Continuous monitoring of surface deformation with satellite SAR sensors

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Outlines:

» Reason behind a slow InSAR uptake

» What is changing

» A continuous monitoring framework

» Case studies

» Conclusions
Why are InSAR Data Useful?

In a nutshell, InSAR data:

- Map the temporal evolution of ground displacements *(time-lapse analysis)*
- Enable a *wide-area* understanding of ground subsidence/uplift
- Spatial *density of measurements points* is usually orders of magnitude higher than any other “conventional” technique.
- Thanks to *historical archives*, whenever available, it is possible to quickly retrieve surface deformation data over remote areas where no *in situ* instrument has been installed.
- InSAR data are *complementary* to *in situ* observations, e.g. GPS-GNSS networks, optical levelling surveys, tiltmeters, etc.
Reasons behind a slow uptake

» No «sponsor»

No DoD behind InSAR

» The space segment

The first InSAR results from SEASAT were a somewhat unexpected, although extremely welcome, outcome. The first satellite sensor specifically designed for InSAR over large areas is Sentinel-1.

» Advanced algorithms:

It took time to understand how deal with phase information:

- the impact of atmospheric disturbances
- temporal decorrelation
Key factors for InSAR from experience

More than 20 years of InSAR analyses, obtained by processing data acquired by different radar sensors over different areas, have highlighted the key points for an operational use of this technology, namely:

- **Advanced processing algorithms:**
  ability to mitigate atmospheric power for time-series generation and visualization

- **Significant processing power:**
  necessary for a regular update over large areas

- **Regular acquisition over large areas:**
  importance of the right space segment
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From interferograms to TS analysis

Now multi-interferogram algorithms, such as SqueeSAR™, can identify coherent scatterers and filter out atmospheric noise. It is then possible to pass from qualitative displacement maps to databases of measurement points.
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It has been already proved that nowadays processing power make it possible to monitor wide areas through the processing of SAR data.

Cloud computing solution available nowadays allow to overcome processing limitation of standard in-house solution, making it possible to think even bigger!
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Historical Analysis

- **RADARSAT-1** (C-band)
- **ERS 1+2** (C-band)
- **Envisat** (X-band)

Monitoring

- **TerraSAR-X** (X-band)
- **Cosmo-SkyMed** (C-band)
- **ALOS** (L-band)
- **ALOS-2** (L-band)
- **RADARSAT-2** (X-band)
- **Sentinel** (6-12 days)

Revisit time (days)

- **RADARSAT-1**: 24 days
- **ERS 1+2**: 35 days
- **Envisat**: 35 days
- **ALOS**: 45 days
- **ALOS-2**: 14 days
- **Sentinel**: 6-12 days
- **TerraSAR-X**: 11 days
- **Cosmo-SkyMed**: 8 days

**SAR Satellites**

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Present Day

Future
Sentinel-1A/B: The «Game Changer»

- C-band – **Specifically designed for InSAR!**
- **Large swath**
- 6-12 days repeat cycle
- Regular **free** InSAR acquisitions
Now the technology is mature enough to exploit the Sentinel radar to create a national database of terrain movements. It can be extremely useful, for Civil Protection authorities, to characterize and address areas prone to risk based on homogeneous and reliable measurements.

Each year

126 People .................casualties
7000 People ...............displaced
0.5% PIL ..................is lost

* National landslide risk map
Continuous monitoring work flow

Automatic Processing

Download
Storage
SqueeSAR analysis
Results

TRE ALTA Mira

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Large areas monitoring at full resolution

Analysis of wide areas, at a national scale, without losing resolution
Every day the SqueeSAR analysis over millions of points is updated over different areas and delivered to the final user.

It will be impossible, for the final user, to check every new update all the delivered time-series. It necessary to highlight every new update the points where something has changed, based on the criteria agreed with the final user.
All delivered time-series, at each update, are processed to identify measurement point to highlight to the final user.
The work-flow previously described make it possible to automatically update the SqueeSAR analysis over wide areas at each new acquisition.

The objective is to provide a monitoring tool able to highlight, to the final users, areas prone to risk within the area of interest.

For some specific applications, which require higher accuracy, this analysis can provide the identification of the areas which deserve a more detailed analysis using:

- in situ instruments (GPS, total station, etc.)
- use of X-band data for better geocoding and measurement accuracy

In last case the same continuous monitoring work-flow can be adopted using as input data X-band InSAR data.
Case Study: Regione Toscana

Revisiting time: 6 days

First application of PS-InSAR Continuous Streaming at regional scale (2016)
Sentinel ascending + descending
(Oct. 2016)

First application of PS-InSAR
Continuous Streaming at regional scale (2016)
Trend change detection
12 days
Trend change detection

**BQHBSSU** - deformation rate: 5.15 - deformation rate standard deviation: 1.80 - coherence: 0.91

**BQ60KDJ** - deformation rate: 7.97 - deformation rate standard deviation: 2.00 - coherence: 0.91

Velocità media [mm/anno]

Temperature variation

TS TREND VARIATION
Warning bulletin

Periodo di riferimento dal 16/02/2017 al 28/02/2017

Anomalie nelle deformazioni del suolo all'interno del territorio comunale
- Almeno una anomalia
- Almeno una anomalia persistente e rilevante
- Almeno una anomalia persistente
- Almeno una anomalia
- Nessuna anomalia

Comuni con anomalia persistente e rilevante:
- Pescaglia (LU)
- Pistoia (PT)

Nessuna anomalia
Case study: Milano sewer system

High resolution continuous monitoring to detect displacement anomalies related to pipeline failure
In general, the growth rate of InSAR applications will depend on:

space segment:
- # of available data sources
- data Redundancy, Consistency and Predictability (important to guarantee interferometric “consistency” among different Sentinel processor releases and improve data-hub access and download)
- acquisition policies (double geometry data!) –
- satellite repeat cycle

quality and maturity of InSAR products and services;

Why things may change:
InSAR data have been validated (>100 papers comparing InSAR vs GPS-GNSS or levelling data)
- Growing awareness about the potential of InSAR data
- Algorithms are much more reliable compared to 10 years ago
- Growing number of SAR sensors (Sentinel-1, PAZ, CSK2, NISAR..)

Where are we going:
- InSAR is already an operational monitoring tool and is becoming more and more accepted as a tool for risk mitigation and prevention at national scale.
THANKS!