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Pre-seismic phenomena that preceded the M7.0 earthquake recorded in Acapulco (Mexico) on September 8, 2021

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ABSTRACT

This study analyzes the strong earthquake, magnitude 7, that occurred near Acapulco, Mexico, on September 8, 2021. The earthquake, originating at a depth of about 20 km, waspreceded by a series of electromagnetic phenomena, detected by the Radio Emissions Project station in Rome and the international Radio DirectionFinding network. The electromagneticsignals were compared with the data collection, recordedsince 2008, and fallinto the typology of pre-seismic signals of potentially destructive earthquakes. The study is proposed both to add new data for the understanding of the mechanism of earthquakes and a crustal diagnosis and, in perspective, for a pre-earthquake alert function.

Keywords: Seismic Precursors, Mexico, Solar Activity, Spaceweater, Radio-anomaly.

1 – INTRODUCTION

Since 2008, researchers from the Radio Emissions Project have highlighted a series of electromagnetic signals that always seem to precede strong earthquakes, these studies were presented for the first time in 2013 [**1**] thanks to the use of the NASA INSPIRE VLF-3 radio receiver. Later, the group of researchers were able to build a series of radio receivers capable of detecting the Earth's geomagnetic variations that were able to detect the electromagnetic variations that seemed to precede the strong earthquakes [**2**] [**3**]. In 2014, these studies were able to observe a clear correlation between solar activity and the occurrence of earthquakes. The evidence was observed on the "near Earth" solar wind proton density variation [**4**]. The discoveries that took place in 2014 were able to provide greater information for understanding Earth's seismogenesis, in relation to solar activity, in which the group of researchers then continued to perform studies to understand its mechanisms [**5**] [**6**] [**7**] [**8**] [**9**] [**10**] [**11**] [**12**] [**13**] [**14**] [**15**] [**16**] [**17**] [**18**]. In 2017, researchers from the Radio Emissions Project started using an electromagnetic detection system based on RDF - Radio Direction Finding technology [**19**]. The studies carried out with this new technology, used for the first time in the field of research of geomagnetic seismic precursors, provided further important information on the mechanisms that seem to precede earthquakes, and in general provided azimuth indications capable of highlighting, through triangulation of the electromagnetic signals, the geographical area where an earthquake will then occur [**19**] [**20**] [**21**] [**22**] [**23**] [**24**] [**25**] [**26**] [**27**] [**28**] [**29**] [**30**] [**31**] [**32**] [**33**] [**34**]. The studies carried out with the RDF methodology have allowed us to understand that there are electromagnetic signals located at the hypocentral level, where energy from tectonic stress is concentrating, in the fault surface [**35**] [**36**] [**37**]. These studies were supported by working hypotheses put forward by the group of researchers starting from 2009.

In this case, the methodology used by the Radio Emissions Project exploits the study of solar activity and the precursors identified already in 2012 (Solar Seismic Precursors or SSPs; Interplanetary Seismic Precursors or ISPs; Seismic Geomagnetic Precursors or SGPs), following a long work of electromagnetic environmental monitoring achieved thanks to the electronic devices designed by the group of researchers [**1**] [**2**] [**3**] [**4**] [**5**]. To date, the methodology of the Radio Emissions Project sees the use of the study of solar activity and the monitoring of the Earth's geomagnetic field (through the RDF network), to obtain fundamental data for the identification of the future seismic hypocenter, on a global scale.

As regards this earthquake, which occurred in Mexico, in Acapulco, the monitoring data provided the same results. In the next chapters, the group of researchers will provide technical information on this monitoring work, in relation to the earthquake in question.

2 – METHOD AND DATA

As already mentioned, the methodology used by the researchers involved in this study considered the monitoring of solar activity and the Earth's geomagnetic activity, in relation to the temporal data of the M7.0 Mexican earthquake recorded on September 8, 2021 at 01:47:47 UTC, and at a depth of 20 km. The purpose of this type of monitoring was to track down electromagnetic anomalies related to the destructive seismic event.

2.1 – ELECTROMAGNETIC DATA

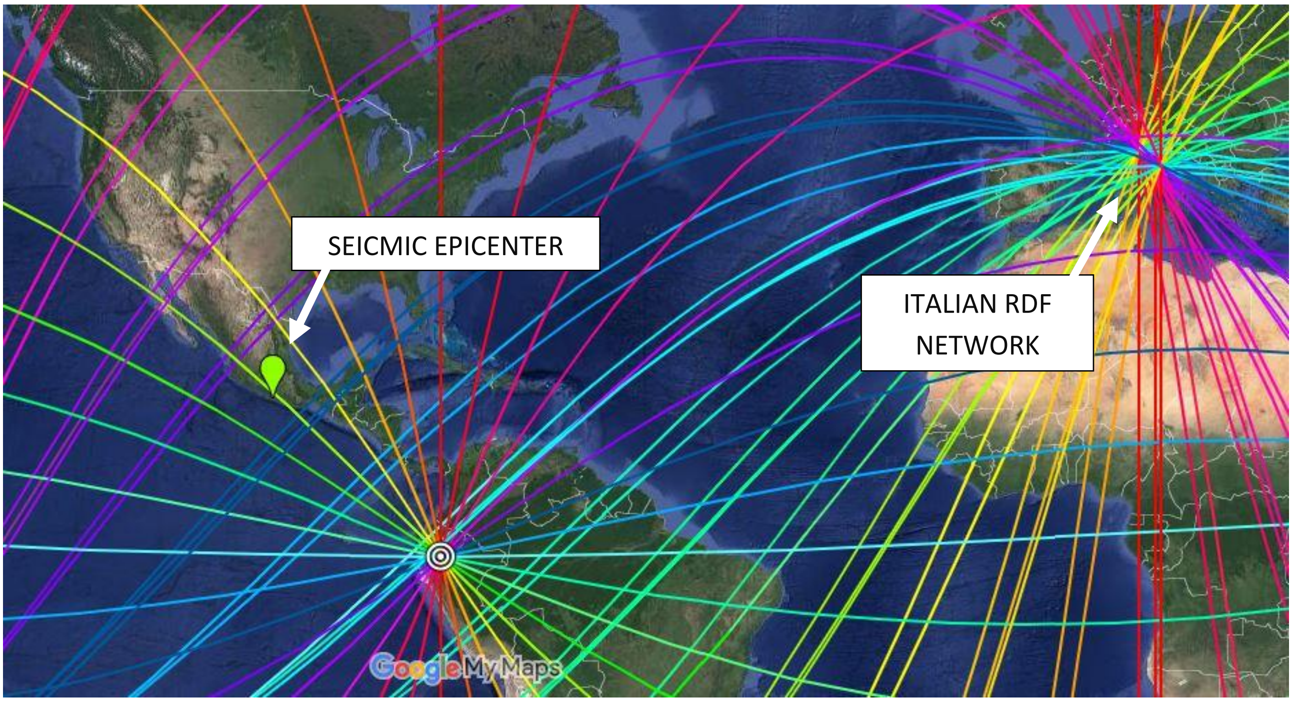

Fig. 1 - World map of the RDF network developed by the Radio Emissions Project. **The image above highlights the position of the seismic epicenter of the M7.0 earthquake that occurred in Mexico on September 8, 2021. Credits: Radio Emissions Project, USGS.**

The first interesting indications on which the researchers based their study are those coming from the RDF monitoring system and the world network developed by the Radio Emissions Project. **Fig. 1** shows part of the world mapping of the RDF network, characterized by several monitoring stations located on the globe.As can be seen on the same map, the earthquake occurred along the blue/violet azimuth, which starts from the Italian RDF network. The map is used to help understand which are the azimuths of origin of the electromagnetic signals emitted by the Mexican geographical area before the earthquake may have occurred. The propagation of these signals occurred in the right direction of the blue/purple azimuth, and at a distance of over 10,200 km from the RDF detection stations located in the Italian territory.This indicates that the signals emitted before the earthquake and detected by the Italian stations had a blue/purple color, such as to be discriminated and recognized by the computerized electromagnetic detection system (RDF).

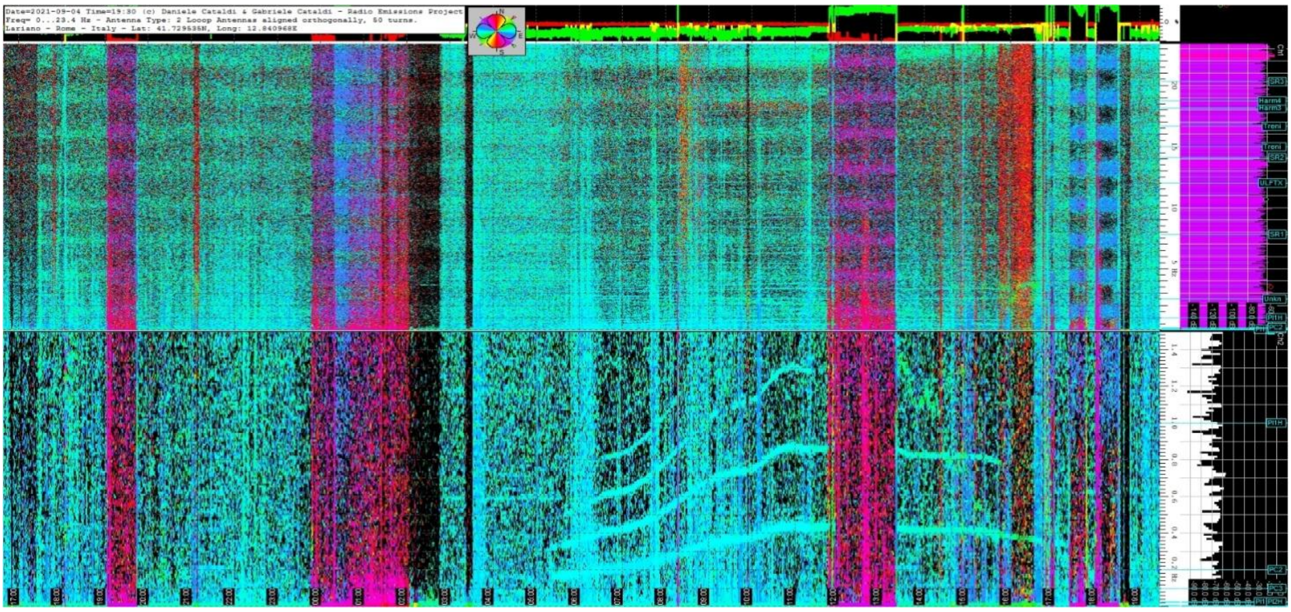

Fig. 2 - Dynamic spectrogram recorded by the RDF station of Lariano, Rome, Italy.Spectrogram recorded between 3 and 4 September 2021. It highlights electromagnetic emissions characterized by blue/violet azimuth. On the Cartesian axis of the ordinates, we have the electromagnetic frequency of the recorded signals, while on the Cartesian axis of the abscissa we have the time reference (UTC), within which the signals were recorded. Credits: Radio Emissions Project.

Interesting information is provided by the spectrograms visible in **Fig. 2**-**3** and represent the first signals recorded by the Italian RDF electromagnetic network, precursors of the earthquake that occurred in Mexico. The first important signal is the one recorded between 19:00 UTC and 20:00 UTC on 3 September 2021, followed by a strong increase recorded again from 00:00 UTC and 02:00 UTC on 4 September 2021.

After this strong increase which lasted about two hours, a strong lowering of the natural geomagnetic background was observed which lasted almost an hour.After that the emissions continued and reappeared in the direction of the seismic epicenter from 12:00 UTC to 13:30 on 4 September 2021. These emissions all appeared in the SELF band (0-3 Hz) and in the SELF-ELF band (0-30 Hz).

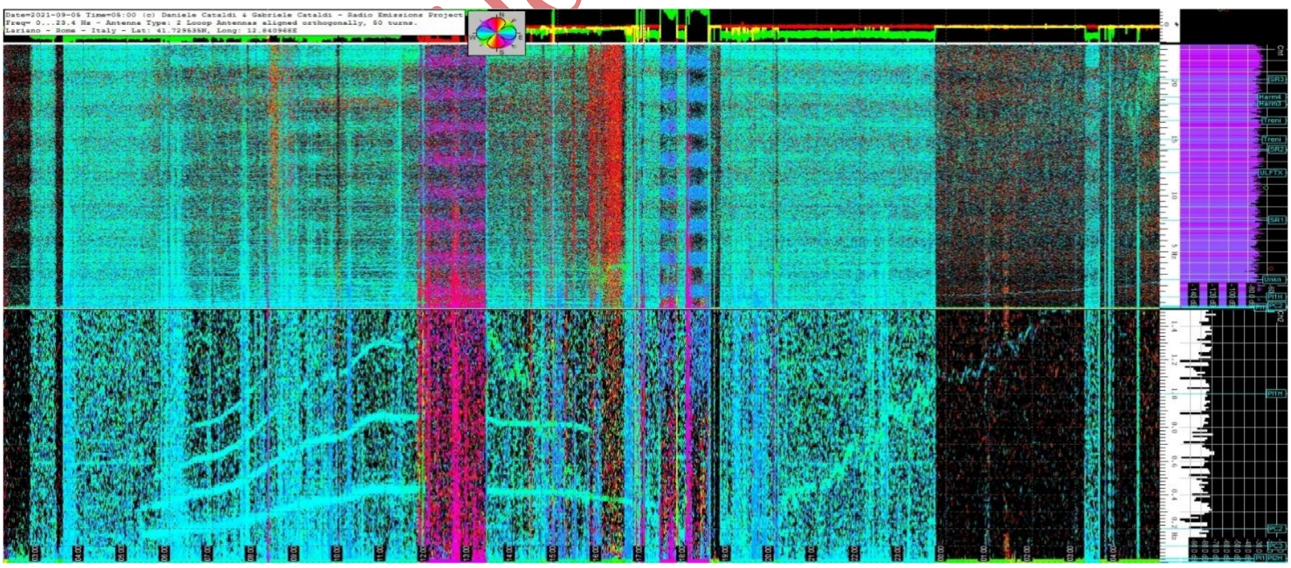

Fig. 3 - Dynamic spectrogram recorded by the RDF station of Lariano, Rome, Italy.Spectrogram recorded between 4 and 5 September 2021. It highlights electromagnetic emissions characterized by blue/violet azimuth. On the Cartesian axis of the ordinates, we have the electromagnetic frequency of the recorded signals, while on the Cartesian axis of the abscissa we have the time reference (UTC), within which the signals were recorded. Credits: Radio Emissions Project.

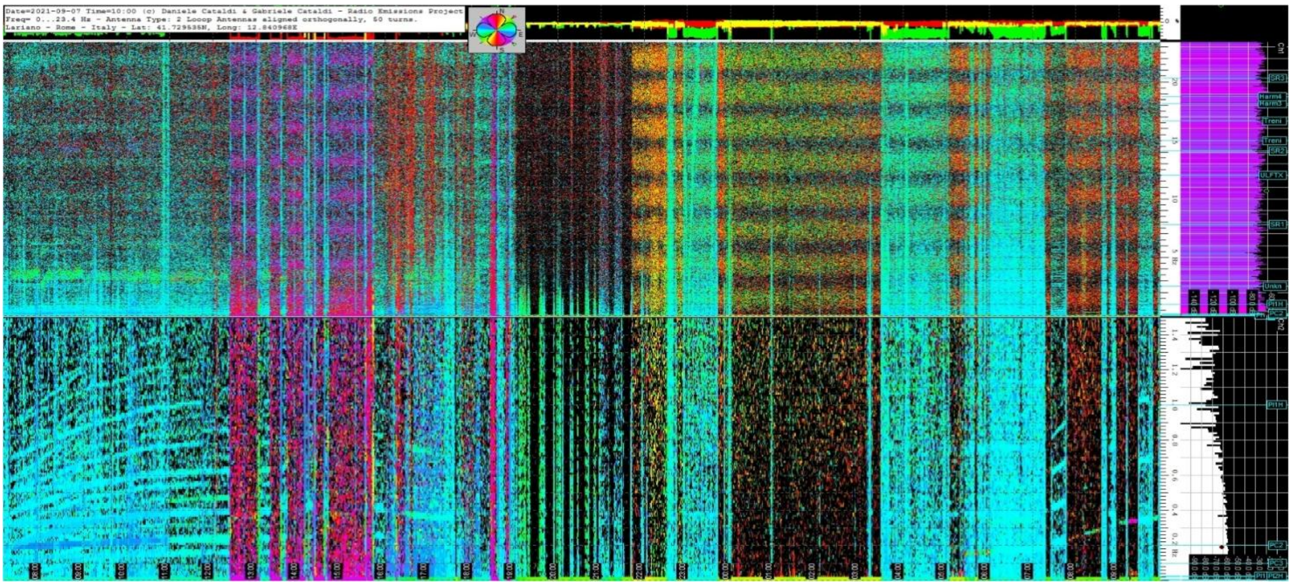

Fig. 4 -Dynamic spectrogram recorded by the RDF station of Lariano, Rome, Italy.Spectrogram recorded between 6 and 7 September 2021. It highlights electromagnetic emissions characterized by blue/violet azimuth. On the Cartesian axis of the ordinates, we have the electromagnetic frequency of the recorded signals, while on the Cartesian axis of the abscissa we have the time reference (UTC), within which the signals were recorded. Credits: Radio Emissions Project.

The emissions then attenuated and disappeared, to reappear on 6 September 2021 from 12:30 UTC to 14:00 UTC on the same day. All signals were located in the SELF-ELF band (0-30 Hz) and highlighted with blue/violet azimuth from the RDF station of Lariano, Rome, Italy (as shown in **Fig. 4**). Further electromagnetic perturbations were then recorded on 7 September 2021, from 10:00 UTC to 14:00 UTC on the same day and characterized by impulsive increases of varying duration and intensity, again with blue/purple azimuths (**Fig. 5**).

After the appearance of these signals, the emissions disappeared and then reappeared close to the time of the earthquake around 00:10 UTC on 8 September 2021, lasting for several hours (**Fig. 5**) until 09:30 UTC for then reappear several hours later until 9 September 2021. The earthquake occurred a few minutes after the appearance of these electromagnetic signals and precisely at 01:47 UTC on 8 September 2021, an hour and thirty minutes after the reappearance of the electromagnetic signals highlighted in **Fig. 5**.

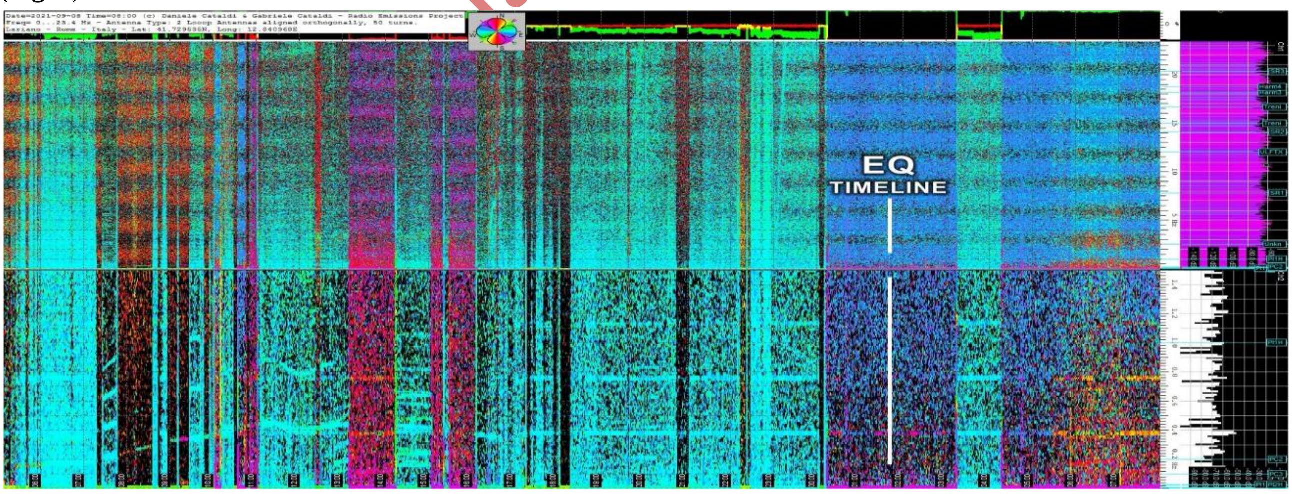

Fig. 5 - Dynamic spectrogram recorded by the RDF station of Lariano, Rome, Italy.Spectrogram recorded between 7 and 8 September 2021. It highlights electromagnetic emissions characterized by blue / violet azimuth. On the Cartesian axis of the ordinates, we have the electromagnetic frequency of the recorded signals, while on the Cartesian axis of the abscissa we have the time reference (UTC), within which the signals were recorded. Credits: Radio Emissions Project.

This indicated to the researchers that the Earth's crust was emitting an important series of signals in the direction of the blue/purple azimuth, and from the frequency of their appearance and their intensity with respect to the natural geomagnetic background, these must have indicated a strong earthquake. When the earthquake occurred in Mexico, the researchers had this confirmation, on signals recorded from 5 days before the earthquake occurred. These data indicate just that. The dynamic spectrograms also showed the appearance of different decreases in the natural electromagnetic background (dark areas), decreases that had different duration and characterized the days preceding the strong Mexican earthquake. The data that have been presented so far are the result of recordings conducted on the environmental radio frequency. Electromagnetic signals correlated from the azimuthal point of view to a seismic epicenter must be considered as radio emissions generated in the focal zone of the earthquake. Furthermore, if these radio emissions precurs the seismic event it is evident that they must be considered "Electromagnetic Seismic Precursors" (ESPs): by definition, this type of seismic precursor can be identified as a "local" electromagnetic source.

In the next chapter, instead, "non-local" electromagnetic phenomena will be presented.

2.2 – Solar Activity

That seismic activity is related to solar activity is nothing new. This close correlation was observed many years ago [**60-61**] and, more recently, it has been possible to understand obtaining a lot of data confirming this which, at the beginning, was only a hypothesis. Today we know with certainty that solar activity, that is, the characteristics of the solar ion flux, are closely related to the potentially destructive activity that is recorded on Earth. The authors are engaged in the monitoring of solar activity and terrestrial geomagnetic activity as part of a scientific project started in 2012 [**3**] which aims to identify electromagnetic phenomena related to the potentially destructive seismic activity that is recorded on global scale. This project has allowed us to prove that the M6+ seismic activity recorded on our planet is always preceded by an increase in the solar ion flux [**39**]. Between 6 and 9 September 2021 (**Fig. 6**) the DSCOVR Satellite (in Lagrangian orbit L1) recorded an increase in the solar proton flux. Exactly, the increase started on September 6, 2021 at 09:15 UTC and ended on September 9, 2021 at 06:53 UTC. On September 7, 2021 at 14:11 UTC, the increase reached its maximum density (30.6 p/cm^3); on September 8, 2021 at 08:12 UTC, the proton flux reached a second density peak (29.24 p/cm^3), and then decreased until it reached the basal level on 9 September 2021 at 06:53 UTC.During this increase, two potentially destructive seismic events were recorded (**Fig. 7**):

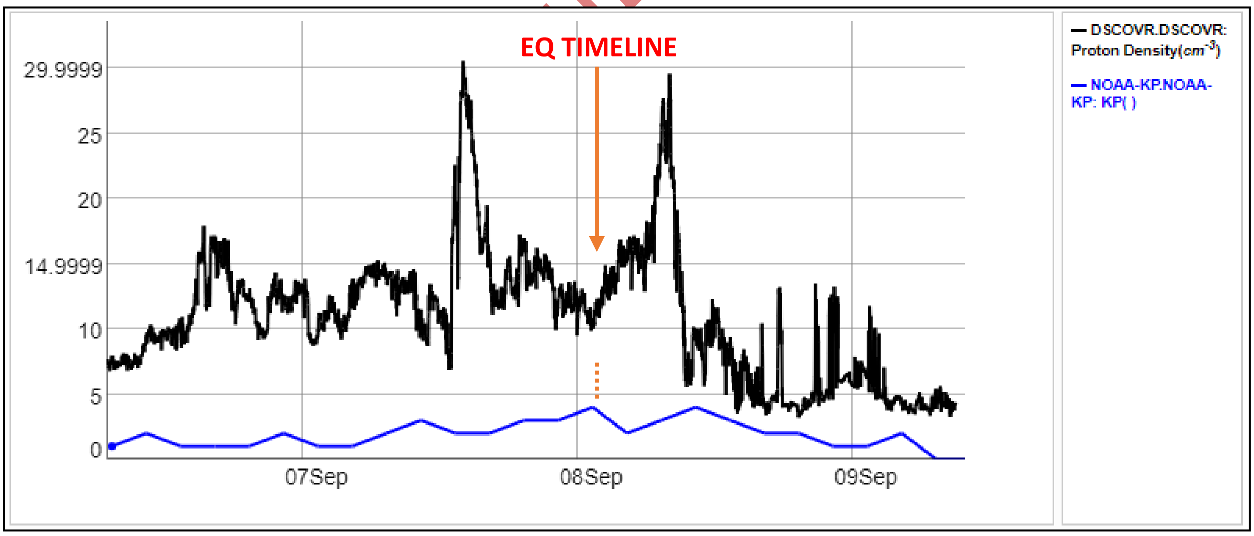

Fig. 6 – Solar ion flux and Kp-Index recorded between 6 and 9 September 2021.In the graph above it is possible to observe the variation of the density of the solar proton flux and the variation of the Kp-Index recorded between 6 and 9 September 2021. Credits: iSWA.

- M6.0 Tonga earthquake, recorded on September 7, 2021 at 09:49:57 UTC;
- M7.0 Mexico earthquake, recorded on September 8, 2021 at 01:47:47 UTC.

Fig. 8 demonstrates that the Mexican M7.0 earthquake was recorded during an increase of AL-Index and DST-Index. The DST-Index is a direct measure of the Earth's geomagnetic horizontal (H) component variation due to the equatorial ring current, while the AL-Index (Auroral Lower) is at all times, the minimum value of the variation of the geomagnetic H component of the geomagnetic field recorded by observers of reference and provides a quantitative measure of global Westward AuroralElectrojet (WEJ) produced by increased of ionospheric currents therein present.

In other words, it is evident that the M7.0 earthquake recorded in Mexico was recorded during a perturbation of the Earth's geomagnetic field caused by an increase in the density and velocity of the solar ion flux (**Fig. 7** and **9**). To confirm what has just been stated, it is possible to observe **Fig. 10**. The first seismic event (M6.0) was recorded during the phase of increase of the solar proton flux, while the second seismic event, decidedly more intense than the first (M7.0), was recorded in the time frame that divides the two major proton increase peaks (**Fig. 6**).

But that is not all. Between September 7, 2021 at 04:00 UTC and September 8, 2021 at 22:30 UTC there was an increase in the Kp-Index which reached the value of 4 on September 8, 2021 (**Fig. 6** and **7**).

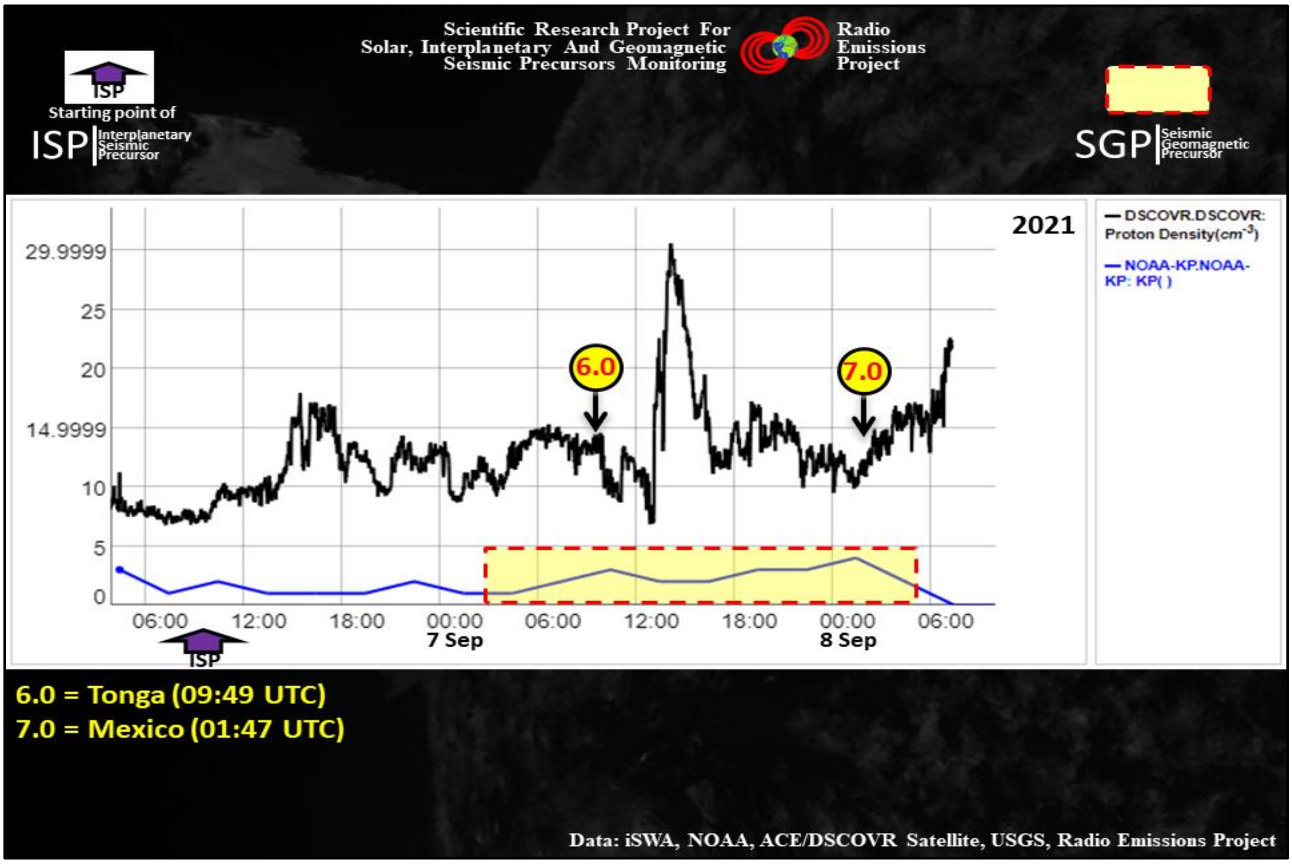

Fig. 7 – Variation in solar ion flux and Earth's geomagnetic activity related to the M6+ earthquake recorded between 7 and 8 September 2021.The graph above shows the time marker of M6+ earthquakes recorded between 7 and 8 September (black vertical arrow). Analyzing the data in the graph it is evident that the Tonga and Mexico earthquakes was preceded by a solar wind proton density increase (Interplanetary Seismic Precursor; black curve) and by an increase of Kp Index (Seismic Geomagnetic Precursor; blue curve highlighted by the yellow area)whose maximum value was recorded on September 8, 2021 (Kp = 4). The purple arrow indicates the start of solar wind proton density increase. Credits: iSWA, USGS, Radio Emissions Project.

Analyzing the variation curve of the solar wind speed (**Fig. 9**) it is possible to understand that the Mexican earthquake M7.0 was recorded after a sudden increase in the speed of the solar ion flow that preceded the earthquake by about 12 hours, and that continued to increase reaching 439 km/s on September 8, 2021 between 10:17 UTC and 11:10 UTC.Analyzing the variation curve of Interplanetary Magnetic Field (IMF) (**Fig. 10**) it is possible to note that the Mexican M7.0 earthquake was recorded during a vast perturbation of IMF, the most important variation of which was observed between September 7, 2021 at 13:15 UTC and September 8, 2021 at 10:06 UTC.
This type of correlation is not new to the authors [**8**] [**12**] [**14**] [**44-59**] (even with respect to Mexico), in fact it was observed for the first time between 2010 and 2011.

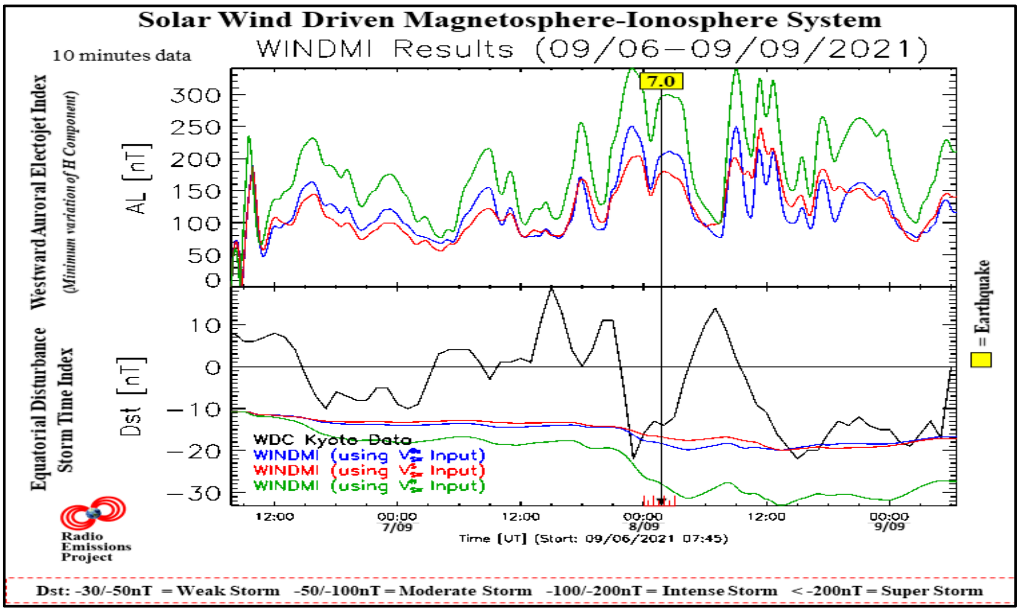

Fig. 8 – Low-dimensional model of the energy transfer from the solar wind through the magnetosphere and into the ionosphere (WINDMI). The picture shows the variation of the AL-Index (at top) and the DST-Index (at bottom) in the hours that preceded the M7 Mexico earthquake recorded on September 8, 2021. The DST-Index is a direct measure of the Earth's geomagnetic horizontal (H) component variation due to the equatorial ring current, while the AL-Index (Auroral Lower) is at all times, the minimum value of the variation of the geomagnetic H component of the geomagnetic field recorded by observers of reference and provides a quantitative measure of global Westward AuroralElectrojet (WEJ) produced by increased of ionospheric currents therein present. The WINDMI data analysis showed that the M7 Mexico earthquake recorded on September 8, 2021 was preceded by an increase of solar and geomagnetic activity. The black vertical arrow shows the temporal marker of the M7 earthquake. Model developed by the Institute for Fusion Studies, Department of Physics, University of Texas at Austin. Credits: iSWA, USGS, Radio Emissions Project.

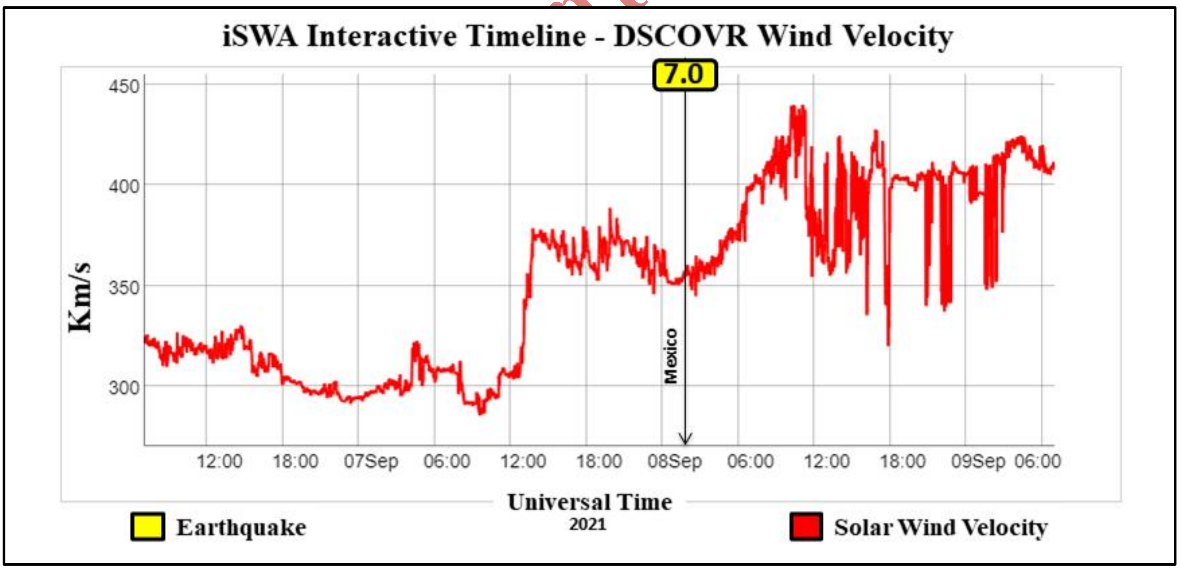

Fig. 9 – Solar wind velocity correlated to M7Mexico earthquake recorded on September 8, 2021. The graph shows the variation of solar wind velocity recorded between 6 and 8 September 2021 by Deep Space Climate Observatory (DSCOVR) Satellite, in orbit at L1 Lagrange point. Analyzing the variation curve it is possible to understand that the M7 Mexico earthquake was preceded by an increase of the solar wind speed. The black vertical arrow shows the temporal marker of the M7 Mexico earthquake occurred on September 8, 2021. Credits: iSWA, USGS, Radio Emissions Project.

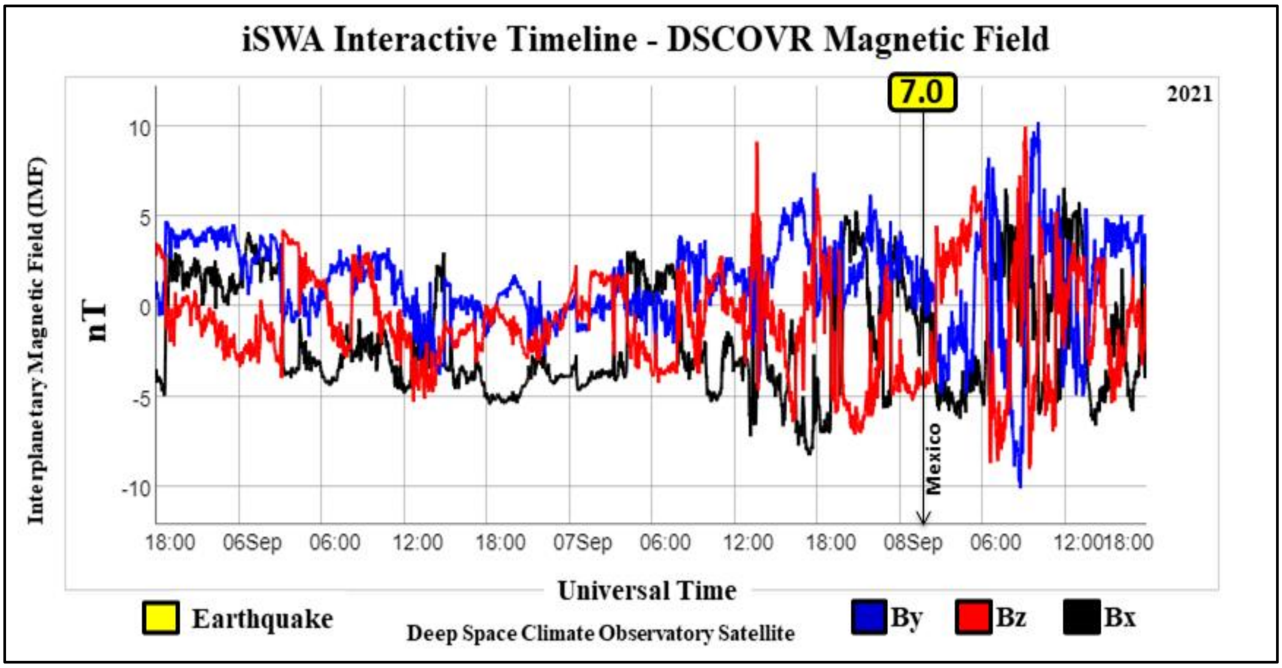

Fig. 10 – Solar wind magnetic field perturbation correlated to M7 Mexican earthquake recorded on September 8, 2021.The chart above shows the variation of the interplanetary magnetic field (IMF) recorded through the Deep Space Climate Observatory (DSCOVR) Satellite in orbit at L1 Lagrange point between 5 and 8 September 2021. The recording was done on 3 axes (By, Bx, Bz). Analyzing the variation curves it is evident that the M7 earthquake recorded in Mexico has been preceded by a perturbation of the interplanetary magnetic field (IMF) whose greater intensity was recorded between 7 and 8 September 2021. The long black vertical arrow represents the temporal marker of M7 earthquake. Credits: iSWA, USGS, Radio Emissions Project.

In conclusion, the increase in solar proton flux preceded the M7.0 Mexican earthquake by about 40 hours, while the geomagnetic increase preceded the Mexican earthquake by about 21 hours.

Below you can see a synthesis of time intervals recorded on a series of electromagnetic phenomena (of a solar nature or related to the coupling phenomena between solar activity and the Earth's magnetosphere) that preceded the Mexican earthquake:

- protonicflux ≈40 hours;
- geomagnetic field (Kp-Index) ≈21 hours;
- Interplanetary Magnetic Field (IMF) variations ≈12 hours;
- solar wind velocity ≈15 hours.

Comparing these time intervals it is evident that the solar proton flux is the electromagnetic phenomenon with the best predictive characteristics.

In fact, the authors ascertained that not only the solar proton flux is the electromagnetic phenomenon that is highlighted before all the other "Interplanetary Seismic Precursors" (ISPs), but always precedes the potentially destructive seismic activity [**3**] [**39**] [**8**].

From a study conducted by the authors between January 1, 2012 and September 8, 2021 it appears that the average time interval corresponds to 105.16 hours (4.38 days) and that an increase in the solar proton flux is correlated on average to 2.87 potentially destructive seismic events (averages calculated on a sample of 1266 M6+ seismic events; corresponding to all M6+ seismic events recorded between January 1, 2012 and September 8, 2021).

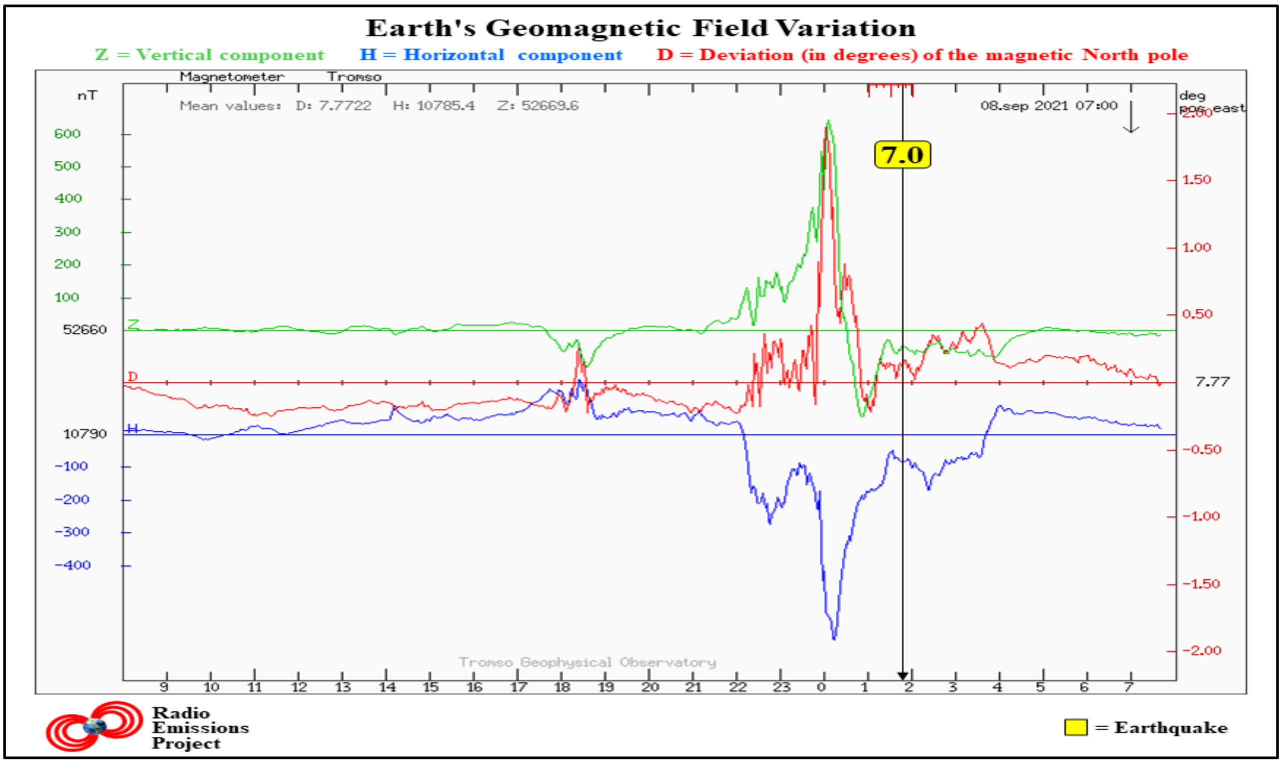

Fig. 11 – Earth's geomagnetic field variation recorded by Tromso Geomagnetic Observatory. Magnetogram containing the variation of the Earth's geomagnetic field, relative to Z (green line), H (blue line) and D (red line) component, registered by the Tromso Geomagnetic Observatory (TGO), Norway, between 7 and 8 September 2021.

The Z component is a vertical component, assumed positive when it's directed towards the inside of the Earth. The H component is the horizontal component, namely the component aligned in the direction of the magnetic North. The D component is magnetic declination angle between the direction of H and the geographic meridian passing through the point in question (Tromso Geomagnetic Observatory), taken as positive when H is directed to the East of the geographic Nord. The vertical black lines represent the temporal markers of M7.0 earthquakes occurred in Mexico on September 8, 2021; while the numbers represent the magnitude (Mw) of earthquake.Analyzing the chart, can be seen that the strong Mexican earthquake was preceded by intense geomagnetic perturbation started at 18:30 UTC on September 7, 2021.

In particular, the Tromso Geomagnetic Observatory detected a oscillation of the magnetic North pole that exceeded almost +2 degrees. In addition, the vertical vector component (Z) reached an increase of almost 700 nT in a few hours. Authors have observed this kind of correlation since 2012. Credits: Tromsø Geophysical Observatory, USGS, Radio Emissions Project.

At the current state of knowledge, there is no other type of seismic precursors capable of always preceding the M6+ seismic activity which is recorded on a global scale.

As already mentioned above, solar activity has a significant impact on the Earth's magnetosphere since the solar ion flux (solar wind) carries with it the Interplanetary Magnetic Field (**Fig. 10**) which, touching the Earth, disturbs its magnetic field.

The graphs visible in Fig. E, F and G highlight this phenomenon just described: it is no coincidence, in fact, that strong earthquakes occur during or after a geomagnetic perturbation.

Through Fig. B it was possible to ascertain that the strong M7.0 Mexican earthquake was recorded during a reduction of DST-Index which reached the value of -33 nT: a value compatible with a weak geomagnetic storm.

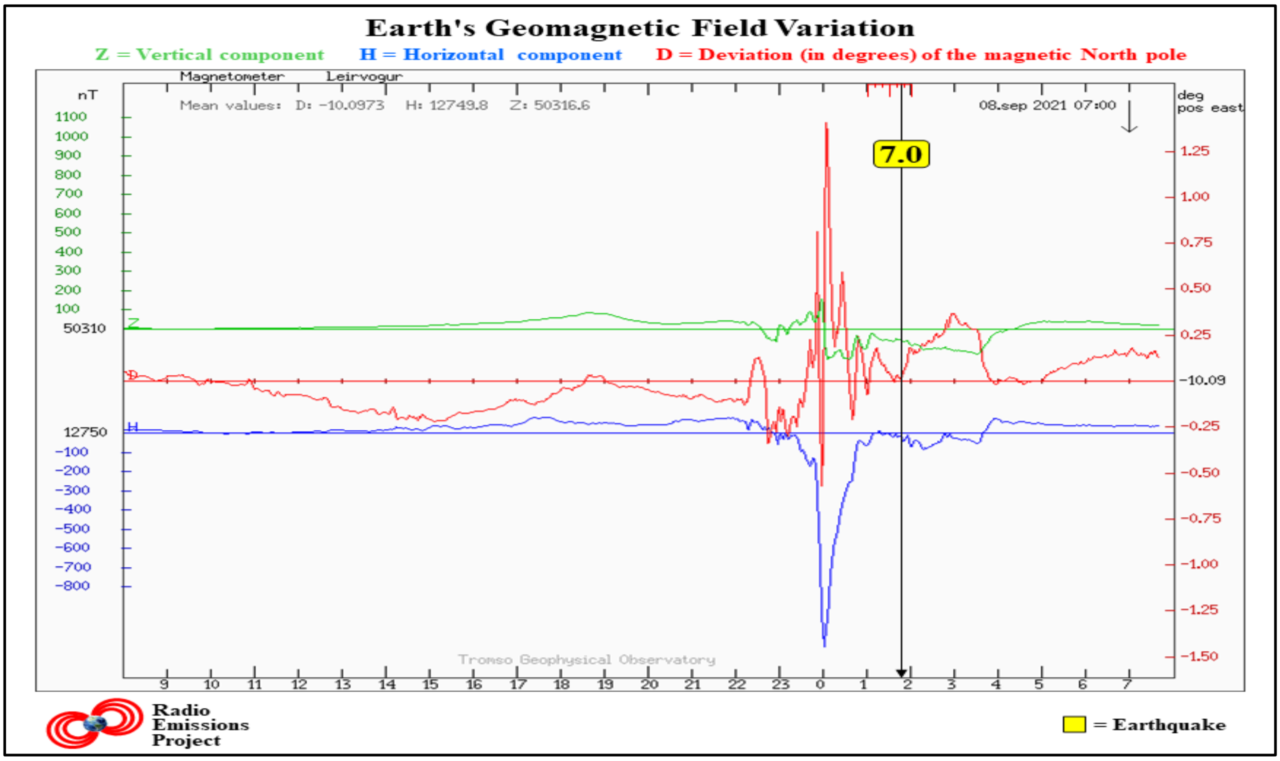

Fig. 12 – Earth's geomagnetic field variation recorded by Leirvogur Geomagnetic Observatory. Magnetogram containing the variation of the Earth's geomagnetic field, relative to Z (green line), H (blue line) and D (red line) component, registered by the Leirvogur Geomagnetic Observatory (LRV), Iceland, between 7 and 8 September 2021. The Z component is a vertical component, assumed positive when it's directed towards the inside of the Earth. The H component is the horizontal component, namely the component aligned in the direction of the magnetic North. The D component is magnetic declination angle between the direction of H and the geographic meridian passing through the point in question (Leirvogur Geomagnetic Observatory), taken as positive when H is directed to the East of the geographic Nord. The vertical black lines represent the temporal markers of M7.0 earthquakes occurred in Mexico on September 8, 2021; while the numbers represent the magnitude (Mw) of earthquake.Analyzing the chart, can be seen that the strong Mexican earthquake was preceded by intense geomagnetic perturbation started at 22:20 UTC on September 7, 2021. In particular, the Leirvogur Geomagnetic Observatory detected a oscillation of the magnetic North pole that exceeded almost +1.5 degrees. In addition, the horizontal vector component (H) reached a decrease of almost -1100 nT in a few hours. Authors have observed this kind of correlation since 2012.Credits: Tromsø Geophysical Observatory, USGS, Radio Emissions Project.

The reduction of DST-Index started on September 6, 2021 at 15:00 UTC and accelerated on September 7, 2021 at 21:00 UTC. The value of -33 nT was reached on September 8, 2021 at 13:30 UTC. The Tromsø Geophysical Observatory has made it possible to highlight that a few hours before the M7.0 Mexican earthquake recorded on September 8, 2021 at 01:47 UTC the Earth's geomagnetic field suffered a major disturbance. The authors analyzed the temporal characteristics of this perturbation through the data provided by Tromso Geomagnetic Observatory (TGO), Leirvogur Geomagnetic Observatory (LRV) and Masi Geomagnetic Observatory (MAS) (Fig. E, F, G) and found that it preceded 3.5-7 hours the Mexican earthquake.
Below are the time intervals related to the Mexican M7.0 earthquake and the geomagnetic disturbance recorded between 7 and 8 September 2021 by Tromso Geomagnetic Observatory (TGO), Leirvogur Geomagnetic Observatory (LRV) and Masi Geomagnetic Observatory (MAS):

- TGO ≈7 hours;
- LRV ≈3.5 hours;
- MAS ≈7 hours.

As proved through the analysis of the geomagnetic data relating to the Tromsø Geophysical Observatory, the time intervals related to the geomagnetic perturbation are lower than those provided through the analysis of the solar wind characteristics (**Fig. 7**, **9** and **10**): a data confirming of the coupling function between the solar wind and the terrestrial magnetosphere. Currently the authors do not have a scientific proof capable of proving the close correlation that exists between the variations/perturbations of the Earth's geomagnetic field and the potentially destructive seismic activity that is recorded on a global scale but, given the enormous amount of data to confirm of this correlation, it is possible to suppose that at the basis of this seismogenic correlation there may be a form of electromagnetic interaction.

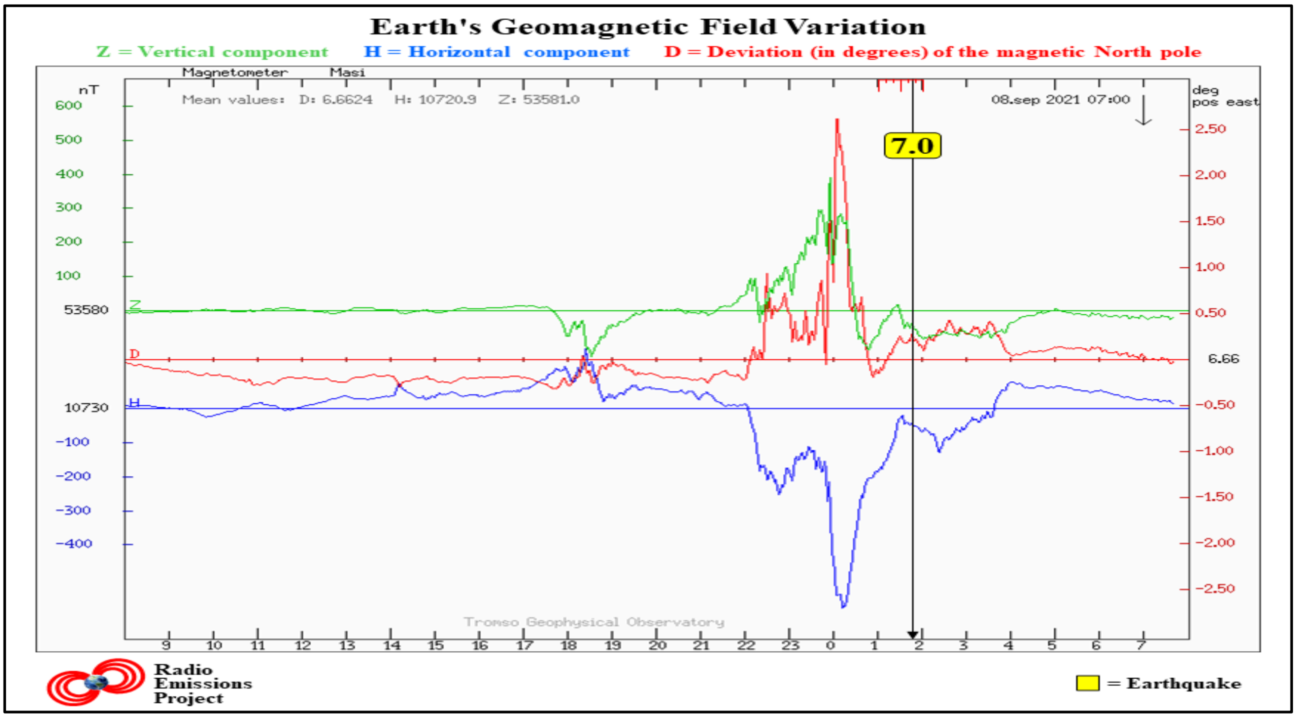

Fig. 13 – Earth's geomagnetic field variation recorded by Masi Geomagnetic Observatory. **Magnetogram containing the variation of the Earth's geomagnetic field, relative to Z (green line), H (blue line) and D (red line) component, registered by the Masi Geomagnetic Observatory (MAS), Norway, between 7 and 8 September 2021. The Z component is a vertical component, assumed positive when it's directed towards the inside of the Earth. The H component is the horizontal component, namely the component aligned in the direction of the magnetic North. The D component is magnetic declination angle between the direction of H and the geographic meridian passing through the point in question (Masi Geomagnetic Observatory), taken as positive when H is directed to the East of the geographic Nord.**

The vertical black lines represent the temporal markers of M7.0 earthquakes occurred in Mexico on September 8, 2021; while the numbers represent the magnitude (Mw) of earthquake.Analyzing the chart, can be seen that the strong Mexican earthquake was preceded by intense geomagnetic perturbation started at 18:30 UTC on September 7, 2021. In particular, the Masi Geomagnetic Observatory detected a oscillation of the magnetic North pole that exceeded almost +2.15 degrees.

In addition, the vertical vector component (Z) reached an increase of almost 400 nT in a few hours and the horizontal vector component (H) reached a decrease of almost -600 nT. Authors have observed this kind of correlation since 2012. Credits: Tromsø Geophysical Observatory, USGS, Radio Emissions Project.

The data obtained by the researchers by means of the geomagnetic monitoring of the natural electromagnetic background highlighted the presence of strong electromagnetic increases that preceded the Mexican M7.0 earthquake by 5 days. The Italian RDF - Radio Direction Finding network has not only highlighted these signals but has provided azimuth indications (direction of arrival of the signals). This again represents a fact already obtained through previous studies, always carried out by the same team of researchers.Electromagnetic monitoring made it possible to highlight the presence (again) of electromagnetic signals capable of anticipating earthquakes. In this regard, the signals had an electromagnetic frequency between 0 and 30 Hz, that is, localized in the SELF-ELF band. These signals therefore have an electromagnetic frequency ranging from hundredths of Hz to a few tens of Hz.

There is still no verified evidence on site about the mechanism of formation of this type of pre-seismic radiofrequency, but the authors think it may be a phenomenon related to the creation of microfractures in the earthquake preparation zone. Microfractures are small cracks in the rock which, from a geological point of view, generally have a length of a few millimeters (or less) and a width of less than 0.1mm and are formed in the phases preceding the macrofractures [**62**]. Since the size of a microfracture substantially depends on the homogeneity of the rock subjected to tectonic stress, it is evident that fractures of much more varied dimensions have also been observed [**62**]. The first microfractureswere observed in 1850 through transmitted light microscopy (TL), while only in 1960 it was possible to observe them through scanning electron microscopy (SEM) [**62**].

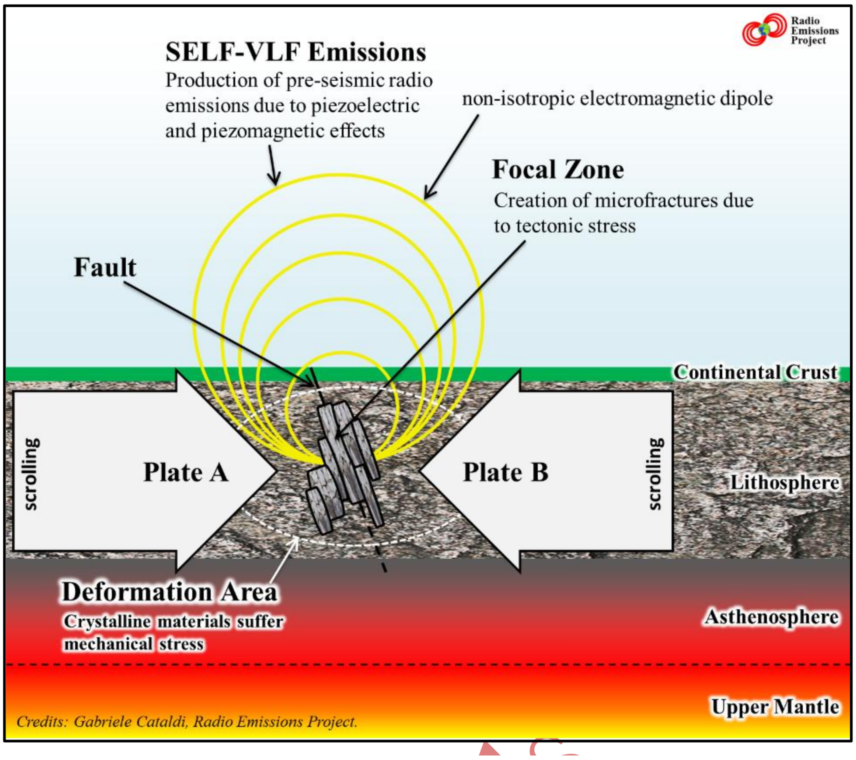

Fig. 14 – Pre-seismic radiofrequency generated through the phenomenon of piezoelectricity. In the image above the geodynamic mechanism responsible for the pre-seismic radiofrequency emission has been represented. Credits: Gabriele Cataldi, Radio Emissions Project.

The creation of experimentally induced microfractureswas demonstrated for the first time through triaxial compression tests [**63**] and currently the study of microfractures produced in the laboratory has allowed us to provide important information on rock breaking processes and a better understanding of faults and formation of microfractures in nature [**64**]. Since the faults do not have a planar morphology but are irregular, they can be described graphically as a fractal [**65-66**]. This condition means that when tectonic stress accumulates, the geometric irregularities of the fault influence each other leading to the formation of additional microfractures in the surrounding rock that have a different orientation than the main ones [**67-69**]. It is therefore evident that the volume of the Earth's crust involved in the creation of microfractures is larger than the area defined as the "earthquake preparation zone": according to some estimates [**70**] this volume could be between 24 and 520 times larger than the earthquake preparation area. The locally generated pre-seismic radiofrequency is an electromagnetic phenomenon caused by the tectonic stress that deforms and creates microfractures and macrofractures in the rocks present in the earthquake preparation area through the phenomenon of piezoelectricity [**71**] (**Fig. 14**). The amplitude of the electromagnetic signals caused by the formation of microfractures of the rocks subjected to tectonic stress in the earthquake preparation area mainly depends on the density of the microfractures and their size; the morphology of the electromagnetic field depends on the orientation of the microfractures; on the other hand, the period of oscillation of the electromagnetic field (temporal modulation) depends on the geological characteristics of the fault and on the characteristics of the tectonic stress that determine a growth of the microfractures that does not proceed linearly. This explains why the pre-seismic radiofrequency produced through the creation of microfracturescan be considered “inconsistent” [**72**]. It is not yet clear how these electromagnetic signals propagate, but since there is an azimuth correlation it is correct to think that there may be a propagation inside the Earth-Ionosphere cavity. Furthermore, electromagnetic signals that have a frequency $0.001 \leq f \leq 1000$ Hz have the characteristic of undergoing negligible attenuation when they cross the Earth's crust [**73**]: this means that an electromagnetic signal generated in the earthquake preparation area can propagate for long distances within the Earth's crust. This characteristic of radio waves could allow an electromagnetic signal generated in the earthquake preparation area to reach an electromagnetic monitoring station located on the Earth's surface hundreds of km or even thousands away. In fact, the antenna of the RDF detection system consists of two loop antennas that have the characteristic of having good sensitivity even when the electromagnetic signals that reach them are inclined by 40° (efficiency of the loop antenna = 76.6%) with respect to the leader aligned perpendicular to the center of the loops [**74**]. This efficiency is maintained at acceptable values even when the inclination of the electromagnetic signals rises to 60° (loop antenna efficiency = 50%). At an inclination of 75°, the antenna efficiency reaches 25.8%. In other words, thanks to an electromagnetic detection system equipped with loop antennas, it is possible to capture electromagnetic signals from sources that are located below the horizontal plane, with angles that even reach -75°, while maintaining a sensitivity of 25.8%. What has just been said could explain why it is possible to detect low and very low frequency electromagnetic sources even thousands of km away from the RDF monitoring station. As for the close correlation that has been observed between the Mexican M7.0 earthquake and solar activity, it is right to remember that this type of correlation is typical of potentially destructive earthquakes. In fact, the authors ascertained that all M6+ seismic events that are recorded on a global scale are always preceded by an increase in the solar ion flux. In this case we are dealing with electromagnetic seismic precursors of "non-local" type (since they can be identified as electromagnetic phenomena of a solar nature or generated through the solar wind-magnetosphere coupling function). Instead, the electromagnetic signals correlated from the azimuthal point of view (RDF) to the Mexican earthquake are radio emissions generated locally, ie from the focal zone of the earthquake and for this reason they have been classified by the authors as "local" electromagnetic seismic precursors.

4 - Conclusions

The RDF monitoring network, developed by the Radio Emissions Project, was able to detect electromagnetic signals from a geographical area where, five days later, a strong earthquake (M7.0) occurred. This indicates that the RDF network is capable of providing important pre-seismic indications. The monitoring of solar activity and terrestrial geomagnetic activity is able to provide valuable information on the resumption of potentially destructive seismic activity that is recordedon a global scale. In particular, from the data obtained through the various studies conducted by the authors on the solar wind, the variation in proton density is associated with a resumption of M6+ seismic activity: this phenomenon was observed for the first time by the authors in 2010-2011 and currently appears to be the only phenomenon that has a high degree of reliability in the predictive field.

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