Recursive and robust InSAR Phase Estimation

Francesco De Zan
DLR - Remote Sensing Technology Institute

EUSAR 2022
Closure phases and mean velocity biases

• 2015, TGRS, *Phase inconsistencies and multiple scattering in SAR interferometry*
  • Closure phase are among us, just compute them!
  • We predicted the existence of biases in InSAR deformation products

• 2020, TGRS, *Study of Systematic Bias in Measuring Surface Deformation with SAR Interferometry*
  • Sentinel-1 (C-band) data over Sicily (Italy)
  • Different temporal bandwidth for interferograms (~30 days, ~60 days, ~4 years)
  • We’ve observed different mean-velocity bias (3-6 mm/yr)
  • The bias depends on the temporal baseline (longer temporal baselines are less affected)

<table>
<thead>
<tr>
<th>Deformation rate</th>
<th>Bias wrt PS’s (mm/year)</th>
<th>Dispersion wrt PS’s (mm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 5 (~30 days)</td>
<td>-6.50</td>
<td>2.58</td>
</tr>
<tr>
<td>Band 10 (~60 days)</td>
<td>-3.05</td>
<td>1.55</td>
</tr>
<tr>
<td>Full covariance</td>
<td>-0.24</td>
<td>0.70</td>
</tr>
</tbody>
</table>
Phase estimation algorithms

Once could just recommend covariance-based algorithms

- Phase linking (Tebaldini 2008), EMI (Ansari 2018), …

or adding some long-span interferograms (Doin)

or de-biasing solutions

- Zheng 2022, Maghsoudi 2022

and proceed with feeding the phases to a e.g. PS-like chain to derive deformation products

However… this is not fully satisfying, as we would like to have:

- Continuous updates for a phase product (Analysis Ready Product)
- Automatic long-term stability & short term quality

I’m trying to develop a new approach

- Generation of simple interferograms
- Linear combination (“filtering”) of acquisitions in time
- Recursive implementation
- Special care for long-term phase quality
Recursive InSAR Phase Estimation

• A new phase estimation algorithm
  • Simple & Fast
  • Minimal I/O requirements

\[ \phi_N = \angle <\text{SLC}_N, \text{ref}'> \]
Recursive InSAR Phase Estimation

• A new phase estimation algorithm
  • Simple & Fast
  • Minimal I/O requirements

\[ \phi_{N+1} = \angle \langle \text{SLC}_{N+1}, \text{ref}' \rangle \]
Recursive InSAR Phase Estimation

- A new phase estimation algorithm
  - Simple & Fast
  - Minimal I/O requirements
  - Good short-term quality (like 6-day interferograms)
  - Good long-term quality (like full covariance)

\[ \varphi = \angle<\text{ref'}, \text{ref}> \]
\[ \text{ref'} \leftarrow \text{ref'} \cdot \exp(-j \varphi) \]
\[ \text{ref'} \leftarrow w \cdot \text{ref'} + \text{SLC}_N \cdot \exp(-j \varphi_N) \]
Usage of phase product

• Nominally, all interferograms are referred to the same reference
• Computing any “interferogram” is easy:
  \[ \phi_{ab} = \phi_a - \phi_b \pmod{2\pi} \]
• Users will still have to do the phase unwrapping
• Long- and short-term coherence as quality measures
Simulations based on complex coherence model

Displacement bias

Displacement error std
RIPE with and w/o anchoring

Temporal separation 1032 days
Short-term (top) and long-term coherence (bottom)
RIPE – Recursive Interferometric Phase Estimation
DS - PS mean velocity difference

- Average difference: -0.32 mm/yr
- Comparable to using full stack (-0.24 mm/yr for DS)
- It might be possible to reduce it further
- It’s going to be smaller with longer time series
Towards an phase product

• Test and tune algorithm on different climates and land covers

• Design for forward compatibility with ESD, split-spectrum, etc.

• Probe product usability, users of this intermediate product should “just” unwrap the phases
To conclude…

• New algorithm based on interferograms and linear combination of images
  • No covariance matrix
  • It’s possible to give continuous updates

• A recursive formulation minimizes the storage and I/O needs

• The algorithm tackles explicitly
  • Short term coherence
  • Long term stability (small velocity bias w.r.t. PS’s)

• The results on simulated and real data are meaningful

\[
\text{ref’} \leftarrow w \cdot \text{ref’} + SLC_N \cdot \exp(-j \phi_N)
\]