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Monitoring of mining branches according to satellite radar interferometry

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SUMMARY

These studies are aimed at establishing the current capabilities of radar interferometry methods and the prospects of their use for observations of vertical deformations on the example of the mine field "Khotin" Kalush-Golinsky field. The comparative study of PS and SBAS radar data processing methods justifies the use of radar interferometry technology to analyze the dynamics of deformation processes of the earth's surface and near-surface objects. Over a short period of time, these methods make it possible to analyze the deformation of the earth's surface. Features of PS and SBAS methods are analyzed. To verify the results of these methods, measurements of shear values in the most problematic areas were observed by high-precision geometric leveling with a short beam. The results of observations by ground (geometric leveling with a short beam) and space (radar interferometry) methods correlate and confirm the presence of a zone of active sedimentation in the mining area.

Introduction

The development of methods for forecasting natural and disasters which were made by human is constantly faced with the problem of choosing methods for observing the deformations of the earth's surface (Fanti R. et. al., 2013). The use of inclinometers, global positioning systems, unmanned aerial vehicles, ground-based laser scanning, etc., despite their reliability mostly give only a static picture of the state of the study area during each measurement. Therefore, to determine possible areas of development of subsidence and deformation of the earth's surface are almost always used geodetic and geophysical methods of observation, which are characterized by high complexity and cost of work.

The efficiency of obtaining up-to-date spatial information about the earth's surface is an important need that can be addressed by analyzing current data from remote sensing of the Earth (remote sensing). Satellite radar interferometry is the most dynamically developed area of Earth exploration from space.

Unfortunately, many deformation processes that occur are not natural, ie they are caused by human action or inaction (Petrov S, 2015). Areas such as mining branches are the result of interference with the natural geological structure of the Earth. And this in turn causes deformation of the earth's surface. That is why it is extremely important to monitor the condition of such man-made objects.

Formulation of the problem. Kalush-Golynske deposit of potassium salts is located in the inner zone of the Pre-Carpathian advanced depression in the Kalush district of Ivano-Frankivsk region. In recent decades, there has been a tendency to intensify dangerous exogenous geological processes, such as landslides, subsidence of the earth's surface, karst phenomena (National report on the state of technological and natural safety in Ukraine in 2007, 2008). In recent years, Ukraine has suffered multimillion-dollar losses due to geological emergencies. These emergencies are mainly associated with the development of exogenous geological processes, including karst. The (National report on the state of technological and natural safety in Ukraine in 2007, 2008) deals with the development of technogenic karst in the area of the Kalush salt mine, which led to the emergence of regional emergencies, which in turn led to the formation of karst and failure. funnel with a volume of 7.6 million m^3. Approximately 1,300 residential buildings in five settlements and 23 industrial buildings are located in the development zone. In order to control the course of such processes and take appropriate measures, it is necessary to monitor the development of these processes in a timely manner.

Materials and Methods. Interferometry is one of the methods of radar imaging (radar) that captures the amplitude and phase of the reflected signal. One image obtained using synthesized aperture radar (X-ray diffraction) is mostly of no practical value, while two images (interference pair) obtained at different angles can be used to build a digital terrain model or monitor the displacement of the earth's surface.

According to the results of comparing two images of the same area, an interferogram is obtained, which is a network of colored bands, the width of which corresponds to the phase difference of both exposures. Since there are some sources of error in radar data (temporal and geometric decorrelation, atmospheric signal delay, etc.), there are a number of methods of differential interferometric processing of time series, which in turn weaken the influence of these sources of error (Ferretti A. et. al., 2007; Costantini M. et al.). Given that the study area is built-up and covered with vegetation, the method of permanent scatterers (PS) and the method of small baselines (SBAS) (Berardino R. et al., 2002) were used, the features of which are given below.
PS method processing is generally considered more reliable because it uses 30 or more images of the same area on different dates taken in the same satellite radar survey geometry, so the accuracy of displacement can reach several millimeters. The main disadvantage of the technology of permanent diffusers is its suitability only for built-up areas or areas without vegetation, as well as for individual

buildings and structures when shooting with a high spatial resolution. This method focuses on a subset of points that demonstrate relatively constant scattering properties over time.

For PS, the SBAS method is less sensitive to the number of images because it uses spatially distributed coherence instead of considering only individual points, as in PS. With the help of small baselines, both the geometric and temporal decorrelation effect is reduced. Due to the small baselines and multi-visibility of image pixels that are often used, SBAS is particularly suitable for distributed scattering mechanisms that occur in rural areas with unsown areas (Feoktistov A. A. et al., 2015).

Results of investigations. To study the characteristics of the earth's surface and near-surface objects of the mine field "Hotin" by PS and SBAS methods selected a series of images for the period from 03.04.2016 to 31.10.2017 from the spacecraft Sentinel-1A, B. For PS and SBAS methods, the interferometric processing cycle in ENVI SARscape is performed for each pair of interferometric series images. Pairs of images are selected by the program automatically from the given series of images on the basis of the set parameters before the beginning of calculations (fig. 1). The specified parameters determine which pairs of images meet the criteria for each method, depending on the limitations on the choice of interferometric pairs for further automated processing. For the SBAS method, the number of pairs was 82, for the PS method – 33.

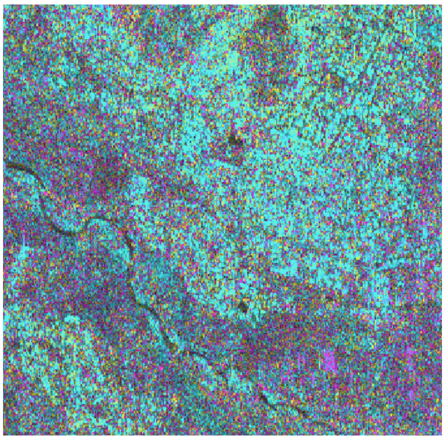
	Persistent Scatterers
Baseline Threshold (%)	500
Range Looks	-2
Azimuth Looks	1
Rg Looks for Quick View	1
Az Looks for Quick View	5
PS Resampling	4th Cubic Convolution
PS Density for Statistics	200
Product Coherence Threshold	0.65
Atmosphere Low Pass Size (m)	1200
Area for Single Reference Point (sqkm)	25
Atmosphere High Pass Size (days)	365
Area Overlap for SubAreas (%)	30
Max Residual Height (m)	70
Min Residual Height (m)	-70
Max Displacement Velocity (mm/year)	250
Min Displacement Velocity (mm/year)	-250
Residual Height Sampling (m)	2
Displacement Sampling (mm/year)	1
Shape Max Nr of Points	100000
Kml Max Nr of Points	50000
Generate Dint Multilooked for Quick View	False

a

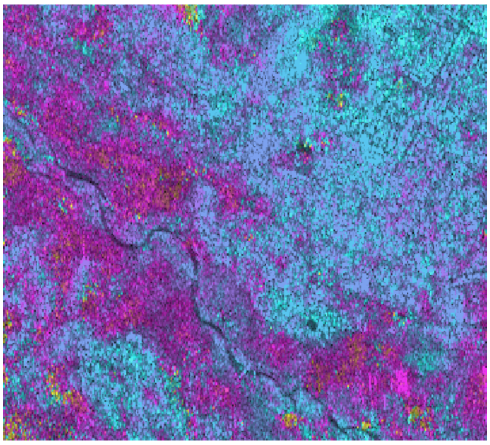
	SBAS
Min Normal Baseline (%)	0
Max Normal Baseline (%)	45
Min Temporal Baseline (days)	0
Max Temporal Baseline (days)	35

b

Figure 1. *Configuring ENVI SARscape software settings for PS (a) and SBAS (b) methods*



a)



b)

Figure 1. *Differential interferogram for the period 03.04.2016 - 15.04. 2016:*
a) before filtering the interferogram;b) filtered interferogram using a Goldstein filter

To separate several components of the complex interferogram, such as topographic phase, deformation phase, atmospheric phase, electromagnetic noise, it is necessary to perform a complex

element-by-element multiplication of the phases of radar images of the interferometric series of images.
The main source file of this procedure is a differential interferogram (Fig. 2 a), which is the result of "removal" of the synthesized phase of the terrain from the complex interferogram. To reduce the noise level, we used adaptive filtering of the differential interferogram using a Goldstein filter (Fig. 2 b). To obtain a continuous phase, it is necessary to perform the procedure of its deployment. Deployment was performed by the method of Minimum Cost Flow (minimum cost flow) with Delaunay triangulation (Fig. 3).

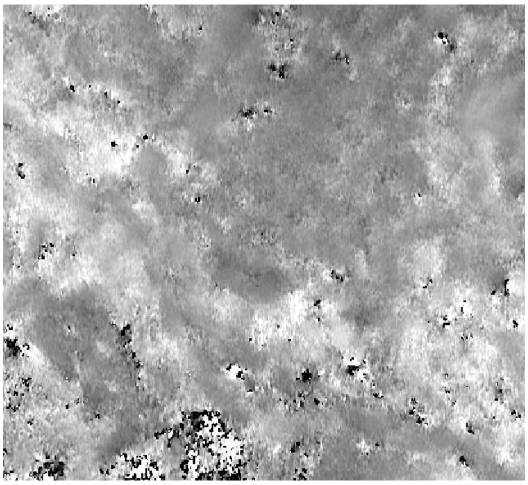


Figure 3. *Detailed interferogram for the period 2016.04.03 - 2016.04.15*

Inversion was used to restore the sequence in time of the dynamics of shifts from cross-time pairs of images. The results were then geocoded and converted to a vector format with a set of points (radar reflectors). At these points, the algorithm found constant stable reflectors of the radar signal (72 points by the SBAS method and 1557 points by the PS method). At each point, the vertical displacements of the object for this period were determined (Fig. 4), which are plotted on a digital map and reflect the average sedimentation rates during the year in places of radar measurements.

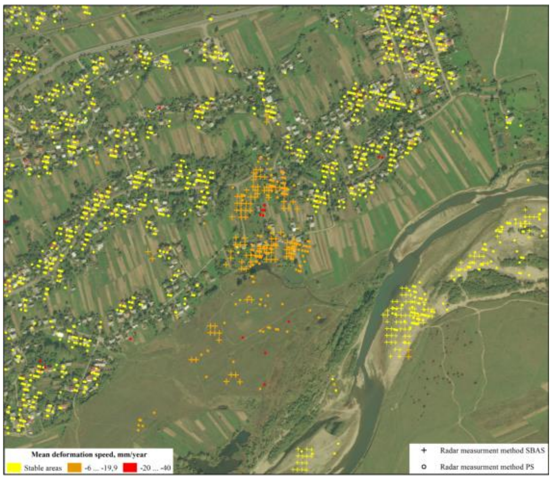


Figure 4. *A fragment of a space image with the results of monitoring the rate of subsidence of the earth's surface by radar interferometry*

Using PS, SBAS methods, three zones were recorded in the study area: stable zone (radar measurements are marked in yellow; 1331 points were determined by PS method), active zone of subsidence at a speed of 6 mm / year ÷ 20 mm / year (radar measurements are marked in orange). 206 points were determined by the PS method, 72 by the SBAS method). The boundaries of the core zones clearly coincide with the landslide trough caused by underground workings, which was built as a result of instrumental observations. Individual points with subsidence up to 40 mm / year (marked in red) were identified by the PS method, a total of 20 radar measurements.

Conclusion

1. Before starting to process radar data, it is necessary to study the features of the object of study, the lack of buildings or vegetation, or vice versa. Permanent diffuser (PS) technology should be used only for built-up areas or areas without vegetation, as well as for individual buildings and structures during removal, and SBAS - for undeveloped area that is not covered with dense vegetation. As buildings and agricultural lands are present on the territory of the Khotyn minefield, radar data processing was performed by two methods.

2. The result of the GIS analysis of radar data is a thematic map (created on the basis of data processed by PS and SBAS methods), which reflects the geodynamic processes in c. Want. Due to this, the study area was divided into several zones: yellow - in which no sediments were detected; orange - with a settling rate of 6 ÷ 20 mm / year; single points with subsidence up to 40 mm / year red. Therefore, geodetic measurements are recommended to confirm the presence of active subsidence zones on the territory of mining.

3. Satellite radar methods for monitoring geodynamic processes complement and expand the capabilities of traditional geodetic and geophysical methods for monitoring the deformation of the earth's surface of man-made objects. Radar interferometry methods allow for a short period of time to analyze the deformation of the earth's surface and identify problem areas where it is advisable to use traditional monitoring methods (eg geometric leveling with a short beam).

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