The Impact of Closure Phases on InSAR Processing

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We can reach 1 mm/yr at 100’s km with S1 by correcting

- Troposphere (ERA-5)
- Ionosphere
- Solid Earth tides
Interferograms vs. closure phase

3 images
3 interferograms

3 closure phases

\( \Phi_{1,2,3} = \text{atan} \exp[j(\phi_{12} + \phi_{23} + \phi_{31})] \)

Mis-closures "require" spatial averaging!

Closure phase +/- 40 deg
Interferometric phases and velocities are biased

- The presence of closure phases implies a **path dependency** in the temporal integration

![Diagram showing path dependency](image)

- Presence of **systematic closure phases** means that
  - the interferometric phases are biased, at least some of them
  - velocity estimates are biased

- We now know that **short term** interferograms are the culprit!
Performance Comparison Study

Data set:

- **Sentinel-1 A/B time series**: IW mode
- **acquisition time span**: 4 years (Oct. 2014-Sep. 2018)
- **size of the time series**: 184 SLCs
- **extent of the chosen area**: ≈ 30,000 km²

Benchmark: Persistent Scatterer Interferometry (PSI)

- **StBAS Bandwidth 5**
- **StBAS Bandwidth 10**
- **EMI Full Covariance**
StBAS
Bandwidth 5
905 Interferograms

Deformation Velocity [mm/yr]

Mount Etna
Syracuse
Reference Point
Ragusa
StBAS
Bandwidth 10
1785 Interferograms

Mount Etna
Syracuse
Ragusa
Reference Point
<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</td>
<td>-6.50</td>
<td>2.58</td>
</tr>
<tr>
<td>Band 10</td>
<td>-3.05</td>
<td>1.55</td>
</tr>
<tr>
<td>Full Stack</td>
<td>-0.24</td>
<td>0.70</td>
</tr>
</tbody>
</table>
Bias for each lag: (multilooked interf. phase – full-cov phase)

12 mm / 365 days * 6 days = 0.2 mm = 2.6 deg

Lag\(^{-1}\) ≈ 6 days
Lag\(^{-2}\) ≈ 12 days

≈ PS phase
Modeling the velocity bias

Complex coherence model

\[ \gamma = 0.2 + 0.08 \cdot \exp(j \cdot 0.03 \cdot t) \exp\left(-\frac{t}{20}\right) \]

Some scatterer (electrically) moving 0.1 mm / day away from the satellite
Moisture inversion (Kumamoto, ALOS-2)

Moisture cycle? Biomass accumulation?

- **Moisture cycle hypothesis: not really working!**
  - Typical moisture cycle is fast wetting and slow drying
  - My moisture model predicts that slow change dominates => drying dominates
  - Scatterers should apparently move **towards** the satellite

- **Different hypothesis: Biomass accumulation in plants** (water)
  - More biomass = more delay = motion **away** from the satellite
  - 0.03 rad/day = 47 mm/yr = 5.4 mm/yr (water)
  - To convert in tons/ha we need extra assumptions…
Conclusions and recommendations

• Depending on the choice of interferograms:
  velocity biases for short lags can reach 5-10 mm/yr (or more)

• Modeling the bias
  • Moisture related phases do not seem to explain the velocity biases
  • Biomass growth could explain the bias sign

• The velocity biases can easily be a performance bottleneck!
  • Modeling => compensation
    • Use of long-term interferograms, as in Phase Linking or EMI
    • Single-look interferometry (PSI)