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MONITORING SLOW GROUND MOUVEMENTS AROUND TUNIS CITY BY DIFFERENT SAR INTERFEROMETRIC MEASURES

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ABSTRACT

This paper presents an application of DInSAR techniques for the assessment of ground subsidences around Tunis City. A long-term analysis using two interferometric techniques were carried out to attempt reliable measurements. In this work, some aspects of interferometric processing softwares are reviewed and possible improvements are proposed in order to get better results.

The convergence of the two different interferometric techniques done simultaneously and independently confirms results accuracy.

Index Terms— Differential interferometry, interferometric coherence, subsidence.

1. INTRODUCTION

A precise knowledge of the Earth surface and its dynamic deformations is fundamental for a great number of scientific problems. SAR and differential SAR interferometry (DInSAR) are operational tools for topographic profile reconstruction [1] [2] and ground surface deformation monitoring [3] [4]. Since 1992, differential interferometry has improved considerably ground deformation measurements and several softwares have been developed for that purpose. The DInSAR approach proved to be an efficient tool (millimetric precision) in many geophysical important applications such as volcano inflations, earthquakes, ground subsidences, landslides, etc.

During the last years, Tunis City (Tunisia, North Africa) has launched a huge city planning project by banking water areas and has known a big growth in urban building and infrastructure. Nevertheless, this investigation may conduct to some residual consequences on the area notably ecological system perturbations causing some ground movements. The differential SAR interferometry is applied to detect, map and quantify the subsidence occurred around Tunis City. A large database of ERS and ENVISAT images has been acquired on this geographical area. This paper describes the temporal survey of Tunis City by different SAR interferometric measurements. These measurements

are obtained using two well known and high-performance interferometric tools which are DIAPASON [5] and ROI_PAC [6].

In this paper, we are interested in testing two DInSAR ground movement estimation methods since interferograms generation to deformation analysis. The first technique is based on correlation analysis (section 2.1) and the second method introduces a new multi-temporal filtering approach (section 2.2). The purpose of this study is to compare ground movement measures obtained by several DInSAR techniques to evaluate the accuracy of the results (section 3).

2. DIFFERENTIAL SAR INTERFEROMETRY PROCESSING

In this study, SRTM DEM and several SAR images, including ERS Tandem data, are used to produce multiple interferograms. Two methods for interferogram generation and deformation detection, done simultaneously and independently are discussed. The first method generates differential interferograms using DIAPASON tool. The estimation of ground movement is done by applying multi-scale complex correlation between interferograms to reduce atmospheric effects. For the second approach, ROI_PAC software is used to produce the same. A new filtering technique based on a multi-temporal coherence map is proposed to deal with ROI_PAC filtering errors especially in poor coherent regions. Then, ground movements are quantified by stacking unwrapped interferograms covering the same period. Finally, a comparison between the two set of retrieved measurements is done to validate ground movement estimation.

2.1. Ground movement estimation based on correlation analysis

The starting point of our study was an archive of SAR images acquired by ERS and EnviSat. At first, an important interferometric data base has been generated. About fifty interferograms were produced, by means of DIAPASON software, aiming at determining the spatial extension and the amplitude of the vertical deformations of the Tunis City region. The information contained in these interferograms is

so various [7] (atmospheric effects, deformations, decorrelation noise, etc.) that their interpretation is difficult. To facilitate the first observation of the generated products and reduce the risk of interpretation errors, HSV (Hue-Saturation-Value) compositions have been computed [Ref]. The idea was to exploit the capacity of the coherence image to represent the reliability of interferogram values. The purpose is to show the interferogram fringes proportionately to their coherence degree, and so, filter out non reliable phases.

The interferometric products (the interferogram, the coherence image and the amplitude image) define the three channels (the phase as the Value, the coherence as the saturation and the amplitude as the Hue). The contribution of this treatment consists not only in the improvement of visual quality but also in the removal of the noise since we highlights only ground deformation in coherent areas.

The figure 1 shows an example of the HSV compositions produced.

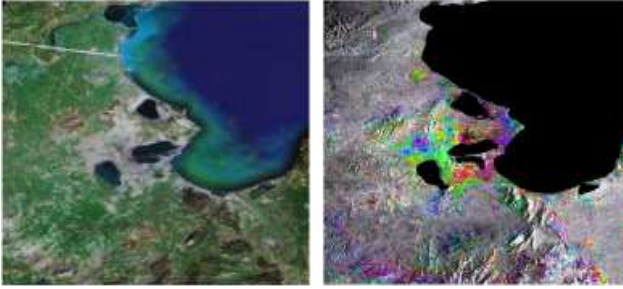


Figure1: Comparison between regions in the HSV compositions (right) and the reality around Tunis City – Google Earth image (left): resulted coherent areas fit perfectly urban regions.

Then, based on the random behavior of troposphere, there are supposedly poor chances that atmospheric fringes related to two different acquisitions occur with the same manner at the same place. Therefore, the common fringes of two interferograms resulting from four different acquisitions are most probably due to ground movements. In this logic, the correlation method measures the dependence of two phase signals in order to detect subsidence. This method proceeds in two stages.

First, the regions presenting similar behavior in two interferograms are selected, which consists in making a multi-scale complex correlation. The two images are browsed pixel by pixel to generate a correlation image. The complex correlation term is computed following this equation:

$$Corr_rate_{\varphi_1\varphi_2} = \frac{\sum_{i \in W_k} (\varphi_{1i} - \overline{\varphi_1})(\varphi_{2i} - \overline{\varphi_2})}{\sigma_1 \sigma_2} \quad (1)$$

where $\varphi_i, i=1,2$ is the complex phase, $\sigma_i, i=1,2$ the standard deviation and k the correlation scale.

A correlation scale processing is introduced to increase the accuracy of the method, since it controls the spatial extension of the event to be detected. This parameter is completely linked to the resolution of the images and the size of the subsidence. Regions having the same fringes in the tow interferograms can be then recognized by their high correlation rate. In the fig 2, we show the result of the correlation of the same interferograms couple using 3 different scales.

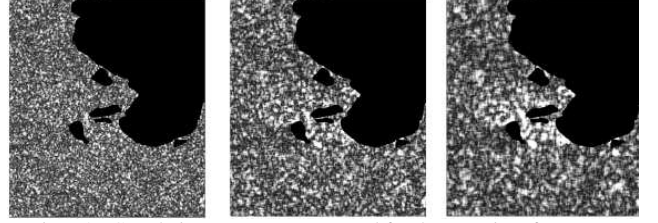


Figure2: Correlation rate maps computed for the same interferograms using different scales (respectively from left to right 4, 7, and 10).

Second, the ground movements are measured by applying a complex average between phases. HSV composition is then used to analyze subsidence results.

Before applying this method, it is necessary to choose carefully the interferograms couples. Their acquisitions must cover approximately the same period of time, so that they can frame the same geophysical event.

The results related to this method are presented and discussed in section 3.

2.2. Ground movement estimation based on filtering method

After applying the different ROI_PAC processing steps on SAR images in order to generate the same interferograms as previously, we notice that as some other filtering techniques ROI_PAC filtering one, presents some limits. Figure 3 shows an example of filtering errors which consists on fringes overflow in some areas characterized by poor coherence values.

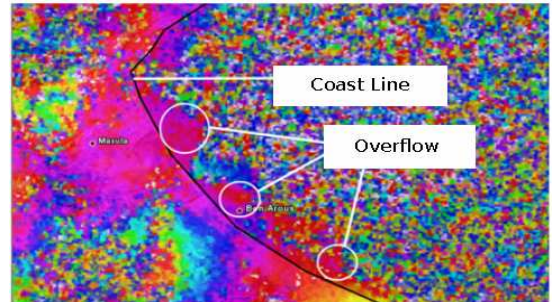


Figure3: ROI_PAC filtering errors for coastal regions.

We have observed this phenomenon over many coast-wise areas. These errors are due to the fact that ROI_PAC

filtering technique described in [8] and based on a non linear adaptive spectral filtering, was designed to operate on high-coherence areas. For this reason, there is an overflow on the frontiers between urban areas and vegetation or sea areas. Thus, we propose a new filtering approach based on temporal coherence information: starting from the generated interferograms, a global coherence map is calculated taking into account the pixel spatial, contextual and temporal information. The schematic overview of the method is summarized in figure 4.

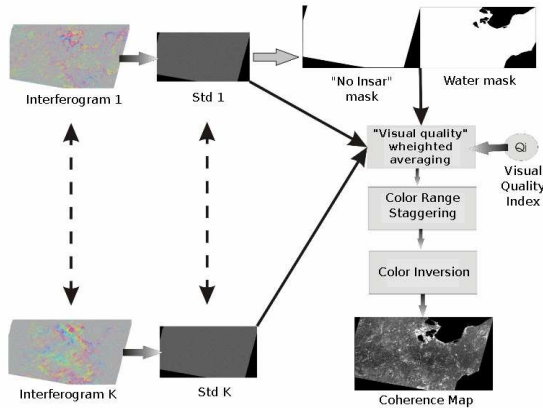


Figure4: Temporal coherence map calculation steps.

Standard deviation images are produced for each individual interferogram and then combined by a weighted averaging. The weighting coefficients are based on visual quality Q of the interferograms. Q represents the Visual Quality which decreases from 3 to 1).

Two masks are introduced to process the temporal coherence map:

- A “water mask” which corresponds to high standard deviation values.
- A “No Insar mask” which corresponds to very low standard deviation values.

Obviously, to reduce computation time, it is not necessary to use all interferograms to process these masks. Only six images, selected randomly, are taken into account but this selection is done several times in order to get the best results.

Thus, post-processing steps (colour range, staggering and inversion) produces the final coherence map. (cf. figure 5).



Figure5: Temporal coherence map obtained using all the generated interferograms. The coherent regions correspond to urban areas.

The resulted coherence map provides global information which persists for all acquisitions. It highlights regions corresponding to reliable phase values which are going to be used for ground movement’s estimation. To extract these regions, three cases are distinguished: very coherent regions are kept, non coherent ones are rejected, and the other regions are interpolated by taking for each pixel a neighbour's value selected relying on a compromise between distance and coherence. This is done by ranking the three nearest neighbours of current pixel according to a score taking into account the distance and the coherence value. Figure 6 shows the result of the filtering process applied on the Tunis City south area. By comparing this result to the one proposed by ROI_PAC, we notice that the proposed method preserves coherent fringes without overflowing on non coherent ones.

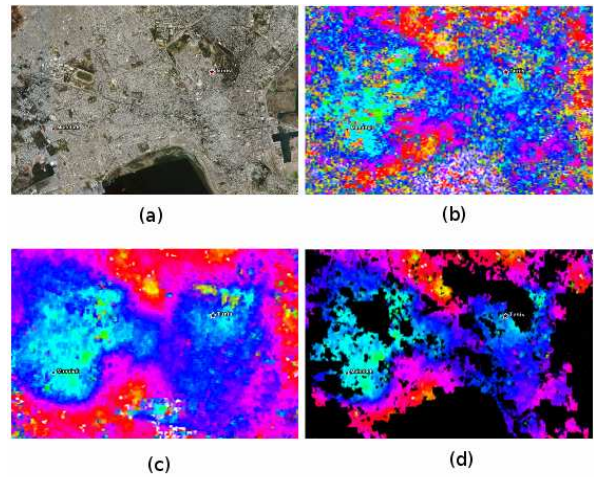


Figure6: Comparison between the filtering proposed technique and ROI_PAC one. (a) the area of study, (b) original interferogram, (c) ROI_PAC filtering results, the proposed method filtering results.

Interferometric fringes which are not filtered by this technique correspond to subsidence or atmospheric artefacts [5]. In order to differentiate between these two kinds of information, we stack unwrapped interferograms covering the same period. Noisy regions indicate pixel phase variable in time related to atmospheric effects while homogeneous regions show constant temporal pixel phase behaviour associated with ground movement effects.

3. RESULTS

This work is experimented using 26 archive ENVISAT and 7 archive ERS radar images covering the region of Tunis City (acquired by means of ESA project C1P.5054). Two sets of 58 differential interferograms were calculated and treated separately by means of DIAPASON and ROI_PAC processing. These interferograms allow the detection and the measurement of several ground movements around the Tunis Lake (cf. figure7). The convergence of the two

different interferometric techniques done simultaneously and independently confirms results accuracy (see table1). The two proposed techniques have the same logic and there is equivalence between the temporal coherence map and the HSV representation. Similar results have been obtained by both methods. This tends also to prove that ground

movements really occurred on this area. It is new information highlighted by the way of differential interferometry. Before this study only few ground measures are done and they do not put in evidence this subsidences.

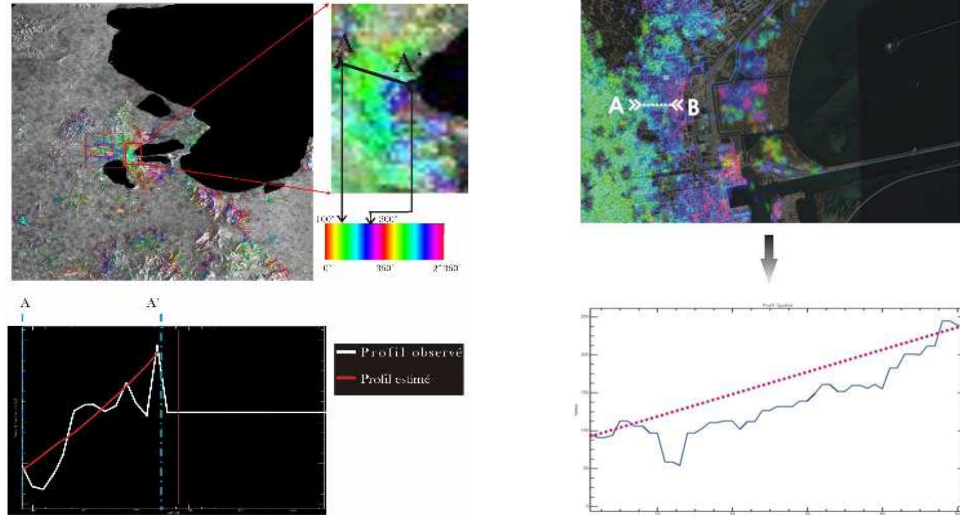


Figure7: The same SAR couple Subsidence profiles-Lake West Region. (left) Interferogram resulted from the first interferometric technique: 0.74mm/mois; (right) Interferogram resulted from the second interferometric technique: 0.69mm/mois.

Table1: Comparison between the two interferometric subsidence measures for three selected regions around Tunis City

| | Surface area | Subsidence measure (mm/mois) | |
|---------------------------|--------------|------------------------------|---------------------|
| | | Correlation technique | Filtering technique |
| Region1: Ben Arous town | 7.32 km | 0.80 | 0.76 |
| Region2: Lake West region | 600m | 0.71 | 0.68 |
| Region3 : El Kram Town | 3.36km | 0.36 | 0.29 |

4. CONCLUSION

This paper highlights the use of DInSAR for ground subsidence with a millimetric precision. Two multi-temporal interferometric processing are developed for this purpose. The obtained results are 98% similar (few millimetres difference) and confirm the subsidence event around Tunis City Lake. The multi-temporal filtering technique seems to be more appropriate for regions with low coherence since it take into account pixel neighborhood. In a future work, more reliable measurements will be produced based on Permanent Scatterers technique [9].

5. ACKNOWLEDGMENTS

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