The study of the geomagnetic diurnal variation behavior associated with Mw>4.9 Vrancea (Romania) Earthquakes

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1. Introduction

Diurnal geomagnetic variations are generated in the magnetosphere and last for about 24 hours. These can be seen on the recordings of all magnetic observatories, with amplitudes of several tens of nT, on all magnetic components. The shape and amplitude of diurnal variations strongly depend on the geographical latitude of the observatory.

In addition to the **dominant external source** from the interaction with the magnetosphere, the diurnal geomagnetic variation is also influenced by **local phenomena**, mainly due to internal electric fields:

-External influence remains unchanged over distances of hundreds of kilometers;
-Internal influence may differ over very short distances due to the underground conductivity.

The ratio of the diurnal geomagnetic variation at two stations should be stable in calm periods and could be destroyed by the phenomena that can occur during the preparation of an earthquake, when at the station inside the seismogenic zone, the underground conductivity would change or additional currents would appear. The cracking process inside the lithosphere before and during earthquakes occurrence, possibly modifies the underground electrical structure and emits electro-magnetic waves.

1. Introduction

The Vrancea zone, located at the bent arc of the South-Eastern Carpathians, represents one of the most active seismic zones in Europe. The seismic activity in Vrancea area is generated both in the crust with moderate size earthquakes (Mw<5.6) and in the mantle at intermediate depth with strong earthquakes, exceeding Mw=7.0. The intermediate-depth earthquakes occur between 60 and 200 km depth.

In this paper, we study how the diurnal geomagnetic field variations are related to moderated size, intermediate depth earthquakes, occurred in Vrancea, Romania, after 2016. For this purpose, we use the recordings from **two magnetometers** situated at 150 km away from each other, Muntele Rosu – MLR inside the seismic zone and Surlari – SUA, outside it, and the ROMPLUS seismic catalogue of NIEP.

We have studied the ratio of the daily ranges of the magnetic diurnal variation (**DBi= Bimax-Bimin**), during a 24 hours period, at MLR and SUA, to identify behavior patterns associated with external or internal conditions: **$R = DBi_{MLR}/DBi_{SUA}$**, where i is the component of the geomagnetic field.

2. Geomagnetic data

The **geomagnetic field data** from 2016 till present were acquired from Muntele Rosu Observatory (MLR-National Institute for Earth Physics), and from Surlari (SUA - INTERMAGNET Observatory and SULR - National Institute for Earth Physics and Bucharest University) – Table 2. The magnetometers are three component Bartington fluxgate type, capable to measure small-amplitude geomagnetic fluctuations. In this study, we have used recordings at 1 minute of the **geomagnetic field**.

Based on the distance from the epicenter (see Table 1, chapter 3), MLR served as the primary station and SUA as the remote station.

In order to distinguish the effects of **global geomagnetic activity** and avoid false precursor, we have used a global geomagnetic index, namely the planetary Kp-index recorded during the same period of observation.
The planetary K-index used to characterize the magnitude of geomagnetic storms were taken from the National Oceanic and Atmospheric Administration (NOAA)/ Space Weather Prediction Center and also from GFZ Potsdam (https://www.gfz-potsdam.de/kp-index).

Temperature measurements were made by using a temperature sensor included in the radon sensor (2016) were made by using a temperature sensor included in the radon sensor.

2. Geomagnetic data

Table 2. Geomagnetic Observatories that provided the data

Observatory	Code	Type	Latitude	Longitude	Altitude (m)
Muntele Rosu	MLR	Bartington MAG03	45.49N	25.95E	1360
Surlari INTERMAGNET	SUA	Bartington MAG01	44.68N	26.12E	84
Surlari INCDFP	SULR	Bartington MAG03	44.68N	26.25E	97

3. Seismicity

The intermediate depth Vrancea seismicity with earthquakes $M_L \geq 5.0$ that occurred between 2016 and 2022 is presented in Figure 1 and Table 1, together with the epicentral distance (De) between the earthquakes and MLR geomagnetic station, and the “strain radius” (Rd) computed from the Dobrovolsky equation.

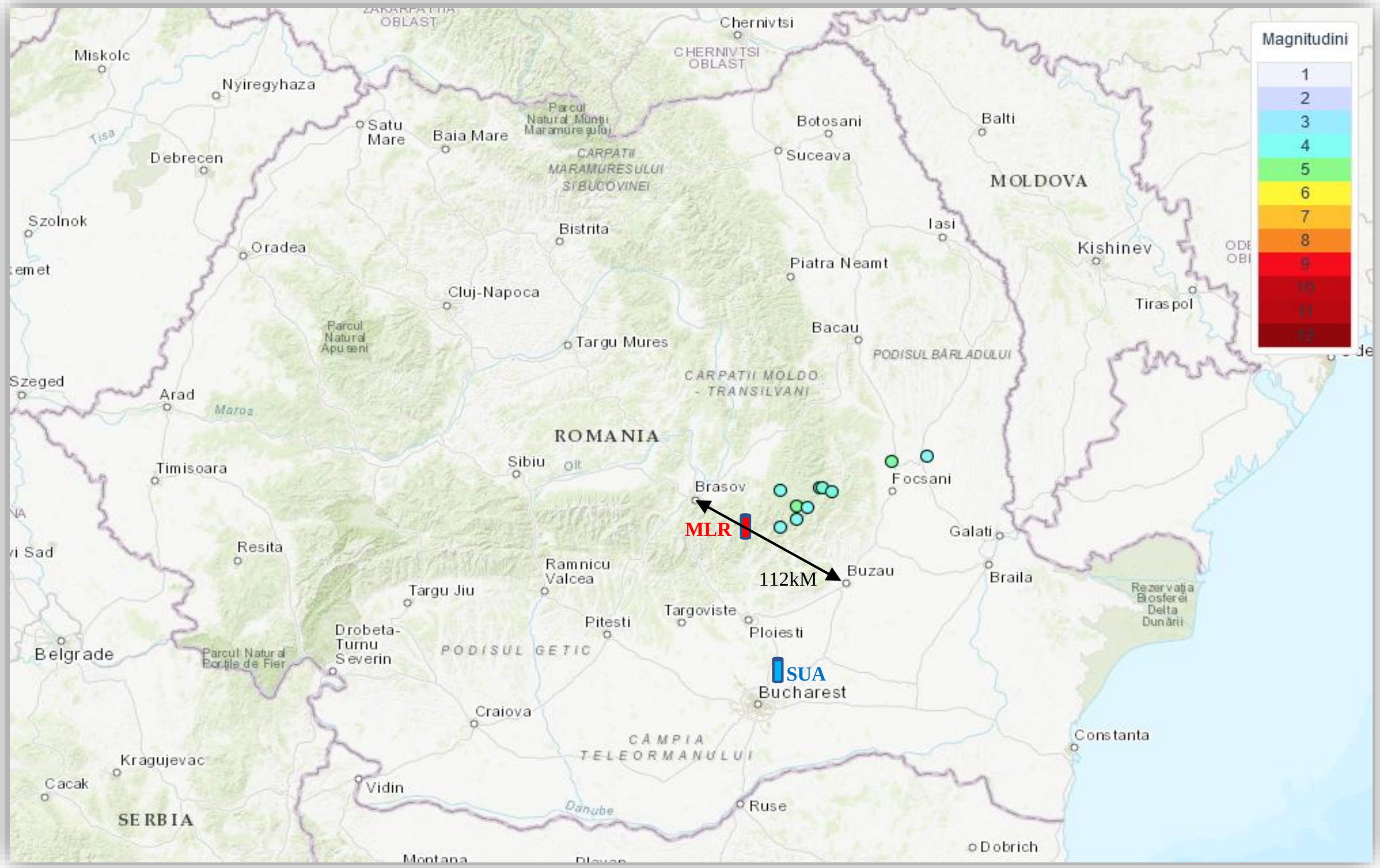


Figure 1. Vrancea Seismicity $M_L \geq 5.0$, 2012-2022 - http://phenomenal.infp.ro/

3. Seismicity

The intermediate depth Vrancea seismicity with earthquakes $M_L \geq 5.0$ that occurred between 2016 and 2022 is presented in Figure 1 and Table 1, together with the epicentral distance (De) between the earthquakes and MLR geomagnetic station, and the "strain radius" (Rd) computed from the Dobrovolsky equation.

Table 1. Seismicity in Vrancea region

No	Date	Time (UTC)	Latitude	Longitude	Depth	M_L	Mw	De(Km)	Dh(Km)	Rd(Km)
Eq1	2016/09/23	23:11:20.06	45.7148	26.6181	92.0	5.8	5.5	56	107.7	231.74
Eq2	2016/12/27	23:20:55.94	45.7139	26.5987	96.9	5.8	5.6	55	111.42	255.86
Eq3	2017/02/08	15:08:20.89	45.4874	26.2849	123.2	5.0	4.8	25	125.71	115.88
Eq4	2017/08/02	02:32:12.68	45.5286	26.4106	131.0	5.0	4.6	35	135.59	95.06
Eq5	2018/10/27	00:38:42.52	45.6049	26.3986	151	5.8	5.5	38	155.71	231.74
Eq6	2020/01/31	01:26:23.20	45.6937	26.6918	118	5.0	4.8	58	131.48	115.88

We have assumed that the zone of effective manifestation of the precursor deformations is a circle with the centre in the epicentre of the preparing earthquake. The radius of this circle called 'strain radius' may be calculated from the equation Rd=10^(0.43*M*) *km* where Mw is the magnitude (Dobrovolsky et al, 1979). De and Dh are epicentral and hypocentral distances for MLR station.

2. Seismicity

Besides the formula of **Dobrovolsky**, 1979 (**Rd=10^0.43*M**), we have also implemented **Hayakawa** et al. (2007) hypothesis that the Rmax condition needs to be satisfied for the ULF signal emitted from an earthquake epicenter to be detectable by a magnetometer station, based on the distance between the two locations (epicentral distance, De), and the earthquake magnitude (*M*): **Rmax=(M-4.5)/0.025**

Using **Hayakawa** formula **(Rmax)**, the medium sized earthquakes from Table 1 were located very close to the area defined by Rmax, and only **Eq5** was inside it **(De<Rmax)**, and using **Dobrovolsky** formula **(Rd)** , all six events were inside the preparation area (**De<Rd**):

Eq1 5.8 – Rmax = 52 Km, Rd = 231 Km, and De = 56 Km
Eq2 5.8 – Rmax = 52 Km, Rd = 255 Km, and De = 55 Km
Eq3 5.0 – Rmax = 20 Km, Rd = 116 Km, and De = 25 Km
Eq4 5.0 – Rmax = 20 Km, Rd = 95 Km, and De = 35 Km
Eq5 5.8 – Rmax = 52 Km, Rd = 231 Km, and De = 38 Km
Eq6 5.0 – Rmax = 20 Km, Rd = 115 Km, and De = 58 Km

In this short presentation, will be shown only the results obtained for eq 1 and eq 5, same magnitude, but eq 1 is very close to the preparation zone and Eq5 is inside it.

4. Geomagnetic data – processing methodology

The diurnal variation processing methodology was taken from KA Yusof et al. (2019) and Xu et al. (2013), and was further applied.

*The **following steps** were applied to each geomagnetic component for both stations, MLR and SUA, individually. Data were sampled at 1-min sampling period.*

Then, the diurnal variation range, $\Delta B_{j,i}$, was calculated by subtracting the minimum value from the maximum daily value:

$$\Delta B_{j,i} = \max(B_{j,i}) - \min(B_{j,i})$$

where: i refers to horizontal (East – West – By and North – South – Bx), and vertical Bz components and j refers to MLR and SUA stations.

The ratio of daily variation of the primary (MLR) to the remote (SUA) station, R_i , was calculated for each component

$$R_i = \Delta B_{MLR,i} / \Delta B_{SUA,i}$$

For anomaly identification, we have used Xu et al. (2013) methodology:

$MR_i \pm k \cdot SDR_i$ (k = 3) threshold where any daily R_i value exceeding this threshold is considered an anomaly. Parameters MR_i and SDR_i in the expression are the mean and the standard deviation of R_i , calculated for the whole period of observation (one month - the month when the earthquake occurred – for Eq1, and two months – one months before and the month when the earthquake occurred – for Eq5).

SD =SQRT[((SUM(Ri(n)-MRi)^2)/(n-1)], where n is the number of values in the data set (30 for Eq1 and 61 for Eq5)

In this paper, we have used k = 2 (red line) and k =3 (dark red line) since the earthquake focused in this study has a much lower magnitude than the one in Xu et al. (2013) where M = 9 thus, for our study, a lower threshold was more suitable.

4. Geomagnetic data processing

In this short presentation, the geomagnetic data processing using the diurnal variation method and the anomaly detection was applied for magnetic data from the current month of eq1 (September 2016) and from two month, one before (September 2018) and the current month of eq5 (October 2018). For the current months of Eq1 and Eq 2, also the time diagrams were represented.

For Eq1, no significant anomalies were observed, on any of the three components of the magnetic field.

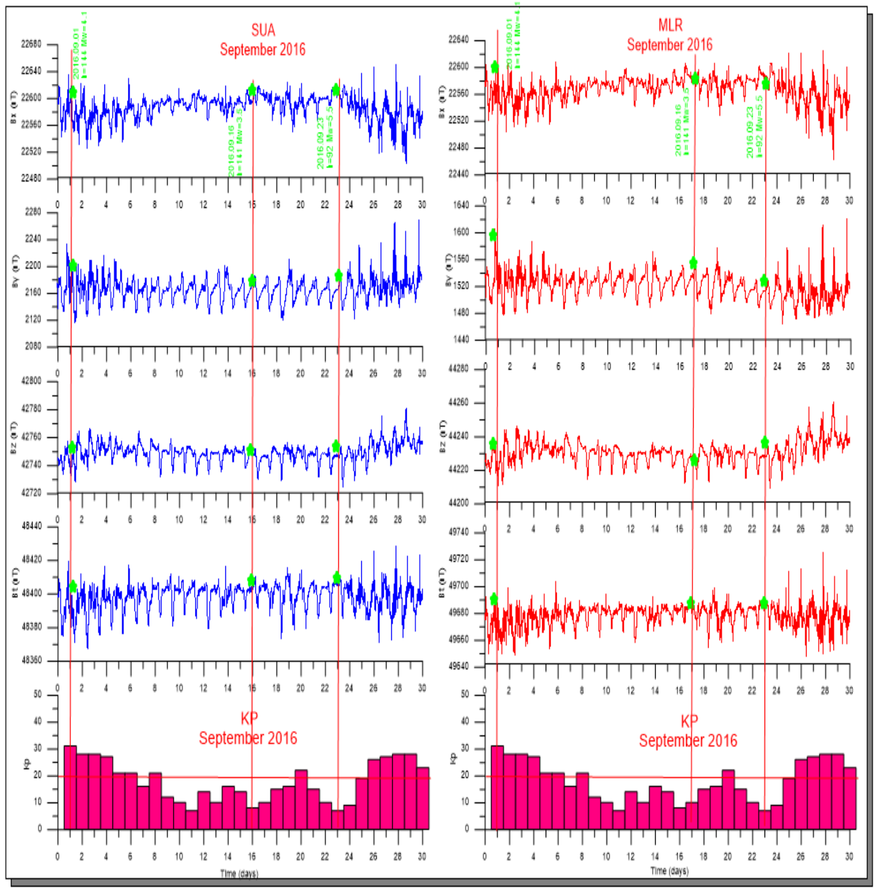
For Eq5, one strong anomaly was detected, 22 days before the earthquake (on the 5th of October) on the horizontal Bx (NS) component, and also on the total field.

To certify the anomaly as being a precursor one, we have also represented the daily sum of 3 hours Kp variation for October 2020. No magnetic storm was observed during the day of the anomaly (5th of October 2018).

On the monthly time diagram in Figure 4, the anomaly appears like a “spike”, but on the daily time diagram from Figure 5, the “spike” is in fact an one step decrease of the magnetic field, lasting for about one hour.

At this moment we cannot explain the origin of the anomaly, but we have searched to identify such spikes on all the magnetic recordings, and tried to associate them with their real causes.

5. Geomagnetic data processing – diurnal variation ratio



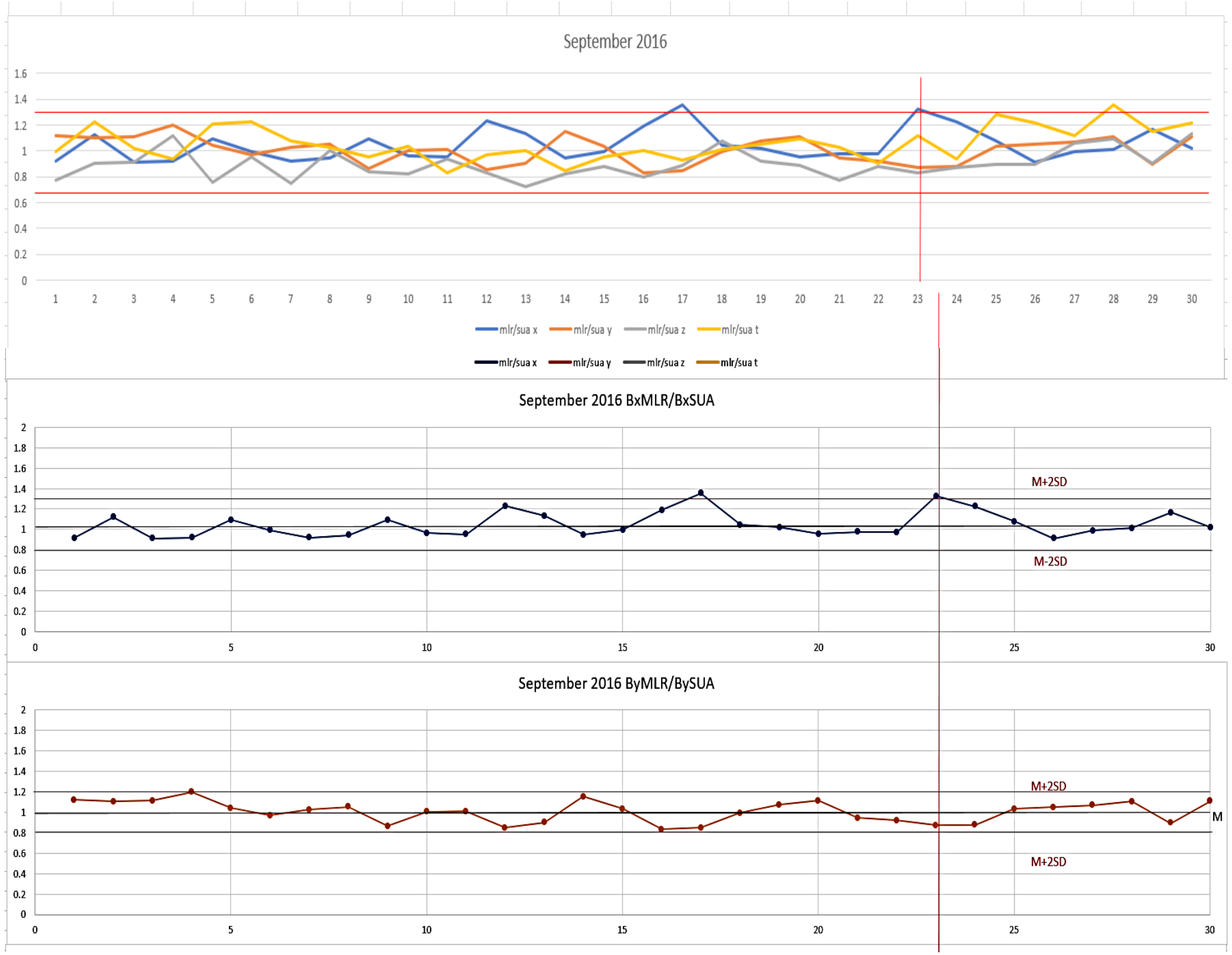


Figure 2a. Geomagnetic data processing – diurnal variation on x and y horizontal components for **September 2016 (Eq 1)** – NO significant anomaly

5. Geomagnetic data processing – diurnal variation ratio

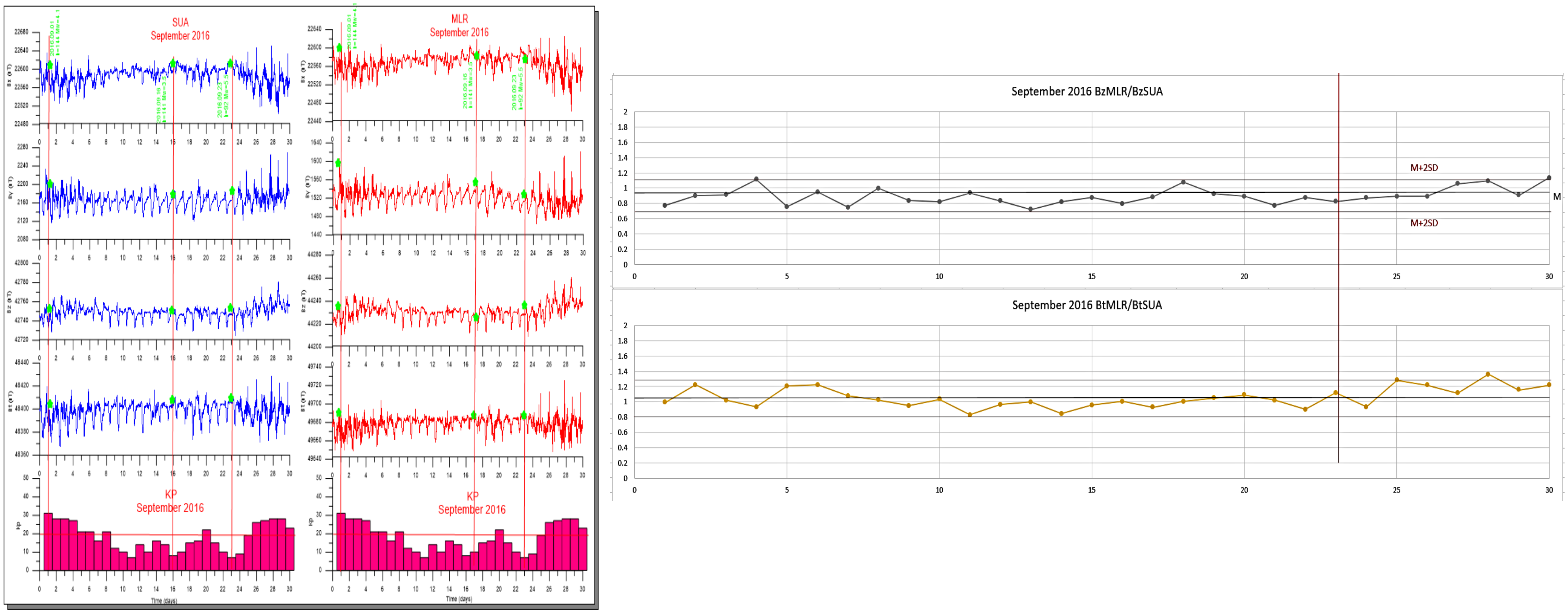


Figure 2a. Geomagnetic data processing – diurnal variation on the z and total component for **September 2016 (Eq 1)** – NO significant anomaly

5. Geomagnetic data processing – diurnal variation ratio

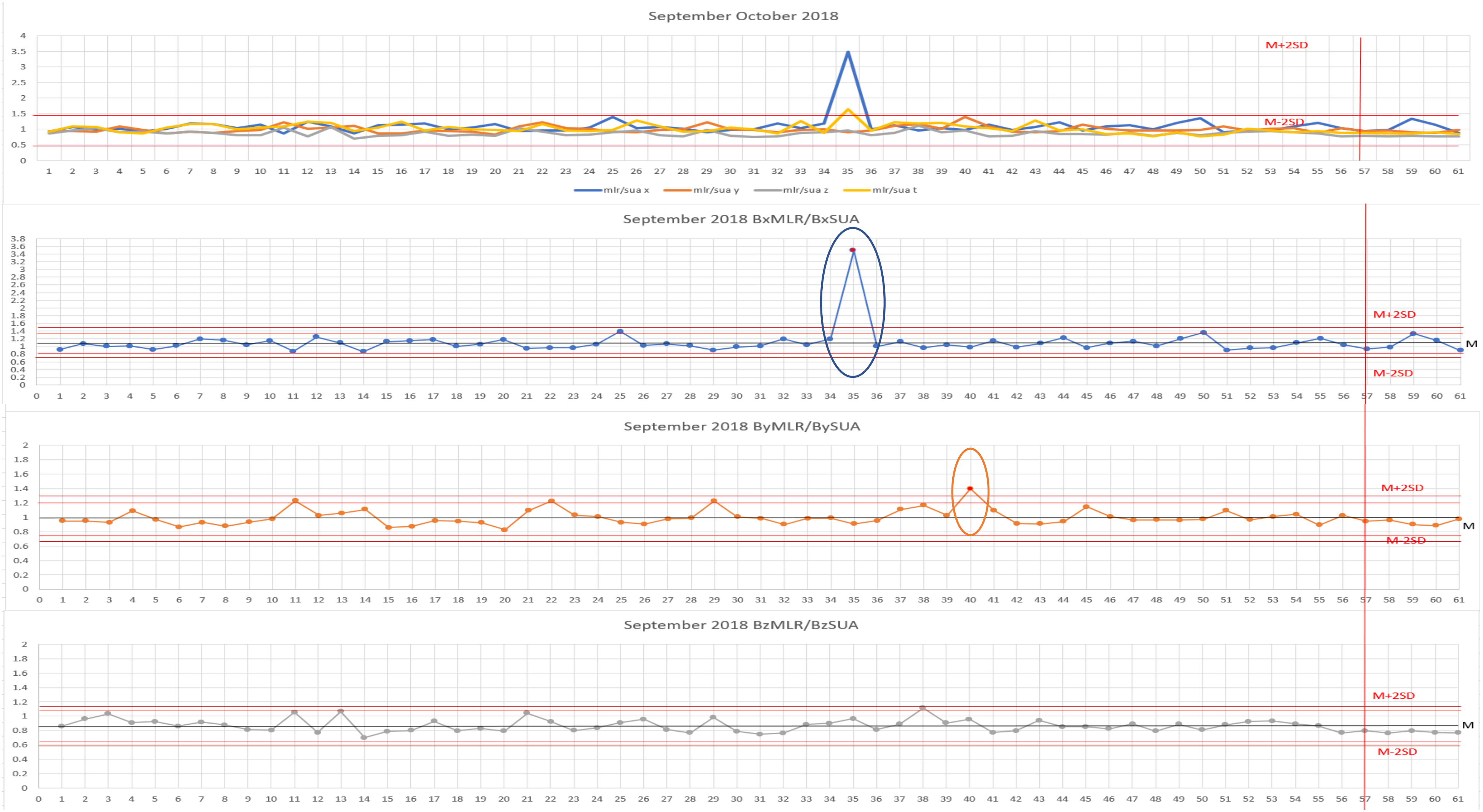


Figure 3a. Geomagnetic data processing – diurnal variation on x and y horizontal and z vertical components for September – **October 2018 (Eq 5)** – 1 strong anomaly on x and 1 anomaly on y

5. Geomagnetic data processing – diurnal variation ratio

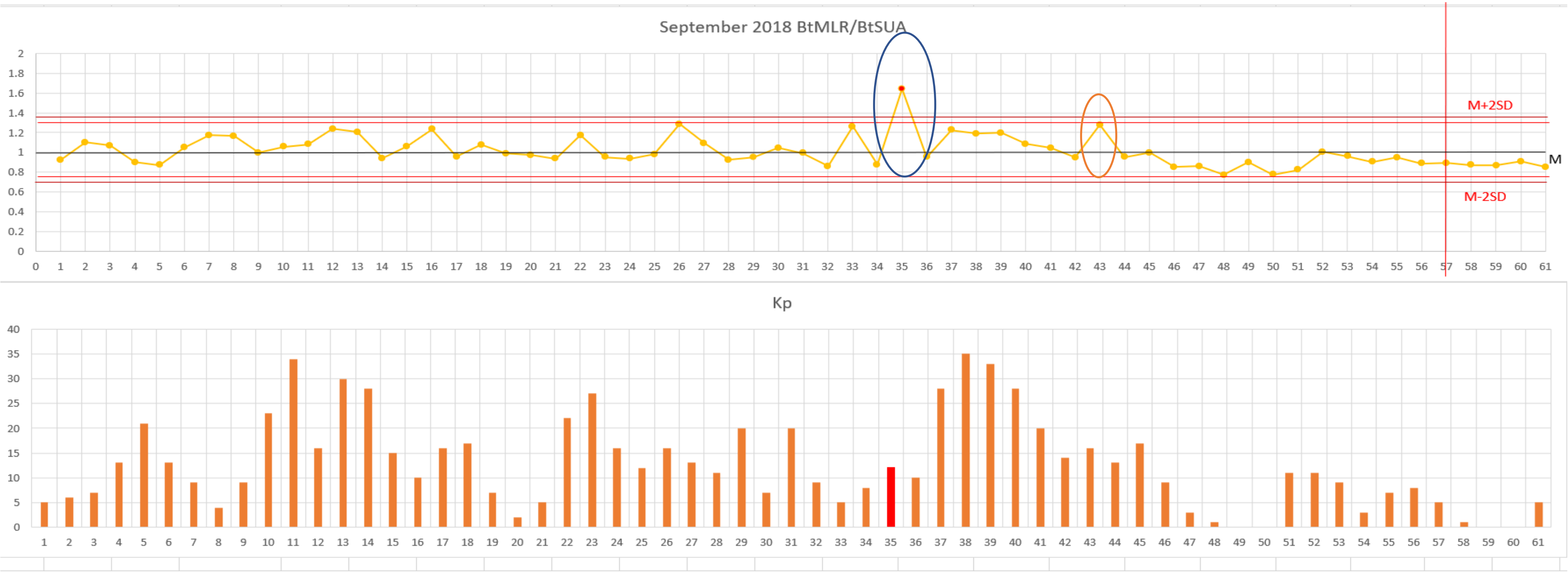


Figure 3b. Geomagnetic data processing – diurnal variation on total field and the Kp for September – October 2018 (Eq 5) - ONE visible anomaly

5. Geomagnetic data processing – time diagrams

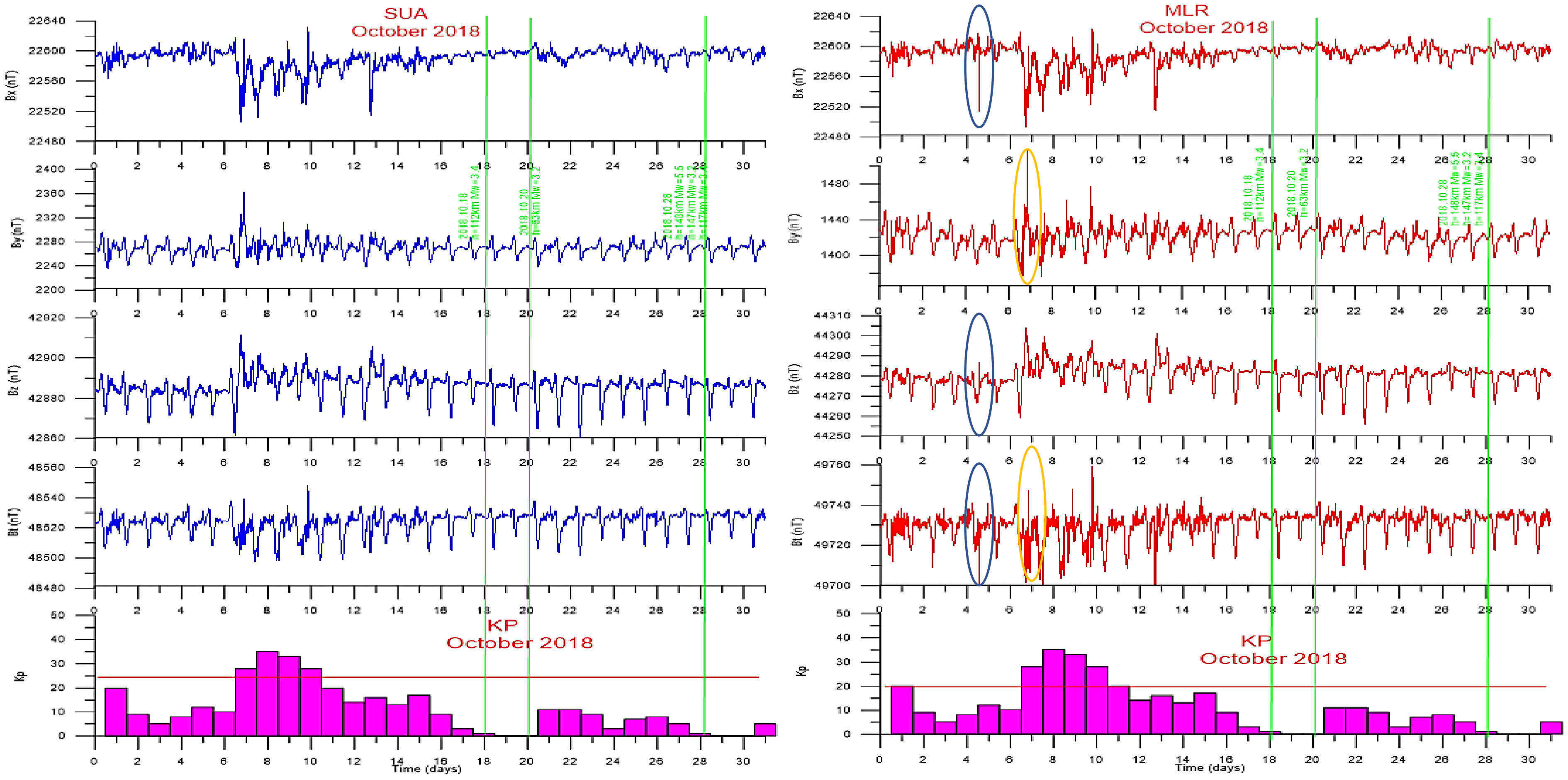


Figure 4. Time diagram - geomagnetic raw data processing October 2018 for identification of the origin of the anomalies – blue elipse for anomaly 1 and orange for anomaly 2 (Eq 5)

5. Geomagnetic data processing – time diagrams

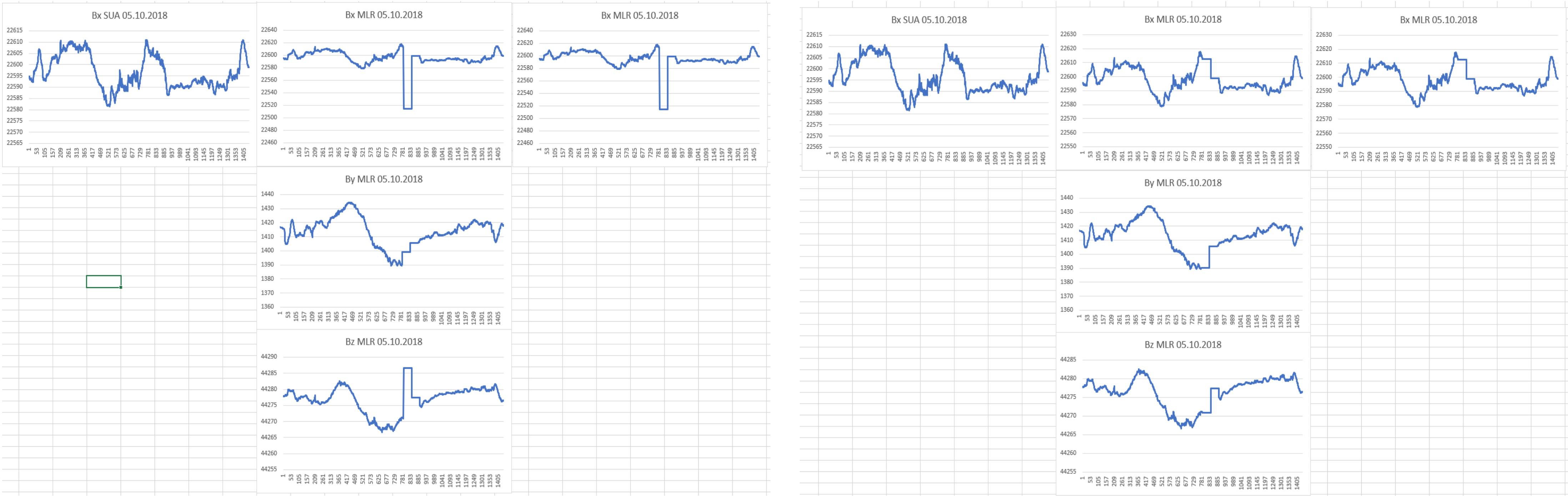


Figure 5. Geomagnetic data processing for the day when the anomaly was observed - 5th October 2018

6. Conclusions

The main purpose of this study was to correlate the anomalies in the magnetic field, recorded at MLR and SUA observatories and represented as one months time diagrams and diurnal variation, with Vrancea (ML>5.0) intermediate depth seismicity occurred in the last 5 years. The six moderate size intermediate earthquakes that occurred in this interval provided an opportunity to investigate the link between the seismicity and the presence of magnetic anomalies.

Using **the simple visualization method** for data processing we have observed that most of the anomalies appeared on the By component from MLR and the degree of By component drop is directly proportional with the released seismic energy. Large drops on By components can be followed by medium size earthquakes but also small and short anomalies can be followed by a significant events.

Using **the diurnal variation method** for data processing, we found out that the method is useful both to detect up coming seismic events, and also odd data on past magnetic records.

Although the diurnal variation ratio method did show perceivable fluctuations before moderate sized earthquakes, we cannot consider them as a precursor until we will perform studies on all geomagnetic data to give a statistical significance to the results .

Un**fortunately** during the geomagnetic monitoring period , the largest Vrancea earthquake was 6.0 in 2004, so the detectability of anomalies is relatively low and the area where the anomalies could appear is very small.

Future studies which utilize more seismic events and also the entire geomagnetic database need to be conducted to reach a better conclusion.

The results of this paper could be used as a benchmark for the future anomalies, and the future anomalies will reshape these results.

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THANK YOU!

HOPING AGAIN TO SEE YOU ALL NEXT YEAR (2023) IN VIENNA!