Sensing urban dynamics with COSMO-SkyMed Persistent Scatterer Interferometry in Naples, Italy

Advances in the Science and Applications of SAR Interferometry and Sentinel-1 InSAR
Sensing urban dynamics with COSMO-SkyMed Persistent Scatterer Interferometry in Naples, Italy

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Overarching objectives

>> Utilise a 300+ SAR image-long stack to depict deformation processes within a large and densely populated city

>> Test new approaches to analyse “Big InSAR data”

>> Exploit Web Data Mining: newspapers & social networks
Big InSAR data

...the 4+ Vs of Big Data!

**SAR** → - TB of input data available for most areas of the Earth’s surface
- Need for HW and SW capable to efficiently process the data
- Lots of different sensors, modes, resolutions, formats

**InSAR** → - Datasets of thousands or millions of deformation time series
- SW requirements for data handling and manipulation
- Quality check to ensure the data are precise and accurate

Area of interest

Geological setting

UNESCO WHL site
- Buffer Zone
- Core Area

Urban sinkholes and collapses (since 1990)
[not exhaustive inventory]

Geology 1:50,000

European Space Agency
Key assets: cultural and natural heritage

Maschio Angioino (Castel Nuovo)

San Francesco di Paola Church

Royal Palace

Phlegraean Fields
Urban sinkholes and collapses
Existing satellite InSAR studies

Historical data and more recent studies (1990s, 2000s & 2010s)

ERS/ENVISAT (1993-2010)

COSMO-SkyMed (2009-2011)

Sentinel-1A (2014-2015)

Sansosti et al. 2014
Int. J. Applied EO and Geoinformation

Contains Copernicus data (2015)/ESA/IREA-CNR

Copernicus data (2015)/ESA/DLR Microwaves and Radar Institute/INGV/e-GEOS/GFZ-SEOM INSARAP study
Our input data

# scenes: 316
Mission: COSMO-SkyMed
Mode: StripMap HIMAGE, HH pol.
Orbits: ascending
Period: 16/12/2008 - 03/08/2014
Revisit: 6 days (average), 8 days (mode)

COSMO-SkyMed data grant UNIBAS Fenomeni Geofisici
Big data processing approach

SARProz
SAR PROcessing tool by periZ

Persistent Scatterer Interferometry

Luo et al. 2014
Remote Sensing
Annual motion rates

LOS velocity [mm/year]

-50.42 - 20.00
-19.99 - 10.00
-9.99 - 2.50
-2.49 - 2.50
2.51 - 10.00
10.01 - 20.00
20.01 - 34.09

411,581 PS → 8,400 PS/km²

-0.01 ± 3.46 mm/year
Land cover characterisation

Urban Atlas

- High-resolution land cover information based on SPOT-5 imagery
- Reference dates: 2006 & 2012
- $\bar{\delta}_x$: mean PS density for class $x$
Land cover characterisation

Density outliers: 
\[ \delta_i - \bar{\delta}_x > \pm \sigma_{\delta_x} \]

Identified causes:
- Engineering works
- Land use changes
- Collapses/urban sinkholes

\[ \Delta \delta_i = \frac{\delta_i - \bar{\delta}_x}{\sigma_{\delta_x}} \]

\( \delta_i \): density in parcel \( i \)

\( \delta_x \): compared with the corresponding \( \bar{\delta}_x \), and normalised to \( \sigma_{\delta_x} \)
Identification of non-linear trends

PS-Time tool

Identification of non-linear trends

<table>
<thead>
<tr>
<th>Type</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrelated</td>
<td>66,405</td>
<td>16%</td>
</tr>
<tr>
<td>Linear</td>
<td>22,007</td>
<td>5%</td>
</tr>
<tr>
<td>Quadratic</td>
<td>18,318</td>
<td>4%</td>
</tr>
<tr>
<td>Bilinear</td>
<td>212,582</td>
<td>52%</td>
</tr>
<tr>
<td>Disc. with constant velocity</td>
<td>30,266</td>
<td>7%</td>
</tr>
<tr>
<td>Disc. with variable velocity</td>
<td>62,003</td>
<td>15%</td>
</tr>
<tr>
<td><strong>TOT</strong></td>
<td>411,581</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Initial assessment**

- The distribution of annual periodicity appears correlated with geotechnical zoning of Napoli municipality area
- Deformation trends correlate well with both geological units and geotechnical properties
Hotspot #1: Riviera di Chiaia

Palazzo Guevara del Bovino
04/03/2013

13/09/2007

19/06/2013
Hotspot #1: Riviera di Chiaia

Web data mining: Newspapers & social networks
Hotspot #1: Riviera di Chiaia

LOS velocity [mm/year]
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SAR amplitude time series

Before the collapse

Collapse + Consolidation works
Building classification indices

$I_{ci}$: Completeness of Information Index

Expressing the degree of PS coverage over a building, i.e. how many PS fall over the building compared with the average density of the whole dataset.

<table>
<thead>
<tr>
<th>PS coverage grade (object area), partial score</th>
<th>PS coverage grade (surrounding area), partial score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (PS/m²)</td>
<td>&gt; D₀</td>
</tr>
<tr>
<td>Partial score</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Max velocity rating

Maximum velocity observed for each building, classified according to an A to E rating.

<table>
<thead>
<tr>
<th>PS maximum LOS velocity value - object area</th>
<th>Object conservation criticality index - $I_{oc}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_{max}$ ($mm$/yr)</td>
<td>Displacement trend</td>
</tr>
<tr>
<td>≤ 1.5</td>
<td>Linear</td>
</tr>
<tr>
<td>&gt; 1.5</td>
<td>&gt; 2.0</td>
</tr>
<tr>
<td>Class</td>
<td>Velocity distribution index - $I_{vd}$</td>
</tr>
<tr>
<td>A</td>
<td>Linear</td>
</tr>
<tr>
<td>B</td>
<td>Acceleration</td>
</tr>
<tr>
<td>C</td>
<td>&quot;t&quot; superscript</td>
</tr>
<tr>
<td>D</td>
<td>no superscript</td>
</tr>
<tr>
<td>E</td>
<td>&quot;d&quot; subscript</td>
</tr>
</tbody>
</table>

Mapping interactions between geology, subsurface resource exploitation and urban development in transforming cities using InSAR Persistent Scatterers: Two decades of change in Florence, Italy

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Hotspot #2: Historic buildings

Key assets
1 = San Francesco di Paola Church
2 = Royal Palace
3 = San Carlo Theathre
4 = San Ferdinando Church
5 = Castel Nuovo (Maschio Angioino)
6 = Galleria Umberto I
7 = Santa Brigida Church
8 = Augusteo Theatre

LOS velocity [mm/year]
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- 2.51 - 10.00
- 10.01 - 20.00
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Max velocity rating
A Stable (V < 2.5 mm/yr)
B Medium (2.5-10 mm/yr)
C High (10-20 mm/yr)
D Very high (> 20 mm/yr)
Hotspot #2: Historic buildings

Maschino Angioino (Castel Nuovo)

- Unstable tower (?): a few PS with non-linear trend (bilinear and discontinuous with variable velocity)
- Engineering works for the construction of the underground?

Royal Palace

- In July 2014 some blocks detached from the western facade ($V_{LOS}$ up to -10 mm/year)
- Neoclassical Hall: $V_{LOS}$ up to -6 mm/year
Conclusions & future perspectives

- High-resolution data processing of densely urbanised areas can result in thousands or even millions of PS targets (even > 15,000 PS/km$^2$)

- Data handling and analysis of such datasets pose huge challenges for InSAR data interpreters and end users

- Naples has acted as testing ground for such a **Big InSAR data** analysis approach, enhancing the need to implement post-processing steps to “screen” the data

- Sentinel-1, COSMO-SkyMed and other SAR constellations are building SAR archives consisting of over 100, 200, 300+ images per frame

- The role of semi-automated tools, screening methods and web data mining for the analysis and interpretation of these data becomes vital
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Italian Space Agency, ASI

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