The Application of InSAR for Crustal Deformation in Central and Southwestern Taiwan

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Application

Landers coseismic deformation (1992)

(Price & Sandwell, 1998)
Radial dike intrusion and eruption on Fernandina Volcano, Galápagos.

(Jonsson et al, 1999)
The theorem and principle of InSAR technique

• What is SAR?
  – SLAR (Side-looking Aperture Radar)
    Azimuth resolution: $R_a = \frac{R\lambda}{L}$ (4.8 km for ERS)
  – SAR (Synthetic Aperture Radar)
    Azimuth resolution: $\approx 25 \text{ m}$ in ground range (for ERS)

• What is InSAR?
  – InSAR (Interferometry SAR)
  – D-InSAR (Differential InSAR)
SLR (Side-looking Radar system)

(a) Propagation of one radar pulse (indicating the wavefront location at time intervals 1-17)

Lillesand, 2000
Concept of antenna in SAR radar

For ERS, a pulse emitted at position 1 is received between position 10 and 11, and the spacecraft moves c.a. 40 m between transmitting and receiving the pulse.
Effect of foreshortening and layerover

Lillesand, 2000
Foreshortening and layover effect in Northern Taiwan
What is interferometry?

- InSAR (interferometry SAR) – based on the measurement the phase differences between two SAR images.
- Sensitive to the variation (including topography, deformation, etc.) along Slant Range Resolution (SRD), presented by the fringes.
The geometry of InSAR

B – baseline
θ - looking angle
How it works?

\[ y_1 = |y_1| e^{i\psi_1}, \quad y_2 = |y_2| e^{i\psi_2}, \quad v = y_1 y_2^* = |y_1||y_2| e^{i(\psi_1 - \psi_2)} \]

\[ \phi = \psi_1 - \psi_2 = \frac{2\pi}{\lambda} |2R_1 - 2R_2| = \frac{4\pi}{\lambda} \delta \rho \approx \frac{4\pi}{\lambda} B \sin(\theta - \alpha) \]

\[ \psi_1 = \frac{2\pi}{\lambda} 2R_1 \]
\[ \psi_2 = \frac{2\pi}{\lambda} 2R_2 \]
\[
\phi \approx \frac{4\pi}{\lambda} B \sin (\theta - \alpha) \quad \partial \phi = -\frac{4\pi}{\lambda} B \cos (\theta - \alpha) \partial \theta \quad \partial \theta = -\frac{\lambda}{4\pi B \cos (\theta - \alpha)} \partial \phi
\]

\[
H_{sat} = R_1 \cos \theta \quad \partial H_{sat} \approx -R_1 \sin \theta \partial \theta = -H_p
\]

\[
\therefore \quad H_p = -\frac{\lambda R_1 \sin \theta}{4\pi B \cos (\theta - \alpha)} \partial \phi = -\frac{\lambda R_1 \sin \theta}{4\pi B_\perp} \partial \phi
\]

\[
h_{2\pi} = \frac{R_1 \sin \theta}{2B_\perp}
\]

\[
\phi_p = \frac{4\pi}{\lambda} \left( B \sin (\theta - \alpha) - D_p - \frac{B_\perp}{R_1 \sin \theta} H_p \right) + \phi_x
\]
Amplitude image (master)  Coherence between 2 SAR images
Differential InSAR

InSAR, contains topo. and
defformation

topography

D-InSAR = InSAR - topography
Phase Unwrapping

• The interferogram of last procedure is the result of crustal deformation, but its value is between $2\pi (-\pi \sim \pi)$. If we want to calculate the magnitude of deformation, we need to reconstruct the phase in modulo $2\pi$ to original phase period, which called “phase unwrapping”.
The geometry of InSAR to ground

- Real deformation
- Deformation in horizontal or vertical
- Horizontal or vertical deformation projects to line of sight
- SRD (Slant Range Deformation)
Case Study

• Central Taiwan
  – The deformation of footwall during the Chi-Chi earthquake

• Southwestern Taiwan
  – The uplift of the Tainan Tableland
Study Area

Taichung
- 19990401
- 19990715
- 19990923
- 20000106
- 20000316

Tainan
- 19960516
- 19981112
- 19990121
- 19990506
- 19991028
- 20001012
Taichung area (track: 232, frame: 3123)
The Chi Chi earthquake
SAR interferometry during the Chi-Chi earthquake
Profile AA’ of interferograms A and B in SRD. Notice that the profile is slightly increasing when passing through Paguashan.
GPS data in coseismic deformation

Velocity on hanging wall can exceed 8 m, toward northwest.

Velocity on footwall is about 20~100 cm.
Observed Land Subsidence
SAR images in Tainan area

- 1996/05/16
- 1998/11/12
- 1999/01/21
- 1999/05/06
- 1999/10/28
- 2000/10/12

(track: 232, frame: 3135)
Houchiali Fault

topography

Tainan
Differential InSAR
Differential InSAR

2.8 cm
Phase Unwrapping
The interpretation of the result of SRD
Slant Range Deformation (SRD) along profile II

Distance (km)

SRD (cm)

960516_981112 (910 days)
960516_990121 (980 days)
960516_990506 (1085 days)
960516_991028 (1260 days)
960516_001012 (1610 days)

Houchiali Fault
Crustal Deformation of Southwestern Taiwan
GPS and Leveling Network in Taiwan
Slant Range Deformation (SRD) along profile II

Distance (km)

SRD (cm)

Houchiali Fault
To investigate the subsurface slip rate and locking depth of the Houchiali fault
PS-InSAR: Stable Point Network

10 ERS1/ERS2 images from 31/01/1996 to 12/10/2000