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Land Deformation Monitoring Using PS-InSAR Technique Over Sahel-Doukkala (Morocco)

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Abstract **– Even if land deformation in Sahel-Doukkala may not directly threaten human life, it could lead to serious economic losses. Therefore, the monitoring of this deformation becomes a priority. In this study, PS-InSAR technique was applied in order to extract information regarding land deformation. This method was successful in detecting a considerable amount of PS targets from which the land deformation was estimated. The deformation rate was between -2.4 mm/year and 1.9 mm/year showing an alternation between uplift and subsidence. The origin of this deformation is suggested to be related to tectonic and climatological origins.**

Keywords – Land deformation; PS-InSAR; Sahel-Doukkala.

I. INTRODUCTION

Land deformation can be the result of natural factors such as seismic, volcanic and karst activities as well as anthropogenic factors like groundwater and oil extraction, underground excavation and so on. In Sahel-Doukkala, land deformation is mainly related to karst activities leading to the apparition of sinkholes, dolines, poljes, etc. Moreover, in the Oulja sector, the overexploitation of groundwater for agricultural goals can have a direct impact on this sector characterized by recent deposits. Even if this deformation may not directly threaten human life, it could lead to serious economic losses. For these reasons, comes the need to study and monitor the land deformation in order to understand the extent and the causes of this phenomenon.

Several methods can be used to monitor land deformation. These include extensometers, leveling, GPS surveys, etc. Nowadays, a novel and robust method was introduced by Spaceborne radar interferometry [1], [2]. By means of the analysis of the evolution of SAR phase signals among different acquisitions and subtracting the topographical relief, information regarding the land deformation can be extracted. The technique used for this purpose is called “Differential Interferometry” or D-InSAR and it is used for computing ground displacement or deformation of scatters on the ground between two acquisitions in the Line of sight (LOS) direction. However, D-InSAR suffers from many limitations, where the major limiting factors are spatial and temporal decorrelation, together with atmospheric signal delay. All these factors make correlation too low affecting the precision of displacement measurements in interferograms. These limitations are circumvented to a certain limit by using multiple interferograms of the same imaged area resulting into so-called Multi-Temporal InSAR techniques [1], [3]–[5]. These techniques involve a simultaneous processing of multiple interferograms of the same area in a consistent framework; instead of a single interferogram, in order to reduce errors associated to uncorrelated phase noise, enabling a good separation of various phase contributions such as deformation phase, topographic phase, and atmospheric phase delay. Currently, these techniques can be broadly categorized into two main categories optimized for a specific mechanism of surface scattering which are persistent scatterer InSAR (PS-InSAR) introduced by Ferretti et al. [1], and small baseline SAR interferometry (SBAS) introduce by Berardino et al. [3].

PS-InSAR was first developed and introduced by Ferretti [1], [4], then several PS-InSAR algorithms have been developed in order to improve the selection of PS pixels by using amplitude variations in series of interferograms [6]–[10]. These algorithms have been very successful for urban areas where SAR scenes contain large numbers of man-made structures, which tend to be angular and often represent very efficient reflectors that dominate background scattering. The displacement due to deformation is then estimated based on the similarity of phase history to an existing functional model of temporal displacement [11]. Later, Hooper et al. developed StaMPS algorithm (Stanford Method for Persistent Scatterers) [12], [13], which does not require any prior information of the temporal variation and try to identify and extract the deformation signal from stable pixels in all terrains, including non-urban areas.

The main objective of this paper is to test the application of PS-InSAR technique in order to detect expected land deformation in Sahel-Doukkala. After differential interferograms formation by means of DORIS software package, PS pixels were selected and the deformation information was estimated by using StaMPS algorithm.

II. MATERIALS AND METHODS

A. *Description of study area and dataset used*

Sahel-Doukkala region is located in Moroccan Atlantic coast between latitudes 33°20’N and 33°15’N. The topography of the area includes two most significant units, which are the

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Sahel and the Doukkala. The Sahel which consists of a combination of many consolidated dunes formed by Pliocene-Quaternary limestone, represents a gently rolling hills with the presence of some local steep slopes. In addition, the Sahel includes a sub-unit called the Oulja, which is located near to the ocean. This area is a quite big depression containing wetlands and important agricultural activity. The second main geomorphological unit is the Doukkala, and it remains as wide plain characterized by very low topographic variation. The area of interest to investigate the application of PS-InSAR method is covering an area of 15 km x 15 km (212 km^2) containing the Oulja and Sahel sectors (Fig. 1). The dataset used for this processing consists of 26 SLCs SAR images acquired by Envisat ASAR between November 2003 and September 2010 along descending orbit with an incidence angle of 23˚.

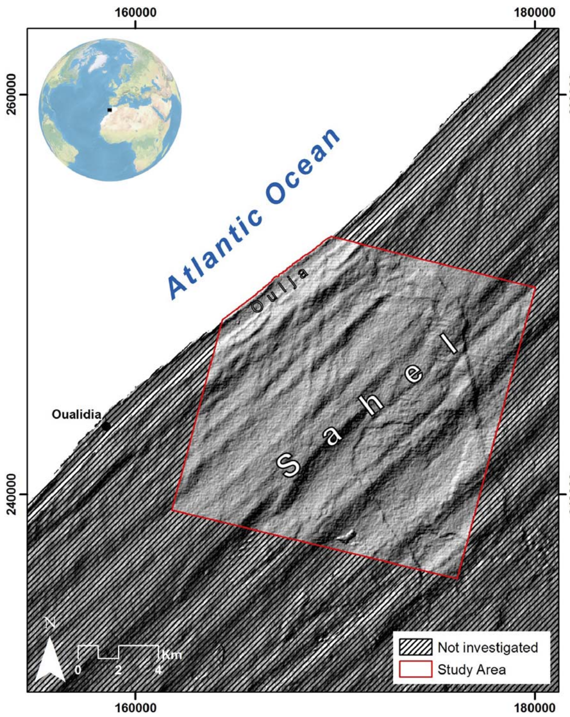

Fig.1. Location of the study area.

The master image has to be selected in such a way there is less decorrelation in most of the interferogram pairs which can be caused by large perpendicular and/or temporal baseline [13], [14]. The baseline that causes maximum decorrelation is called critical baseline which is around 1.1 km for Envisat SAR images, while the temporal decorrelation is site specific and depends on the study area. For our case, the master image with date acquisition 07-03-2006 was chosen as master image on the basis that should not have too large temporal baseline and not have perpendicular baseline greater than critical perpendicular baseline. For all dataset, the absolute values of perpendicular baselines are less than 1000 m and don't exceed the critical value, while the temporal baselines vary from -840 to 1645 days.

B. *PS-InSAR analysis*

In this paper, StaMPS v3.2.1 (Stanford Method for Persistent Scatterers) was chosen for performing PS-InSAR analysis over the investigated area. StaMPS which originally developed to monitor volcanic activities [11] has shown its large applicability and effectiveness in non-urban areas. It is adapted as an open-source solution to LINUX system, by combining mainly three other softwares, among others, which are ROI_PAC for focusing raw SAR data, DORIS software for forming differential interferograms and MATLAB for PS processing. The flowchart in Fig. 2 demonstrates the analysis scheme used in this paper.

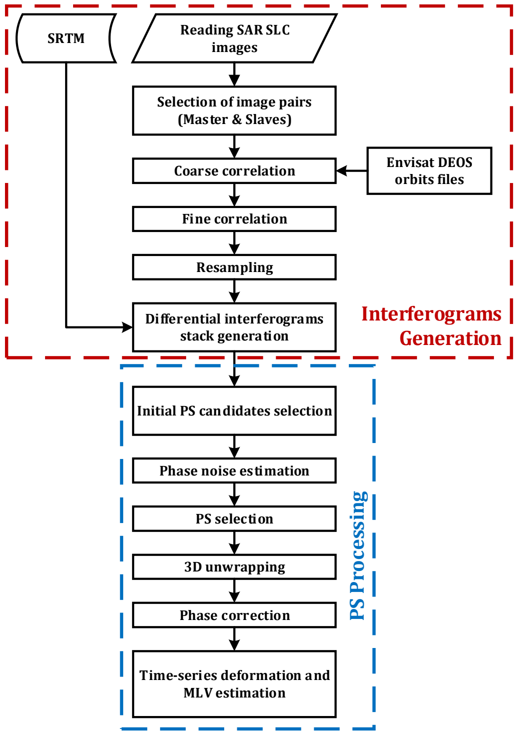

Fig.2. Framework used for estimating deformation.

1) *Interferograms Generation*

After reading SLC images, SAR image with date 07-03-2006 was chosen as master image while the others were called as slave images. Then, co-registration of all the slave images according to the master image was performed to identify the same ground position in different repeat-passes. This procedure was separated into two steps: coarse and fine co-registration. The first step which aligns master image and slave images on pixel level accuracy was performed by using high precise DEOS orbits files of Envisat. Next, a fine co-registration was done by applying automatic correlation techniques in order to obtain sub-pixel alignment accuracy. At the end of this step, the overlap region in each slave image was resampled to the master image.

Once all slave images were co-registered and resampled to the master image, they were processed to generate interferograms by complex multiplication of the master image and the slave image, where the phase information consists of the difference observed between both acquisitions. Then the reference phase (w.r.t WGS84) for every pixel in the master image and slave image was subtracted from the corresponding interferogram. Next, SRTM DEM was used as reference DEM in order to remove the topographic phase and to generate the differential interferograms. After obtaining differential interferograms, work will proceed on PS processing.

2) PS Processing

PS processing in StaMPS was performed in eight main steps. The first step consists of an initial PS pixel candidates selection by using the amplitude dispersion index. Then the phase stability of PS candidate pixel was determined by estimating the phase noise value for each candidate pixel in every interferogram. After that, pixels were selected on the basis of their noise characteristics, dropping those that are due to signal contribution from neighboring ground resolution elements and those deemed too noisy. Then, selected PS pixel candidates were corrected for spatially-uncorrelated look angle error (SULA) to estimate the phase due to deformation. Then, a 3D phase unwrapping method was performed on the selected PS for converting wrapped phase into unwrapped phase. The following step consists of estimating the spatially correlated look angle error (SCLA) simultaneously with master atmosphere and orbit error (AOE), which will be subtracted from the wrapped phase. At the final stage, the obtained wrapped phase was unwrapped once again and used later to estimate the Mean Line of sight velocity (MLV) in mm per year.

III. RESULTS AND DISCUSSION

In this study a set of 25 differential interferograms was generated with respect to the master image (07-03-2006), covering a time period between 18-11-2003 and 07-09-2010 (Fig. 3). The colored areas in each interferogram show the wrapped phase of each interferogram where areas present high coherence. Areas that lack interferometric coherence are uncolored. For example, interferogram from 01-12-2009 shows a stable and smooth wrapped phase with a relatively good coherence, while strong decorrelation can be seen in the case of 18-11-2006, 11-05-2004, 20-07-2004, 26-04-2005, 05-07-2005 and 27-03-2007, where almost a total loss of coherence occurs and nearly whole scene is regarded as noise. The same behavior is also observed in the unwrapped phase of selected PS (Fig. 4). In this figure, all unwrapped interferograms were referenced to the master image to observe unwrapping errors (SCLA and master AOE), which were perceived as phase ramps in the unwrapped interferograms. The stronger presence of these errors was observed at the same interferograms mentioned above. Moreover, interferogram from 11-01-2005 shows fringes parallel to dune ridges which may be caused by inappropriate subtraction of topographic phase, while interferogram from 18-10-2005 shows a hammock pattern which may refer to the presence of atmospheric effects (e.g. cloud with high humidity). This pattern was also observed in the corresponding unwrapped interferogram. As the differential interferograms and unwrapped phase still need some enhancement by removing interferograms with high decorrelation; large SCLA and AOE, we just show here the initial Mean Line of sight velocity (MLV) along the LOS direction.

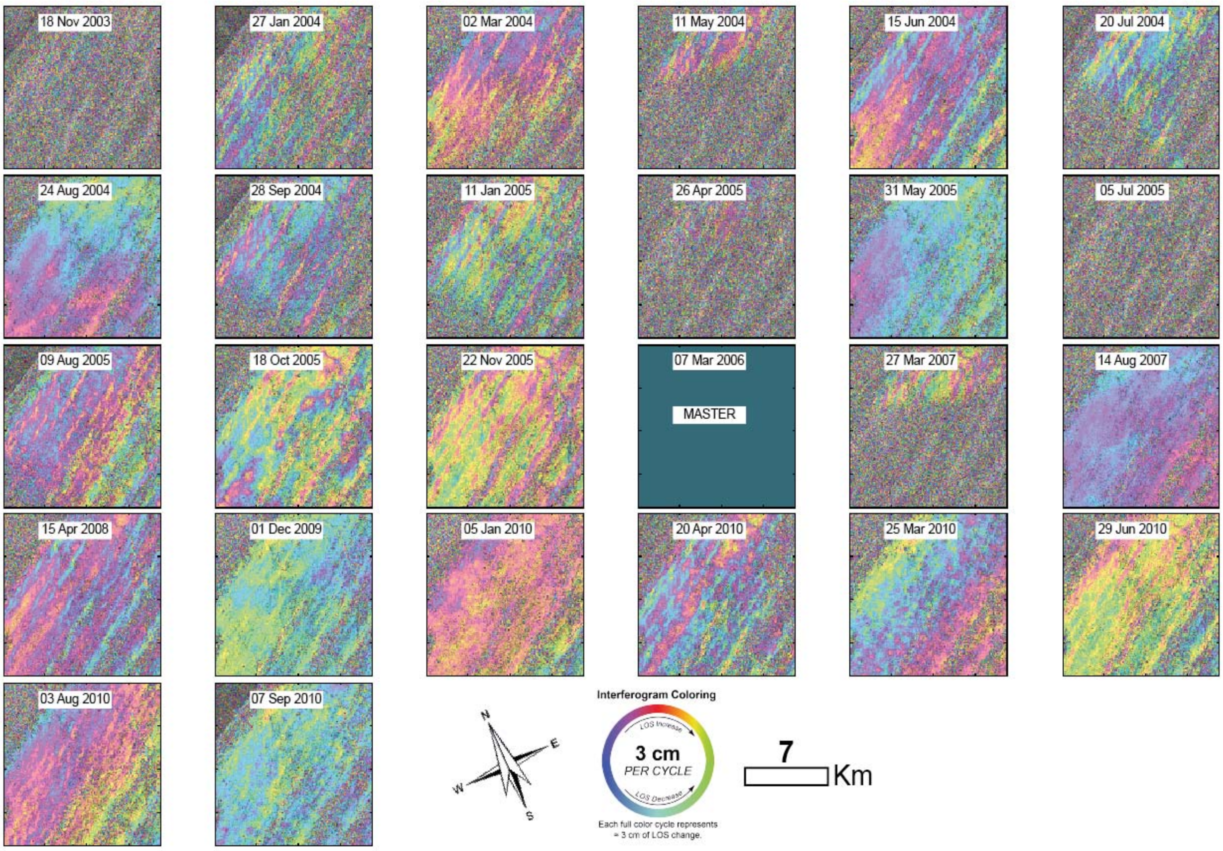

Fig. 3. Differential interferograms referenced to the master image (07-03-2006) after subtraction of reference phase and phase due to DEM (each full color cycle represents ≈ 3 cm of displacement in LOS direction).

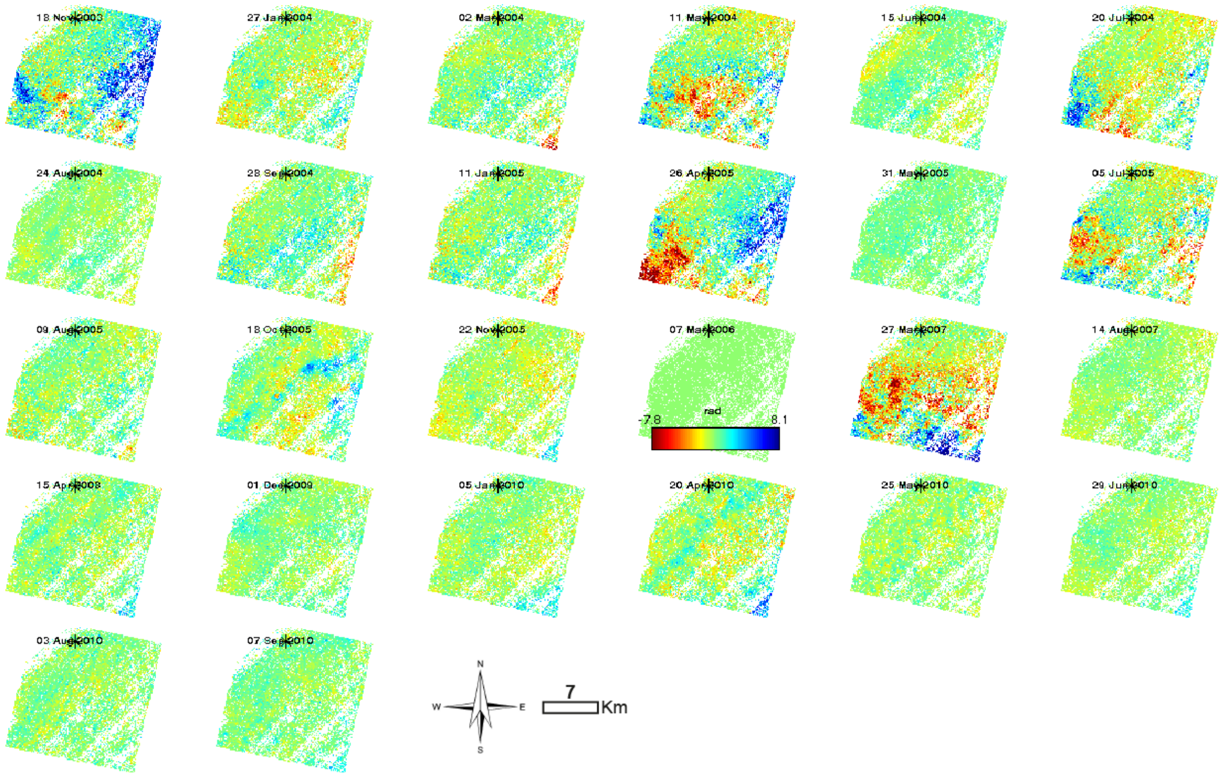

Fig. 4. The unwrapped phase of each interferogram referenced to the master image.

The obtained unwrapped phase was then used to estimate Mean Line of sight velocity (MLV) along the LOS direction in mm/year w.r.t the reference area (marked by the asterisk mark in the North part of the study area) (Fig. 5). Positive values (green to blue) represent a decrease of the sensor-to-target range distance, in other words, displacement toward the satellite (uplift), while negative values (yellow to red) indicates displacement away from the satellite (subsidence). The total number of all PS obtained was around 119791 points. The empty sector over the Oulja indicates that the used approach failed in detecting PS over agricultural plots.

It can be revealed that the obtained MLV map shows that the study area is relatively stable (green to light blue) with a little ground motion up to ±2 mm/year. Areas in southwestern and eastern parts of the study area show a moderate uplift around 1.5 mm/year, while a strong subsidence area was observable in the extreme southeast corner of the study area. This subsidence may not reflect a ground deformation, but it can be due to residual processing errors such as SCAL or AOE errors. This effect is also seen in the unwrapped phase shown in Fig. 4 (interferograms 02-03-2004 and 20-04-2010). However, a remarkable deformation was observed in the north of the study area. This deformation shows a subsidence up to 2.3 mm/year which is located within the damage zone of the fault of Sidi Abdallah ben Youssef with a linear pattern oriented EES to NW, which suggests a tectonic origin of this deformation. Moreover, the active state of this deformation may indicate an actual reactivation of this fault which reveals a neotectonic activity in the study area.

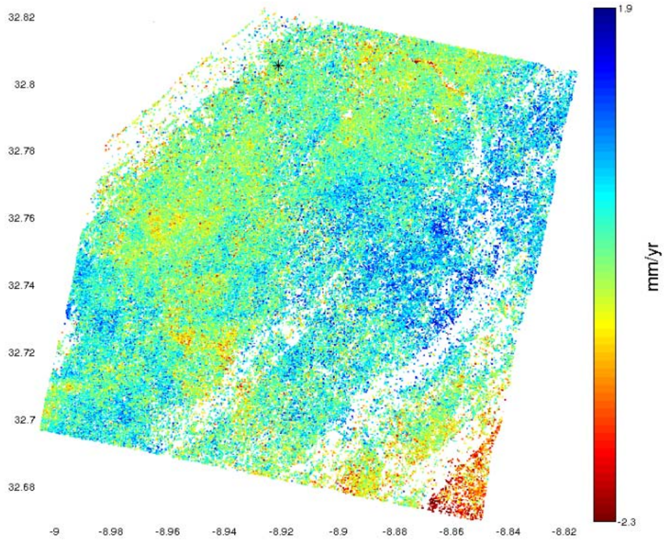

Fig.5. Deformation expressed as Mean LOS Velocity (MLV) in mm/year relative w.r.t reference area (the asterisk mark in the North of the study area).

A time series analysis of some few PS targets in specific regions was performed and discussed in order to provide a deformation estimate to each of the acquisition dates the used SAR images. Fig. 6 shows the location of different regions of interest with the temporal ground motion deformation in each region. The temporal analysis shows an alternating behavior between subsidence and uplift with a considerable variation (may be related to noisy PS). For region *A*, a considerable decrease in MLV was observed indicating a linear deformation (subsidence) in time, while region *B* shows a stable trend of MLV. The alternation between uplift and subsidence from year to year cannot be related to a tectonic origin as the example shown before but rather to a phenomenon that changes annually. Therefore, a further comparison between the region *A* and rainfall measurements for the years 2003 and 2005 was performed (Fig. 7). This comparison shows a strong correlation between interferograms with decreasing MLV (subsidence) and dry season, while the increase of MLV (uplift) is strongly correlated with heavy rainfall seasons. Since the study area is mainly composed of hard rocks formed by Cenomanian and Pliocene-Quaternary limestone, this correlation between rainfall and surface deformation can be related to volume variation in surface features (clay and silt) due to water/solid interaction at a microscopic scale.

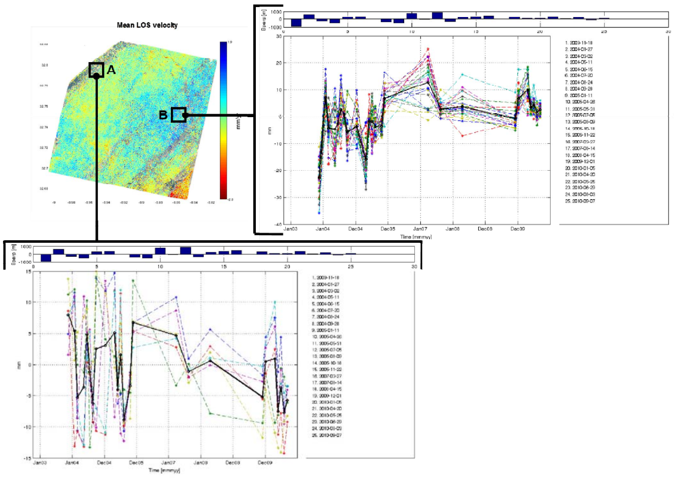

Fig.6. MLV of ground deformation in mm/year marked in Oulja (A) and Sahel (B) sectors.

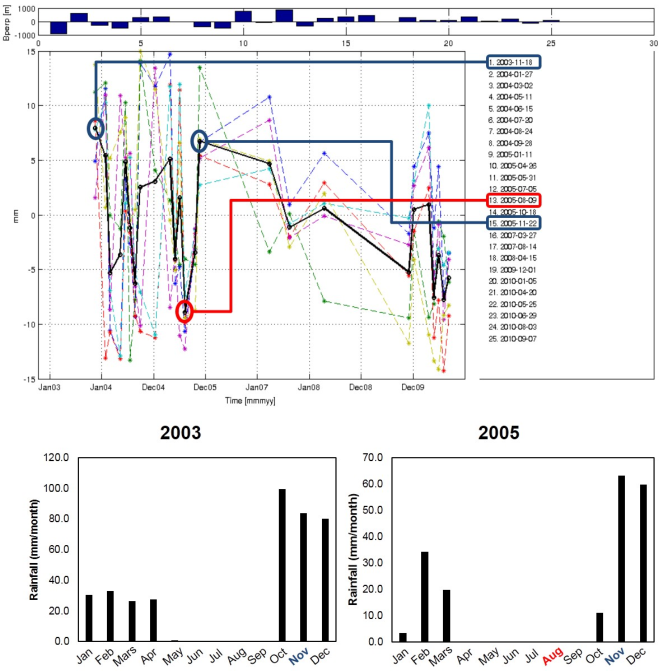

Fig. 7. The relationship between ground motion in region A, and rainfall in 2003 and 2005.

IV. CONCLUSION

The main objective of this study was to explore the ability of PS-InSAR technique in detecting land deformation over Sahel-Doukkala by using Envisat SAR data. This technique was successfully able to identify a considerable amount of PS pixels and therefore to measure the land deformation of the study area. Deformation rate was between -2.4 mm/year and 1.9 mm/year showing an alternation between uplift and subsidence. The origin of this deformation is suggested to be related to tectonic and climatological origins. Our results are considered preliminary since the processing needs more enhancement, therefore, final conclusions can't be made.

However, our results are considered originals and very encouraging as this is the first time that this kind of works was realized in our study area. Therefore, future research studies, will concentrate on the enhancement of the technique by trying advanced techniques such as Small Baseline (SBAS) and MTI techniques. Also, exploiting the large archives of both ERS and Envisat SAR in addition to actual SAR data such as Sentinel-1A/1B will be considered. This large dataset will allow us a good monitoring of surface deformation over a long period and also will allow us to decompose this deformation into horizontal and vertical displacements using both ascending and descending track which will give a reliable information for better understanding of the neotectonic, karst activity and surface deformation related to groundwater overexploitation.

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