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# Application of the MT-SAR method for monitoring ground movements in the area of the Studena-quarry for the extraction of inert materials.

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**Summary**
The research interest is focused on monitoring the changes occurring on the earth's surface in the area of the quarry for mining and production of inert materials „Studena“ near the town of Pernik. Based on the Multi-Temporal SAR Interferometry (MT-SAR) method and data for a time period of 5 years, monitoring and analysis of the occurring and recorded ground movements are carried out. In this study, products freely provided by the European Ground Motion Service (EGMS) based on data from Synthetic Aperture Radar (SAR) aboard the ESA (European Space Agency's) Sentinel-1A/B satellites for the period from January 2019 to the end of December 2023 were used. SAR data were used to register the crustal displacements by creating interferometric images, from which information was extracted about the subsidence and uplift caused by anthropogenic processes in the studied area.

## Introduction
The Earth's surface is in constant motion. Whether due to natural phenomena such as tectonic activity or landslides, or to human activities such as groundwater extraction or mining, surface dynamics can have significant impacts on infrastructure and natural ecosystems. In recent years, increasing awareness of the potential risks associated with ground motion has led to a search for comprehensive and reliable information about these movements (European Ground Motion Service).

## Methods
Differential Interferometry for Processing SAR Data (DInSAR), obtained from remote sensing of the Earth, is a method that can be used to quantify small surface displacements. Using data from the Sentinel satellite and applying DInSAR, topography mapping of large areas is performed, as well as registration of surface displacements. The basis of the DInSAR method is the use of two images of the phase signal reflected from the Earth's surface, obtained in the same region at different times, and based on it, it is possible to accurately measure the relative displacements.
In this study, the main source of data for registering geodynamic movements is the SAR data located on board the Sentinel-1A satellite (Copernicus DataSpace Ecosystem). Data provided by the European Ground Motion Service for the period January 2019 - December 2023 (European Ground Motion Service) are used. EGMS Ortho uses the information provided by the ascending and descending orbits to extract two additional layers; one with purely vertical displacements (EGMS Ortho Vertical), the other with purely east-west displacements (EGMS Ortho East/West). Each point is associated with a displacement time series, i.e. a graph with displacement values for each satellite acquisition (European Ground Motion Service).
Monitoring of randomly selected points located within the Studena quarry for the extraction of inert materials was used to track geodynamic processes in it. In order to determine vertical displacements, SAR data from ascending and descending orbits are required. Each point corresponds to the registered displacement along the LOS line of sight in the time interval of 6 days from January 2018 to December 2021 and in the 12 days after January 2022 to December 2023. We use data from descending orbits 7 and 80 and ascending orbits 29 and 102.
Surface deformation can be determined from the time series only for targets that show coherence across the stack (group of consecutive images) of SAR images. Such targets /marks, reflectors/ correspond, for example, to rocks (natural reflectors) or buildings (artificial reflectors), which act as permanent reflectors, maintaining constant dielectric properties over the observation period.

## Results

In the present study, displacement in the LOS (Line of sight) direction and the displacements along the vertical and along the W-E horizontal component were determined. As is known for SAR sensors, the measurement of deformation has low sensitivity in the N-S direction and its determination is limited. The interferometric images obtained with ascending and descending acquisition geometry are sufficient to calculate vertical and horizontal (E-W) displacement components. The data from the European Ground Motion Service are based on interferometric satellite radar images from the Sentinel 1-A mission for a relatively long time period from January 2019 to 2024.

In this study, in order to determine vertical displacements, we need data from both types of orbits - ascending and descending. The average speed of displacements per year in the LOS direction, the root mean square error with which the speed was determined (RMSE) and the coherence values were obtained. The reliability of the obtained results (accuracy) is characterized by coherence and at coh<0.3 the pixels are removed. Their values are not considered reliable. Figure 1 presents registered ground deformations in the LOS direction (European Ground Motion Service) from ascending and descending orbits for a 5-year time period for the area of interest. Based on these data, the vertical and horizontal displacements in the west-east direction are determined. In the north-south direction, it is not possible to determine displacements of the earth's crust.

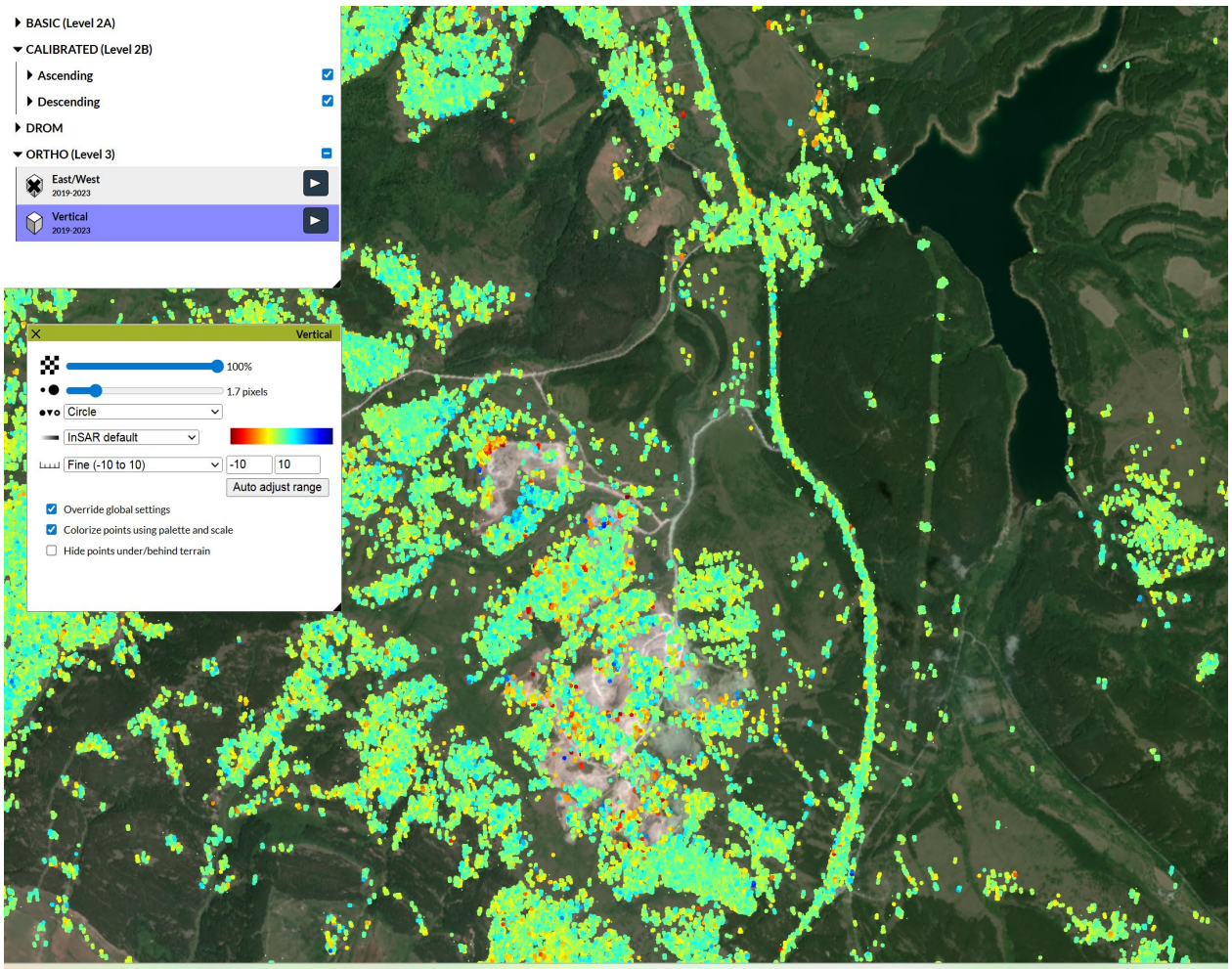



**Figure 1.** Displacements in the LOS direction from ascending and descending orbits for a 5-year time period and vertical displacement for the area Studena quarry (European Ground Motion Service)

Figure 2 shows how the vertical displacements (time series in dark blue) were obtained from the LOS displacements determined by SAR data from four orbits. Figure 3 presents vertical displacements determined by descending orbits 7 and 80 and ascending orbits 29 and 102 (Copernicus DataSpace Ecosystem).

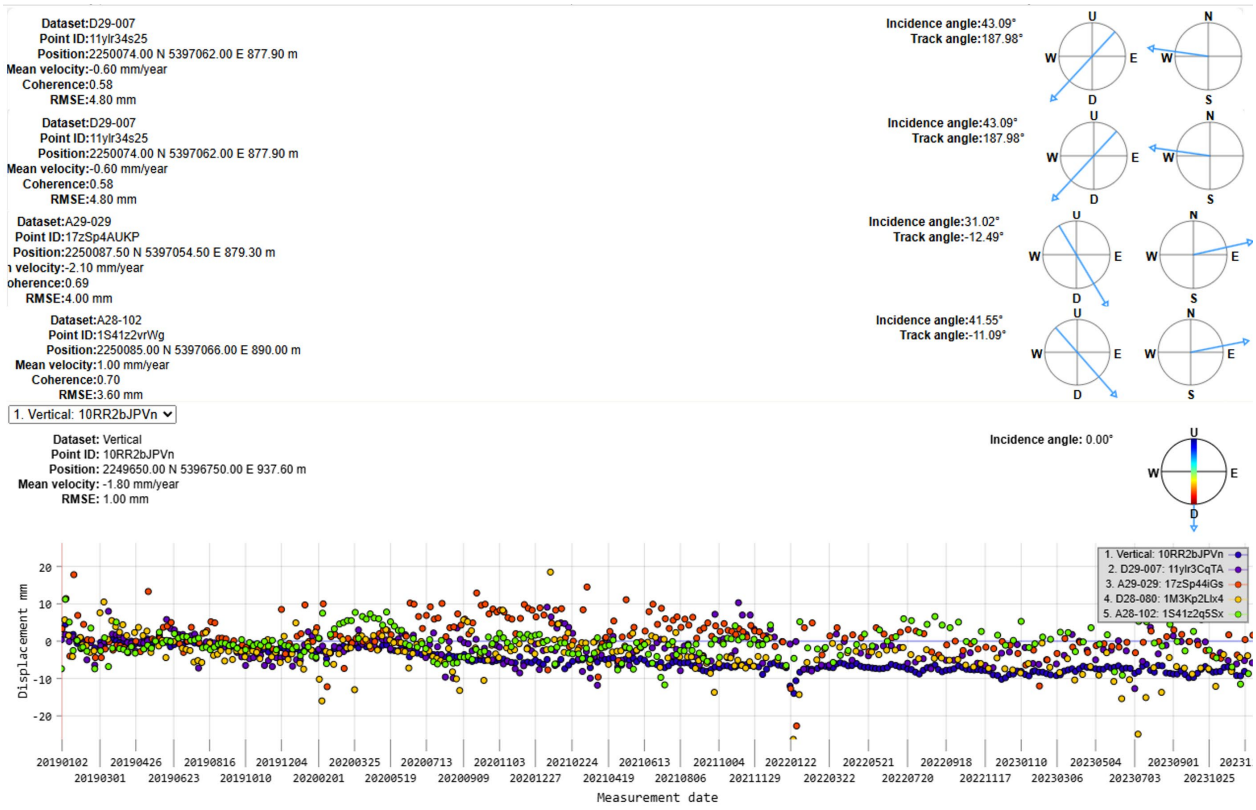



**Figure 2.** Determined surface displacements in the LOS direction of a point in the Studena quarry for the period January 2019 - December 2023 (European Ground Motion Service) and the vertical displacements obtained as a result of SAR data from two ascending and two descending orbits; modified by https://egms.land.copernicus.eu/.

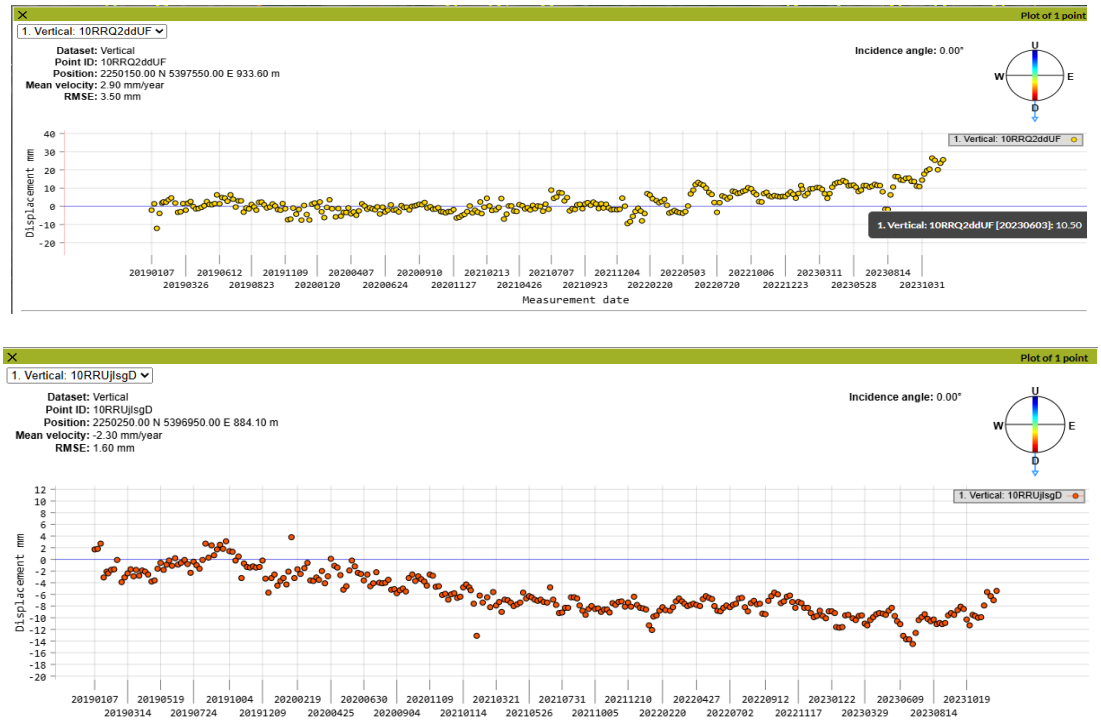



**Figure 3.** Time series of vertical displacements for points in the area of the Studena stone quarry with the occurrence of subsidence or uplift (removal or accumulation of inert material) (European Ground Motion Service) modified from https://egms.land.copernicus.eu/.

## Discussion

Based on satellite data and the applied InSAR method, the dynamics of the change of the earth's surface only within the boundaries of the Studena quarry, due to the mining activities of inert materials and the used blasting equipment and other anthropogenic processes (see Fig. 4) are very clearly visible. The results of a sufficiently long time series (5 years), which is necessary for a reliable assessment, have been examined and analyzed. It can be categorically stated that the earth changes that have occurred are a consequence of the mining technologies, and are not coseismic displacements. It has been established in the world scientific literature that coseismic deformations are registered by this method in earthquakes with a magnitude above M>5. Over the past 5 years, earthquakes with a magnitude above 3.0 have not been registered in this region. Figure 4b presents an example of monitoring deformation processes of the dam wall of the Studena dam. The stability of the dam wall and the lack of registered displacements for the last 5 years are very clearly expressed.




**Figure 4.** Vertical displacements for the area of the Studena stone quarry and stability of the dam wall of the Studena dam (European Ground Motion Service); modified by https://egms.land.copernicus.eu/.

## Conclusions

EGMS, using synthetic aperture radar (InSAR) data, is designed to detect and measure ground motion across Europe with millimetre accuracy and provides a product that represents the state-of-the-art in remote sensing technology. The product is updated annually and is used for a variety of applications; monitoring the structural integrity of dams, bridges, railways and buildings. EGMS data can be used to study the impacts of climate change, such as coastal subsidence, and to assess the likelihood of natural disasters such as landslides. In this study, EGMS was used to monitor the stability of the Studena dam wall.

## Acknowledgements

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