Abstract—The DInSAR technique enables to determine with precision the surface displacements, using a combination of multiple interferograms. The DInSAR processing steps generate different kinds of errors, which propagate in the entire chain. This work is focused on a particular type of error generated during the DInSAR processing: the unwrapping related errors. The errors generated during the unwrapping process and the use of a procedure to automatically detect and correct them are presented in this work. By an iterative process and exploiting the SVD least squares method for outliers rejection, this procedure determines the phases values associated with each SAR image, starting from a stack of interferograms. It works on previously selected pixels and provides good results with high observation redundancy. The effectiveness of the procedure is illustrated by using ERS SAR data acquired over Barcelona (Spain).

Keywords- unwrapping errors, redundancy, outliers rejection, differential interferograms.

I. INTRODUCTION

The paper is focused on land deformation monitoring based on remotely sensed radar data and advanced differential interferometric SAR techniques (A-DInSAR). A-DInSAR techniques make use of large stacks of complex SAR images acquired over the same target area, and of advanced processing and analysis procedures to estimate the land deformation, separating the deformation signal from the phase contributions due to topography, atmosphere and noise. The capability of A-DInSAR to measure wide area deformation fields has been extensively documented in the literature of the last decade [1][2][3][4]. The A-DInSAR applications can be classified as follows: The applications devoted to the detection of unknown (or at least only partially known) deformation phenomena, where A-DInSAR is used as an “early detection tool” [5] to monitor wide areas. And the quantitative analysis of deformation phenomena, where major emphasis is given to the precision, accuracy and reliability of the A-DInSAR products [6][7].

In this work the attention is focused on the propagation of errors in an A-DInSAR processing chain, which receives as input a time series of SAR images, and estimates the time deformation history of the observed persistent scatterers, the map of the so-called topographic errors, and the atmosphere phase screens. Typically the differential interferometric phase component has three main error contributions: atmospheric contribution, unwrapping error and noise. This work is focused on the elimination and, under given conditions, the correction of the unwrapping errors. The paper presents the main steps of the estimation procedure to automatically detect the outliers generated during phase unwrapping, and to correct them. This outlier detection procedure, which is implemented in the frame of a least squares estimation procedure, gives good results with redundant configurations, i.e. when there is a good ratio between observations (the interferometric phases) and unknown parameters (basically the number of SAR images, which usually coincides with the samples of the estimated deformation time series). The example shown in this work is based on the results obtained at the Institute of Geomatics and the Earth Sciences Department of the University of Milan, in particular in the frame of an ongoing research project funded by the Italian Space Agency.

The paper is divided in two main parts: firstly a description of the proposed procedure is given, where the main steps of the proposed method are described, and secondly one example of results is described.

II. PROPOSED ALGORITHM

The presented procedure determines, given a stack of differential interferograms, the value of the phases for each SAR image by an iterative procedure which exploits the SVD least squares method. Hereafter we call “phase estimation” the proposed algorithm. The implemented algorithm is based on the proposal of Berardino et al. [8].

The input data are unwrapped differential interferogram phases. These data contain different types of errors due to atmospheric effects, unwrapping errors and noise. The proposed algorithm step overcomes the second and third type of errors. In the following we briefly describe the main steps of the input data preparation for the phase estimation.

- Choose suitable pairs of SAR images. The perpendicular baseline has to be generally below few hundred meters.
- Calculates the interferograms and the associated coherence images.
Phase reconstruction (unwrapping): in this step the original differential phase is reconstructed adding or subtracting multiples of 2π from the original values of the differential phases. This step is a critical point because although the phase reconstruction works usually well over high coherence areas, it can produce important errors where the phase noise contaminates the phases. The proposed procedure contributes to correct for this type of errors.

Select a stable area: For each interferogram, the mean phase of this area is subtracted to all the pixels.

Pixel selection: at this point, the pixels which present high coherence along the stack are selected as inputs of the proposed procedure.

Once the input data have been generated we proceed to describe the main steps of the phase estimation algorithm. The used algorithm is an iterative least squares process. It works point wise, that is for each point of the selected interferograms it calculates the correspondent phase values. The phase values of the first image in time (phase 0) are assumed to be zero. The algorithm consists on the following key steps which are repeated iteratively until all the outliers are rejected as observations. For each point/pixel:
1. The phase values are estimated by means of least squares and the residuals are computed.
2. By using of residuals the outlier candidates are defined. These are observations that have residuals bigger than a defined threshold.
3. The observation associated with the biggest residual is temporally removed (outlier candidate).
4. Solve the system again. If the residual of the outlier candidate is a multiple of 2π then the observation is corrected and reaccepted. This represents a correction for the unwrapping errors.
5. Test if the removed observation can be re-entered or rejected, by comparing the new and old residuals.
6. Repeat from the beginning until the list of outliers candidates is empty.

Finally we obtain the values of the phases with respect to the initial phase. That is the phase(0) represent the phase contribution due to the deformation accumulated between the phase 0 and the phase(i), plus the atmospheric component of the original phase image(i).

As a final comment, note that a critical parameter is the available redundancy. Redundancy plays a key role in the steps of the procedure because a good outlier rejection is not feasible with poor redundancies. This should be carefully considered when the images are chosen. The phase estimation algorithm performs a check on the redundancy for each eliminated outlier. This is done because the elimination of few observations could result in a weak network. The phase estimation algorithm checks the topological network which is formed by images and interferograms.

III. ANALYSIS OF RESULTS

In this section we briefly describe the first results achieved with the proposed procedure. The test site is located in Barcelona. The used network consists on 151 interferograms derived from 35 ERS SAR images.

On Figure 1 we report the residuals behaviour for a one pixel stack. In the first picture, which corresponds to the first estimation, we note that the most part of the residuals have high values, which are basically due to the presence of the unwrapping errors. All the residuals which are bigger than a given threshold are considered outlier candidates. The next image represents different points of the iteration process and the last one the final results. The figure shows different examples of behaviour:

- Rejected outliers: observations as 93 or 139 are finally considered as bad observations. Their residual do not improve along the iterations.

- Corrected outliers: see light blue squares. These are points which have residuals multiples of 2π.

- Re-accepted outliers: see points 53 and 149. These points are points that, although after the first step have big residuals, finally are considered as good observations (their bad residuals were due to other outliers).

Although they are based on preliminary analyses, these results are promising. They suggest that the algorithm works properly. This has to be tested over more difficult areas from the unwrapping viewpoint. This will represent the next step in the analysis of the proposed procedure.

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Figure 1: Example of results achieved with the proposed iterative algorithm. The figures show the residuals of the observations in different iterations. The light blue squares correspond to corrected outliers (multiples of $2\pi$), the red circles to candidate outliers, the red arrows to the re-accepted outliers, and the yellow arrows to the rejected outliers.