Experimentation of the rdf network for research on pre-seismic electromagnetic signals

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ABSTRACT

On 5 May 2023, a strong earthquake of magnitude Mw 6.2 occurred in Japan, this event was preceded by variations in the earth's geomagnetic field, recorded by the radio receiver network (RDF) developed by the Radio Emissions Project and located in Italy, Malaysia and in Somalia. This seismic event was preceded not only by electromagnetic emissions, but also by some variations produced by solar activity. In this study, the group of researchers intends to underline the importance of the presence of possible electromagnetic precursors and variations of the proton density measured in the space near planet Earth, which could predict the occurrence of earthquakes, in an innovative monitoring technique that could be used to understand whether an earthquake can be expected to occur in a given geographical area.

Keywords: RDF, Seismic Electromagnetic Precursors, Earthquake, Japan, Solar Activity.

1 - PREMISE

The study of electromagnetic emissions associated with earthquakes has very ancient foundations compared to the scientific knowledge present today, which concern the mechanisms of production of radio emissions through rocks subjected to tectonic stress. Electromagnetic anomalies were observed, for example, on March 11, 2011 before the earthquake in Japan [42], or those that preceded the Peruvian earthquake of September 25, 2013 [43], or even those recorded on August 24, 2016 in Italy [12], these are just some of the earthquakes preceded by a series of electromagnetic emissions or electromagnetic anomalies recorded or witnessed by researchers on a global scale [44]. The bibliography is very vast and cannot be cited completely [45-50].

It was 1890 when the British geologist John Milne, inventor of the eponymous horizontal seismograph, a professor at the Imperial College of Engineering in Tokyo and founder of the Seismological Society of Japan (SSJ), in his work entitled “Earthquakes in connection with electric and magnetic phenomena” [51], described some electrical magnetic phenomena and related to seismic activity.

It was the first scientific publication ever in which they were described a series of electromagnetic phenomena, about one hundred years later, the international scientific community renamed as “Electromagnetic eismic Precursors” or ESPs [52].

In 2007, Gabriele Cataldi and Daniele Cataldi founded a scientific research project (Radio Emissions Project) dedicated to monitoring and study of Electromagnetic Seismic Precursors (ESPs) and, in the course of a few years, they have developed an innovative electromagnetic tracking method, who was able to provide valuable data on the pre-seismic electromagnetic anomalies, meaning by this term also electromagnetic phenomena of solar origin and those of geomagnetic nature. [53]

1.2 - Mechanism of genesis of pre-seismic radio emissions

To understand and understand the genesis of the electromagnetic signals [62] used to predict telluric events, we need to consider the phenomenon of piezoelectricity.

Piezoelectricity is the phenomenon whereby some crystalline materials become electrically polarized when subjected to mechanical deformation (direct piezoelectric effect) or deform elastically when subjected to an electric field (inverse piezoelectric effect or Lippmann effect).

The breaking of the crystalline lattices inside the rocks due to the effect of microfractures [62], located in a fault, generate the leakage of ions that accumulate in the rock. In this case, the lithosphere has its own electrical conductivity which varies with the variation of its composition, within which the electrical charges are distributed, similar to what happens in an electrical conductor. [56] [57]

The movement of these electric charges generates, as we know, an electromagnetic field. [58] According to some studies, the presence of these electric charges would be partly correlated with terrestrial seismogenesis and the properties of rocks that determine piezoelectricity are implicated in this process, [59] in fact these particles emit an electromagnetic field detectable at distance. In these rocks of the lithosphere, the electric accumulation has been identified for some time now, as well as the mechanisms that determine it. [60]

In essence, therefore, the electromagnetic emissions emitted by rocks under tectonic stress, by means of piezoelectricity [61] [62], propagate in the earth-ionosphere cavity and can be captured at a distance.

1.3 - The RDF – Radio Direction Finding System

Between 2008 and 2017, researchers at the Radio Emissions Project in Italy experimented for the first time with radio receivers capable of detecting pre-seismic electromagnetic emissions, temporally associated with the occurrence of strong earthquakes.

The studies conducted made it possible to create in 2017 [41], the first electromagnetic monitoring system equipped with RDF - Radio Direction Finding technology, i.e. capable of identifying not only the appearance of natural electromagnetic signals, but also their direction of arrival with respect to the geographical position of the receiving station.

Under this scope, two or more RDF sensors are able, by means of the "radio triangulation" technique, to identify the geographical position of origin of the electromagnetic signals of natural origin and therefore provide a more or less precise indication of the radio carrier nature that emits these signals.

Radio triangulation is a technique used to determine the location of an object or radio signal source using information gathered from three or more antennas or receivers. Radio triangulation is used extensively in applications such as navigation, vehicle tracking, aircraft surveillance, and wireless communication.

In general, radio triangulation works using the geometric principle of triangulation, which involves determining an object's location using knowledge of the object's distance from three or more known points.

In the case of radio triangulation, the antennas or receivers are the known points and the location of the object or radio signal source is determined based on the arrival time difference of the signals received from the antennas, in that scope, the identification capability of the position of the radio carrier, by means of this technique, is very high [54] [55].

This has prompted the researchers of the Radio Emissions Project to use for the first time a global network capable of identifying and studying electromagnetic emissions of a natural type, in the seismic field.

In fact, since 2017 [41], the Radio Emissions Project has deployed some electromagnetic sensors (radio receivers) on a global scale, precisely for this purpose, first on the Italian territory, to then reach other areas of the planet, thanks to important active scientific collaborations between Somalia and Malaysia.

1.4 - The RDF network

In 2017, as already mentioned, the Radio Emissions Project began to build the RDF worldwide network, located for the first time in Italy alone. This is the world's first network of sensors capable of detecting the weak electromagnetic emissions associated with earthquakes (SEP - Seismic Electromagnetic Precursors). The stations that are part of it today are the following:

1. RDF Station of Lariano, Rome, Italy – Radio Emissions Project.
2. RDF Station of Pontedera, Rome, Italy – Radio Emissions Project.
3. RDF Station of Malaya, Malaysia – Radio Cosmology Research Lab, Department of Physics, Faculty of Science, University of Malaya.
4. RDF Station of Mogadishu, Somalia – Jamhuriya University of Science and Technology.

The effective international scientific collaboration between the Italian Radio Emissions Project and these universities, has been able to create a unique research project that has never existed before, which has as its purpose the research of electromagnetic seismic precursors (SEPs) and the construction of a forecasting system.

In this study the RDF stations considered, which detected the electromagnetic signals indicating the Japanese area, are the following:

- RDF Station of Lariano, Rome, Italy – Radio Emissions Project.
- RDF Station of Mogadishu, Somalia – Jamhuriya University of Science and Technology.

2 - METHOD AND DATA

The authors, engaged in this study, used the electromagnetic monitoring of the natural type radio signals observed in the geographical area within which, subsequently, the earthquake occurred. This monitoring took place through the RDF radio stations, positioned between Italy and South Africa.

The monitoring technique used is based on the observation of natural electromagnetic emissions, by means of the RDF network, and the monitoring of solar activity, closely linked to terrestrial geomagnetic activity and space weather, or space meteorology (the conditions in the space around the Earth, mainly influenced by the activity of the Sun. It is the set of changes in environmental conditions in space, such as magnetic fields, charged particles and radiation, which can affect space technology, communication networks, satellites, terrestrial infrastructures and even on human health [63-66]) and in this case by monitoring the proton density measured outside space, at a short distance from the Earth.

The electromagnetic type data analyzed are then considered in relation to the indication of certain geographical areas that the RDF sensor network, by means of the radio triangulation technique, suggest and within which earthquakes occur. This forecasting technique has been used by the Radio Emissions Project since 2017 [41].

The data used for the forecasting system are as follows:

- Variation of proton density in space determined by solar activity.
- Appearance of electromagnetic emissions of a natural type, in the SELF-ELF band (with a frequency between 0.01 Hz and 30 Hz).
- Variation and behavior of electromagnetic emissions over time, detected by the RDF network.
- Temporal context in UTC time, obtained from the dynamic spectrograms generated by the worldwide RDF network, in relation to the electromagnetic variations captured.
- Density and variation of the ionospheric TEC.
- Seismic activity monitoring (USGS archive).

By correlating the appearance of electromagnetic signals of a natural type, coming from a specific geographical area, with reference to certain azimuths indicated by the RDF stations, it is possible to understand whether in that precise point on the Earth there is an increase in energy accumulation at of the lithosphere.

These electromagnetic emissions, being generated by the action of tectonic stress, indicate that an earthquake may soon occur, precisely due to the effect of the mechanisms mentioned on the fault surface.

These radio emissions are preceded by variations in solar activity and consequently by modifications of the TEC and proton density in space, as observed by the Radio Emissions Project since 2012 [1-20].

The next chapters will list the series of data obtained from this monitoring to give substance to the study and the hypotheses considered by the group of researchers.

2.1 - The RDF Data of Mogadiscio

On October 9, 2021, an important international cooperation was born between the Radio Emissions Project and the Jamhuriya University of Science and Technology, Faculty of Engineering in Mogadisho, Somalia. This cooperation has the aim of integrating the RDF network with other sensors and through the joint efforts of the researchers, obtaining more information on electromagnetic seismic precursors.

Between 4 and 5 May 2023, the RDF monitoring station in Mogadishu, Somalia (South Africa), recorded a series of electromagnetic signals, located along a precise azimuth of origin, i.e. on the NE-SW axis (green colour). These signals branched out from a very low electromagnetic frequency (SELF band - 0.01 - 3 Hz), reaching the ELF band (3-30 Hz) and settling at a maximum frequency of 7 Hz (Figure 4).

The electromagnetic increases appeared at 22:15 UTC on 4 May 2023, until around 05:25 UTC on 5 May 2023, a few minutes before the telluric shock, which occurred in Japan and of magnitude Mw 6.2:

- Mw 6.2 - Honshu, Japan – date: 2023-05-05, time: 05:42:04 (UTC) – GPS: 37.540°N 137.305°E, at a depth of 8.7 km (USGS Data).

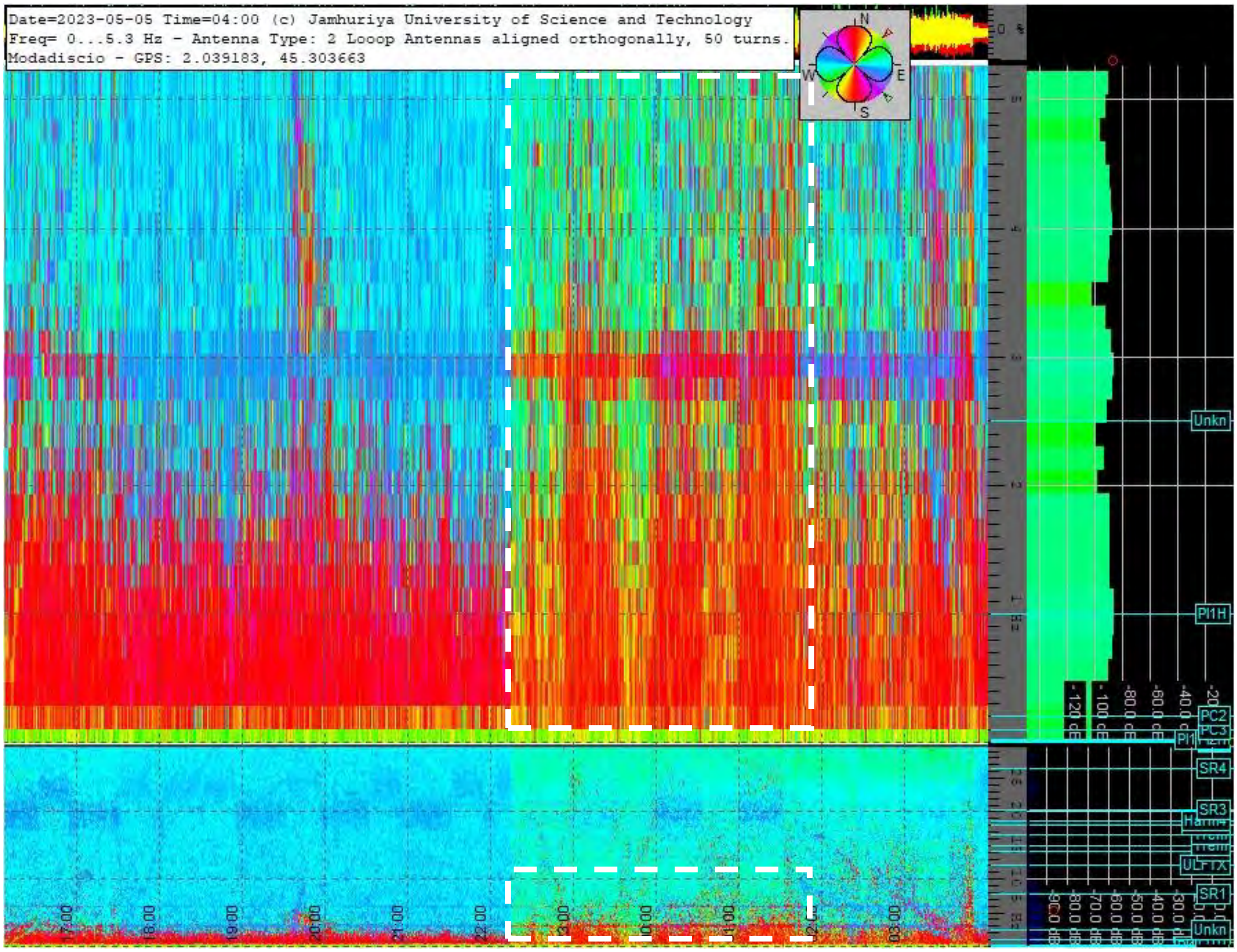

Fig. 3 – Dynamic spectrogram of the RDF station in Mogadishu, Somalia, showing a "snapshot" of natural electromagnetic emissions. The recording took place between 4 and 5 May 2023. The electromagnetic frequency of these emissions is visible on the ordinate axis, the time context in UTC time on the abscissa axis, the colors indicate the azimuth of origin of the signals electromagnetic than the city of Mogadishu. Credits: Jamhuriya University of Science and Technology; Radio Emissions Project.

The signals appeared without any advance, after several hours in which the natural electromagnetic background showed the presence of signals from the blue-turquoise (E-W) azimuth. This indicates that there has been an important electromagnetic emission with a different azimuth of arrival, compared to the signals of the natural geomagnetic background. This fact can justify the appearance of a natural electromagnetic carrier located in a specific point of the planet (Fig. 3 and 4).

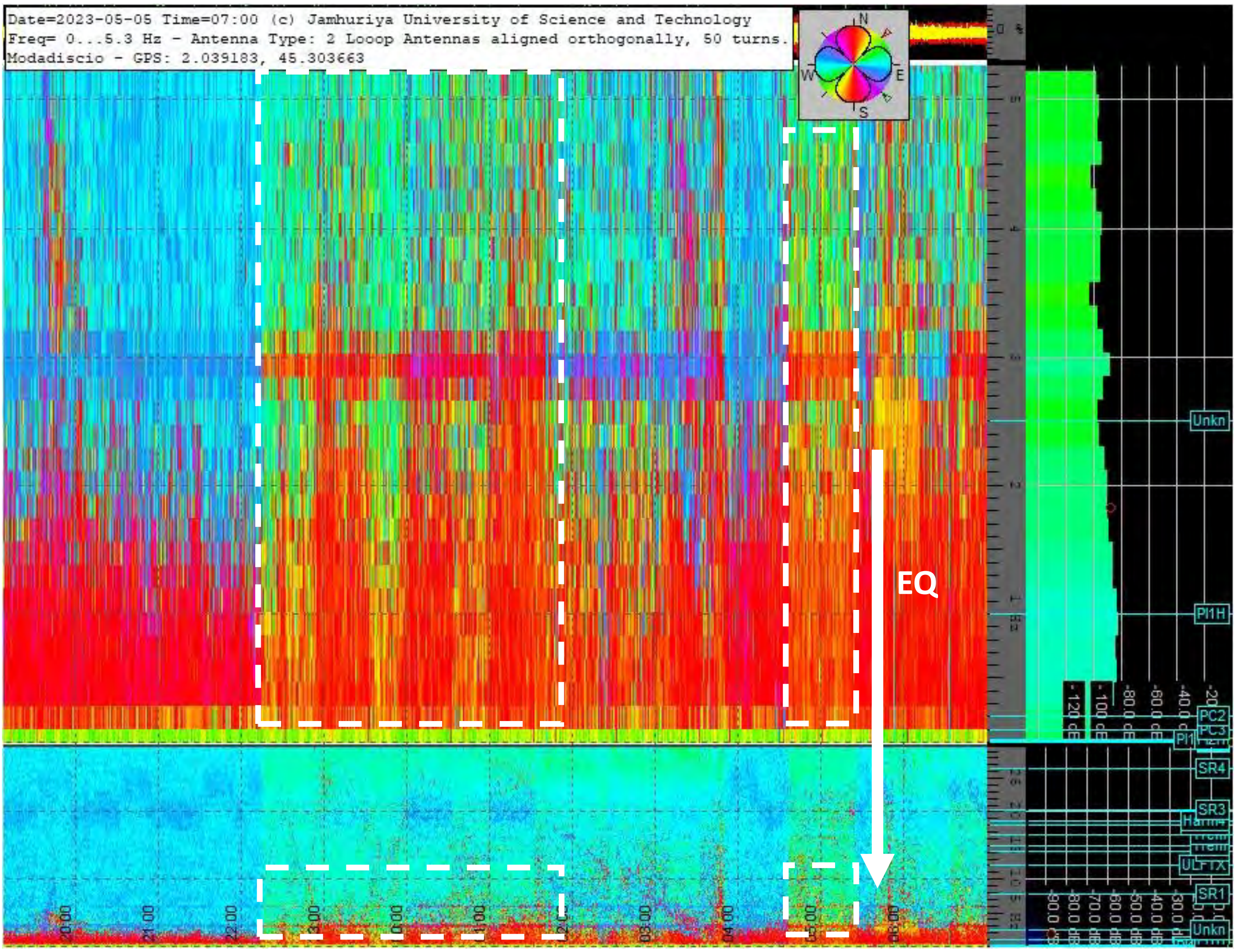

Fig. 4 – Dynamic spectrogram of the RDF station in Mogadishu, Somalia, showing a "snapshot" of natural electromagnetic emissions. The recording took place between 4 and 5 May 2023. The electromagnetic frequency of these emissions is visible on the ordinate axis, the time context in UTC time on the abscissa axis, the colors indicate the azimuth of origin of the signals electromagnetic than the city of Mogadishu. Credits: Jamhuriya University of Science and Technology; Radio Emissions Project.

2.3 - The RDF Data of Lariano

The RDF station in Lariano, Rome, Italy, also experienced electromagnetic surges from the same geographical area of Japan, hours before the earthquake occurred. In this case the signals appeared between 05:00 UTC and 18:00 UTC on 4 May 2023, at an electromagnetic frequency between 0.09 Hz and 0.2 Hz (SELF band - 0.0-3 Hz).

Other electromagnetic emissions were recorded by the same RDF station, between 15:00 UTC and 18:30 UTC on 4 May 2023, to then reappear at about 05:30 UTC on 5 May 2023, at an average electromagnetic frequency about 28 Hz (ELF band – 3-30 Hz).

In this case all the signals had an impulsive characteristic, i.e. brief appearances followed by the disappearance of the electromagnetic signals. These signals appeared without warning and showed a signal detached from the signals of the natural electromagnetic background, just as happened for the RDF station of Mogadishu in Somalia. In this case the signals are green, given that the position of the

Japanese seismic epicenter, with respect to the position of the city of Lariano, Rome, Italy, is located along this azimuth, as visible in Figure 5.

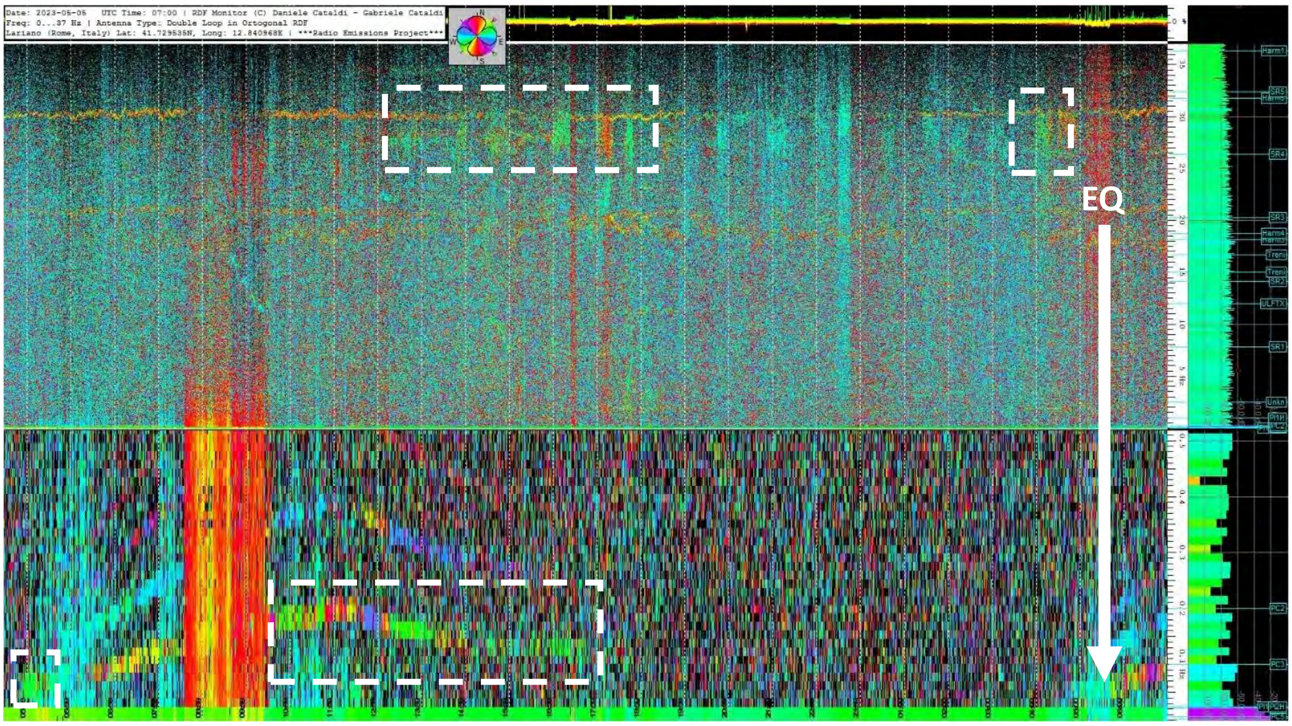

Fig. 5 – Dynamic spectrogram of the RDF station of Lariano, Rome, Italy, showing a "snapshot" of natural electromagnetic emissions. The recording took place between 4 and 5 May 2023. The electromagnetic frequency of these emissions is visible on the ordinate axis, the time context in UTC time on the abscissa axis, the colors indicate the azimuth of origin of the signals electromagnetic waves with respect to the city of Lariano, Rome, Italy. Credits: Radio Emissions Project.

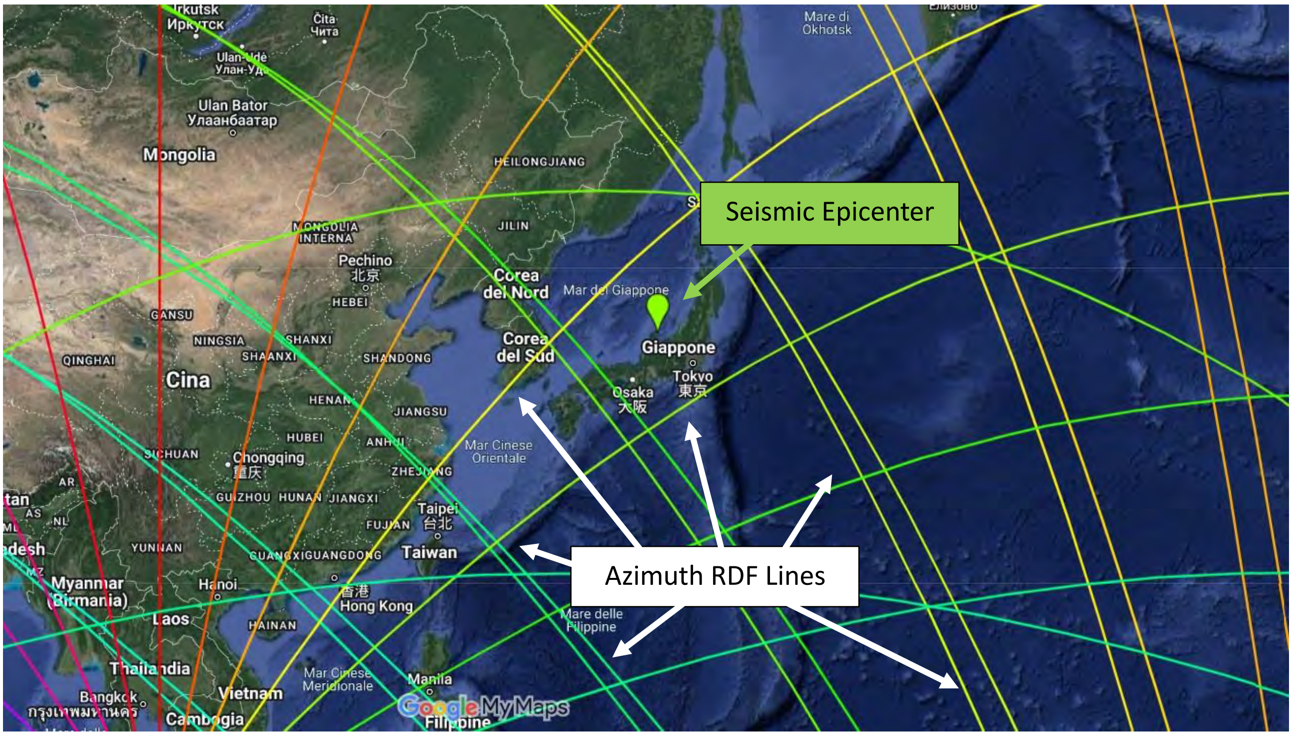

Fig. 6 – Worldwide colorimetric mapping of the RDF network, with particular reference to the Japanese area and the seismic epicenter (green markers). The colored lines represent the different azimuths of origin of the electromagnetic signals, with respect to the RDF stations themselves. Credits: Radio Emissions Project.

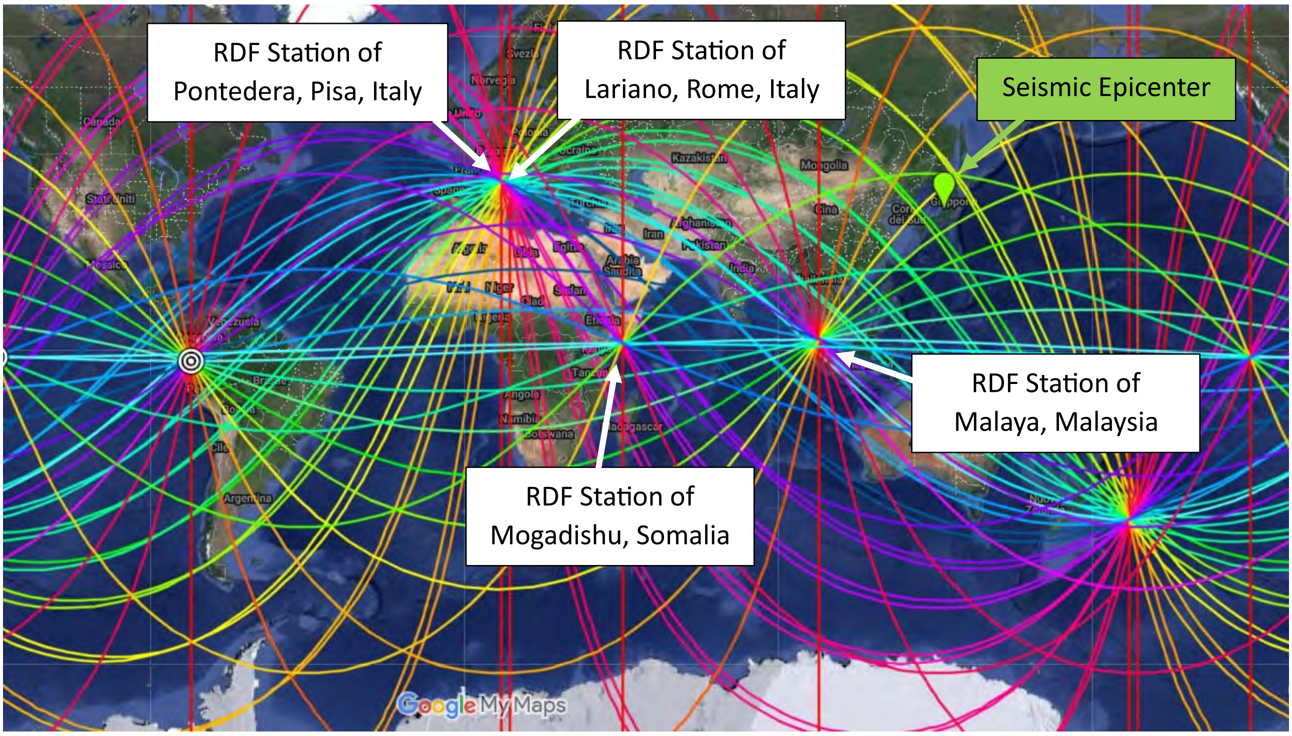

Fig. 7 – Worldwide colorimetric mapping of the RDF network, where the position of the world's RDF stations and the position of the Japanese seismic epicenter are highlighted. Credits: Radio Emissions Project.

If we look at the RDF world colorimetric map, we notice that the seismic epicenter of the Japanese earthquake occurred within the green azimuths, with reference to the RDF stations of Lariano, Rome, Italy and that of Mogadishu in Somalia (Figure 6 and 7).

It is no coincidence that these colors appeared on the dynamic spectrograms of the respective RDF stations, which identified these electromagnetic signals coming from precisely this point of the earth's crust.

2.4 - Geomagnetic Activity Data

The authors, together with the radio-electromagnetic emissions detected by the RDF network, also analyzed the variation of the solar ion flux density in the days preceding the Japanese Mw 6.2 seismic event recorded on May 5, 2023, and found that on May 4 , 2023 at 18:00 UTC the density of the solar proton flux underwent a clear increase (Figure 8) which subsequently produced a perturbation of the earth's geomagnetic field.

To confirm this, it is possible to observe the variation curve of Kp-Index which quantifies the disturbance of the horizontal component of the earth's geomagnetic field (Fig. 8).

The increase in solar proton flux precedes by about 13 hours the Mw 6.2 seismic event recorded in Japan on May 5, 2023 at 05:52 UTC, and this data confirms the observations conducted by the authors since 2012:

all potentially destructive seismic events occurring on a global scale are always preceded by an increase in the solar ion flux density which can have a more or less significant impact on the earth's geomagnetic field [1-40].

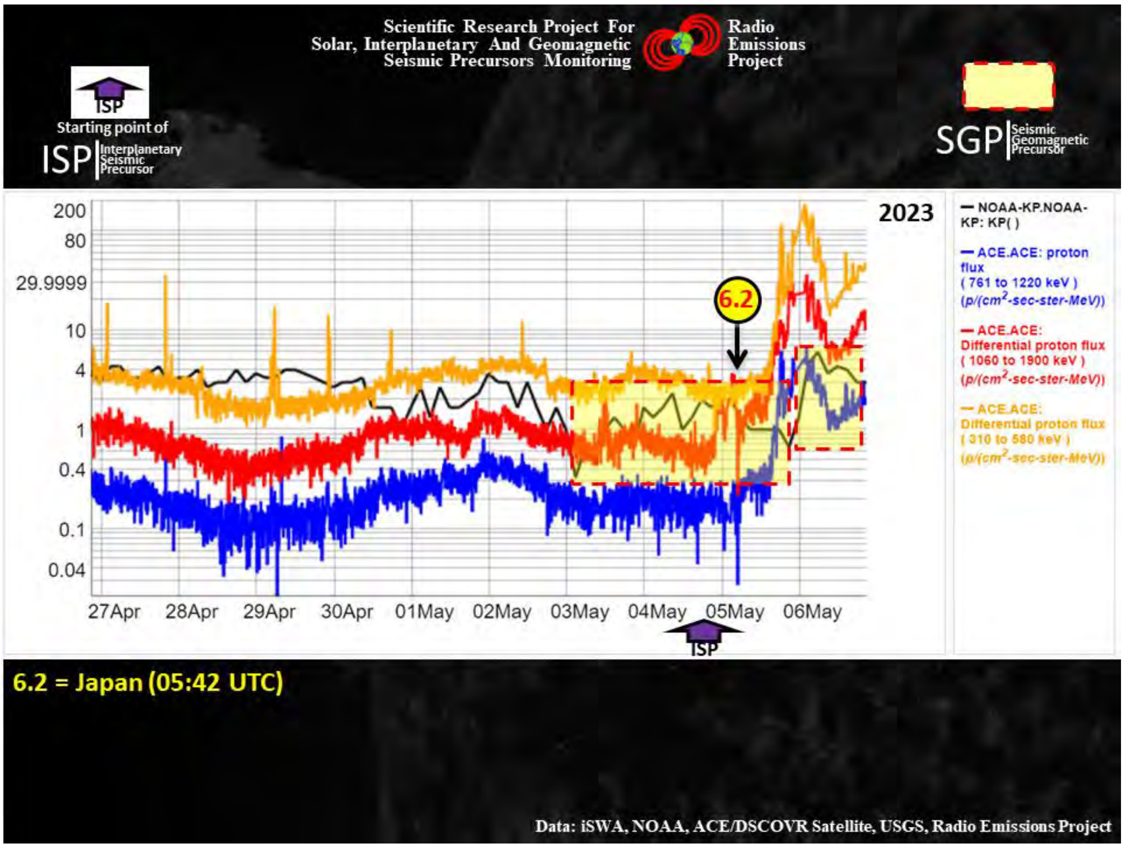

Fig. 8 – Interplanetary Seismic Precursors (ISPs). In the image above it is visible the variation curve of the proton density of the solar wind (energy fractions: 761-1229 keV, 1060-1900 keV and 310-580 keV) recorded between 3 and 5 May 2023 through the Advanced Composition Explorer (ACE or Explorer 71) Satellite, in L1 Lagrangian orbit. The black curve indicates the variation of Kp-Index. The purple arrow indicates the beginning of the proton increase related to the Japanese seismic event. The vertical black arrow indicates the time marker of the Japanese Mw6.2 earthquake recorded on May 5, 2023. The yellow area delimited by the red dashed line indicates the increase of the Kp-Index (Seismic Geomagnetic Precursor) which preceded the seismic event Japanese M6.2. Credits: iSWA, USGS, Radio Emissions Project.

2.5 – TEC data

Another source of data relating to the study of the seismic precursors of this telluric event was the TEC - Total Electron Content (Fig. 9). It is a measure of the total amount of free electrons in a column of air between an orbiting satellite and a receiver on the earth's surface. This quantity is often used to study the interaction between the Earth's upper atmosphere (ionosphere) and the radio wave signals traveling through it. The ionosphere is a layer of the Earth's atmosphere that extends from about 60 kilometers to over 1,000 kilometers in altitude. It contains a significant concentration of free ions and electrons, which can affect the propagation of radio waves. When a communication signal crosses the ionosphere, it interacts with the electrons present, causing a variation in its propagation speed. This effect is known as ionospheric lag. TEC is measured in terms of electrons per square meter (electrons/m²) along the line of sight between a Global Positioning System (GPS) satellite or similar navigation satellite and a GPS receiver on the earth's surface. In this case, the group of researchers involved in this study verified whether there were phenomena capable of interacting with the ionosphere and its modifications, close to the time of the earthquake. Well, the data confirm that close to the Japanese earthquake some variations of the TEC were observed in correspondence with the hours preceding the earthquake, this could suggest that the modifications of the TEC may have originated both from solar activity and from phenomena that influenced on the modification of the TEC at the level of the Earth-Ionosphere cavity, produced by earthquake preparation phenomena.

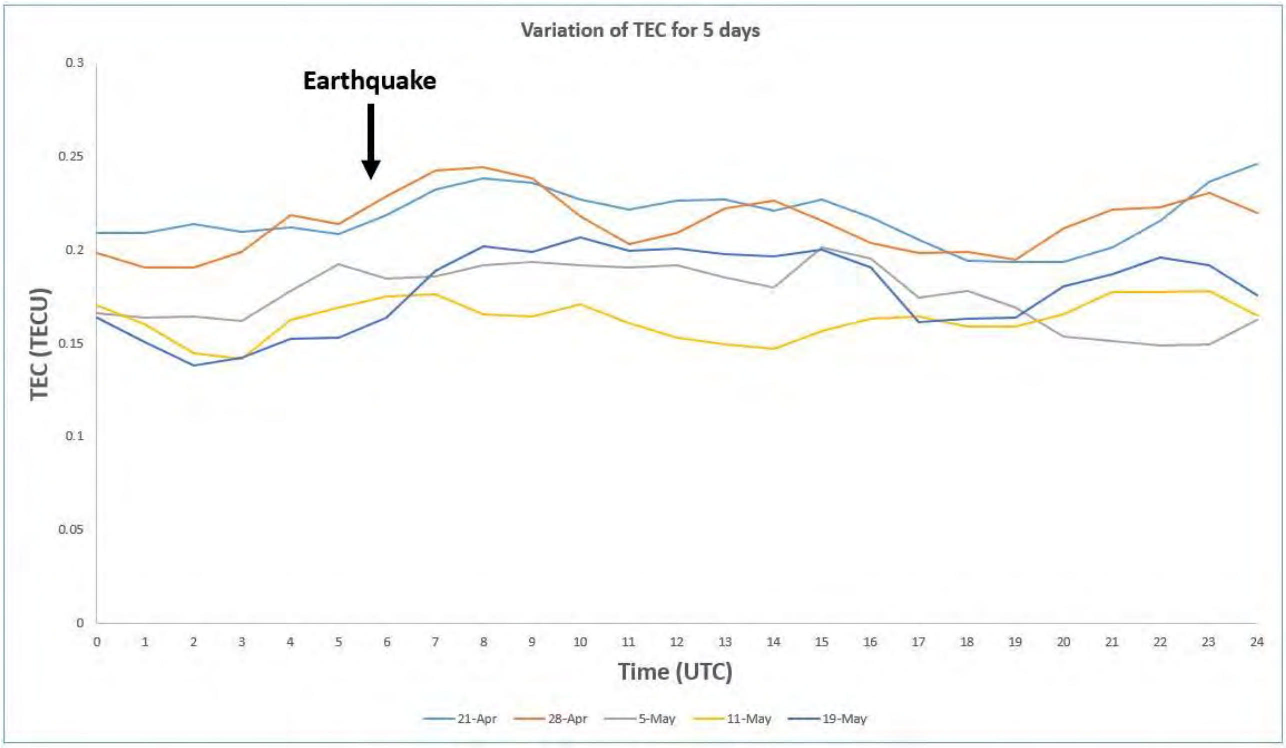

Fig. 9 – TEC - Total Electron Content, measured in the ionosphere, close to the period in which the Japanese earthquake occurred. Note the gray line (May 5) and the time of the Japanese earthquake indicated with a black arrow indicating a change in the concentration of electrons in the ionosphere shortly before the earthquake occurred. Credits: NASA - Crustal Dynamics Data Inforamtion System's global ionospheric map for day of the earthquake and 2 days before and after the event.

2.6 – Proton Density

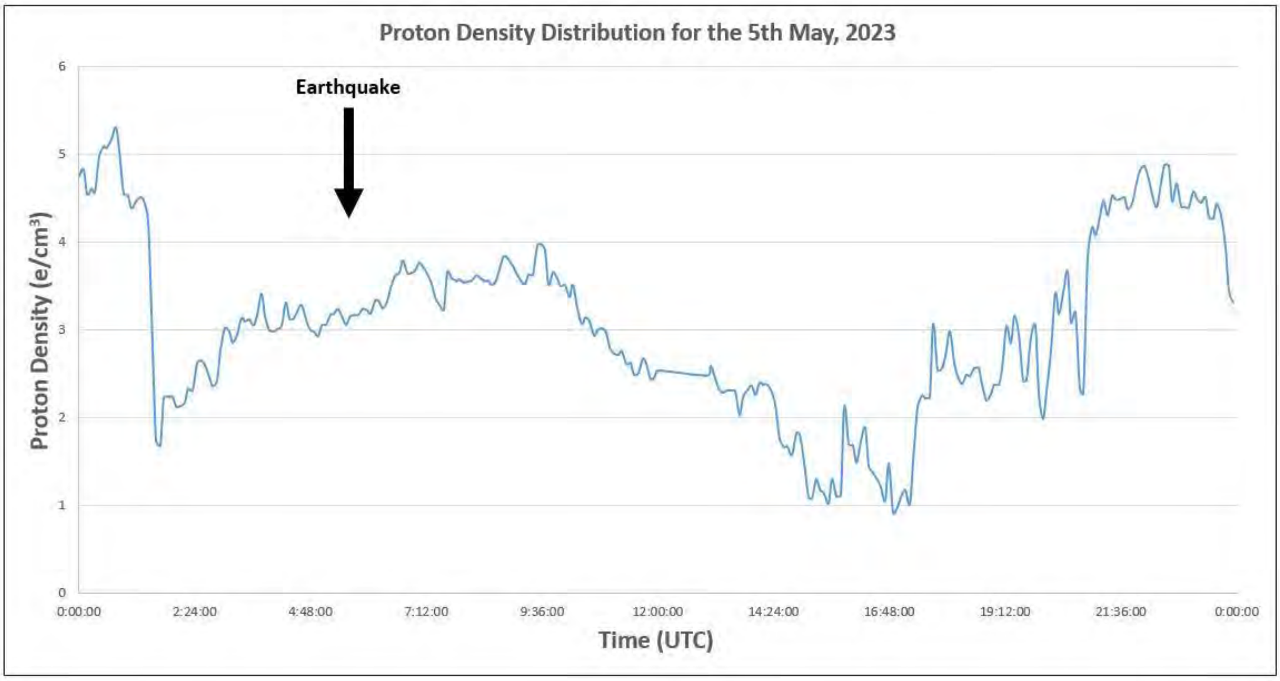

Fig. 10 – Variation of proton density measured outside the planet Earth, in relation to solar activity. We highlight micro-variations that followed and preceded the seismic event that occurred in Japan. Credits: NASA Solar and Heliospheric Observatory (SOHO) database.

The proton density data, as visible in Fig. 10, indicate the presence of micro variations in the amount of protons in space, close to our planet that preceded the Japanese earthquake. This evidence has been demonstrated for years by the Radio Emissions Project through studies started in 2012. The proton variation always follows the terrestrial seismic activity and this indicates a close relationship between terrestrial earthquakes and solar activity.

3 – DISCUSSION

If we look at the data acquired by the RDF station of Mogadishu, Somalia, we realize that these signals indicate the azimuth in the direction of Japan, as well as the signals highlighted by the RDF station of Lariano, Rome, Italy. The group of researchers therefore wondered if these signals could be evidence of electromagnetic signals of a pre-seismic type, or rather precursors that could herald the occurrence of the strong Japanese earthquake.

As we have been able to observe, the temporal closeness of the appearance of these signals, compared to the time of the Japanese earthquake, at least establishes a temporal correlation of these signals with the earthquake itself, data that have already been highlighted by previous studies by the Radio Emissions Project.

In this research context, it is also essential to evaluate the data relating to the TEC and the proton variation observed in space, around the Sun, elements which always indicate how solar activity is directly correlated with global seismic activity. Also in this case the data confirm that variations, even if minimal, of the TEC and of the ion density have been recorded, a datum that confirms once again how strong earthquakes are influenced or triggered by a series of still little known mechanisms, linked to solar activity.

Is it possible to consider the activity of the TEC and the space-weather as a predictive index of a seismic type, capable of suggesting the occurrence of destructive earthquakes within a few hours of the appearance of their variation? Yes, since in this case, the variation of the proton density always varies before a strong earthquake, while the variation of the TEC seems to be correlated but in a smaller percentage.

4 - CONCLUSIONS

In conclusion of this study, it is confirmed that the variations observed in relation to the TEC and the proton density measured in space near our planet underwent variations directly correlated (temporally) with the Japanese earthquake, these signs were preceded by the variation of electromagnetic emissions from the Japanese area where the earthquake occurred a few hours earlier, electromagnetic waves detected thousands of kilometers away (Somalia and Italy).

It is important to note that this result was obtained thanks to the continuous monitoring of the terrestrial geomagnetic activity which took place between Somalia and Italy, and this indicates that the main road to follow in the future is precisely the use of multiple RDF survey stations located in various parts of the globe, stations that will be able to provide more information in order to understand when an earthquake will hit a certain area of the planet.

The identification of electromagnetic signals propagated by specific areas of the planet, before these are hit by strong earthquakes, is the basis of a forecasting system that all researchers, on a global scale, should consider with a view to studying and analyzing electromagnetic signals that actually seems to be related to phenomena capable of generating earthquakes.

The recording and analysis of pre-seismic electromagnetic signals is extremely easy compared to the analysis and identification of other types of precursors, since these are signals that can also be detected at a huge distance from the future seismic epicenter. Their propagation, in the earth-ionosphere cavity, allows these signals to reach every part of the globe, in relation to their emission power (kW), in addition to the fact that no particular technologies or equipment are required to be picked up.

As it is understandable to understand, the future of seismic prediction seems to be linked to the study and analysis of this type of signals, also in relation to solar activity and space weather.

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