Mid-term review results of the ESA STSE Pathfinder CHARMING project (Constraining Seismic Hazard Models with InSAR and GPS)


(1) INGV, (2) IREA, (3) ESA/ESRIN
Outline

• Project context
  – Probabilistic Seismic Hazard (PSHA)
  – Areas of interest
• Data availability (SAR and GPS)
• Deformation measurements
• Modelling results (preliminary)
  – Earthquake rates & PSHA
• Discussion and conclusions
Typical PSHA outputs show values of shaking parameters (e.g. H-PGA) which, at a given confidence level, have a 90% probability of NOT being exceeded during a specified time frame.
PSHA steps: where does geodesy come in?

- PSHA steps (Reiter, 1991 – after TERA corporation, 1978)
  - Generate interseismic surface deformation maps for SAR and GPS
  - Incorporate interseismic deformations in recurrence relation derivation
  - State-of-the-art PSHA modelling
CHARMING workflow

- SAR LoS deformation
- GPS deformation
- Tectonic signal discrimination
- Earthquake rate modelling
- PSHA modelling
Areas of Interest

Focus on Central Apennines (Italy)

- High fault density and seismic risk
- Good availability of SAR and GPS data
- Developed approaches can be exported to other contexts

2\textsuperscript{nd} invariant of strain tensor (Riguzzi et al., 2012)
GPS networks
SAR data (ERS and ASAR desc.)

ERS-1/2
ENVISAT
SAR data (ERS and ASAR asc.)

ERS-1/2
ENVISAT
SAR data (ALOS PALSAR asc.)
SAR LoS measurements

• StaMPS
  – Used for all datasets
  – Combined PS/SB method found to work best for all tracks
  – Quadratic ASAR LO drift compensation applied
  – No “ramp removal”, no atmospheric compensation

• SBAS
  – Carried out at IREA for one track (ASA-DES-T308)

• ISBAS
  – Investigated for potential coverage increase
Standard processing results 1/2
(best of tens of processing runs)

StaMPS ASA-DES-T308  StaMPS ASA-DES-T036  StaMPS ASA-ASC-T129

Reference area (1 km radius around a GPS station)
Standard processing results 2/2
(best of tens of processing runs)

**SAR vs GPS**

<table>
<thead>
<tr>
<th>Method</th>
<th>R</th>
<th>Std. Dev. (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>StaMPS T308</td>
<td>-0.4</td>
<td>6.0</td>
</tr>
<tr>
<td>SBAS T308</td>
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<td>2.0</td>
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<tr>
<td>StaMPS T036</td>
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<tr>
<td>ISBAS T129</td>
<td>0.3</td>
<td>2.1</td>
</tr>
</tbody>
</table>

SBAS ASA-DES-T308

ERS+ASA-ASC-T129
GPS calibration

Uncalibrated

Global calibration

Piecewise calibration

Calibration based on LoS-projected GPS
SAR vs. GPS LoS (T036)

Uncalibrated

STD = 3.3 mm/yr
R = 0.1

Global calibration

STD = 1.0 mm/yr
R = 0.73

Piecewise calibration

STD = 0.8 mm/yr
R = 0.87
### LoS SAR vs GPS comparisons

<table>
<thead>
<tr>
<th></th>
<th>Ngps</th>
<th>Standard Deviation (mm/yr)</th>
<th>R</th>
</tr>
</thead>
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<td></td>
<td></td>
<td>Uncal.</td>
<td>Global</td>
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<tr>
<td>StaMPS T308</td>
<td>13/21</td>
<td>6.3</td>
<td>1.9</td>
</tr>
<tr>
<td>SBAS T308</td>
<td>26/36</td>
<td>2.0</td>
<td>1.9</td>
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<tr>
<td>StaMPS T036</td>
<td>25/30</td>
<td>3.3</td>
<td>1.0</td>
</tr>
<tr>
<td>StaMPS T129</td>
<td>27/38</td>
<td>4.4</td>
<td>1.4</td>
</tr>
<tr>
<td>ISBAS T129</td>
<td>14/38</td>
<td>2.1</td>
<td>1.6</td>
</tr>
</tbody>
</table>
Cartesian components (East, Up)

- Resampling of LoS mean velocities to common grid (200 m)
- GPS North velocity component interpolated to same grid
- LS inversion for East and Up velocity carried out if at least one asc. and one desc. pass
- Blockmedian average-subsampling (to reduce noise and number of points for subsequent modelling)
East velocities – 200 m grid
East velocities – blockmedian 2.5 km

Tectonic signal
Up velocities – 200 m grid
Up velocities – blockmedian 2.5 km – esa

Mean Velocity (mm/year)
SAR vs GPS comparison

**East component**

STD = 0.9 (0.8) mm/yr  
R = 0.66 (0.71)

**Vertical component**

STD = 1.4 (0.9) mm/yr  
R = 0.67 (0.87)

In volcanic areas
Seismic Hazard Modelling

• Earthquake rates
  – Neokinema FEM modelling based on Seismic Hazard Inferred from Tectonics (SHIFT) approach
  – Comparison with historical seismic catalog

• PSHA modelling
  – Statistical validation against accelerometric network stations (RAN)
  – Comparison with macroseismic intensities
Earthquake rates from GPS

Mw > 5.5
Epicentres (EC) / m^2 / s

Corresponds to e.g.
EC=10^-3 in 50 yr in a 1 km x 1 km area

EC=10^-4
EC=10^-5
PGA from GPS-based EQrates

PGA (g) 10% probability of exceedance in 50 years

RAN stations
Soil class “A”
Earthquake rates from SAR

EC = 0.5 \times 10^{-3} \text{ in 50 yr in a 1 km x 1 km area}

EC = 0.5 \times 10^{-4}

Mw > 5.5

Epicentres (EC) / m^2 / s
Conclusions: deformations 1/2

• Apenninic deformation gradients are small but measurable with Multi Temporal DInSAR
  • Tectonic signals: up to 2 mm/yr LoS over 20 km @23° inc. angle)
  • Local subsidence: up to 4 mm/yr

• Under favourable conditions MT-DInSAR can:
  • Confirm/disconfirm long wavelength trends (e.g. coast to coast) measured by GPS
  • Provide context for GPS measurements (local vs. regional patterns) and fill in the gaps between stations (very useful given high fault density)
Conclusions: deformations 2/2

• Under favourable conditions means:
  a) Small impact of large-scale phase unwrapping errors
  b) Few ifgs with large-scale atmospheric trends
  c) Small impact of height-correlated atmospheric effects

• When processing ERS/ASAR archive data on the central Apennines with 2nd generation MT-DInSAR
  • Operator choices are critical (processing parameters, data selection, quality assessment)
  • GPS availability is essential to compensate large-scale processing errors and for quality assessment
Conclusions: modelling

• Critical assumptions
  • Stationarity of underlying interseismic deformation

• GPS-based results
  • Pass PSHA statistical validations for several RAN stations (8 out of 10 considered so far)
  • Local “anomalies” need to be investigated

• SAR-based results
  • Our very first modelling attempt yields “unrealistic” earthquake rates (spatial distribution and order of magnitude in several areas)
  • Outlier removal and average-subsampling procedures need to be revised
Thank you!
Previous SAR measurements

Hunstad et al., 2009

STD = 2.4 mm/yr
R = -0.75

East velocities