ARTICLES

VLF electromagnetic signals unrelated to the Central Italy earthquakes occurred between 26 and 30 October 2016

Gabriele Cataldi[1], Daniele Cataldi[2] and Valentino Straser[3]

[1]Radio Emissions Project, Rome. ltpaobserverproject@gmail.com
[2]Radio Emissions Project, Rome. ltpaobserverproject@gmail.com
[3]Independent Researcher. valentino.straser@gmail.com

Abstract: Since 2013 the authors of this study have been monitoring the Earth's electromagnetic background in search of radio emissions related to strong earthquakes (M6+). This research method has allowed us to verify the existence of an electromagnetic anomaly that preceded more than 142 hours the Italian M6.2 earthquake occurred on August 24, 2016 at 01:36:32 UTC. The same monitoring method did not allow us to detect natural radio emissions related to other two strong Italian earthquakes occurred in October 2016.

Keywords: *Seismic Electromagnetic Precursors, VLF radio-anomalies, Earthquake Prevision, Central Italy Earthquake, Earthquake Precursors, VLF Monitoring.*

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Introduction

Between August 24, 2016 and October 30, 2016, the Central Italy recorded three high intensity seismic events: 1) M6.2 occurred on August 24, 2016 at 01:36:32 UTC; 2) M6.1 occurred on October 26, 2016 at 19:18:08 UTC; 3) M6.6 occurred on October 30, 2016 at 06:40:19 UTC.

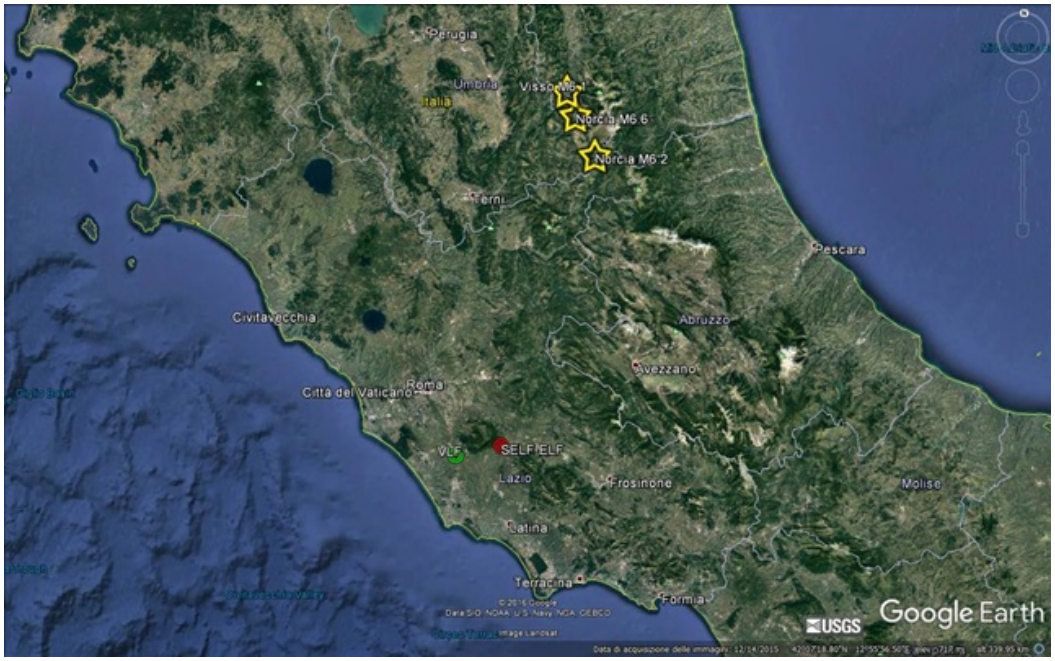

Fig. 1. August-October 2016 Italian M6+ earthquakes epicenter. The image shows the map of Italy (relative to the regions of Central Italy) with the three M6 + earthquakes epicenters (three yellow stars) registered between August 24, 2016 and October 31, 2016 (USGS - United States Geological Survey data). The green circle indicates the location of the Radio Emissions Project's VLF monitoring station located in Albano Laziale (RM), Italy. Lat: 41°42'7.52"N; Long: 12°49'17.34"E. Credits: Google Earth.

The electromagnetic environmental monitoring is a scientific research method that has enabled us to scientifically prove the existence of short-term seismic electromagnetic precursors (SEPs) (Hayakawa, 2015), and has allowed one to identify seismic epicenter of destructive earthquakes (Ohta et al., 2013). Unfortunately, to date, there does not exist yet any SEPs monitoring project shared globally in that only few nations in the world have created a scientific research projects dedicated to the study of SEPs. Italy, after Greece, is certainly the second European nation to have the highest seismic risk, but unfortunately, no official network of detectors for the study of SEPs have been installed. The only Italian project of electromagnetic monitoring active for 24 hours a day – 7 days a week dedicated to SEPs is represented by Radio Emissions Project which is managed and fully financed by Dr. Gabriele Cataldi and Dr. Daniele Cataldi. The Radio Emissions Project deals with the monitoring of SEPs since 2009 and has become an important point of reference at national level because it offers its technical and scientific advice to most private electromagnetic monitoring projects dedicated to SEPs. It was also technical and scientific consultant for the creation of electromagnetic monitoring projects supported by universities[1].

VLF Anomalies

The Radio Emissions Project's monitoring station is equipped with two main radio receivers through which the SELF-ELF and VLF bands can be monitored. A few days before the M6.2 earthquake on August 24, 2016, the VLF monitoring station of Radio Emissions Project detected electromagnetic emission (radio-anomaly) (**Fig. 2**) that had never been seen before, and has never been observed in the following months (Straser et al., 2016).

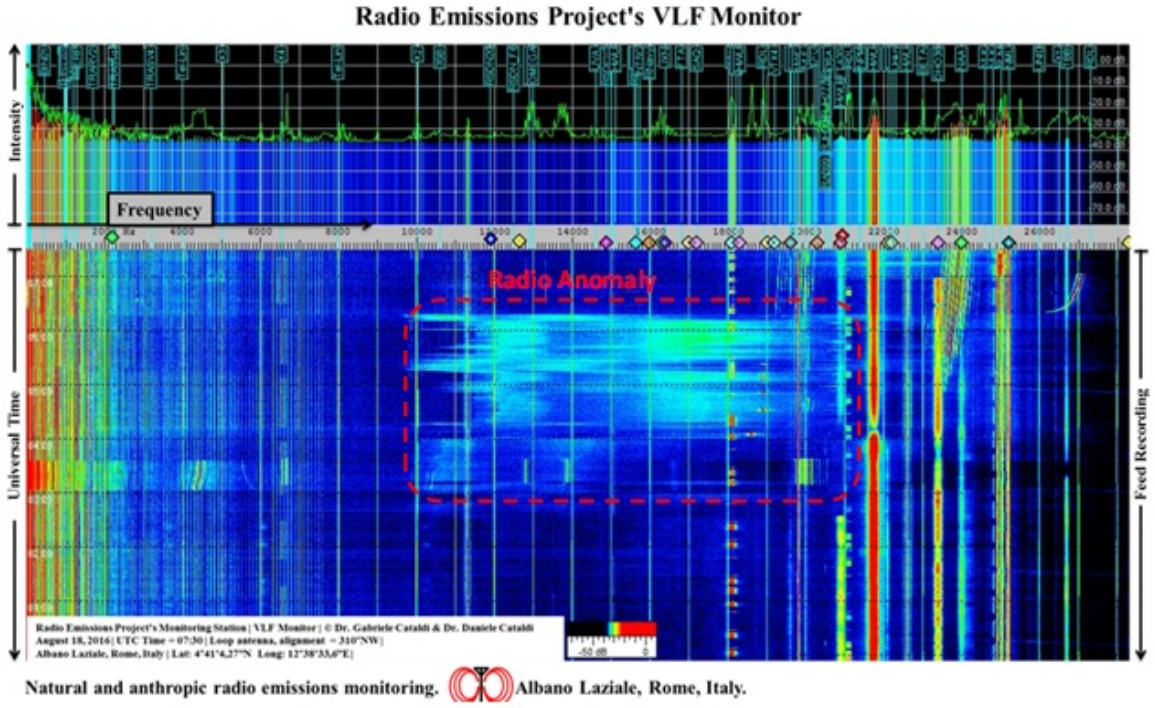

Fig. 2. VLF Monitor and Seismic Electromagnetic Precursors of M6.2 Central Italy Earthquake. The picture shows the dynamic spectrogram of the Earth's electromagnetic field recorded on August 18, 2016 between 00:00 and 07:30 UTC from the electromagnetic environment monitoring station of Radio Emissions Project, located at Albano Laziale (RM), Italy. At the center of the spectrogram, inside the red dotted line, is present the radio anomaly that has been recorded precede the M6.2 Italian earthquake occurred on August 24, 2016 at 01:36 UTC. The emission appeared at 02:47 UTC and disappeared at 06:21 UTC. The labels at the top of the spectrogram (in light blue) indicate known radio stations, prevalently of anthropic type. The Y axis of the spectrogram indicates the UTC time of the registration; this proceeds from top to bottom at 1 horizontal line to minutes. The X axis is the emission frequency of radio signals (the frequency increases going to the right): these are represented in different colors according to their intensity.

[1]Project to launch a stratospheric balloon for the Master's Degree in "Advanced Communications and Navigation Satellite Systems", University of Rome "Tor Vergata". The payload was equipped with a magnetic induction magnetometer for monitoring the Earth's geomagnetic field made by the authors.

This electromagnetic anomaly that has been recorded on August 18, 2016 between 02:47 UTC and 06:21 UTC, thus remained visible for about 3 hours and 34 minutes between 9.63 kHz and 23 kHz, with greater intensity between 9.63 kHz and 20.5kHz and preceded the Italian M6.2 earthquake of the August 24, 2016 of 142 hours and 49 minutes (almost 6 days). In respect to the human radio emissions visible in the spectrogram prevalently between 18 kHz and 26 kHz (indicated by the light blue label at the top of the spectrogram), the radio anomaly has an enormous bandwidth that reaches 13.37 kHz. This is the first radio anomaly with these features that has been recorded from the VLF monitoring station of the Radio Emissions from Project since its operation (2013), perhaps because from 2013 to until August 24, 2016 had not been recorded strong seismic events intensity (M6+) in Italy.

The radio-anomaly recorded on August 18, 2016 has typical spectrometric and spectrographic characteristics of a non-anthropic emission, ie. a natural phenomenon: 1) high bandwidth; 2) rare and sporadic event; 3) gradual appearance/disappearance. Conversely, the more intense anthropic broadcasters (radio stations) present in the same spectrogram have completely different characteristics from the anomaly: 1) low bandwidth; 2) always visible or rarely absent; 3) sudden appearance/disappearance; 4) known emission frequency; and 5) variable intensity compared to ionospheric conditions. Between anthropogenic broadcasters, we find more visible emissions in the spectrogram (**Fig. 3**):

- **ICV**–20.27kHz – Tavolara Island, Italy

Latitude: N 40° 55' 23.26"(+40.923127°)
Longitude: E 009° 43' 51.64"(+009.731011°)

- **HWU**–21.75kHz - Rosnay, France

Latitude: N 46° 42' 47.26"(+46.713129°)
Longitude: E 001° 14' 42.89"(+001.245248°)

- **DHO38**–23.4kHz - Rhauderfehn, Germany

Latitude: N 53° 04' 44.04"(+53.078900°)
Longitude: E 007° 36' 54.00"(+007.615000°)

- **NAA**–24kHz - Cutler, ME

Latitude: N 44° 38' 41.77"(+44.644936°)
Longitude: W 067° 16' 53.90"(-067.281639°)

- **JXN**–16.4kHz - Novik, Norway

Latitude: N 66° 58' 27.67"(+66.974353°)
Longitude: E 013° 52' 25.02"(+013.873617°)

- **TBB**–26.7kHz - Bafa, Turkey

Latitude: N 37° 24' 45.81"(+37.412725°)
Longitude: E 027° 19' 24.03"(+027.323342°)

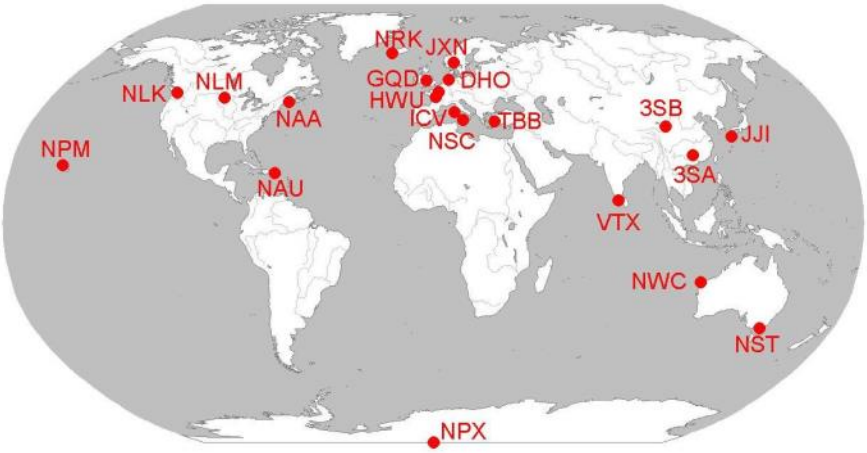

Fig. 3. Main VLF radio stations scattered on the globe: The image shows the location of the main VLF radio stations on the terrestrial globe. Credits: http://nova.stanford.edu/.

Performing a careful analysis of the spectrogram we have observed that the anomaly seems to be interfering with some of the VLF radio stations visible in the spectrogram (**Fig. 2**): The "RDL" radio stations (**Fig. 4**) that transmit at a frequency of 18.1kHz (located in Krasnodar, Nizhny Novgorod and Arkhangelsk in Russia) are attenuated by about 15 dB in the hours when the anomaly reaches its maximum intensity (-37dB) remaining attenuated for more hours even after the disappearance of the anomaly radio.

Fig. 4. 18.1 kHz Russian RDL stations. The image shows the location of the three Russian RDL stations (circles cyan) that transmit the 18.1kHz frequency relative to the position of the Italian peninsula and the seismic epicentres of the three M6+ earthquakes (yellow stars) occurred in Central Italy between 24 August 2016 and 30 October 2016. The red lines represent the direction of propagation of the 18.1 kHz RDL signals respect to the Radio Emissions Project's VLF monitoring station (little green circle). Credits: Google Earth.

For the purpose of finding a cause that can explain the radio-anomaly recorded on August 18, 2016 and the effects on RDL radio broadcasters we accomplished an analysis of the geomagnetic parameters of August 18, 2016: the Kp-Index reached a maximum value of 3 remaining for the most part of the day to a value of 1 and 2; these variations do not justify the radio anomaly that was recorded and even the level of attenuation of RDL stations. Also, we excluded malfunctions on radio equipment of the VLF monitoring station.

The three RDL radio stations are located at an altitude next to the sea level (*ie*, a few tens of meters above sea level), while the VLF monitoring station of Radio Emissions Project is located at an altitude of 173m above sea level. Given the enormous distance as the crow flies between the VLF monitoring station by the three RDL radio stations (Krasnodar = 2093 km, Nizhny Novgorod = 2764 km; Arkhangelsk = 3126 km), the first mode of propagation of 18.1kHz radio signal is due to electromagnetic wave reflection on an ionospheric layer with adequate electron density: this occurs in the night hours because in the daytime there is a physiological absorption of the electromagnetic waves from the lower layers of the atmosphere and therefore the RDL signal propagates exclusively for ground waves (see **Fig. 9**) losing, yet, much of its intensity: the authors calculated a loss of intensity of about 20 dB between 05:00 UTC and 17:00 UTC.As regards to the VLF anomaly observed, this occurs precisely during the phase of attenuation of VLF propagation and the authors believe that the attenuation of the RDL radio carriers is to be attributed to the physiological absorption of the VLF propagation in the hours in which we observed the anomaly. As regards to the presence of the anomaly, the only data related to this event was the Italian M6.2 earthquake occurred on August 24, 2016 at 01:36:32 UTC, almost six days later.

Between 26 and 30 October 2016, in Central Italy were registered two strong earthquakes: M6.1 occurred on October 26, 2016 at 19:18:08 UTC; M6.6 occurred on October 30, 2016 at 06:40:19 UTC. From 21 October 2016 until November 2016 the VLF monitoring station of Radio Emissions Project began to detect the unknown radio emissions in the VLF band (**Figs. 5-10**), which had never been detected before. It consisted of a series of radio signals visible in practically all the VLF band:

1) a horizontal signal that had appeared around 23 kHz, and that in about 20 minutes had increased its frequency reaching 30 kHz. Further analysis of this signal allowed us to ascertain that its emission frequency never exceeded 30 kHz. It was a medium-low intensity signal, with a very small bandwidth on which the authors suggested that it may be of anthropogenic nature (for example an interference caused by an electric motor or something like that) even if the VLF monitoring station is located in an area with a low population density and far from construction sites and/or factories;

2) between 5.5kHz and 22kHz were visible instead a series of weak emissions (between 4 and 6 emissions) with intensity slightly higher than that of the natural background (the background intensity corresponds to -31dB) which have had a temporal progression exactly opposite to that of the first signal of which has been discussed: these signals have undergone of a reduction in their emission frequency: 10kHz in about 90 minutes (as regards the visible signal on the left side of the spectrogram, **Fig. 5**). The most obvious spectrographic characteristic of these signals consists in the fact that they are still almost parallel to each other even if it is difficult to give explanations on their effective nature, the authors believe that it is not of natural emissions also because they have a small bandwidth. Another hypothesis is that it may ultimately be the resonant harmonics of anthropogenic stations not directly visible on the VLF band. In **Fig. 7** and **Fig. 8** the electromagnetic anomaly present on the left side of the spectrogram even has main signal resonance harmonics.

Radio Emissions Project VLF Monitor – Unknown anthropic broadcaster of October 21, 2016

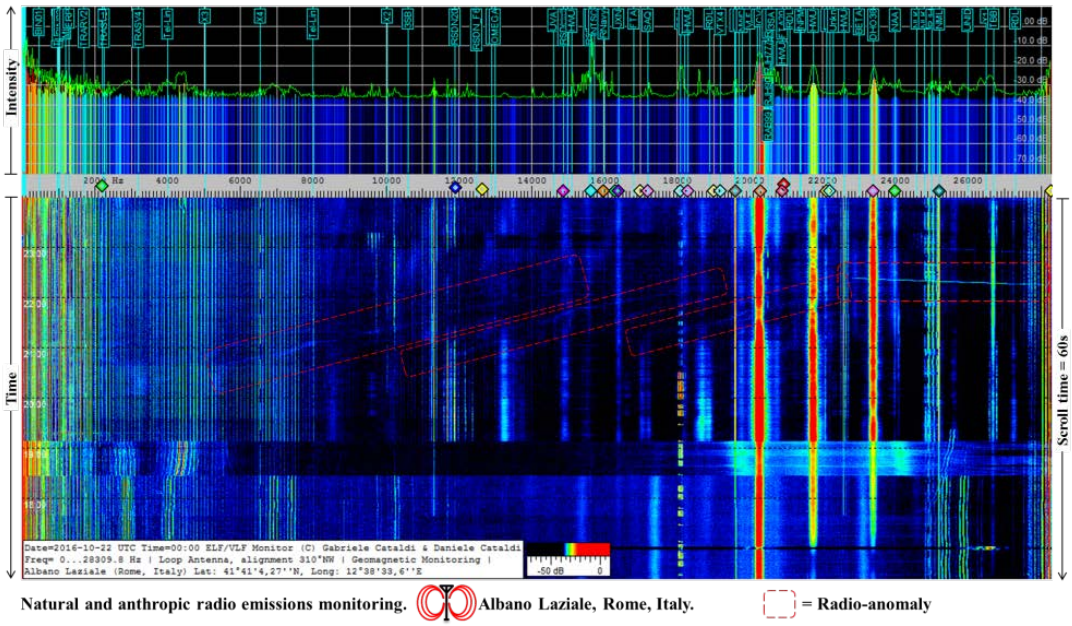

Fig. 5. Radio-anomaly observed on October 21, 2016. The picture shows the VLF (3-30 kHz) dynamic spectrogram of the Earth's electromagnetic field recorded between 17:00 UTC on October 21, 2016 and 00:00 UTC on October 21, 2016 from the electromagnetic environment monitoring station of Radio Emissions Project, located at Albano Laziale (RM), Italy (Lat: 41°42'7.52"N; Long: 12°49'17.34"E). The labels at the top of the spectrogram (in light blue) indicate known radio stations, prevalently of anthropic type. The Y axis of the spectrogram indicates the UTC time of the registration; this proceeds from top to bottom at 1 horizontal line to minutes. The X axis is instead reported the emission frequency of radio signals (the frequency increases going to the right): these are represented in different colors according to their intensity. The areas marked by the red dashed line identify the electromagnetic anomalies recorded by the station.

Radio Emissions Project VLF Monitor – Unknown anthropic broadcaster of October 22, 2016

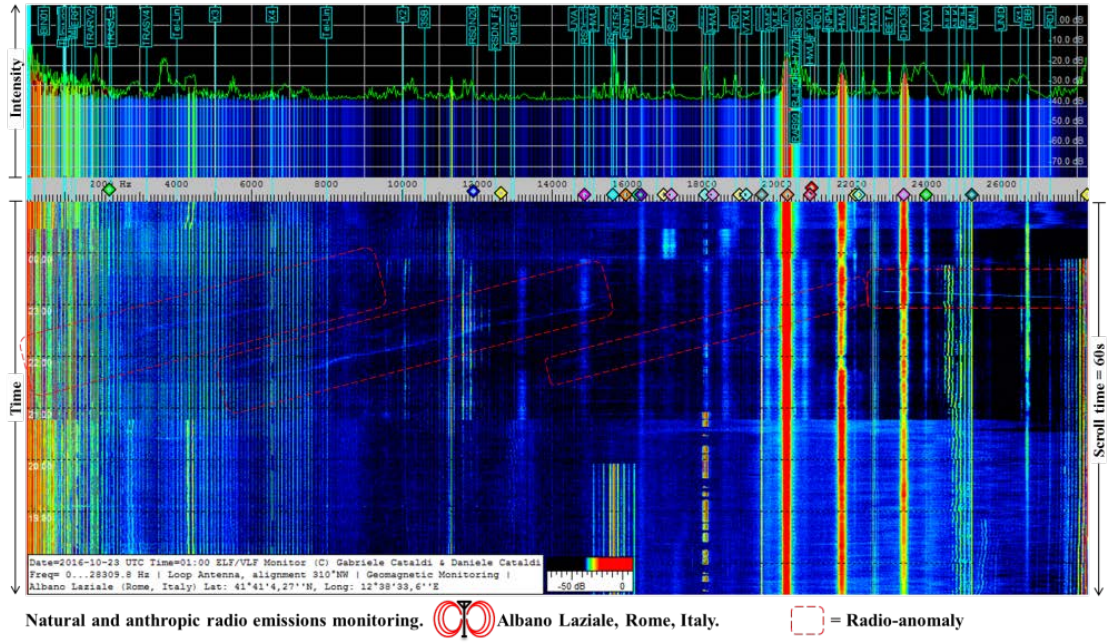

Fig. 6. Radio-anomaly observed on October 21, 2016. The picture shows the VLF (3-30 kHz) dynamic spectrogram of the Earth's electromagnetic field recorded between 21:00 UTC and 23:30 UTC on October 21, 2016 from the electromagnetic environment monitoring station of Radio Emissions Project, located at Albano Laziale (RM), Italy (Lat: 41°42'7.52"N; Long: 12°49'17.34"E). The labels at the top of the spectrogram (in light blue) indicate known radio stations, prevalently of anthropic type. The Y axis of the spectrogram indicates the UTC time of the registration; this proceeds from top to bottom at 1 horizontal line to minutes. The X axis is the emission frequency of the radio signals (the frequency increases to the right): these are represented in different colors according to their intensity. The areas marked by the red dashed line identify the electromagnetic anomalies recorded by the station.

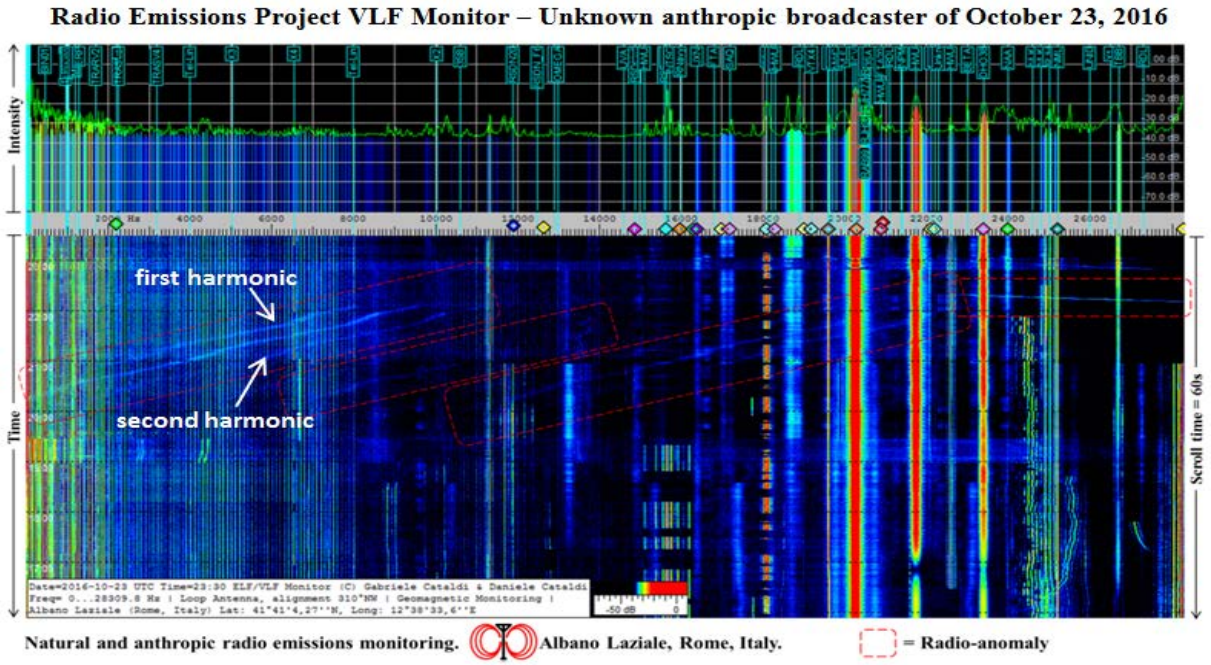

Fig. 7. Radio-anomaly observed on October 21, 2016. The picture shows the VLF (3-30 kHz) dynamic spectrogram of the Earth's electromagnetic field recorded between 20:00 UTC and 22:30 UTC on October 23, 2016 from the electromagnetic environment monitoring station of Radio Emissions Project, located at Albano Laziale (RM), Italy (Lat: 41°42'7.52"N; Long: 12°49'17.34"E). The labels at the top of the spectrogram (in light blue) indicate known radio stations, prevalently of anthropic type. The Y axis of the spectrogram indicates the UTC time of the registration; this proceeds from top to bottom at 1 horizontal line to minutes. The X axis is the emission frequency of the radio signals (the frequency increases going to the right): these are represented in different colors according to their intensity. The areas marked by the red dashed line identify the electromagnetic anomalies recorded by the station. The white arrows indicate two resonant harmonics present behind the anomaly on the left side of the spectrogram.

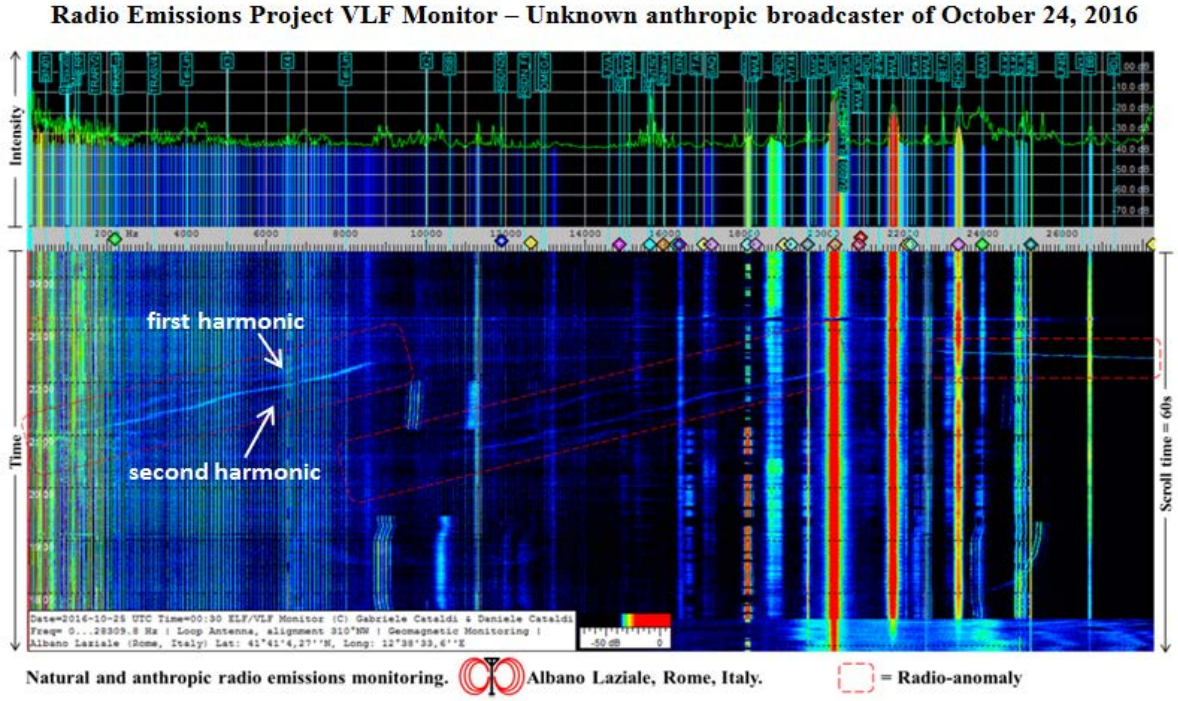

Fig. 8. Radio-anomaly observed on October 21, 2016. The picture shows the VLF (3-30kHz) dynamic spectrogram of the Earth's electromagnetic field recorded between 20:30 UTC and 22:30 UTC on October 24, 2016 from the electromagnetic environment monitoring station of Radio Emissions Project, located at Albano Laziale (RM), Italy (Lat: 41°42'7.52"N; Long: 12°49'17.34"E). The labels at the top of the spectrogram (in light blue) indicate known radio stations, prevalently of anthropic type. The Y axis of the spectrogram indicates the UTC time of the registration; this proceeds from top to bottom at 1 horizontal line to minutes. The X axis is the emission frequency of the radio signals (the frequency increases going to the right): these are represented in different colors according to their intensity. The areas marked by the red dashed line identify the electromagnetic anomalies recorded by the station. The white arrows indicate two resonant harmonics present behind the anomaly on the left side of the spectrogram.

The presence of resonant harmonics close to a main radio signal (more intense) is a conventional phenomenon associated with anthropogenic radio signals whose nature, however, in the specific case, is not known. The authors' aim was to see if these signals were related to M6+ seismic activity and this was possible only after the M5.8 Italian earthquake occurred on October 28, 2016 at 20:02 UTC (**Fig. 10**). Between 16:00 UTC and 23:30 UTC on 28 October 2016 the Radio Emissions Project's VLF electromagnetic monitoring recorded a spectrogram which clarified all doubts (**Fig. 10**): radio anomalies appear after the M5.8 earthquake time marker making clear that they do not have to do with the local Italian seismic activity, because if they had been emissions produced in the focal zone of the earthquake, they would have to undergo a shutdown after the M5.8 earthquake, and instead they continued even after the M6.6 Italian earthquake occurred on October 30, 2016 at 06:40:19 UTC.

Radio Emissions Project VLF Monitor – Unknown anthropic broadcaster of October 26, 2016

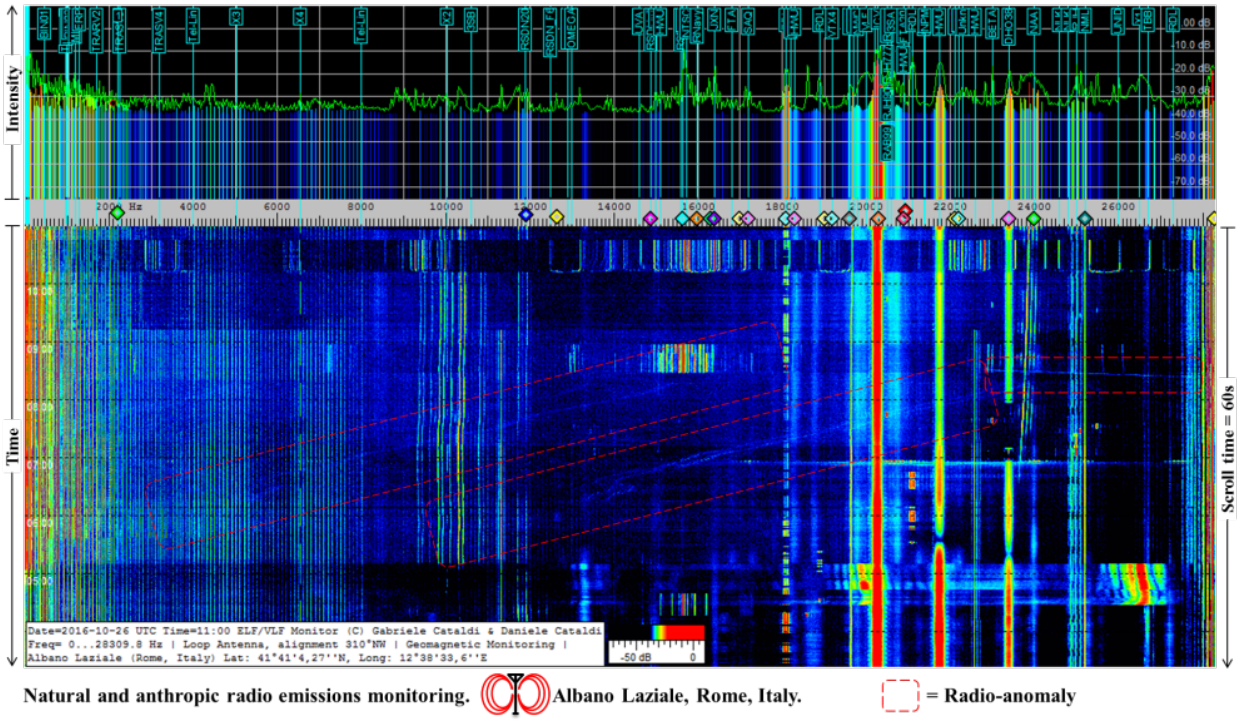

Fig. 9. Radio-anomaly observed on October 21, 2016. The picture shows the VLF (3-30kHz) dynamic spectrogram of the Earth's electromagnetic field recorded between 06:00 UTC and 08:30 UTC on October 26, 2016 from the electromagnetic environment monitoring station of Radio Emissions Project, located at Albano Laziale (RM), Italy (Lat: 41°42'7,52"N; Long: 12°49'17,34"E). The labels at the top of the spectrogram (in light blue) indicate known radio stations, prevalently of anthropic type. The Y axis of the spectrogram indicates the UTC time of the registration; this proceeds from top to bottom at 1 horizontal line to minutes. The X axis indicates the emission frequency of the radio signals (the frequency increases going to the right): these are represented in different colors according to their intensity. The areas marked by the red dashed line identify the electromagnetic anomalies recorded by the station.

Radio Emissions Project VLF Monitor – Unknown anthropic broadcaster of October 28, 2016

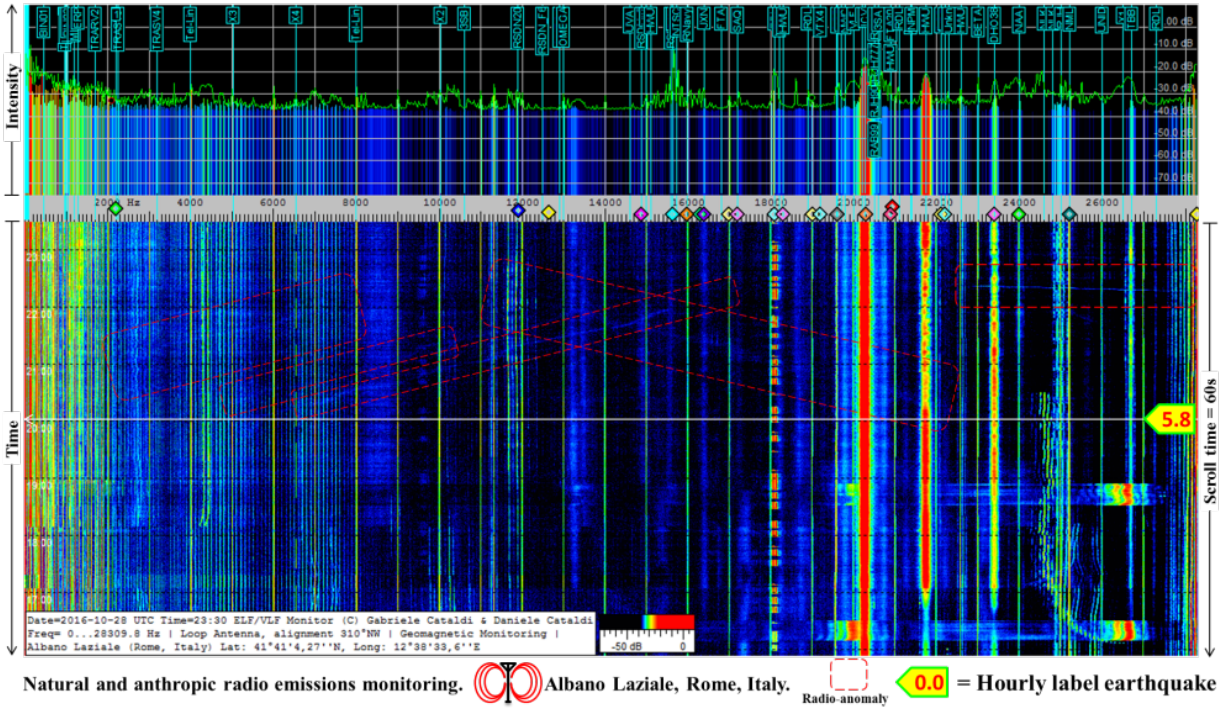

Fig. 10. Radio-anomaly observed on October 21, 2016. The picture shows the VLF (3-30kHz) dynamic spectrogram of the Earth's electromagnetic field recorded between 20:10 UTC and 22:30 UTC on October 28, 2016 from the electromagnetic environment monitoring station of Radio Emissions Project, located at Albano Laziale (RM), Italy (Lat: 41°42’7,52”N; Long: 12°49’17,34”E). The labels at the top of the spectrogram (in light blue) indicate known radio stations, prevalently of anthropic type. The Y axis of the spectrogram indicates the UTC time of the registration; this proceeds from top to bottom at 1 horizontal line to minutes. The X axis is the emission frequency of radio signals (the frequency increases going to the right): these are represented in different colors according to their intensity. The areas marked by the red dashed line identify the electromagnetic anomalies recorded by the station. The visible yellow label on the right side of the image represents the temporal markers of the M5.8 Italian earthquake occurred on October 28, 2016 at 20:02 UTC.

Fulminations

To confirm the objectivity of the electromagnetic monitoring related data, the authors have verified whether or not in the vicinity of the VLF monitoring station storms occurred on August 18, 2016. The radio signals produced by lightning, in fact, can be detected by radio receivers tuned to a wide range of frequencies, for this reason it is essential to reject the hypothesis that electromagnetic anomalies detected by the VLF monitoring station of Radio Emissions Project are in reality the marks left by a storm. To run this check, weather data were utilized; they were provided by the Italian Air Force (AMI). We found that on August18, 2016 there were no thunderstorms near the VLF monitoring station, but light rain was recorded in Northern Italy. In addition, from 21 October 2016 to 30 October 2016 thunderstorms near the VLF monitoring station of Radio Emissions Project did not occur except for October 26 and October 27, which recorded 5 and 25mm of rain, respectively. On October 27, 2016 storms were recorded in the city of Catania, Sicily (at a distance of 509 km point to point), South-East direction, from the VLF monitoring station). Moreover, from a spectrographic point of view, on VLF spectrograms are not found typical signals related to lightning discharges, ie. the so-called "Spherics" (abbreviation of "atmospherics", also known as "statics"): the duration of spherics corresponds to fractions of a second and, in addition, do not remain visible for hours undergoing a frequency variation.

Conclusions

The SEPs are natural radio emissions that precede earthquakes of high intensity and can be used to understand with a good accuracy where a next earthquake will occur (Ohta et al., 2013). Current research on SEPs is affected by the absence of internationally-shared research projects that deal with the study of this new class of natural radio emission discovered in 1880 (Milne, 1990).The monitoring of the environmental electromagnetic field remains a method of research of fundamental importance for the study of SEPs and it will also be in future, especially for understanding the seismic epicenter. The authors have proposed many times in the international arena the creation of a task force dedicated exclusively to monitoring SEPs but until today the results have been disappointing. Yet, studies conducted in the last decade on SEPs are very encouraging and suggest that the electromagnetic monitoring combined with solar activity monitoring (including also the heliophysics) represent a new scientific substrate to build a seismic prediction method based on premonitory phenomena and not on merely statistical data. This is the challenge of the future.

Environmental electromagnetic monitoring allows us not only to monitor the SEPs but also to exclude all radio anomalies that do not have characteristics compatible with the natural emissions. The creation of a network of wideband electromagnetic receivers (SELF-VLF) installed all over the globe (especially near the faults) and implemented with "RDF" (Radio Direction Finder) technology would result in a quantity of data on SEPs superior to all the data that the international scientific community has gotten through the last 100 years of field research. To create a monitoring network of this type, international cooperation is highly required between researchers and government institutions. The greater effort is surely represented by the abandonment of the old erroneous scientific beliefs that many researchers have on SEPs and seismic forecasting in general, and that is that we cannot foresee potentially destructive earthquakes. The authors are convinced, in fact, that today the main problem that hinders research on earthquake prediction is cultural and not technological-organizational and for remove this constraint it is necessary to create a super specialized international research group dedicated to the monitoring and study of SEPs and all electromagnetic seismic precursors, including those of geomagnetic nature (geomagnetic seismic precursors or SGPs) (Cataldi et al., 2013).

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