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Tropospheric path delays derived from very high-resolution GNSS-based troposphere models and spaceborne SAR interferometry

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³Gamma Remote Sensing, Gümligen, Switzerland
Motivation

days - weeks between SAR acquisitions

different atmospheric conditions, especially for water vapor

tropospheric phases may be misinterpreted as deformations

Source: F. Alshawaf, PhD thesis
Motivation

• The long-term goal is to use GNSS-derived tropospheric path delays to mitigate DInSAR images (as a first correction).

• Another possible application is to be able to derive tropospheric path delays with very high resolution from InSAR images.

• In the first step, we compare the tropospheric delays derived from both techniques – GNSS and InSAR from the PS (persistent scatterers).

• Specific case in high mountains (high relief causing large spatial and temporal variability of the atmospheric signals).
Study area (Alpine region Valais, Switzerland)

Data period: 2008 – 2013

32 SAR acquisitions (June – October)

5 – 12 GNSS permanent stations in the area of interest

source: swisstopo

InSAR: Cosmo-SkyMed

X-band, $\lambda=3.12$ cm

326552 identified persistent scatterers

test area: ~12 km x 25 km

height: 1200 m – 4100 m a.s.m.l.
Persistent scatterer interferometry (PSI)

- The SAR interferometry is essentially exploiting the phase differences among two or more SAR images, and estimates the deformation by extracting the deformation-related phases among other phase contributions.
- PSI is a state-of-the-art method for deformation assessments.
- PSI identifies the coherent targets for which the atmosphere-induced phase can be isolated from other phase components, mainly residual topography and deformation.
- The natural terrain in alpine regions generally limits PS behavior (few scatterers).
- PS calculated using IPTA toolbox from Gamma software.

\[ dSTD_{InSAR} = APD \frac{\lambda}{4\pi} \]

Methodology – GNSS interpolation

- COMEDIE: Least-squares collocation software developed at ETH Zürich
- Stochastic and deterministic interpolation and screening of meteorological/tropospheric data
- Outline: using software COMEDIE to interpolate ZTDs from the GNSS stations to the locations of PS

\[ l = f(u, x, t) + s(C_{ss}, x, t) + n \]

More about methodology:
Wilgan K et al. J Geod (2017) 91: 117
doi.org/10.1007/s00190-016-0942-5
Differential STDs from GNSS

\[ STD = \frac{1}{\cos \theta} ZTD \quad 24.5^\circ < \theta < 25.4^\circ \]

\[ dSTD(x, t) = \]
\[ = \left( STD(x, t) - STD(x, t_m) \right) \]
\[ - \left( STD(x_{ref}, t) - STD(x_{ref}, t_m) \right) \]

\( t_m \) - master acquisition
\( 2010-09-20, 17:46:45 \)
\( x_{ref} \) - reference point

More about ZTD models in the Alps:
Wilgan K & Geiger A J Geod (2018)
doi.org/10.1007/s00190-018-1203-6
GNSS vs InSAR – good agreement

$$R = 0.82 \quad \text{ioa} = 0.63 \quad \text{bias} = -1.2 \text{ [mm]} \quad SD = 3.2 \text{ [mm]} \quad SD \text{ GNSS} = 5.5 \text{ [mm]}$$

**20110923**

**InSAR**

**GNSS**

**InSAR-GNSS**

**Correlation**

**Histogram of dSTD**

**Histogram of dSTD differences**
GNSS vs InSAR – good agreement

<table>
<thead>
<tr>
<th></th>
<th>R</th>
<th>ioa</th>
<th>bias [mm]</th>
<th>SD [mm]</th>
<th>SD GNSS [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.84 [-]</td>
<td>0.64 [-]</td>
<td>-3.0</td>
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<td>5.4</td>
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</table>

**20111013**

**InSAR**

**GNSS**

**InSAR-GNSS**

**correlation**

**histogram of dSTD**

**histogram of dSTD differences**
IGS Workshop 2018, Wuhan, China

Karina Wilgan et al.

GNSS vs InSAR – average agreement

<table>
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<tr>
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<th>R</th>
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<th>SD [mm]</th>
<th>SD GNSS [mm]</th>
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<tr>
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</table>

![Graphs showing correlation and histogram of dSTD and dSTD differences between GNSS and InSAR.](image-url)
GNSS vs InSAR – bad agreement

<table>
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<tr>
<th>R</th>
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<th>bias</th>
<th>SD</th>
<th>SD GNSS</th>
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</thead>
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<tr>
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<td>0.24 [-]</td>
<td>-16.7 [mm]</td>
<td>5.9 [mm]</td>
<td>2.6 [mm]</td>
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</tbody>
</table>
GNSS vs InSAR – bad agreement

<table>
<thead>
<tr>
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<th>bias</th>
<th>SD</th>
<th>SD GNSS</th>
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GNSS vs InSAR – bad agreement

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<th>SD GNSS</th>
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<td>0.38</td>
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</table>

**Table 20100904**

**InSAR**

**GNSS**

**InSAR-GNSS**

**Correlation**

**Histogram of dSTD**

**Histogram of dSTD differences**

**Plot**
## Assessment overview

<table>
<thead>
<tr>
<th>Date</th>
<th>(R)</th>
<th>(\text{ioa})</th>
<th>(\text{bias})</th>
<th>(\text{SD})</th>
<th>(\text{SD \ GNSS})</th>
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<td>1.4</td>
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<td>2008-09-30</td>
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<td>0.24</td>
<td>-16.7</td>
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<td>2008-10-16</td>
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<td>0.26</td>
<td>-11.8</td>
<td>4.7</td>
<td>3.5</td>
</tr>
</tbody>
</table>

- \(R\) [-] – Pearson correlation coefficient
- \(\text{ioa}\) [-] – index of agreement (Willmott, 1981)
- \(\text{SD \ [mm]}\) – standard deviation
- \(\text{Bias \ [mm]}\) – mean error
ZTDs without topography

20110923  ZTD GNSS no topography [mm]

20120909  ZTD GNSS no topography [mm]

20080930  ZTD GNSS no topography [mm]

20120707  ZTD GNSS no topography [mm]

Good agreement

Bad agreement
Phase unwrapping error's detection

20110823

InSAR

GNSS

InSAR-GNSS

3 acquisitions with errors detected!
Conclusions

• We compared the GNSS and InSAR-derived dSTDs on the PS points for 32 InSAR acquisitions

• The highest agreement between GNSS and InSAR is for days of varying troposphere

• For such days, GNSS-based models could be used for mitigating the troposphere errors in InSAR

• For days with stable troposphere, the models from InSAR are more reliable

• GNSS can also help detecting the phase unwrapping errors
Thank you! 謝謝！
Questions? 問題？
kwilgan@ethz.ch
Methodology COMEDIE

Deterministic part (zenith total delay):

\[ ZTD(x, y, z, t) = (ZTD_0 + a_{ZTD} (x - x_0) + b_{ZTD} (y - y_0) + c_{ZTD} (t - t_0)) \cdot \exp \left( -\frac{z}{H_{ZTD}} \right) \]

Stochastic parts:

\[ n \sim N(0, C_{nn}) \quad \text{stochastic uncorrelated noise} \]

\[ C_{nn} \quad \text{diagonal matrix consisting of noise of particular measurements} \]

\[ s \sim N(0, C_{ss}) \quad \text{stochastic correlated signal} \]

\[ C_{ss} \quad \text{empirically determined covariance function, e.g.} \]

\[ C_{ss}(i, j) = \sigma_0^2 \cdot \frac{1}{1 + \left( \frac{x_i - x_j}{\Delta x_0} \right)^2 + \left( \frac{y_i - y_j}{\Delta y_0} \right)^2 + \left( \frac{z_i - z_j}{\Delta z_0} \right)^2 + \left( \frac{t_i - t_j}{\Delta t_0} \right)^2} \cdot e^{-\frac{z_i + z_j}{2z_0}} \]