SAOCOM 1A Interferometric Error Model and Analysis

Pablo A. Euillades, Leonardo D. Euillades, Mario Azcueta and Gustavo Sosa
Objective

➢ Present SAOCOM system interferometric error model and analysis for DInSAR applications.

Structure

1. SAOCOM system brief description
2. General considerations for the analysis
3. DInSAR accuracy results
4. Conclusions
SAOCOM Mission Overview

- Constellation of two satellites, SAOCOM 1A and 1B
- Space Agency: CONAE (Argentina)
- Polarimetric L-Band SAR (1.275 GHz)
- Sun synchronous nearly circular frozen polar orbit (620 km)
- 16 day repeat cycle (one satellite)
- 8 day repeat cycle (two satellites)
- Mission lifetime: 5 years
- Launch Date:
  - SAOCOM 1A: 11/2016
  - SAOCOM 1B: 2017

<table>
<thead>
<tr>
<th>acquisition mode</th>
<th>polarization mode</th>
<th>swath width</th>
<th>spatial resolution</th>
<th>minimum incidence angle range</th>
</tr>
</thead>
<tbody>
<tr>
<td>StripMap</td>
<td>SP: HH or HV or VH or VV</td>
<td>&gt; 40 km</td>
<td>&lt; 10 m</td>
<td>21° - 50°</td>
</tr>
<tr>
<td></td>
<td>DP: HH/HV or VV/VH</td>
<td>&gt; 40 km</td>
<td>&lt; 10 m</td>
<td>21° - 50°</td>
</tr>
<tr>
<td></td>
<td>QP: HH/HV/VH/VV</td>
<td>&gt; 20 km</td>
<td>&lt; 10 m</td>
<td>20° - 35°</td>
</tr>
<tr>
<td>TOPSAR Narrow</td>
<td>SP: HH or HV or VH or VV</td>
<td>&gt; 150 km</td>
<td>&lt; 30 m</td>
<td>25° - 45°</td>
</tr>
<tr>
<td></td>
<td>DP: HH/HV or VV/VH</td>
<td>&gt; 150 km</td>
<td>&lt; 30 m</td>
<td>25° - 45°</td>
</tr>
<tr>
<td></td>
<td>QP: HH/HV/VH/VV</td>
<td>&gt; 100 km</td>
<td>&lt; 50 m</td>
<td>20° - 35°</td>
</tr>
<tr>
<td>TOPSAR Wide</td>
<td>SP: HH or HV or VH or VV</td>
<td>&gt; 350 km</td>
<td>&lt; 50 m</td>
<td>25° - 45°</td>
</tr>
<tr>
<td></td>
<td>DP: HH/HV or VV/VH</td>
<td>&gt; 350 km</td>
<td>&lt; 50 m</td>
<td>25° - 45°</td>
</tr>
<tr>
<td></td>
<td>QP(1): HH/HV/VH/VV</td>
<td>&gt; 220 km</td>
<td>&lt; 100 m</td>
<td>20° - 35°</td>
</tr>
<tr>
<td></td>
<td>CL-POL: RH/RV or LH/LV</td>
<td>&gt; 350 km</td>
<td>&lt; 50 m</td>
<td>25° - 45°</td>
</tr>
</tbody>
</table>

- **TOPSAR Wide QP assigned for Strategic Applications**
Error Model

\[ d_{pq}^{LOS} = \frac{\lambda}{4\pi} \cdot \Delta \Phi_{pq}^{DInSAR} \]
\[ = \frac{\lambda}{4\pi} \cdot [E\{\Delta \Phi_{pq}^{defo}\} + \Delta \Phi_{pq}^{res\_orbit} + \Delta \Phi_{pq}^{res\_topo} + \Delta \Phi_{pq}^{atm} + \Delta \Phi_{pq}^{noise}] \]

\[ \sigma_{d_{pq}}^{2} = \frac{\lambda}{4\pi} \cdot \left[ \sigma_{\Delta \Phi_{pq}^{res\_orbit}}^{2} + \sigma_{\Delta \Phi_{pq}^{res\_topo}}^{2} + \sigma_{\Delta \Phi_{pq}^{atm}}^{2} + \sigma_{\Delta \Phi_{pq}^{noise}}^{2} \right] \]

- \( r \sigma_{B_{\perp}} \)
- \( \frac{r}{B_{\perp}} \sigma_{B_{\perp}} \)
- \( \sigma_{z} \Delta z_{pq} \)
- \( pq \) sep
- inc angle
- model parameters
- terrain \( \sigma^{0} \)
- NESZ
- \( B_{Lc} \)
- \( B_{\perp} \)
- \( \Delta f_{dc} \)
- \( B_{A} \)
- Processing
Error Model

Residual Orbital Variance

\[
\sigma_{\Delta \phi_{\text{res orbit}}}^2 = \left[ \frac{4\pi}{\lambda} \int_0^{r_q} \frac{1}{r \cdot \sin \theta_0} \left( \cos \theta_0 - \frac{r}{R_E + H} \right) \cdot dr \right]^2 \cdot \sigma_{B_{\text{perp}}}^2
\]

(Pepe A., 2006)

Residual Topographic Variance

\[
\sigma_{\Delta \phi_{\text{restopo}}}^2 = \left[ \frac{4\pi B_{\text{perp}}}{\lambda} \frac{1}{r_p \sin \theta_p} \right]^2 \cdot \sigma_{z_p}^2 + \left[ \frac{4\pi B_{\text{perp}}}{\lambda} \frac{1}{r_q \sin \theta_q} \right]^2 \cdot \sigma_{z_q}^2
\]

\[
- \left[ \frac{4\pi B_{\text{perp}}}{\lambda} \right]^2 \frac{2}{r_p r_q \sin \theta_p \sin \theta_q} \cdot \sigma_{z_p z_q}^2 + \left[ \frac{4\pi z_q}{\lambda r_q \sin \theta_q} \right]^2 \sigma_{B_{\text{perp}}}^2
\]

(Pepe A., 2006)

Decorrelation Variance

\[
\sigma_{\phi}^2 = \int_{-\pi}^{\pi} [\phi - \mathbb{E}\{\phi\}]^2 \text{pdf}(\phi) d\phi
\]

\[
\text{pdf}(\phi) = \frac{(1 - |\gamma|^2)^L}{2\pi} \cdot \left\{ \frac{\Gamma(2L - 1)}{[\Gamma(L)]^2 2^{2(L-1)}} \times \left[ \frac{(2L - 1)\beta}{(1 - \beta^2)^L+1/2} \left( \frac{\pi}{2} + \sin^{-1}\beta \right) + \frac{1}{(1 - \beta^2)^L} \right] \right\}
\]

\[
+ \frac{1}{2(L - 1)} \sum_{r=0}^{L-2} \frac{\Gamma(L - \frac{1}{2} - r)}{\Gamma(L - 1 - r)} \frac{\Gamma(L - 1 - r + 2 r + 1 \beta^2)}{\Gamma(L - 1)}
\]

\[
\gamma = \gamma_{\text{thermal}} \cdot \gamma_{\text{geom}} \cdot \gamma_{\text{doppler}} \cdot \gamma_{\text{proc}} \cdot \gamma_{\text{temporal}}
\]

(Bamler & Hartl., 1998)
Implementation

Python programmed Application

5 [PROCESADORES]
6 coherencia interpolacion = 0.999
7 coherencia registracion = 0.96
8 coherencia enfocador = 0.999
9 coherencia bkg = 0.995
10
11 [PROCESAMIENTO]
12 modo = s2_qp
13 #s3_qp,s4_qp,s5_qp,s6_qp,s7_qp,s8_qp,s9_qp,s10_qp
14 rango = medio
15 tiempo dinsar = 8.24
16 bperp dinsar = 0,2000
17 bperp insar = 100,500,1000,2000,3000
18 filtrado azimuth = si
19 filtrado rango = si
20 filtrado hamming rango = si
21 filtrado hamming azimuth = si
22 error baseline = 0.1
23 error baseline paralela = 0
24 deltat analisis = 0
25 multilook rango = 10
26 multilook azimuth = 10
27 umbral coherencia = 0.2
28 umbral coherencia temporal = 0.75
29 atmosfera = si
30
31 [TERRENO]
32 error dem = 3
33 modelo coherencia = userdef
34 #formato pointscat = {[[si,valor de coherencia],[no]]
35 pointscat = no
36 latitud zona de interes = -34
37 #pendiente local debe ser un vector de igual dimension (5 puntos
38 #correspondiente al punto de referencia (p). se establece el pr
39 pendiente local = 0,1,5,9,11,14
40 #pendiente local = 0,2,4,8,16,25
Analysis considerations: Base Scenario

- Type of scatterers: distributed
- Multilooking 10x10 (12m – 25m x 40m) and common band filtering
- Thermal (~0.98) and processing decorrelation (~0.95)
- Temporal coherence: 0.6 – 0.99

- Perpendicular Baseline: 0 – 2km
- Interferometric baseline knowledge error (after correction):
  - Perpendicular: $\sigma_{B_{perp}} = 0.1m$

- Atmospheric error: not considered
- DEM error: $\sigma_z = 3m RMS$
- Topographic profile: plain terrain
Results: Base Scenario

- **LOS Displacement Error [cm]**
  - **Near Range**
  - **Far Range**

- **Extension [m]**

### Phase Aliasing Limit

- **B_{perp}=2\text{km}, \gamma_{\text{temp}}=0.6**
- **B_{perp}=2\text{km}, \gamma_{\text{temp}}=0.99**
- **B_{perp}=0, \gamma_{\text{temp}}=0.6**
- **B_{perp}=0, \gamma_{\text{temp}}=0.99**

- **Locations**: South Belridge, Cruz de Piedra, Maracaibo, Nabesna Glacier, Tasman Glacier, Upsala Glacier, Moreno Glacier, Lascar, Kilauea, Chaiten, Las Vegas, Yellowstone, Hudson, Huson, Fogo, Margarita Island, Sequalam

*volcanic deformation examples taken from http://www.geo.cornell.edu/eas/PeoplePlaces/Faculty/matt/volcano_table.html
Analysis Considerations

Analysis considerations: Realistic Scenario

- Type of scatterers: distributed
- Multilooking 10x10 and common band filtering

- SNR (~0.98) and processing decorrelation (~0.95)
- Temporal coherence: 0.6 – 0.99

- Perpendicular Baseline: 0 – 2km
- Interferometric baseline knowledge error (after correction):
  - Perpendicular: $\sigma_{B_{perp}} = 0.1m$

- DEM error: $\sigma_z = 3m$ RMS
- Topographic profile:
  - Height change: 3600m btw near and far range
  - Local slope: 0 – 14 degrees
Results: Realistic Scenario

DInSAR - SAOCOM S7_DP

LOS Displacement Error [cm]

Near Range

Far Range

Phase Aliasing Limit

B_{perp}=2km, \gamma_{temp}=0.6

B_{perp}=2km, \gamma_{temp}=0.99

B_{perp}=0, \gamma_{temp}=0.6

B_{perp}=0, \gamma_{temp}=0.99

Extension [m]

- South Belridge
- Cruz de Piedra
- Las Vegas
- Fogo
- Maracaibo
- Kilauea
- Lascar
- Moreno Glacier
- Upsala Glacier
- Tasman Glacier
- Naresna Glacier
- Chaiten
- Seguam
- Hudson
- Yellowstone
Results for Stripmap Modes

10km Realistic Scenario
10km range, 11 deg slope, Bperp=2km, 3400m height change, $\gamma_{\text{temp}}=0.6$, atmospheric signal

10km Intermediate
10km range, 2 deg slope, Bperp=1km, 300m height change, $\gamma_{\text{temp}}=0.75$, atmospheric signal

10k Base Scenario
10km range, 0 deg slope, Bperp=0, flat relief, $\gamma_{\text{temp}}=0.99$, no atmospheric signal
Stacking

After Emardson et al (2003) *Atmospheric Delay in InSAR Applications*

\[
\hat{v}_{\text{min}} = \frac{3\sqrt{3}}{2} \sigma \sqrt[3]{\frac{T_{\text{orb}}}{(T_{\text{obs}} + T_{\text{orb}})^3}}
\]

Minimum detectable deformation rate

Beam S7 Dual Polarization:

- Tobs=16 days (1 satellite)  
  Torb=5 years  
  \( \sigma \) btw 1.8 – 16.6 mm  
  \( v_{\text{min}} = 0.9 - 8 \text{ mm/year/100km} \)

- Tobs=8 days (2 satellites)  
  Torb=5 years  
  \( \sigma \) btw 1.8 – 16.6 mm  
  \( v_{\text{min}} = 0.6 - 5.7 \text{ mm/year/100km} \)

- Tobs=8 days (2 satellites)  
  Torb=7 years  
  \( \sigma \) btw 1.8 – 16.6 mm  
  \( v_{\text{min}} = 0.34 - 3.4 \text{ mm/year/100km} \)
Conclusions

- SAOCOM SAR Interferometric capabilities have been studied by considering relevant error terms.
- Expected error is systematically lower in Dual Polarization Modes than in Quad Polarization ones.
- Expected error of modes S5DP to S9DP are between ~0.6cm and ~1.4cm depending on the atmospheric influence considering a reasonable scenario (already described).
- After a 5 years mission, deformation gradients compatible with inter-seismic tectonic deformation could be characterized through time-series processing.
That’s all...

Thank you for your attention!!!
The displacement between p and q can be expressed:

\[ d^{los}_{pq} \left[ \frac{m}{\text{pixel}} \right] * \frac{\Delta R_{pq}}{R_r} = \frac{\lambda}{4\pi} * \Delta \phi \left[ \frac{\text{rad}}{\text{pixel}} \right] * \frac{\Delta R_{pq}}{R_r} \]

limit: \[ \Delta \phi = \pi \left[ \frac{\text{rad}}{\text{pixel}} \right] \]