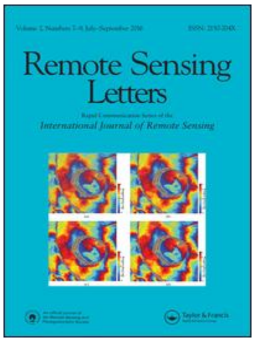

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Semi-automatic selection of optimum image pairs based on the interferometric coherence for time series SAR interferometry

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ABSTRACT
Time series synthetic aperture radar (SAR) interferometry (TS-InSAR) has been widely used for monitoring ground deformation. The selection of interferometric image pairs directly affects the quality of the interferograms and the accuracy of deformation monitoring. The Small BAseline Subset (SBAS) method has been widely adopted to form interferograms in TS-InSAR. However, the selection of low-quality interferograms or missed selection of good interferograms due to temporal and/or spatial baselines exceeding the thresholds sometimes occurs in the traditional SBAS method. This letter proposes a new method, namely, the semi-automatic selection of optimum image pairs (SASOIP), based on the interferometric coherence. By quantitatively evaluating the coherence of point targets in a small feature region, the SASOIP results in high-quality interferometric image pairs selected from all possible interferometric combinations for any two SAR images. The SASOIP method can effectively reduce the probability of poor selection and missed selection of quality image pairs. Twenty-nine COSMO-SkyMed SAR images acquired from 27 August 2011, to 29 July 2015, over Tianjin, China, are used to test the proposed algorithm. Validation with 102 levelling data points demonstrates that the accuracy of ground deformation derived from the interferograms by the SASOIP method is 23.13% higher than that based on the SBAS method.

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1. Introduction

Since the 1990s, time series synthetic aperture radar (SAR) interferometry (TS-InSAR) technologies, such as persistent scatterer (PS) InSAR and Small BAseline Subset (SBAS) InSAR based on the stable point targets, have greatly improved the ground deformation monitoring ability. TS-InSAR has been widely used in monitoring ground subsidence, volcanic deformation, seismic displacement, and large-scale man-made construction deformation. In TS-InSAR, the selection of interferometric image pairs directly affects the quality of the generated interferograms and the ultimate accuracy of deformation monitoring. Methods for selecting SAR image pairs typically include a single master-image combination in PS-InSAR and a small baseline combination in SBAS-InSAR.

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In PS-InSAR (Ferretti, Prati, and Rocca 2001; Ferretti et al. 2011), the selection of the optimal common master image is critical for generating interferograms. Much research has been devoted to this problem (Zhang et al. 2005; Liu et al. 2015). The drawbacks of the method are that the number of generated interferograms is small and that the coherence of some interferograms is low, both of which can result in difficulty in phase unwrapping. Moreover, it requires a large number of SAR images, generally more than 30, resulting in high application cost. The SBAS method (Berardino et al. 2002; Mora, Mallorqui, and Broquetas 2003) is widely employed in TS-InSAR. Each SAR image can be used as a master image or a slave image; thus, the number of generated interferograms by SBAS-InSAR is much higher than that by PS-InSAR. Eliminating the limitation of a single common master image greatly reduces the number of SAR images required for SBAS-InSAR processing, leading to improved efficiency (Wu et al. 2011; Zhang et al. 2016). However, this method does not consider the coherence of the interferograms, so the poor selection and missed selection of interferometric image pairs often occurs.

Avoiding the poor selection and/or missed selection of interferometric image pairs and automatically eliminating low-quality interferograms are key issues to be solved for TS-InSAR. This letter proposes a new method, the semi-automatic selection of optimum image pairs (SASOIP), based on the interferometric coherence. Twenty-nine COSMO-SkyMed SAR images acquired from 2011 to 2015 over Tianjin city, China are used to validate the method.

2. Methodology

2.1. Selection of a feature region with high coherence

A representative area with high coherence throughout the study area is selected as a feature region, such as an urban area, to enable subsequent selection of high-quality point targets in Section 2.3. Region size should be considered, because it increases the data processing demand; generally, a region ranging from 500 × 500 pixels to 1000 × 1000 pixels is appropriate.

2.2. Generation of all possible interferograms in the feature region

Within the feature region, all possible interferograms are generated between each SAR image and others. Supposing there are M SAR images in the time series over the same region, $N = \frac{M(M-1)}{2}$ interferometric image pairs are generated by a complete combination from all of the SAR images.

2.3. Extraction of point targets with high signal-to-clutter ratios

The local signal-to-clutter ratio (SCR) was chosen as the criterion for extracting point targets or PSs. The SCR method is divided into a three-step procedure: first, the coarse point targets are detected with high amplitude for each SAR image; second, the SCR is estimated for the coarse point targets to extract candidate point targets; finally, point targets in the feature region are obtained by the intersection of the candidate point targets of all the SAR images.

For a coarse point target P in an SAR image, the local SCR is defined as:

$$SCR_{\mathrm{P}} = \frac{\mathrm{Re}\{u_{\mathrm{P}}\}^2 + \mathrm{Im}\{u_{\mathrm{P}}\}^2}{E\left\{\mathrm{Re}\{u_{\mathrm{c}}\}^2 + \mathrm{Im}\{u_{\mathrm{c}}\}^2\right\}} \tag{1}$$

where u_{P} is the complex value of the coarse point target P, u_{c} is the complex value of the clutter surrounding P in a square window with a size of 5×5 pixels or 7×7 pixels, and $E\{\cdot\}$ is the expectation of powers from all of the clutters. If SCR_{P} is greater than a given threshold (usually 2 is suitable in most cases), the pixel P is defined as a candidate point target.

2.4. Selection of optimum interferometric image pairs based on coherence

Based on the coherence of the point targets, the average coherence of these targets of each interferogram in the feature region can be calculated. The average coherence of each interferogram is then sorted from high to low. The N' interferograms with the highest coherence are selected as high-quality interferograms. Usually, it is suitable to set N' as 3 times M with the corresponding image pairs as the optimum interferometric combinations. The minimum value of N' should result in a connected interferometric image pair network for the subsequent ground deformation inversion. If there are isolated clusters, one or two image pairs with small perpendicular or temporal baseline can be selected to connect them.

3. Study area and datasets

The central part of Tianjin city, located in northern China, was chosen as the study area. It includes six districts of the city, covering not only the urban areas with high coherence but also the rural areas with low coherence. The dataset includes 29 COSMO-SkyMed descending SAR images acquired in stripmap mode from 27 August 2011, to 29 July 2015, with an azimuth pixel spacing of 1.80 m and a range pixel spacing of 0.97 m. The images are multilooked by a factor of 3 in both the azimuth and range directions, with a ground pixel spacing of approximately 5 m. The multilooked image size is 8500 pixels (azimuth) ×5733 pixels (range), covering an area of approximately 1200 km^2. A Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) with a resolution of 1 arc second was applied to remove the topography phase. A total of 102 levelling data points covering the study area were acquired to validate the proposed method. These measurements were carried out every December from 2011 to 2015 by the Tianjin Institute of Surveying and Mapping.

4. Results and analysis

4.1. The interferometric image pairs selected by the SASOIP method

An urban area with a size of 600×600 pixels was selected as the feature region, as shown by the white block in Figure 3(a). A computer equipped with 3.4 GHz Intel Xeon CPU E5-2687W with 64 GB RAM took 576 seconds to generate 406 interferograms from any two SAR images of the 29 total SAR images. The local SCR of each pixel with the amplitude above 1.8 was calculated for the 29 images by using a square sliding window with a size of 5×5 pixels.

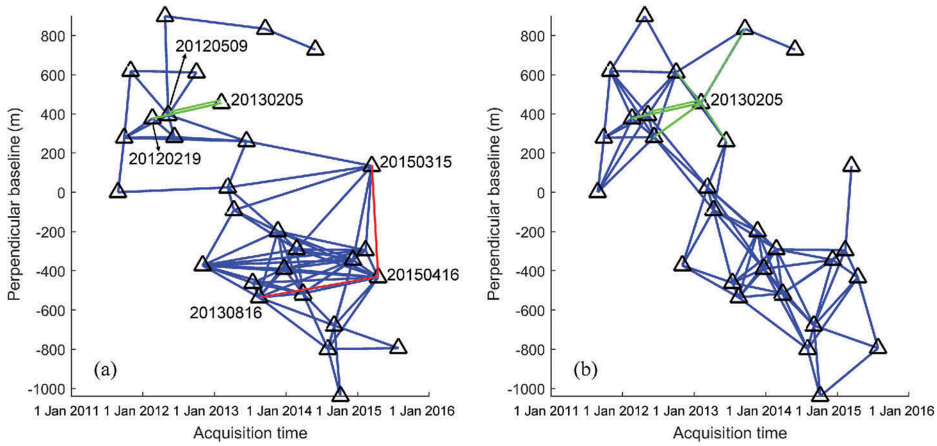

Figure 1. The spatial-temporal baseline distribution of the 86 interferograms generated by the SASOIP (a) and SBAS (b). The interferograms with red or green lines will be discussed in Section 4.4.

Pixels with SCRs greater than 2 were selected as candidate point targets. By taking the intersection of the candidate point targets through the 29 SAR images, a total of 7276 point targets were obtained in the feature region. Then, the average coherence of these targets for each interferogram was calculated and sorted. Eighty-six interferograms with the highest coherence are considered high-quality interferograms. The corresponding image pairs are the optimum interferometric combination. Figure 1(a) shows the spatial-temporal baseline distribution of the 86 interferograms.

4.2. The interferometric image pairs selected by the SBAS method

The SBAS method was also tested to compare the above results. To achieve the same number (86) of interferometric image pairs obtained by the SASOIP method, the temporal baseline threshold was set at 353 days and the spatial baseline threshold was set at 430 m. The spatial-temporal baseline distribution of the 86 generated interferograms is shown in Figure 1(b).

4.3. Coherence analysis of the two kinds of interferometric image pairs

Comparing Figure 1(a,b), we can see that the spatial-temporal baseline distributions determined by the two methods are quite different. Only 54 image pairs between them are the same. Thirty-two image pairs are different. Figure 2 shows the average coherence distribution over the point targets of the 32 different interferograms obtained by the two methods. Triangles represent the SBAS method with an average coherence of 0.70. Circles represent the SASOIP method with an average coherence of 0.74. Obviously, the coherence of the interferograms obtained by the proposed method is higher.

4.4. Comparison of phase quality between the two methods

Figure 3(a-f) shows the six interferometric phases related to image 20130205 generated by the SBAS method, corresponding to the green image pairs in Figure 1(b). Among

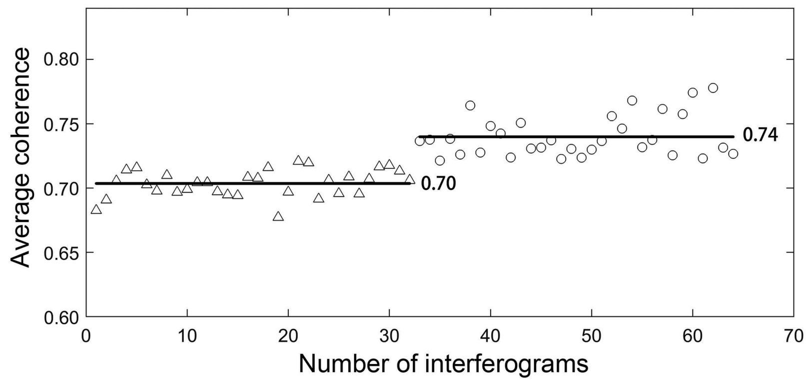

Figure 2. Average coherence of the 32 different interferograms generated by the two methods. Triangles represent the SBAS method. Circles represent the SASOIP method.

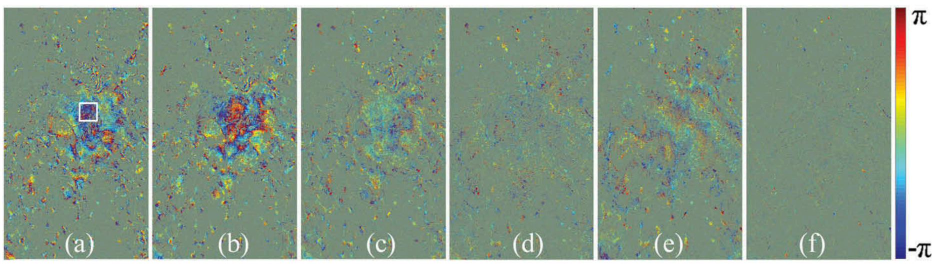

Figure 3. The interferometric phases generated by the SBAS method associated with SAR image 20130205; (a) 20120219-20130205, (b) 20120509-20130205, (c) 20120610-20130205, (d) 20120930-20130205, (e) 20130205-20130613, and (f) 20130205-20130917. The white block in (a) is the selected feature region.

them, the interferograms 20120219–20130205 (a) and 20120509–20130205 (b) were also generated by the SASOIP method, corresponding to the green image pairs in Figure 1(a). It can be seen that their phases are much better than the others. The proposed method excludes these lower-quality interferograms, demonstrating an improvement over the SBAS method.

On the other hand, some image pairs with high coherence generated by SASOIP were missed by SBAS, such as pair 20130816–20150416 (with baselines of 102 m and 608 days) and pair 20150315–20150416 (with baselines of 568 m and 32 days), as shown in Figure 1(a) with red lines. The interferometric phases of these two interferograms are shown in Figure 4, indicating that the SBAS method may miss some high-quality image pairs with unfavourable spatial and/or temporal baselines.

4.5. Comparison of deformation results retrieved from the two methods

The interferograms generated by both methods were applied to retrieve the ground deformation using the multiple-master coherent target small-baseline InSAR (MCTSB-InSAR) method described in (Zhang et al. 2016). The linear deformation model was

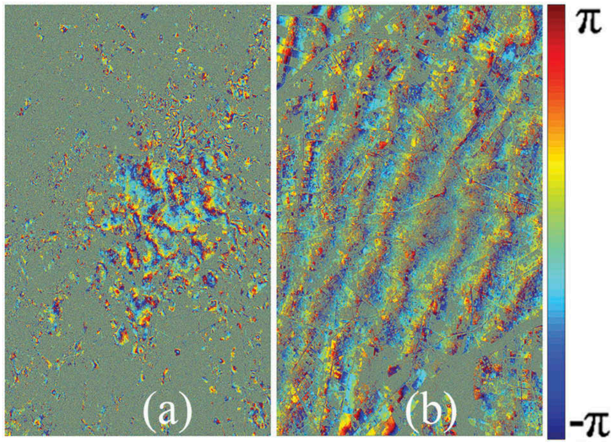

Figure 4. The interferometric phases generated by the SASOIP method using image pairs (a) 20130816-20150416 and (b) 20150315-20150416.

applied for the two methods and the model coherence threshold was set as 0.7. Figure 5 illustrates the ground deformation rate derived from the interferograms generated by the SASOIP method (a) and the SBAS method (b) and their difference map (c). The deformations were projected into the vertical direction with the SAR viewing angle, under the assumption that ground subsidence and uplift are the dominant ground deformations in the North China Plain (He, Liu, and Li 2006).

The average deformation rates of 102 levelling data points measured from 2011 to 2015 were calculated to validate the InSAR results. It is noted that only those levelling points in a circle neighbourhood with an 80-m radius centred where there is at least one coherent target are applied. The difference in deformation rates between InSAR and levelling measurements was calculated. The standard deviations of the difference demonstrate that the accuracy of the deformation rate by the SASOIP method is 4.52 mm year^{-1}, while the accuracy of the SBAS method is 5.88 mm year^{-1}. The accuracy of SASOIP is 23.13% higher than that of SBAS. Moreover, deformation is retrieved over more points from the SASOIP method than from the SBAS method. For example, in the region marked by the white dashed ellipse in Figure 5, almost no deformation is retrieved in Figure 5(b), while there are many points in Figure 5(a). This is because the phase quality of some interferograms generated by the SBAS method is not good enough.

5. Conclusions

This letter proposes an efficient semi-automatic method for selecting the optimum interferometric image pairs (SASOIP) based on the coherence of the interferograms. Compared with the traditional SBAS approach, the SASOIP method can avoid the selection of poor-quality interferograms affected by spatial-temporal decorrelation and include high-quality interferograms that SBAS may miss due to unfavourable baselines. Thus, the proposed method captures all the best interferograms from all possible image pair combinations to improve the ground deformation retrieval in TS-InSAR analysis.

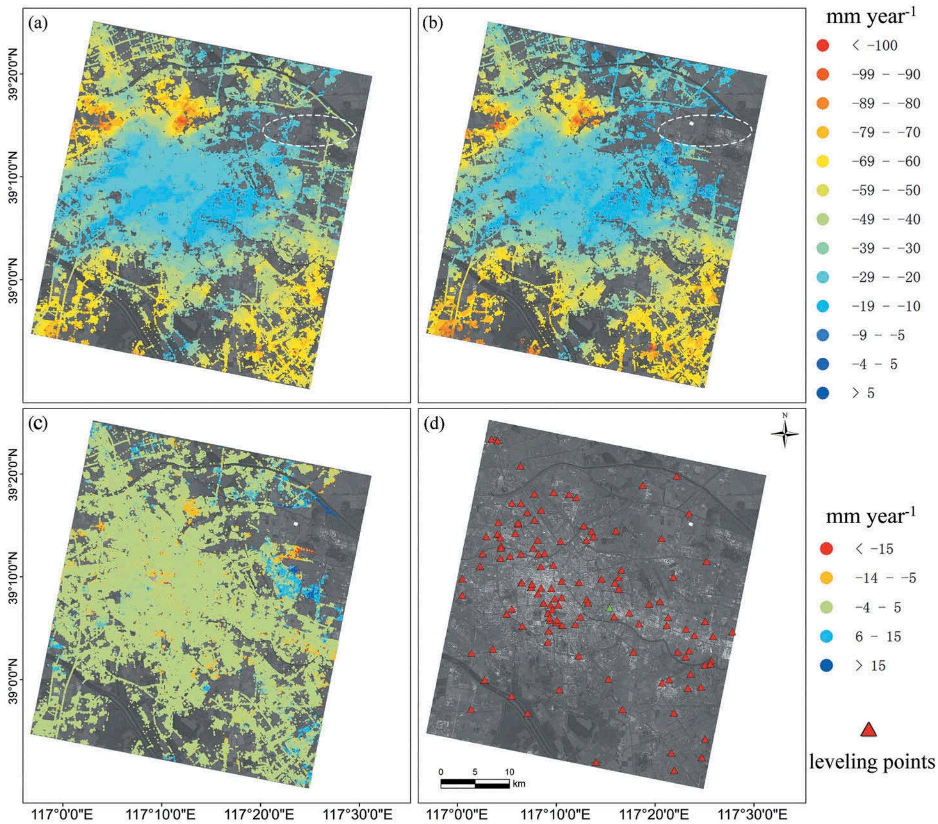

Figure 5. Ground deformation rates in Tianjin city, located in northern China, retrieved by the SASOIP method (a), the SBAS method (b), and their difference map (c). Location of the levelling points is shown in (d), where the green triangle is the reference point.

A key issue in SASOIP is the selection of an appropriate feature region. In this letter, a high-coherence urban area was selected as the feature region. For suburban areas, regions covered with buildings can be selected. In mountainous areas, regions with sparse vegetation would be preferred. Selecting a feature region over an area fully covered by dense vegetation or other low-coherent terrain types would be very hard; however, under such circumstances, the TS-InSAR technique is also less effective.

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