Using Sentinel-1 SAR data to detect earth surface changes related to neotectonics in the Focșani basin (Eastern Romania)

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Abstract—**Ground deformations are the result of interactions between terrain and various processes. Their identification and monitoring becomes an important step as they can provide insights about Earth's dynamics or process triggering conditions. This paper aims to show the potential use of Sentinel-1 SAR images to identify ground deformations induced by neotectonics. Hence, we applied PS-InSAR stacking technique on Sentinel-1 ascending dataset in the area of Focșani basin, Eastern Romania. High density of PS obtained in populated areas allows the detection of tectonic fractures. They are characterized by blocks movement in opposite direction with 5-10 mm/year. Detection of geologic lineaments using free Sentinel-1 data presents a great advantage for future geological surveys which permits a better delineation of tectonic accidents, especially where seismic data are not available.**

INTRODUCTION

Changes in earth surface occur due to several geological, geomorphological and environmental processes which interact with the superficial topography. In the case of neotectonic activity, ground deformations are caused by earthquakes with seismic faults generation, active aseismic faults, mountain building (accretion), tectonic subsidence and active volcanic belts, processes that directly change the ground surface and might affect anthropic structures and infrastructures constituting a worldwide problem. Hence, detection and quantification of displacements due to tectonics represent an important task for the understanding of Earth surface and subsurface dynamics. An efficient method to measure surface changes is through differential interferometry [1] by making use of Synthetic Aperture Radar (SAR) images. The principle of this technique relies on the exploitation of signal phase property. Thus, it is possible to measure the terrain changes considering the phase differences of backscattered echo registered between 2 acquisitions over the same area, called interferogram [2], from which the differences due to different geometry in acquisitions, topography and effects, are subtracted.

The interest for differential interferometry increased after the launch of ERS-1 satellite when accurate measurements of earthquake related displacements [3, 4] and volcanic deflation [5] were obtained, pointing out the capabilities and suitability of this approach. The progress of interferometric stacking algorithms and the growing availability of spaceborne SAR data introduced new possibilities, not only to compute displacements for long periods [6,7], but also to calculate displacement rates allowing a better monitoring of geological deformation processes [7].

The aim of this work is to test the capability of DInSAR to obtain spatial and temporal information on ground deformations induced by tectonics, by using available Sentinel-1 SAR data of the Focșani neotectonic area.

STUDY AREA

Located in Eastern Romania (Fig. 1), the study area (500 km^2) is part of the Eastern Flank of Focșani Basin [8], an asymmetric syncline formed during the Pliocene-Quaternary out-of-sequence contraction event. Related to the collision of Carpathian Orogeny with undeformed foreland (East-European, Scythian and Moesian Platforms), the Focșani Basin consists of Upper Miocene to Quaternary deposits accumulated during the post-collisional subsidence. The sediments of western sector cover parts of Subcarpathian Nappe, while in the Eastern flank the beds are overlaying discontinuously the older deposits of foreland [9].

Tectonic deformations are mainly determined by active aseismic faults with offsets of up to 200 m. Normal faults oriented NW-SE and dipping SW with different angles and E-W strike-slip faults affect the Upper Miocene to Quaternary deposits (Fig. 1). The genesis of faults is related to the current Quaternary contraction stage of the basin, characterized by uplift of the external SE Carpathians nappes (for example Subcarpathian Nappe) and subsidence in Moesian foreland [8]. Evidences of regional uplift/subsidence activity were also reported based on tectonic geomorphology [10] and by calculating displacement velocity fields in horizontal and vertical directions by GPS measurements [11].

DATA AND METHODS

Data

This study was carried out by using the C-band SAR data acquired in ascending orbit by Sentinel-1A and B satellites, which are free downloadable from the European Space Agency (ESA) DataHub (https://scihub.copernicus.eu). Dataset consists of 134 SAR images acquired from October 2014 until January 2018. They are characterized by small spatial and temporal baselines due to improved specifications of sensor and short repeating cycle between observations (12 days for the first 20 months, when only satellite 1A was active, and 6 days after the launch of satellite 1B). For the orbital refinement we used the Precise Orbit Data provided by ESA, while a 5 m cell size LiDAR DEM, offered by Prut-Bârlad Water Administration, was used for topographic phase removal and geocoding.

Methods

SAR images were processed using Advanced Differential SAR Interferometry (A-DInSAR) techniques, implemented in SARscape COTS software, which allow to estimate ground deformations along the satellite Line of Sight (LOS). The techniques were developed in the beginning of 2000's with the purpose to overcome some of differential interferometry limitations and to increase the accuracy and reliability of results. This is done by filtering and refining the stack of interferograms to reduce the atmospheric influence, refine the phase unwrapping and decrease spatial and temporal decorrelations. In the last years, many A-DInSAR techniques have been proposed [12] and references therein, which are based on two main approaches: Persistent Scatterers (PS-InSAR) [13] which considers highly coeherent targets over time and Smal BAseline Subset (SBAS) [14] which takes into account only pairs of images with small temporal and spatial baselines.

In the present study, the first approach was considered because the large number of SAR images presents good specifications, such as short repeating cycle between two consecutive acquisitions and fair ground resolution of 18 by 18 meters. Furthermore, to identify the fault trace on ground, the PS-InSAR approach is more suitable compared with SBAS which smooths the results as an effect of the filtering steps performed to obtain more spatial information.

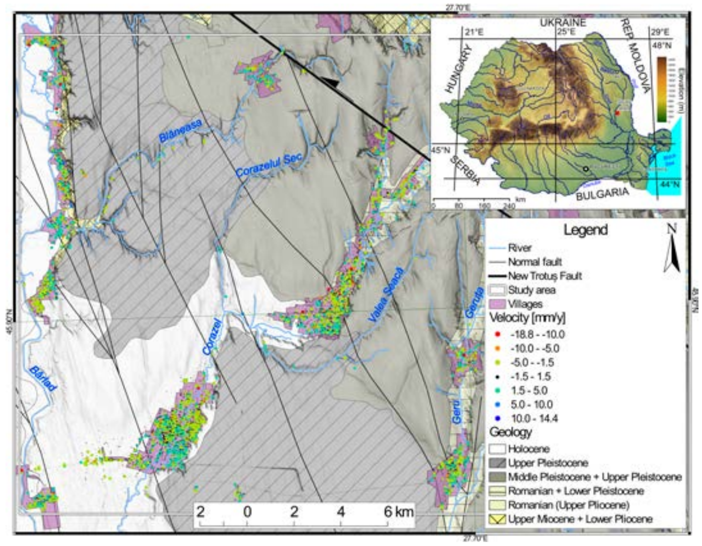

Figure 1. Location and geology of the study area. Geology was drawn after the Romanian Geological Map, scale 1:200 000. Fault lines were traced after [8].

The outputs of PS-InSAR processing are expressed as mean velocity and time series of displacement for each coherent target during the observation period.

RESULTS

The processing of SAR images with PS-InSAR technique resulted in the generation of more than 31500 Persistent Scatterers (PS) characterized by mean velocity values and rates of displacement specific for the 134 different acquisitions of analyzed period (Fig. 2). Most of PS (~ 27000) show low rate of displacement (between -1.5 and 1.5 mm/year) and can be considered stable, the remaining show positive or negative values, in some cases higher than ± 10 mm/year, pointing out the deformation affecting the earth surface. These displacements are calculated along the Line Of Sight of satellite and do not reflect the real 3D displacement of objects. Regarding this issue, further investigations will be performed to evaluate 3D deformations.

Displacements mostly affect relatively flat surfaces such as floodplains, terraces and plateaus; thus, they cannot be related to gravitational slope instabilities or other near surface processes (Fig. 3). The presence of PS moving towards the satellites (negative values) on floodplains can be connected to the consolidation of recent alluvial sediments. We expect such phenomena to have a local distribution, whereas in our case, the tectonic activity underlines a regional subsidence pattern.

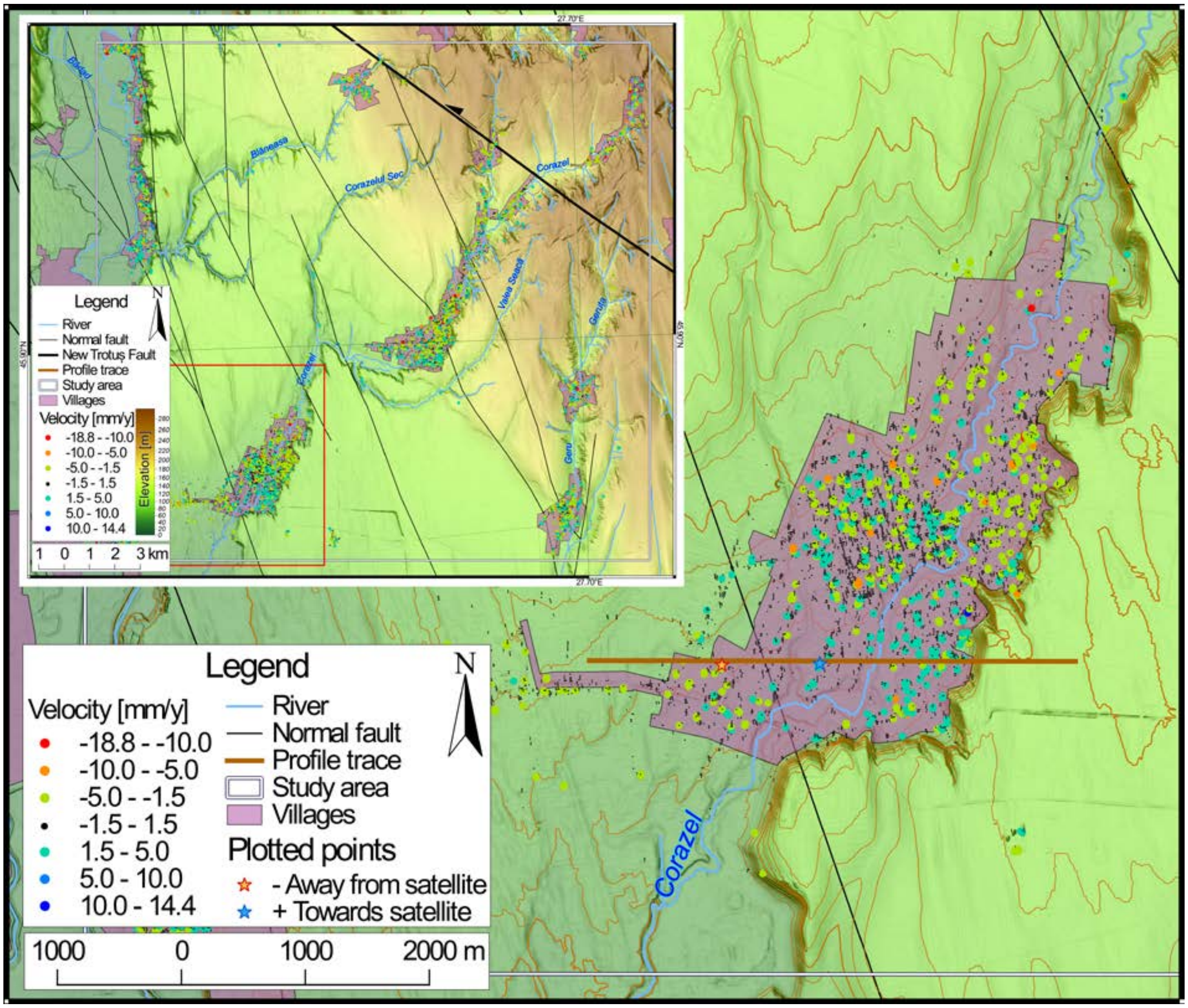

Figure 2. PS velocity map. Direction of displacement in each block is in accordance with kinematics specific to normal fault.

In our study area, we find regional patterns of negative values which are bordered by positive values, features which correlates well with tectonic lineaments (Fig. 2), identified by [8]. We consider that this pattern is consistent with the movement of tectonic blocks separated by faults. The kinematics of the movement will be better defined in the next step of our research after the evaluation of 3D displacements from interferometric data.

Analyzing the displacement time series of two points from each block (Fig.4), it can be noticed that the rate of displacement is constant over the time in both cases, a pattern specific to aseismic active faults [15].

CONCLUSION

The aim of this study was to detect surface deformations produced by active tectonics using Sentinel-1 SAR data. The results show opposite trend displacement along geological lineaments with velocities around ±10 mm/year and no seasonal fluctuations in time series of displacement. To better define the kinematics of moving tectonic blocks, further investigations are necessary to evaluate the 3D displacements. To this end, SAR data acquired by Sentinel-1 in descending geometry and available images of ERS-1/2 and ENVISAT missions will be processed and compared with available GPS measurements [11]. Testing high resolution data acquired by X-band sensor will be also considered because we expect more accurate results which will

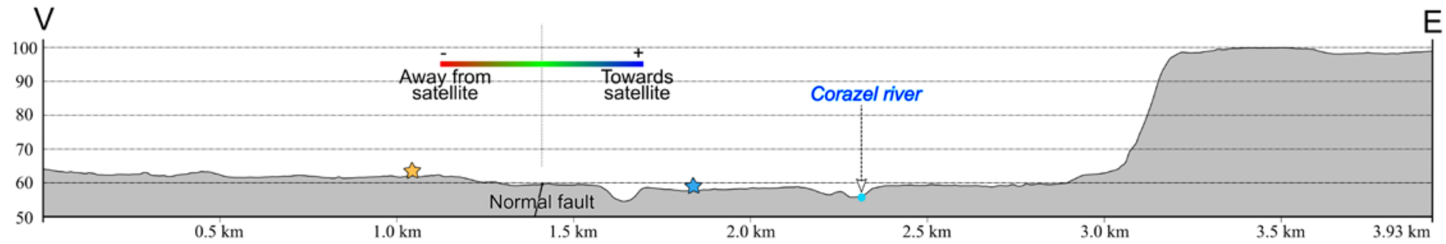

Figure 3. Topographic section obtained from 5m LiDAR DEM showing the predominantly flat morphology of the study area. The stars represent points characterized by opposite displacement values due to the fault activity.

help us identifying possible relationships between ground displacement, earthquakes and fault activity.

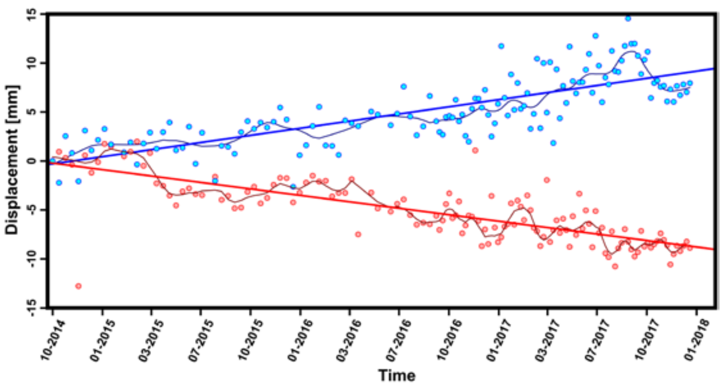

Figure 4. Displacement graph of moving points illustrating the opposite direction of displacement specific to each block separated by fault.

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