Type of the Paper (Article)

Possible Correlations Between the ULF Geomagnetic Signature and Mw6.4 Coastal Earthquake, Albania, on 26 November 2019

Dragoș Armand Stănică[1*] and Dumitru Stănică[2*]

[1,2,] Department of Electromagnetism and Lithosphere Dynamics, Institute of Geodynamics of the Romanian Academy, R-020032 Bucharest, Romania;

* Correspondance: (1) armand@geodin.ro ; (2) dstanica@geodin.ro
Tel.: +40-0788-419-041(D.A.S); +40-0788-825-5522 (D.S)

Abstract: An earthquake of Mw6.4 hit the coastal zone of Albania on 26 November 2019, at 02:54:11 UTC. It was intensively felt at about 34km far away, in Tirana City, where damages and lives lost occurred. To emphasize a geomagnetic signature before the onset of this earthquake, the data collected on the interval 15 October–30 November 2019, at the Panagjurishte (PAG)-Bulgaria and Surlari (SUA)-Romania observatories are analyzed by using both the polarization parameter (BPOL)-time invariant in non-seismic conditions, becoming unstable before this seismic event, and the strain effect for geomagnetic signal identification. Consequently, BPOL time series and its standard deviations are performed for the both sites using ULF-FFT band-pass filtering. A statistical analysis, based on a standardized random variable equation, was applied to emphasize on the BPOL*(PAG) and ABS BPOL*(PAG) time series the anomalous signal's singularity and, to differentiate the transient local anomalies due to Mw6.4earthquake, from the internal and external parts of the geomagnetic field, taken PAG observatory as reference. Finally, the ABS BPOL*(PAG-SUA) time series are obtained on the interval 1-30 November, 2019, where a geomagnetic signature greater than 2.0, was detected on 23 November and the lead time was 3 days before the onset of Mw6.4earthquake.

Keywords: ULF geomagnetic signature; Mw6.4 earthquake; (PAG)-Bulgaria and Surlari (SUA)-Romania geomagnetic data; BPOL, BPOL*and BPOL*(PAG-SUA) time series.

1. Introduction

The results carried out using ground-based geomagnetic data and ionospheric perturbations, associated with the catastrophic earthquakes Mw9.0 Tohoku, Japan on March 2011, Mw8.3 Coquimbo, Chile on September 2015 and Mw8.1Chiapas-Mexico, on September 2017 and the Vrancea seismicity, Romania, give useful information to elaborate a specific methodology able to emphasize possible inter-relations between the pre-seismic ULF anomalous geomagnetic signature and the above mentioned earthquakes [1-10], taking into account the following three possible earthquake generation mechanisms [11]: a) Piezomagnetic effect, based on the idea that a secondary magnetic field is induced by changes in ferromagnetic rocks magnetization, due to the applied stress [12]; b) Magneto-hydrodynamic effect, which supposes that the conducting fluid flow, in the presence of a magnetic field, generates a secondary induced component [13]; c) Electrokinetic effect that results from the flow of electric currents in the earth, in the presence of an electrified interface at solid-liquid boundaries [14,15]. As regards the Mw 6.4 earthquake analysis, the following previously contributions at the EGU2020 "Sharing Geosphere Online" are briefly presented further on: A multi parameters analysis of satellite and ground based data (satellite thermal anomalies, atmospheric chemical potential, radon level variation and VHF propagation in lower atmosphere) which revealed a transient phenomenon in the atmosphere before the earthquake [16]; A statistical analysis for the identification of precursory signatures of Mw6.4 earthquake occurrence in Total Electron Content was presented in [17]; Lower Ionospheric turbulence variations during the intense seismic activity of the last half of 2019 in broader Balkan region, including Mw 6.4 earthquake have been done by [18]; Variations revealed by INFREP Radio Network in correspondence of six earthquakes with Mw greater than 5.0 occurred in the Balkan Peninsula and Adriatic Sea on 26 and 27 November 2019 are analyzed in [19]; Investigation of pre-earthquake ionospheric anomalies before Albania 2019 earthquake using the Romanian receivers of the VLF/LF Infrep and Gnss Global European Networks is presented in [20] and Satellite thermal monitoring of Balkan region by means of Robust Satellite Technique-TIR anomalies in the framework a multi-parametric system are emphasized in [21]. All this information enlarges our knowledge about the origin of the different pre-seismic signals associated with the above-mentioned catastrophic earthquakes and, subsequently, in this study, the data collected from the two geomagnetic observatories Panagjurishte (PAG), Bulgaria and Surlari (SUA), Romania are analyzed in correlation with Mw6.4 earthquake. Further on, to differentiate a pre-seismic anomalous signal associated with this earthquake, by the internal and external parts of geomagnetic field, a statistical analysis based on the standardized random variable equation, taken observatory PAG as reference, was applied. Finally, it is to mention that an anomalous interval, having an apex on 23 November, 2019 on the all following time series of BPOL(PAG), BPOL*(PAG), ABS BPOL*(PAG) and ABS BPOL*(PAG-SUA) was identified, with three days before the earthquake occurrence on 26 November, 2019.

2. Methodology, Data Collection, Processing and Analyzing

A major earthquake of Mw6.4, which was generated at about 10km depth, hit the coastal zone of Albania on 26 November, 2019 at 02:54:11 UTC, as it was determined by the Euro Mediterranean Seismic Centre (http://www.emsc-csem.org). The main shock was felt in Montenegro, Italy and Greece (Corfu Island), and it has been followed by more than hundred after-shocks, from which 22 with magnitudes larger than Mw4.0 and 4 with Mw ≥ 5.0. Both the earthquake epicenter and hypocenter were located near the coastal zone of Albania, at about 30km distance from the capital city Tirana (Figure 1) and, respectively, on the Adriatic plate subduction zone [22], (Figure 2).

Figure 1. The placements of the Mw6.4 earthquake (red full circle), the geomagnetic observatories Panagjurishte (PAG), Bulgaria and Surlari (SUA), Romania (blue marks) on the Euro Mediterranean Seismic Centre (EMSC) map.

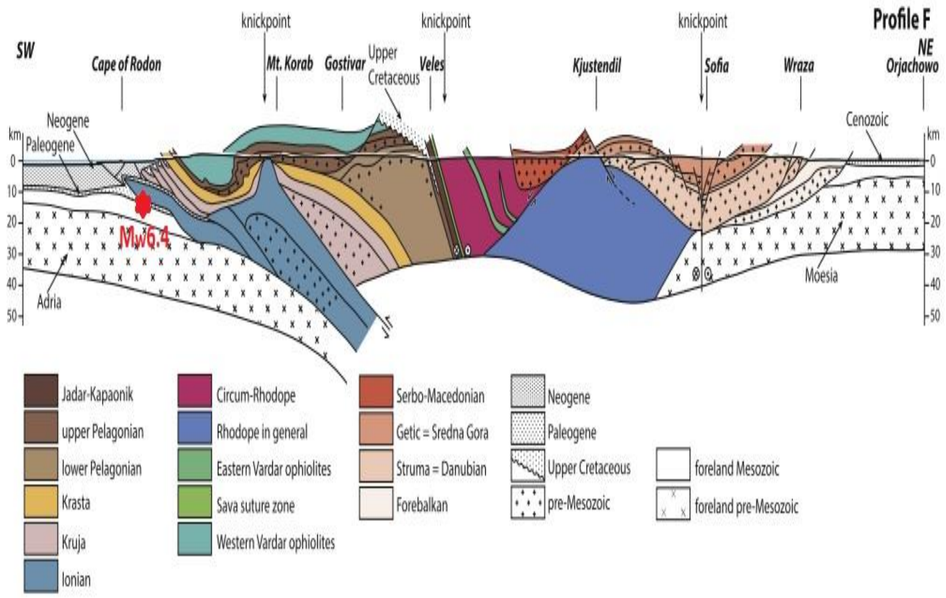

Figure 2. Geotectonic cross-section emphasizing the Mw6.4 earthquake location (red star) on the Adria plate subduction zone, Profile F in [22].

2.1. Basic theoretical concepts

To identify pre-seismic geomagnetic signature associated with Mw6.4 earthquake, in this paper, the geomagnetic data were collected, on the interval 15 October–30 November, 2019, via internet (http://www.intermagnet.org), from the geomagnetic observatories Panagjurishte (PAG), Bulgaria and Surlari (SUA), Romania, and the following relations were used:

a) Polarization parameter (BPOL) expressed as:

$$BPOL(f)=Bz(f)/SQRT(Bx^2(f)+By^2(f), \qquad (1)$$

where Bx, By and Bz are horizontal and vertical components of the geomagnetic field in μT, f is frequency in Hz [23]. For a given 2D geoelectric structure the vertical magnetic component (Bz) is a totally secondary field being essentially produced by the horizontal magnetic components (Bx, By) and, consequently, BPOL is time invariant in non-seismic conditions that becomes unstable before the onset of the seismic event. Thus, in this 2-D particular case, **the insulator** (Tectonic units of the Alpine collision zone) - **conductor** (Adria Plate subduction boundary), Figure. 2, gives rise to an anomalous distribution of BPOL, orientated perpendicular to them, and has magnitude proportional to the intensities of the geoelectric current concentrations, due to the tectonic stress generated by the Mw6.4 earthquake;

b) The long-range effect of the strain related to the pre-seismic geomagnetic signals, for which it was used Relation (2), given in [24]

$$R(km) = 10^{0.5-0.27}, \qquad (2)$$

where R is epicentral distance and M is earthquake magnitude.

In conformity with Relation (2), the range effect of the strain-related to the Mw6.4 earthquake may be felt at R ≈ 800 km, as in this particular case, where the distances between the earthquake epicenter and the both geomagnetic observatories are about 450km for PAG and 750km for SUA, there are conditions to identify a pre-seismic geomagnetic signature, taken PAG observatory as reference.

Further on, the daily mean distributions of the following parameters BPOL(PAG), BPOL(SUA) with standard deviations (SD), BPOL*(PAG), ABS BPOL*(PAG) and BPOL*(PAG-SUA) are obtained by using the following procedures:

1. FFT Band-pass filtering analysis (FFT-BPF) in the ULF frequency range (1E-3 – 0.0083 Hz) has been performed for two successive time windows of 1024 samples, with 40% overlapping, on the entirely BPOL time series of 1440 data points acquired every day, in the both observatories (PAG and SUA), and un example for PAG is presented in Figure 3.

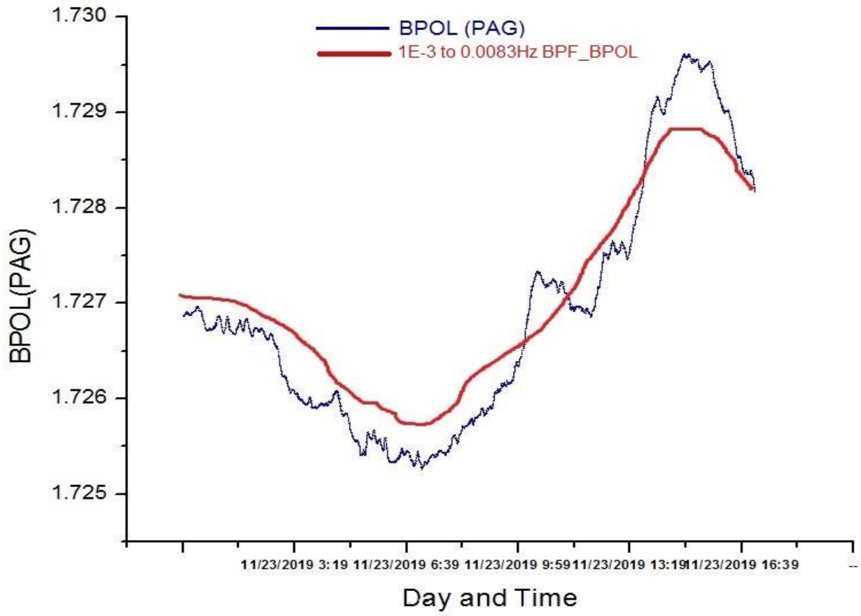

Figure 3. FFT (fast Fourier transform) Band-pas filtering (red line) applied on BPOL (PAG) (geomagnetic polarization parameter) distribution for a time windows of 1024 samples (Δt=60s), recorded on 23 November 2019.

2. Statistical analysis based on the standardized random variable equation (3) was applied for two particular cases:
   - to assess the singularity of the pre-seismic anomalous signal, related to the Mw6.4 earthquake, observed on the daily mean distributions of the BPOL* (PAG) and BOPL* (SUA), by using following relation:

$$\mathbf{POL^*} = (\mathbf{X} - \mathbf{Y})/\mathbf{W}, \qquad (3)$$

where

- **X** is the value of the of BPOL for a particular day, starting with 1 November, 2019 and ending on 30 November, 2019;
- **Y** is 15 days running average of BPOL obtained for 30 consecutive days before a particular day;
- **W** is 15 days running average of SD obtained for 30 consecutive days before a particular day;
- **BPOL*** emphasizes the threshold for anomaly using SD;

   - to differentiate the transient local anomalies associated with Mw6.4 earthquake by the internal and external parts of the geomagnetic field, taking the Geomagnetic Observatory (PAG) as reference, we used the following relation:

$$\mathbf{BPOL^*(PAG\text{-}SUA)} = (\mathbf{A} - \mathbf{B})/\mathbf{C}, \quad (4)$$

where

- **A** is the value of the (BPOL PAG-BPOL SUA) for a particular day, starting with 1 November and ending on 30 November 2019;
- **B** is 15 days running average of (BPOL PAG-BPOL SUA) obtained for 30 consecutive days before a particular day;
- **C** is 15 days running average of (SD PAG-SD SUA) obtained for 30 consecutive days before the particular day;
- **BPOL*(PAG-SUA)** time series emphasizing the threshold for anomaly using SD.

3. Results

In this paper, the pre-seismic anomalous geomagnetic signature is postulated to be generated by the electrical conductivity changes, the most probably associated with the earthquake - induced tectonic stress, followed by rupture and electrochemical processes deployed along the Adria Plate subduction zone (Figure 2)**.** Based on relations (1), (3), (4), in the next three sections (3.1, 3.2, 3.3), the pre-seismic geomagnetic signatures related to Mw6.4 earthquake are presented.

3.1. BPOL(PAG) and BPOL(SUA) time series Carried Out Using Relation (1)

To have a comprehensive view regarding the applied methodology, the daily mean distributions of the BPOL (PAG) and BPOL(SUA) related to the major Mw6.4earthquake are presented in Figures 4 and 5.

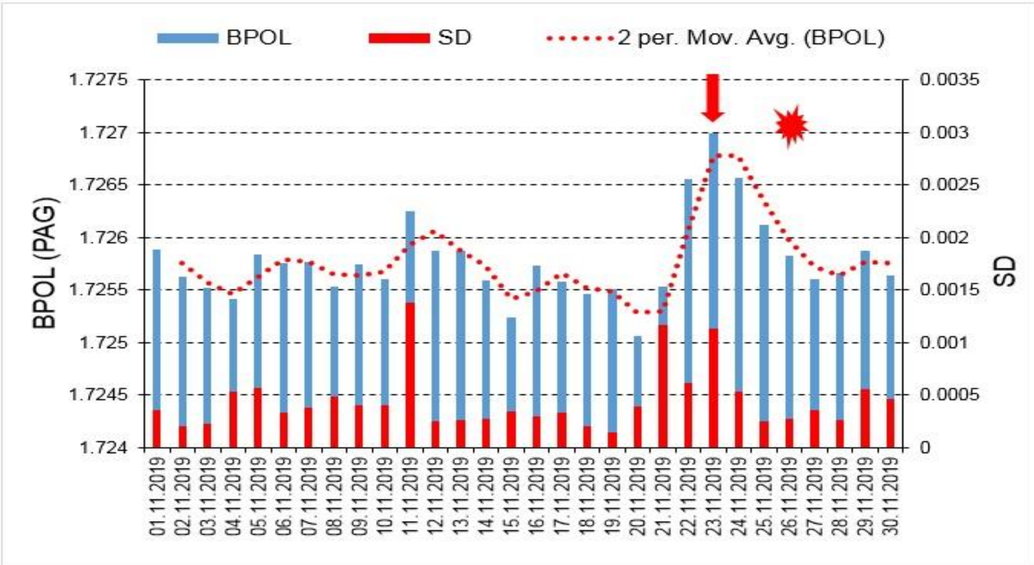

Figure 4. Daily mean distributions of the BPOL (PAG) and SD carried out on the interval 1–30 November 2019; vertical red arrow indicates a pre-seismic anomalous signature on 23 November, 2019; red star is Mw6.4 earthquake; red dotted line is two days averaged distribution of BPOL.

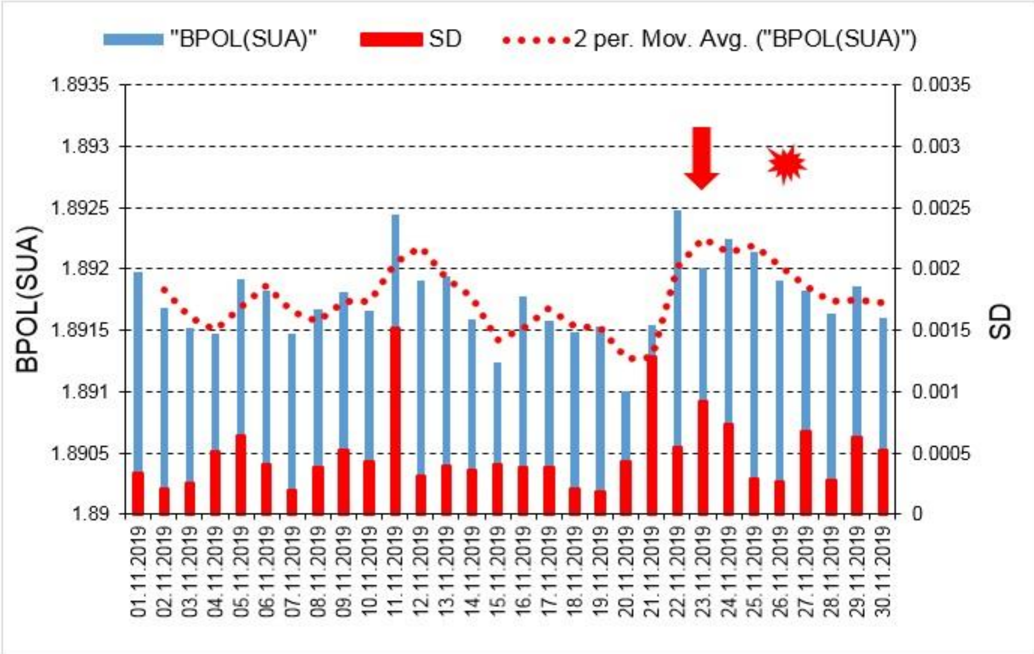

Figure 5. Daily mean distributions of the BPOL (SUA) and SD carried out on the interval 1–30 November 2019; vertical red arrow indicates a pre-seismic anomalous signature on 23 November, 2019; red star is Mw6.4 earthquake; red dotted line is two days averaged distribution of BPOL.

3.2. *BPOL*(PAG) and ABS BPOL*(PAG) Time Series Carried Out Using Relations (3)*

To assess the singularity of the pre-seismic anomalous signal, related to the Mw6.4 earthquake, the daily mean distributions of the BPOL* (PAG), ABS BOPL*(PAG) are presented in Figures. 6 and 7.

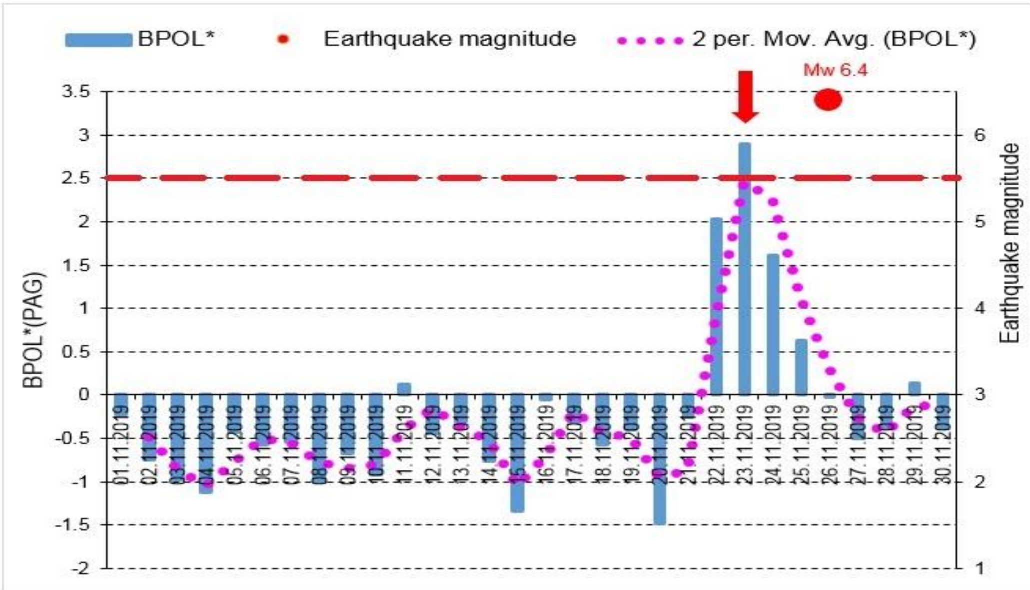

Figure 6. BPOL* (PAG) time series carried out on the interval 1 – 30 November 2019; vertical red arrow indicates a pre-seismic anomalous signature on 23 November, 2019; red full circle is Mw6.4 earthquake; dotted pink line is two days averaged distribution of BPOL*; red dashed line is threshold for anomaly using SD.

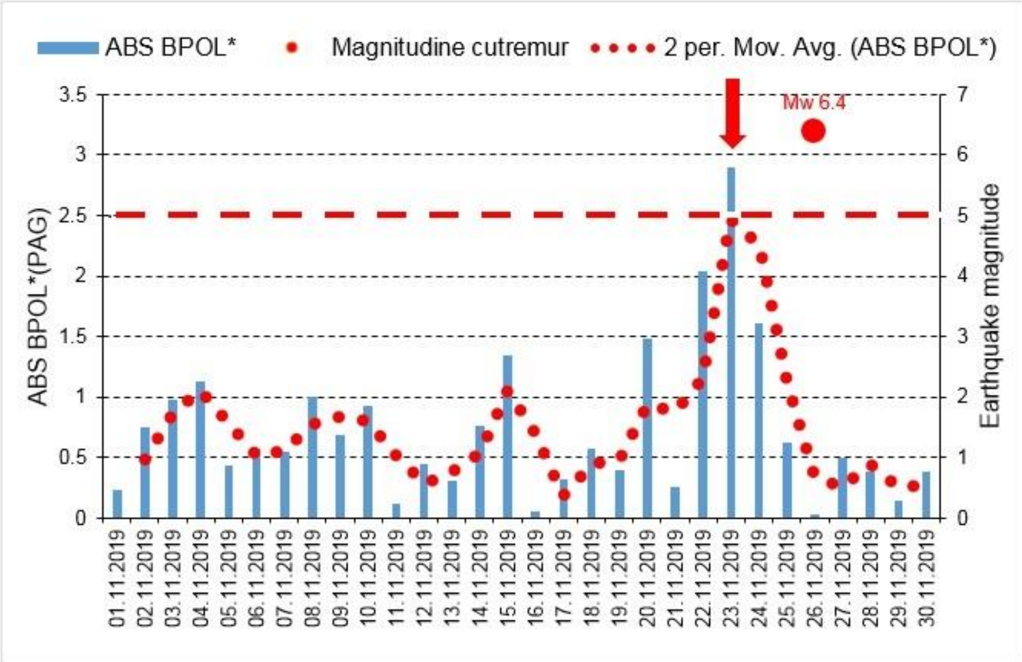

Figure 7. ABS BPOL* (PAG) time series carried out on the interval 1 – 30 November 2019, vertical red arrow indicates a pre-seismic anomalous signature on 23 November, 2019; red full circle is Mw6.4 earthquake; dotted red line is two days averaged distribution of BPOL*; ABS is absolute value; red dashed line is threshold for anomaly using SD.

3.3. BPOL (PAG – SUA) Time Series Carried Out Using Relation (4).*

Finally, the BPOL*(PAG – SUA) time series, carried out on the interval 1 – 30 November 2019, are presented in Figure 8, the geomagnetic observatory (PAG) was taken as reference.

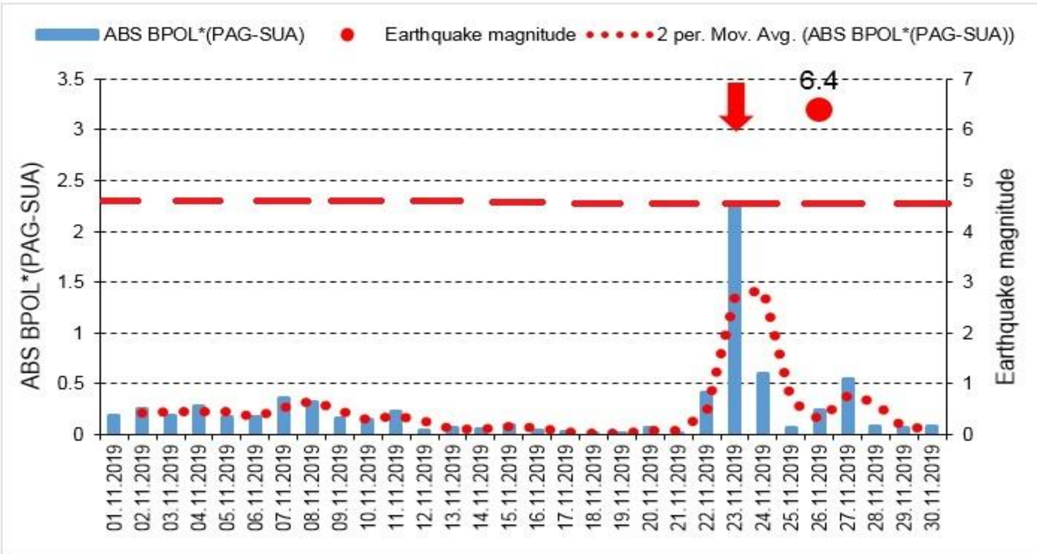

Figure 8. ABS BPOL*(PAG – SUA) time series carried out on the interval 1 – 30 November 2019, vertical red arrow indicates a pre-seismic anomalous signature on 23 November, 2019; red full circle is Mw6.4 earthquake; red dotted line is two days averaged distribution of BPOL*(PAG-SUA); red dashed line is threshold for anomaly using SD.

4. Discussion and Conclusion

With the aim to identify possible correlation between the pre-seismic geomagnetic signature and the coastal Mw6.4 earthquake, in this paper we have investigated the geomagnetic data recorded, on the interval 15 October- 30 November, 2019, at the Panagjurishte (PAG), Bulgaria and Surlari (SUA), Romania, the first one taken as reference, and the following results are inferred as:

- Daily mean distribution of the BPOL(PAG) and BPOL (SUA), obtained on the interval 1-30 November using (Relation 1), emphasizes two pre-seismic anomalous signatures, extended on the intervals 21 - 27 November for PAG and 21 - 28 November for SUA, on which two maximum amplitudes where identified on 23 November (1.727 for PAG and 1.892 for SUA), with 3 days before the occurrence of Mw6.4earthquake. These results are presented in Section 3.1, Figures 4 and 5;

- A precursory signature associated to the above-mentioned earthquake was identified on the BPOL* (PAG) and ABS BPOL*(PAG) time series carried out on the interval 1-30 November, using a statistical analysis based on Relation 3, and the results are emphasized in Section 3.2, Figures 6 and 7. On the both BPOL*(PAG) and ABS BPOL*(PAG) time series an anomalous interval, extended between 22 and 24 November, with a maximum value of 2,5 (Figures 6 and 7), was identified with 3 days before the Mw6.4 earthquake occurrence.

To differentiate the transient local anomalies related to Mw6.4 earthquake, by the internal and external parts of the geomagnetic field, we applied Relation 4 to obtain, on the interval 1 – 30 November the ABS BPOL* (PAG - SUA) time series, the geomagnetic observatory (PAG) taken as reference. The result related to the pre-seismic geomagnetic signature, summarized in Section 3.3 and Figure 8, consists in a very clear anomaly of maximum extended on 22-24 November, having an apex of about 2,274 on 23 November, identified on the BPOL*(PAG-SUA) time series, with 3 days prior to the onset of the M6.4 earthquake, so as it was indicated by threshold for anomaly (red dashed line).

In conclusion, the above-mentioned results offer opportunities to develop geomagnetic methodologies for the earlier detection of specific pre-seismic anomalies related to the major earthquakes. Consequently, any a priory information related to a major seismic event occurrence, transmitted in time to the authorities responsible in this domain, represents an useful contribution for prevention, management and decrease of the catastrophic risks.

Author Contributions: Conceptualization, D.A.S.; methodology, D.A.S.; software, D.A.S.; validation, D.A.S., and D.S; writing—original draft preparation, D.A.S.; writing—review and editing, D.A.S. and D.S. Both authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: In this paper, we used the data collected at the Geomagnetic Observatories located in Panagjurishte (PAG), Bulgaria and Surlari (SUA), Romania. We would like to thank the national institutes that support them and INTERMAGNET for promoting high standards of magnetic observatory practice (http://www.intermagnet.org).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hayakawa, M.; Hobara, Y.; Yasuda, Y.; Yamaguchi, H.; Ohta, K., Izutsu, J.; Nakamura, T. Possible precursor to the March 11, 2011, Japan Earthquake: ionospheric perturbations as seen by subionospheric very low frequency/low frequency propagation. *Ann. Geophys.* **2012**, 55 (1), 95-99. http://dx.doi.org/10.4401/ag-5357
2. Nagao, T.; Orihara, Y.; Kamogawa, M. Precursory phenomena possibly related to the 2011 M9.0 off the Pacific coast of Tohoku earthquake. *J. Disaster Res.* **2014**, 9, 303-3010.
3. Ouzounov, D.; Pulinets, S.; Romanov, K.; Tsybulya, D.; Kafatos, M.; Taylor, P. Atmosphere-ionosphere response to the M9 Tohoku earthquake revealed by multi-instrument space-borne and ground observations: preliminary results. *Earthquake Sci.* **2011**, 24, 557-564.
4. Sarlis, N.; Skordas, E.; Varotsos, P.; Nagao, T; Kamogawa, M.; Tanaka, H.; Uyeda, S. Minimum of the order parameter fluctuations of seismicity before major earthquake in Japan. *Proc. Natl. Acad. Sci. USA*. **2013**, 110, 13734-13738. http://dxdoi.org./10.1073/pnas.1312740110.
5. Hayakawa, M.; Schekotev, A.; Potirakis, S., Eftaxias, K. Criticality features in ULF magnetic field prior to the 2011 Tohoku earthquake, *Proceedings of the Japan Academy, Series B*, **2015**, 91, 1, 25-30, https://doi.org/10.2183/pjab.91.25
6. Stanica, D. A.; Stanica, D.; Vladimirescu, N. Long-range anomalous electromagnetic effect related to M9 Great Tohoku earthquake, *Earth Sciences.* **2015**, 4(1), 31-38 http://www.sciencepublishinggroup.com/j/earth.
7. Stanica, D. A.; Stanica, D.; Blecki, J.; Ernst, T.; Jozwiak, W.; Slominski, J. Pre-seismic geomagnetic and ionosphere signatures related to the Mw5.7 earthquake occurred in Vrancea zone on September 24, 2016, *Acta Geophys.* **2018**, 66, 167-177, https://doi.org/10.1007/s11600-018-0115-4.
8. Stanica, D. A.; Stanica, D. ULF pre-seismic geomagnetic anomalous signal related to Mw8.1 offshore Chiapas earthquake, Mexico on September 8, 2017, *Entropy.* **2019**, 21, 29, 1-11, https://doi.org/10.3390/e201010029.
9. Stanica, D. A.; Stanica, D. Geomagnetic anomalous signal associated with Mw8.3 Coquimbo-Chile earthquake on September 16-th, 2015. GEOSCIENCE 2019, Bucharest, Romania, November 22, *Romanian Society of Applied Geophysics Symposium*, https://appliedgeophysics.ro/geoscience -symposium-2019/
10. Stanica, D. A.; Stanica, D.; Valeca, M.; Iordache, Ș. Electromagnetic contribution to the resilience improvement against the Vrancea intermediate depth earthquakes, Romania, *Annales of Geophysics*, **2020**, 63, 5, PA551, 1-12, DOI: https://doi.org/10.4401/ag-8096.
11. Petraki, E.; Nikolopoulos, D.; Nomicos, C.; Stonham, J.; Cantzos, D.; Yannakopoulos, P.; Kottou, S. Electromagnetic pre-earthquake precursors: Mechanisms, data and models-a review. *J Earth Sci Clim Change.* **2015**, 6;1 doi:10.4172/2157-7617.1000250.
12. Fitterman, D. V. Electrokinetic and magnetic anomalies associated with dilatant regions in a layered Earth. *J. Geophys Res.* **1978**, 83, 5923-5928.
13. Sasai, Y. Tectonomagnetic modeling on the basis of the linear piezomagnetic effect. *Bull Earthquake Res Inst Tokyo*. **1991**, 66, 585-722.
14. Fitterman, D. V. Theory of electrokinetic-magnetic anomalies in a faulted half-space. *J. Geophys Res*. **1979**, 84, 6031-6040.
15. Varotsos, P.; Alexopoulos, K.; Nomicos, K.; Lazaridou, M. Earthquake prediction on electric signals, *Nature.* **1986**, 322: 120.
16. Ouzounov, D.; Pulinets, S.; Guiliani, G.; Velichkova-Istova, S.; Kafatos, M.; Taylor, P. Pre-earthquake processes associated with the M6.4 of Nov 26, 2017 in Albania. A multi parameters analysis, EGU General Assembly 2020, Online, 4–8 May 2020, https://doi.org/10.5194/egusphere-egu2020-6251.
17. Colonna, R.; Tramutoli, V.; Filizzola, C.; Genzano, N.; Lisi, M.; Pergola, N. Statistical analysis for the identification of precursory signatures of earthquake occurrence in Total Electron Content (TEC), EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-9800, https://doi.org/10.5194/egusphere-egu2020-9800.
18. Contadakis, M. E.; Arabelos, D.; Vergos, G.; Scordilis, E. M. Lower Ionospheric turbulence variations during the intense seismic activity of the last half of 2019 in the broader Balkan region., EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-1444, https://doi.org/10.5194/egusphere-egu2020-1444.

19. Biagi, P. F.; Nina, A.; Ermini, A.; Nico, G. Variations revealed by INFREP Radio Network in correspondence of six earthquakes with MW greater than 5.0 occurred in the Balkan Peninsula and Adriatic Sea on 26 and 27 November, 2019, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-9200, https://doi.org/10.5194/egusphere-egu2020-9200.
20. Moldovan, I. A.; Toader, V. E.; Oikonomou, C.; Haralambous, H.; Biagi, P. F.; Muntean, A.; Mihai, A.; Khadka, A. Investigation of pre-earthquake ionospheric anomalies before Albania 2019 earthquake using the Romanian receivers of the Vlf/Lf Infrep and Gnss Global European Networks, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-13952, https://doi.org/10.5194/egusphere-egu2020-13952.
21. Tramutoli, V.; Genzano, N.; Colonna, R.; Filizzola, C.; Lisi, M.; Pergola, N.; Satriano, V. Satellite thermal monitoring of Balkan region by means of Robust Satellite Techniques: the case of Albania (26 November 2019, Mw 6.4) earthquake, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-9068, https://doi.org/10.5194/egusphere-egu2020-9068.
22. Schmid, M. S.; Fügenschuh, B.; Kounov, A.; Matenco, L.; Nievergelt, P.; Oberhänsli, R.; Pleuger, J.; Schefer, S.; Schuster, R.; Tomljenović, B.; Ustaszewski, K.; Douwe J.J. van Hinsbergen. Tectonic units of the Alpine collision zone between Eastern Alps and western Turkey, *Elsevier, Gondwana Research*, 2020, 308-374 https://doi.org/10.1016/j.gr.2019.07.005
23. Hayakawa, M.; Kawate, R.; Molchanov, O.A.; Yumoto, K. Results of ultra-Low-frequency magnetic field measurements during the Guam earthquake of 8 August 1993. *Geophys. Res. Lett.* 1996, 23, 241–244.
24. Morgunov, V.; Malzev, S. A multiple fracture model of pre-seismic electromagnetic phenomena. *Tectonophysics* **2007**, 431, 61-72