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ESTIMATION OF EARTH'S SURFACE MOVES AND DEFORMATION OF THE TERRITORY OF MINE "KHOTIN" OF KALUSH-GOLINSKYY FIELD BY METHOD OF RADAR INTERFEROMETRY

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Abstract. The article present processing techniques of radar data for calculating the deformations of the earth's surface on the example of minefield, that is situated under the exogenous influence of underground workings of the "Khotin" minery Kalush-Golinskyy deposit. The estimation of accuracy of radar image processing methods, namely, the interferometry of the permanent radar scatterers and the interferometry of a series of small baseline lines, is made, by comparison with the results of processional geometric levelling with a short beam of deformation soil rappers of the profile lines of the mine field. On the basis of geodetic instrumental field observations, shells of sediments of the earth's surface were constructed and the boundaries of zero deposition caused by deformation processes in the area of hollow fields were established. Working out of an array of measurements by two methods of interferometry allowed to put on the digital map the data that reflect the average sedimentation rates in the year at the radar measurement locations. Due to the ranking of average annual sedimentation rates, areas of interest were outlined where significant precipitation was observed. This made it possible to assert that the earth's crust was caused by the anthropogenic influence on the Khotin miner, which was observed since 1977 and continues existing, albeit at lower speeds. The use of expensive and labour-intensive processional levelling only on pre-determined problem areas is rational both from a scientific and from a production point of view, as it allows better use of material and human resources. Therefore, there is a need for an integrated monitoring system to prevent an exogenous catastrophe on an ongoing basis.

Keywords: interferometry, deformation of the earth's surface, methods of remote sensing of the Earth, high-precision geometric levelling.

Introduction

Earth remote sensing data (RSD) is actively used for solving the tasks of monitoring mineral deposits, transport infrastructure and strategically important objects. The use of optical and radar satellite imageries reduces financial and time costs in comparison with traditional methods, thanks to a wide range of possible applications for the detection of forest fires, monitoring of oil spills, control of incineration of associated petroleum gas and, more recently, abroad, the detection and monitoring of deformations the earth's surface (Zakharov & Khrenov, 2004; Filatov & Yevtyushkin, 2009).

The radar interferometry is an effective method of the Earth's surface deformation monitoring and man-made objects. Satellite radar interferometry uses mathematical processing of several coherent amplitude-phase measurements of one and the same area of the earth's surface with a displacement in space of the receiving antenna of synthetic aperture radar antenna (RSA). The advantage of RSA is the ability to obtain images of the earth's surface, regardless of the conditions of illumination and cloudiness, which is especially relevant to the northern latitudes (Ramon, 2001).

Traditionally, in national practice for determining surface displacement and deformation due to the influence of underground mining, used engineering-geodetic observations, namely geometric leveling, the data of which are the most accurate and reliable. At the same time it can be attributed to the shortcomings of the high complexity and

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cost of such works. The methods of radar interferometry in Ukraine for observing earth's deformations have been successfully investigated at the Center for the Adoption and Processing of Special Information and Navigation Field Controls (CPCCIs and CNCs) and are used to detect the deviations of object parameters and the environment from the safety criteria with the assessment of the risk of process development (Lyaska, Pakshin, & Stasyuk 2017, Mordvinov et al., 2018).

1. Analysis of recent research works and publications

It is well-known (Verba, Neronsky, Osipov, & Turuk, 2010; Rys, 2006; Richards, 2007) according to the results of multi-pass space radar surveys of the same territory, made with the same parameters and geometry, it is possible to estimate the displacement of the earth's surface or buildings and structures with centimetre (for the earth's surface) and even millimetre (for buildings and structures) accuracy.

In work M. Constantini and others (Costantini et al., 2009) the methods for processing interferometry data are improved, as well as ways to remove systematic errors.

Successful use of interferometry to detect soil sediments in the areas of coal mines in England, oil fields in Russia, major metropolitan areas in Europe, earthquake zones and active volcanoes is highlighted in (Zakharov & Khrenov, 2004; Melnikov, A. I. Kalashnik, & N. A. Kalashnik, 2014; Filatov & Yevtyushkin, 2009).

In (Feoktistov, Zakharov, Gusev, & Denisov, 2015) the main characteristics of the method of small baseline (Small Baseline, SBAS) and the results of complex experimental studies at the territory of Tiba Prefecture (Japan) are presented.

2. Problem statement

Conducting a comparative analysis of different methods of space-based radar interferometry techniques with data received from field-based instrumental geodetic measurements (high-precision geometric levelling) under assessing the geodynamic state of the territory of the "Khotin" mine of the Kalush-Golynskyy deposit.

3. Main research material

The Kalush-Golynskyy deposit of potassium salts is located in the inner zone of the Pre-Carpathian mountain trench in Kalush district of Ivano-Frankivsk region. From different perspectives, it is the unique object, which was exploited to extract the rock salt for many centuries.

The Kalush mine had been exploited for more than one hundred years. Currently, the miner has been liquidated by partial filling of waste cavities with salt brines in the amount of 2502 thousand m^3, which allowed only partially stabilizing the process of subsidence of the earth's surface.

As a result of the mistaken decisions made at the time about the development of the deposit, the location and operation of tailing dumps, accumulation capacities and the way of mine cavities liquidation formed by an economic activity of chemical enterprises in Kalush district, the ecological balance was violated in the rock mass of Kalush-Golynskyy deposits of potassium salts. It caused numerous earthquake failures over the area of mine fields in Kalush, the destruction of buildings and communications.

The necessity of conducting observations on such an exogenously dangerous object is obvious. Therefore first series of measurements by the traditional method of high-precision geometric levelling had been carried out on this object from 1965 till 2010 and was stopped due to the lack of financing.

Particularly noteworthy is the part of the mine field, through which the high-pressure gas pipeline with a diameter of 250 mm passes. To assess its operational reliability, a set of measures was carried out in 2017, some of which are aimed at establishing the boundaries of the subsidence trough in the area of the gas pipeline. For these reasons, the series of observations the reference benchmark's displacement at the part of the profile lines in the area of the gas pipeline and investigation the displacement of this region by the method of radar interferometry was conducted. From the analysis of geodetic surveys of previous years and the last series of measurements in 2017, zones with abnormal sedimentation (displacement) values were identified and subsidence trough were constructed (Figure 1).

Also, the data from radar interferometry from the spacecraft Sentinel-1A and Sentinel-1B were used for the determination of the places of concentrated deformations and the high-accuracy estimation of vertical displacements of the area during 03.04.2016 to 31.10.2017.

The Sentinel-1A satellite is re-surveys the same areas every 12 days. In 2016, the twin satellite Sentinel-1B was launched; the period of re-filming was reduced to 6 days, which allows monitoring the changes even more quickly. Imaginaries from Sentinel-1A, B show excellent radar phase stability and correct satellite orbit, what says about readiness for practical and scientific research, primarily for radar interferometry.

To solve the problems of space radar monitoring of landslides, terrain and structures deformations the interferometry processing technologies are used, such as the Persistent Scatterers Interferometry and Small Baselines Series Interferometry, implemented in the SARscape software program (SARMAP, Switzerland) (Berardino, Fornaro, Lanari, & Sansosti, 2002; Ferretti, Monti-Guarnieri, Rrati, & Rossa, 2007; Goel & Adam, 2013).

Among the all technologies of interferometry processing of radar images, the most accurate vertical displacements calculation is achieved according to the interferometry of the permanent radar signal scatters by the PS method; the average speed of vertical displacements is calculated with an accuracy of 2–4 millimetres (Crosetto,

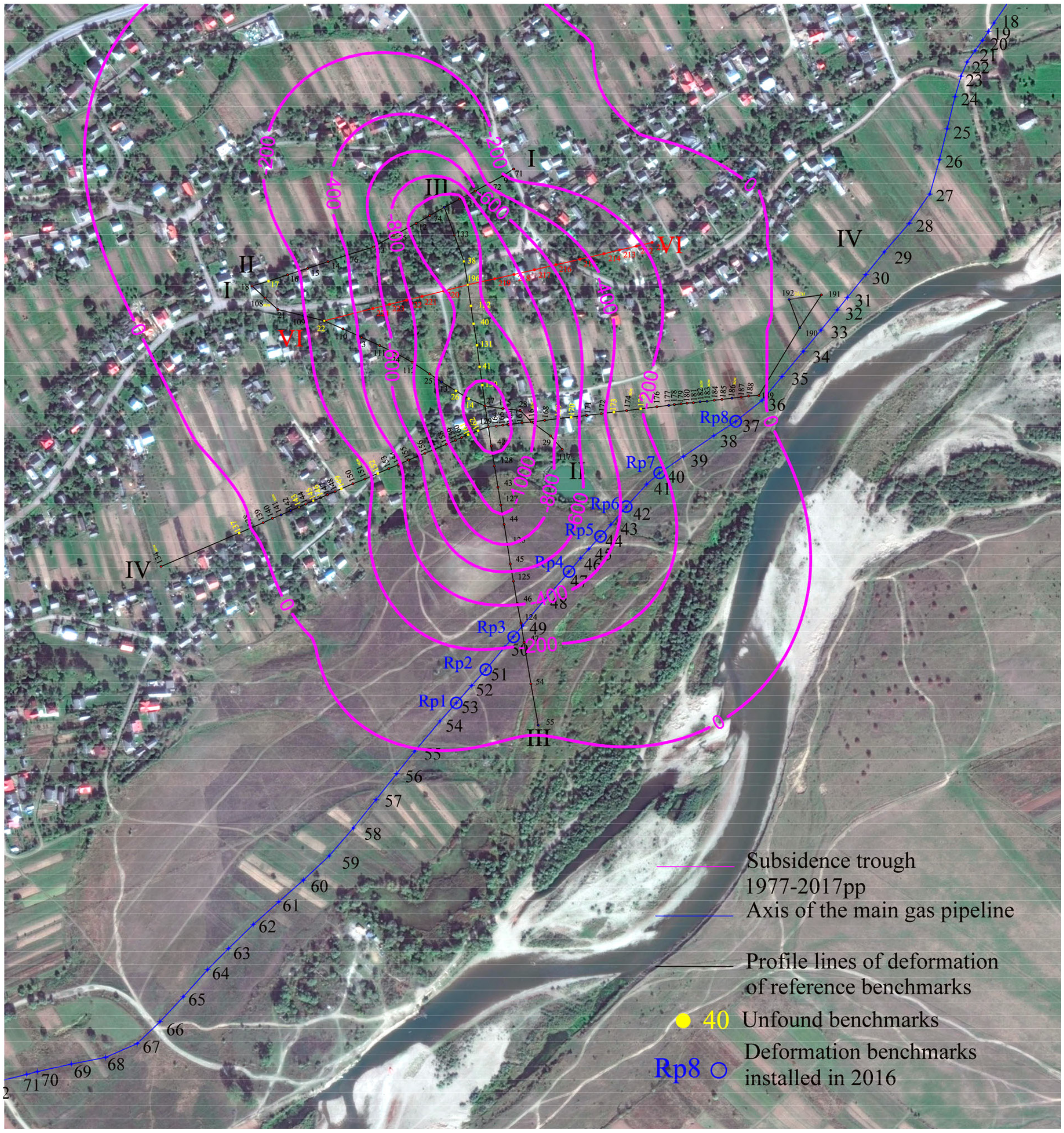

Figure 1. Map of the placement of profile lines of deformation of reference benchmarks, the axis of the main gas pipeline and the subsidence trough

Monserrat, Cuevas-González, Devanthéry, & Crippa, 2016; Kantemirov, 2012).

In the framework of the SBAS method, the possibility of forming spatially "dense" permanent reflectors of the radar signal is realized, however, in the urbanized areas its possibilities are sharply limited. It is less automated and is used to determine vertical displacements on unplanned and non-vegetated areas with centimetre accuracy.

Processing of an array of measurements by both methods allowed to reflect the data on the digital map (Figure 2). This data presents the annual average subsidence per year in the areas at the radar measurement. The sedimentation rates obtained by means of instrumental observations (by the method of high-precision geometric leveling with a short beam in the period from 04.03.2016 to 31.10.2017) should be commensurate with the precipitation rates obtained from satellite data (2016–2017 years).

The comparative analysis of data for the of reference benchmarks of "Khotin" profile lines mine field and interferometric measurements are shown in Figure 3.

Particular attention should be paid to determining the subsidence (displacement) of the earth's surface above the main gas pipeline, which is in close proximity to the previously fixed limit of zero sedimentation.

Using the methods of PS, SBAS on the studied area, three zones were defined: *stable zone* (radar measurements are indicated by yellow color, the 1331 point is determined by the PS method), *active sedimentation zone* at a speed of 6 mm / year to 20 mm / year (radar measurements are indicated by orange color; according to the PS method, 206

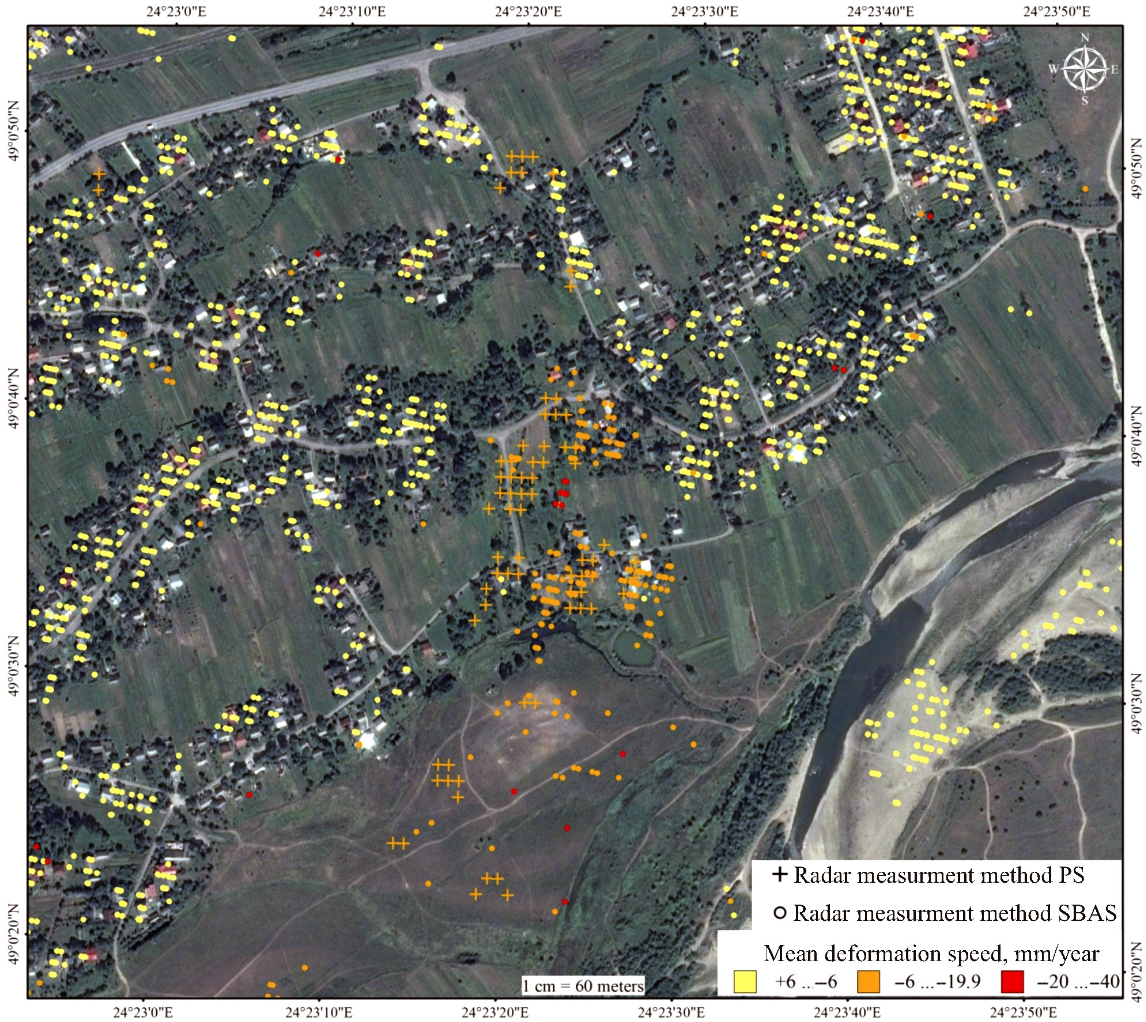

Figure 2. Layout of permanent stable reflectors of the radar signal

points were determined, using the SBAS method 72 points were determined), the boundaries of which clearly coincide with the displacement trough due to underground workings, which is based on the results of instrumental observations, and *individual points*, with sedimentation up to 40 mm / year (radar measurements are red), determined by PS (only 20 radar measurements).

The results of the measurements obtained using the data of interferometry and high-precision geometric leveling of the sedimentation zone coincide, although the rates of these sediments are somewhat different. For direct comparison of measurements by both methods, it is necessary to use the angular reflectors or active transponders in the of reference benchmarks locations.

The measurements are correlated and speak for additional possibilities in solving problems of estimating vertical displacements of the earth's surface and objects by the PS method.

Geodynamic monitoring of the research zone allowed to determine areas with concentrated deformations of the earth's surface and to assess the state of objects in them. It was determined that the buildings located inside the trough of sediment are located on a plot that sinks at an average speed of −12 to −24 mm / year. Also, using radar data, accumulations of permanent signal reflectors were obtained by automated processing of satellite images that are within the trough of the sediment and near the gas pipeline. The (Figure 4, Figure 5) shows the dynamics of vertical displacements at individual points T№1 and T№2 (Figure 3), the maximum average sediment velocity of which is −27 mm / year and −10 mm / year.

The data describes the processes of slow motion of the territory on which the gas pipeline is located and there are deformations of the earth's surface with the intensity of subsidence from −6 to −36 mm / year. Individual single radar measurements, that determine the subsidence and are outside the trough sediment and near radar measurements, that are stable, will require a different research. They, as a rule, or indicate a separate object that is not associated with the general geodynamic situation, for example, the subsidence of a separate building as a result of a weak foundation or washing it with water, etc.

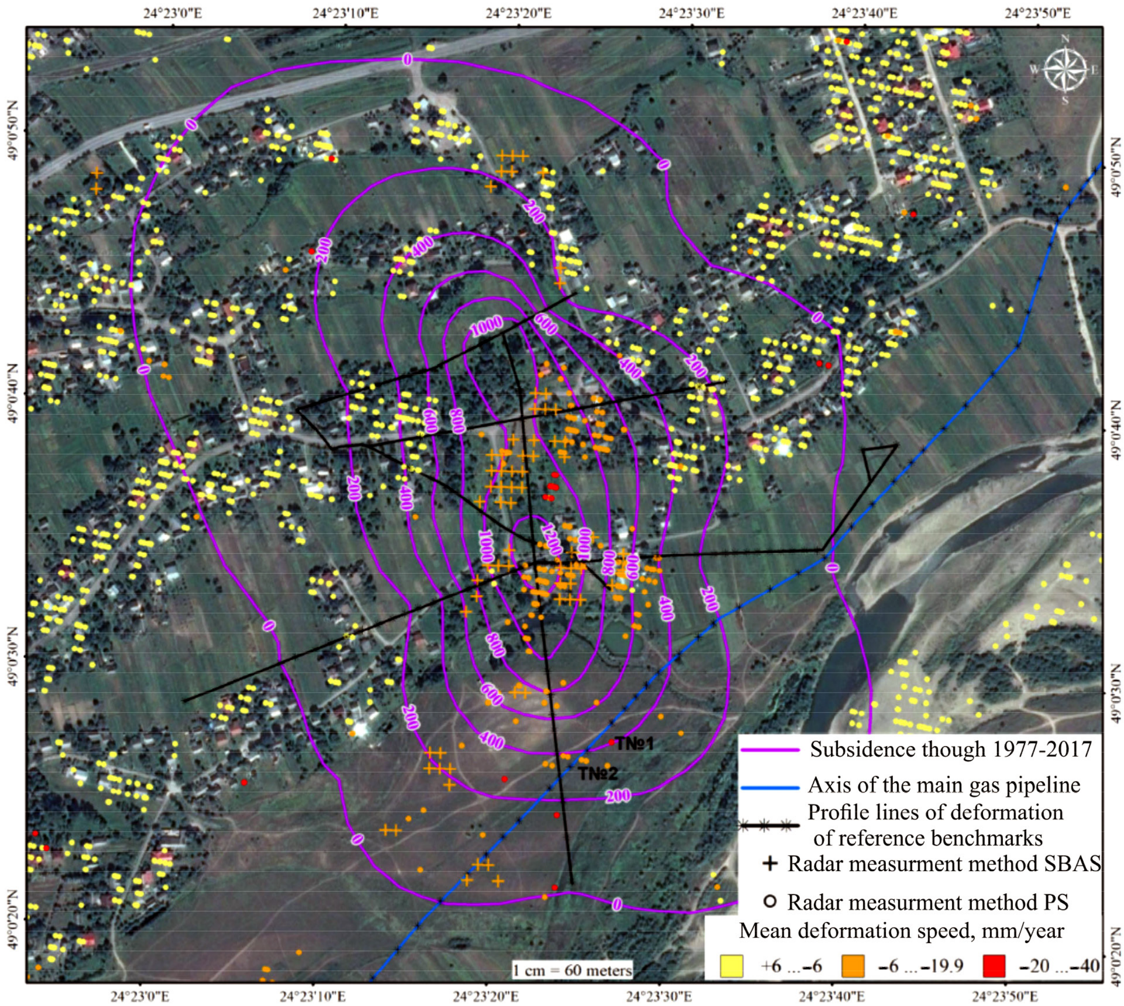

Figure 3. Combined scheme of the results of processes monitoring the displacement of the research area

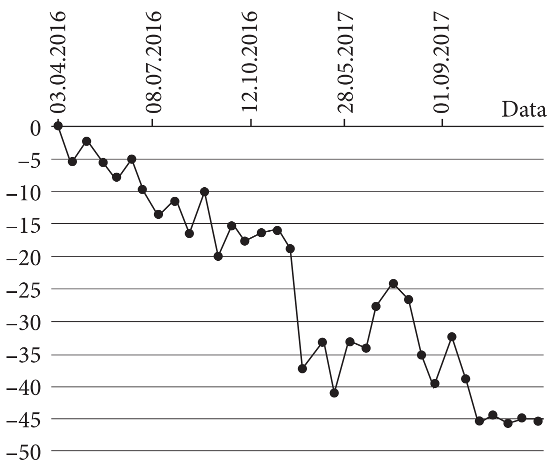

Figure 4. Dynamics of the vertical displacement at the point No. 1

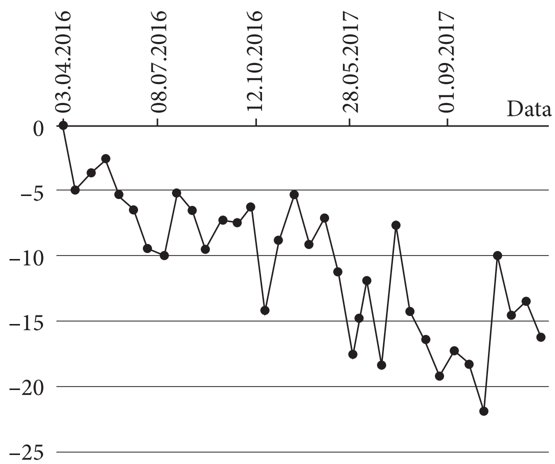

Figure 5. Dynamics of the vertical displacement at the point No. 2

On the basis of the obtained results of geodetic and satellite observations of the territory of interest, it can be argued that the subsidence of the earth's surface caused by the technogenic influence of the Khotin mine, which has been observed since 1977, and continues to exist, although at lower speeds. Therefore, there is a need to organize on the ongoing comprehensive monitoring system to prevent exogenous disaster.

The use of radar interferometry technology for monitoring the territory allows the identification of dangerous areas in which non-typical deformations of the earth's surface are observed, which allows the zones for further detailed observations. Satellite monitoring methods allow operative and high validity determination of the deviation of objects parameters.

Conclusions

1. By means of high-accuracy geometric leveling with short beam and radar measurements using interferometry methods in the period from 03.04.2016 to 31.10.2017 the estimation of the geodynamic state of the natural-man-made system the territory of Khotin mine of Kalush-Golinskyy deposit and adjoining territory are given. The areas of land with significant displacement were identified and the speed of these displacement was established. 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 with active sedimentation on the territory of mining.

2. The use of archival data from space imagery allows the analysis of both current and previous geodynamic states of objects and territories, which makes it possible to determine the dynamics of these processes.

3. Satellite radar methods for monitoring geodynamic processes complement and extend the possibilities of traditional geodetic methods for monitoring deformations of the earth's surface, buildings and structures, and other technologically dangerous objects. For a short period of time the interferometry methods allowed to analyze the deformation of the earth's surface and, high-precision geometric leveling with a short beam, to clarify the magnitude of landslides in the most problematic areas. The use of expensive and time-consuming precise levelling only on previously defined problem areas is rational from a scientific terms and in terms of engaging material and human resources.

Disclosure statement

The authors declare no conflict of interest.

References

Berardino, P., Fornaro, G., Lanari, R., & Sansosti, E. (2002). A new algorithm for surface deformation monitoring based on Small Baseline differential SAR Interferometry. *IEEE Aerospace and Electronic, 40*(11).

Crosetto, M., Monserrat, O., Cuevas-González, M., Devanthéry, N., & Crippa, B. (2016). Persistent Scatterer Interferometry: A review. *ISPRS Journal of Photogrammetry and Remote Sensing, 115*(2016), 78-89. https://doi.org/10.1016/j.isprsjprs.2015.10.011

Costantini, M., Falco, S., Malvarosa, F., & et al. (2009). Method of Persistent Scatterer Pairs (PSP) and high resolution SAR Interferometry. *IGARSS*. No. *3*. https://doi.org/10.1109/IGARSS.2009.5417918

Ferretti, A., Monti-Guarnieri, A., Rrati, C., & Rossa, F. (2007). *InSAR principles: Guidelines for SAR Interferometry Processing and Interpretation* (TM-19, February 2007). ESA Publication (48 p.)

Feoktistov, A. A., Zakharov, A. I., Gusev, M. A., & Denisov, P. V. (2015). Study of the capabilities of the small baseline method using the example of the SBAS module of the SARscape software package and PCA data ASAR / ENVISAT and PALSAR / ALOS. Part 1. Key points of the method. *Journal of Radio Electronics, 9*. Retrieved from http://jre.cplire.ru/jre/sep15/1/text.html

Filatov, A. V., & Evtyushkin, A. V. (2009). Estimation of deformations of the earth's surface in areas of intensive oil production in Western Siberia using X-ray diffraction by interferometry according to ENVISAT \ ASAR and ALOS \ PALSAR. *Modern problems of remote sensing of the Earth from space*, *6*(2), 46-53.

Goel, K., & Adam, N. (2013). Distributed scatterer interferometry approach for precision monitoring of known surface deformation phenomena. *IEEE Transactions on Geoscience and Remote Sensing, 52*(9). https://doi.org/10.1109/TGRS.2013.2289370

Kantemirov, Yu. I. (2012). Brief theoretical foundations of radar interferometry and its multipass PS and SBASS variations. *Geomatics, 1*, 22-26.

Lyaska, I. I., Pakshin M. Yu., & Stasyuk, V. M. (2017). More information about the geodynamic processes in Ukraine using methods that are based on radio communications. *Aerokosmichni tekhnologiï, 1*, 15-22.

Melnikov, N. N., Kalashnik, A. I., & Kalashnik, N. A. (2014). On the need to ensure the geodynamic safety of oil and gas facilities in the Western sector of the Russian Arctic. *Problems of the Arctic and Antarctic, 2*(100), 95-103.

Mordvinov, I., Pakshin, M., Laskas, I., Zayats, O., Petrov, S., & Tretyak, K. (2018). Monitoring of vertical lines of the territory of "Polimineral" from the interferometric methods of interfering methods of satellite radar spawn. *Modern geodesic advances of sciences and industry*, *I* (35), 220-226.

Rys, U. (2006). *Basics of remote sensing*. Moscow: Technosphere (336 p.).

Ramon, R. F. (2001). *Radar interferometry: data interpretation and error analysis*. Kluwer Academic Publishers.

Richards, M. (2007). A Beginner's guide to interferometric SAR concepts and signal processing. *IEEE Aerospace and Electronic, 22*(9). https://doi.org/10.1109/MAES.2007.4350281

Verba, V. S., Neronsky, L. B., Osipov, I. G., & Turuk, V. E. (2010). *Space-based ground observation radar systems*. Moscow: Radio Engineering (432 p.).

Zakharov, A. I., & Khrenov N. N. (2004). Radar interferometric methods of Earth observation in the task of monitoring gas pipeline movements. *Gas industry, 3*, 44-48.