AN EFFECTIVE APPROACH TO SELECT THE INTERFEROMETRIC SAR DATA PAIRS BASED ON SIMULATED ANNEALING

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ABSTRACT

We present a new procedure to efficiently select the interferometric SAR data pairs exploited by the Small BAseline Subset (SBAS) DInSAR approach to generate surface deformation time-series. SAR data pair selection represents a key step within DInSAR processing since a not efficient choice can lead to deformation products with degraded quality. A way to face this problem is to compute a Delaunay triangulation in the temporal/perpendicular baseline plane. However, such a triangulation may still involve interferograms corrupted by severe decorrelation phenomena. Hence, we propose a new algorithm relying on a Simulated Annealing (SA) strategy, which is aimed at minimizing the decorrelation noise present in the generated interferograms by maximizing an appropriate cost function. The capability of the proposed method to select interferograms less affected by decorrelation phenomena as well as the derived-enhancement within the SBAS-DInSAR processing is demonstrated.

1. I NTRODUCTION

Differential Synthetic Aperture Radar Interferometry (DInSAR) is a microwave remote sensing technique that allows investigating Earth surface deformation phenomena with centimeter to millimeter accuracy. It exploits the phase difference of SAR data pairs relevant to temporally-separated observations of the investigated area [1]. While the DInSAR has first been applied to analyze single deformation episodes, it has recently moved toward the study of the deformation temporal evolution [2, 3] via the generation of deformation time-series. To this aim, the information available from each SAR acquisition can be properly linked to those included in the other ones via the generation of a proper sequence of differential interferograms.

SAR data pairs selection can be carried out by computing a Delaunay triangulation in the Temporal/ Perpendicular baseline $(T \times B_{\perp})$ plane. However, Delaunay triangulation may still involve interferograms corrupted by significant decorrelation noise effects [4].

To efficiently identify the SAR data pairs involved in the generation of surface deformation time-series, we propose in this work a new method that minimizes the decorrelation noise. In particular, we implemented a procedure based on the Simulated Annealing (SA) search algorithm [5, 6]. Simulated Annealing (SA) is a probabilistic method that allows finding the global maximum of a cost function that may possess several local maxima. The key point of this method is the selection of the most appropriate cost function to be maximized; in our case, the exploited cost function takes into account the decorrelation noise that may be present in the generated (multilook) interferograms.

In this work, we present the result of the first experiment we carried out on a set of 39 ENVISAT SAR data acquired on descending orbits (track 79) relevant to the Abruzzi area (Central Italy) spanning the 2002-2010 time interval. The obtained results demonstrate the effectiveness of the proposed method to select interferograms less affected by decorrelation noise as well as the derived-enhancement of the SBAS-DInSAR performances.

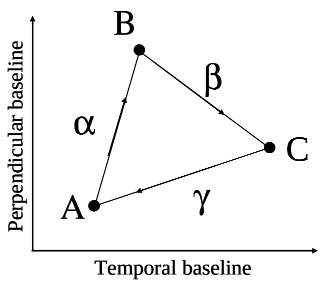

Figure 1. Elementary loop (triangle) formed by the three acquisitions labeled to as A, B and C within the $(T \times B_{\perp})$ baseline plane.

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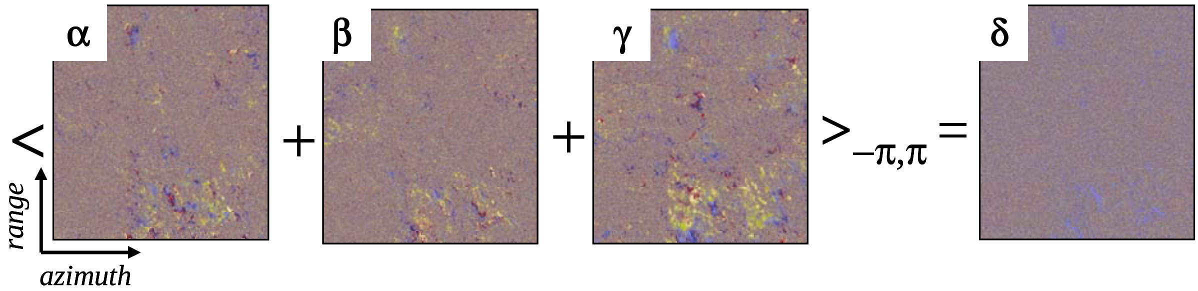

Figure 2. Wrapped sum(δ) of the three multilook interferometric phases α, β and γ

2. INTERFEROMETRIC SAR DATA PAIR SELECTION BASED ON SIMULATED ANNEALING

As said before, SAR data pairs can be efficiently selected by computing a Delaunay triangulation in the $(T \times B_{\perp})$ plane, however this strategy is not optimal because the generated interferograms may still be characterized by significant decorrelation noise effects.

To circumvent this problem, among all the possible triangulations in the $(T \times B_{\perp})$ plane, we can search for the one that minimizes the decorrelation phenomena. To this aim, we present a procedure based on the application of the Simulated Annealing searching algorithm [5,6].

Simulated Annealing is a probabilistic method for finding the global maximum of a cost function that may possess several local maxima. The key point of this method is the selection of the most appropriate cost function to be maximized.

To this aim, few considerations are due.

Let us consider three SAR acquisitions labeled to as A, B and C, and the three corresponding interferograms labeled to as α, β and γ. They form an elementary loop (triangle) that can be represented in the $(T \times B_{\perp})$ baseline plane as shown in Fig. 1.We observe that:

- the interferometric phase relevant to each interferogram is corrupted by an additive noise term, hence:

$$\phi^{meas} = \phi^{true} + \nu \tag{1}$$

- the (wrapped) sum of the three interferometric phases, say δ, is equal to zero at the singlelook scale, while at the multilook scale it is:

$$\delta = \left\langle \phi_{\alpha}^{meas} + \phi_{\beta}^{meas} + \phi_{\gamma}^{meas} \right\rangle_{-\pi,\pi} = \left\langle \nu_{\alpha} + \nu_{\beta} + \nu_{\gamma} \right\rangle_{-\pi,\pi} \tag{2}$$

since the multilook operation is carried out independently on each interferogram (see Fig. 2). Thus, δ can be used to reveal the decorrelation noise within a single triangle.

Of course, this analysis can be extended to the case of a set of SAR acquisitions which are coupled in such a way that they form a triangulation within the $(T \times B_{\perp})$ plane. Accordingly, we can search for the triangulation (among all the possible ones) which is less affected by decorrelation noise by maximizing the following cost function:

$$\eta = \frac{\sum_{i=1}^{N_P} \left| \sum_{k=1}^{N_T} \exp\left(j\delta_k \right) \right|}{N_P N_T} \tag{3}$$

where N_T is the number of triangles and N_P the number of the pixels of the interferograms. Note that high values of η correspond to a triangulation whose interferograms are less affected by noise.

More specifically, the initial state of the implemented SA procedure is represented by the Delaunay triangulation. In each iteration, the algorithm mutates the current triangulation by performing a simple flip-edge operation [7] that makes the new triangulation legal. This new triangulation is accepted, thus leading the SA procedure to a new state, with a probability computed as follows:

$$p = \exp\left\{ \frac{1}{\omega T_e} \min\left[0, \eta_{new} - \eta_{old} \right] \right\} \tag{4}$$

where η_{new} and η_{old} are the cost function values of the new and old triangulation, respectively, T_e is the initial temperature (in our implementation, the cost function value of the Delaunay triangulation), and ω is the temperature decay factor (0.9). Note that if the new triangulation is rejected, the new state is equal to the previous one (i.e., the triangulation does not change).

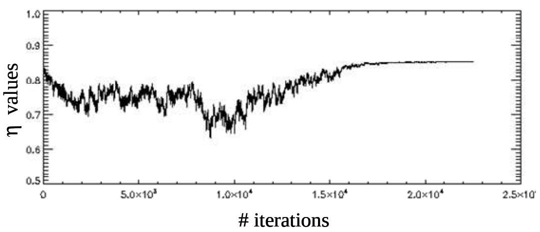

Figure 3. Plot of the cost function values vs. the number of iterations performed by the SA procedure.

The algorithm goes on until the convergence condition, i.e., the current state remains unchanged within a fixed number of iterations, is satisfied.

3. EXPERIMENTAL RESULTS

To illustrate the performance of the proposed approach, we consider a SAR data set relevant to the Abruzzi (Central Italy) area, consisting of 39 ENVISAT images acquired from descending orbits (track 79) during the 2002-2010 time interval. In Fig. 3 we show the plot of the cost function values vs. the number of iterations performed by the SA procedure; we observe that the SA converges to the maximum value of η, obtained in correspondence to the optimal triangulation shown in Fig. 4a.

To further demonstrate the effectiveness of the proposed approach, we compared the temporal coherence maps computed by considering the sequence of the so-identified multilook interferograms (Fig. 4a) and the one relevant to the Delaunay triangulation (Fig. 4b).

In both cases, we unwrapped the interferograms by applying the Extended Minimum Cost Flow (EMCF) approach [7] and inverted them via the Small BAseline Subset (SBAS) algorithm [2]. The achieved results show the increasing of the spatial coverage as we move from the Delaunay triangulation to the SA one, see Figs. 4c and 4d, respectively.

4. CONCLUSION

In this work we have proposed a method to effectively select the interferometric SAR data pairs based on Simulated Annealing algorithm. The implemented technique has been applied to a set of ENVISAT SAR data relevant to the Abruzzi area. The retrieved results show the effectiveness of the proposed approach and the increasing of the average temporal coherence obtained within the SBAS-DInSAR processing as we move from the Delaunay to the SA triangulation.

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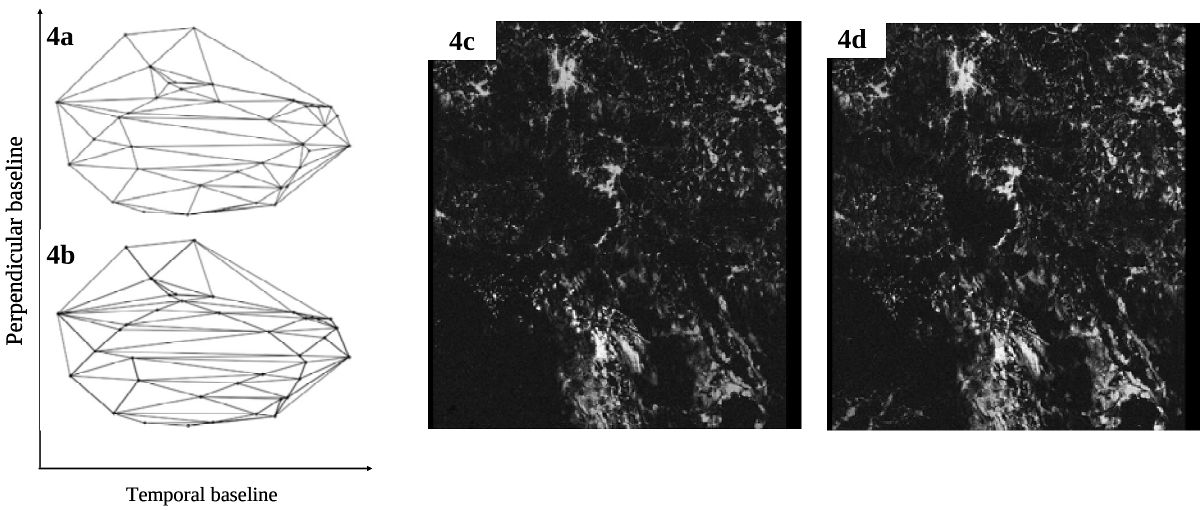

Figure 4. (a) Delaunay triangulation. (b) Optimal triangulation. (c) Temporal coherence map for the SAR data pair distribution shown in (a). (d) Same as (c) but for the distribution in (b).

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