Magnetotelluric Field Campaign in the Nógrád–Gömör Volcanic Field (Northern Pannonian Basin)

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Abstract

In planning a magnetotelluric survey, there are several requirements to consider in order to record high-quality electromagnetic time series for geological investigation. In this paper, we present an example of a magnetotelluric field survey recently conducted in the Nógrád–Gömör Volcanic Field (Northern Pannonian Basin) during the summer of 2024, focusing on the recommended conditions for magnetotelluric station deployment. We begin with the geological goals and the motivation behind the magnetotelluric survey, followed by a suitable site selection, and conclude with some direct electromagnetic field observations from the time series obtained. Finally, we summarize the preliminary results of the magnetotelluric field campaign and suggest potential improvements that could enhance the quality of future field measurements.

Keywords: magnetotellurics, electromagnetic deep structure investigation, field campaign planning.

Introduction

The Institute of Earth Physics and Space Science in Sopron has been conducting field magnetotelluric (MT) measurements in the Carpathian–Pannonian region for more than 60 years, for both near-surface and deep structural investigations (e.g., Ádám and Wesztergom, 2001; Ádám et al., 2017). The current MT instrumentation allows for high-precision electromagnetic (EM) field recording, with an accuracy of <0.1 nT for the magnetic field and <0.1 mV/km for the electric field during long-period MT recordings. The magnetometer and electrodes used during the measurement are capable of detecting changes in the magnetic

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field generated by the electric current systems of the ionosphere and the magnetosphere, as well as changes in the electric and magnetic fields originating from the subsurface medium, created simultaneously through electromagnetic induction.

During the deployment of MT measurements, it is important to ensure that the station site aligns with the necessary MT field conditions. The most critical requirements are to position the MT station on a flat ground surface and at a sufficient distance from anthropogenic noise sources, such as the electrical infrastructure. The main challenge is typically finding sufficient spatial distance from electrical infrastructure, such as high voltage power transmission lines, railway lines, solar panel farms, and even smaller devices with lower performance like electric pumps, pylons, electric fences etc. These sources, even several hundred meters to a few kilometers away (depending on conductivity of shallow structures), can cause significant EM noise, detectable in the measurements due to the high sensitivity of MT sensors. In many cases, anthropogenic EM noise cannot be effectively completely removed from the time series, which can compromise MT time series processing, leading to inaccurate MT response functions. Therefore, it is crucial to establish MT measurement sites where EM noise is minimized. A good example of selecting near-optimal MT measurement sites can be seen in the long-period MT measurements conducted in the Transylvanian Basin (Novák et al., 2024).

Note that in mountainous and hilly regions, such as the Transdanubian Range, soil may barely cover the hard bedrock at the surface. Therefore, it is not recommended to establish MT sites in such locations, as the MT sensors should be placed approximately 0.5 m below the surface to avoid temperature fluctuations, wind effects and other environmental factors during measurement (Rubóczki et al., 2024). Given the challenges posed by these criteria, this paper presents the main steps of a recent MT field measurement campaign carried out in 2024 in the Nógrád–Gömör Volcanic Field.

The Geological Objective

The Neogene magmatic evolution of the monogenetic Nógrád–Gömör Volcanic Field (NGVF), and its impact on both the surface and the entire lithosphere, has long been a subject of research. The volcanism (e.g., Konečný et al., 1995) and the melt-wall rock interactions within the crust (e.g., Kovács and Szabó, 2005) and lithospheric mantle (e.g., Szabó and Taylor, 1994) has been investigated in details. The occurrence of carbon dioxide–rich springs in this area suggests that fluids are still actively migrating from the rootzones of the volcanic field to the surface. It is also important to note that the Hurbanovo–Diósjen Line, a boundary between the northern Alpine and Central Western Carpathians units on its northern side and the southern Alpine (Transdanubian) and Dinaridic (Bükk) units on its southern side (Kováč et al., 2016), possibly plays a key role in the volcanism, as it is likely crosses this area and is associated with active seismicity (Wéber, 2016).

To gather more geological information on the deep lithosphere of the NGVF, colleagues from the Earth Physics and Space Science Research Institute conducted a series of MT measurements in 2013–2014. During this fieldwork, 14 stations were established along a northwest–southeast trending section (Fig. 1a), with station spacing of 3–5 km and a total section length of approximately ∼60 km. The electrical resistivity distribution from these MT measurements reflects subsurface geological structures, including the presence of well-conductive body (<1 Ωm) underneath the Moho in the central NGVF (Fig. 1b). This corresponds to the same area where upper mantle xenoliths with wehrlitic modal composition were collected from six quarries (Patkó et al., 2020). The estimated electrical resistivity of the wehrlites (∼132 Ωm) alone could not account for the observed low resistivity values, leading to further modelling to assess the potential role of melt. The models revealed that even ∼2–3 vol.% of interconnected melt could reduce the electrical resistivity to below 1 Ωm in the wehrlites (Patkó et al., 2021). The goal of the new MT measurements in 2024 was to extend the previous 2D MT section into a 3D model, allowing for a more detailed spatial delineation of the electrically well-conducting domain identified in earlier inversion models.

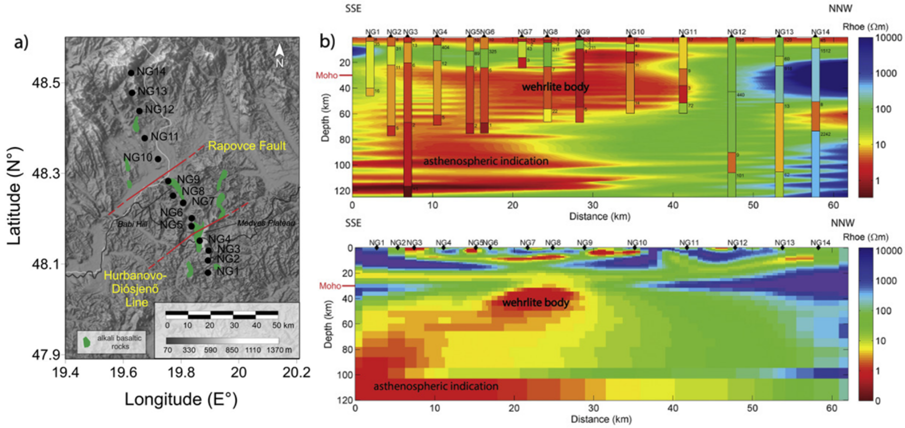

Fig. 1. **a)** Map of the Nógrád–Gömör MT section, showing measurement locations (black dots), major fault zones (red lines), and surface alkali basaltic outcrops (green fields), **b)** 1D inversion (top), 2D inversion (bottom) of the NG MT section (from Patkó et al. (2021)).

Planning of the MT Sites in the Nógrád–Gömör Volcanic Field in 2024

The location of the planned new MT stations (NGn) was determined based on the subsurface resistivity anomalies identified along the previously measured NG section. Fortunately, the geophysicist colleagues of the Slovak Academy of Sciences informed us, they have MT data from the NGVF region, the so-called 2T section (Vozár et al., 2021). This section traverses Slovakia in a northwest–southeast direction, running parallel to the NG MT section, approximately ∼15 km east of it, and has a comparable MT station spacing to the NG section. The key difference between the MT datasets of the NG and 2T sections is that the NG MT section consists of long-period MT measurements (max. ∼10000 s), whereas the 2T section contains short-period MT data (max. ∼100–500 s). Since our primary objective is to achieve maximum penetration depth in the lithosphere, follow the path of the 2T section. This approach ensures that, after completing the NGn MT measurements, both the NG and 2T MT sections will have long-period MT data, significantly enhancing the depth of investigation. Moreover, the existing 2T MT section data will support the time series processing of the new NGn MT sites. Once the datasets from the NG and 2T sections are combined, they will be suitable for conducting a regional-scale 3D MT inversion, providing a comprehensive view of the lithospheric structures beneath the NGVF.

The planning of the new MT sites required careful consideration of the terrain and the proximity of electrical infrastructure. In the study area, there are primarily small villages located a few kilometres apart with nearby towns such as Lučenec (Losonc) and Fiľakovo (Fülek) more than 10 km away from the closest MT sites (Fig. 2). Most of the suitable land between these villages was under cultivation, making it unsuitable for MT station placement. Additionally, the research area included high-voltage power lines, several stone quarries, and railway lines, all of which needed to be avoided as much as possible. Fortunately, the railway was not electrified, allowing us to place stations nearby without significant concern. Another crucial factor was the planned long-period nature of the MT measurements, which required an operating time of 9 to 14 days. Therefore, it was essential to locate the MT stations in sufficiently safe areas, preferably out of sight. In the unlikely event that someone did discover the MT site, we provided a bilingual Slovakian–Hungarian warning notice on the box, along with the contact details for our colleagues.

The exact site locations were selected using the Google Earth satellite images, taking into account both the geological targets and the field conditions. While other geo-information systems can be utilized, it is crucial to ensure that the maps indicate industrial buildings and agricultural areas that should be avoided. Regularly updated satellite images provide the easiest solution for this purpose. It is highly recommended to conduct a field trip before starting the MT campaign, as field conditions may differ from what is shown on the maps. This trip also helps assess the accessibility of potential sites. After assigning the MT stations, we undertook a field visit to verify the site conditions. Some planned MT locations appeared accessible on the map, but we found that there was no passable road leading to them. In other instances, we encountered heavier vegetation than anticipated, prompting us to search for alternative site locations.

We would like to note that during the magnetotelluric (MT) measurements, two pairs of electrodes with a length of 50 meters each, measuring two horizontal electric components, are preferably oriented in the north–south and north–west directions to capture the dominant regional geological structures. Therefore, when selecting a site, it is essential to ensure a clear area of 50 × 50 meters for the installation. Although, in theory, the distance between the electrodes and their orientation can be varied — since these field changes can be accounted for during the MT time series processing — it is usually best to use the default MT instrument setup mentioned above. Once the planned MT locations were selected and the field check was successful, we were ready to launch the field MT campaign.

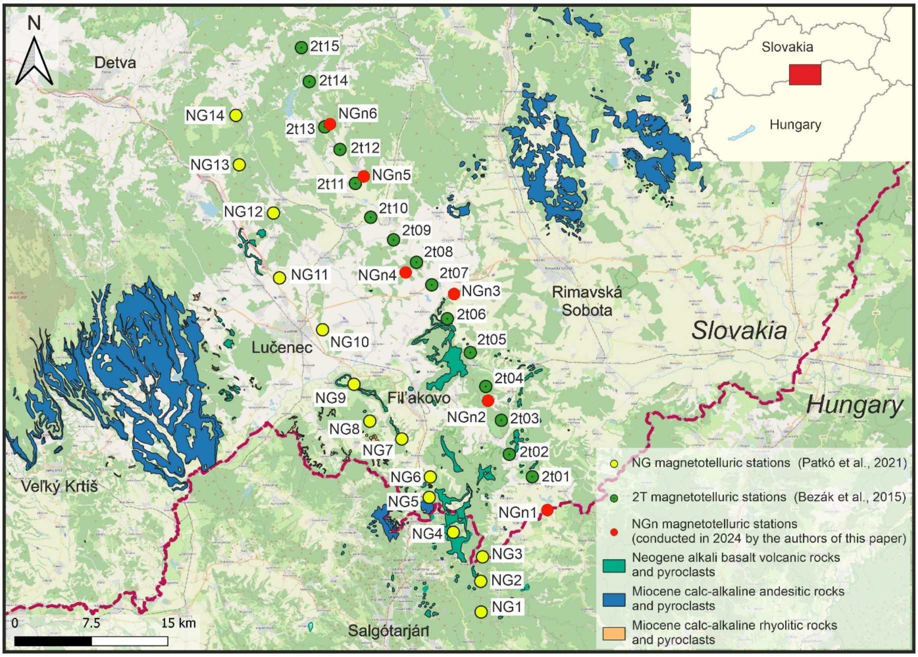

Fig. 2. Simplified map showing MT measurements in the Nógrád–Gömör Volcanic Field and its surroundings, with the distribution of various volcanic products based on the map of Káčer et al. (2005) and Gyalog and Síkhegyi (2005).

MT Field Measurements Experiences

The new NGn MT survey involved 6 long-period MT measurements, as shown in Fig. 2, carried out between July and September 2024. Planning the logistics of the deployment was a challenge, as the round trip between Sopron and NGVF took around 9 hours, and cost efficiency is typically a key factor in any MT campaign. Additionally, concealing the instruments was crucial, particularly given the extended duration of the field measurements, which increased the likelihood of the devices being found, as well as the possibility of errors during data collection, such as animals damaging or chewing on the cables. In the worst-case scenario, this could result in sensor loss. In terms of the location selection, most of the MT stations were situated at least 1 km away from any known electrical infrastructure, to minimize electromagnetic noise. However, the terrain in certain parts of the NGVF was quite hilly, which made it difficult to always find completely flat areas for the installation. Figure 3 provides an example of the local terrain characteristics encountered during the survey.

Some Characteristics of the Nógrád–Gömör MT Time Series

The MT field measurements capture both the horizontal and vertical components of the magnetic induction vector (B_x, B_y, B_z) along with the horizontal electric field components (E_x, E_y). The measurements were performed using a LEMI417 long-period MT instrument, the sampling frequency was 4 Hz in all stations. Figures 4, 5, 6 and 7 illustrate some of the most common patterns in the time series from these field measurements. The time series of the EM field components are sorted. The x component of the magnetic field vector (B_x) aligns with the N–S direction. According to Faraday's law, changes in the magnetic field along this direction induce a corresponding electric (telluric) current in the E–W direction. This is why the second row of the time series (E_y) corresponds to this induced current in the E–W direction. Similarly, the third row (B_y) reflects the E–W component of the magnetic field vector, while its corresponding electric field component (E_x), which lies along the N–S direction, is shown in the fourth row. The near-zero values of B_y ($\approx$0 nT) can be attributed to the orientation of the magnetometer relative to the magnetic E–W direction, which reduces signal amplitude in this component. The 5th row in the time series displays the vertical component of the magnetic field (B_z).

Figure 4 shows the time series of the EM field recorded by the NGn3 MT station on 5 August 2024. By the time the measurements began on 1st of August, the surrounding fields had already been harvested, leading to the assumption that no significant anthropogenic noise from the harvesting would affect the data. However, some moderate electrical noise and occasional overshooting peaks were still observed in the time series of the electrical channels E_x and E_y. This disturbance is likely attributed to activity from a nearby stone mine

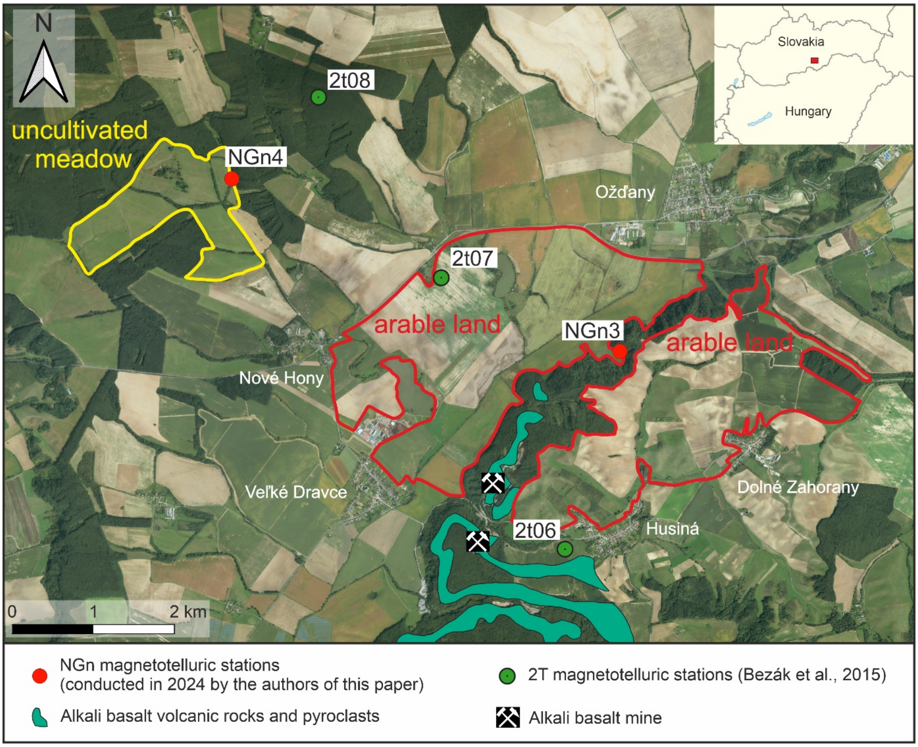

Fig. 3. The area around the NGn3 and NGn4 MT sites (see Fig. 2 to identify these neighbourhoods), where red circles indicate locations unsuitable for deployment, while the areas within the yellow frame are considered suitable for MT installation. The distribution of the alkali basalt volcanics and pyroclasts are based on the map of Káčer et al. (2005).

(∼1 km), particularly since the time series was recorded on a Monday, a typical workday. It is a common observation in the MT fieldwork that anthropogenic noise caused by human activities tends to be present in the electric channels between ∼6 a.m. and ∼6 p.m. on weekdays. While the exact source of the electrical noise is often difficult to identify, the magnetic field components usually exhibit no such noise or at least a much-attenuated version of it. This pattern is evident in the NGn3 time series from 5 August, where the electric channels show noticeable noise between 8 a.m. and 8 p.m., while the magnetic channels remain largely unaffected. Overall, this particular measurement from NGn3 displays a relatively low level of noise compared to other cases, where higher levels of noise were often detected.

The NGn4 MT station was situated in a meadow area, away from cultivated land, leading us to anticipate a lower level of noise intensity during the measurements. However, some of the recorded time series exhibited variations, as

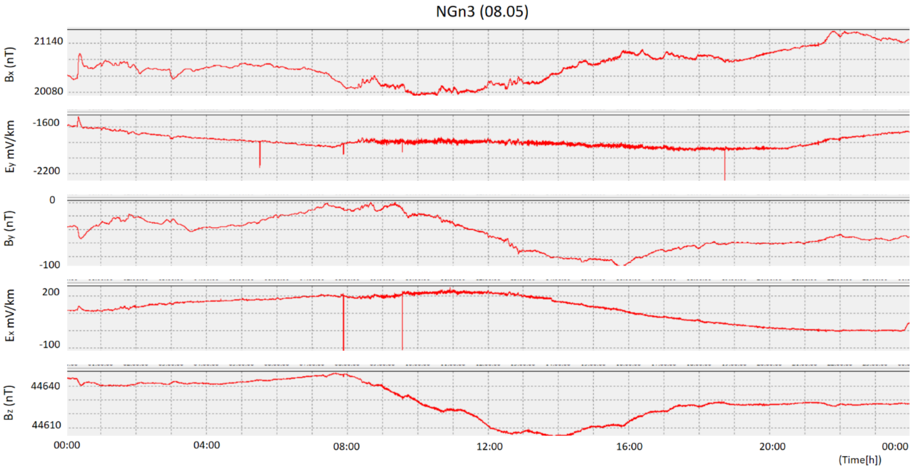

Fig. 4. Time series of NGn3 MT station B_x, B_y, B_z, E_x, E_y, on Monday, 5 August 2024.

illustrated in Fig. 6. Initially, we suspected that a nearby high-power electrical device might be the source of this noise, as such devices can produce both direct electrical noise and magnetic induction components. To investigate further, we compared the time series from the NGn4 MT station with those from the NGn3 MT station, which was operating simultaneously and located about 5 km away (Fig. 3). Notably, both stations recorded very similar field variations throughout most of the day on 11 August. Given the proximity of the two stations, it seemed unlikely that a single anthropogenic electromagnetic source could be responsible for the rapid field changes observed at both locations. As supporting evidence, we also examined the magnetic field components recorded by the nearest magnetic observatory in Slovakia (Fig. 7). The variations in the field at the observatory closely mirrored the signal shapes observed in the time series from both NGn3 and NGn4. This correlation indicates that the rapid changes in magnetic field recorded by the MT measurements on 11 August were likely caused by increased activity from natural electromagnetic sources, rather than by anthropogenic interference.

In the NGn3 MT time series shown in Fig. 5, we observed that the electrical channel in the E–W direction (second row) exhibited signs of malfunction, entering saturation several times. Upon investigation, we discovered that the cable at the site had likely been completely torn, possibly by an animal. This type of issue was not uncommon; the fields that seem ideal for MT stations also attract wildlife. Unfortunately, wild animals tend to roam these areas, and it is not unusual for them to chew or break the cables as they move through the site. During the 2024 MT measurements in the NGVF, we frequently encountered cable damage caused by animals. Given that such damage was a recurring challenge, especially during long-period MT measurements, it has become evident that a permanent solution is needed to mitigate these failures in the future.

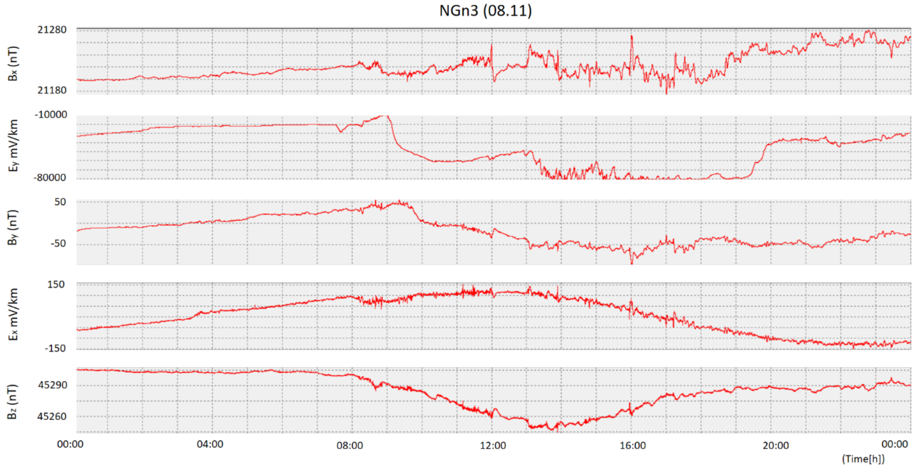

Fig. 5. Time series of NGn3 MT station B_x, B_y, B_z, E_x, E_y, on Sunday, 11 August 2024.

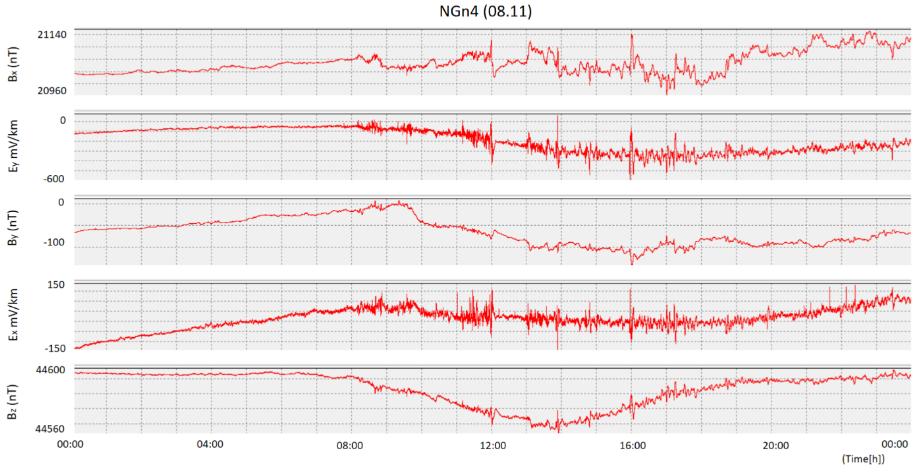

Fig. 6. Time series of NGn4 MT station B_x, B_y, B_z, E_x, E_y, on Sunday, 11 August 2024.

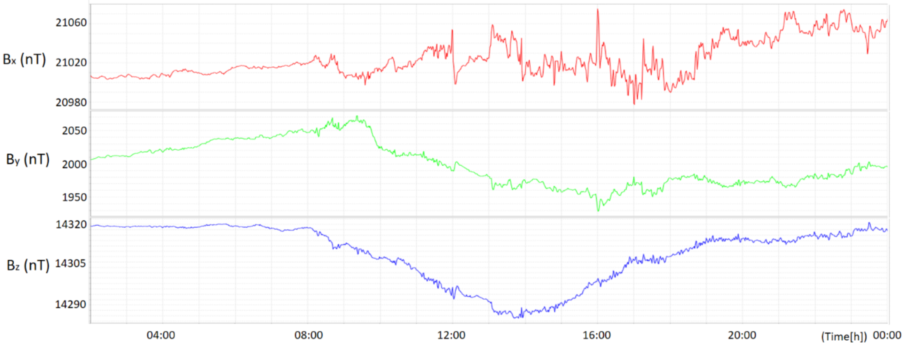

Fig. 7. Time series of Hurbanovo Magnetic Observatory B_x, B_y, B_z fields on Sunday 11 August 2024.

Evaluation of the 2024 MT Fieldwork in the Nógrád–Gömör Volcanic Field

During the new MT survey in the NGVF, we successfully identified new MT site locations that met both the geological and technical requirements for MT deployment. More detailed information on the quality of the 2024 MT measurements will be available after the time series processing. However, it appears that the quality of the recorded time series is comparable to the previous 2013–14 NG MT section measurements. A significant difference is the duration of the 2024 MT measurements, which was 3 to 4 times longer than the prior measurements. The extended recording period offers several advantages: in cases of noisy time series, longer continuous data segments may contain more periods with less noise, such as weekends. Additionally, longer recordings allow for the calculation of impedances with smaller errors over longer periods. The logistics for the long-period MT sites were appropriate, especially given that short-period data had already been collected along the 2T MT section (Bezák et al., 2015). However, we would like to point out that if additional short-period MT measurements had been necessary, it would not have been possible to complete them in a single day. In that case, we would have needed to plan the MT campaign with a different time and cost schedule.

In addition, when selecting the MT stations, it is important to consider both local and seasonal conditions. For example, during the NGn measurements, none of the areas suitable for us had been recently mown. It is crucial to avoid installing an MT station just before mowing, as this could result in equipment damage. Fortunately, during the MT deployment, we were lucky: the 6 new MT measurements were conducted between 9 July and 3 September 2024, and all the selected areas had already been mown before the measurements began. Since there was no significant precipitation during this period, the vegetation grew minimally, and there was no risk of additional mowing.

During the installation of the MT stations, the data logger box was hidden in bushes, which proved to be an effective practice, as the station was not visible even from a few dozen meters away. However, the cables for the electrical channels were frequently disturbed by animals. In the future, the cables should be secured to the ground in some way, as wild boar, deer, roe deer and rabbits tend to chew them. Additionally, it would be helpful to be notified immediately if there is a malfunction at the MT station, rather than only discovering it when collecting the equipment. A good solution would be remote access to the MT station, which is something we are planning to implement in the near future.

Conclusions

In the summer of 2024, between July and September, we successfully carried out MT measurements in the NGVF, establishing 6 new long-period MT stations along a previously measured 2T MT section, which had only short-period (max 100–500 s) data. The aim of the new MT measurements is to extend the dataset to longer-periods (up to 10000 s), allowing for deeper penetration to provide more accurate data at depths of at least 50–100 km. In this short communication, we have reviewed the necessary conditions for planning of the MT measurements, balancing both the geological objectives and the technical suitability of the locations. We have also suggested potential solutions to address challenges such as anthropogenic noise and cable damage caused by animals, both of which can reduce the efficiency of MT measurements. Additionally, we have illustrated the impact of these disturbances on the recorded EM field time series. An interesting observation from the MT measurements was a geomagnetic active period, detected not only in the time series of two parallel operated MT stations but also confirmed by a nearby magnetic observatory.

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