Geomonplus – Application for Storage, Allocation, Exchange, and Visualization of Historical and Actual 4d-Postion-Data within Mining Areas

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Key words: *ground movement monitoring*; *spatial data application*; *time series analysis*; *web service; data democratizing*

ABSTRACT

Over decades RAG has collected spatial data from different sensors for the purpose of monitoring and analyzing ground movement caused by underground hard coal mining activities. With monitoring scopes from small objects, like delicate industrial installations surveyed by geometric leveling, to wide area observation by radar satellites, data was stored in several systems. Since there is still ground movement caused by the controlled flooding of former underground mine buildings, RAG will continue surveying the surface and collecting deformation data. To handle and analyse this deformation data and to create a value-adding application RAG cooperated with the company Atos to design Geomonplus. The following main requirements were identified at the start: To store data from different databases with different structures as well as current and future geodetic data sources, the data model needs to have a generic structure. The chosen platform needs to be future-oriented and should be established within RAG. The application also should be integrated into RAG's spatial data infrastructure. The ground movement information needs to find its way into an internal web service to reduce expert's workload and to share insights and expertise. This paper presents the main functions of the newly developed solution for experts as an extension for Esri ArcGIS Pro as well as web service tools for non-experts. Furthermore, some time series examples of leveling data in combination with satellite-based PSI and GNSS evaluations are illustrated. Finally, an outlook on plans to add more time series data such as ground water levels, mine water levels or weather data into the internal web service, is outlined.

I. INTRODUCTION

A. *Mining Activities of RAG Aktiengesellschaft*

When RAG Aktiengesellschaft (hereinafter RAG) was founded as Ruhrkohle AG in 1968 it consolidated the hard coal mining activities of more than twenty mining companies in the Ruhr region and held by far a major part of German hard coal mines. At that time about 186.000 workers were employed at RAG and other Ruhr region mineries (Junker *et al.*, 2019). Companies in other German regions with hard coal deposits like the Saar region and the Tecklenburger Land remained independent until the end of the 1990ies. Then the companies Saarbergwerke AG and Preussag Anthrazit GmbH were also merged with RAG. As a result, RAG became the last German hard coal mining corporation and was operating in three regions in a wide spatial extend (Figure 1):

1. Ruhr, approx. 110 x 40 kilometers
2. Saar, approx. 40 x 25 kilometers
3. Ibbenbueren, approx. 20 x 10 kilometers

These three regions have in common that their mines were operating in deep underground deposits with depths down to 1.500 meters below ground level.

Since state subsidization for coal mining were no longer permitted in the European Union since 2019, the last German mines Bergwerk Prosper-Haniel and Bergwerk Ibbenbueren stopped their production at the end of 2018.

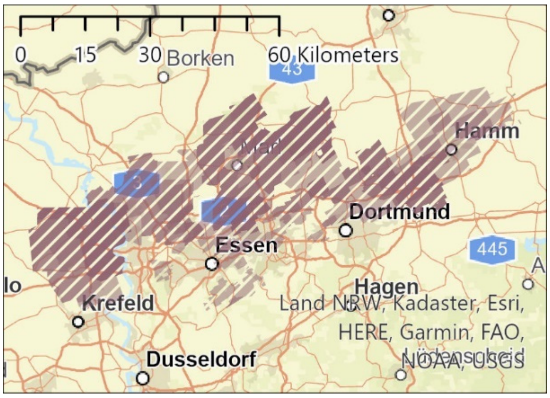

Figure 1. Mining areas in the Ruhr region.

The closure of the last mines was another milestone in a long-planned transition process from a mining corporation to a midsize post-mining company responsible for the mining legacy in the named regions.

B. *Post-Mining Tasks*

RAG's post-mining tasks can be divided in two categories, ending and non-ending obligations. Examples for ending obligations are redevelopment of former mining sites and shafts, regulating mining damages or surveying ground movement. Examples for non-ending obligations are pumping mine water to keep it in a certain secure level or controlling surface water in subsided areas.

To bear the costs of the non-ending obligations the foundation RAG Stiftung was formed from all profitable assets of former RAG Aktiengesellschaft. However, the costs of all ending obligations must be paid by formed reserves. That means RAG cannot act uneconomical and must find ways to improve processes to handle all obligations stable with only about 500 remaining employees.

C. *Deformation Monitoring*

In addition to a not insignificant self-interest to preserve its financial and legal goods, RAG must fulfil regulatory requirements and run a system of appropriate geo-monitoring measures to detect ground movement and other incidents (like micro seismic, outgassings, groundwater level, shaft backfilling, et cetera).

Deformation monitoring in areas with active deep underground mining generally means ground subsidence. The hereby induced terrain depressions mainly have a vertical component with its maximum in the centre. However, beside the vertical component of ground movement, a horizontal component arises towards the edges of the depression. This is caused by a sliding into the depression which in turn causes terrain tension and pressing. Depending on the geological composition, the thickness of the mined coalbed and others, active mining provoked ground movement that can have values between centimetres and few decimetres per month in vertical direction. In sum, a few meters to several ten meters can accumulate over years and decades. Whether all or only some of the above deformation components were observed, mainly depends on the affected surface infrastructure.

On the other hand, deformation monitoring in the post-mining era means monitoring of relatively slow and little terrain uplifting. These are caused by the flooding of former underground mines and have values of a few decimetres. With few exceptions the hereby induced horizontal impact and the resulting terrain tension and pressing are so little that they can be neglected. The uplift has values of few centimetre per year at its peak phase and is limited to few decimetres in its maximum. This comes along with higher requirements for the precision of measurements. The occurrence of mining damages to the surface infrastructure is highly unlikely and not yet recognized but nevertheless ground movement observations will be performed until stillstand of the fading uplifts.

D. *Associated Manuscripts*

This paper is only one in a series of manuscripts that addresses RAG's efforts to detect and analyse anthropogenically induced ground movement as well as providing data and results. For a better and more comprehensive understanding, the authors recommend articles from Spreckels, V., Kipp, A., Niemeier, W. and Schulz, M..

II. Geodetic Methods and Sensors

This chapter gives an overview of typically applied methods to capture deformations and an impression of the data diversity. With one exception (pure position determinations), all methods are performed to observe a specific geometric measurand at a specific location at a specific time, with other words: 4d position data.

A. *Geometric Levelling*

Since the vertical component is a major part of ground movement in both active mining and during the flooding of abandoned mines, geometric levelling has been the most important method for deformation monitoring in the past. Despite other technologies like GNSS or satellite-based radar interferometry the geometric levelling is still a frequently used method. This is because geometric levelling is a wide established method with a long history and good precision/effort ratio. Hence, the amount of data observed by this method currently represents the largest part of all used methods.

In this context the high-precision levelling campaigns by the state survey authorities, especially in North Rhine-Westphalia (Geobasis NRW), should not remain unmentioned. The so called Leitnivellements[1] (hereinafter LN) are performed every second year and reach back into the 1960ies in the Ruhr region (see Figure 2). Single official survey points even have a times series that reaches back in the year 1873. Until today the LN play a significant role in deformation monitoring since they are the frame for most levelling's by RAG and others.

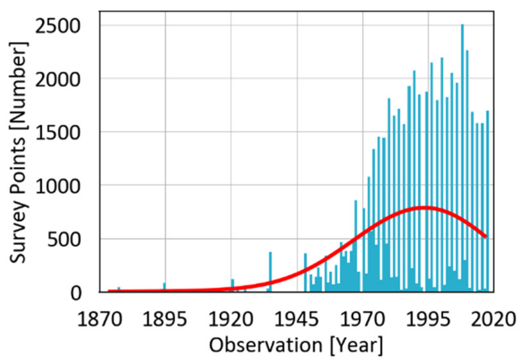

Figure 2. Histogram of officially observed height points in the Ruhr region, showing the beginning of the LN.

[1] Leitnivellements: Leading levelling campaigns

Due to open data offensive by the authorities in North Rheine-Westphalia, this dataset is free for download[2].

B. *Total Station*

Due to relatively high costs, nowadays measurements with total stations come rarely into use. This method is mostly applied in case that the knowledge of vertical movement is not sufficient. This mainly concerns the deformations monitoring of delicate buildings, for example to detect a tilting of parts of a building. Only in single cases and in areas without sufficient GNSS signals traverse lines are surveyed to determine the 3-dimensional coordinates. In contrast, before GNSS was broadly established and mine surveyors were equipped with such instruments the total station measurements were carried out to determine coordinates, for example to measure ground control points for airborne photogrammetry or to determine terrain shifts (Figure 3).

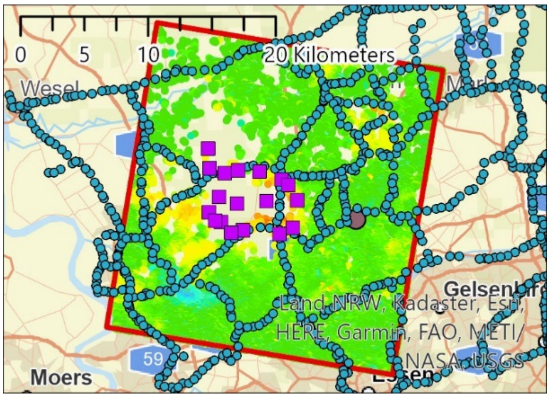

Figure 3. Levelling net, GNSS- and PSI-points from the Geomonplus data base within the map view of ArcGIS Pro.

To survey terrain tension and pressing often tape measurements were carried out.

C. *GNSS*

The importance of GNSS at RAG increases more and more. Based on typically achievable precision in RTK-mode GNSS was for example used to survey the areas with maximum subsidence but also to roughly verify the edge of terrain depressions (subsidence trough). With the set-up of several permanent operating GNSS-stations, partly combined with corner reflectors for satellite-based radar interferometry, GNSS becomes an integrator and makes it possible to combine terrestrial and remote sensing methods (Spreckels *et al*., 2020). Another example: today all reference points for airborne photogrammetry are determined by RTK-GNSS in this network.

D. *Satellite-Based Radar Interferometry*

RAG is following the developments of wide area deformation monitoring by satellite-based radar interferometry since 1999 (Spreckels *et al*., 2001). Over these twenty plus years RAG worked together with scientific institutes as well as with commercial providers. Data from different satellite systems (*e.g*., Envisat, Radarsat-2, TerraSAR-X, Sentinel-1A/B, and on) were processed and varying evaluation approaches were evolved and applied. This leads to a variety of different data structures which need to be handled.

The latest activities of both state survey authorities, Geobasis NRW[3] (North Rhein-Westphalia) and LVGL[4] (Saarland), to launch web services to provide state-wide ground movement information based on Copernicus Sentinel-1 radar data make it clear that RAG was very foresighted. The web service from Saarland (SaarBoBeKa[5]) is already in service and NRW is planning the same for this year (Riecken *et al*., 2019), (Engel and Busch, 2018). It must be assumed that in the mid-term this method will be fully established and that it will at least partly replace geometric levelling.

III. Spatial Data Infrastructure

Spatial data is an essential part of many corporate processes within RAG. From the address of a reported mining damage to the information about pipelines in the underground of an ex-mining site or the level of mine water in different mine water retention provinces, spatial data is the basis for a multitude of decisions and activities. Hence it is crucial to provide this information in a reliable manner and obviously a spatial data infrastructure is necessary for this. At RAG this system is called RAG-GDI[6].

Over the years RAG-GDI has vastly grown. Today it consists of more than 20 servers and several desktop components. Esri products play a significant role for both server and desktop applications. So, the Database Management System ArcSDE is used to administer some of the Oracle Database Server within RAG-GDI, experts work with ArcMap and ArcGIS Pro on their PC's and the ArcGIS API for JavaScript is applied to build up internal and external web services.

The most prominent web service, accessible to all employees, is a RAG internal map centred search engine named Digitale Service Akte (hereinafter DSA). It provides content for over 300 different issues and allows users to carry out tasks such as map exporting (PDF), finding aerial image footage or measurements without further software installations. It is RAG's integration platform to bundle data from diverse expert systems (Koslowski and Telenga, 2014).

[2] https://www.opengeodata.nrw.de/produkte/geobasis/rb/fd/
[3] Bezirksregierung Köln, Abteilung 7
[4] LVGL: Landesamt für Vermessung, Geoinformation und Landentwicklung.
[5] SaarBoBeKa: Saarländisches Bodenbewegungskataster / Saarland's Ground Movement Cadastre: https://geoportal.saarland.de /article/Bodenbewegungskataster/
[6] RAG-GDI: RAG Geo-Daten-Infrastruktur.

IV. FORMER SYSTEMS, DATA SETS AND SOURCES

A. *Former Systems*

Geomonplus (hereinafter GMP) is not a start from scratch. It is more the latest solution to handle survey point data for deformation monitoring purposes. Self-evidently that data was registered even before computer systems existed and stored while computer systems were developed. Hence there are numerous former systems such as:

1. Handwritten table books or paper file cards.
2. Software on mainframe systems.
3. Software on a few decentral Unix server (HVZ).
4. File-based data storage (Excel, CSV, ASCII).
5. ArcMap-AddIn with DB-based storage (GeoMon).

In particular, the Unix server solution HVZ[7] and the ArcMap-AddIn GeoMon had to be considered while developing GMP. The reason for this is that both systems were containing the most relevant data and were providing some indispensable functions (Figure 4).

HVZ was the height register component in a software package[8] which included solutions for most of the geodetic scope of RAG in the Saar region. Levelling measurements *e.g.*, were evaluated in one component (NIV) and then directly brought in to HVZ. The mainly used function of HVZ was the creation of text reports on ground subsidence.

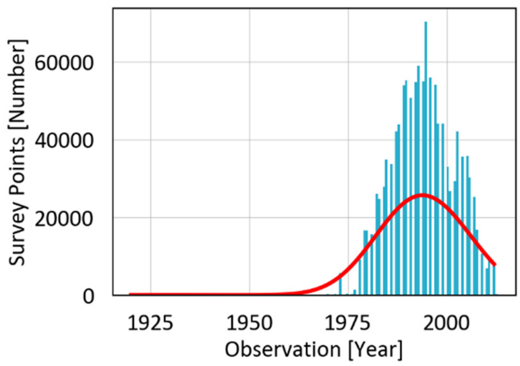

Figure 4. Histogram of observed height points in the Saar region, showing the operational period of HVZ.

GeoMon was the first attempt to set up a GIS-integrated tool to store and analyse time-variant geodetic information of ground movement within RAG. It was designed as an AddIn for ArcMap within the framework of a RAG-R&D project in cooperation with the Technical University of Clausthal (hereinafter TUC) in cooperation with RAG (Kamphans *et al.*, 2008). The main advantages were first the integration of terrestrial geodetic information and satellite-based radar interferometry data in one system and second the direct useability of several other spatial data from the RAG-GDI. This made it possible to spatially view and evaluate the deformation data together with information about the impacting mining activities in a map. But in the course of use, the import function became more and more outdated and turned out to be disadvantageous, so that less data was imported.

B. *Data Sets and Sources*

During the operational period of HVZ more than 1.2 million height observations were stored in a static structured form (Table 1). However, the position data could not be saved and were therefore outsourced in CAD files. Unfortunately, these CAD files had such a diverse layer structure and differing labelling et cetera that the position data could not have been extracted automatically. Moreover, CAD files do not exist for all survey points either. But since position is an essential element of any survey point and is required in GMP (Keyword: 4d position data), over 81,000 points had to be determined. About 36,600 points have been digitized manually. Furthermore, approx. 5,700 points were interpolated between two manually defined points. The remaining approx. 38,700 points could not be determined properly. These points were assigned provisional coordinates (somewhere in France) in the first instance.

Table 1. GMP Data Volume (03/2022)

Source	Data Amount	
	Points	Observations
HVZ[9]	81,435	1,208,830
GeoMon	4,060	5,490
AFIS NRW[10]	27,590	100,192
Import	2,027	5,454

In addition, the system was also used to store length measurements. Since length and height measurements are similar (both 1-dimensional values), this information can easily be integrated.

The amount of data that was imported into the GeoMon database consisted of more than 12,500 unique survey points with overall 64,700 observations, whereof approx. 4,000 points were transferred into GMP. These are 3d determined reference points for the evaluation of airborne photogrammetry campaigns. Most of the remaining points could be neglected because they were either in the HVZ or AFIS NRW inventory.

In addition to the already described data there are different further sources which had not yet been imported. For example, between the beginning of the production phase of GMP in the year 2021 and the de facto shutdown of HVZ and GeoMon in the years 2013 and 2014, FGDB[11] were used as an intermediate

[7] HVZ: Höhenverzeichnis, can be understood as height register.
[8] Designed by Poppenhäger Grips GmbH, since 2005 part of Intergraph, which merged into Hexagon in 2020.
[9] Without virtual points for the storage of length measurements.
[10] AFIS NRW: Amtliches Festpunkt-Informations-System NRW, Official Reference Point Information System of the Federal State North Rhine-Westphalia (includes the named LN data).
[11] FGDB: File Geodatabase by Esri.

solution. Until today this data has not been imported into GMP. This also applies to an extensive amount of Excel files which have been used over many years. Especially importing Excel files means a lot of manual work. An event-driven approach is the way to go here.

V. GEOMONPLUS

As the name suggests, GMP was designed with the claim to be an enhancement of GeoMon. It should preserve the advantages of GeoMon (and HVZ) on the one hand and come with crucial improvements on the other hand. To meet this challenge, a group of users, IT experts and scientists came together in the year 2015 and developed initial ideas. The group was made up of members from Atos[12], TUC and RAG's spatial data department. After the initial specification phase the group was reorganized and continued to operate without TUC. From here on, the development was carried out in tight cooperation with Atos as an agile project using the Scrum[13] method.

GMP consists of different components or layers. Visible to the user are the dialogs or GUI for controlling GMP and displaying information, data, and charts, all in German language. In addition, there is the Oracle-based data base (ArcSDE) with multiple Table and Relationship Classes to store and provide all data (Figure 5). The exception here is radar data, which is stored in FGDB on a network drive due to performance reasons. Finally, scripted interfaces are part of GMP. The applied programming languages are C# for all GMP features and Python for the writing layer (GMP >> Oracle) and scripted interfaces. All dialogs are created with the UI tool kit Windows Presentation Foundation (WPF).

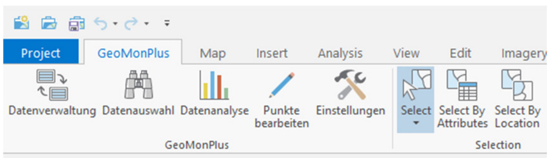

Figure 5. GMP main functions.

A. *Requirements*

The following requirements were initially identified and partly adapted to new circumstances.

1) Generic data model: As the explanation of the former systems and data sources above show, a generic data model is crucial to integrate a heterogenous data stock. The GMP data model must be able to handle all known former models.

2) Import interface: The experience has shown that the Import GUI must be highly flexible and user-friendly and cannot be a bottleneck.

3) Platform: GMP must be implemented into the RAG-GDI and based on a future-orientated application. Since GMP is a GIS tool, Esri's ArcGIS Pro was the best choice. Starting with Sprint versions (in the sense of the Scrum method) for ArcGIS Pro version 1.0, the current GMP version is built for ArcGIS Pro 2.7.3.

4) Interfaces: One of the most important requirements of GMP is the exchange of data with other internal information systems in order to make the observation results available for a wider range of users.

5) Geodetic reference system: Both RAG and the mining authorities in North Rhine-Westphalia and in Saarland remain working with the former official geodetic reference system DHDN with the Gauss Kruger projection. This is due to extensive analogue datasets, such as official mine map inventories. Besides, DHDN (as the bulk) further geodetic reference systems were used over the decades. This leads to the requirements for the geodetic reference system in GMP as follows: First all geometries are basically stored with reference to DHDN[14] / 3-degree Gauss zone 2 and second, further coordinate information with other geodetic reference systems can be attached. This is also true for the vertical reference system. Standard is DHHN2016[15], further vertical coordinates can be stored for the same point.

B. *Entity relation model and attributes*

The presentation of the complete ER model would exceed the scope of this paper by far. However, at least the most important entities and some of their attributes shall be described as follows.

1) Delivery: For deformation monitoring, survey points are measured periodically. This usually happens in the context of a definable field campaign, an epoch. In GMP all survey points from one field campaign and epoch are defined as a so-called Delivery. This table holds information about origin, deliverer, purpose, region, epoch, et cetera (Figure 6).

Figure 6. GMP Data Management.

[12] Atos IT-Dienstleistung und Beratung GmbH.
[13] https://scrumguides.org/docs/scrumguide/v2020/2020-Scrum-Guide-US.pdf

[14] DHDN: Deutsches Hauptdreiecksnetz, German Main Triangulation Net (EPSG:31466)
[15] DHHN2016: Deutsches Haupthöhennetz 2016, German Main Height Net 2016 (EPSG:7837)

2) Survey Point: Contains a representation of each physically existing at least once measured survey point and ties all corresponding point measurements together. Even if the point name differs. This is managed by a position comparison during the import process and allows user interaction in case of wrongly identified corresponding.

3) Measurements: As the name suggests all measured coordinates regardless of the geodetic reference system are stored as X, Y, Z in this table. In addition, standard deviation for each coordinate component can be saved. Information concerning the geodetic reference system is held in a related table.

4) Spatial Reference: Provides distinct geodetic reference system definition to the related table Measurements as Geodetic Datum, Projection, Vertical Reference System and Vertical Reference Surface.

5) Display Point: Every measurement is represented by a point feature and carries the most relevant information like point name, observation date, observation method, point type and a few other. All Display Points are stored with Gauss Kruger coordinates and transformed on the fly in case the ArcGIS Pro Map Frame differs.

6) Survey Point Group: Is a construct of Table and Relationship Classes to organize groups of Survey Points divided into epochs. This makes it possible to combine Survey Points from different Deliveries to one grouping without generating redundant data entries. Hereby the same Survey Point can be used in several Concerns.

7) Observation Line: Allows it to organize a similar structure as the Survey Point Group does but additionally an order of all containing points is set.

8) Radar Evaluation: Every evaluation of satellite-based radar data registered within GMP is represented by a polygon which matches the minimum bounding geometry of all evaluated points (*e.g.*, Persistent Scatterer). This polygon feature carries, like the Display Point, the most relevant information about the evaluation. For example, name of the evaluation, date of the first and last used scene, date of the reference scene and a hyperlink to the corresponding File Geodatabase in which all evaluated points are stored. Information about the source satellite system and the used height model are stored in related tables.

9) Project: Is also a structuring entity without its own significant attributes. It makes it possible to tie the above-named objects Survey Point Group, Observation Line and Radar Evaluation.

C. *Main Functions*

As in ArcGIS Pro usual, the main functions are embedded as a Tab into the Ribbon at the top of the screen in an own category. The GMP Tab can be customized and more Esri functions can be added. The main functions are from left to right Data Management, Data Selection, Data Analysis, Point Editing and Settings.

1) Data Management: This functionality is inspired by the ArcGIS Pro Catalog and gives the users a structured list view on all yet imported data sets as well as access to several further functions such as Survey Point Importing, Adding Items to the Map, Adding Items to a Project, et cetera. It is the central control element of GMP.

The importing of Deliveries into GMP can be conducted by an ASCII interface. Users control this interface by an Import Wizard which supports either fixed ASCII formats or separator formats. In a few steps all required and optional information is queried by the Import Wizard and if present matching points from prior epochs will be linked.

Once imported, Survey Points can be upgraded in several ways. They can be grouped with Survey Points from other Deliveries to a Survey Point Group or to an Observation Line, each with epoch subsets. Survey Point Groups and Observation Lines again can be assigned to Projects. Together with Radar Evaluations these objects build the main data structure within the Data Management tool. To ensure a good user experience the inventory of all items is further structured. Below the main object grouping are further groupings by region and purpose. In case that users still cannot find a desired item, text and time filters can be set.

2) Data Selection: This tool enables the users to find GMP content based on attributes, temporal filter, or spatial specifications. This helps if a user is uncertain whether there is data or not to answer a specific question. For example, following query could be defined: Show all survey points from the class levelling point with measurements between 01.01.1990 and 31.12.1990 within the current map extent.

3) Data Analysis: To visualise and analyse deformation data from different sensors is the main purpose of GMP. The most important tool is the time series charting (see Figures 7 and 8). The users can either select GMP Display Point in the map and open the Data Analysis dialog by a click on the button in the ribbon or enter the dialog from the context menu of an item within the Data Management.

4) Point Editing: This dialog can be used if any changes or corrections on survey points need to be done.

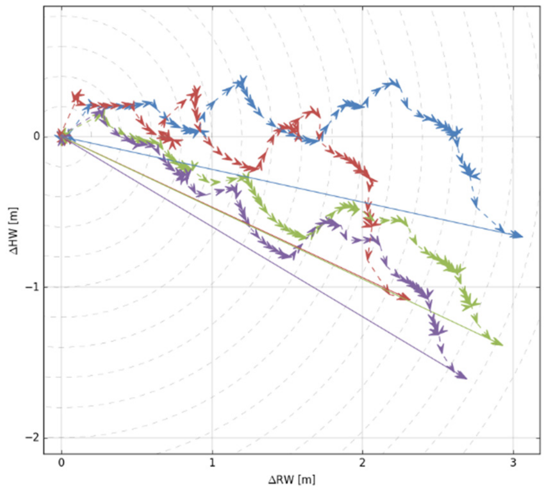

Figure 7. Time series. Detail view on the horizontal displacements of four in Figure 9 highlighted and framed survey point. X: ΔEasting, Y: ΔNorthing in m.

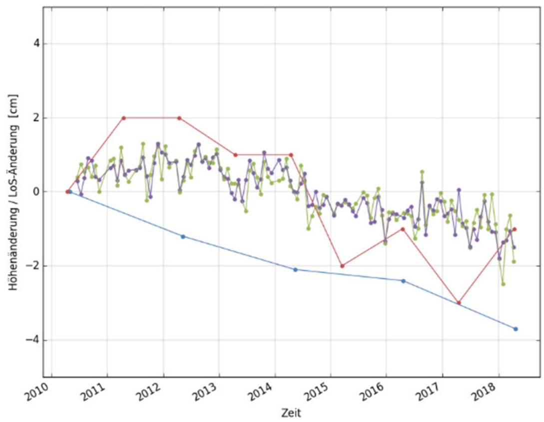

Figure 8. Time series. Comparison of PSI, levelling (blue) and GNSS (red) measurements. X: time in years, Y: height changes / Line-Of-Sight changes in cm.

D. *Interfaces*

Currently there is an automated interface with the DSA as target system. With the help of regularly running transformation scripts, a simplified respectively flat image of selected data is written and provided to the DSA users. In the first step only height measurements are transferred to the DSA. Whether displacement measurements will also be transferred is still in the decision-making process.

At present, an interactive chart[16] is available to DSA users. For example, by using slide controls or the mouse wheel it is possible to change the time or height extend. By hovering the mouse pointer over data points in the chart, information about date and height is displayed. These are merely two examples to indicate the potential of the used charting library.

VI. Outlook

The development work on GMP is largely completed, therefore only small improvements are planned for the near future and of course maintenance work like updating GMP for newer ArcGIS Pro versions. But thanks to the deep integration of Python in ArcGIS Pro (ArcPy), more functions are planned for realization as custom tools within an Esri ArcToolbox. The displacement vectors in Figure 9 are an illustrating example in how external functions can use the GMP data to generate an additional value. Generating vertical bars to display height changes in the printed or PDF maps will be the next custom tool.

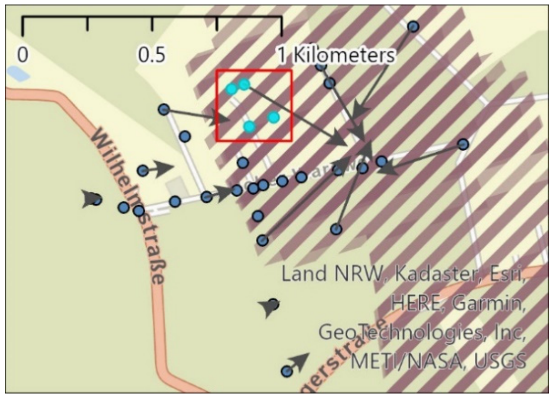

Figure 9. Horizontal displacement caused by underground mining activities in the course of 15 years. Vector scale 1:200.

In addition, a bidirectional interface between GMP and GLOMON[17] (Schulz and Schäfer, 2022) will be realized during 2022. The aim here is to transfer daily determined 3d coordinates from GNSS stations from GLOMON to GMP and then again levelling results from GMP to GLOMON.

Asides from GMP, the development of tools for the analysis of time series in DSA will continue (Figure 10). The enrichment of further non-geometric data like rainfall or air temperature et cetera is currently in the developing stage. A joint representation of time series of two different sensor types in one chart will allow to visualise correlations between effect and phenomenon. Imagine data from a sensor observing the controlled rise of underground mine water level (as the effect) combined with slowly gaining height data of a GNSS sensor (as phenomenon). That provides an easy approach to conclude whether a ground movement is natural or induced.

VII. Conclusions

The knowledge of past and recent ground movement in former mining areas is necessary for RAG to meet its obligations in order to complete the dismantling of abandoned underground mines as well as to be able to assess potential mining damages. To this end, both accurate geodetic observation methods and reliable data management including workflows and storage are vital. With developing GMP, RAG ensures the reliability of the deformation monitoring process for future tasks

[16] The library amCharts 5 is used for the time series charts.

[17] GLOMON: Global Monitoring web service by Allsat GmbH.

and significantly increases the accessibility of the created results.

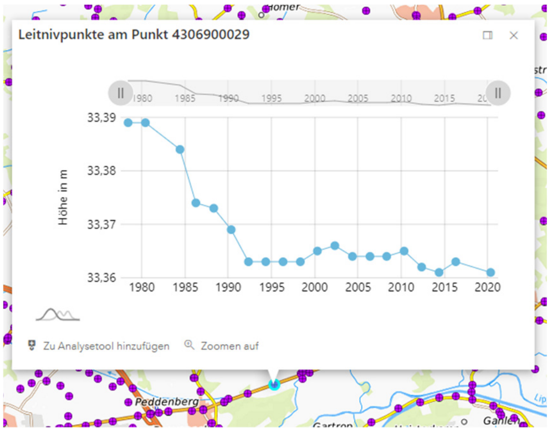

Figure 10. Interactive time series charting in the map of the current DSA version 4.3.

All previously formulated requirements could be met and overall, a versatile tool for deformation monitoring has been created. The additional capabilities of ArcPy make the system even more complete. However, any data-driven application is only as good and comprehensive as its volume. That means, the success of GMP is necessarily linked to the integration of other data. Great efforts will be needed here in the future.

The first times series functions with interactive charts in RAG's internal web service Digitale Service Akte have been met with great acceptance among test users. More data sets and analytics will be added over the next few months and contribute to preserve expertise in a shrinking organization.

VIII. Acknowledgements

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