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Use of optical image correlation and interferometric synthetic aperture radar in the identification of seismic faults, In northeastern (ne) algeria

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ABSTRACT:

The assessment of the seismic risk in the North-East of Algeria is one of the main challenges for the development of the region. The seismic hazard diagnosis begins with the identification of active structures and the traceability of seismic faults. This approach comes up against various difficulties, in particular the complexity of the geological context, the weakness and imprecision of the existing geo-cartographic background, the predominance of terrigenous facies and the degradation of the morphological expressions of the deformations.
Remote sensing by its two techniques: the correlation of optical images and Interferometric Synthetic Aperture Radar, constitutes a valuable means not only for the monitoring of disasters but also for the management of risks and the integration of these hazards into the sustainable development plans of urbanization.
This study presents the mapping and analysis of coseismic deformations, based on Sentinel images, following the shock of magnitude 4, 9 on August 2020 in Wilaya of Mila, and that, which occurred on November 2020 in Wilaya of Skikda, of magnitude 5, 2.

Keywords: *Correlation of optical images, Interferometric Synthetic Aperture Radar, earthquake, sentinel, active fault.*

1. INTRODUCTION

Assessing seismic risk in North-East Algeria poses a significant challenge for regional development. The initial step in diagnosing seismic hazards involves identifying and tracking seismic faults, but this process encounters several obstacles. These obstacles include the intricate geological context, the limitations and inaccuracies in the current geospatial mapping, the prevalence of terrigenous features, and the rapid deterioration of morphological signs of deformations.

The seismic faults (The previously unmapped seismic faults) that activated the one earthquake of MW = 4.9 that hit the Wilaya of Mila on 07/08/2020, The second

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seismic event is the Mw 5, 2 earthquake that occurred on 22 November 2020, in the Wilaya of Skikda (North-East Algeria). Was detected following the mapping and analysis of the deformations co-seismic, and was identified through the utilization of radar interferometry applied to sentinel radar satellite imagery. Additionally, optical image correlation using the MicMac open-source correlator developed by IGN, combined with seismological data, played a significant role in the detection and analysis of these seismic events.

Studying those deformations enabled us to gain a deeper understanding of the underlying causes and mechanisms of the events.

In the viewpoint of geology, northern Algeria is part of the Maghrebides Alpine chain, extending from Gibraltar to the Calabria region [1].

Several geological domains have been identified in this region (from north to south): the internal zones known as the Kabylian basement (Greater and Lesser Kabylies, hereafter named GK and LK respectively) are made of granitic, gneissic and metamorphic rocks (schist and Ordovician series) [2], characterized by Pan-African and Variscan radiometric ages [3] and [4]. These basement blocks are bordered to the south by the Djurdjura Range and the ‘’Dorsale Calcaire’’ [5] and [4] which represents the former southern European tethyan margin. On its northern border, the Kabylian basement is overlain by unconformed Oligo-Miocene conglomeratic clastics of the OMK (“Oligo-Miocene Kabyle”) unit of fluvial origin [6] and [4] including a siliceous lithostratigraphic marker at the top, made up of chert and dated at 19 ± 1 Ma [4], [1] and [7]. Further northward, the Numidian flysch nappes, frequently associated with olistostromes, were emplaced over the OMK unit [1] and [5] by gravity sliding [4]. The commonly thrusted Tellian series are overlain by a Middle Miocene molasse [4] that was deposited after the onset of the collision between the Kabylides and Africa.

The LK block is found to be in an overthrusting position relative to the external zones which involves the nappes of the Tellian flysch as well as underlying para-autochthonous units derived from the former African passive margin [8], [9] and [10].

The Tellian Atlas of Algeria underwent significant tectonics during the Neogene time. Neotectonics’ features correspond to E-W to NE-SW trending folds, reverse faults affecting Quaternary deposits [11] and [12]. Along the folded mountains, intermountain Neogene post-nappe Basins are characterized by the presence of Miocene and Plio-quaternary sediments (e.g., Soummam, Hodna, Constantine, and pull-apart Guelma basins [11] and [13]).

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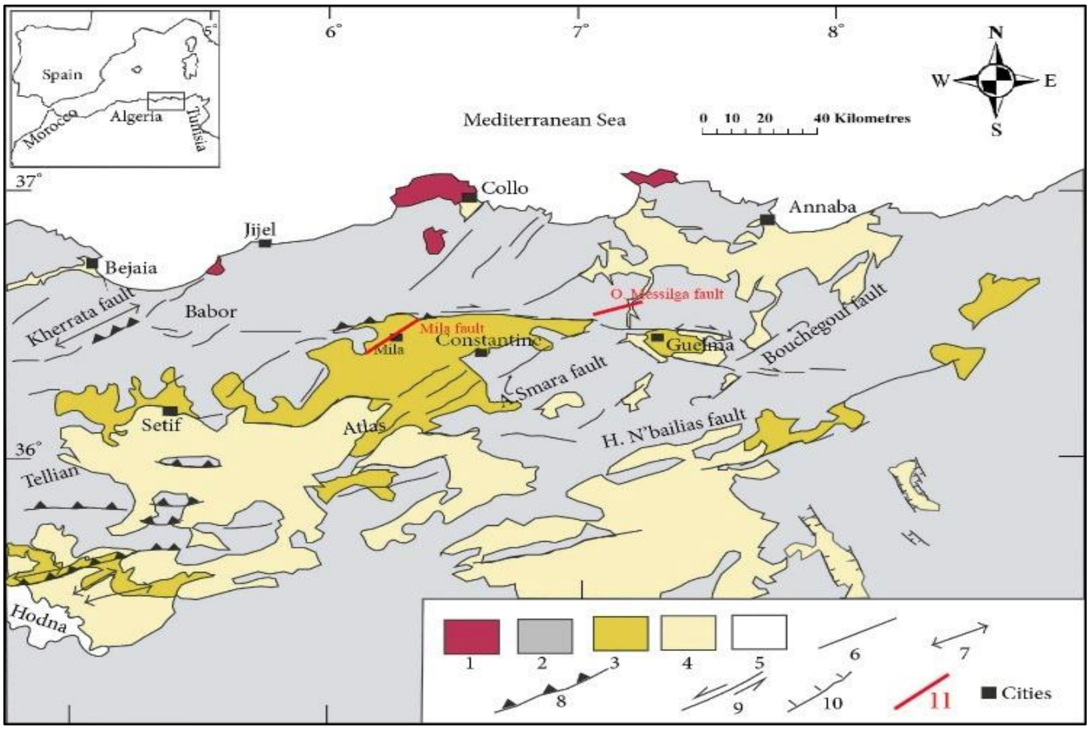

Figure 1: Tectonic map of the Eastern Tellian Atlas of Algeria modified from [14]:
(1) Volcanism, (2) Jurassic-Cretaceous and lower Cenozoic basement,
(3) Neogene post-nappe deposits, (4) Plio-Quaternary deposits,
(5) Quaternary deposits, (6) fault, (7) anticline, (8) reverse fault,
(9) strike-slip fault, (10) normal fault and (11) seismic faults from this study.
Source : S. Maouche et al. Tectonic and Hydrothermal Activities in Debagh, Guelma Basin (Algeria)

2. METHOD AND MATERIALS

A. Correlation of opticals images :

Micmac has been developed at the *National Institute of Geographic and Forestry Information* (IGN) and the *National School of Geographic Sciences* (ENSG), since 2003. Initially, the software tools were developed having in mind exclusively the IGN’s cartographic production. The independent tools were interfaced in 2005 via an XML framework, allowing the user to freely parametrize the calculations at all processing stages. In 2007, IGNbegan to freely distribute Micmac under the CECILL-B license that is a version of the L-GPL license adapted to the French law.

Since September 2011, MicMac has acquired a tool for quantifying earthquakes. Although there is other software to do this (Cosi-corr and MEDISIS), the goal was to have a completely free tool, which scientists can use in open-source mode; and to have a more configurable tool.

The module used for the calculation of the deformations is "MM2DPosSism", which makes it possible to calculate the horizontal deformation in sub-pixel from two satellite images, ortho-rectified and co-recorded, one acquired before the earthquake and the other after the chock.

B. Interferometric Synthetic Aperture Radar (InSar):

Interferometric synthetic aperture radar (InSAR) has achieved great success in various geodetic applications, and its potential for ground deformation measurements on the large scale has attracted increasingly more attention in recent years. The increasing number of synthetic aperture radar (SAR) satellite systems have steadily provided a large amount of SAR data. Among these systems, the Sentinel-1 mission can be considered a milestone in the development of InSAR techniques, offering new opportunities to monitor global surface deformation with high precision, due to its wide coverage, short revisit time, and free access.

3. CASES STUDIES AND DATASET:

The case studies we present are two recent events occurred in 2020. One investigated case is the earthquake that took place on 07 August 2020, in Wilaya of Mila. It is an Mw 4, 9 event, and its focal mechanism is representative of an inverse type fault. The second seismic event is the Mw 5, 2 earthquake that occurred on 22 November 2020, in the Wilaya of Skikda.

3.1. Mila event:

Interferometry Synthetic Aperture Radar (InSAR) Images. In order to understand the extension and the spatial distribution of the triggered landslides, we used two Sentinel-1A.Interferometry Synthetic Aperture Radar (InSAR) images taken before and after the August 7th earthquake. The events of this seismic crisis are summarized in the following table:

Table 1. Earthquake and aftershocks studied, linked to the Mila fault

Date	Mw	Localization
1/8/20 13:38	3.3	5 Km North-east of Grarem
7/8/20 7:15	4.9	2 Km South-East of Hammala
7/8/20 12:13	4.5	3 Km South of Hammala
10/8/20 11:31	3.2	2 Km North-East of Grarem
11/8/20 14:50	3,5	5 Km North-west of Grarem
23/8/20 15:24	3.3	3 Km Oust de Grarem
23/8/20 18:14	3.3	2 Km south of Hammala
31/8/20 14:09	3.3	2 Km North-west of Grarem
1/9/20 21:57	3	9 Km Oust de Grarem

The 4.9 magnitude earthquake, which occurred on August 07, 2020, in the Wilaya of Mila. Its focal mechanism represents an inverse fault. The main shock triggered a massive landslide that affected much of the town of Mila.

Figure 2. Panorama and disorders of the Mila landslide.
Source: Author's 2020

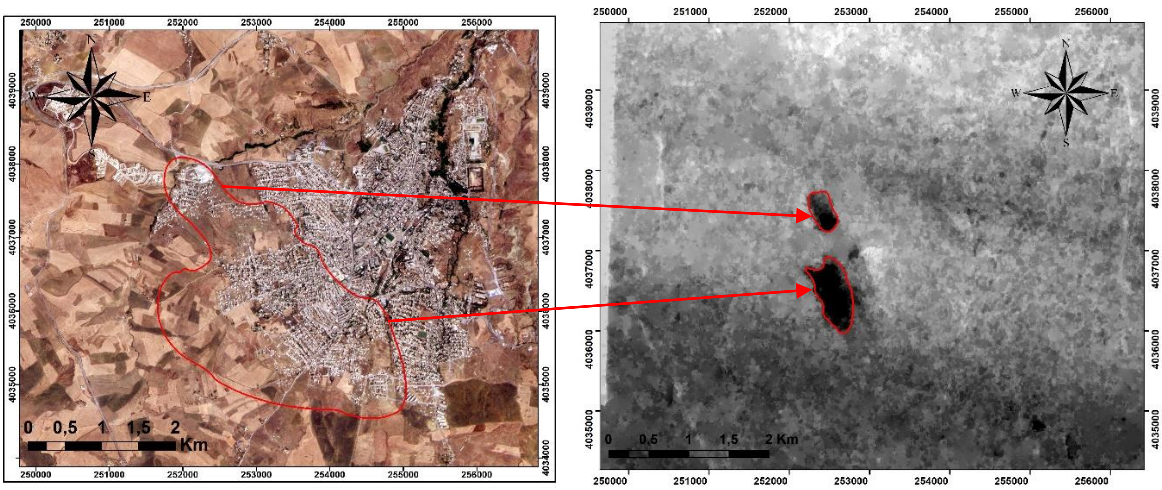

Figure 3. Extract of Planet optical satellite ortho-images showing the El Kherba landslide Of Mila's region; Planet image showing the landslide perimeter with the several affected and threatened constructions

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3.2. El Harouch event:

The events of this seismic crisis are summarized in the following table:

Table 2. Earthquake and aftershocks studied, linked to the Oued Messilga fault.

Dat e	Mw	Localization
22/11/20 04:53	5,2	12 km SW of El Harrouch
22/11/20 06:17	3,9	12 km SW of El Harrouch
22/11/20 12:10	3,9	12 km SW of El Harrouch
23/11/20 11:55	3,4	12 km SW of El Harrouch
24/11/20 10:14	3	11 km SW of El Harrouch
17/12/20 04:53	3,8	10 km West of B. Hamdane

The atmospheric conditions forced us to choose the two images of the Sentinel 2B satellite, in descending mode, acquired on 02/11/2020 at 10:21 a.m. (20 days before the earthquake), and 01/01/2021 at 10:24 a.m. (40 days after the earthquake), and 16 days after the earthquake of 11/17/2020.

The two images used to establish the interferogram are "SLC" type from the Sentinel 1B satellite, in descending mode, these images were acquired on 11/13/2020 at 5:37 am, (10 days before the earthquake) and on 11/25 / 2020 at 5:37 a.m.

(3 days after the main earthquake, and a few hours after the last aftershock of magnitude 3 (Mw3)).

Figure 4. Damage of 22/11/2020 earthquake in El Harrouche
Source: Author’s 2020

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4. RESULTS AND DISCUSSION:

Two previously unknown faults were identified as being the seismic faults that generated the studied earthquakes:

4.1. Mila fault:

The two techniques present deformations, which are linked to the same seismic fault. A strike-slip fault, which connects the epicenter, confirmed by the deformations of both sides.

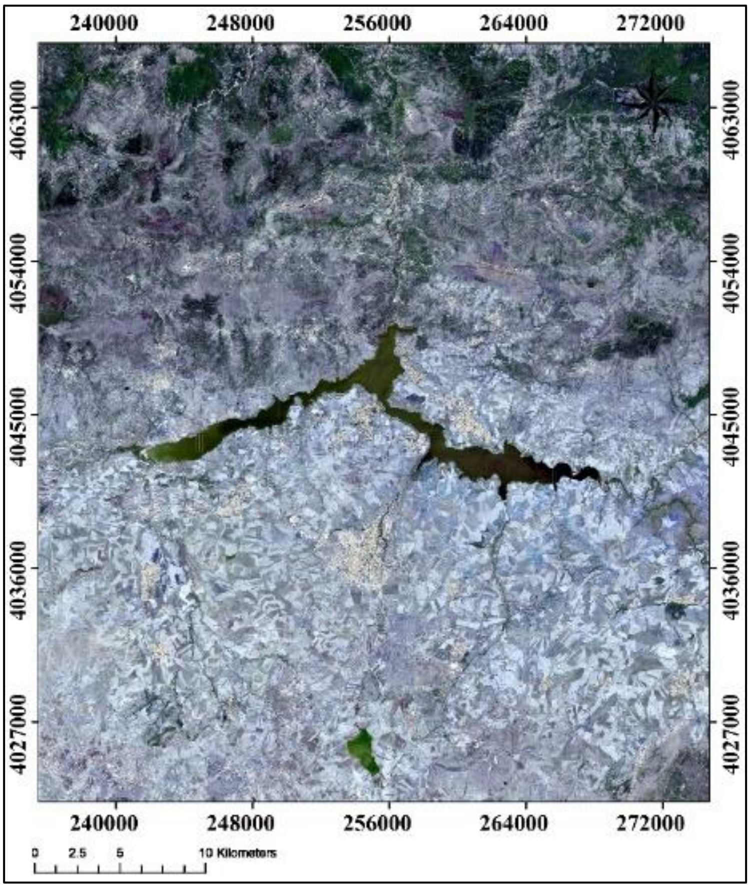

Figure 5. Extract of Sentinel 2 image of Mila's region

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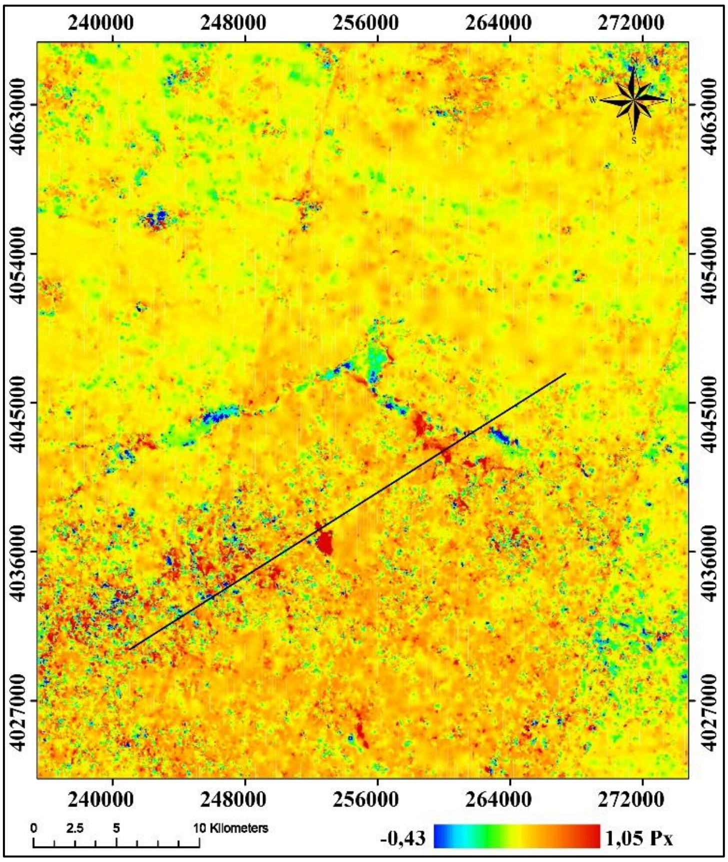

Figure 6. Horizontal displacements between the **02/08/2020** and **20/08/2020**

Although the nature of the focal mechanism according to the USGS is a front strike-slip fault, the co-seismic displacement map shows that the vertical component is also important; a differential uplift is clearly emerging on either side of the activated fault sections. By this seismic crisis.

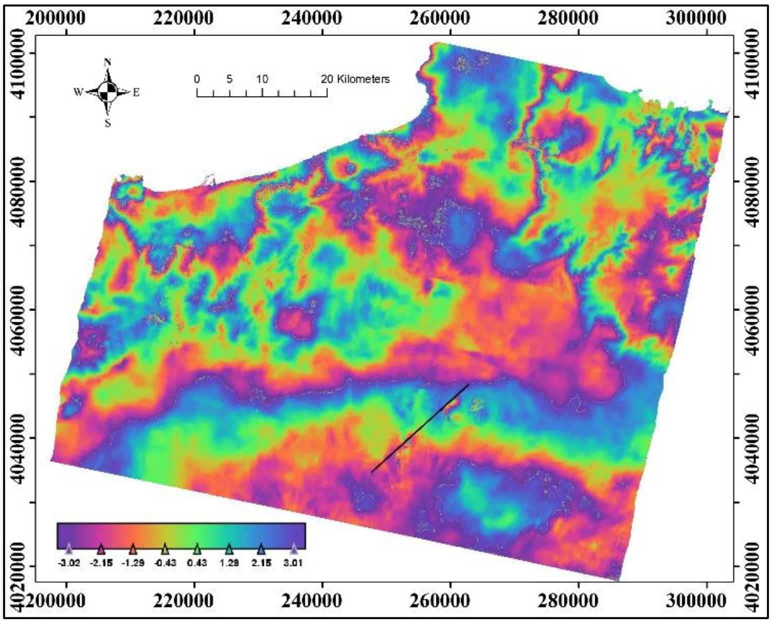

Figure 7. Interferogram from the **07/08/2020** earthquake in Mila

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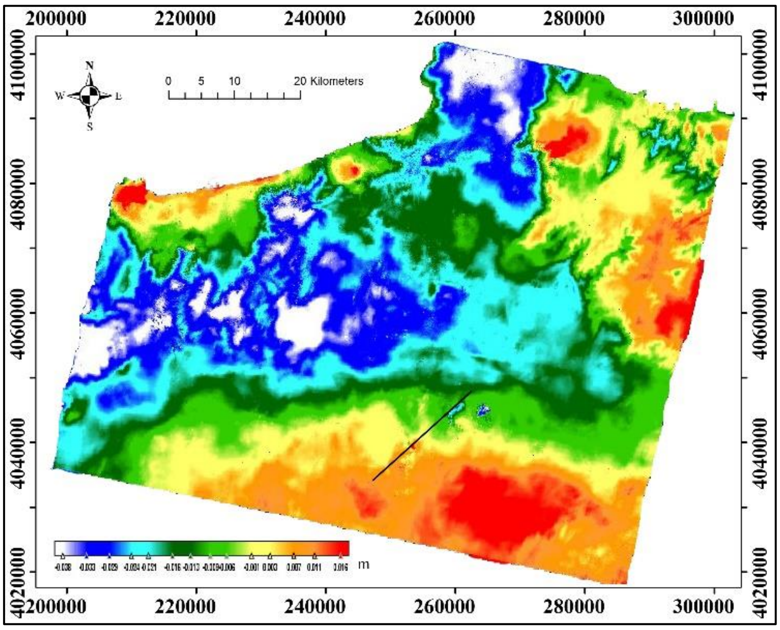

Figure 8. Vertical movements of the **07/08/2020** earthquake

The two techniques present deformations, which are linked to the same seismic fault, a strike-slip, fault which connects the epicenter, confirmed by the deformations of both sides.

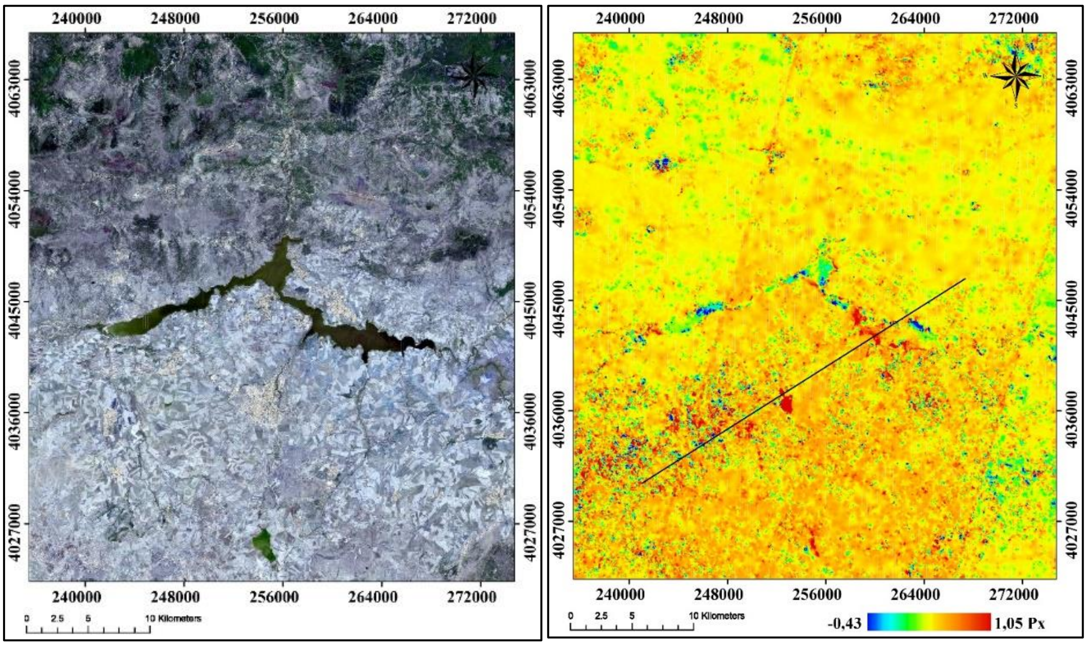

Figure 9. Sentinel 2 image of Mila's region & Horizontal displacements

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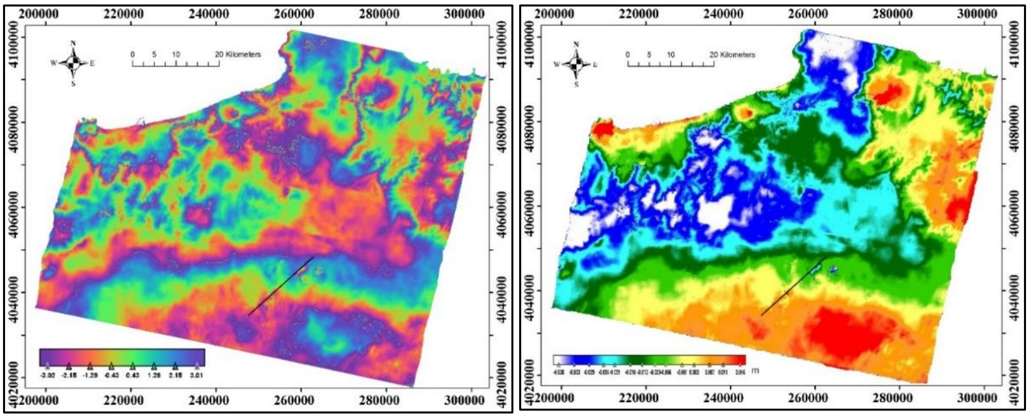

Figure 10. Interferogram & Vertical displacements

4.2. Oued Messilga fault

A very clear loss of cohesion affects the phase following the two major lineaments; NE-SW, which passes south of El Harrouch, and East-West, the epicenter of the earthquake is located at the intersection of these two faults.

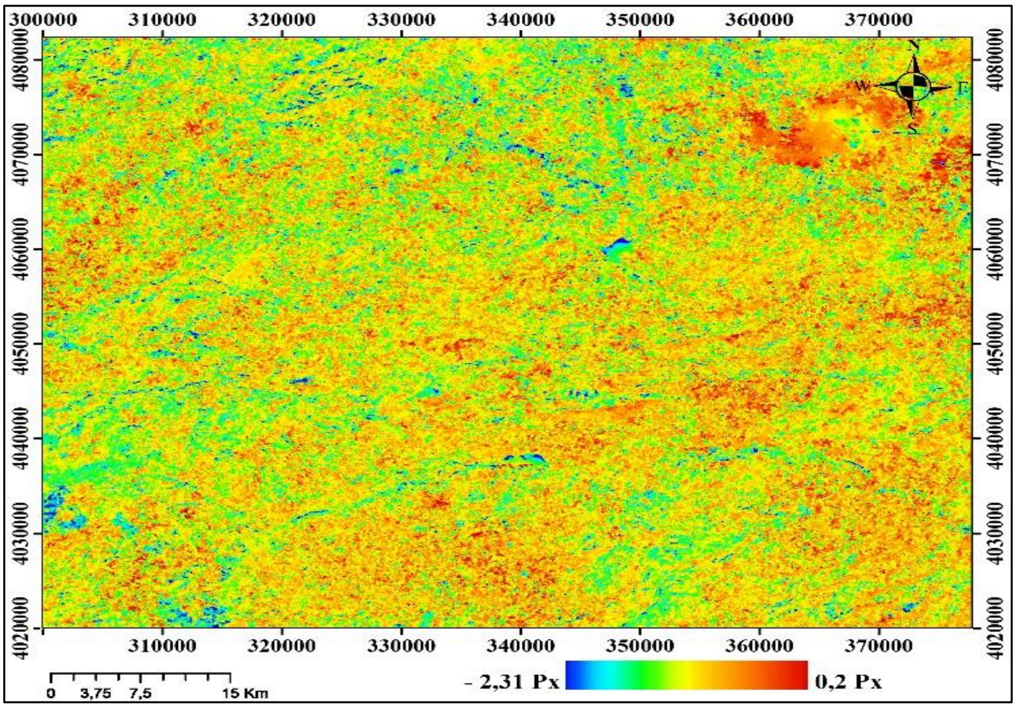

Figure 11. Horizontal displacements Skikda (El Harrouch) earthquake

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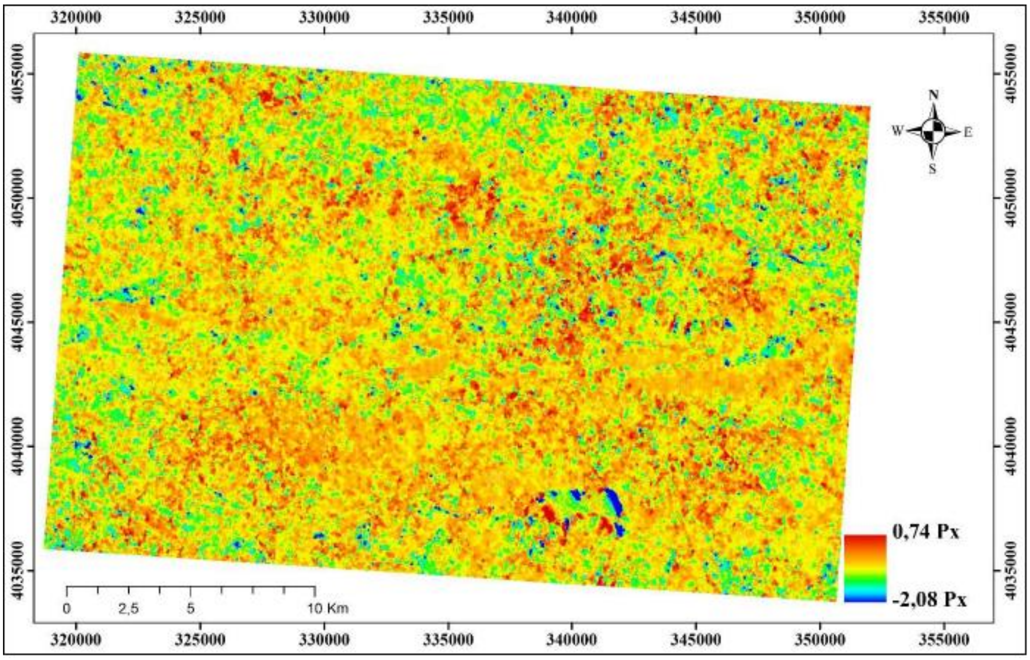

Figure 12. Horizontal displacements between the **02/11/2020** and **01/01/2021**

Another lineament NE-SW in north of Roknia, delimits a very clear disturbance of the phase, this lineament is superimposed on the Oued Messilga fault, mapped by [15].

Although the nature of the focal mechanism according to the USGS is a front strike-slip fault, the co-seismic displacement map shows that the vertical component is also important; a differential uplift is clearly emerging on either side of the activated fault sections. By this seismic crisis.

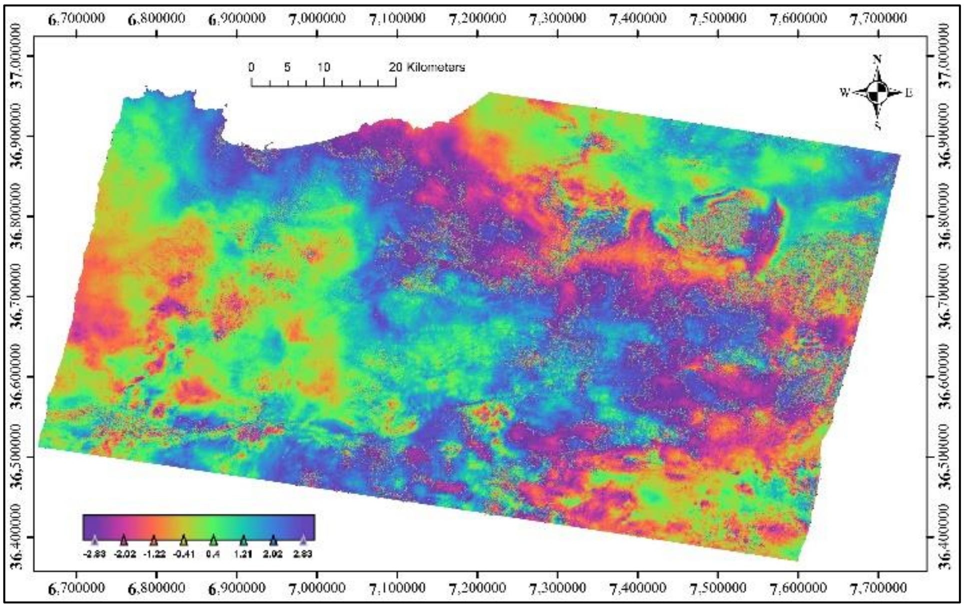

Figure 13. Interferogram from the 22/11/2020 earthquake in El Harrouche

The results of the radar interferometry perfectly corroborate the measurements of horizontal deformations by correlation of the optical images.

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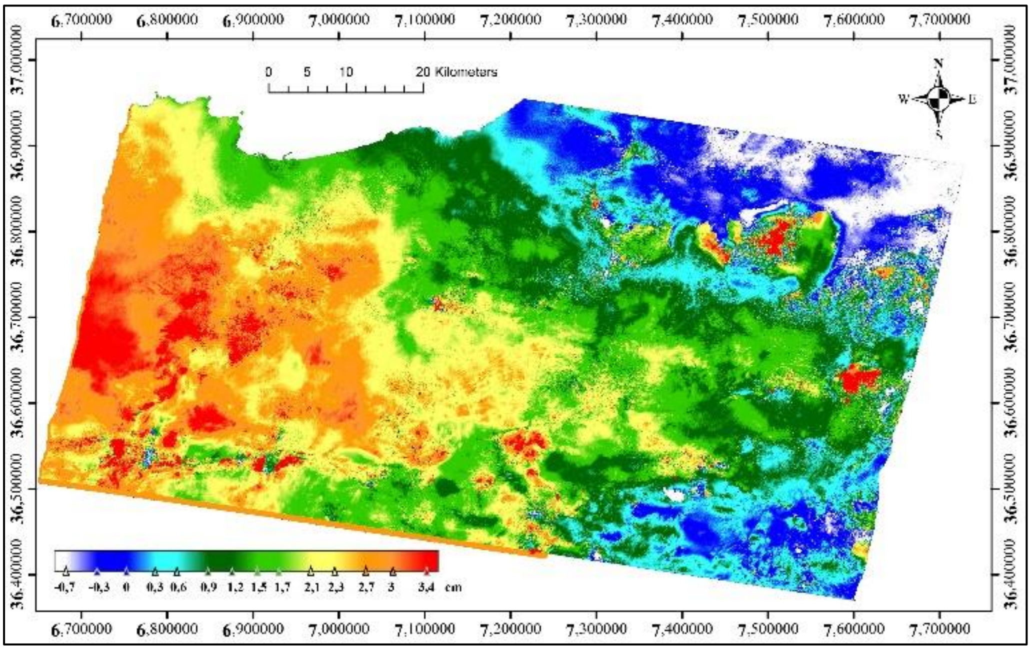

Figure 14. Vertical movements of the 22/11/2020 earthquake

If the seismic rupture is caused by the El Kantour accident is the cause of the quake, the induced movements of the East-West faults and that of Oued Messelga, of centimeter order are also pronounced.

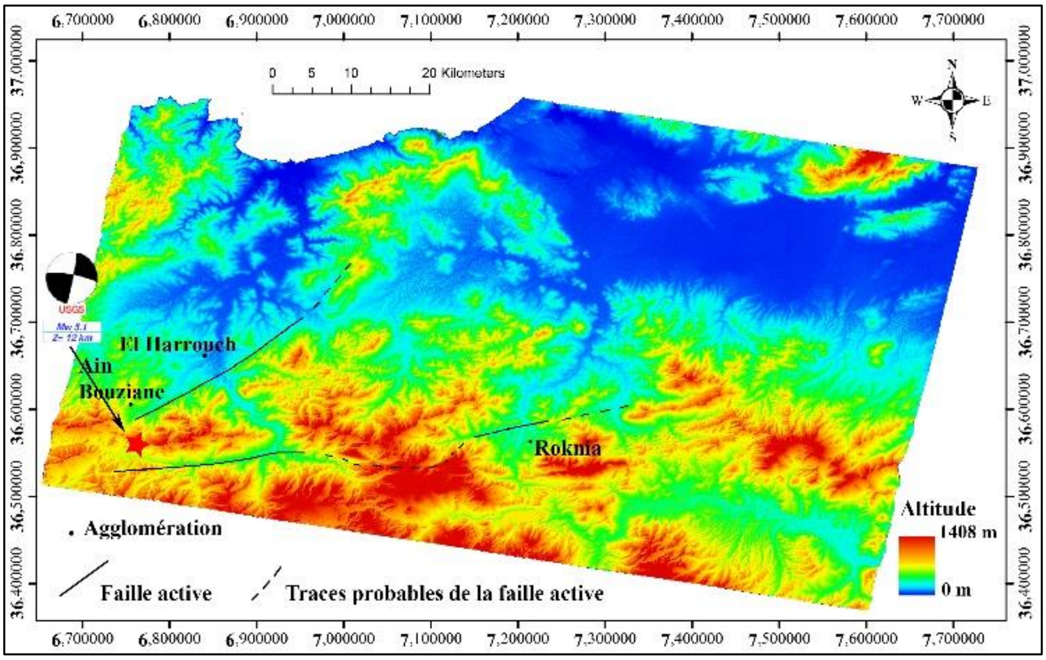

Figure 15. Localization of seismic faults on DEM of the studied region

The realities on the ground and the seismotectonic data (epicenters and focal mechanisms) have confirmed the nature and characteristics of these faults.

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5. CONCLUSIONS:

The use of correlation of optical images, Interferometric Synthetic Aperture Radar allowed us not only to finely map seismic faults, but also to characterize them well. The realities on the ground and the seismotectonic data (epicenters and focal mechanisms) have confirmed the nature and characteristics of these faults.

the Mila August 2020 (Mw 4.8) and El Harrouche November 2020 (Mw 5,2) earthquake raised out the effect of geohazards associated with earthquakes, particularly, in mountainous area as shown in several other earthquakes that occurred in the past in Algeria and throughout the world.

The earthquake of 22/11/2020 allowed us to confirm the active tectonic character of the fault d'Oued Messilga.

The obtained results may urge us to reassess the seismic hazard and the related risks and understand its role in initiating seismicity (induced seismicity).

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