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AERIAL PHOTOGRAMMETRY OBSERVATION OF THE SUBSIDENCE DEPRESSION NEAR KARVINÁ

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ABSTRACT
Aerial photogrammetry was chosen as an additional observation method of the subsidence depression that was created above exploited coal mining panels near Karviná. While individual points of a permanent observation network were repeatedly surveyed by GNSS, the whole subsidence depression was surveyed by the aerial photogrammetry. As this method was applied three times (during three years) we can compare its results in individual years and observe the major surface changes on the undermined area. Also, a comparison was realized between the points' coordinates gained from both aerial photogrammetry and GNSS. The results show that the method of aerial photogrammetry enriches and complements the GNSS observation in monitoring the spatial development and shape of the subsidence depression, especially in the areas of active recultivation.

KEYWORDS: subsidence depression, monitoring, aerial photogrammetry, GNSS

INTRODUCTION

In 2006, the Institute of Geonics started a project of the observation of a subsidence depression in the mining area near the town Karviná in the north-eastern part of the Czech Republic. GNSS was chosen as a primary observation method. That is why nearly 100 geodetic points were fixed mostly in profiles on the surface affected by undermining from black coal exploitation. These points were repeatedly geodetically surveyed by GNSS (c. once a month with Leica GPS System 1200) which provided data on changes of spatial positions of the points. Aerial photogrammetry was chosen as an additional observation method to observe the whole subsiding area. This method was applied once a year for three years to enable the comparison of its results in individual years and observation of major surface changes on the undermined area. Also, a comparison was done between the points' coordinates gained from both aerial photogrammetry and GNSS.

The effects of the coal exploitation in the conditions of the Upper Silesian Coal Basin were researched and published e.g. by Knothe (1953, 1984); Neset (1984). Through the years, the surface movements and deformations from undermining were measured using various methods of geodetic surveying (Schenk, 1999; Schenk, 2000; Mikulenka et al., 2000; Blachowski and Milczarek, 2007; Blachowski et al., 2009; Kadlečík et al., 2010). This paper is a continuation to Doležalová et al. (2009) and Doležalová et al. (2010) where the subsidence and horizontal shifts from the GNSS measurements were analysed in given observation network near Karviná. But the maintenance of the long term repeated GNSS measurements on the permanent points proved to be problematic in this area, mainly due to the ongoing recultivation. The permanent points are often destroyed, covered with mine spoils, flooded, etc. Thus, the GNSS surveying alone cannot provide the long term monitoring of the whole area, also with regard to the landscape, where a regular point network cannot be fixed. Therefore, we decided to use also the method of the aerial photogrammetry, which allows capturing the landscape pattern, although with lower accuracy.

In this paper, we would like to present the results from the aerial photogrammetry that was realized in the area of interest. This method can be generally used for mapping or monitoring of the surface (e.g. Hildebrandt, 1996). We used it to monitor the major surface changes in the mining area and its shape.

AREA OF INTEREST

The area of interest is situated in the Upper Silesian Coal Basin near the town Karviná in the north-eastern part of the Czech Republic. Since 2006, several horizontal coal mining panels were gradually exploited at the depth of c. 1,000 m under the surface. The exploited thickness of the mining panels varied from 1.4 to 3.2 m. The observed locality is a part of

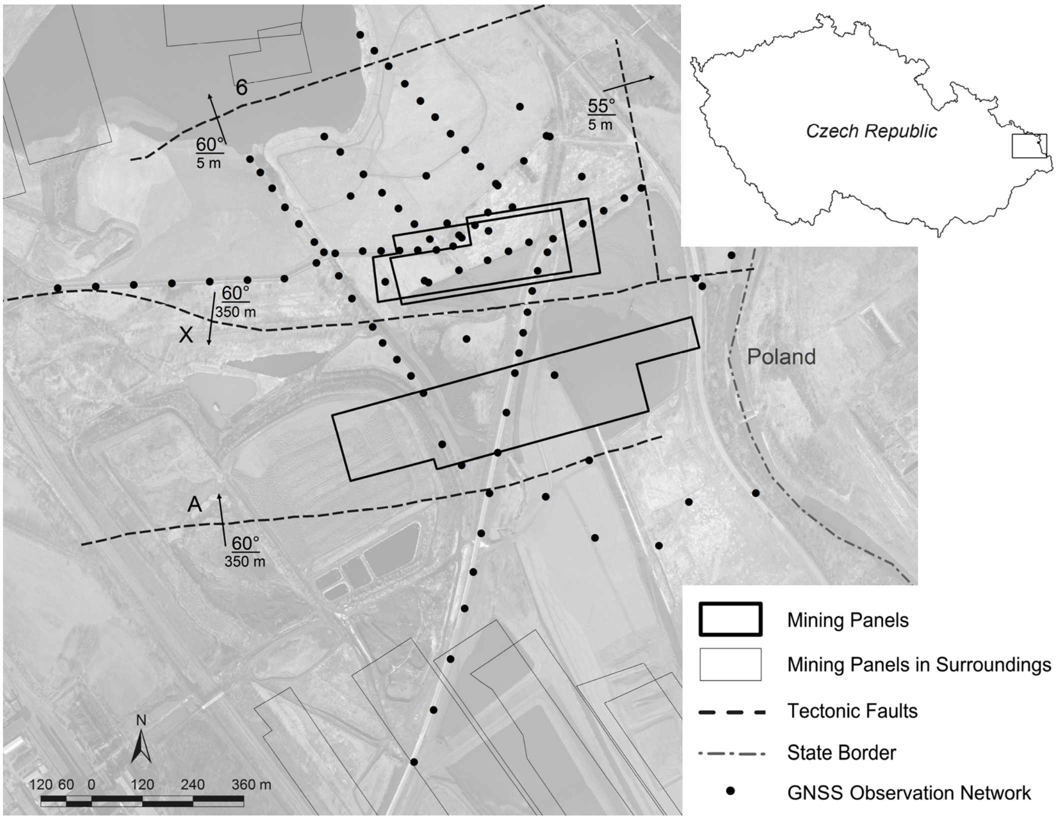

Fig. 1 GNSS observation network, tectonic faults and mining panels exploited from 2006 to 2009 in given locality and its surroundings.

a wider mining area. Several mining panels were also exploited there in late nineties but the surface in 2006 was almost stabilized, with the maximum subsidence of c. 5 cm a year. The rock mass is disturbed by four tectonic faults (see Fig. 1). For the detailed information on locality, exploited mining panels and tectonic faults please see Doležalová et al. (2009). The results of the GNSS monitoring were published in e.g. Doležalová et al. (2008; 2009, 2010), Kajzar et al., 2009; Staš et al., 2009.

AERIAL PHOTOGRAMMETRY

Although GNSS was the primary observation method, it could only provide data on individual points of the observation network. The models of the whole subsidence depression can be created from such data but due to irregularity of the network and the lack of points in several areas affected by surface recultivation, these models suffer from bias. Also, the shape of the subsidence depression may not be reliably captured on the basis of such point network. The recultivation was active here, even in the period of our GNSS surveying, and it means that in some subareas, the surface was covered by several meters thick layer of mine spoils and also some subareas were flooded. It destroyed some of our points that were fixed for long term repeated GNSS surveying and thus the network had to be often changed. The area was changing through the years (see Fig. 2). That is why the aerial photogrammetry was chosen as an additional observation method. This method enables to observe the whole subsiding area, i.e. given subsidence depression and its wider surroundings, including the surface changes in the areas of active recultivation or the situation behind the Czech-Polish state border.

The aerial photography of given locality including the photogrammetric data processing was performed by firm ARGUS GEO SYSTEM s.r.o. once a year from 2007 to 2009. Aerial photography was realized in the spring of each of these years, after the snow melted, but before the vegetation grew up. The scanned area was about 2.5 x 2.5 km. The first aerial photography was performed with analogue camera, the flying height was 600 m and the images were scanned on 5 cm ground sample distance. The aerial photography in 2008 and 2009 was performed with a new digital camera, the flying height was 900 m with the ground sample distance of 7 cm. During the aerial photographing, photogrammetric ground control points were signalized in the corners and in the middle of the observed locality. Also, most of our monitoring points of the permanent network were signalized too. Subsequently, the correspondence between the signalized points' coordinates that were surveyed by GNSS and coordinates of the same points obtained

Fig. 2 Area of interest in 1958, 2003, 2006 and 2009 (source: VGHMÚř Dobruška, Geodis Brno).

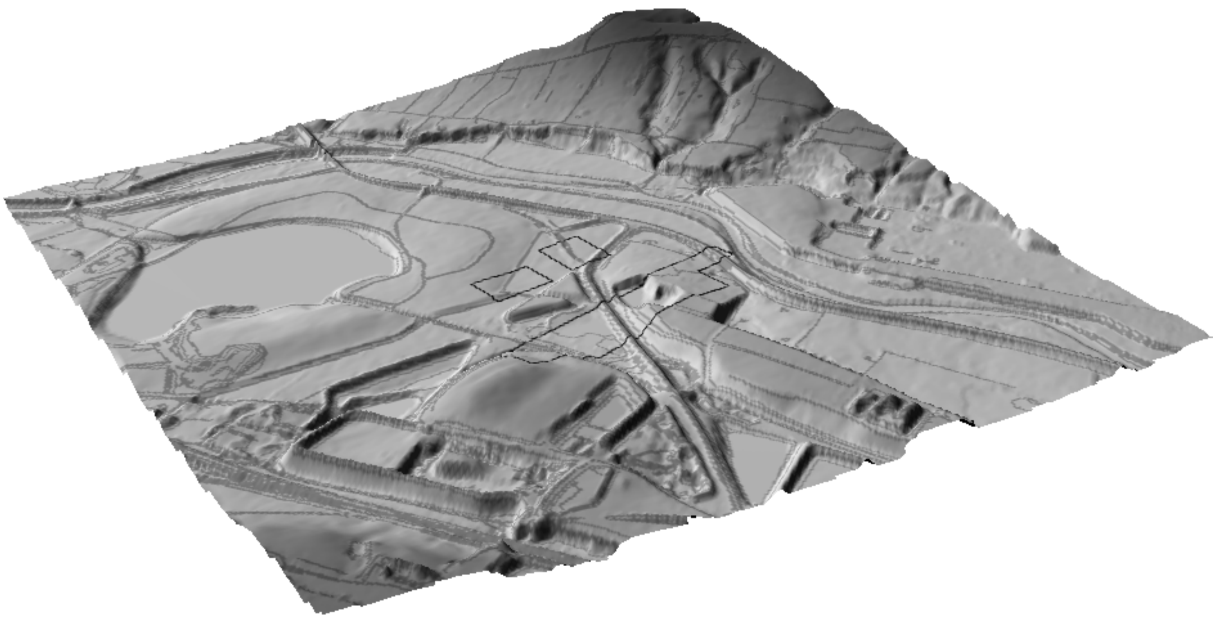

Fig. 3 DTM for 2009.

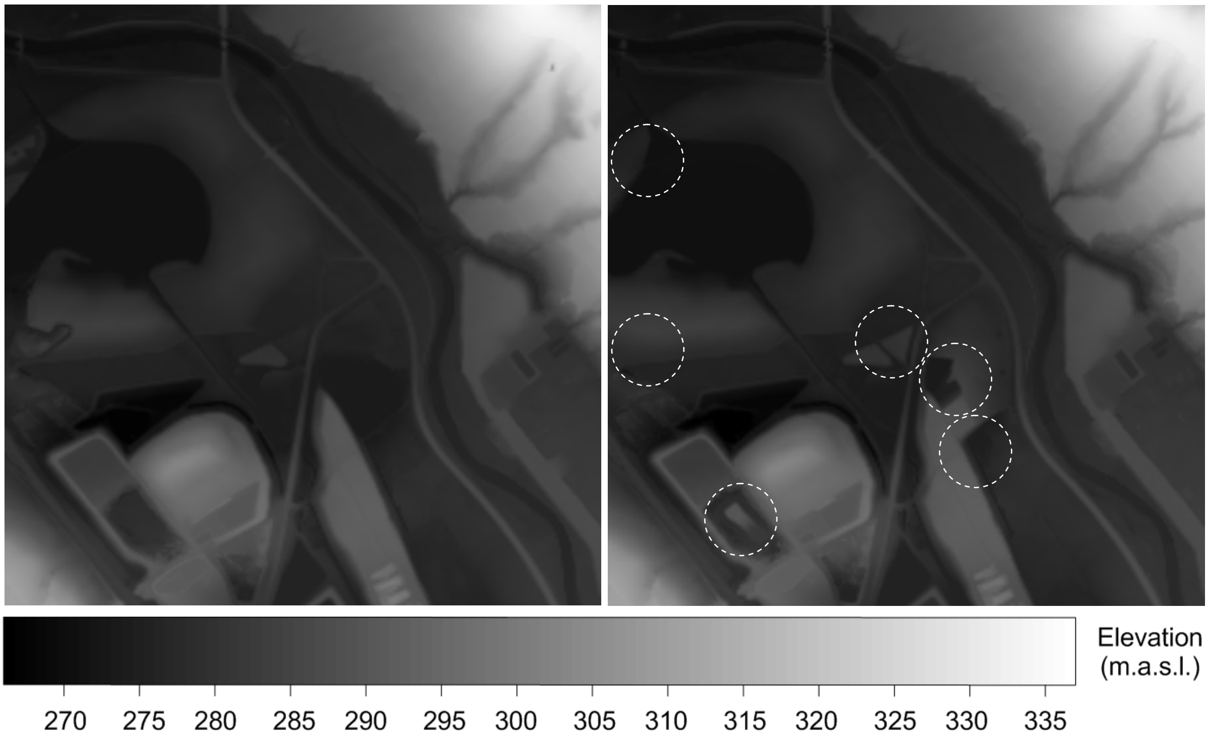

Fig. 4 DTM image maps for 2007 and 2009.

from aerial photographing was reviewed. A set of spatial coordinates of several thousand surface points in 20 x 20 m grid and also significant terrain edges were the resulting raw data from the aerial photography. Such data were ready for evaluation, comparison and for a digital terrain model (DTM) preparation. Also the orthophotomap of the whole area was provided.

From delivered data, network of points and terrain edges, it was possible to create digital terrain models that describe the shape of the observed area (see Fig. 3). Digital terrain models are prepared with the spatial resolution of 10 m, in WGS-84 datum and UTM coordinate system. DTM image maps for 2007 and 2009 that describe the surface of the observed area at the date of individual aerial photography can be seen in Figure 4. On the basis of the visual comparison of created models, places of the significant surface changes caused by recultivation can be distinguished (circle markers). Surface height changes caused by undermining are not distinguishable in these models with almost 75 m of maximum elevation difference and at a given resolution of compared images.

COMPARISON

During the aerial photographing, not only the photogrammetric ground control points were signalized with white targets (in the corners and in the middle of the observed locality) but also most of our monitoring points of the permanent network were signalized too. Coordinates of these points obtained from both aerial photogrammetry and GNSS surveying allow comparing as the GNSS points were measured at the same time as the photogrammetry was acquired. Such independent comparison procedure can determine the correctness and quality of the photogrammetric data – degree of reliability and usability of data from the aerial photogrammetry. A simplified overview of these results is presented in Table 1. In this table, differences in GNSS and aerial photogrammetry coordinates of individual points are presented, i.e. horizontal, vertical and total difference in the position of each point whose coordinates were gained from the aerial photogrammetry and GNSS measurements at the same time. It is presented in the form of percentage of photogrammetric points (broken down by plan and height components) which fall within 5/10 cm difference of the corresponding GNSS point coordinates.

It is obvious that the best and quite satisfactory results of this comparison have been gained from aerial photography in 2009: nearly all points had the difference in position to 10 cm, roughly three-quarters of points meet the tolerance of 5 cm. In contrast, the position of only 60 percent of points gained from previous aerial photographs meet the tolerance of 10 cm, and the comparison results for the tolerance of 5 cm difference are even worse. The comparison results show that in some cases the input data may be burdened with some inaccuracies. Therefore, it is

Table 1 GNSS vs. aerial photogrammetry coordinates comparison.

		2007	2008	2009
Count of points		46	71	76
Difference within 10 cm	***horizontal difference***	87 %	92 %	99 %
	vertical difference	67 %	68 %	97 %
	total difference	**61 %**	**59 %**	**97 %**
Difference within 5 cm	***horizontal difference***	52 %	66 %	92 %
	vertical difference	48 %	37 %	75 %
	total difference	**28 %**	**24 %**	**72 %**

necessary to keep this fact in mind for further processing and evaluation.

TERRAIN CHANGES FROM AERIAL PHOTOGRAMMETRY EVALUATION

When the data from aerial photogrammetry and GNSS were compared and we obtained the idea about the accuracy of the aerial photogrammetry data, it was possible to evaluate the terrain changes. These changes can be determined from the digital terrain models. A set of various digital terrain models in grid format was created for each aerial photography. Then, a set of various differential models was created for each compared period, i.e. 2007-2008, 2008-2009 and 2007-2009.

For processing we used a combination of GIS software ESRI ArcGIS inc. extensions and geostatistical software Surfer that are both suitable for processing spatial data and performing required spatial analyses (ArcGIS, Surfer). For each year we received a set of points representing the surface, i.e. several thousand points with x, y and z coordinates. Surface points in 20 m step represent the surface in each year of photography. The evaluated surface points are usually not identical in individual years, i.e. they do not represent the surface in the same position defined by x and y coordinates (but this is not decisive for the creation of a DTM). The digital terrain models were generated using kriging method of gridding with spatial resolution of 10 m.

Three types of digital terrain models were created from a different set of the delivered input data (each type of a DTM was created from a specific subset of the delivered data from the aerial photogrammetry).

The first type of a created DMT is the DTM made from the spatial position of all delivered surface points from the aerial photogrammetry. Then, differential models between digital terrain models from individual years were created (see Fig. 5a at the end of the article).

The second type is the DTM generated from the same points, i.e. all delivered surface points, but also terrain edges were included - significant terrain edges, transitions of surface types, roads, bridges, etc. Again, differential models between digital terrain models from individual years were created (see Fig. 5b at the end of the article).

But neither of these models suits for a full-area evaluation, mainly due to the different position of entry points. In the case of broken terrain and at the required accuracy of results (in order of cm), this unfortunately leads to incorrect descriptions of size of the deformations. Partial conclusions can be made from them only for smaller subareas.

The ideal solution is to compare digital models created on the basis of coincident surface points, i.e. the points representing the surface in the same place (with the same x and y coordinates) on each of the two compared photogrammetry imaging. This condition is only met by a certain number of points. The resulting differential models give us a good overview of the surface changes of the terrain, particularly in areas that were well covered by these points.

So, the last type is the pair of digital terrain models that were created from photogrammetry coincident points only, i.e. the input data points, which position is identical on both currently processed images (years). Differential models were created from such pairs of digital terrain models (see Fig. 5c at the end of the article). This type of evaluation provides the best results. Models in this case are relatively smooth, rapid transitions of values appear sporadically in small areas. However, the values of these models in the parts where no coincident points are available should be taken with caution and the ideas about the behaviour of the terrain in these locations should be supplemented with the analysis of other described types of differential models.

However, all types of the resulting differential models are influenced by the degree of inaccuracy of determining the spatial positions of individual geo-elements, which enter the model calculation (based on the above GNSS vs. aerial photogrammetry comparison), as well as their number, their placement in the area respectively.

EVALUATION OF DIFFERENTIAL IMAGES

The models were represented as the image maps. For the evaluation, we have differential image maps for periods 2007-2008, 2008-2009 and 2007-2009. It is obvious that the major part of the study area is in motion. Different size of the subsidence is apparent in the differential models, throughout the study area. In all differential models, there are also large areas, where significant height surface changes of several meters caused by ongoing recultivation are evident.

To illustrate, the differential model 2007-2009 was chosen. It describes the development of surface changes between the first and the last aerial photography (see Fig. 6 at the end of the article). A differential image map is created from the digital terrain models that were generated from coincident points. There are quite a lot of coincident points obtained from these two aerial photographs and they are distributed throughout the observed area. Large areas with an increase of elevation of the ground surface, caused by its covering with mine spoils are clearly visible on the image (hatched purple coloured areas). Such area can be seen in the central part of the image map, above the observed mining panels. Another wide area of spoil deposits is in the western part of the scanned area. The evaluation of the data from the aerial photogrammetry shows that the areas of spoil deposits were covered up to 11 m. Due to such covering, it is not possible to determine the magnitude of mining induced subsidence in these places.

The image map in Figure 6 proves that the aerial photogrammetry is able to show the dynamism of changes on the surface of the observed area. Beside the height changes caused by covering of the surface with mine spoils, the map shows the height changes caused by undermining. Major subsidence can be identified above the middle of the southern observed mining panel. This sub-area with the subsidence of more than 1 m was also confirmed by GNSS measurements in the permanent network.

Apart from the surface changes caused by the exploitation of the observed mining panels (in the centre of the scanned area), it is also possible to see strong mining influences manifested by another major subsidence of the terrain in the southern part of the scanned area where the surface subsided even more than 1.5 m. Here, the aerial photogrammetry detected a subsiding sub-area outside the permanent network and these changes are caused by undermining from the exploitation of other mining panels southwards, in the wider surroundings. These results confirm the conclusions of the analysis of horizontal shifts that were realized on the basis of GNSS measurements; the analysis of horizontal shifts of the permanent network points showed that some of these points are being affected by the exploitation in the surroundings (horizontal shifts of these points were directed towards south, see Doležalová et al., 2010). The evaluation of the aerial photogrammetry confirmed this conclusion.

In the rest of the scanned area, a minor subsidence was detected. We may recognize a subsidence subarea above the northern observed mining panel with the subsidence to 50 cm. Here, the size of the subsidence is rapidly decreasing with increasing distance.

It is very difficult to distinguish the detailed size of the subsidence below 50 cm, especially due to quality of the output models. The quality of these models is depending on many factors such as the input data accuracy (see Table 1) or spatial distribution of processed surface points and the quality is also influenced by the effects of ongoing recultivation in the locality.

The results of the analysis of the data from the aerial photogrammetry also verify that the area located behind the Czech-Polish border is not significantly affected by the exploitation of the observed mining panels.

CONCLUSIONS

- GNSS proved to be sufficiently accurate but due to the permanent network limitations it will not record the surface of the whole area and we are not able to qualitatively describe the shape of the subsidence depression and the subsidence mechanism on the basis of profile surveying. Therefore, the aerial photogrammetry as an additional observation method is very useful because it qualitatively records the shape changes of the whole subsidence depression.
- On the basis of the results from the aerial photogrammetry we can specify the nonstandard moves in the subsidence depression, which can be later treated by land surveying in a new GNSS profile.
- The results from the aerial photogrammetry show that a large part of the scanned area is affected by mining. The exact extent of the surface manifestation of the observed mining panels' exploitation cannot be set because of the ongoing recultivation and the accuracy of this method. The whole area is also affected by the influence of exploitation in the surroundings and by the subsidence that was caused by the prior

exploitation. The area located behind the Czech-Polish border is not significantly affected by the exploitation of the observed mining panels.

- The evaluation of the aerial photogrammetry using several types of digital terrain models shows that the best results were gained from the evaluation using the coincident points.
- It was confirmed, that the method of aerial photogrammetry is suitable for the monitoring of the surface where significant changes are expected. Therefore, the method enables to observe the surface changes in the areas of active recultivation (surface covered with mine spoils, flooded areas…) where land surveying is not possible. Repeated use of the aerial photogrammetry enables to observe the progress of such area.
- Due to a lower accuracy of the aerial photogrammetry, it is useful to use this method in combination with other methods (GNSS, levelling, InSAR).

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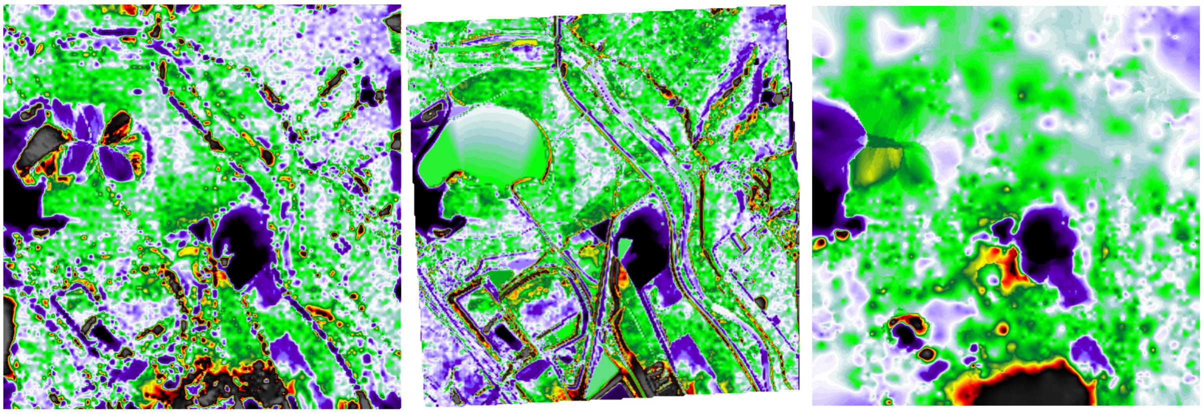

Fig. 5 Types of differential image maps from digital terrain models for period 2007 – 2009. Digital terrain models created (from left): (a) from all points; (b) from all points and terrain edges, (c) only from coincident points in 2007 and 2009.

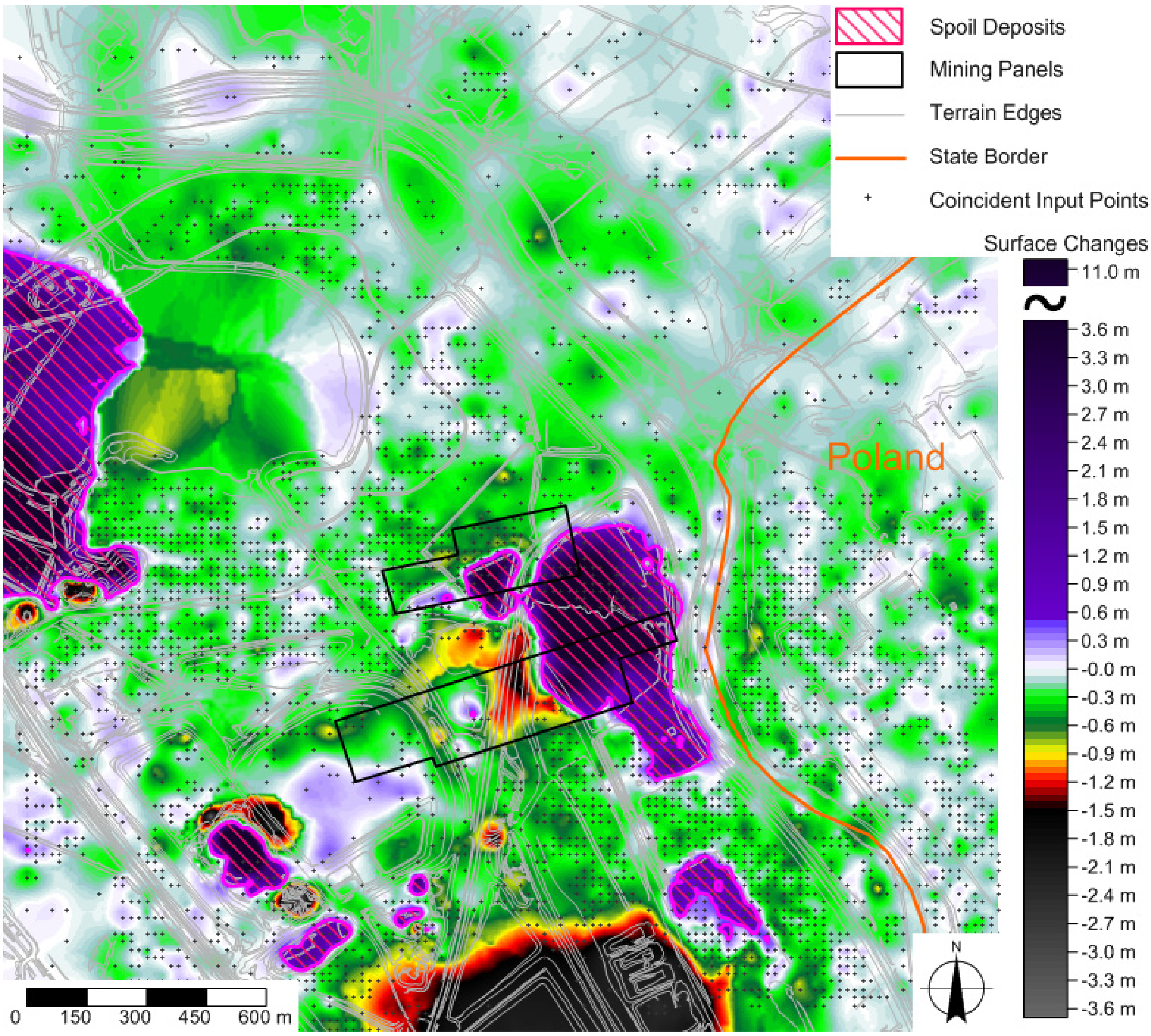

Fig. 6 Vertical changes between 2007 and 2009 generated from coincident points.