Crustal Deformation during Interseismic Period from SAR Interferometry and Geodetic Observation
1. Concept of DInSAR
2. DInSAR Case study : Tainan (Huang, 2009)
3. Concept of PSInSAR (Hooper, 2007)
5. Conclusions
6. References
DInSAR: the phase difference

Interferogram (lower) showing modeled uplift of 10 cm; Illustration by G. Bawden, USGS
Geometry of InSAR

Figure 2-1: Geometry of a satellite interferometric SAR system. The orbit separation is called the interferometer baseline, and its projection perpendicular to the slant range direction is one of the key parameters of SAR interferometry.

Figure 2-2: Geometric parameters of a satellite interferometric SAR system.
DInSAR: flatten

- Remove the topography of each image

Didier Massonet, Kurt Feigl, Marc Rossi, Frédéric Adragna
Radar interferometric mapping of deformation in the year after the Landers earthquake
DInSAR Case study: Tainan (Huang, 2009)

- The Tainan tableland is a significant morphological expression of an active growing structure near the deformation front located in SW Taiwan.
- Tainan tableland, Tawan lowland, and the Chungchou terrace are separated by two major thrust faults: the Houchiali fault and the Chungchou fault.
- This Tainan fault is regarded as the outermost thrust and probably corresponds to the outermost deformation front of the collision zone between the Eurasian Plate and the Philippine Sea Plate.
2003-2005 Velocity field

Minimum of Coastal Range
The leveling data surveyed during 2001 to 2003 (2 years) indicate similar deformation pattern to the topography of the same profile (Rau et al., 2003)
ERS data set

<table>
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<th>ID</th>
<th>Master</th>
<th>Slave</th>
<th>B⊥ (m)</th>
<th>Ha (m)</th>
<th>Delta days</th>
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<td>12 Nov 1998</td>
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<td>28 Oct 1999</td>
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<td>12 Oct 2000</td>
<td>50</td>
<td>103.6</td>
<td>1610</td>
</tr>
</tbody>
</table>
DInSAR of 5 pairs (1996-2000)
Real Displacement?

Real displacement
Displacements project into parallel or perpendicular to the orbit trajectory
Displacements project into horizontal or vertical direction
Horizontal or vertical displacements project into line of sight
SRD (Slant Range Deformation)

\[
\begin{align*}
\begin{bmatrix}
a' \\
b' \\
c'
\end{bmatrix} &=
\begin{bmatrix}
\cos \phi & \sin \phi & 0 \\
-\sin \phi & \cos \phi & 0 \\
0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
a \\
b \\
0
\end{bmatrix} =
\begin{bmatrix}
ac\cos \phi + bs\sin \phi \\
-as\sin \phi + bc\cos \phi \\
0
\end{bmatrix}
\end{align*}
\]

\[
h \cos \theta + (ac\cos \phi + bs\sin \phi) \sin \theta = \Delta r
\]

\[
h = \Delta r \sec \theta - (ac\cos \phi + bs\sin \phi) \tan \theta
\]
The SRD rate is increasing with time, and the curve of SRD rate is roughly linear with values of about:

- I: 7.7 mm/yr
- II: 11.6 mm/yr
- III: 18.9 mm/yr
Weakness of DInSAR

Isla Isabela

Amelung, Jonsson et al. [2000]  
NASA, Visible Earth website
Persistent Scatter

- Phase simulations for (a) a distributed scatterer pixel and (b) a persistent scatterer pixel.
PS candidates select

- Amplitude of a pixel
- St. deviation / mean

Ferretti, et al. 2001
Atmosphere effect

Atmosphere Correction in PSInSAR

\[
\phi_{x,i} = \phi_{\text{def},x,i} + \phi_{\text{\(\alpha\)},x,i} + \phi_{\text{orb},x,i} + \phi_{\text{\(\varepsilon\)},x,i} + n_{x,i}
\]

- \(\phi_{x,i}\) : interferometric phase
- \(\phi_{\text{def},x,i}\) : surface displacement
- \(\phi_{\text{\(\alpha\)},x,i}\) : atmospheric effect
- \(\phi_{\text{orb},x,i}\) : orbit effect
- \(\phi_{\text{\(\varepsilon\)},x,i}\) : DEM residual effect
- \(n_{x,i}\) : noise
Atmosphere Correction in PSInSAR

\[ \phi_{int,x,i} = \phi_{def,x,i} + \Delta \phi_{\varepsilon,x,i} + \phi_{atm,x,i} + \Delta \phi_{orb,x,i} + \phi_{n,x,i} \]

Spatially correlated

Mean value in a given distance L.

\[ \bar{\phi}_{int,x,i} = \bar{\phi}_{def,x,i} + \bar{\phi}_{atm,x,i} + \Delta \bar{\phi}_{orb,x,i} + \bar{\phi}_{n,x,i} \]

Small value

\[ \phi_{int,x,i} - \bar{\phi}_{int,x,i} = \Delta \phi_{\varepsilon,x,i} + \phi_{n,x,i} - \bar{\phi}_{\varepsilon,x,i} \]
Atmosphere Correction in PSInSAR

\[ \phi_{int,x,i} = \phi_{def,x,i} + \Delta \phi_{\epsilon,x,i} + \phi_{atm,x,i} + \Delta \phi_{orb,x,i} + \phi_{n,x,i} \]

• Then, high-pass filtering in time and low-pass filtering in space.
ERS vs Envisat

Manzo et al, 2011, Pure and Applied Geophysics
Small BAaseline Subset
Modified SBAS-DInSAR

(Berardino et al, 2002.)

Figure 2
Block diagram of the exploited SBAS-DInSAR processing chain
Orbital Ramps

• “Orbital” fringes representing the phase difference from the change in viewpoint between the two images. Hundreds of cycles, or fringes, may be created across an interferogram several thousand pixels wide.

• Most can be predicted and removed using knowledge of the satellite trajectories.
Misinterpreted vs Corrected
Schmidt and Bürgmann, 2003.
Land subsidence observed from 1934 to 1960 (reproduced from Poland and Ireland, 1988)

- Unit: meter
Dataset

- Perpendicular baselines of <200 m.
- Track 478: gray bars
- Track 70: black bars
Inversion for Differential Interferograms

Figure A1. Schematic showing the relationship between data and model matrices in the inversion.
Inversion Result of Profile AA’

- **InSAR time series profiles** (heavy solid line and dotted error envelope)
- **Individual interferograms** (thinner solid line)
- Constant offsets or gradients: orbital or long-wavelength atmospheric artifacts.
Seasonal Uplift Pattern
Compare to Leveling data
Compare to Extensometer

SBAS

MARTHA

SUNNY

MARTHA (well level)
Summary

- The recovery of groundwater levels which began in the 1960s appears to have continued through the 1990s as inferred from the regional uplift in the Santa Clara Valley.
- Uplift is also resolved east of San Jose where the Silver Creek fault has restricted the flow of groundwater to the west.
- While a small, latent subsidence signal may still persist, compaction does not appear to be a significant source of deformation.
Conclusion

- Multi-temporal InSAR techniques are able to observe interseismic deformation.
- Non-tectonic deformation is also detectable, ex: groundwater recovery.
- PS identification is an efficient and necessary approach to deal deformation in rural area.
Any Comments are Welcome
Why high-pass filter in time?

- Because atmospheric effect is uncorrelated in time.
Goal

For general applications, we would like a PS method that works:

a) In rural areas without buildings (low amplitude)

b) When the deformation rate is irregular
Our PS Method

Exploits spatial correlation of the deformation signal.

We create a series of interferograms and remove an estimate of the topographic signal. We are left with:

\[ \phi_{\text{int}} = \phi_{\text{defo}} + \phi_{\text{atmos}} + \Delta\phi_{\text{orbit}} + \Delta\phi_{\text{topo}} + \phi_{\text{noise}} \]
Our PS Method

Exploits spatial correlation of the deformation signal.

We create a series of interferograms and remove an estimate of the topographic signal. We are left with:

$$\phi_{\text{int}} = \phi_{\text{defo}} + \phi_{\text{atmos}} + \Delta\phi_{\text{orbit}}$$

$$+ \Delta\phi_{\text{topo\_uncorr}}$$

$$+ \Delta\phi_{\text{topo\_corr}}$$

$$+ \phi_{\text{noise}}$$

- Correlated spatially - estimate by iterative spatial bandpass filtering
Estimation of Spatially Correlated Terms

= crude low-pass filter (in spatial domain)

Replaced with a band-pass filter in frequency domain.

- Low frequencies plus dominant frequencies in surrounding patch are passed.

Frequency response

Example frequency response (different for every pixel)
Our PS Method

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\]

- Correlated spatially - estimate by iterative spatial bandpass filtering
- Correlated with perpendicular baseline - estimate by inversion
Estimation of Topographic Error

Subtract estimate of topographic error and what’s left is an estimate of the noise.
PS Selection Algorithm

1. **Initial Pixel Selection**

2. **Estimate spatially correlated terms**

3. **Estimate residual topographic term and $\gamma_x$**

4. **Weight pixels on $\gamma_x$**

5. **Select PS Probabilistically**

$\gamma_x$ is a measure of noise variance.
PS Selection Algorithm

Initial Pixel Selection

Estimate spatially correlated terms

Weight pixels on $\gamma_x$

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6. Select PS Probabilistically
Results in Long Valley

- 29,000 persistent scatterers
Wrapped PS Phase

- Interferogram phase, corrected for topographic error