Non-Closure Phase of Multi-Look InSAR Triplets: A New Algorithm for the Mitigation of Phase Bias Phenomena

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ABSTRACT

The measures of the Earth's ground deformation by using multi-temporal interferometric synthetic aperture radar (InSAR) algorithms [1], [2] is nowadays a consolidated and mature practice that allows to have a really high accuracy, of the order of few millimeters [3], [4] in the line-of-sight direction of the SAR sensor. Among the different multi-temporal InSAR processors, a significant role is played by those algorithms based on the use of small-baseline (SB) multi-look (ML) interferograms [2], [5], which are less affected by decorrelation noise artefacts [6]. The conventional ML interferograms are independently generated by averaging adjacent neighbor pixels, in this way, the signal-to-noise ratio drastically increases and the analysis of the distributed scatterers becomes possible, or to some extent, less challenging. The previous multi-look operation involves the average of the information relating to each family of scatterers present in the single look pixels that will contribute to each multi-look pixel. Recently, in [7] has been observed that some inconsistencies in the InSAR products (i.e., ground deformation time-series and mean deformation velocity maps) may happen when sets of multi-look SAR interferograms with very short temporal baselines are processed, compared to those obtained using interferograms with longer temporal baselines. Such spurious signals lead to systematic biases [7] that, if not adequately compensated for, might lead to unreliable InSAR ground displacement products. In this work, we propose a technique to estimate and correct a set of multi-look SB interferograms that is based on computing and analyzing exclusively sets of (wrapped) non-closure phase triplets.

REAL RESULTS ON MONTE CRISTO RANGE AREA, NEVADA, U.S.

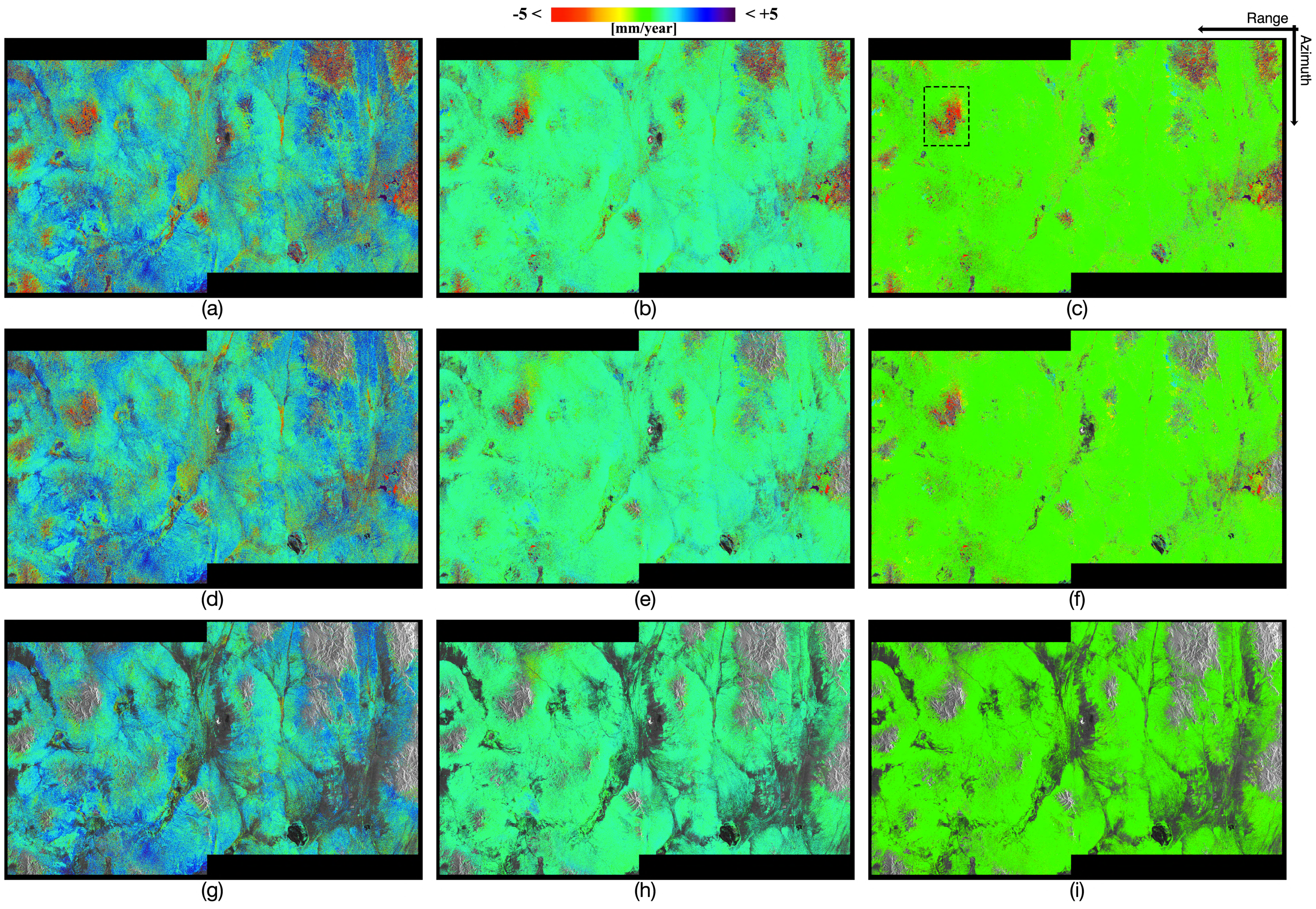

Fig. 1. Nevada test-site area maps of the ground deformation velocity differences between the case at 12 days and 96 days, where only pixels larger than given values of the temporal coherence are depicted. a), d) and g) Ground deformation velocity bias considering the original interferograms. b), e) and h) Ground deformation velocity bias when the time-invariant correction method is applied. c), f) and i) Ground deformation velocity bias when the time-variant correction method is applied. a)-c) Temporal coherence ≥ 0.7. d)-f) Temporal coherence ≥ 0.9. g)-i) Temporal coherence ≥ 0.98.

PHASE BIAS COMPENSATION TECHNIQUE:

Let us assume that the biased phases are time-invariant, i.e., the bias phenomena depends only on the temporal baseline values $\Delta t_{h,k}$, thus we model the InSAR biased phases with a second order expansion as follows:

$$\Delta\phi_{h,k}^{bias}\left(\Delta t_{h,k}\right) \cong \left[v + \Delta v\left(\Delta t_{h,k}\right)\right]\Delta t_{h,k} \tag{1}$$

where v is a constant decay phase velocity factor and Δv is a temporal-baseline-dependent phase velocity difference term. If we consider two generic interferometric SAR data pairs with temporal baselines $(\lambda-1)\delta$ and $\lambda\delta$, where δ is the repetition time of the considered SAR constellation (i.e., 6 days for Sentinel-1A/B sensors) and , Equation (1) particularizes as:

$$\Delta\phi^{bias}\left(\lambda\delta\right) \cong \left[v + \Delta v\left(\lambda\delta\right)\right]\lambda\delta \tag{2}$$

$$\Delta\phi^{bias}\left[\left(\lambda-1\right)\delta\right] \cong \left\{v + \Delta v\left[\left(\lambda-1\right)\delta\right]\right\}\left(\lambda-1\right)\delta \tag{3}$$

Equations (2) and (3) can properly be combined with each other, and the following iterative relation is found:

$$\Delta\phi^{bias}\left[\left(\lambda-1\right)\delta\right] \cong \frac{\lambda-1}{\lambda}\Delta\phi^{bias}\left(\lambda\delta\right) + \left\{\Delta v\left[\left(\lambda-1\right)\delta\right] - \Delta v\left(\lambda\delta\right)\right\}\left(\lambda-1\right)\delta \tag{4}$$

Once the whole set of triplets that could be formed using short baseline ML interferograms is identified, and considering the mathematical properties of the triplets non-closure phases, the unknown phase bias velocity differences $\boldsymbol{\Delta v}$ terms can be estimated, assuming that the measured (wrapped) triplet phases are not ambiguous, by solving the following system of Λ linear equations:

$$\Delta\Phi^{triplets} = \mathbf{Z}\cdot\Delta\mathbf{V} \tag{5}$$

The Least-Squares (LS) solution is: $\Delta\hat{\mathbf{V}} = \mathbf{Z}^{\dagger}\cdot\Delta\Phi^{triplets}$ where $\mathbf{Z}^{\dagger}$ is the pseudoinverse of the design matrix. The estimates $\Delta\hat{\mathbf{V}}$ are finally used to iteratively compute the phase biases at the different temporal baselines $\Delta t_{\lambda} = \lambda\delta, \forall\lambda = 1,2,\ldots,\Delta t_{\max}/\delta$ through Eq. (4) assuming as initial condition that $\Delta\phi^{bias}\left(\Delta t_{\max}\right) = 0$. Then, the integrated phases are used to correct the original wrapped interferograms to obtain a new set of free-bias wrapped InSAR pairs.

We focused on 65 descending Sentinel-1 A/B SAR images acquired with TOPSAR mode (Path 71, VV polarization) from January 06, 2020, to January 30, 2021, over the Nevada, U.S. area. Starting from the available SAR images, 895 ML SB interferograms were generated, by considering a temporal baseline threshold of 96 days. For the interferograms generation, we adopted an ML factor of four and twenty pixels for the azimuth and range directions, respectively. The one-arc sec SRTM DEM of the scene and precise orbits of the Sentinel-1 A/B satellites were used to compute the topographic phase and flatten the interferograms. We have applied the phase bias estimation method to the Nevada SAR data set using networks of SB interferograms, with a different maximum temporal baseline (i.e., 96 days and 12 days). The selected SB ML interferograms were independently corrected, unwrapped (via Minimum Cost Flow solver [8]) and inverted through the SBAS technique [2]. Figure 1 shows the maps of the ground deformation velocity differences between the results at temporal baselines of 12 days and 96 days, for different temporal coherence estimator [9] threshold values, to gradually exclude the effects of phase-unwrapping errors. More specifically, Figure 11 (a)-(c) shows the ground deformation velocity bias map for the original interferograms (a), those compensated using the time-invariant phase bias estimation method (b) and finally those obtained using the time-variant ones (c). The maps portray only SAR pixels with temporal coherence values larger than 0.7. Figure 11 (d)-(f) is the same as (a)-(c) but shows only SAR pixels with a temporal coherence larger than 0.9, and Figure 11 (g)-(i) portrays only those with a temporal coherence larger than 0.98. Finally, the phase bias estimation methods can reduce the effects of the ground displacement velocity biases of the ML interferograms with respect to what happens using the original, uncompensated interferograms.

CONCLUSIONS

A method for the estimation and their subsequent mitigation of biased phase signals in a sequence of ML differential SAR interferograms has been proposed. As a first approximation, we focused on the simplified case that the phase bias artefacts are time-invariant (stationary), i.e., they depend exclusively on the temporal baseline of the selected interferograms and not on the single acquisition times of the relevant interfering SAR images. We have also developed a general time-variant method, which is able to discriminate the phase bias for each generic time window, i.e., for each SAR interferogram. The simulated and real results demonstrate the effectiveness of the methodologies developed. Further studies are also required to discriminate the scatterers families inherent phase contributions from the estimated (compound) phase bias terms.

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