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### Geodetic monitoring of the Kaniv HPP dam using satellite radar

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#### SUMMARY

Satellite radar system method was used to study the deformation of the Kaniv hydroelectric power plant dam. Vertical displacements of the dam were determined by processing a pair of Sentinel-1 radar images in the SNAP software. The period corresponding to 0,6 calendar year is chosen. It is revealed, that from 29.07.2020 to 03.09.2020 there was a raising of all points of a dam, then the subsequent half-year lowering of a terrestrial surface was observed. The received results are confirmed by the data of survey by ground methods and on GNSS observations. It is proposed to carry out geodesic monitoring based on remote sensing data, especially of technogenic territories.

*Keywords:* Satellite radar system; geodetic monitoring; interferometry; land surface deformations; technogenic-loaded territories

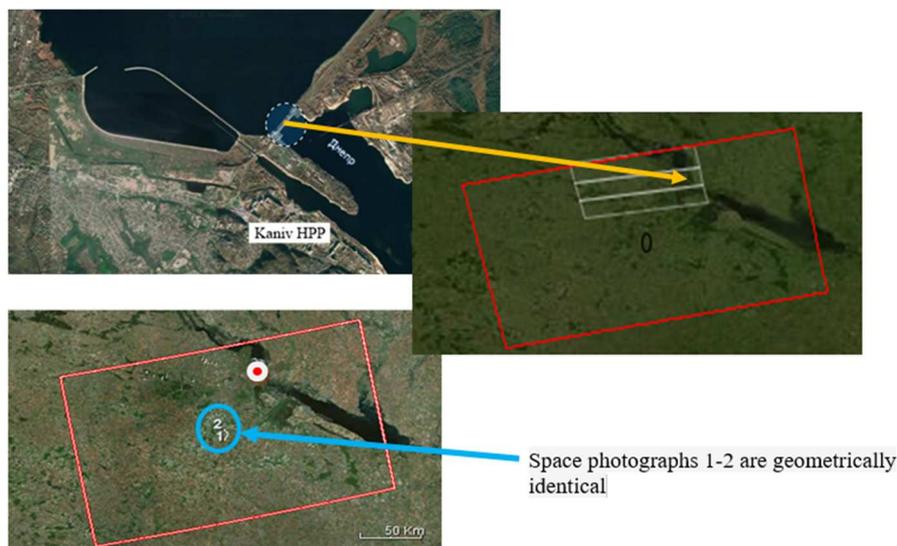
## Introduction

Modern scientific research in the field of natural sciences is impossible to imagine without the using of remote sensing data of Earth, as well as their elaboration with the help of geoinformatics information systems (Dovhyi, 2020). Web-based retrieval platforms for space imagery afford access to numerous satellite datasets. Optical and radar satellites provide an information base successfully used for planning and monitoring on land and in the ocean.

Optical-electronic systems offer detailed images of the Earth and objects on it, but these systems operate only during daylight hours and without cloud cover (Burshtynska, 2019). It became possible to use the C-band Sentinel-1 radar satellite system of the European Space Agency to solve geodesic tasks (ESA). Active Synthetic Aperture Radar (SAR) gives radar images of the earth's surface at any time of day regardless of meteorological conditions and natural light levels (Kumar, 2019). InSAR remote sensing technology allows comparing two radar images of the same area, which were obtained with the equal imaging geometry, but with different sensor positions. This is how the distance to the topography of the Earth is determined. Merging the phases of these two images after correction creates an interferogram in which the phase is strongly correlated with the topography of the terrain, and it is possible to plot the character of the deformation on the map. If the phase shift associated with the topography is removed from the interferograms, the difference between the products obtained will show the character of the surface deformation between the two data collection dates (differential interferometry DInSAR) (Sentinel Online).

## Method and Theory

The application of satellite radar for studying the deformation of the Earth's surface becomes possible in case the geodesic accuracy of the results is satisfactory. Kaniv hydroelectric power plant (Fig. 1) was picked for the selective research and detailed analysis of the DInSAR method, where the automated geodesic monitoring of the set points has been carried out since 2014. The results of ground geodesic survey combined with GNSS observations and analysis of point stability were published in the works (Tretyak, 2014, 2017, 2022).



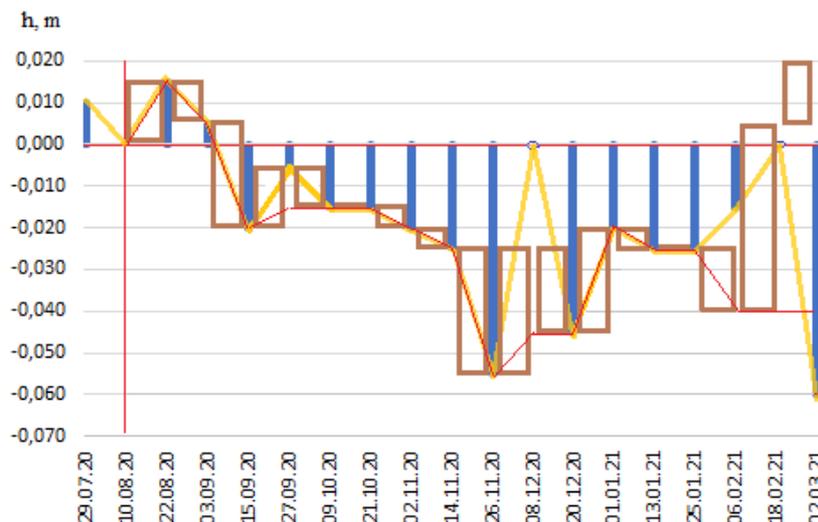
**Figure 1** General view of the Kaniv HPP location on the satellite image Google Earth and on the strip IW SLC

The vertical displacement maps construction is based on Sentinel-1 radar image pair processing in SNAP (Sentinel Application Platform) software. The source of the satellite radar images is Copernicus Open Access Hub. It is possible to set the polygon with coordinates or specify the area, and additionally specify the search parameters, such as period of sounding, satellite, Product Type, Sensor Mode. Some parameters are set by default.

We choose Product Type SLS for our purposes, which is a processed complex Single Look data-containing complex of images with amplitude and phase. SLS products consist of focused SAR data with georeferencing through orbital and orientation data of the satellite. Sensor Mode IW is a broadband interferometric imaging mode that collects data with a swath of 250 km. The IW mode captures three additional bands using Terrain Observation with Progressive Scans SAR (TOPSAR) technology. The TOPSAR method is additionally provided with homogeneous image quality over the entire field of view (Sentinel Online). IW SLC products contain one image per sub-band and one per polarization channel, three in total in a single polarization. The Sentinel-1 can collect several different images from the same pulse series, using its antenna simultaneously to receive certain polarizations. It can transmit with horizontal H or vertical V polarization and then receive with both H and V polarizations. Select VV to create a vertical displacement map. The radar signal is emitted vertically and received vertically.

## Results

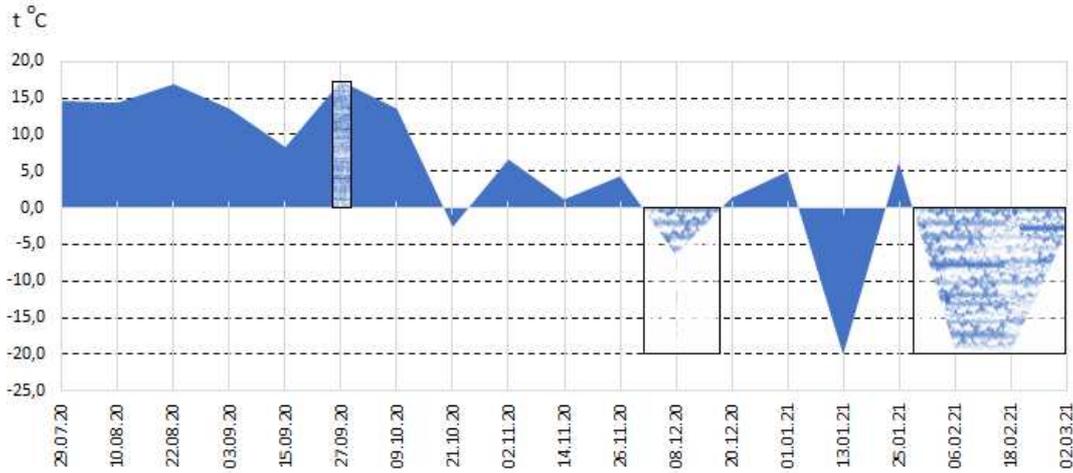
The selected period of analysis corresponds to 0.6 calendar year. As Sentinel-1 satellite is potentially capable of displaying the same territory in broadband interferometric imaging mode every 12 days, the space images from 29.07.2020 every 12 days until 02.03.2021 were subject to processing. The total number of images is 19. A set of researches was conducted, the results of which are summarized in the graph of vertical displacements of the Kaniv HPP dam (Fig. 2).



**Figure 2** Graph of Kaniv HPP dam vertical displacement for the period 29.07.2020 - 02.03.2021: in blue - displacement of each of the images compared to the data for 10.08.2020; in yellow - the dynamics of land surface deformation for this period relative to 10.08.2020; in brown - the movement of each neighbouring pair of radar images; in red - probably the trend of land surface movements based on complex analysis

According to Fig. 2 in period 29.07.2020 - 03.09.2020 there was observed lifting of all points of a dam on  $0,005 \div 0,015$  m, further the subsequent half-year there was observed constant lowering in relation to 10.08.2020,  $h_{\max} = 0,052$  m for 26.11.2020. Constructing displacement maps of each neighbouring pair of images yielded confirmatory results in 13 periods (18 periods in total).

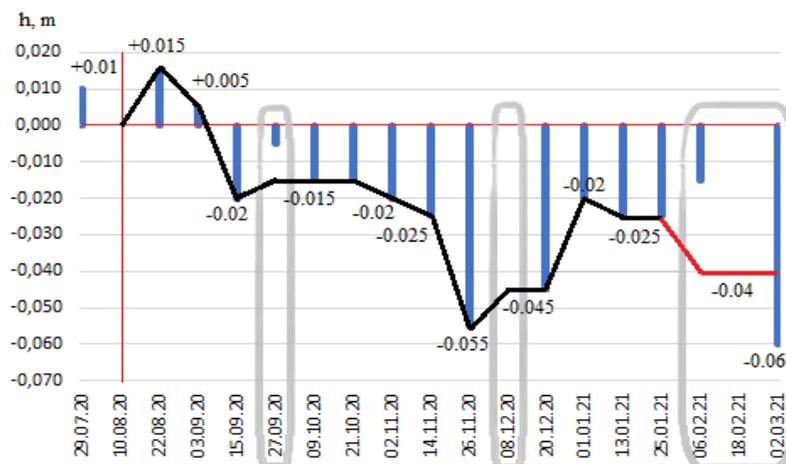
In order it was decided to check the meteorological characteristics of the state of the atmosphere on these dates in this area to search for the causes of anomalies in the other five periods. The presence of precipitation was recorded on 5 images: 27.09.2020 - rain (precipitation height  $\delta=0.4$  cm); 08.12.20 ( $\delta=1$  cm), 06.02.21 ( $\delta=2$  cm), 18.02.21 ( $\delta=26$  cm), 02.03.21 ( $\delta=1$  cm) - snow (Fig. 3). Considering that during the day the air temperature values change, the lower limits of the quantitative daily temperature values were taken for the analysis in order to identify the days with the value below  $0^{\circ}\text{C}$ . Precipitation in the form of snow and icing is possible at subzero temperatures, which significantly falsifies information on the absolute altitude of the radar reflection surface.



**Figure 3** Thermodynamic parameters of the atmosphere in the city of Kaniv, Cherkassy region, in the period from 29.07.2020 to 02.03.2021

As we know from physics, radio waves are highly permeable and allow you to get images of objects through clouds, snow and ice cover. However, maps of vertical displacements of the Earth's surface indicate the possibility of false results on dates with heavy rain or snowfall. Among the results obtained due to a small amount of precipitation 27.09.2020 and 08.12.2020 we can predict a likely trend of the Earth's surface movement (red line), but the results of observations based on satellite images 06.02.2021, 18.02.2021 and 02.03.2021 we reject (gross errors).

As a result of this work, we obtain a general graph of vertical displacements of Kaniv HPP dam from 29.07.2020 to 02.03.2021 in relation to 10.08.2020 (Fig. 4), where the black color indicates the trend of movements of the Earth's surface based on observations, which requires re-study. It is necessary to select other «meteorologically clean» days and construct displacement maps on their basis to determine the deformation of the Earth's surface in this uncertain period. It is necessary to remember that in order to ensure the same geometry of the area survey, the images are compared with a 12-day cycle. The DInSAR differential interferometry method is used to investigate vertical and horizontal deformations of planar surfaces. The constant scattering interferometer (PSI), which uses point scatterers with strong radar backscatter over a long period of time, must be used to estimate the displacements of individual geodetic points. In this work, the analysis of vertical displacements of the whole Kaniv HPP dam as a planar element to check the reliability of the exceedances obtained by satellite radar system.



**Figure 4** The graph of vertical displacements of Kaniv HPP dam for the period 29.07.2020 - 02.03.2021 in relation to 10.08.2020: in black - identified exceedances based on observations, in red - period of gross mistakes

## Conclusions

Nowadays, satellite radar system becomes especially important in conditions of martial law. We take into account that a part of Ukraine is in complex geodynamic conditions, including various technogenic-loaded areas. Therefore, constant geodetic monitoring and control of changes in the situation is necessary to prevent man-made disasters. Access to engineering structures located in places of combat operations is dangerous, which is why ground surveys and GNSS observations are impossible. In such cases, remote sensing data remains the only method of geodetic monitoring.

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