MODIFIED STACKING AND SBAS ALGORITHMS FOR MAPPING OF GROUND DEFORMATION IN TAUPO VOLCANIC ZONE, NEW ZEALAND WITH ALOS PALSAR

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ABSTRACT

The L-band PALSAR sensor on the ALOS satellite is the instrument of choice for mapping of ground deformation in densely vegetated regions such as the Taupo Volcanic Zone (TVZ), New Zealand. ALOS interferograms, even those with large perpendicular baselines over 2000-3000 meters, are substantially more coherent than interferograms from C-band sensors. However, due to the larger wavelength, there are limitations in detecting slow deformation using L-band. For pairs with large perpendicular baselines the residual topographic noise is significant and because of the particular acquisition geometry (e.g., perpendicular baselines correlate with the time of acquisition) it can not be removed accurately using standard processing algorithms. In this work we propose a robust modification of stacking and small baseline subset (SBAS) algorithms that significantly improves the accuracy of results and at the same time is easy to implement. The proposed technique is tested on ALOS PALSAR data acquired over Mt Ruapehu in the Taupo Volcanic Zone, New Zealand.

Key words: ALOS PALSAR, InSAR, stacking, SBAS, topographic correction, Taupo Volcanic Zone, New Zealand.

1. INTRODUCTION

On the large spatial scale ground deformation in New Zealand are caused by the subduction of the Pacific tectonic plate beneath the Australia Tectonic plate (1). This motion causes frequent earthquakes and volcanic eruptions as well as geothermal activity at the back-arc region known as the Taupo Volcanic Zone (TVZ) located in the central part of the North Island, New Zealand (9). The large scale motion in TVZ is measured by the continuous Global Positioning System (GPS) since 1990s and the campaign GPS starting from 2005. A few attempts to use C-band interferometry for mapping fine scale ground deformation in TVZ produced valuable results, however, their coverage was limited to urban areas around township Taupo (4) because of phase decorrelation. The Permanent Scatterers (PS) analysis was also undertaken, however, due to specific land cover the PS network in TVZ was found to be very sparse (3).

Since late 2006 we started acquiring L-band ALOS PALSAR (5) images from four ascending paths 324-327 and one descending path 628. The standard interferometric processing of ALOS PALSAR data produced large number of interferograms for each ascending and descending paths which then were used in advanced processing utilizing stacking (8) and SBAS (2) techniques. The goal of advance processing was to improve signal to noise ratio by removing random atmospheric and residual topographic components and to produce mean deformation rates and time series. However, it was noticed that residual topographic noise was amplified during stacking and SBAS processing. It was determined that this effect is caused by the particular temporal pattern of ALOS orbits (7). A clear correlation between perpendicular baselines and the time of acquisition (Fig. 1) produces non-randomly distributed residual topographic noise of a magnitude similar or even larger than the magnitude of ground deformation, which makes interpretation of stacking and SBAS results impossible.
2. METHODOLOGY

In order to remove residual topographic noise we developed two techniques that can be used in stacking and SBAS processing. The complete description of the techniques can be found in (6) and presented here in a short form.

A stack of $K$ interferograms is calculated for each pixel by the following equation

\[
V_{obs} = \sum \frac{\phi_{obs}^k}{t^k},
\]

where $V_{obs}$ is the average deformation rate and $\phi_{obs}^k$ is the observed phase of the $k$th interferogram calculated over a time period $t^k$. It is generally assumed that $\phi_{obs}^k$ consists of deformation $\phi_{def}^k$, topographic $\phi_{topo}^k$ and atmospheric $\phi_{atm}^k$ components:

\[
\phi_{obs}^k = \phi_{def}^k + \phi_{topo}^k + \phi_{atm}^k.
\]

Here we assume that the atmospheric component also includes all other small errors that are uncorrelated in time (orbital, thermal noise, and so on). In order to estimate and remove the topographic component in case when perpendicular baselines correlate with the time of acquisition it is proposed to apply the following technique consisting of four steps:

- Step 1: Calculate initial stack using equation (1).
- Step 2: For each pixel of each differential interferogram $k$ calculate the deviation of observed phase from the spatial average calculated in a neighborhood window $\phi_{topo}^k = \phi_{obs}^k - \phi_{obs}^k$. The residual term $\phi_{topo}^k$ contains mostly topographic contribution because the deformation contribution and spatially correlated atmospheric noise averaged over some spatial window are removed.
- Step 3: Apply linear regression between the calculated term $\phi_{topo}^k$ and $B_{perp}^k$ in order to calculate residual topographic ratio $H_{\text{topo}(\theta)}$.
- Step 4: Calculate corrected stack applying topographic correction according to the following equation:

\[
\sum \frac{\phi_{def}^k}{t^k} = \sum \left( \phi_{obs}^k - \frac{H_{\text{topo}(\theta)}}{H_{\text{atm}(\theta)}} B_{perp}^k \right).
\]

In case of correlated baselines the methodology proposed above can be successfully applied for removing residual topographic noise in the Small Baseline Subset (SBAS) processing. However, if only a partial correlation is observed it is possible to solve for velocities and residual topographic error simultaneously utilizing standard SBAS approach.

In the matrix form the standard SBAS method is formulated in the following form

\[
AV = \Phi_{obs},
\]

where matrix $A$ has dimensions $K$ lines by $N - 1$ columns ($N$ is the number of SAR images). The vector $V$ consist of $n - 1$ velocities that are to be calculated and vector $\Phi_{obs}$ consist of $k$ observed phases $\phi_{obs}^k$.

Since $\phi_{obs}^k$ consists of both deformation $\phi_{def}^k$ and topographic $\phi_{topo}^k$ components eq (4) can be modified in order to solve for both velocities and topographic errors simultaneously by adding to matrix $A$ the column with perpendicular baselines and an unknown term at the end of the vector $V$ that represent residual topographic ratio.

For example, let’s assume that we have three SAR images acquired at times $t_1$, $t_2$, and $t_3$ and three interferograms were created, spanning time intervals $t_{21}$, $t_{32}$, and $t_{31}$ with perpendicular baselines $b_{21}$, $b_{32}$, and $b_{31}$. In this case the SBAS formulation looks like this:

\[
\begin{pmatrix}
  t_{21} & 0 & b_{21} \\
  t_{31} & t_{32} & b_{32} \\
  b_{31} & t_{32} & b_{31}
\end{pmatrix}
\begin{pmatrix}
  v_1 \\
  v_2 \\
  v_3
\end{pmatrix}
= 
\begin{pmatrix}
  \phi_{2-1} \\
  \phi_{3-2} \\
  \phi_{3-1}
\end{pmatrix}.
\]

The solution of this problem can be found by applying Singular Value Decomposition (SVD) to matrix $A$ and by solving inverse problem $V = A^{-1} \Phi_{obs}$, where $A^{-1}$ is the pseudoinverse of matrix $A$ calculating with SVD.

3. RESULTS

For mapping ground deformation of Mt Ruapehu located in the south-western part of the Taupo Volcanic Zone we acquired and processed nine ALOS PALSAR images from descending path 628 frame 4420 (FBS and FBD, HH polarization). The interferometric processing was performed with GAMMA software starting from data in raw format. In total twenty one differential interferograms were created with perpendicular baselines less that 2500 m (Table 1) and topographic phase was removed using SRTM DEM with the resolution of 90 m.

Calculated interferograms were used for time series analysis based on the SBAS technique. Three different runs were performed. In the first run we solved for the deformation rates, in the second run the topographic correction was applied by separating deformation and residual topographic components as in Eq 3. In the third run we solved simultaneously for the deformation rates and the residual topographic noise as in Eq 5.

The results for each run are presented in Fig 2 along with the intensity image covering approximately the same
Figure 2. Linear deformation rates for Mt Ruapehu and south-western part of Taupo Volcanic Zone, New Zealand calculated by fitting linear trend to SBAS time series without topographic correction 2(b) and with topographic correction using Eq 3 2(c) and Eq 5 2(d). Topographic correction calculated with Eq 3 2(e) and with Eq 5 2(f). Intensity image of same area (not-geocoded) 2(a).
Table 1. ALOS PALSAR differential interferograms used in this study from descending path 628 frame 4420 (HH polarization).

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<th>Master</th>
<th>Slave</th>
<th>$B_{\perp}, m$</th>
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The best results were achieved when deformation rates and the residual topographic noise was calculated simultaneously using modified SBAS algorithm proposed here. These deformation rates are shown in Fig 2(d) and the residual topographic noise is shown in Fig 2(f).

4. CONCLUSIONS

In this paper we present InSAR results for Mt Ruapehu and south-western part of the Taupo Volcanic Zone, New Zealand. In order to remove residual topographic noise caused by large perpendicular baselines and particular temporal variation of ALOS orbits we developed two types of topographic corrections that can be applied in stacking and SBAS processing. The first technique removes spatially uncorrelated topographic noise by separating spatially correlated deformation and atmospheric component from the observed signal. The second technique can be applied only in SBAS processing by solving simultaneously for deformation rates and the residual topographic noise.

Both techniques were used to remove residual topographic noise from SBAS processing of data covering Mt Ruapehu located in the south-western part of the Taupo Volcanic Zone, New Zealand. Both techniques were successful, however, the first technique removed only spatially uncorrelated topographic noise.

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REFERENCES
