IMPROVEMENT OF THE TROPOSPHERIC CORRECTION BY ADAPTED PHASE FILTERING

F. Chaabane[*]*,A .Avallone*[**]*, F. Tupin*[*]*, P. Briole*[**]*,*
E .Trouvé[*]*, Y. Trembley*[**]*, J.-M. Nicolas*[*]*, H. Maître*[*]*.*

[*]*Ecole Nationale Supérieure des Télécommunications*
Département TSI – CNRS URA 820 – 46 rue Barrault, 75013 Paris, France
Tel : +33 1 45 81 78 89, Fax : +33 1 45 81 37 94, E-mail : chaabane@tsi.enst.fr

[**]*Institut de Physique du Globe*
Laboratoire de Sismologie – UMR CNRS 7580 – 4 place de Jussieu 75005 Paris, France

ABSTRACT

Tropospheric inhomogeneities can form a major error source in DinSAR (Differential SAR Interferometry) measurements used in slow deformation monitoring. Previous studies introduced techniques to correct these artefacts. In [1] they propose to evaluate and correct tropospheric effects directly from raw differential interferograms by estimating the phase/altitude correlation. Since the wrapped phase noise in these interferograms influences the correction of tropospheric artefacts its removal is mandatory. In this paper, we aim to show that adapted wrapped phase filtering greatly improves the retrieval of tropospheric effects. The filtered interferograms are then used to model these artefacts. Filtered and unfiltered results are compared to quantify the improvement.

1 INTRODUCTION

DinSAR is a unique tool for measuring with great accuracy topography and ground surface motion. However, the microwave radar pulse undergoes an additional time delay when passing through the troposphere due to the index of refraction. This phenomenon causes a phase distortion in radar images. Thus, differential interferograms contain ground deformation fringes mixed with tropospheric fringes.

In order to avoid that atmospheric effects are misinterpreted as ground displacement, it is mandatory to evaluate their contribution and retrieve it from differential interferograms. The method of extraction of tropospheric artefacts, used in this paper, was previously proposed in [1]. This technique uses directly the wrapped phase values to estimate the troposphere. However, most of differential interferograms presents a high level of noise because of the temporal and spatial decorrelation [2]. This problem represents another kind of perturbations that is decorrelated with tropospheric artefacts but has to be removed in order to restore the wrapped phase. In this paper, we show the improvement of the tropospheric correction by phase filtering using a technique proposed in [3].

In Section 2, we present the method of evaluation of the tropospheric effects which is based on modelling the phase/topography correlation computed for the most coherent pixels. Then, we briefly introduce the filtering process used to generate less noisy interferograms in Section 3.1. This method is likely to be appropriate to our problem of tropospheric correction because it restores the wrapped phase.

Section 3.2 underlines the improvement of the tropospheric perturbation estimation when using the filtered phase. We demonstrate that modelling becomes easier and more efficient since many residues due to the wrapped phase noise have been removed. A comparison between filtered and unfiltered interferograms by means of the mean square error is realized to show the improvement impact.

2 EVALUATION OF THE TROPOSPHERIC EFFECTS

Recent works [4][5][6] introduced new techniques aimed at overcoming the problem of tropospheric contribution. When the auxiliary data such as pressure, temperature and water vapour, measured by several meteorological agencies, are known, a possible approach is to compute analytically the tropospheric path delay and to retrieve it directly from the phase [4]. Otherwise, [5] propose a new algorithm able to estimate the acquisition geometry parameters with high accuracy directly from the SAR data, and then derive the space-time terrain displacement map reducing the impact of artefacts contribution. Other studies [6] propose the selection of some corner reflectors (permanent scatterers) to improve their neighbouring pixels coherence and thus have a better tropospheric correction.

Another solution to the tropospheric fringes estimation was proposed in [1]. The main idea is that variations in temperature, pressure or humidity are function of altitude only, especially in the presence of relief, which modulates the thickness of the lowest atmospheric layer crossed by the wave. In this case, we can evaluate and correct tropospheric artefacts directly from interferograms by estimating the phase/altitude correlation. The analysis of the phase/altitude regression requires the selection of a subset of pixels that maintain their coherence over long time intervals in order to better discern the different signals that concur to the interferometric phase. A global coherence map is computed for this goal. It is obtained by classifying the pixels stability on each interferogram using for instance the phase gradient method and by combining the 43 results into one image [1]. The originality of this global mask is that it is based on a large number of images and consequently is expected to be less affected by local and temporal effects related to deformations or local tropospheric effects (see Figure 1). Applying the obtained mask on each interferogram, we study the relation phase/elevation for the most coherent pixels.

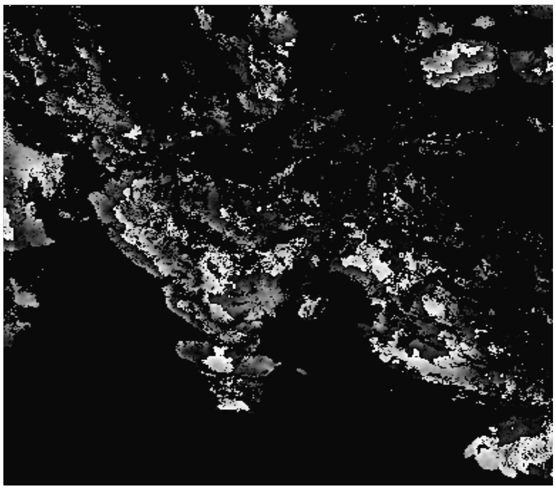


Figure 1: *Data kept after filtering the differential interferograms by the global coherency map.*

A simple analysis indicates that a correlation between topography and phase exists (see Figure 2) and can be estimated with a polynomial model. Because of the wrapped phase, we compute for each selected pixel, the sum of complex numbers with argument the difference between observed phase φ_{obs} and modelled phase φ_{mod}. Therefore the final modulus is maximum when phase differences are constant in average. We use the coherency mask values w_i as a weight for each pixel. The likelihood (or fitness) function to be maximized is then defined as :

$$L(m) = \left| \sum_i w_i e^{j2\pi(\varphi^i_{obs} - \varphi^i_{\mathrm{mod}}(m))} \right|. \qquad (1)$$

where m represents the parameters of the polynomial model.

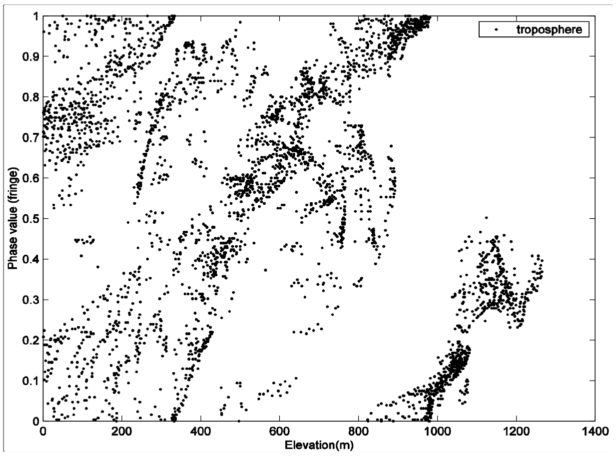


Figure1: *An example of Correlation between the wrapped phase and the elevation related to tropospheric effects. 3810 pixels were selected from a 40kmx40km differential interferogram covering the North part of the Golf of Corinth.*

We use the complex phase for the fitness function because of the problem of phase unwrapping. The lack of coherency introduces many residues and discontinuities in the fringes (see Figure 3 (b) top left corner). In this case unwrapping algorithms unwrap the phase correctly in a local area where fringes are connected but fail to add the right 2kπ between two disconnected zones. This limitation does not allow us to estimate the phase/elevation relation directly from unwrapped interferograms which would permit to use higher order models.

3 IMPROVEMENT OF THE TROPOSPHERIC CORRECTION BY ADAPTED PHASE FILTERING

3.1 ADAPTED PHASE FILTERING[3]

Restoration of the wrapped phase of interferometric data is known as a difficult task mostly because of decorrelation noise. Most of the reduction techniques used to improve interferogram quality rely on the assumption that the phase is locally continuous. This assumption is no longer valid for narrow fringes as deformation fringes for example. Therefore, an estimation of the fringe local orientation and frequency becomes necessary to adapt filters to fringe patterns. This is the purpose of the following method proposed in [3]. The filtering process is based on a local compensation of the terrain slope by a spectral estimation of the two-dimensional frequency of the complex phase signal. Indeed, using a local approximation of the terrain slope by its tangent plane, the fringe pattern is modelled by a complex sine-wave with 2-D frequency *(f_x,f_y):*

$$s(m,n) = e^{j\varphi(m,n)} = e^{j2\pi(mf_x + nf_y)}. \qquad (2)$$

This model is used to perform the fringe measurement by spectral analysis. A modified version of the well-known algorithm called MUSIC is proposed to provide an estimate of the local frequency $(\hat{f}_x(m,n), \hat{f}_y(m,n))$. In order to analyse various fringe patterns with the same accuracy, the algorithm is iterated at several scales. The filtering process is an adaptation of the complex multilooking estimation of the phase to the local fringe pattern by subtracting the local phase variations approximated by the sine-wave of (2). In a filtering window W centred on a pixel P taken as origin, the corrected phase is given by:

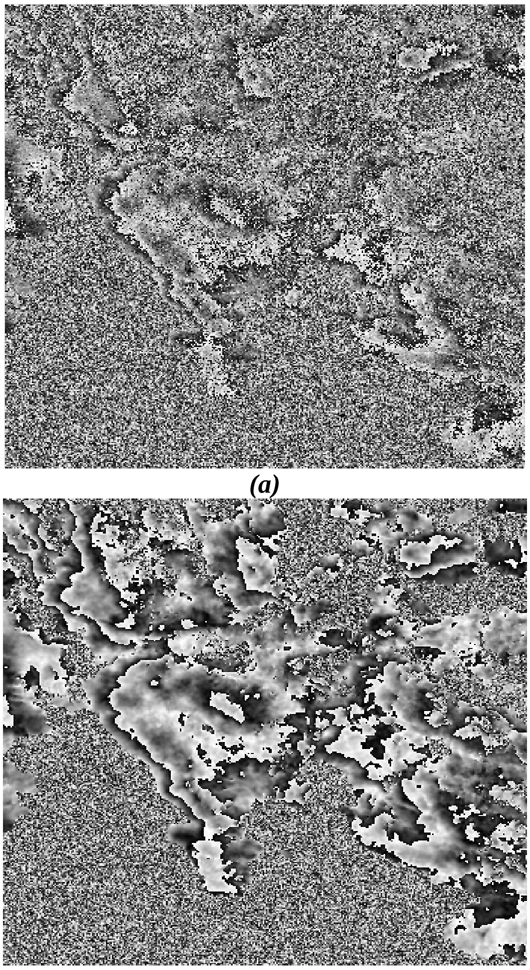
$$\psi(m,n) = \varphi(m,n) - 2\pi(m\hat{f}_x + n\hat{f}_y) \quad (\mathrm{mod}\, 2\pi) \qquad (3)$$

After this local slope compensation, the phase Ψ is a stationary process that only varies because of noise and the differences between the exact fringe pattern of the estimated model.

Accordingly, the slope compensated filter, which extends the spatial complex averaging over a window W, is given by:

$$\tilde{co}(P)e^{j\tilde{\phi}(P)} = \frac{\sum\limits_{(m,n)\in W} am^2(m,n)co(m,n)e^{j\phi(m,n)}e^{-j2\pi(m\hat{f}_x+n\hat{f}_y)}}{\sum\limits_{(m,n)\in W} am^2(m,n)} \quad (4)$$

Where $\tilde{f}$ denotes the filtered phase, $\tilde{co}$ the filtered correlation and *am* the amplitude image. The results of filtering may first be seen visually from the fringe pattern legibility in Figure 3. It is clear that filtering strongly reduces the number of residues.



(a)

(b)

Figure 3: *Filtering process applied to a differential interferogram. (a) Original data. (b) Result of the slope compensated filter. This method reduces strongly the number of residues.*

3.2 IMPROVEMENT OF THE TROPOSPHERIC MODELLING

3.2.1 Data set

In this study, a total number of fifteen ERS1-2 SAR images covering the Gulf of Corinth (Greece) and acquired from 1992 to 1999, was used to produce 43 differential interferograms (the average duration of the interferograms is 3.47 years). The analysis of these interferograms aims to detect the deformation field related to the Ms=6.2 Aigion earthquake occurred the 15th of June 1995. Most of them still contain wide fringes after retrieval of orbital and topographic fringes (the perpendicular baselines do not exceed 100m to allow a better retrieval of the topography phase term). This is probably due to the fact that the region of Golf of Corinth is a coastal and mountainous area and interferometric pairs are influenced by rapid changes of the tropospheric conditions. An analysis of these differential interferograms reveals that observed fringes are topography correlated.

We selected a zone of *40kmx40km* from the North of the Golf of Corinth as a test area. This area is far enough from the earthquake impact. Thus, we assume that it can be treated as a non deformation area. If both effects are present, with the same order of magnitude, no correlation is expected to be observed and it might be impossible to separate the two signals using this approach without any information on the deformation field.

3.2.2 Experimental results

The troposphere correction described in Section 2 is applied on a pair of filtered and unfiltered differential interferograms. Figure 4 shows the correlation obtained in the two cases. The filtered phase/elevation distribution is less dispersed and more regular. This is due to the fact that the filtering process corrects the phase value by the compensation of the frequency estimated phase reducing in this way the noise inside the fringes. Thus, the corrected phase values allow determining a polynomial model, which better fits the phase/elevation regression. The improvement of the filtering method is measured by means of the Mean Square Error MSE.

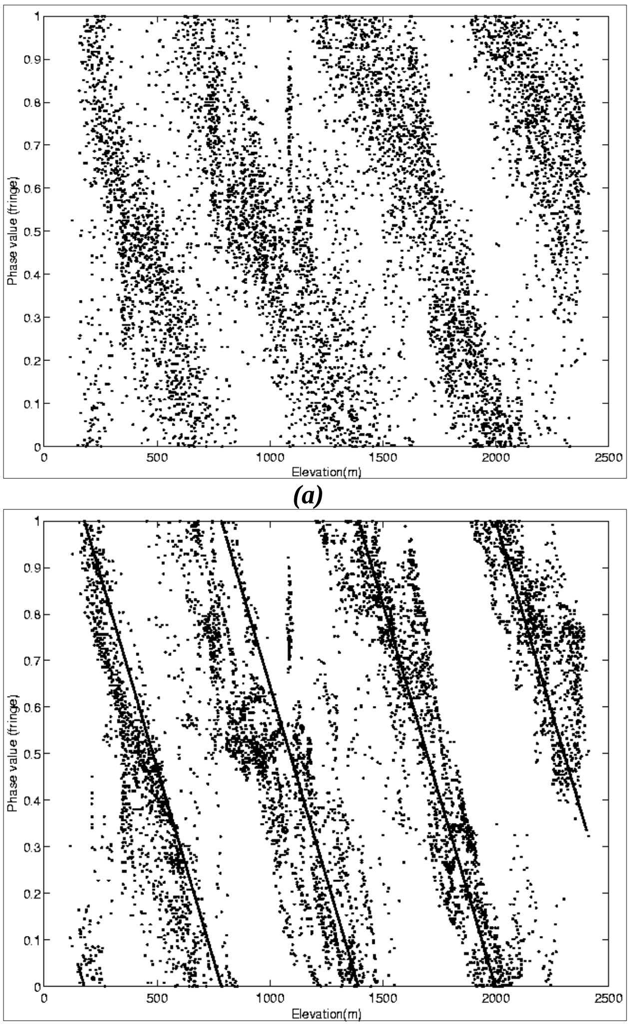
An analysis of the error histograms (Figure 5) shows that these computed residuals are globally lower for the filtered interferograms. Thus the MSE of the filtered case is less than the unfiltered one (1.5 against 3). On one hand, the filtering correction reduces the gap between phase values and the generated model that is why the phase/elevation points are less dispersed in the filtered case. On the other hand, this correction allows to determine a better fitting model because the data points are less dispersed and poor phase values can in some cases bend the model.

An example of tropospheric modelling from filtered interferogram is shown in Figure 6. Compared to Figure 3 (b), it is clear that we reconstruct most of the tropospheric fringes. Therefore, the tropospheric model is in some cases disturbed by local tropospheric variations such as a chain of clouds or rain. This phenomenon causes perturbations in the relation phase/elevation and makes the polynomial fitting a difficult task.

4 CONCLUSION

In this paper we have considered the problem of tropospheric correction in differential radar interferometry techniques. We have shown that the slope compensated filtering technique considerably improves the tropospheric modelling applied on a set of selected pixels. These pixels are filtered twice: first by the global coherency mask and then by the wrapped phase filtering.

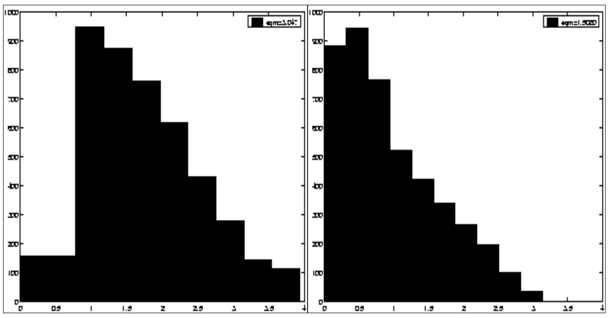
Local tropospheric artefacts are a limitation of this technique but they have a temporary character and are typical to each ERS scene. In [7] a method for the automatic characterization and retrieval of these artefacts is proposed using a combination of interferograms which contain the scene perturbations. This method can constitute a pre-processing treatment of the above tropospheric correction.



(a)

(b)

Figure 4: *Improvement of tropospheric modelling by adapted phase filtering. (a) Un filtered case. (b) Filtered case: Black dots correspond to filtered phase/elevation relation computed for 6663 pixels selected from the coherency mask; gray dots correspond to the theorical* 1^{th} *order model.*



(a) *(b)*

Figure 5: *Histograms of the MSE. (a) Unfiltered case. (b) Filtered case.*

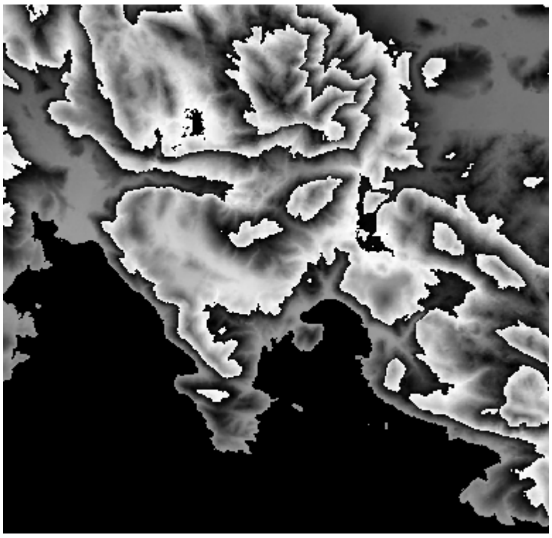


Figure 6: *Example of the tropospheric modelling computed using the MNT and the determined model (y=-0.39x-0.3) then wrapped to be compared to the filtered fringes (Figure 3(b))*.

5 REFERENCES

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