An Efficient Method for Improving Coherence of Multiple Aperture Interferogram (MAI)

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  – Estimation of along-track deformation using MAI

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Introduction

• DInSAR technique
  – Estimation of centimeter-scale surface deformation along the satellite’s LOS direction
  – Measurement of the along-track deformation:
    • Amplitude pixel offset method
      – Using cross correlation of two or more amplitude images
      – Although this method has been in fairly wide use, it has very reduced sensitivity
    • Multiple aperture interferometric SAR method
      – By split-beam InSAR processing, to create forward- and backward- looking interferograms
Introduction

• MAInSAR method
  – Bechor and Zebker (2006)
  – Forward- and backward-looking SLC images are generated by
    • Modifying the Doppler centroid $f_{DC}$
    • Limiting the integration time
  – Squint angles between forward- and backward- SLC images are slightly different.
    • For ERS, about 0.3 deg.
Introduction

- MAInSAR method (cont.)
  - $\chi$ : along-track displacement
  - $l$ : the effective antenna length
  - $n$ : a normalized squint changing the aperture width.

- MAI phase depends on antenna length

- For ERS-1/2, $l = 10m$
- For half aperture, $n = 0.5$

$$\phi_{MAI} = \frac{4\pi}{l} nx$$
Introduction

• Conventional MAInSAR method
  – Generation of three interferograms is required.
    • Forward-looking interferogram
    • Backward-looking interferogram
    • Multiple aperture interferogram
  → Three co-registration and resampling steps.
  → Time-consuming & reduction of coherence
  – Nonconsideration of flat earth and topographic phase contributions
    • Flat earth and topographic phases are caused by the difference of perpendicular baselines between forward- and backward-looking interferograms.
Objectives

- **Improvement of the coherence of MAI & reduction of processing time**
  - Co-registration of forward- and backward-looking SLC images using time shift property of Fourier transform without resampling in RD processing.

- **Development of optimal procedure for MAInSAR technique**
  - Minimization of flat earth and topographic phase contributions using forward- and backward-differential interferograms.
Methodology

- **RD processing for MAI**
  - Range-migration is identically corrected in forward and backward SLC images.
  - Backward SLC image is shifted by using the time shift property of Fourier transform, so that the forward and backward SLC images are co-registered.
Methodology

- Estimation of $f_{DC}$, $f_{DC,f}$ and $f_{DC,b}$

$$f_{DC} = \frac{f_{DC1} + f_{DC2}}{2}$$

$$f_{DC,f} = f_{DC} + n \frac{PBW}{2}$$

$$f_{DC,b} = f_{DC} - n \frac{PBW}{2}$$
Methodology

• **Range-migration correction**
  – Range-migration for forward and backward SLC images is corrected using the central Doppler centroid ($f_{DC}$).
  – Range offset of forward and backward SLC images does not exist.
Methodology

• Azimuth shift
  – Forward and backward SLC images have the offset in the azimuth direction because of the different Doppler centroid.
  – Backward SLC image is shifted in the azimuth direction using Fourier transform
Methodology

- Flat earth and topographic phase contributions
  - The baselines of forward- and backward- looking interferograms are slightly different.
  - Flat earth and topographic phases are caused by the difference of perpendicular baseline ($\delta B_\perp$).
Methodology

- **MAI Generation**
  - Determination of the difference of perpendicular baseline ($\delta B_\perp$)
  - Generation of forward- and backward- differential interferograms for flat earth and topographic phases correction.
  - Generation of MAI using forward- and backward-interferograms.
Results

• Dataset
  – Mw 7.1 1999 California, Hector Mine Earthquake
  – Four interferometric pairs
    • **Pair 1**: Before earthquake, *No along-track deformation*, descending orbit pair of Jan. 10, 1993 (ERS-1) and Jan. 8, 1997 (ERS-2), $B_{\perp} = 10\text{m}$ and $\delta B_{\perp} = 0.05\text{m}$.
    • **Pair 2**: After earthquake, *No along-track deformation*, descending orbit pair of Nov. 24, 1999 and Dec. 29, 1999 (ERS-2), $B_{\perp} = 630\text{m}$ and $\delta B_{\perp} = 0.07\text{m}$.
    • **Pair 3**: descending orbit pair of Sept. 15, 1999 and Oct. 10, 1999 (ERS-2), $B_{\perp} = 21\text{m}$ and $\delta B_{\perp} = 0.005\text{m}$.
    • **Pair 4**: descending orbit pair of Sept. 15, 1999 and Nov. 24, 1999 (ERS-2), $B_{\perp} = 430\text{m}$ and $\delta B_{\perp} = 0.01\text{m}$.
Results

• Result of RD processing for MAI

Forward-looking SLC image  Backward-looking SLC image
Results

• Generation of interferograms

[Images of Forward-looking interferogram and Backward-looking interferogram]
Results

- **Comparison of MAIs**
  - MAIs generated from forward- and backward-interferograms
  - MAI generated from conventional method
  - MAI produced by RD processing for MAI

<table>
<thead>
<tr>
<th></th>
<th>Deg.</th>
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<th>Deg.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>-12~12</td>
<td>-33~33</td>
<td>σ=12.3cm</td>
<td>-8~8</td>
<td>-22~22</td>
<td>σ=7.5cm</td>
</tr>
<tr>
<td>Pair 2</td>
<td>-14~14</td>
<td>-39~39</td>
<td>σ=14.7cm</td>
<td>-10~10</td>
<td>-28~28</td>
<td>σ=9.6cm</td>
</tr>
</tbody>
</table>

*Pair 2*

Conventional Method

Proposed Method
Results

• Improvement of the coherence

Improvement of coherence: 4.7%

Improvement of coherence: 3.1%
Results

- **Flat earth and topographic phase contributions**

  Pair 1
  \[ B_\perp = 10\,\text{m}, \quad \delta B_\perp = 0.05\,\text{m} \]
  About 70 deg.

  Pair 2
  \[ B_\perp = 630\,\text{m}, \quad \delta B_\perp = 0.07\,\text{m} \]
  About 100 deg.
Results

- Generation of forward- and backward-looking differential interferograms

<table>
<thead>
<tr>
<th>Pair 3</th>
<th>Pair 4</th>
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<tbody>
<tr>
<td>$B_\perp = 21m$, $\delta B_\perp = 0.005m$</td>
<td>$B_\perp = 430m$, $\delta B_\perp = 0.01m$</td>
</tr>
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</table>
Conclusions

- **Improvement of the coherence**
  - Coherence of MAI is improved about 4 percents by the proposed RD processing.

- **Reduction of processing time**
  - Two co-registration and one resampling steps are reduced.

- **Removal of Flat earth and topographic phase contributions**
  - Flat earth and topographic phases are removed from forward- and backward- differential interterferograms using the difference of their perpendicular baselines.
Thank you for your attention
Results

\[ \sigma = 0.174 \text{m} \]
Results

• Phase \( \phi_{MAI,e} \) due to earth curvature

\[
\phi_{MAI,e} = \frac{4\pi \cos \theta}{\lambda \rho \sin \theta} \cdot f(\theta, \alpha, B, \delta\theta, \delta\alpha, \delta B) \cdot \Delta \rho
\]

Depending on the difference of parallel and perpendicular baselines between forward and backward interferogram.

If \( f = 0.1 m, \lambda = 5.66 cm, \rho = 850,000 m, \Delta \rho = 38,800 m \) and \( \theta = 20 \text{ deg} \),

\[ \phi_{MAI,e} = 160 \text{ deg}. \]

Half fringe (pi) is changed from near range to far range.
Results

- **Phase** ($\phi_{MAI,t}$) due to topography

\[
(\phi_{MAI,t} - \phi_{MAI,e}) = -\frac{4\pi}{\lambda \rho \sin \theta} \cdot f(\theta, \alpha, B, \delta \theta, \delta \alpha, \delta B) \cdot h
\]

Depending on the difference of parallel and perpendicular baselines between forward and backward interferogram.

If $f = 0.1 m$, $\lambda = 5.66 cm$, $\rho = 850,000 m$, $h = 1,000 m$ and $\theta = 20$ deg.,

$\Rightarrow \phi_{MAI,t} = 4.5$ deg.

When the difference of height is 1000m, 4.5 deg. are changed.