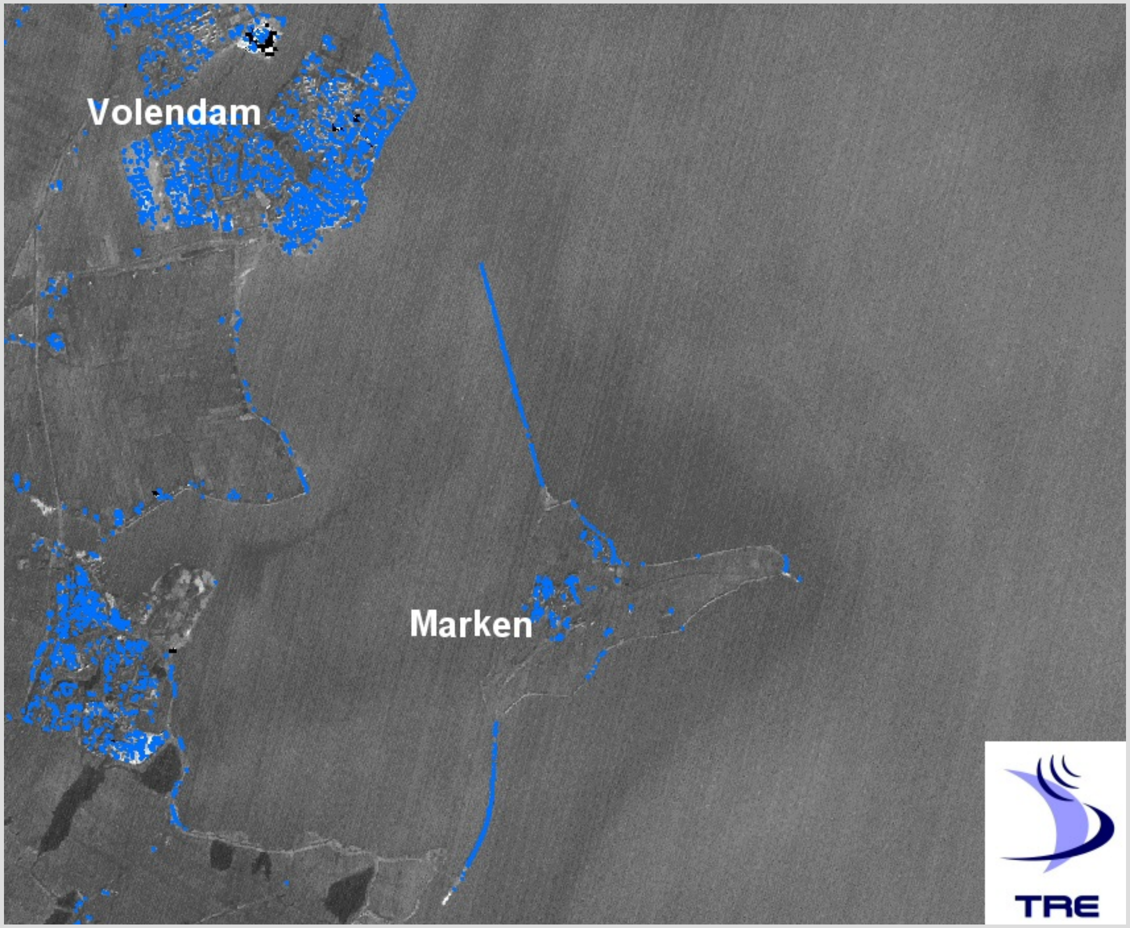
Science, 25-Jun-2004, Vol. 304:
G. Hilley, R. Burgmann, A. Ferretti, F. Novali, F. Rocca

"Dynamics of Slow Moving Landslides from PS analysis"

Applications

- Dams and Dikes

Dikes



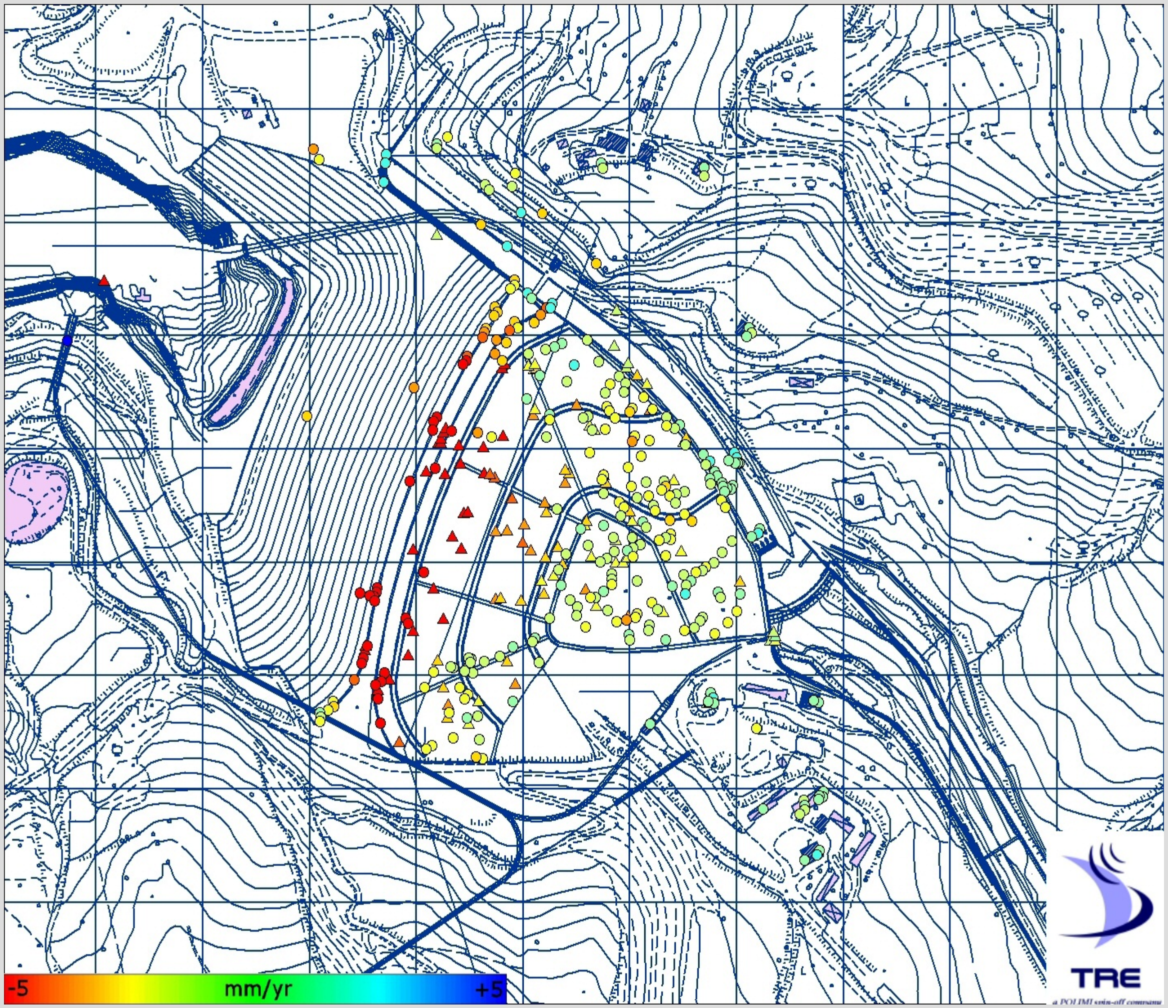
PS Position

Number of processed images:
91

Acquisitions time range:
April 6th 1992
September 25th 2002

Dams

Chiascio, Italy



PS Velocity Field

Number of processed images (descending dataset):
68

Acquisitions time range:
April 21st 1992
March 14th 2003

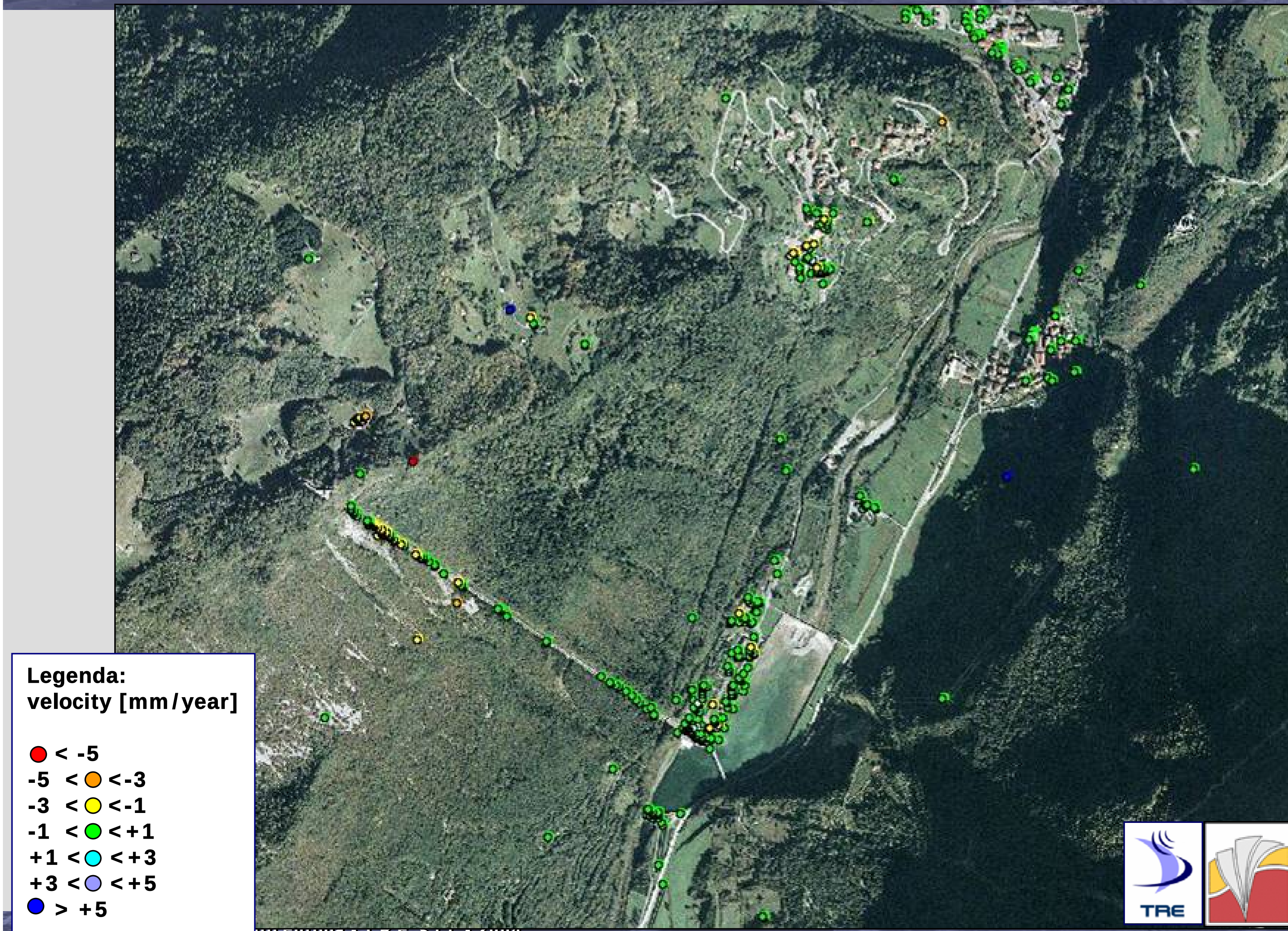
Number of processed images (ascending dataset)
31

Acquisitions time range:
June 30th 1992
May 5th 2003

Applications

- Pipelines

Pipeline Monitoring



Benefits

- Non-intrusive and non-destructive
- Ground control unnecessary
- Precise and reliable
- Cost effective
- Permits pro-active attention to instability problems
- Enables retroactive analysis back to 1992
- Adds value to the site investigation tool box

Limitations

- Sometimes we simply get no PS!
  Problems arise in vegetated and forested areas, steep topography, low-reflectivity targets (wood structures).

- Sometimes we cannot have all the data we need.
  The ERS-1 and -2 satellites have significant global coverage, but not everywhere. Radarsat archive is small.

- Today's satellites are not designed for PSInSAR.
  Image acquisitions for InSAR can sometimes be suborned to other 'priorities'.

- In general, existing phase unwrapping technology limits InSAR to SLOW deformation (<6 cm/yr in LOS).

Some Facts and Figures

If PS density > 5 PS/Km^2 and 12 ~ 15 radar images are available, PS InSAR can be applied

Precision of the deformation rate for a single PS is between 0.1 and 2.0 mm/year

Precision of each single PS deformation measurement is between 1 and 5 mm

TRE has processed:

- 7,000 SAR Images, representing
- 185,000 Km^2 using SPSA
- 15,000 Km^2 using APSA
- 5,000 Km^2 using FPSA