IMPROVEMENT OF APPROACHES FOR MONITORING OF EXOGENOUS GEOLOGICAL PROCESSES WITH USING OF SATELLITE INTERFEROMETRY METHODS

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SUMMARY

The purpose of the work is investigation of possibilities for improving approaches to the monitoring of exogenous geological processes whiperformed within the framework of the State Environmental Monitoring System of Ukraine using radar satellite data. In Ukraine, there is a significant demand for regular studies of hazardous exogenous processes. At the same time, the volume of field surveying works and the number of monitoring sites are decreasing year by year. The authors of the article propose to solve this problem by implementation of two-tier system for monitoring hazardous geological processes with using radar satellite data. In the first stage it is supposed to use the results of processing satellite information processed by interferometric methods, in the second - traditional geodetic measurements. The relevance and accuracy of the proposed approach was tested by the example of geodynamic assessment of the technogenic-dangerous territory of the mining and chemical enterprise "POLYMINERAL" (Stebnik), which was performed in the framework of the study. For this purpose there were applied an innovative interferometric methods of radar data processing of Sentinel-1a, b satellites data: "PS" - Persistent Scatterers Interferometry "and" SBAS "- Small Baseline Subset. According to the results of the study, there were determined the areas with concentrated deformations of the earth's surface and the dynamics of their settling by time. The combination of geodetic and interferometric methods will significantly increase the amount and quality of information about geodynamic situation of territories and objects and reduce the overall cost of the works. Such advanced approaches can be becomed of the basis for establishing an effective mechanism for monitoring of state-wide exogenous geological processes.

УДОСКОНАЛЕННЯ ПІДХОДІВ ДО МОНІТОРИНГУ ЕКЗОГЕННИХ ГЕОЛОГІЧНИХ ПРОЦЕСІВ З ВИКОРИСТАННЯМ МЕТОДІВ СУПУТНИКОВОЇ ІНТЕРФЕРОМЕТРІЇ

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РЕЗЮМЕ

Метою роботи є дослідження можливостей удосконалення підходів до моніторингу екзогенних геологічних процесів, що виконуються в рамках Державної системи моніторингу довкілля України з використанням радарних супутникових даних. В Україні є значна потреба щодо забезпечення регулярних досліджень небезпечних екзогенних процесів. При цьому, обсяги польових геодезичних робіт і кількість моніторингових ділянок скорочуються з кожним роком. Автори статті пропонують вирішити дану проблему шляхом впровадження дворівневої системи моніторингу небезпечних геологічних процесів з використанням радарних супутникових даних. На першому етапі передбачається використання результатів обробки супутникової інформації обробленої за допомогою інтерферометричних методів, на другому - традиційні геодезичні вимірювання. Актуальність та точність запропонованого підходу перевірено на прикладі геодинамічної оцінки техногенно-небезпечної території гірничо-хімічного підприємства «ПОЛІМІНЕРАЛ» (м. Стебник), що була виконана в рамках дослідження. Для цього було застосовано інноваційні інтерферометричні методи обробки радіолокаційних даних супутників Sentinel-1a,b. - «PS» - Persistent Scatterers Interferometry» та «SBAS» - Small Baseline Subset. За результатами дослідження було визначено ділянки місцевості з концентрованими деформаціями земної поверхні та динаміка їх осідання по часу. Поєднання геодезичних та інтерферометричних методів значно збільшить кількість і якість інформації про геодинамічну ситуацію територій і об'єктів і зменшить загальну вартість робіт. Такі удосконалені підходи можу стати основою для створення дієвого механізму моніторингу екзогенних геологічних процесів у масштабах всієї держави.

Introduction

In framework of the territory of Ukraine there are exogenous geological processes occurring due to gravity (landslides, landslides, scree, avalanches); action of surface and groundwater (slope flushing, erosion, villages, karst, suffusion); deforestation, as well as mining related to the disturbance of the geodynamic state of some zones and objects. These processes affect to condition of buildings, structures, roads and railways, man-made facilities and can lead to their partial or complete destruction, causing death or injury, environmental hazards for the country. As a rule, observation of such territories is carried out by traditional surveying and geodetic methods and technologies of high-precision leveling and satellite geodesy with using of global navigation systems. These observations are highly accurate, but it needs considerable material and time costs. Therefore, the volume of field surveying and monitoring sites are decreased every year due to the low level of funding.

The system is in a very poor conditions and needs to be updated in its overall performance. There is an alternative to these methods of observing exogenous geological processes. This is use of radar and interferometric data processing methods. This technology was developed in the department of data processing of remote sensing of the Center for Special Information Reception and Processing and Navigation Field Control (CIP, Dunaivtsi) and it has already been tested within the State Environmental Monitoring System of Ukraine. Its widespread use will allow regular monitoring of areas, both large and individual, with minimal time and funding, high density and frequency, and with the possibility of using retrospective data. This technology makes possible of monitoring where it is impossible to obtain information by other means and it expands greatly the experts' ability for monitoring and prediction dangerous geological processes and phenomena. In this work there is a practical example of monitoring of the natural-technogenic territory of the mining and chemical enterprise "POLYMINERAL" in the western region of Ukraine (Stebnikovsky City Council, 10 km from Truskavets and Drohobych, Lviv region). The enterprise had been completed its activity many time ago. But on September 30, 2017, the company was encountered a dangerous situation due to the erosion of the inter-partition walls in the sections of the western mine field of mine № 2. It was led to the formation of karst dip with a diameter of about 220 m and a depth of 30-35 m. Two supports of 35 kW power lines were destroyed. The distance from the karst dip to the road is about 300 m, and to the nearest buildings 800-900 m. In addition to the classical methods, there were used results of interferometric satellite measurements. It lets to estimated the geodynamic processes in the area of enterprise objects, adjacent territory and settlements. These methods made possible of obtaining complete geodynamic assessment of objects condition of the enterprise, the surrounding area and settlements. Due to the retrospective data, within one month, the situation was analyzed by the specialists of the CIP and NSFCTC for the period from 12.05.2016 to 15.11.2017. In order to work out of measures for ensure ecological balance in the territory of the Stebnytsia potash deposit, the results of the geodynamic situation analysis were considered at the meetings with Head of the Lviv Regional State Administration on 10.12.2017 and during working group of the Department of Ecology and Natural Resources of the Lviv Regional State Administration on 13.12.2017.

Theory

In order to improve the monitoring approaches for exogenous geological processes (EGP) in framework of the State Environmental Monitoring System of Ukraine (SEMS), it is proposed to use more actively satellite radar data processed with using innovative interferometric methods for processing that data, in particular "PS" - Persistent Scatterers Interferometry method. It will be allowed to measure vertical displacements of objects with almost geodetic accuracy (several mm), but more often and much cheaper.

Considering the regularity of receipt and the scale of the survey of the territories with using of Earth Remote Sensing (ERS) satellites, it is possible to compensate a lack of geodetic measurements in the required volume and to use traditional EGP surveillance methods more effectively. For this purpose it is proposed to create a two-tier system for observation of EGP, using both traditional geodetic methods and alternative technology, namely satellite radar data. It will be allowed to restore systematic monitoring of geodynamic processes and to organize it in the modern level. In the first stage, it is proposed to perform the study using interferometric methods.

Their purpose is a detection and identification areas of terrain with concentrated deformations of the earth's surface and to calculate the dynamics of vertical displacements in radar measurements. In the second stage, to carry out high-precision geodetic measurements also in the places with deformations determined by the means of radar space image.

The synthetic aperture radar (SAR) operates in cloudy days and at night. The radar data are highly resolution and allow to quickly receive of information about Earth's surface. SAR forms and emissions of their own sounding signal and it is therefore still called active. SAR sends a radio signal that is reflected from the object of surveillance and recorded on a spacecraft receiver. The radio signal is produced by special generator and the time of its return to the receiver depends on the distance to the object of surveillance. This principle of radar operation (with detecting of different passage time of the sounding impulse to the object and back) is used for obtaining of radar images.

In the field of radar-satellite data processing there are many modern directions with using interferometric methods which are being actively developed in the world. They allow to solve the problem of timely detection of vertical displacements (buildings, structures, roads, bridges, quarry walls, the earth's surface, etc). These methods include the classic differential interferometer "DInSAR", which is performed, as a rule, with use of couple space radar images and serial methods "PS" - Persistent Scatterers Interferometry and "SBAS"- Small Baseline Subset which are high-precision tools for ERS.

Figure 1 schematically presents the classical interferometric DInSAR processing method, which consists of a combination of two radar images of the same territory containing intensity (signal amplitude) and phase information (signal delay time). Repeated radar imaging it allows to determine the phase difference caused by, for example, displacements of the Earth's surface. Figure 1 also schematically shows the technology of modern interferometric processing methods of radar images "PS", "SBAS".

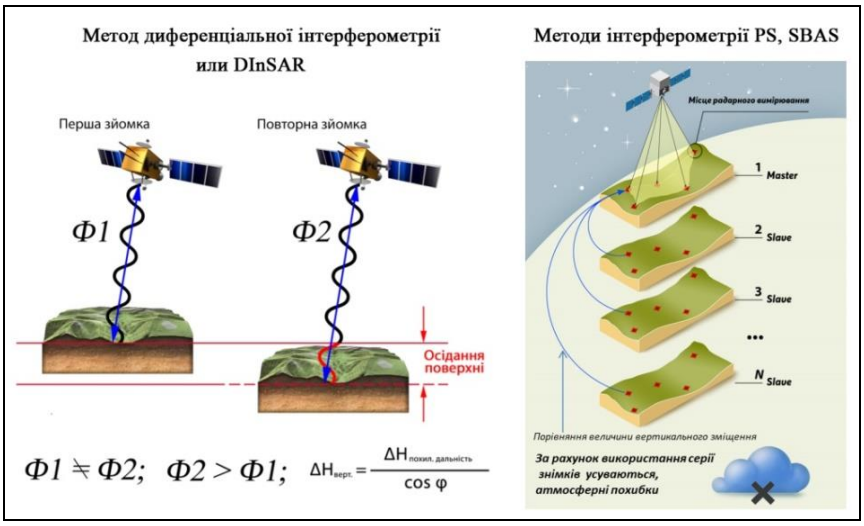

Figure 1 *Schematic explanation of interferometric methods DInSAR, PS, SBAS*

They use almost the same principle of vertical displacement determination as in the classical DInSAR method, but with using long time series images which it is obtained by synthesized aperture radars, there is effective suppression of orbital data errors and effects of atmospheric phenomena are effectively suppressed. The "PS" method is very effective in areas where there are a large number of permanent reflectors, usually man-made (urban development, bridges, flyovers, roads, etc.). This variant of radar interferometry is characterized by the highest possible accuracy of displacement estimation (2-4 mm for buildings and structures provided that at least 30 radar circuits for a period of not less than 1 year).

The input data for processing there must be radar images of the same territory for different dates taken in the same geometry of satellite radar capture (Ferretti, Prati and Rocca. 2000). Small baseline series

interferometry, in contrast to Persistent Scatterers Interferometry, is a less automated method and requires greater skill of the performer. In this case, the contribution of statistics to the final result is enhanced by the cross-processing of a very large number of interferometric pairs at the same number of source images (Gelchinsky et al. 2002). The SBAS interferometric method is used solely to determine vertical displacements on undeveloped and not covered with vegetation and snow areas.
In this work have been done the geodynamic estimation (calculation of vertical displacements) of the zone of interest (Fig. 1), which includes the territory of mining and chemical enterprise "POLYMINERAL", western part of the town of Stebnik, village Solec, a road of national importance between Trusekovets and Drohobych cities. There was processed an array of data from 42 radar images the Sentinel-1a, b for the period from May 12, 2016 to November 15, 2017. According to information of European Space Agency, the Sentinel-1a, b satellites show excellent radar phase stability and correct satellite orbit, which indicated of readiness for data for practical and scientific research, primarily for radar interferometry. Since 2014, the Sentinel-1a satellite has been re-shooting the same areas every 12 days. Since 2016 when its twin satellite, the Sentinel-1b was launched, re-shoot time reduced to 6 days, making it possible to track changes more quickly.
Interferometric processing of radar data is implemented by the SARscape software complex (SARMAP, Switzerland) with using of PS and SBAS permanent reflector methods. Geo-information system ArcGis lets to provide the thematic analysis of satellite radar measurements and preparation of final information products in the form of raster thematic maps and vector layers in the formats "SHP" and "KMZ". These products allow to do a quickly analyze of the surveillance area and obtain numerical data about the dynamics of vertical displacements. For example, the thematic map presented in Figure 2 shows the average vertical displacement rate (mm/year) in the places of radar measurements. Using a vector layer for each of them, it is possible to obtain the vertical displacements data in millimeters which are relative to the first shooting date and beyond at each shooting date.

Results

According to the results of the work, the areas with concentrated deformations of the Earth's surface were determined and there were calculated the dynamics of their settling in time. Identified objects of national importance located in the seams, identified local and global trends in vertical deformation. A digital thematic map (Fig. 2) was constructed and it shows radar measurements (average vertical displacement rate) processed by the PS method and indicated by dots and SBAS indicated by crosses. They are shown on a color scale (yellow-red color defines object settling, blue elevations) with fixed intervals by which the authors project assigned the following categories of geodynamic danger: significant, dangerous, threatening, emergency, critical, emergency.
Accumulations of radar measurements with the velocity of vertical displacements from -20 to -452 mm / year are indicated on the thematic maps (Fig. 2) by rectangles, which are sections with concentrated deformations of the earth's surface (hereinafter referred to as "subsidence zones"). Depending on the intensity, they are divided into three categories (the largest sediments are red rectangles, the intense sediments are pink rectangles, the moderate sediments are orange rectangles). A total of 24 areas of sediment are identified, the degree of danger of each of them, determined depending on the velocity of vertical displacements (the interval in which the measurements are located) and the number of measurements with similar values. State objects are identified in the settling zones using mapping and additional material, and their geodynamic state is estimated by interferometric processing. Graphs have been created showing the dynamics of precipitation at radar locations, which are identified as the most dangerous. It should be noted separately that the failures that have formed in the study area: 30.09.2017, 02.11.2017, 06.04.2018, are in the areas of sediment with high sediment dynamics (PA # 17 - the highest rate of sediment in the work - 452 mm / year, PA # 5 - maximum sedimentation rate - 68 mm / year, PA # 3 - maximum sedimentation rate - 55 mm / year). According to the results of the work, it is determined that in the research area there is a constant high risk of damage to objects of national importance (highway, water supply, power lines, etc.), which is a threat to the safety of people and their life. Within the mine drainage field of mine No. 2 of

the POLYMINERAL natural-technogenic system, and near it, the largest number of sedimentation zones, which could potentially become subsequent failures of the earth's surface, have been recorded. The most likely negative development of the geodynamic situation with a threatening and extraordinary degree of geodynamic danger and near them is determined. For example, in the area of settlement # 3 (threateningly - extraordinary), a dip was formed after the procedures of radar data processing were carried out, and this again confirms the danger of the area.

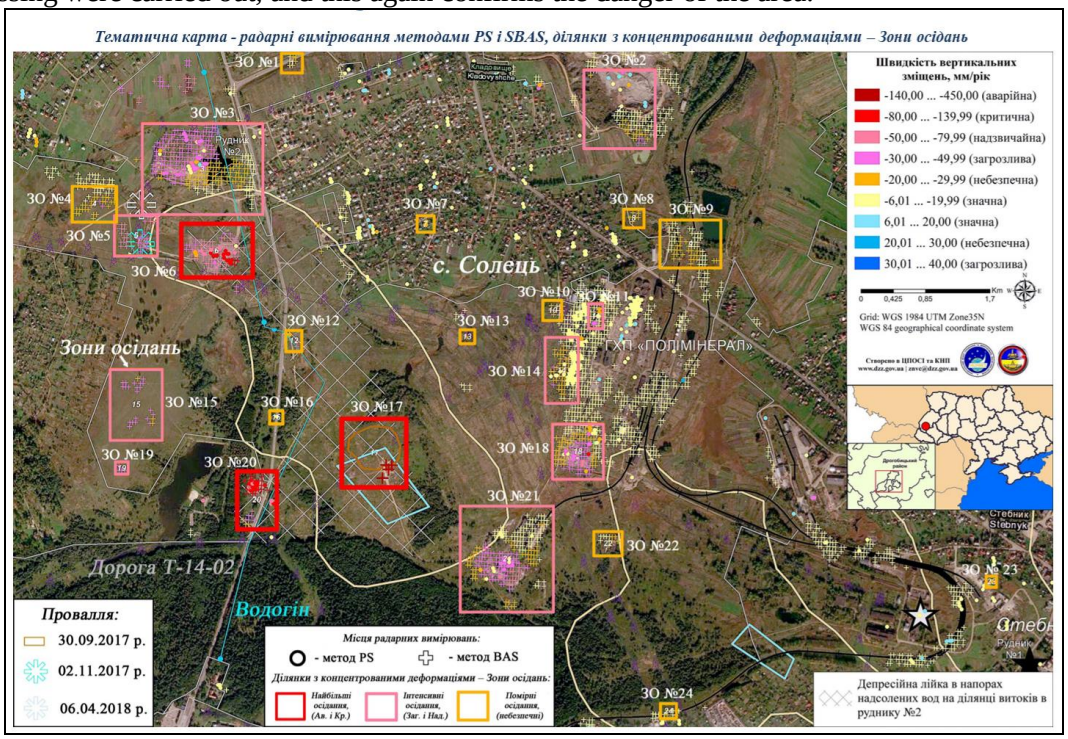

Figure 2 *A thematic digital map showing the average velocity of vertical displacements in radar locations (with an accuracy of 2 - 4 millimeters using the "PS" method); in the upper right corner is a legend of the intervals of mean velocity vertical displacement and color scale (yellow-red color defines object settling, blue elevations); radar measurements "." - method "PS", "+" - method "SBAS" - have colors according to their values of average velocity of vertical displacements and intervals of legend.*

Conclusions

At work is investigated the possibility of improving the approaches for monitoring exogenous geological processes by using radar satellite data within the State Environmental Monitoring System of Ukraine. The combination of traditional geodetic methods with satellite interferometric technologies will allow to create an effective system of monitoring of EGP in Ukraine. This advanced approach allows to increase the quantity and quality of information about the geodynamic situation in certain territories and to reduce the overall "traditional" cost of surveying. The results of interferometric studies of the natural-technogenic system of the mining and chemical enterprise "POLYMINIRAL" are considered in the Department of Ecology and Natural Resources of the Lviv Regional State Administration and used in carrying out works on stabilization and recultivation of the territory of the enterprise.

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