Spaceborne SAR anatomy of a city

D. Perissin, A. Ferretti, C. Prati
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Outline of the presentation

From the available ERS-Envisat radar measurements we can get information on the PS:

- 3D positioning
- Back-scattering pattern
- Back-scattering mechanism

Starting from this information PS’s can be divided into different classes

- Gratings
- Roofs
- Dihedrals
- Poles
- Trihedrals

Examples of PS in Milano
Spaceborne SAR anatomy of a city

Motivations

1) Interpretation of deformation measurements [Ketelaar, Hanssen, Fringe '03].

2) Prediction of targets visible from parallel tracks, ascending and descending passes, different frequencies-polarizations.

3) Identification/reproduction of structural details of buildings that behave as PS.
PS information (1)

3D position

(presented on Monday 28: “Urban DEM”)

30% at ground level
PS information (2)

Scattering pattern

Radar signal amplitude vs. acquisition geometry.

**Trihedral**

- Low directivity in all directions
  - $L_x=0$, $L_y=0$

**Dihedral**

- High directivity in edge direction
  - $L_x=0$, $L_y$

**Mirror**

- High directivity in all directions
  - $L_x$, $L_y$
Amplitude example 1

RCS: 27000sqm, Fit: 0.92, Point: 1/1, Trihedral

- Range [pixel/4]
  - 2 4 6 8 10
  - 0.5 1 1.5 2 2.5

- Azimuth [pixel]
  - 0 2 4 6 8 10
  - ~0.6°

- Amplitudes
  - xRange Pointing: -900m, xRange Width: 0m
  - Normal Baseline [m]
  - From: 1992.5, To: 2004.6, ktemp: 0.1e-2 [°C⁻¹]

- Amplitudes
  - Doppler Centroid [Hz/PRF]
  - Temporal Baseline [years]
  - ~3°
Amplitude example 2

RCS: 2300sqm, Fit: 0.92, Point: 2/2. Mirror

Azimuth Pointing: 0.1Hz/PRF, Azimuth Width: 4m

xRange Pointing: 800m, xRange Width: 0m

From: 1992.5, To: 2004.5, ktemp: 0.0e-2 [°C^{-1}]
Amplitude example 4

RCS: 28000sqm, Fit: 0.87, Point: 14/16, Roof

xRange Pointing: 200m, xRange Width: 11m

Azimuth Pointing: -0.1Hz/PRF, Azimuth Width: 3m

From: 1995.4, To: 1999.7, ktemp: 0.3e-2 [°C⁻¹]
PS information (2)

Scattering pattern

Estimated parameters histograms

- **Range width**
  - 20% of PS’s

- **Azimuth width**
  - 15% of PS’s

- **Birth date**
  - 15% of PS’s

- **Death date**
  - 3% of PS’s
PS information (2)

Scattering pattern

Radar signal amplitude vs. temperature.

The pointing of a Bragg scattering target depends on the distance between the elements. Thermal dilation can modify the pointing of a Bragg scattering target. For a metal horizontal Bragg scattering target 30°C are equivalent to ~300m of normal baseline.

30% of PS’s have temperature-dependent amplitude variations.
Amplitude example 3

RCS: 750000sqm, Fit: 0.79, Point: 2/5, Grating

Azimuth Pointing: 0.1Hz/PRF, Azimuth Width: 5m

From: 1992.5, To: 2004.6, ktemp: 2.4e-2 [°C⁻¹]
PS information (3)
AP auto-interferogram

<table>
<thead>
<tr>
<th>Odd bounces</th>
<th>HH phase</th>
<th>VV phase</th>
<th>Interferometric phase</th>
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<tbody>
<tr>
<td>(e.g. mirrors)</td>
<td><img src="image1" alt="HH phase diagram" /></td>
<td><img src="image2" alt="VV phase diagram" /></td>
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<table>
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<tr>
<th>Even bounces</th>
<th>HH phase</th>
<th>VV phase</th>
<th>Interferometric phase</th>
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</thead>
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<td>(e.g. dihedrals)</td>
<td><img src="image3" alt="HH phase diagram" /></td>
<td><img src="image4" alt="VV phase diagram" /></td>
<td>±π</td>
</tr>
</tbody>
</table>

Objects on the ground have more probability to be dihedrals.

At high elevations odd bounces dominate.

70% of PS’s have a reliable AP phase.
Target typology 1: gratings

Target typology 1: gratings ~ 10% of PS’s in Milano

PS Type: Grating
Coherence: 0.94
Av. def. trend: -1 [mm/years]
Height: +0 [m]
K temp-phase: +0.02 [rad/°C]
AP phase VV-HH: +1.5 [rad]
AP ampl. dev.: 0.3
RCS: 12000 [m²]
Fitting index: 0.80
K temp-ampl.: -1.0e-2 [°C⁻¹]
Ton: 1992.5 [years]
Toff: 2004.5 [years]
Range width: 6 [m]
Azimuth width: 6 [m]
Range pointing: -900 [m]
Azimuth pointing: +0.5 [Hz/PRF]
Target typology 2: roofs

~ 50% of PS’s in Milano

PS Type: Roof
Coherence: 0.97
Av. def. trend: -2 [mm/years]
Height: +38 [m]
K temp-phase: +0.09 [rad/°C]
AP phase VV-HH: +0.5 [rad]
AP ampl. dev.: 0.3
RCS: 47000 [m²2]
Fitting index: 0.91
K temp-ampl.: -4.0e-2 [°C⁻¹]
Ton: 1992.5 [years]
Toff: 2004.6 [years]
Range width: 14 [m]
Azimuth width: 6 [m]
Range pointing: +100 [m]
Azimuth pointing: +0.0 [Hz/PRF]
Target typology 3: dihedrals

Looking direction

~ 20% of PS’s in Milano

PS Type: Dihedral
Coherence: 0.95
Av. def. trend: -1 [mm/years]
Height: +1 [m]
K temp-phase: +0.01 [rad/°C]
AP phase VV-HH: -2.4 [rad]
AP ampl. dev.: 0.0
RCS: 16000 [m²]
Fitting index: 0.91
K temp-ampl.: +0.0e-2 [°C⁻¹]
Ton: 1992.5 [years]
Toff: 2004.6 [years]
Range width: 0 [m]
Azimuth width: 5 [m]
Range pointing: +300 [m]
Azimuth pointing: +0.0 [Hz/PRF]
Target typology 3: dihedrals

Target visible from different parallel tracks

Parallel orbits

Dihedral

~3°

~40km

~40km
Target typology 3: dihedrals

Target visible from different parallel tracks
Target typology 4: poles

~ 10% of PS’s in Milano

Target visible from different parallel tracks, ascending and descending passes.

PS Type: Pole
Coherence: 0.86
Av. def. trend: -2 [mm/years]
Height: +1 [m]
K temp-phase: +0.02 [rad°C]
AP phase VV-HH: +3.1 [rad]
AP ampl. dev.: 0.3
RCS: 160 [m²]
Fitting index: 0.69
K temp-ampl.: +0.0e-2 [°C⁻¹]
Ton: 1996.8 [years]
Toff: 2004.6 [years]
Range width: 4 [m]
Azimuth width: 0 [m]
Range pointing: +600 [m]
Azimuth pointing: +2.9 [Hz/PRF]
Target typology 4: poles

Target visible from different parallel tracks, ascending and descending passes.
Target typology 4: poles

Exploited for geolocating different parallel tracks, ascending and descending passes.
Target typology 5: trihedrals

~ 8% of PS's in Milano

PS Type: Trihedral
Coherence: 0.98
Av. def. trend: -1 [mm/years]
Height: +2 [m]
K temp-phase: -0.00 [rad/°C]
AP phase VV-HH: -0.7 [rad]
AP ampl. dev.: 0.2
RCS: 54000 [m²]
Fitting index: 0.89
K temp-ampl.: +0.0e-2 [°C-1]
Ton: 1992.5 [years]
Toff: 2004.6 [years]
Range width: 3 [m]
Azimuth width: 0 [m]
Range pointing: -700 [m]
Azimuth pointing: +2.1 [Hz/PRF]
The developed tool for target analysis
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Conclusions

Exploiting the following radar measurements

- PS positioning
- Target back-scattering pattern
- ENVISAT AP auto-interferogram

we have characterized urban SAR PS in 5 targets typologies:

- Gratings
- Roofs
- Dihedrals
- Poles
- Trihedrals

allowing the interpretation of deformation measurements and the identification of multi-sensor targets.
## First classification

<table>
<thead>
<tr>
<th></th>
<th>$L_x$</th>
<th>$L_y$</th>
<th>$\phi_{AP}$</th>
<th>$RCS$</th>
<th>$k_T$</th>
<th>$h$</th>
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<td>+</td>
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<td>+</td>
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<tr>
<td>Grating</td>
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<td>+</td>
<td>0</td>
<td>$\propto s_0L_xL_y$</td>
<td>+</td>
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<tr>
<td>Dihedral</td>
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