Studying seismic events via satellite interferometry for the territory of the Balkan Peninsula

Mila Atanasova-Zlatareva
Department of Geodesy, National Institute of Geophysics Geodesy and Geography, Bulgarian Academy of Sciences, Sofia, Bulgaria
mila_at_zl@abv.bg

Hristo Nikolov
Remote Sensing Systems Department, Space Research and Technology Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria
hristo@stil.bas.bg

Outline

Introduction

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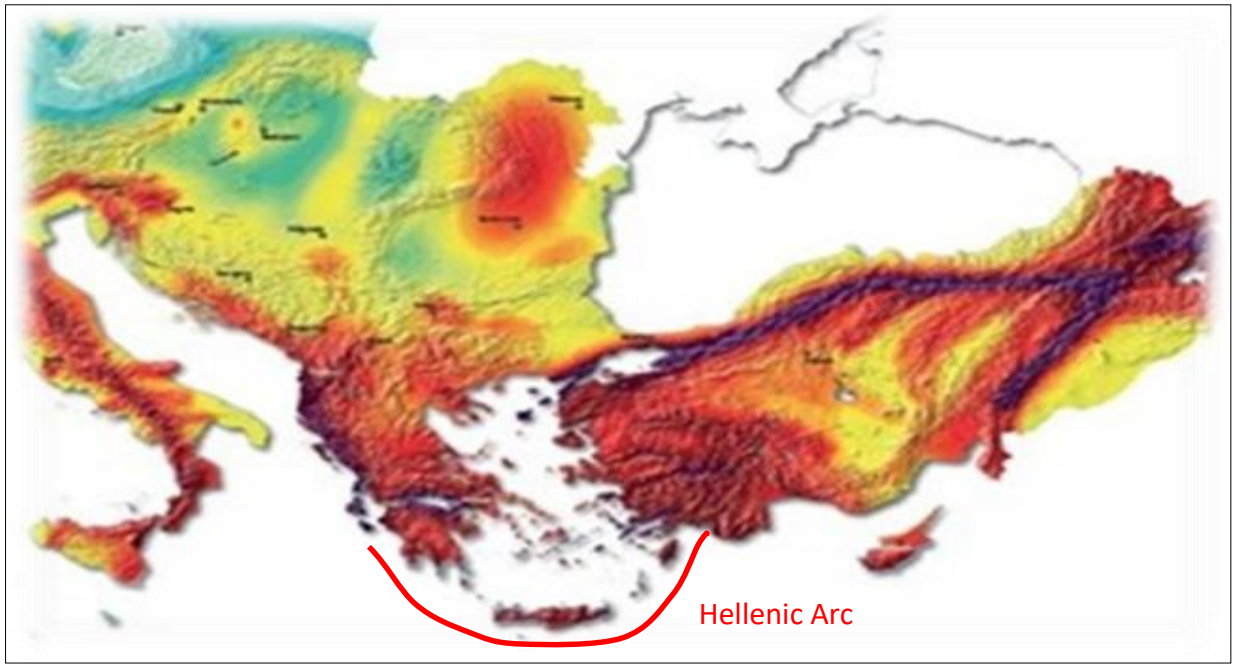
- The focus of this study is to present the pilot achievements under the project *"Study of co-seismic deformations of the Earth's crust for the territory of the Balkan Peninsula based on satellite data"* that started in December 2023.
- The purpose of the project is the regular monitoring of co-seismic deformations of the Earth's crust using innovative methods for processing remotely sensed data.
- The main task is to demonstrate the operational readiness to determine the magnitude of the deformations of the earth's surface, the size of the affected areas and to prepare maps of the displacements that have occurred.

Introduction – cont’d

- This goal will be achieved through creation and realization of a methodology for extracting high-quality information from SAR products aimed at continuous monitoring of areas that could be considered as potential foci of strong earthquakes, integrating information from interferometric images and GNSS observations.
- As a result created will be a working prototype of an information system for monitoring and prevention of the consequences of co-seismic deformation of the earth's crust (landslides, collapses, etc.) based on freely available data provided by ESA and national agencies.

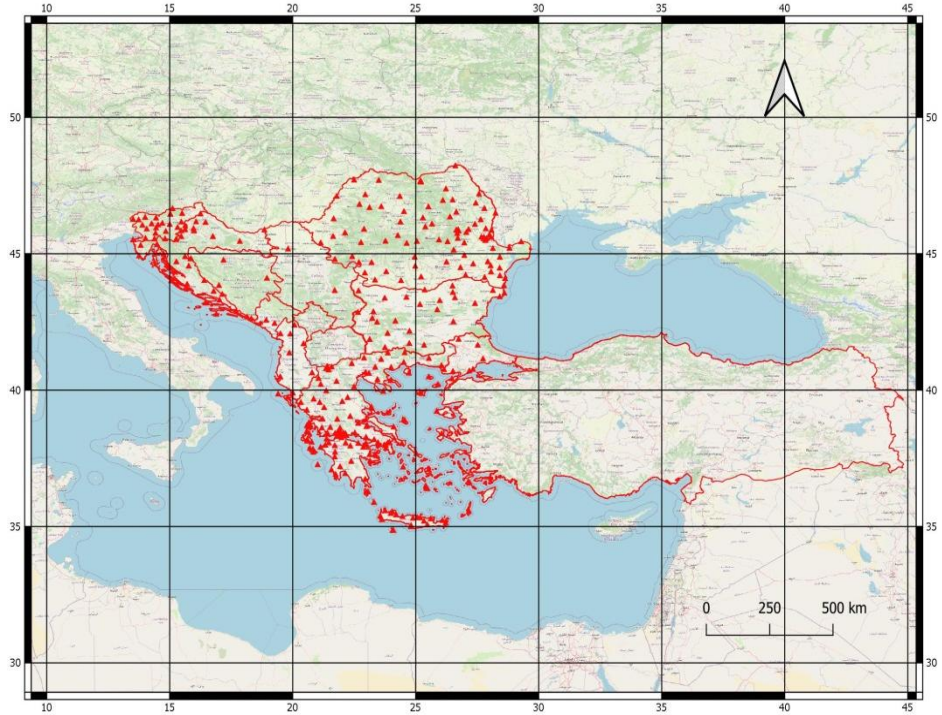
Introduction – cont'd

The Balkan Peninsula is part of the one of the dangerous seismic zones on Earth – Mediterranean Seismic Zone. Most of the seismic events were generated near or in the fault zone known as the Hellenic Arc located near the territory of Bulgaria. The geological development of the region is the result of several boundary interactions between these plates, which include subduction, large scale faulting, compressional mountain uplift, and extension of the Earth's crust. When the African and Arabian plates converge the Eurasian plate leads to the closure of the Mediterranean Sea and at the same time is the reason for the westward movement of the Anatolian block.



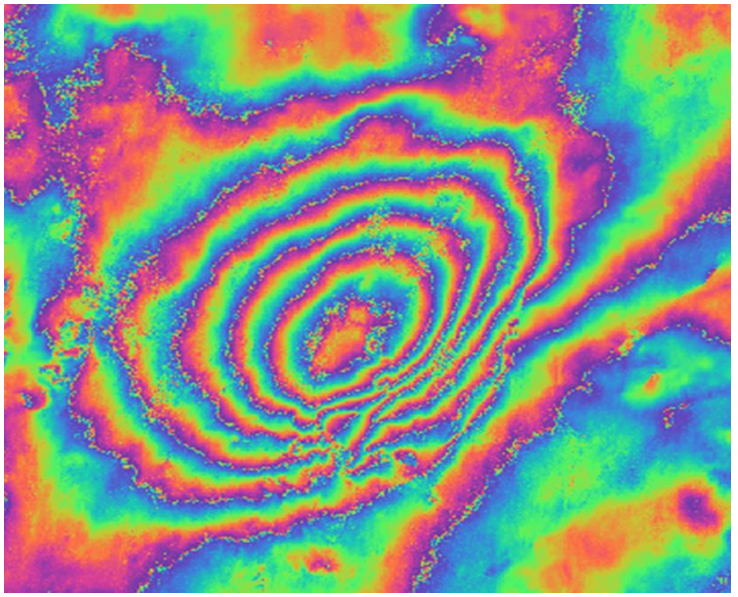
Introduction – cont'd

The basic way to register and measure the strength of an earthquake is through the use of a seismic station, equipped with different types of seismic receivers. In the last decade seismic stations are supplemented by ground-based networks of GNSS receivers, which provide the possibility to determine displacements, occurring at the Earth's surface and the propagation of seismic waves. Using GNSS it is possible to determine the 3D vector of displacement on the earth's surface and calculate errors of 2–3 mm for the horizontal and 5–8 mm respectively for the vertical components, but limited to the position at the point of measurement.



Introduction – cont'd

By processing data from Earth observation satellites registering data with radar instruments by DinSAR method provides greater spatial coverage, but information about displacements is in the line-of-sight (LoS) on the antenna. Additional analysis is necessary to obtain all components of the motion vector of the occurred surface movements. The main sources of data that are planned for use are the SAR products from the Sentinel-1 mission thus achieving extensive territorial coverage. This allows preparation of maps that reveal the scale of deformations on the Earth's surface. Along with these data other data for the epicentre of earthquakes and for the established faults in the research areas are used as well. Due to the fact that the DInSAR method requires the availability of two radar images obtained during a time interval between the registrations of the SAR data the mentioned maps reflect the cumulative effect of all seismic events in this interval. This means that it is not possible determine the contribution of a single event to the produced displacements.



Interferometric image from M 6 event 27Sept2021

Current state of the earthquake research in the investigated area

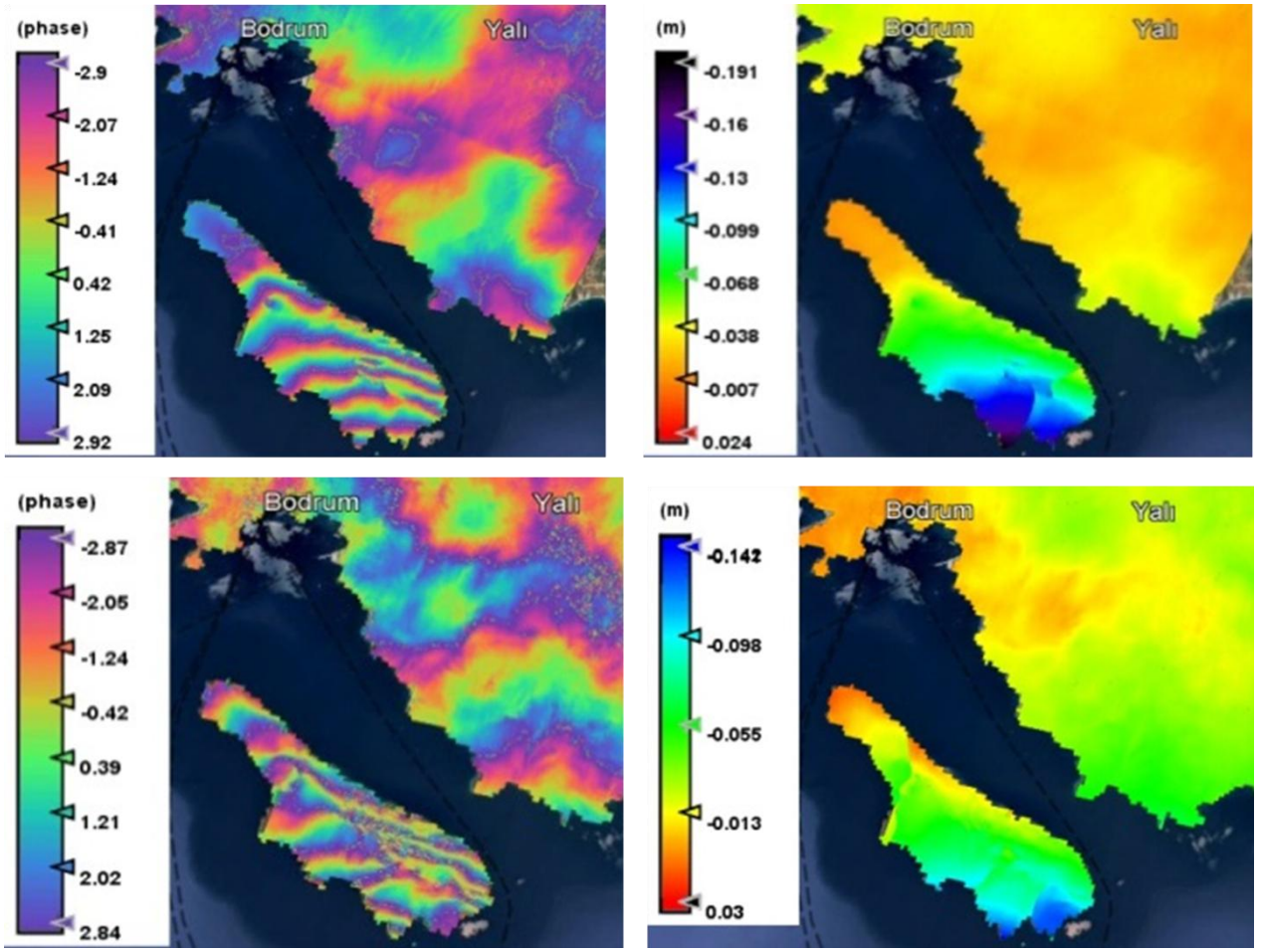
Based on processing and analysis of GNSS data, a number of studies show the recent seismic activity of the investigated region we tryed to give a reasonable and adequate interpretation of the obtained results regarding the processes of movement of the earth's crust in the said area.

N	Name	Latitude Longitude	Mw	Dates, time/UTC
1	Kos-Bodrum Greece-Turkey	36.96 N 27.45 E	6.6	July 20, 2017
2	Zakynthos Ionian Sea	37.53 N 20.62 E	6.8	October 25, 2018
3	Duras - Albania	41.38 N 19.47 E	6.4	November 26, 2019
4	Petrinya -Croatia	45.42 N 16.12 E	6,4	December 29, 2020
5	Larissa - Greece	39.76 N 22.21 E	6.3	March 03, 2021
6	Larissa - Greece	39.80 N 22.20 E	6.1	March 04, 2021
7	Crete – Thrapsanon	25.24 N 25.27 E	6.0	Sept 27, 2021
8	Turkey-Syria	38.07 N 36.47 E	6.0	February 6, 2023
9	Turkey-Syria	38.11 N 37.24 E	7.5	February 6, 2023
10	Turkey-Syria	37.13 N 36.81 E	6.7	February 6, 2023
11	Turkey-Syria	37.17 N 37.08 E	7.8	February 6, 2023

Event at Kos-Bodrum, Greece-Turkey

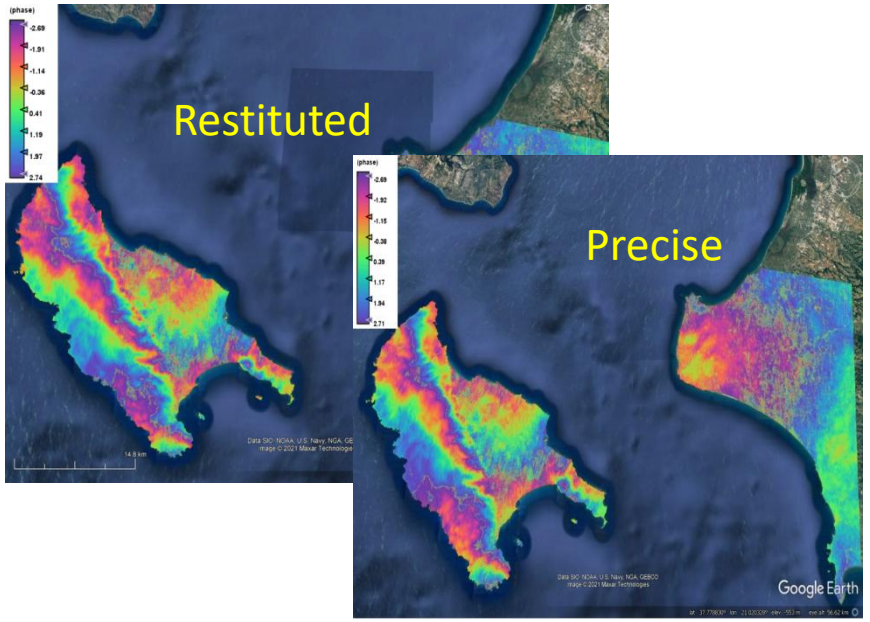
On July 20, 2017, an earthquake occurred near the island of Kos with Mw 6.6 and a depth of 2 km. Maps of the displacement were created and the values of the southern time sinking of Karaada Island in the LoS direction from descending and ascending orbits were determined .

	B_{perp} [m]	coh
Ascending 131	33,24	0,96
Descending 36	5,51	0,98



Two events in Adriatic Sea

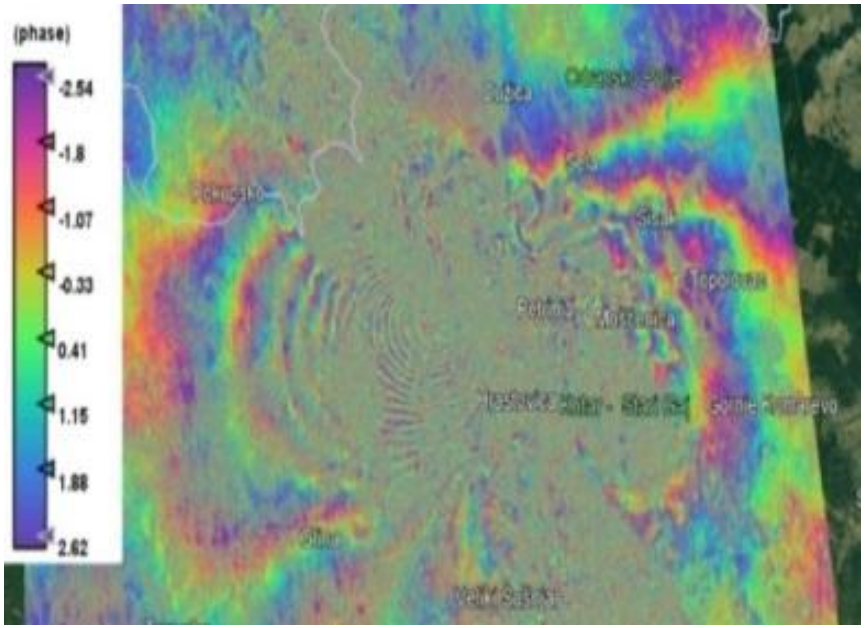
The surface deformations that occurred after an earthquake on October 25, 2018 located about 45 km southwest of the island of Zakynthos with Mw 6.8 and a depth of 10 km) were also determined based on the prepared interferograms. Tested was the influence of precise orbits on the final results.

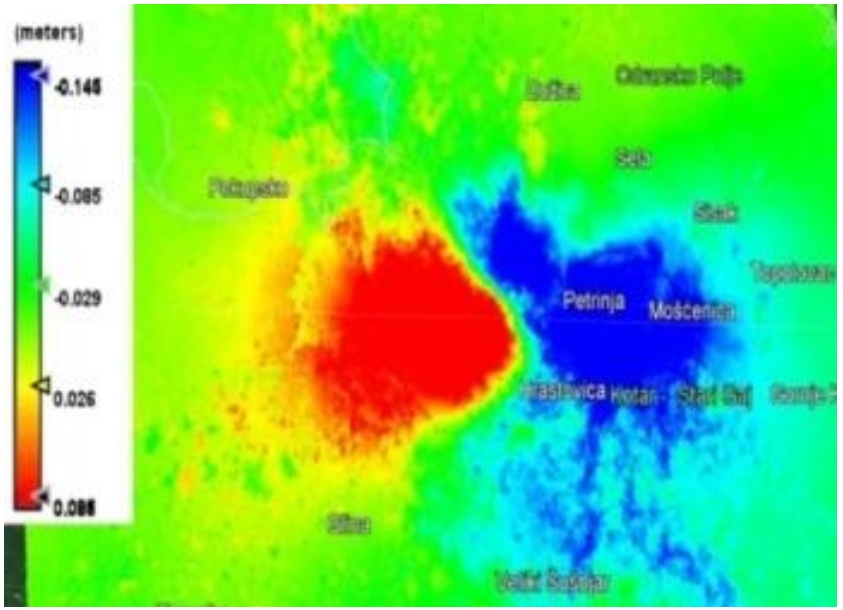


On November 26, 2019, the most devastating earthquake in the last 40 years for the region occurred in the north-western part of Albania, which was the second such event in a period of three months and was located about 8 km northeast of the port city of Durres. Collocated were the data from both orbits in order to decompose the LOS vector

Petrinja, Croatia – December 29, 2020

The devastating earthquake that struck Croatia had a magnitude of 6.4 on the Richter scale. This is the biggest earthquake in Croatia recorded in this century up to now. An earthquake of similar magnitude occurred in 1880 near Zagreb. Three earthquakes of magnitude 6 and greater have occurred since 1900 to date within 200 kilometres of the epicentre of the said earthquake. The main shock and most of the aftershocks are located on the Petrinja Fault, which is well described in the European Database of Seismogenic Faults (EDSF). This phenomenon was investigated by InSAR data and supplemented with seismological results by using Okada method.



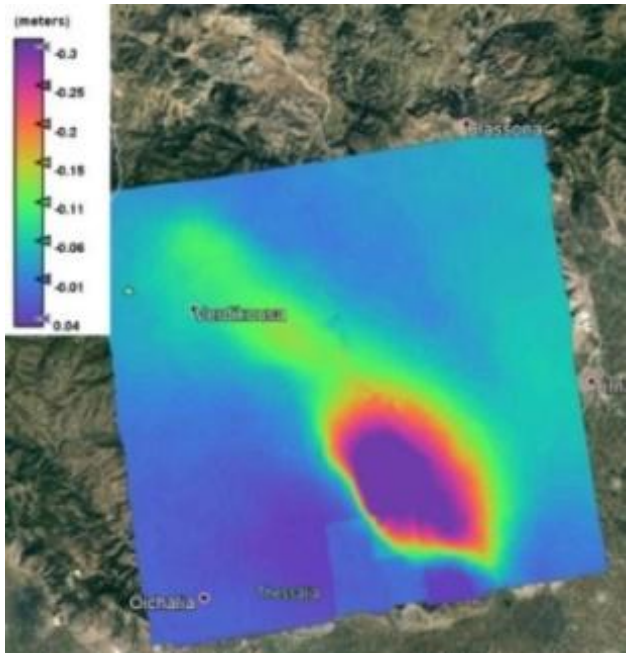


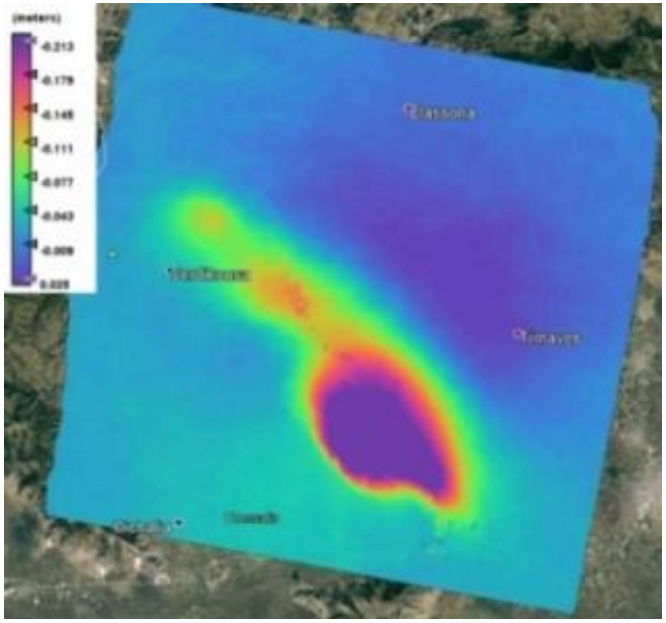
Larissa, Greece – March 3, 2021

The surface deformations that occurred after an earthquake of Mw 6.0, which occurred some 20 km northwest of the city were determined. Usually, using the applied method, the total changes of the Earth's crust are registered for the period between two passes of the satellites, which for the Sentinel mission (for 2021) is a minimum of 6 days.

For this event calculated three types of geometry for the seismic fault near Larissa varying the length, the width and the slip over the fault were modelled via Okada. The vertical (up–down) and horizontal (E–W) displacements coincided well with the results from DInSAR processing.

Descending orbit
02-14 March
2021

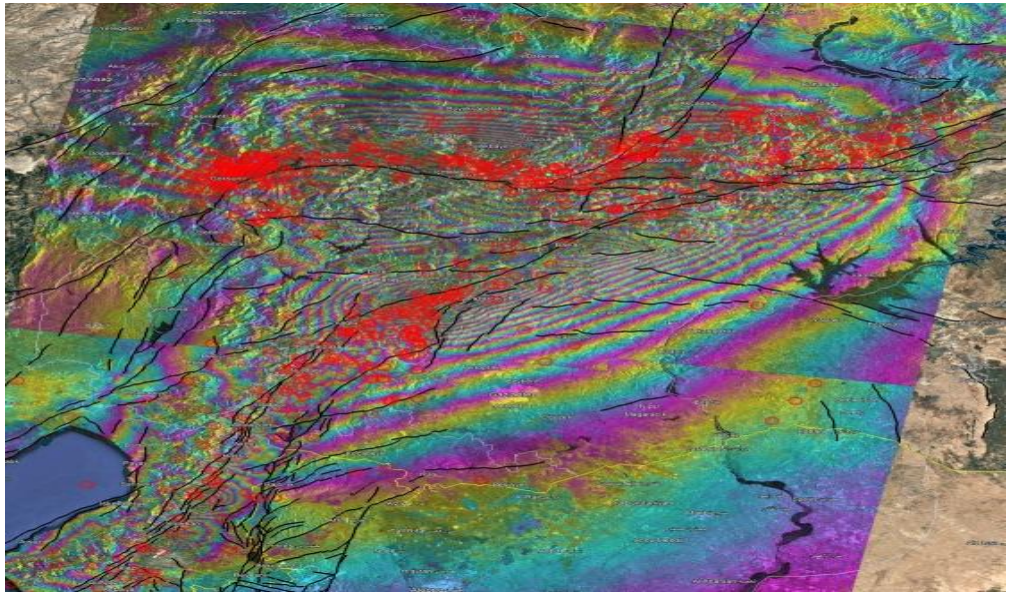


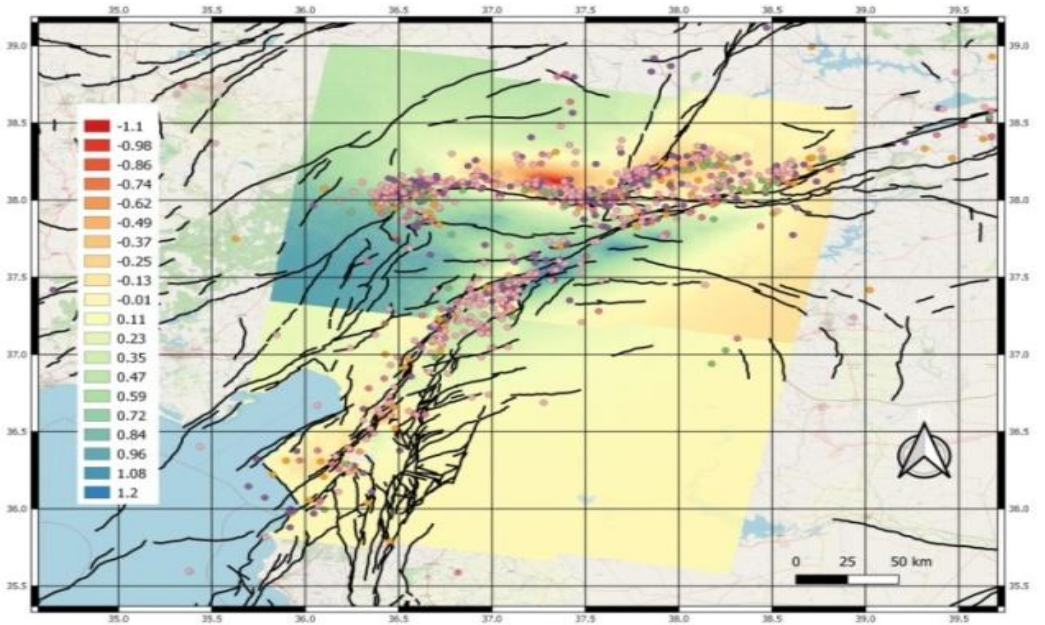


Ascending orbit
02-14 March
2021

Turkey and Syria doublet –February 06 2024

The last event was focused on wide areas deformations that resulted from the two devastating earthquakes of magnitude M 7.8 and M 7.5 on February 6, 2023. They occurred in the East Anatolian Fault Zone, west of Gaziantep town, Turkey. The events were followed by intense aftershocks, the effect of which was proven after interferometric processing of SAR data from the Sentinel-1 data and revealed the size of the affected area and the magnitude of the deformations that occurred after the earthquakes. The figure shows the vertical deformations by descending orbit SAR data, the earthquake area, the epicentres, and the active faults.





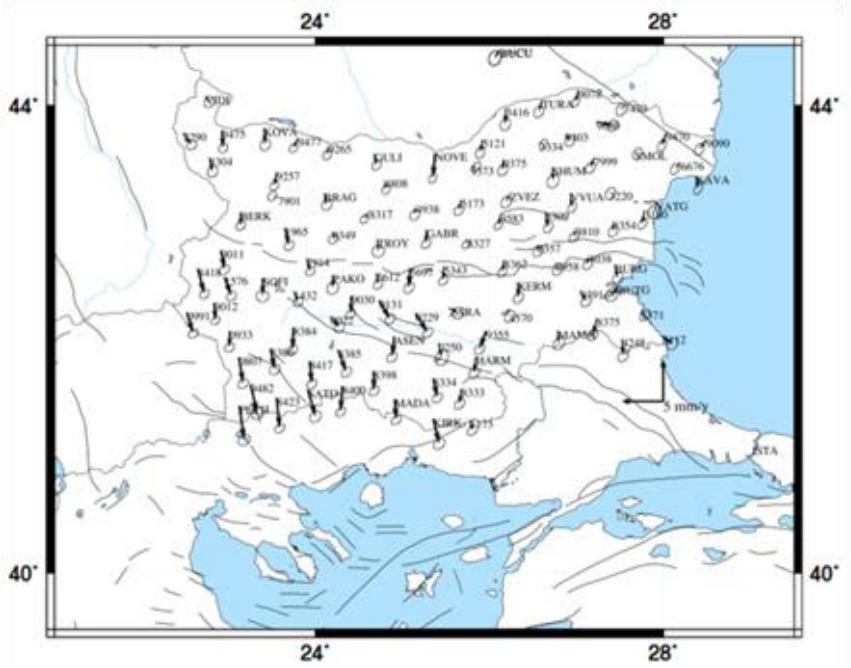
Further development of the project

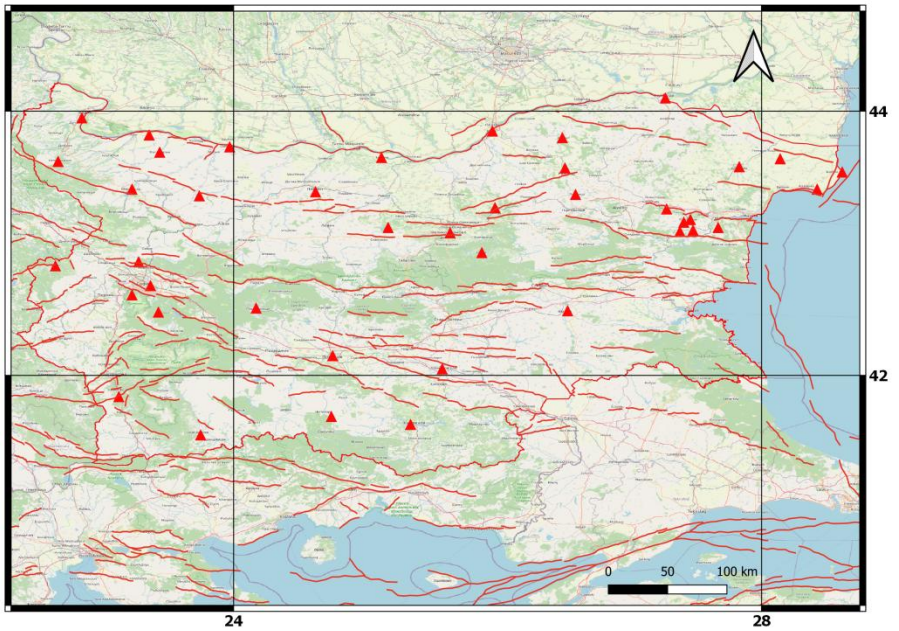
Achievement of the project's goal is realized through following tasks:

- Creation of a catalogue with earthquakes in the Balkan Peninsula having magnitude of 5.0 or more Mw
- Creation of automated methodology for extraction of data from SAR and their unified processing for geocoding.
- Obtaining the coordinates and speeds of the permanent GNSS stations coordinates and velocity of permanent GNSC stations from the national network of NIGGG and freely available data from other types of GNSS stations for the territory of the Balkan Peninsula.
- Analysis of GNSS time series to register changes (jumps) due to seismic events
- Determination of the deformations of the Earth's crust by the method of Okada on geophysical and seismic data and their comparison with the results obtained from the SAR data
- Formation of a data base for the investigated areas , including IFI , geodetic data from permanent stations, seismic and geophysical data, as well as carrying out spatial analysis regarding the presence of deformational processes ;
- Determining the possibility of searching for a connection between the location of the epicentre of an earthquake and the tectonics of the research area, lithospheric plates and the possibility of predicting the occurrence of an event based on changes in the magnetic field or other geophysical factors.

Methods, research equipment and scientific techniques used

1. Data sources
   - ✓ Global navigation satellite systems (GNSS)
   - ✓ Bulgarian seismological network
   - ✓ SAR data
   - ✓ Auxliary GIS data – epicenters, faults, etc.
2. Methods
   - ✓ Differential interferometry
   - ✓ Okada's method





Conclusions

- The goal of the project is formulated on the basis of previous scientific and scientific applied research on the team. The implementation of the project will help to increase the quantity and quality of fundamental scientific research related to problems of regional and national importance. The tasks of the project include both the intensification of the relationship between science and education and society as a whole and the enhancement of the quantity and quality of the internationally visible scientific output.

- The public challenges to which the project is focused on are minimizing the damages caused by natural disasters and accidents and for protecting the environment. The project also responds to them by studying geodynamic processes in the Earth's crust and providing up-to-date information about them.