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Radio direction finding for short-term crustal diagnosis and pre-seismic signals. The case of the Colonna Earthquake, Rome (Italy)

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ABSTRACT

The RDF System is an instrumental analysis method for the detection of electromagnetic anomalies through a colorimetric scale, displayed on a monitor. The signals are recorded daily 24 hours a day, and related to earthquakes that occur in the same direction that indicated by the colorimetric scale. The experimentation allowed to detect the recurrence of signals that appear before the earthquakes, in a four-day time window. The Radio Direction Finding (RDF) system is a multi-channel radio receiver prototype capable of working in the SELF-VLF band ($0Hz<f\leq30kHz$). The detection system, located in Italy, coupled with a system of directional antennas and a software allows to measure the angle of origin of a given electromagnetic emission. The monitoring stations are located in Italy near the cities of Rome, L'Aquila and Pisa, and are constituted by a coil antenna and the RDF device interfaced with a computer. The three monitoring stations allow to apply the triangulation method, which is used to determine with a good approximation the direction of the EM signal. In this study, the report of the Colonna earthquake study (Rome) is proposed, where you can follow the evolution of the signals and the determination of the epicentral area.

Key words: Earthquakes, Seismic precursors, RDF, EM emissions, crustal diagnosis

1. INTRODUCTION

The RDF (Radio Direction Finding) electromagnetic monitoring system is an environmental electromagnetic monitoring system designed and built by Gabriele Cataldi and Daniele Cataldi (founders of the Radio Emissions Project) in 2017 for the study of pre-seismic radio emissions.The system, although based on a technology developed for military purposes in the early twentieth century [1-3] represents an innovative research method that the authors have applied for the research of seismic precursors since March 2017 [4-9].

There are currently 4 RDF electromagnetic monitoring stations:

- Lariano (RM), Italy; Lat: 41.728799°N, Long: 12.843205°E, (Fig. 1);
- Ripa-Fagnano (AQ), Italy; Lat:42.26569°0N, Long: 13.583793°E, (Fig. 1);
- Pontedera (PI), Italy; Lat: 43.672479°N, Long: 10.640259°E, (Fig. 1);
- Kuala Lumpur (University of Malaya), Malaysia; Lat: 3.053346°N, Long: 102.064001°E, (Fig. 2);

The validity of the electromagnetic environmental monitoring, as a tool capable of providing new scientific evidence on the existence of the so-called pre-seismic electromagnetic signals, has been verified by the authors on various occasions since 2012 [10-17]. The data obtained on this type of natural radio signals allowed the authors to guess that it was possible to identify the point of origin of these pre-seismic radio emissions using an innovative environmental electromagnetic monitoring system that would have allowed to identify the epicentral area of a seismic event several hours in advance.This system was designed, built and made operational by the authors in March 2017 and is known by the name "Electromagnetic Monitoring System RDF (Radio Direction Finding)" or "RDF System". Compared to other conventional environmental electromagnetic monitoring systems dedicated to the study of pre-seismic radio signals, the RDF system is able to measure, over a wide bandwidth (Fig. 1), the angle of origin (azimuth) of the electromagnetic signals with respect to the four geographical cardinal points (North, South, East, West) and produce dynamic spectrograms that are able to provide the following information on the electromagnetic signals detected, regarding: frequency, intensity , azimuth, bandwidth, spectrographic characteristics (spectral footprint), recording date and time. Dynamic spectrograms are created through the free-software "Spectrum Lab".This electromagnetic monitoring system has been designed to work efficiently in the SELF-LF band (Super Extremely Low Frequency-Low Frequency; $0<f\leq96$ kHz; (Fig. 3) thanks to the use of low noise electronic components.

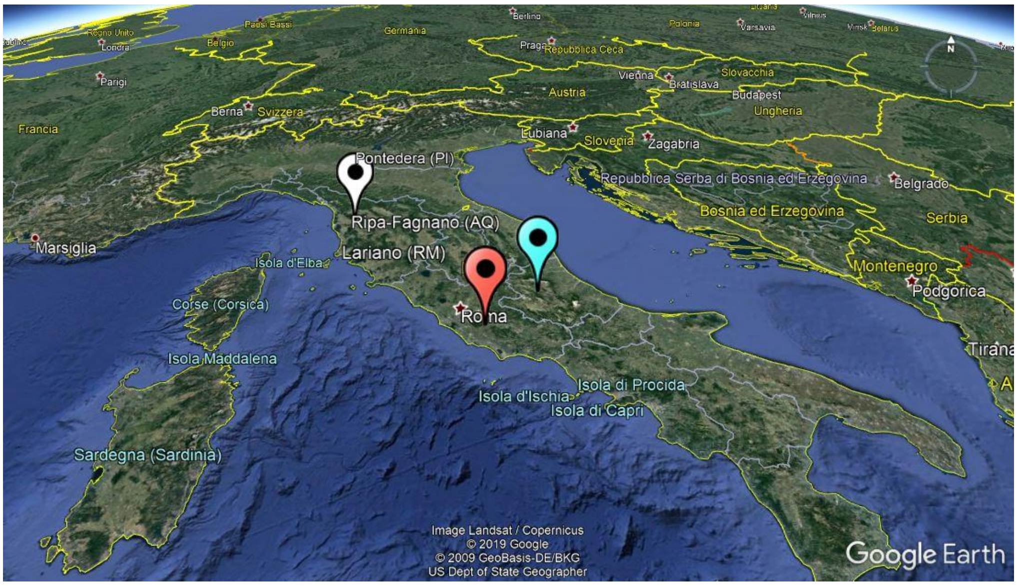

Fig. 1 RDF electromagnetic monitoring stations installed in Italy.

In the image above is visible the Italian map containing the three geographical sites where the three RDF stations of the Radio Emissions Project are installed: Lariano (RM) (red placeholder), Ripa-Fagnano (AQ) (cyan placeholder), Pontedera (PI) (white placeholder). Credits: Radio Emissions Project; Google Earth.

Fig. 2 RDF electromagnetic monitoring station located in Kuala Lumpur, Malaysia

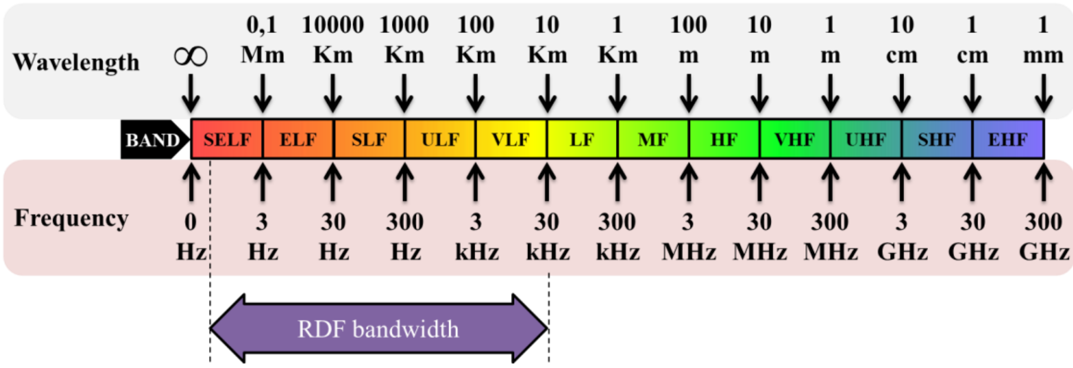

Fig. 3 Electromagnetic spectrum monitored by the RDF system

The top image shows the electromagnetic spectrum monitored by the RDF electromagnetic monitoring system developed by Gabriele Cataldi and Daniele Cataldi in 2007: this has an extension of ≈30kHz, but it can be extended as desired up to 96kHz. Credits: Radio Emissions Project.

The RDF detection system continuously records electromagnetic emissions from variable distances, with a maximum distance of 20,000 km [5]. When a certain signal is detected, the system associates a color with respect to the azimuth, i.e. with respect to the direction of arrival. In this way a dynamic spectrogram is generated whose internal coloring indicates the arrival direction of all the electromagnetic signals captured with respect to: the cardinal points; the location of the RDF station that identifies it [5]; with respect to time. In a synthetic way, the colors indicate this directions from which come the electromagnetic signals: Red = N-S axis; Turquoise = E-W axis; Green = NE-SW axis; Purple = SE-NW axis. As already mentioned, the colorimetric scale applied to azimuth allows the horizontal plane composed of 360° to be divided into 256 color gradations that correspond to an azimuth resolution of 1.4° for each color gradation. A compass on the spectrogram associates the color gradations with the azimuth (Fig. 4).

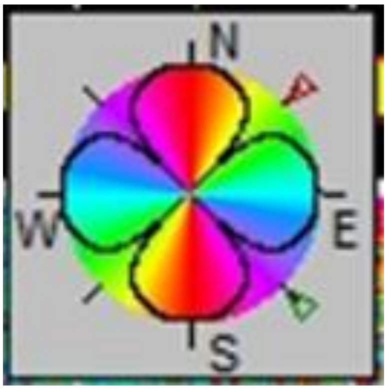

Fig. 4 Compass of RDF System

In the image on the left is visible the compass of the RDF System which is located inside the spectrograms. It indicates the gradations of color (256 tones) associated with the azimuth direction of the electromagnetic signals collected in relation to the four cardinal points (N, S, E, W). The black line in the shape of a four-leaf clover represents the diagram of the sensitivity of the RDF antenna which is made up of two loop antennas aligned orthogonally to each other (that's why 4 lobes are observed) and in the direction of the N-S and E-W lines; while the two small triangles (one green and one red) represent the direction along which the antenna has its least sensitivity.Credits: Radio Emissions Project.

2. THE RDF DEVICE

The heart of the monitoring station is represented by a dual channel radio receiver that works with an amplification of 200x (46dB) using ultra-low noise operational amplifier powered at low voltage (+5V) through the power line of a USB port of the computer to which the receiver is coupled to perform the analysis of the radio signals detected (Fig. 5). This configuration allows to further reduce the electronic noise and improve the environmental readings (Cataldi G, [17]), and allows to reach a sampling of 192kHz.

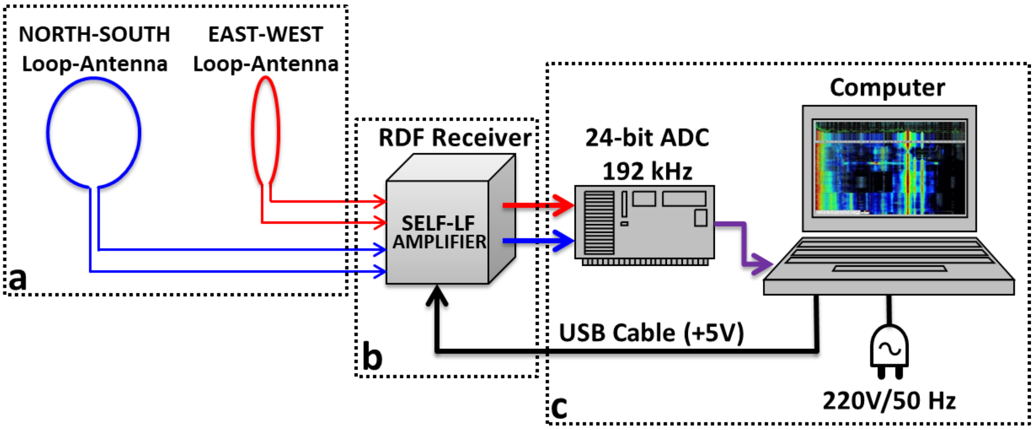

Fig. 5 RDF electromagnetic monitoring system developed by the Radio Emissions Project

The top image shows a schematic representation of the subsystems of which the RDF monitoring station is composed: [a] loop antennas aligned orthogonally to each other and aligned with respect to the geographical cardinal points (North-South; East-West); [b] Dual channel radio receiver (prototype); [c] IT subsystem with 24-bit Analog to Digital Converter (ADC).Credits: Radio Emissions Project.

This conversion allows to perform very detailed measurements on the electromagnetic signals captured by the RDF electromagnetic monitoring station allowing to produce dynamic spectrograms in false colors that have the following characteristics:

- monitorable bandwidth ≈96kHz (SELF-LF band: Super Extremely Low Frequency-Low Frequency; 0<f≤96kHz);
- resolution: 10-15mHz (1mHz = 0.001Hz);
- recording speed/spectrogram advance: 1 vertical line per second. In this way, the electromagnetic monitoring data corresponding to at least 12-15 consecutive hours can be condensed on a single spectrogram;
- radiogoniometric resolution: on the spectrogram it is expressed in false colors (256 tones) and corresponds to 1.4° for each individual tone (360°/256 tones = 1.4°).

The advantages of spectral conversion of electromagnetic monitoring data are many (Cataldi G, 2019):

- allows to get an overview of the data over a wide bandwidth;
- allows to quickly identify the intensity and frequency of radio signals using a color scale (or shades of gray);
- allows to easily identify the presence of harmonics resonance of a radio signal;
- allows to perform a spectrographic comparison of natural and anthropic radio carriers over a wide period of time;
- allows to follow the temporal evolution of changes in frequency and intensity of natural and anthropic radio carriers;
- by saving the data, it allows to create an archive containing all the spectral traces of the radio signals recorded on a certain bandwidth: this allowsto compare the spectral characteristics of the natural and/or anthropic radio carriers over a very long period of time;
- allows to check if, at a certain time, there have been changes in the frequency and intensity of natural and anthropogenic radio signals visible on a certain bandwidth. This feature allows the electromagnetic monitoring station to be used as a "Sudden Ionospheric Disturbance (SID) Monitor", through which it is possible to monitor solar activity in relation to the ionospheric propagation characteristics of VLF and/or LF radio signals.;
- allows to temporally correlate electromagnetic anomalies faster and easier with tectonic and volcanic events;
- allows to identify natural and anthropic broadcasters with greater speed, simplicity and detail by analyzing their spectral footprint.

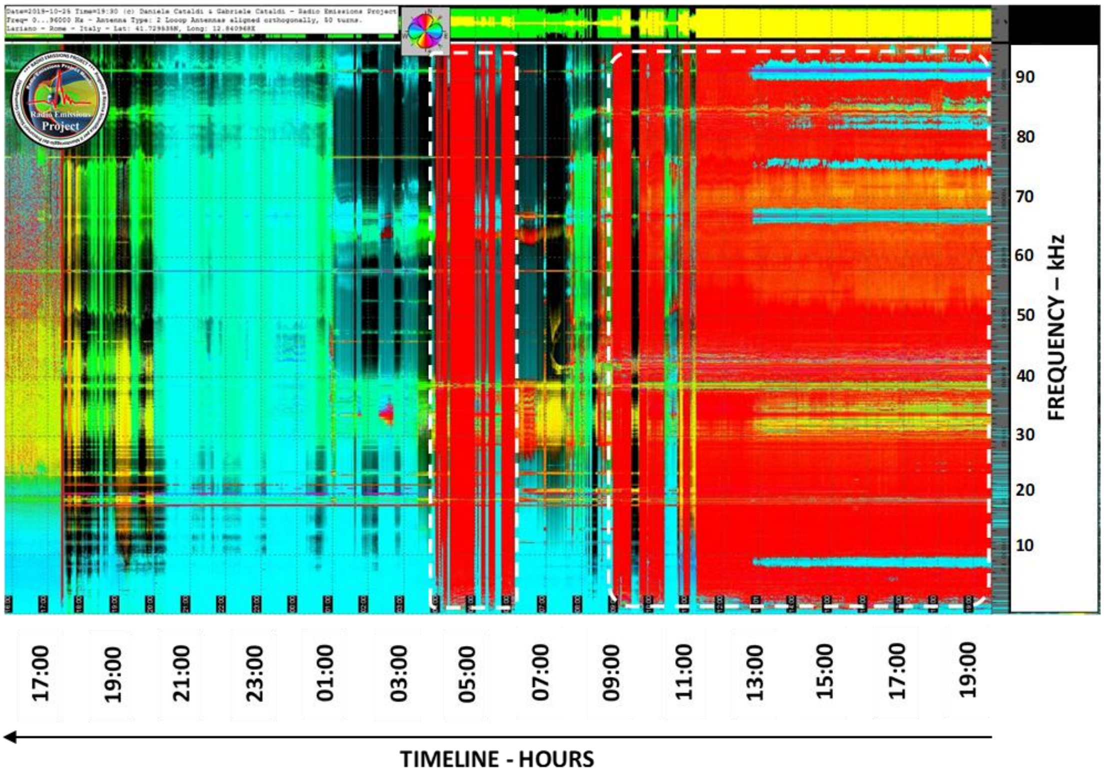

Fig. 6 Azimuthal characteristics of the electromagnetic anomaly related to the Ml 3.3 earthquake recorded in Venice on 25 October 2019.

In the top image is visible a RDF dynamic spectrogram recorded through the electromagnetic monitoring station of Lariano, Rome, Italy on October 25, 2019. It shows an intense increase (red) localized in broadband (1-96kHz) appeared on 25 October 2019 at 04:00 UTC. A few hours later, and exactly at 10:28 UTC, an earthquake of magnitude ML 3.3 was recorded in the Venetian coast (Venice, Italy) at a depth of 8 km. In this context, the earthquake occurred along the azimuth (red) indicated by the RDF system developed by the Radio Emissions Project (as visible in Fig. 6b). Credits: Radio Emissions. Project.

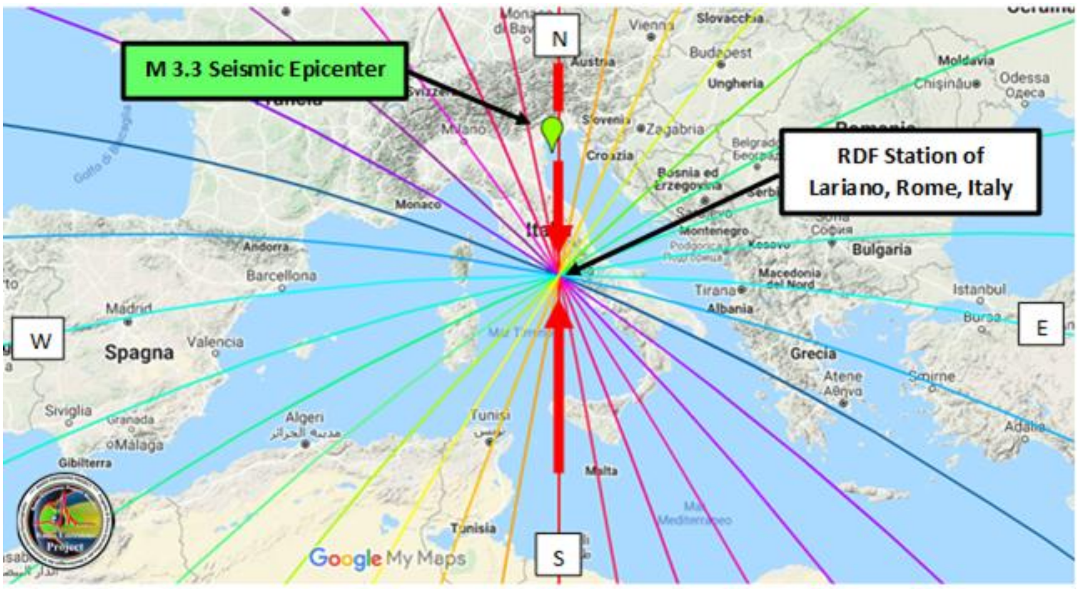

Fig. 6b Analysis of RDF azimuth data related to the Venetian earthquake

The top map shows the seismic epicenter of the Ml 3.3 earthquake that took place on the Venetian Coast on 25 October 2019 (green color placeholder) compared to the RDF station site in Lariano (RM), Italy. In this case the azimuth identified by the red color (which corresponds to the North-South direction) is compatible with the azimuth of the Venetian seismic epicenter. Credits: Radio Emissions Project, INGV, Google Maps.

The analysis of the spectral footprint of an electromagnetic signal can highlight the presence of a modulating signal, that is, information expressed on the base carrier. This technique allows us to identify electromagnetic carriers of an anthropic nature simply by observing their spectral structure.This method of analysis of electromagnetic signals allows to discriminate anthropogenic emissions from natural and, among these, geomagnetic (Fig. 6), atmospheric/meteorological emissions from those that can potentially be candidates as pre-seismic radio emissions.

Electromagnetic emission that is observed before a seismic event. In the field of RDF electromagnetic monitoring, this electromagnetic anomaly originates within the earth's crust, as theorized by many researchers since the 1980s [18-22]. Based on these studies and laboratory evidence obtained since 2000 [23-25] it is now clear that as a result of the accumulation of tectonic stress it is possible that they are pre-seismic electromagnetic dipoles produced through the piezoelectric effect, due to the deformation of rocks included in the fault plane. The position of these electromagnetic emitters can be identified using electromagnetic monitoring systems capable of determining the direction of arrival (azimuth) of the electromagnetic signals; as shown by Ohta et al. [26]

3. DATA

The monitoring data are collected 24/7 (24 hours a day, 7 days a week), analyzed in real time and compared with the earthquake websites (www.ingv.it; earthquake.usgs.gov). The data collection, to date, exceeds 465 cases, of which more than 97 cases with a magnitude less than M6 and 368 cases with a magnitude M6+. The pre-seismic candidate signals have shown to have a 100% relationship with the associated earthquakes, including the estimate of the epicenter. As an example, the discussion of the data is carried out on the Colonna earthquake (RM), with the epicenter located about 16 km from the monitoring station, and not far from Rome.

4. DISCUSSION

On June 23, 2019, at 20:43:48 UTC, an earthquake with magnitude ML3.7 was recorded in Colonna (RM), Italy (Lat.: 41.86°N; Long.: 12.77°E) at a depth of 9km. In the following report it is possible follow the entire chronology of events that led to the definition of the triangulation of the data, with the definition of the potential area of the epicenter, subsequently confirmed.

Earthquake Data						
Date, time, location	Lat.	Long.	ML	Deep	Distance from the estimated epicenter	Signal/earthquake time interval
23-06-2019 at 20:43:48 (UTC); 3 km NE Colonna (Rome)	41.86°N	12.77°E	3.7	9 km	15.9 km (Lariano Rome). 166 km (Pontedera-Pisa).	146 hours respect to Lariano (RM) and 31 hours respect to Pontedera (PI).

This earthquake was preceded by a series of electromagnetic surveys performed through the RDF station of Pontedera (PI) and Lariano (RM). The two stations had recorded intense electromagnetic emissions in the ULF-VLF (Ultra Low Frequency-Very Low Frequency; 0.3-30kHz) band which had almost superimposable azimuth. The subsequent analysis of the azimuth data of these radio emissions allowed to verify that:

- with respect to the RDF station Lariano (RM), the source angle of the signals was identifiable on the NNW-SSE directrix since June 17, 2019 (Fig. 6);
- with respect to the Pontedera RDF station (RM), the source angle of the signals was identifiable on the NNW-SSE directrix since June 22, 2019 (Fig. 7).

The initial data, obtained through the RDF station located in Lariano (RM), between 17 and 18 June 2019, indicated emissions with NNW-SSE directrix at a frequency between 1 and 30 kHz. Subsequently, on June 21, 2019, the RDF station located in Lariano (RM) recorded a second electromagnetic emission that had the same azimuth as those recorded between June 17 and 18, 2019.: in this case the electromagnetic increase had started at 03:00 UTC on 21 June 2019 and involved a bandwidth between 1.5 and 27 kHz (Fig. 7). The researchers had again received indications of a specific azimuth. Subsequently, the RDF station located in Pontedera (PI), detected a series of very interesting electromagnetic increases when compared with the RDF data provided by the RDF station located in Lariano (RM): at approximately 12:15 UTC on 22 June 2019 an electromagnetic signal was detected with red/purplish azimuth that had bandwidth between 12 and 22 kHz which remained visible for about 95 minutes (Fig. 8). This signal was followed by a second electromagnetic increase characterized by a purple/blue azimuth and an emission frequency between 22.5 and 47 kHz and between 12 and 47 kHz (Fig. 8).

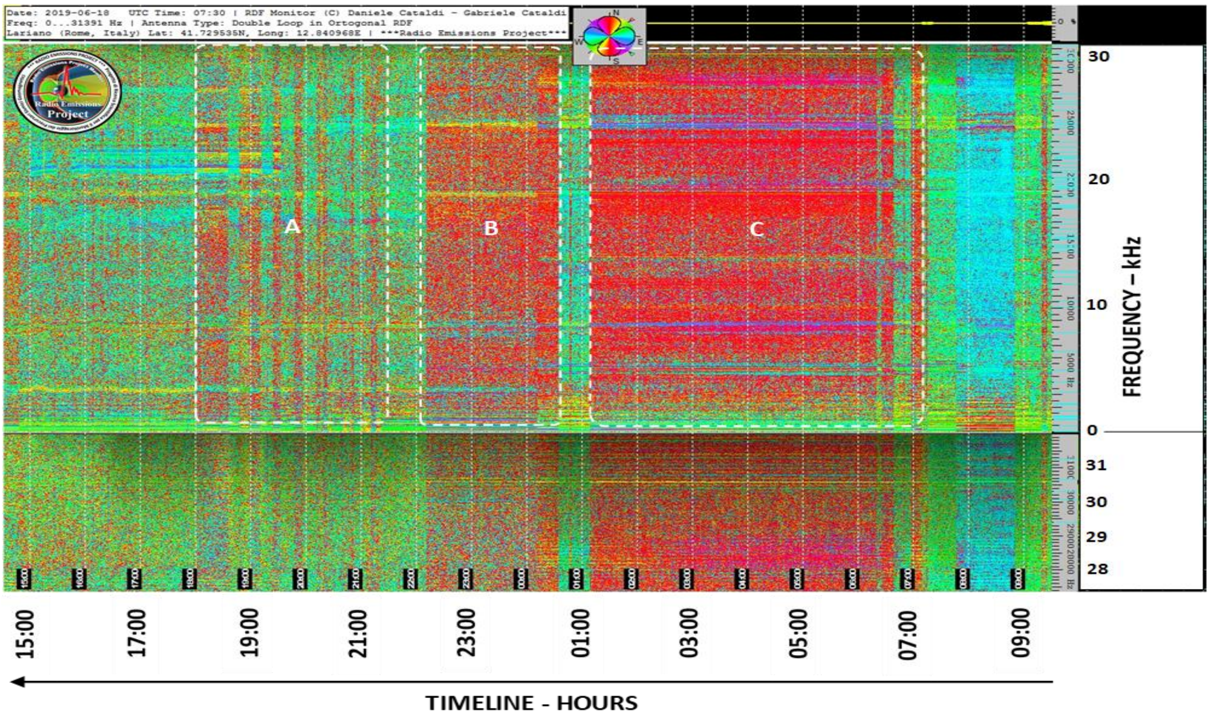

Fig. 6 Azimuthal characteristics of the electromagnetic anomaly related to the Ml 3.7 earthquake recorded in Colonna (RM) between 17 and 18 June 2019.

The spectrogram above shows the dynamic RDF spectrogram recorded through the electromagnetic monitoring station of Lariano (RM) between 17 and 18 June 2019. Within the areas delimited by the white dotted line it is possible to observe broadband electromagnetic emissions which they have a purple azimuth, corresponding to the NNW-SSE line (see Fig. 6b). The appearance of these signals had not been preceded by particular electromagnetic increases. The first issues appeared at around 18:00 UTC on June 17, 2019 (A), with a series of impulsive repetitions between 19:00 UTC and around 21:10 UTC.After a pause of about 50 minutes, the first vast electromagnetic increase recorded by the RDF monitoring system appeared, and exactly at 22:10 UTC on June 17, 2019, remaining visible until 00:30 UTC on June 18, 2019 (two hours and 40 minutes of duration) (B). The intense radio emission, instead occurred around 01:10 UTC on June 18, 2019, remaining visible until 16:35 UTC on June 18, 2019 (C). Credits: Radio Emissions. Project.

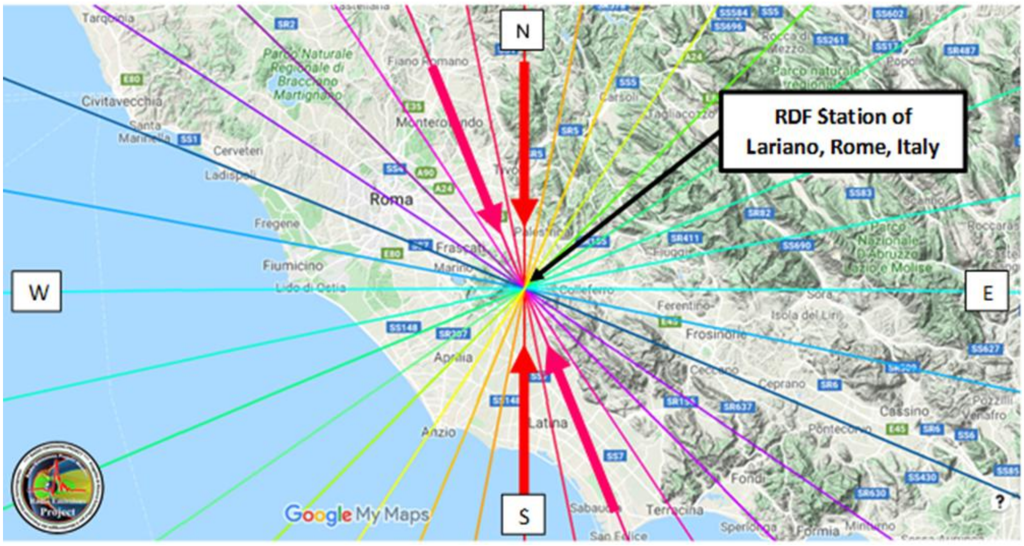

Fig. 6b Preliminary analysis of RDF azimuthal data related to the earthquake occurred in Colonna (RM).
The map above highlighted the geographical area indicated by the RDF station of Lariano (RM), between 17 and 18 June 2019.Credits: Radio Emissions Project, INGV, Google Maps.

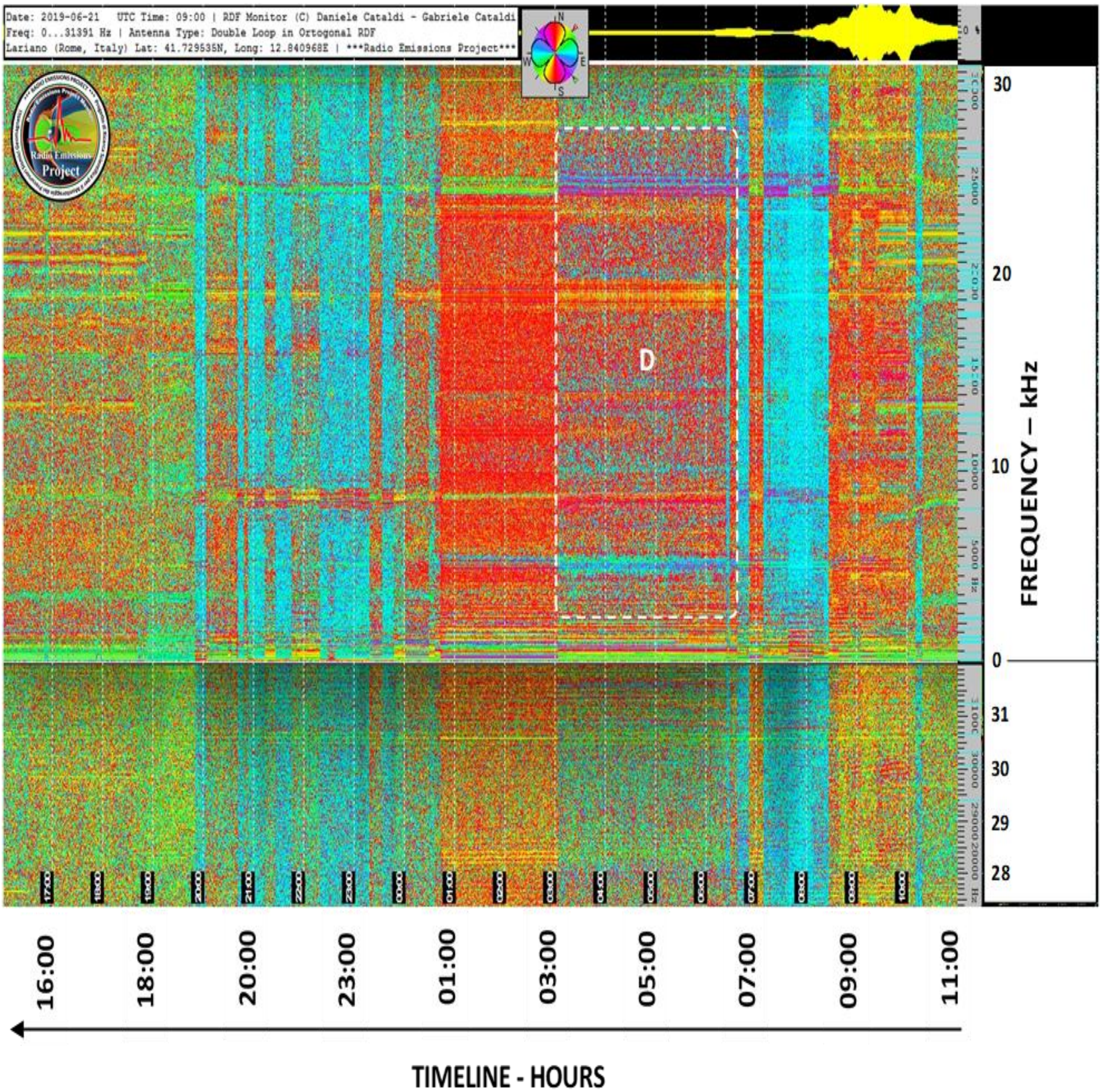

Fig. 7 Azimuthal characteristics of the electromagnetic anomaly related to the Ml 3.7 earthquake recorded in Colonna (RM) on 22 June 2019

In the top spectrogram is visible the RDF dynamic spectrogram recorded through the electromagnetic monitoring station of Lariano (RM), on June 21, 2019. Within the areas delimited by the white dotted line (D) it is possible to observe a broadband electromagnetic emission (1.5-27kHz) which has a purple azimuth, corresponding to the NNW-SSE directrix: azimuth superimposable with that of the electromagnetic signals detected between 17 and 18 June 2019 (Fig. 6) from the same station. Credits: Radio Emissions. Project.

On June 22, 2019, between 13:00 UTC and 20:00 UTC, a second series of radio signals very similar in morphology was recorded. The latter were the result of the presence of a signal placed around 12.5kHz with the respective harmonics resonance visible at 12Hz, 13.5Hz and 14Hz (Fig. 9).

All this series of data described so far (referring to electromagnetic signals that appeared between 17 and 22 June 2019) has no significance on the predictive level if analyzed individually; on the other hand, it is of considerable importance if all these data are observed from an azimuthal point of view with each other.

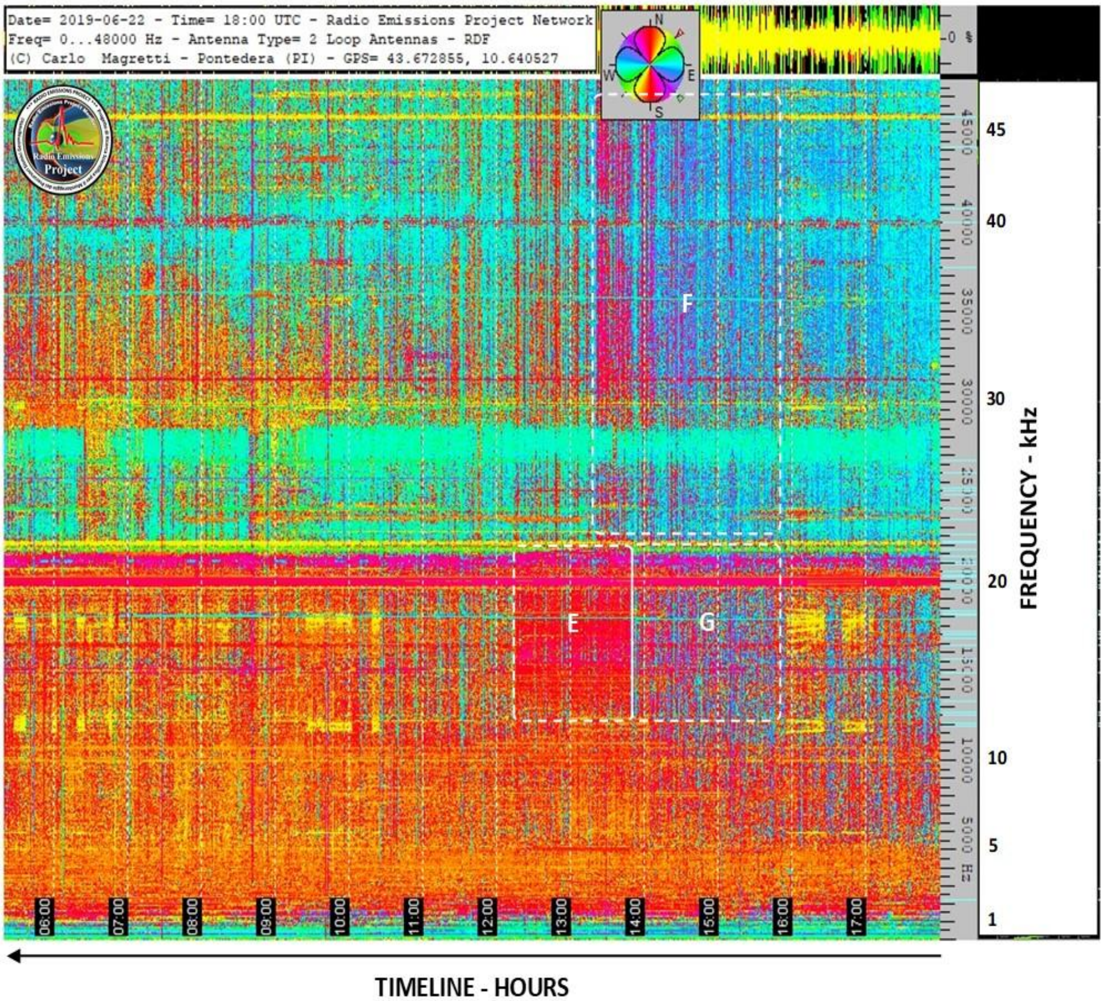

Fig. 8 Electromagnetic signal in the bandwidth between 12 and 22 kHz

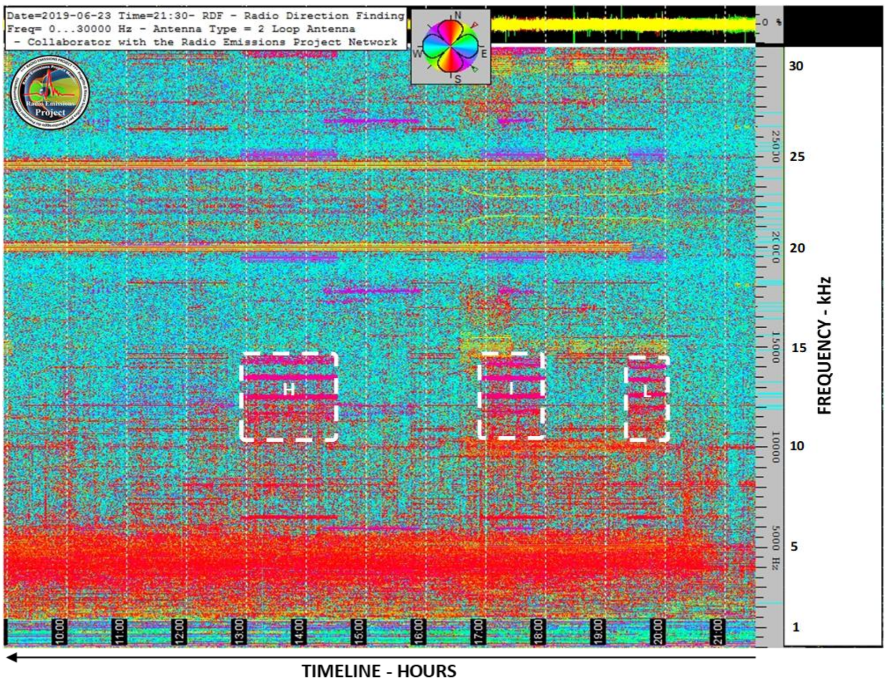

Fig. 9 Azimuthal characteristics of the electromagnetic anomaly related to the Ml 3.7 earthquake recorded in Colonna (RM) on June 21, 2019

The dynamic spectrogram recorded through the RDF monitoring station in Pontedera (PI), on June 23, 2019 is visible in the top spectrogram.The areas delimited by the white dotted line (H, I, L) show three groups of electromagnetic anomalies that appeared between 13:00 UTC and 20:00 UTC which had the same bandwidth (9kHz). The first signal (H) appeared between 13:00 UTC and 14:25 UTC; the second signal (I) appeared between 16:55 UTC and 17:50 UTC approximately; while the third signal (L) appeared between 19:20 UTC and 20:00 UTC approximately. Credits: Radio Emissions Project.

The authors verified the existence of a geographical source common to all the radio signals observed between 17 and 22 June 2019 through the RDF stations of Lariano (RM) and Pontedera (PI), superimposing the azimuth data with each other (triangulation). In fact, the study clearly showed that the Italian RDF monitoring network developed by the Radio Emissions Project, although under development, had been able to indicate a geographical area common to all electromagnetic emissions: an area N-N-E of Rome, Italy (Fig. 10, Fig. 10b and Fig. 10c) whose surface extends for 372 km^2.These data are in clear correlation with the ML3.7 seismic event recorded in Colonna (RM) on 23 June 2019 at 20:43 UTC approximately: the last noteworthy electromagnetic signal received by the RDF monitoring network was recorded at 20:00 UTC of 23 June 2019; while at 20:43:48 UTC (43 minutes after the last signal) the earthquake of magnitude Ml 3.7 occurred at 3 km N-E si Colonna (RM). By checking the geographical coordinates of the earthquake, it is possible be inferred that this occurred within the triangular area highlighted by the RDF monitoring network, starting from June 17, 2019 (almost 6 days before the seismic event). More exactly, the seismic epicenter was located near the West perimeter of the triangular area as shown by the Fig. 11.

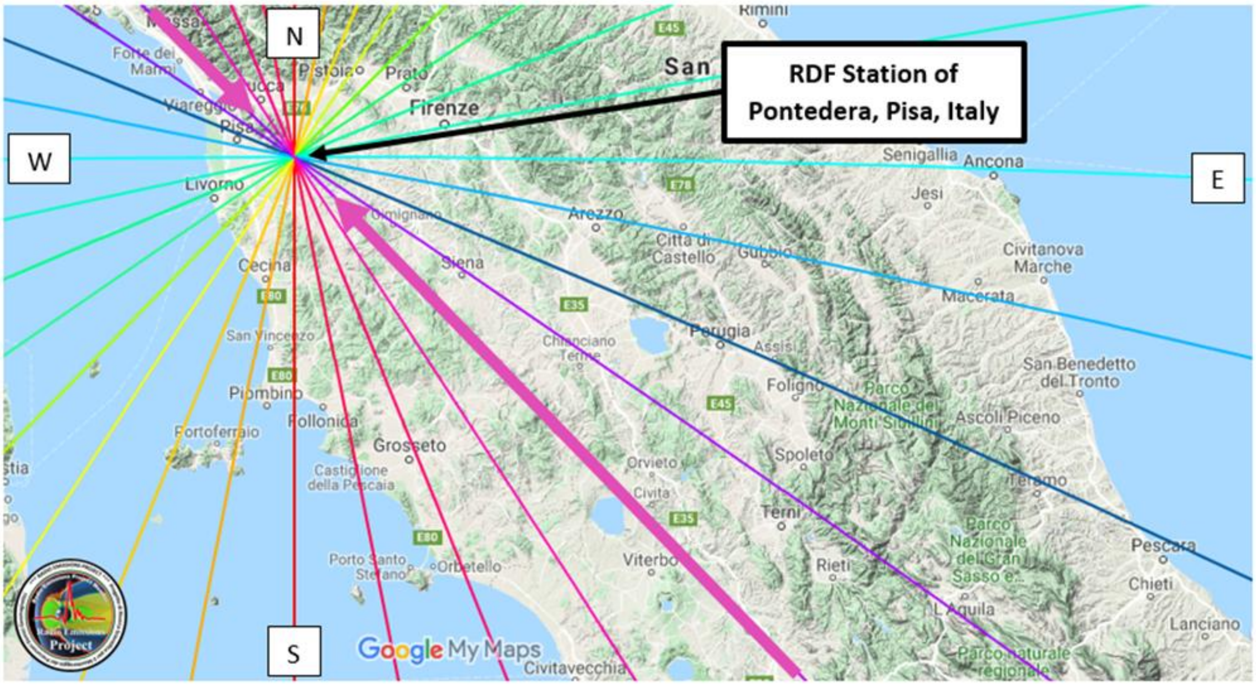

Fig. 10 Final analysis of RDF azimuthal data related to the earthquake in Colonna (RM)

In the map above was highlighted the azimuth direction (purple arrows) of the radio signals picked up by the RDF station of Pontedera (PI), managed by Mr. Carlo Magretti on 22 June 2019. Credits: Radio Emissions Project, INGV, Google Maps.

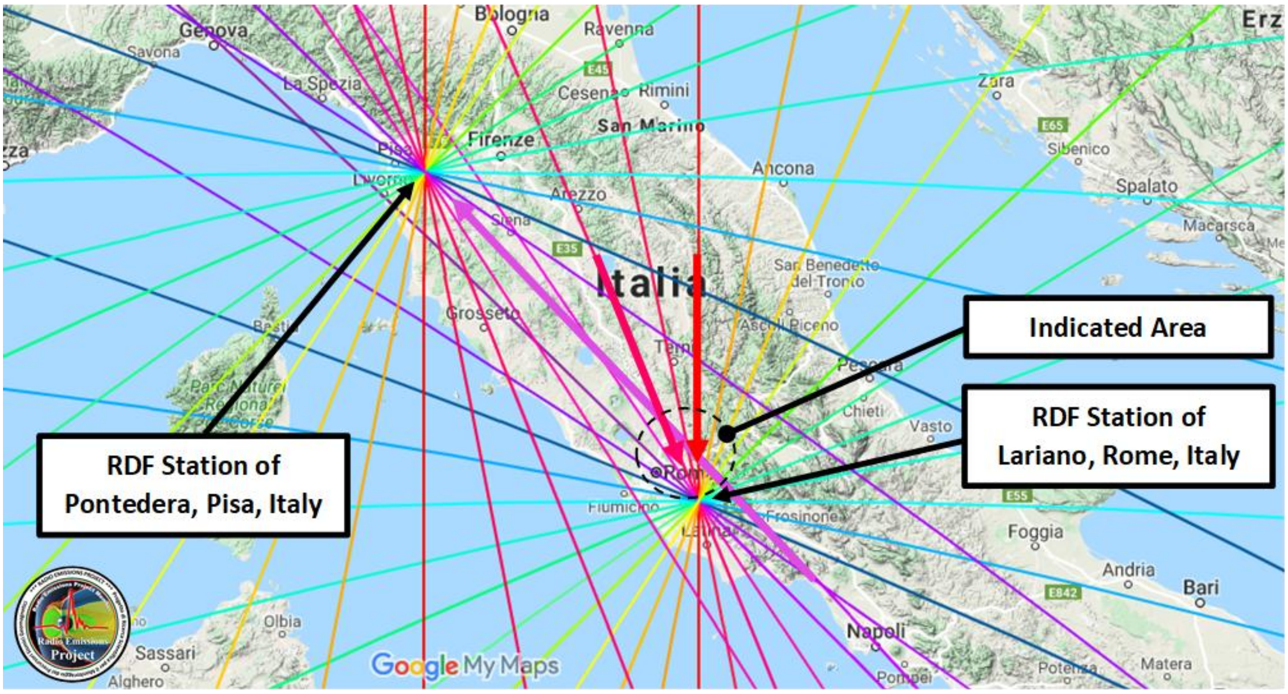

Fig. 10b Preliminary azimuthal triangulation of RDF data related to the earthquake in Colonna (RM)

The top map highlighted the geographical area indicated by the RDF data of the RDF station located in Pontedera (PI) and Lariano (RM) which were acquired between 17 and 22 June 2019. Credits: Radio Emissions Project, INGV, Google Maps.

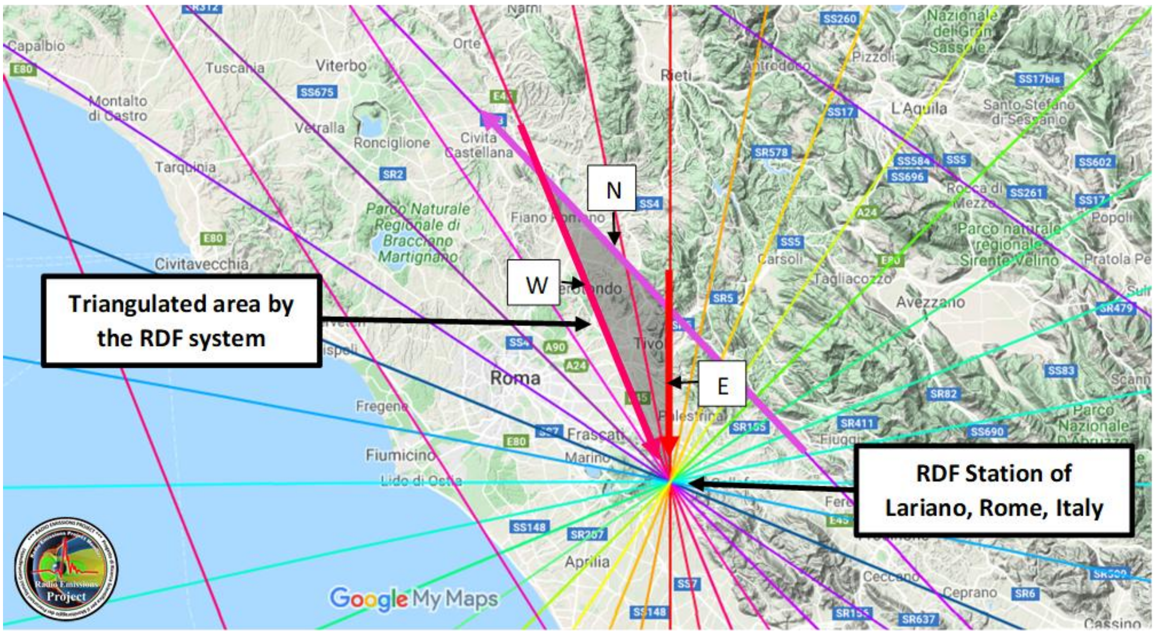

Fig. 10c Final azimuth triangulation of RDF data related to the earthquake in Colonna (RM)

The map above highlighted the geographical area indicated by the RDF data of the RDF station of Pontedera (PI) and Lariano (RM) which were acquired between 17 and 22 June 2019. This has an extension of 372 km^2. Credits: Radio Emissions Project, INGV, Google Maps.

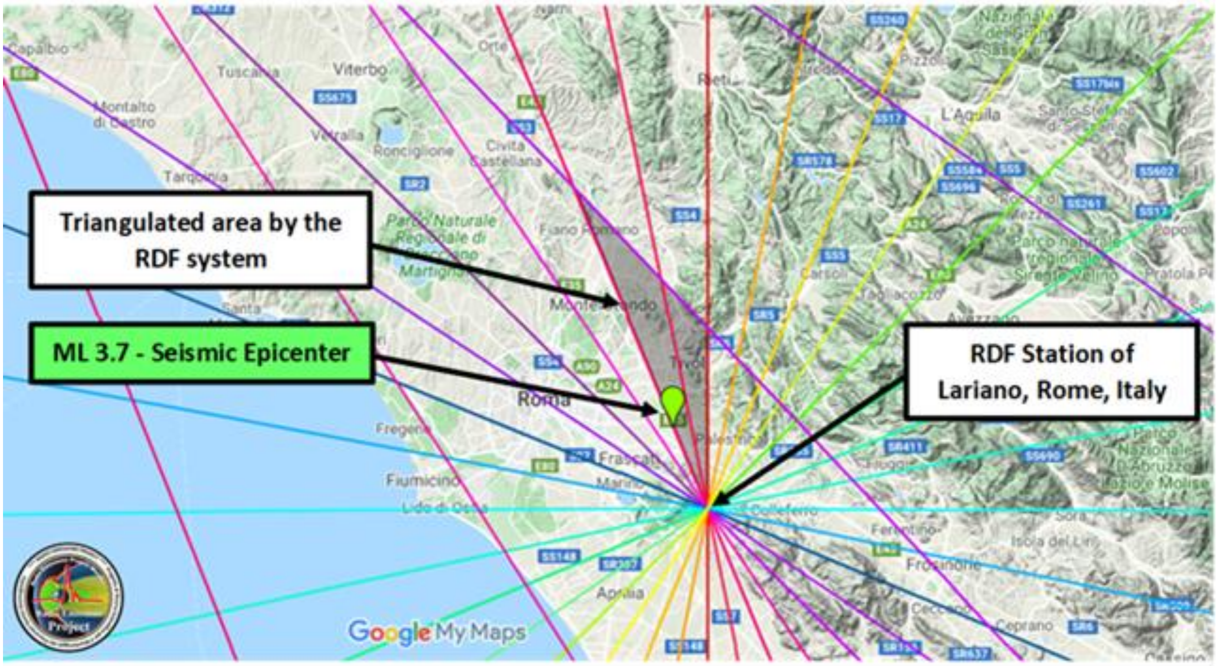

Fig. 11 Azimuthal data compared with the epicenter of the earthquake in Colonna (RM)

In the map above was highlighted the geographical area indicated by the Radio Emissions Project's RDF monitoring network. The epicenter of the Ml 3.7 earthquake recorded in Colonna (RM) is located within the area indicated by the azimuth data provided by the RDF station in Lariano (RM) and Pontedera (RM). Credits: Radio Emissions Project, INGV, Google Maps.

5. CONCLUSION

In this study we asked ourselves if the variations of the EM signals could constitute a new method for the investigation for the identification of reliable pre-seismic signals.The results show that: earthquakes occur along the colorimetric line that indicated by the instrument at least 4-5 days before the quake.

The RDF method is useful if applied it with other monitoring systems methods.In fact the radio anomalies of the RDF System indicates the azimuth, but not the origin point of the EM anomaly. For this reason it is necessary to introduce another parameter: such as the $radon_{222}$ gas, detected in real time not far of the L'Aquila RDF monitoring station. The monitoring stations for the concentration of Radon222 gas have been created and are managed by the G. Giuliani Permanent Foundation. This foundation has been collaborating with the authors since 9 September 2019.The forecast will be more successful when there is a temporal correspondence between the appearance of the EM signal and the peak of radon gas, recorded in the same direction as the colors of the colorimetric map. At the present the RDF System is an effective candidate for the index of crustal diagnosis.We hope that the proposed method can be applied in the future to reduce the seismic risks and to help understand the mechanism of earthquakes genesis.

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