Minería y Geología / v.38 n.1 / enero-marzo / 2022 / p. 1-11 ISSN 1993 8012

ARTÍCULO ORIGINAL

A possible theory connecting seismicity and geomagnetic field

Una posible teoría que relaciona sismicidad y campo geomagnético

Bladimir Moreno-Toirán[1]*

[1]Centro Nacional de Investigaciones Sismológicas, Cuba

*Autor para correspondencia: bladimir@cenais.cu

Abstract

A possible theory connecting geomagnetic field and earthquakes is presented. It was performed several hourly earthquakes distributions for different part of the world to explain, why bay-shape hourly distribution are clear for some areas, but not for others. In this sense, it was observed that earthquakes located in the intertropical zone reveal bay-shape earthquake distribution, but not defined shape is found for earthquakes outside the tropic. The answer is given based on geomagnetic flow orientation. The angle between the geomagnetic field direction and the Earth’s surface is almost parallel in the equator and orthogonal in the poles. Furthermore, considering the Laplace’s force law, the force experienced in the electrical conductor, in presence of magnetic field, is maximum when the angle between the magnetic flow direction and the electrical conductor is 90 degrees. Here, the electrical conductor is found on the global atmospheric electric circuit, where electrical current is flowing orthogonal to the Earth’s surface. The intertropical zone has angles between the geomagnetic flow vector and electric conductor more close to 90 degrees than middle latitudes and polar areas. The hourly earthquake distribution is modelled by the time-varying electrical potential in the global atmospheric electrical circuit, which is more significant in the intertropical zone. The effect of electricity on earthquakes is based on reverse piezoelectric phenomena.

Keywords: geomagnetic field; earthquake; electric circuit; global atmosphere; Earth´s conductivity response; earthquake hourly distribution.

Resumen

Se presenta una posible teoría que relaciona el campo geomagnético y los terremotos. Se realizaron varias distribuciones horarias de terremotos para diferentes partes del mundo para explicar por qué la distribución horaria en forma de bahía es clara para algunas zonas, pero no para otras. En este sentido, se observó que los terremotos ubicados en zonas intertropicales revelan una distribución horaria en forma de bahía, por el contrario esta forma de distribución no se observa para los terremotos fuera de los trópicos. La respuesta se plantea en función de la orientación del flujo magnético. El ángulo entre la dirección del campo magnético y la superficie de la Tierra es casi paralelo en el ecuador y ortogonal en los polos. Por consiguiente, considerando la ley de fuerza de Laplace, la fuerza experimentada en el conductor eléctrico, en presencia de campo magnético, es máxima cuando el ángulo entre la dirección del campo magnético y el conductor eléctrico es de 90^0. Aquí, el conductor eléctrico se encuentra en el circuito eléctrico atmosférico global, donde la corriente eléctrica fluye ortogonalmente a la superficie de la Tierra. Las zonas intertropicales tienen ángulos entre el vector de flujo magnético y el conductor eléctrico más cercanos a los 90^0 que las latitudes medias y las áreas polares. La distribución horaria de los terremotos está modelada por el potencial eléctrico con fluctuación temporal del circuito eléctrico atmosférico global, que es más significativo en las zonas intertropicales. El efecto de la electricidad sobre los terremotos se basa en el fenómeno piezoeléctrico inverso.

Palabras clave: campo geomagnético; terremotos; circuito eléctrico; atmósfera global; respuesta conductiva de la tierra; distribución de terremotos.

---

1. INTRODUCTION

The relationship between geomagnetic field and earthquakes has been a controversial topic for seismologist (Sorokin et al. 2020). Recent studies (Moreno and Calais 2021) found a significant correlation between high frequency variation of Earth's magnetic field and earthquakes in the Caribbean. They state that perturbation in the geomagnetic field, caused mainly by solar activity, induces an Eddy current into the Earth's interior trough the global atmospheric electric circuit, which could trigger earthquakes by reverse piezoelectric effect.

Based on similar idea, it has been shown correlation between proton density (Marchitelli et al. 2020) and geomagnetic Kp index (Urata et al. 2018) with large earthquakes worldwide. On the other hand, through satellite magnetic measurements and ground magnetic stations, an increase in seismicity has been found in areas of negative anomalies of the Earth's magnetic field (Lei et al. 2018).

Others studies have tried to demonstrate the occurrence of electromagnetic induction caused by the propagation of seismic waves when the movement of the particles, that propagates through the interior of the crust, alters the Earth's magnetic field, generating an electric current (Johnston 2002; Gao et al. 2014)

Bay-shape hourly earthquake distribution is common in seismic swarm zones or earthquakes aftershocks (Klein 1976) as well as in volcanic zones (Duma and Vilardo 1998), where the distribution normally includes a significant number of seismic events in a relatively small area. However, in other regions of the world, earthquakes have not any diurnal time preference, that is the hourly distribution is approximately flat. This study try to give a possible theory behind this issue based on the geomagnetic flow direction relative to Earth's surface.

2. MATERIALS AND METHODS

Worldwide earthquakes were selected with magnitudes greater than 4, between 1980 and 2020. The world was divided into two regions: the intertropical zone identified by the red color and the zone outside the tropics in blue. There are also four small areas identified by the letters ABCD which contain smaller earthquakes (Figure 1).

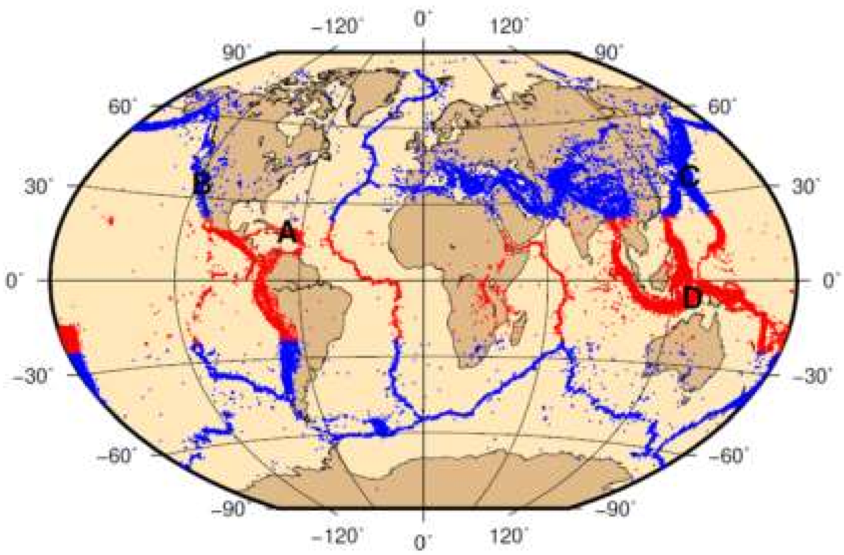

Figure 1. Earthquakes with magnitude greater than 4 from 1980 to 2020. Epicenters located in the intertropical zone are in red color and blue otherwise. Zones identified by letters ABCD include smaller earthquakes, with box-area approximately overlaid by the letter size.

The hourly earthquake distribution of the four areas identified in the previous map is shown in Figure 2. The areas A and D, located in the tropics, show a bay-shape distribution, while areas outside the tropics (B and C) show a flat distribution. Note that similar amount of earthquakes between flat and bay-shape distributions are used, which exclude significant statistic influence.

Figure 3, which includes only earthquakes with magnitudes greater than 4, also shows a bay-shape distribution from all intertropical earthquakes identified in red, while earthquakes outside the tropics identified in blue, does not have a defined shape, of course the origin time was set to local time. Here, a consistency in the bay-shape distribution is also observed when presenting different periods of time for earthquakes located in the intertropical zone, which exclude any anthropogenic source shaping the distribution and statistic influences. It is clear that some spatial-depended factor is modulating this distribution.

2.1. Magnetic field orientation and Earth's conductivity response

It is well known that the values of the horizontal component of magnetic field is higher at the equator and lower at the poles, while the absolute value of the vertical component is higher at the poles and lower at the equator. This indicates that the angle formed between the magnetic flow vector and the Earth's surface is nearly parallel at the equator and nearly orthogonal at the poles. This angle is shown in Figure 4 for each of the selected magnetic stations and it was computed from horizontal and vertical components of the magnetic field during 2020. The angle is negative in the south hemisphere because vertical component of the magnetic field is positive when magnetic flow point to Earth's surface and it is well known that magnetic flow come up from South Pole to North Pole.

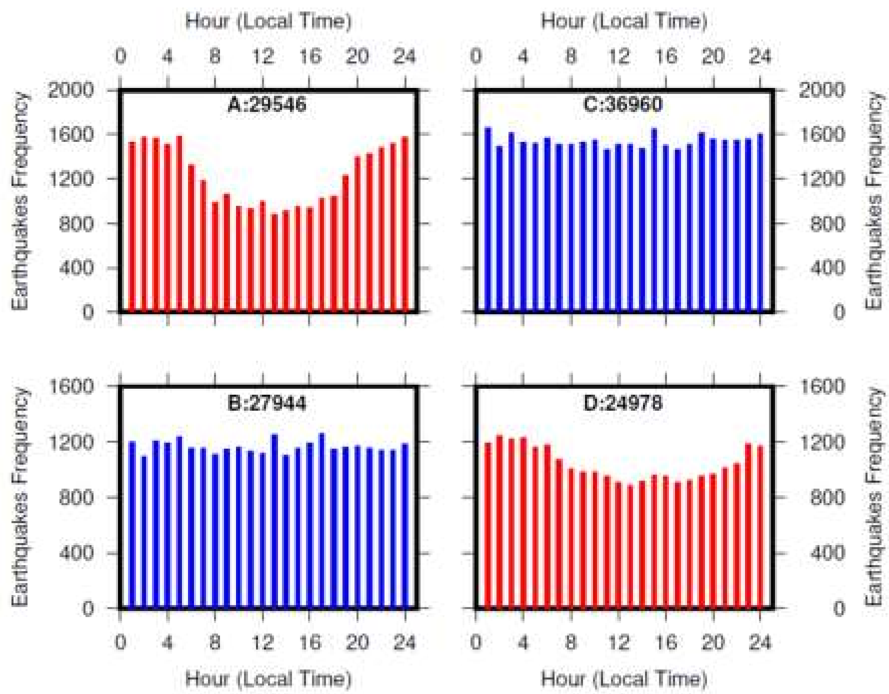

Figure 2. Hourly earthquake distribution for different small areas in the world. Red color identified earthquakes in tropical zones and blue color otherwise. Number of earthquakes in the distribution is shown in parenthesis.

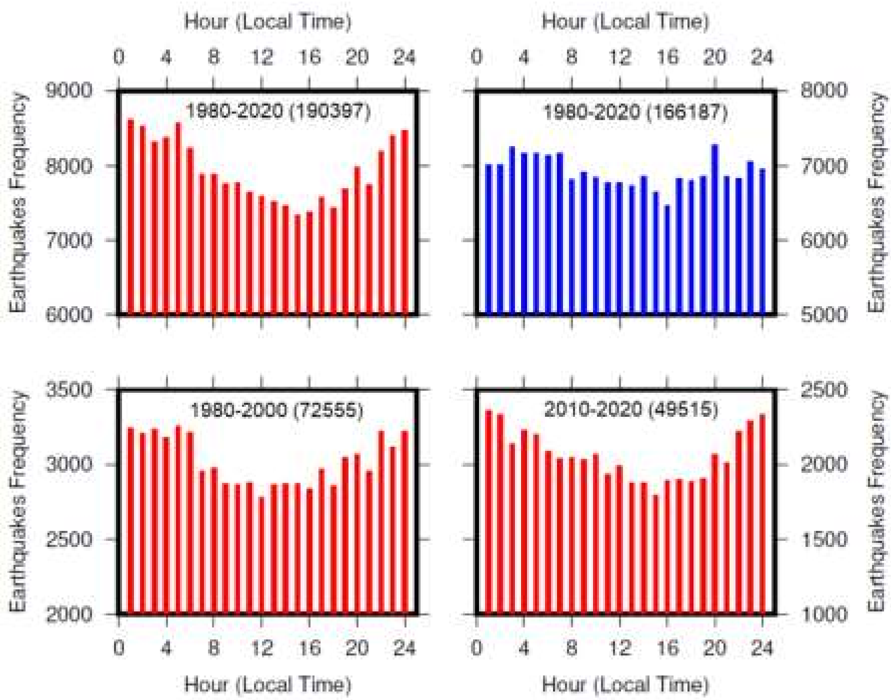

Figure 3. Hourly earthquake distribution for seismic events with magnitude bigger than 4 worldwide. Red color identified earthquakes in the intertropical zone and blue color otherwise. Different period are presented for tropical earthquakes distribution. Each graph shows in parenthesis the total number of earthquakes in the distribution.

Considering the correlation that exists between the diurnal time-varying conductive response of the Earth´s interior and earthquakes (Moreno and Calais, 2021), hourly distributions of this scalar were made for different magnetic stations worldwide. In this sense, it was applied the definition for conductivity response or C-response defined by Fujii and Schultz (2002), considering a 3D electromagnetic response of the Earth. In this case, the C-response for specific location at the Earth's surface is defined in eq. (1)

$$C(\omega) = \frac{R\tan(\theta)B_r(\omega)}{2B_\theta(\omega)} \quad (1)$$

where, B_r and B_θ are the radial and horizontal components of the geomagnetic field, respectively, R is the Earth's radius, θ is the co-latitude of the location and ω denotes the angular frequency. Equation (1) is expressed in frequency-domain, but it was applied on time-domain because the interest is focus to time-varying C-response. The values were calculated from the hourly magnetic field average during 2020. It can be observed in Figure 5, that the diurnal variation of the conductive response at each site located in the intertropical zone (red color) has a bay-shape distribution, while the conductive responses at sites outside the tropics do not have any defined shape, sometimes approximately flat. To understand the connection between the Earth's conductivity response and earthquakes, it is need to understand the foundation of the global atmospheric electric circuit formed between the ionosphere and the Earth's surface (Rycroft et al. 2000; Williams 2009).

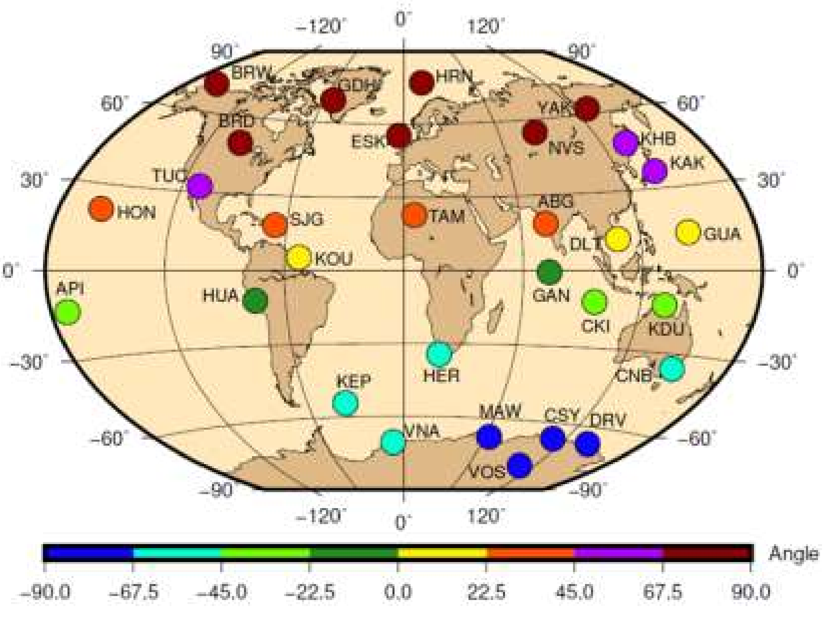

Figure 4. Angle between the magnetic flow vector and Earth's surface for ground-based magnetic stations in the world. It was computed from horizontal and vertical components of the magnetic field during 2020.

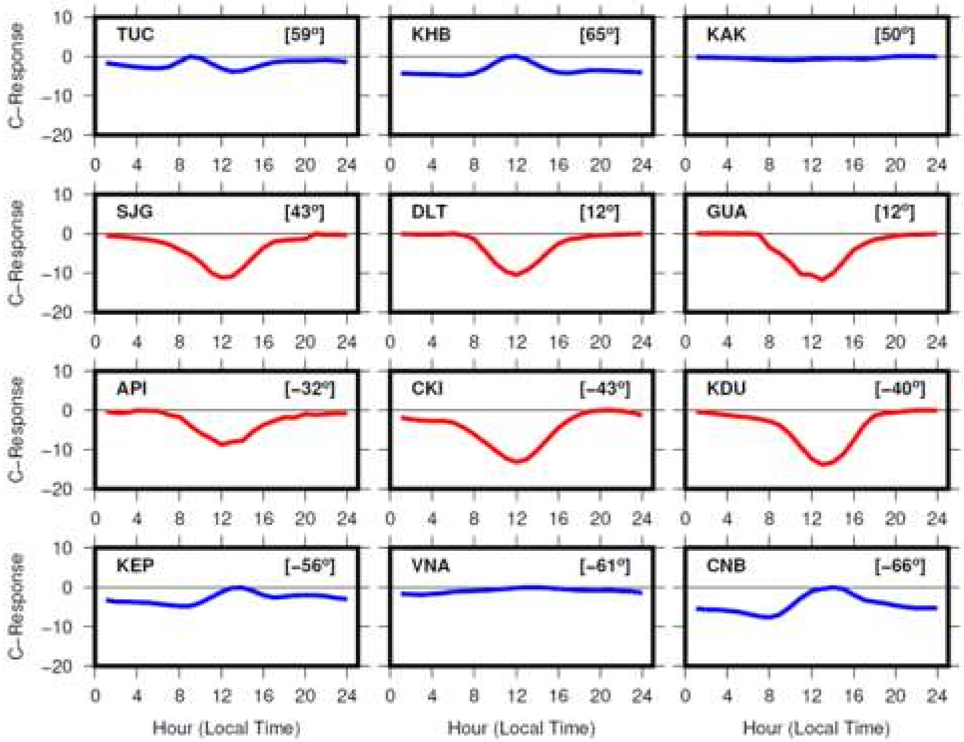

Figure 5**.** Diurnal variation of Earth's conductivity response (C-response) for different locations in the world computed from magnetic field data during 2020. Angles between magnetic flow vector and Earth's surface is shown in brackets. Curves in red color identified magnetic stations located in the intertropical zone. The scalar C is represented as the different from the maximum value.

2.2. Global atmospheric electric circuit

The atmosphere behaves like an electrical conductor because it is ionized by solar radiation. The atmospheric disturbance zones, with high activity of thunderstorms, act as a generator in the circuit, injecting electric current into the ionosphere, which then returns to the Earth's surface in fair weather zones (Figure 6). The upper atmosphere has a small electrical resistance than the lower one. In this sense, when the solar wind disturbs the geomagnetic field and injects charged particles or solar energetic particles (SEP) into the ionosphere, a variation in the electrical potential occurs within the global electric circuit, which has an electrical conductor orthogonal to the Earth's surface. Consequently, the force induced through the conductor is maximum if the angle between the magnetic flow and the electric conductor is 90 degrees, as can be seen in the definition of Laplace's force law shown in Figure 6.

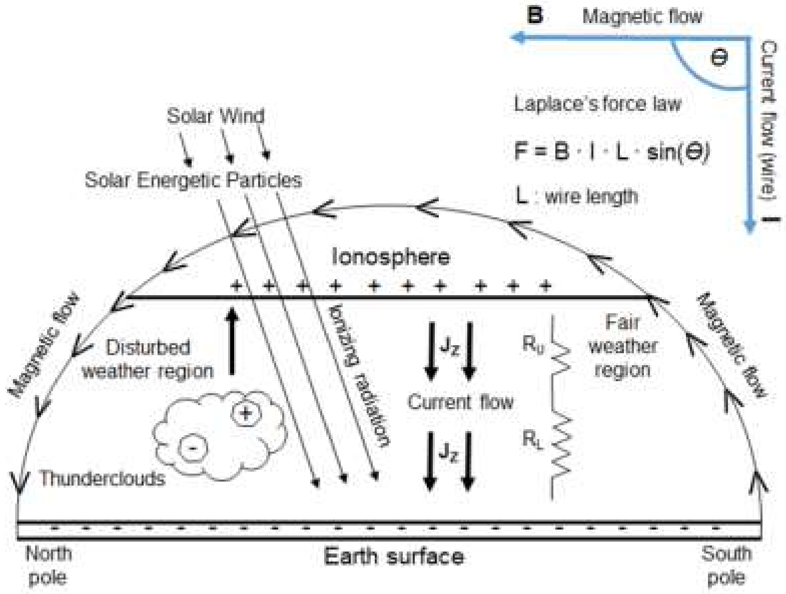

Figure 6. Global atmospheric electric circuit. J_z is the return current flow. R_U is the electrical resistance of the upper atmosphere and R_L the resistance of lower atmosphere. Upper right corner shows the Laplace's force law definition.

3. RESULTS AND DISCUSSION

The diurnal variation of the electrical potential in the atmosphere is much more significant in the intertropical zone because the angle formed between the geomagnetic flow and the atmospheric electric conductor is closer to 90^0. On the other hand, middle latitudes and polar zones decrease significantly the angle below 45^0, which could explain the effect observed in the hourly earthquake distribution for each of the studied areas. It is observed from Figure 4 that tropical zones show angles between geomagnetic flow and Earth's surface below 45 degrees, which means greater than 45 degrees for angles between the magnetic flow and the atmospheric conductor.

Furthermore, any diurnal variation in the atmospheric electrical potential will be more effective to change the electrical current flowing to the Earth's interior when compared to middle and polar latitudes. Consequently, tectonic faults that are considered good conductors of electricity, due to increased porosity and micro-fractures in rocks, experience an electrical current greater than what they are normally exposed to. This electric current can generate a reverse piezoelectric effect, exerting an elastic deformation in rocks (Moreno and Calais 2021; Marchitelli et al. 2020).

For example, it is known that a crystal, such as quartz crystal, becomes electrically charged if it is subjected to high pressures, which is call "piezoelectric effect", but it also oscillates or deforms when exposed to an electric current (Eccles et al. 2005), which is call "reverse piezoelectric effect”. From this, it can be suggested that depending on the piezoelectric properties of minerals in rocks, these can break if they exceed the critical elastic deformation. In this sense, we are not saying that for an earthquake to occur, the existence of reverse piezoelectric effect is necessary, but rather that, these phenomena can be considered a trigger mechanism of earthquakes. The earthquakes will always occur due to the constant deformations induced by the movement of the tectonic plates, but there are trigger factors that can advance them in time. Another important aspect to take into account is the amount of samples used to make an hourly earthquake distribution. For example, taking only earthquakes greater than magnitude 5, will not appear any bay-shape hourly distribution in the intertropical zone because the samples are not statistically significant.

4. CONCLUSION

Diurnal earthquakes distributions are modulated by time-varying electrical potential in the global atmospheric electric circuit. The hourly earthquake frequency describes a bay-shape distribution in the intertropical zone, meanwhile earthquakes outside the tropics did not show any defined shape. The factor making the different between zones is connected with the geomagnetic flow orientation. The intertropical zone has angles between the magnetic flow vector and the atmospheric electrical conductor more close to 90^0 than middle latitudes and polar zones, meaning a more significant time-varying electrical potential in the global atmospheric electric circuit. Areas with angles between the geomagnetic flow vector and Earth’s surface below 45^0 are more susceptible to show bay-shape hourly earthquake distribution based on Laplace’s force law. Reverse piezoelectric phenomena can be considered a trigger mechanism of earthquakes.

5. ACKNOWLEDGEMENTS

The author would like to thanks the Incorporated Research Institutions for Seismology (IRIS) and International Real-time Magnetic Observatory Network (INTERMAGNET) for the earthquakes and geomagnetic data, respectively.

6. REFERENCES

Duma, G. and Vilardo, G. 1998. Seismicity Cycles in the Mt. Vesuvius Area and their Relation to Solar Flux and the Variations of the Earth’s Magnetic Field. *Phys. Chem. Earth,* 23(9-10): 927-931. https://doi.org/10.1016/S0079-1946(98)00121-9

Eccles, D., Sammonds, P.R. and Clint, O.C. 2005. Laboratory studies of electrical potential during rock failure. *International Journal of Rock*

Mechanics & Mining Sciences, 42: 933-949. https://doi.org/10.1016/j.ijrmms.2005.05.018

Fujii, I. and Schultz, A. 2002. The 3D electromagnetic response of the Earth to ring current and auroral oval excitation. *Geophys. J. Int.*, 151: 689–709. https://doi.org/10.1046/j.1365-246X.2002.01775.x

Gao, Y., Chen, X., Hu, H., Wen, J., Tang, J. and Fang, G. 2014. Induced electromagnetic field by seismic waves in Earth´s magnetic field. *J. Geophys. Res. Solid Earth*, 119 :5651-5685. https://doi.org/10.1002/2014JB010962

Johnston, M.J.S. 2002. *Electromagnetic Fields Generated by Earthquakes*. In: Lee, W., Jennings, P., Kisslinger, C., Kanamori, H., (Eds.), International Handbook of Earthquake and Engineering Seismology Part A Vol. 81, Elsevier, San Diego, pp. 621-635. https://doi.org/10.1016/S0074-6142(02)80241-8

Klein, F.W. 1976. Earthquake Swarms and the Semidiurnal Solid Earth Tide. Geophys. *J. R. astr. Soc.*, 45: 245-295. https://doi.org/10.1111/j.1365-246X.1976.tb00326.x

Lei, Y., Jiao, L. and Chen, H. 2018. Possible correlation between the vertical component of lithospheric magnetic field and continental seismicity. *Earth, Planets and Space*, 70(179):1-19. https://doi.org/10.1186/s40623-018-0949-7

Marchitelli, V., Harabaglia, P., Troise, C. and De Natale, G. 2020. On the correlation between solar activity and large earthquake worldwide. Scientific Reports 10 (11495). https://doi.org/10.1038/s41598-020-67860-3

Moreno, B. and Calais, E. 2021. Evidence of correlation between high frequency geomagnetic variations and seismicity in the Caribbean. *Open Journal of Earthquake Research,* 10:30-41. https://doi.org/10.4236/ojer.2021.102003

Rycroft, M.J., Israelsson, S. and Price, C. 2000. The global atmospheric electric circuit, solar activity and climate change. *Journal of Atmospheric and Solar-Terrestrial Physics*, 62 (17-18):1563-1576. https://doi.org/10.1016/S1364-6826(00)00112-7

Sorokin, V.M., Chmyrev, V.M. and Hayakawa, M. 2020. A Review on Electrodynamic Influence of Atmospheric Processes to the Ionosphere. *Open Journal of Earthquake Research*, 9:113-141. https://doi.org/10.4236/ojer.2020.92008

Urata, N., Duma,G. and Freund, F. 2018. Geomagnetic Kp Index and Earthquakes. *Open Journal of Earthquake Research*, 7:39-52. https://doi.org/10.4236/ojer.2018.71003

Williams, E.R. 2009. The global electrical circuit: A review. *Atmospheric Research,* 91:140-152. http://dx.doi.org/10.1016/j.atmosres.2008.05.018

Información adicional

Conflicto de intereses

El autor declara que no existen conflictos de intereses.

ORCID

BMT, https://orcid.org/0000-0002-7830-5184

Recibido: 13/12/2021
Aceptado: 05/01/2022