



# Radio Direction Finding System, a new perspective for global crust diagnosis

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**Abstract:** The RDF - Radio Direction Finding system of the Radio Emissions Project - is a geomagnetic detection system that covers the entire terrestrial surface. This coverage is subdivided into colorimetric areas to which very precise azimuths are associated. The monitoring station, located in Lariano (Rome, Italy), was created by the LTPA Observer Project and the Radio Emissions Project and allows monitoring of "crust diagnosis" in real time, on a global scale.

**Keywords:** *RDF system, earthquake prediction, SELF-VLF*

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## 1. The RDF Receiver

The RDF Receiver developed by the Radio Emissions Project is based on technology that evolved starting from the late 1800s thanks to the studies of Heinrich Hertz, who discovered the directionality of an open loop of wire used as an antenna. Compared to other electromagnetic monitoring systems employed within the scope of scientific research to forecast potentially destructive earthquakes (MW=6+), the RDF system allows 24/7 monitoring of a wide bandwidth of the Earth's background electromagnetic emissions to trace radio anomalies in seismically active areas of the terrestrial surface.

### 1.1 The World Mapping

The RDF - Radio Direction Finding system of the Radio Emissions Project, is a geomagnetic detection system that covers the entire surface of the earth. This coverage is divided into colorimetric areas to which very specific azimuths are associated (**Fig. 1**).

To understand the operation of the RDF system it is necessary to assume that the receiving system is able to provide a stereo signal coming from the antennas, arranged orthogonally and oriented towards the cardinal points.

The flow of radio signals coming from the antennas is subdivided into "colors" to which a forward direction is then associated.

According to the colorimetric scheme used by the RDF station, the cardinal points and the goniometric values associated with the individual composing this scheme, indicate geographic areas (near or far) radially displaced with respect to the position of the monitoring station. The result is a subdivision into "strips" all having the same length (about 20,000 km) that start from the geographic position where the station is located and all join at the "antipodal point" of the station itself.

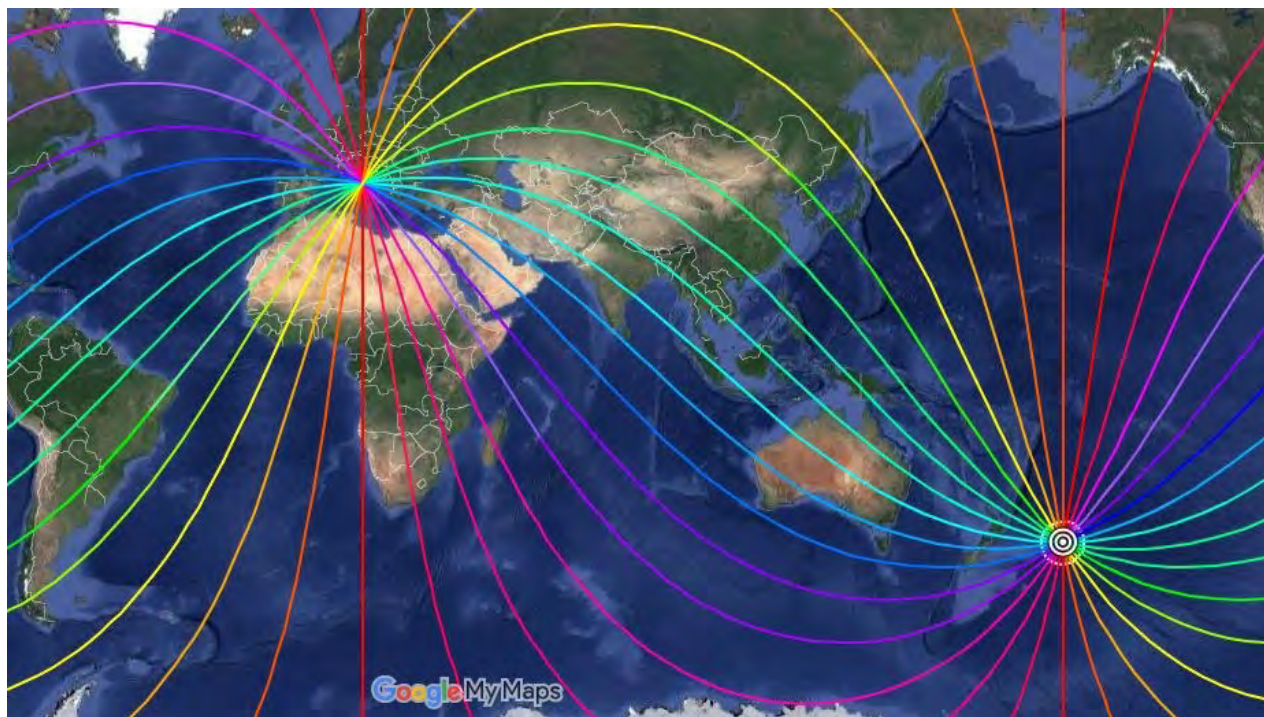


Fig. 1. Colorimetric mapping of the RDF system of the Radio Emissions Project in Lariano (RM).

## 2. Technical characteristics of the RDF Receiver

Compared to other electromagnetic monitoring systems used in this field of research, the RDF system is distinguished by:

- a  $\approx 32\text{kHz}$  bandwidth (SELF AND VLF bands,  $3 > f < 32\text{kHz}$ ).
- a frequency Resolution =  $3.9\text{Hz}$ .
- digital resolution of signal intensity analysis = 24-bit.
- an ability to analyze electromagnetic activity in detail through the production of dynamic spectrograms that make it possible to follow the evolution over time of the emission frequency and intensity, as well as the azimuthal angle.
- a spectrogram recording speed (vertical lines/second) =  $1/20$ . Minimum recording speed =  $1/256\text{msec}$ .
- use of a colorimetric scale that identifies the azimuthal angle of the radio emissions.
- use of a laptop to analyze and store data of an electromagnetic nature (spectrograms).
- low supply voltage for the RDF Receiver ( $5\text{V}$ ).
- a USB-powered receiver. This solution makes it possible to:
  - 1) avoid using secondary power supplies connected to the electrical mains ( $50/60\text{Hz}$ ) thereby considerably reducing network interference;
  - 2) have an autonomy of 1 or 2 hours if the mains power connected to the notebook is interrupted;
  - 3) make the entire electromagnetic monitoring system transportable.
- reduced power consumption of the receiver ( $\approx 1\text{W}$ ).
- reduced maintenance costs: the monitoring station has no hardware and software that require constant maintenance. The solution of using a laptop also allows a reduction in the costs required to purchase a UPS (uninterruptible power source).

- the further possibility of accessing the RDF monitoring system remotely (using free software) to check/modify the configuration parameters of the analysis software and access the monitoring data archive.

The information that the hardware and software can process includes:

- Spectrogram - frequency of each signal in Hz.
- Spectrogram - intensity of each signal in db.
- Spectrogram - timescale of recorded signals.
- Spectrogram - direction/azimuth of the signals recorded in degrees (°).
- Spectrogram - total intensity of the signals from the antennas.
- Plot Monitor graph – timescale, intensity and azimuth of radio signals picked up in certain sub-frequency bands.

### **3. Monitoring Technique**

By combining the RDF information from appropriately spaced stations (at some tens of km) it is possible to locate the source of electromagnetic emission by triangulation. The receiving station can identify the goniometric axis of a radio signal and discriminate the direction of origin. With two or more receiving stations it is therefore possible to obtain the exact position of a radio emission and therefore to determine its distance from the station, as well as its intensity. The technique used by the Radio Emissions Project is therefore able to identify the position of a specific radio signal and to locate it precisely thanks to triangulation.

The system can also provide data on the frequency of signals at their intensity and temporal variation (morphology and behavior).

This is an innovative technique still little used in research on electromagnetic and geomagnetic seismic precursors.

### **4. Strengths of the RDF system**

The strong point of the system for monitoring electromagnetic RDF is its ability to perform a triangulation of the sources of electromagnetic emission using a network of receivers placed at several tens of kilometers from each other: the RDF monitoring station consistently provides indications on the intensity of the radio signals, their frequency, their azimuth direction, and the temporal evolution of these parameters. The production of dynamic spectrograms allows analysis of the morphology of the radio signals picked up (spectrographic characteristics or electromagnetic impression) making it possible to discriminate anthropogenic electromagnetic impressions from natural ones with relative ease, while providing guidance on ionization anomalies in the low-altitude ionospheric layers (D and E regions) caused by solar activity, by tracing signs of any Sudden Ionospheric Disturbances (SID): these show up as an improvement in radio propagation in the VLF band of anthropogenic radio carriers. Thanks to the use of two or more RDF stations, by triangulating the radio anomalies detected, it is possible to have an indication of the number of anomalies concentrated in a given earthquake area coupled with the ability to analyze the electromagnetic impression (variations in bandwidth, emission frequency, intensity and azimuth) in relation to time. This type of data cannot be provided by conventional monitoring stations that use, for example, single axis induction magnetic sensors or, more generally, electromagnetic monitoring systems (even triaxial ones) that produce magnetograms

### **5. Expected results**

Based on the color of the signals received, it is possible to identify their precise axial position, i.e., the direction of origin with respect to the geographical point where the monitoring station is located. It is also possible to know the azimuth (in degrees) with respect to the direction of detection and this therefore provides precise data on the axial location of the recorded radio signal.

Thanks to this innovative technology, the Radio Emissions Project aims to detect pre-seismic radio signals that are also consistent with the seismic epicenter. The new monitoring system has been undergoing testing since March 2017 and has provided positive outcomes for earthquakes greater than magnitude 4. Three case studies are introduced in the Appendices.

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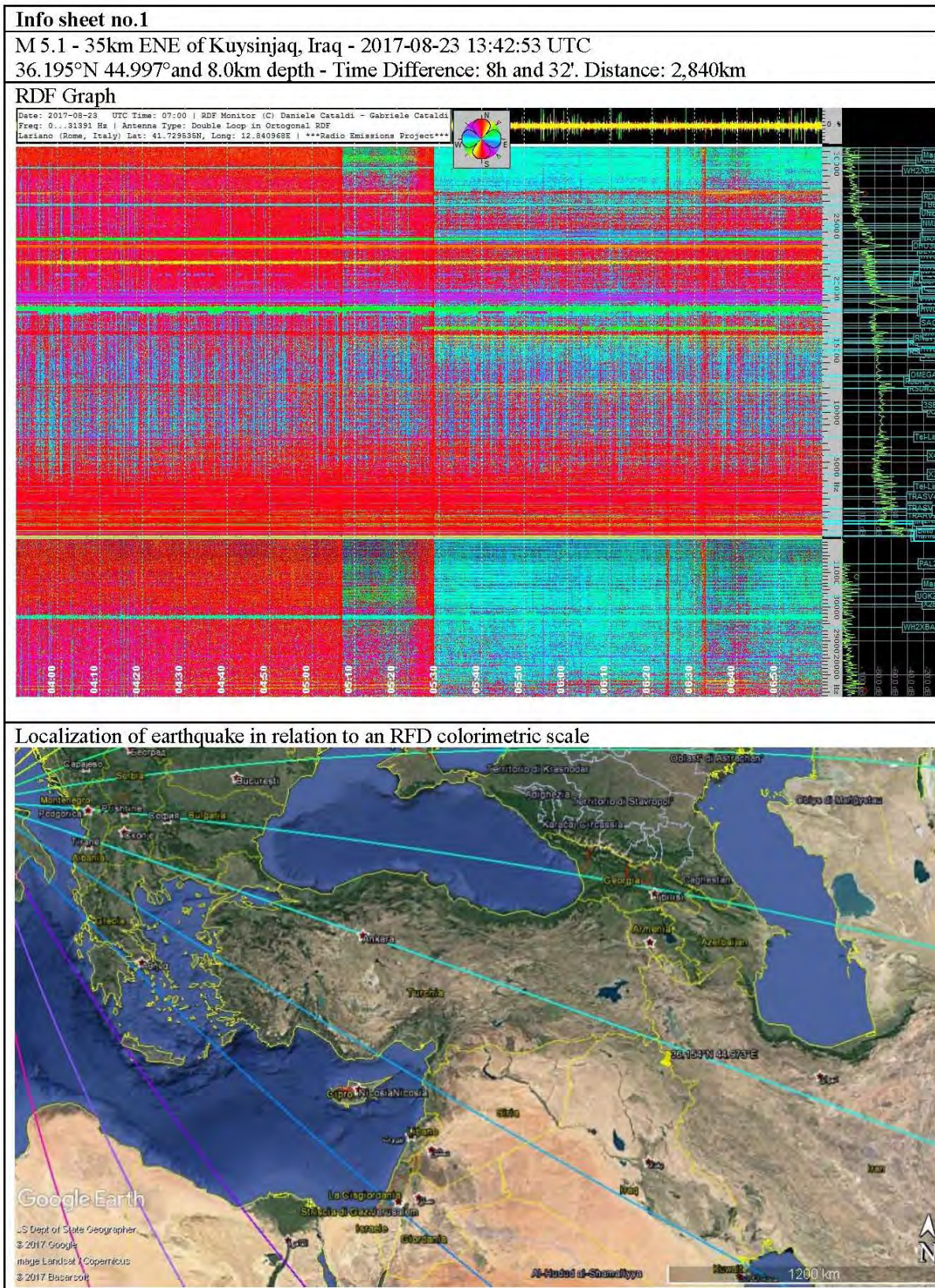
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## APPENDICES

### Three types of "CRUST DIAGNOSIS" made with the RDF system:



M 5.1 - 35km ENE of Kuysinjaq, Iraq - 2017-08-23 13:42:53 UTC. 36.195°N 44.997°E 8.0 km depth – 8 hours before the earthquake.

**RDF Spectrogram.** The spectrogram shows the dynamic spectrogram (SELF-VLF band) realized through the RDF electromagnetic monitoring system. The colors inside the spectrogram indicate the azimuthal direction of the electromagnetic signals captured by the monitoring station. The intensity of the



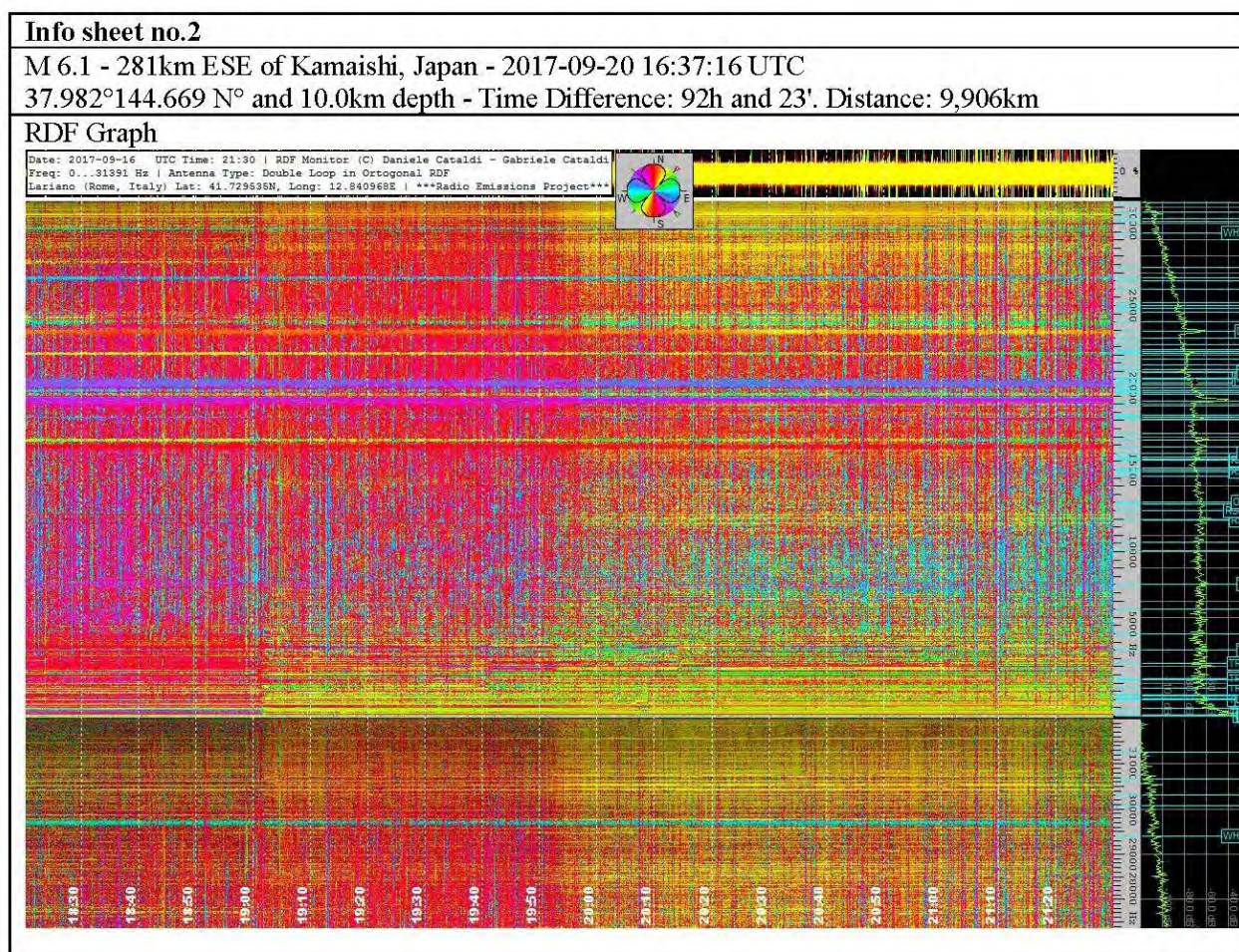
electromagnetic signals is indicated by an increase in color saturation: the higher the color saturation, the greater the intensity of the radio signal and vice versa. The time (UTC) of the recording is visible at the bottom; on the right side of the spectrogram are indicated the emission frequency and the intensity (in decibel) of the radio signals. At the top, proceeding from left to right are visible: the spectrogram summary data, the colorimetric scale in relation to the geographic azimuth and a "total intensity" scale synchronized with the spectrogram registration. Electromagnetic signals related to seismic events are those included within the dashed white line.

**Time interval:** 8 hours and 32 minutes before the earthquake.

**Distance:** 2,840 km

**Azimuthal correlation of the seismic event.** The image shows the seismic epicenter (indicated by the yellow icon) correlated with the azimuthal electromagnetic data captured by the RDF station. The colored lines originate from the geographic site where the RDF station is installed (Lariano, Rome, Italy) and are intended to indicate which association exists between azimuthal direction of the electromagnetic signals captured by the RDF receiver (colors present in the spectrogram) and the real azimuthal direction.

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M 6.1 - 281km ESE of Kamaishi, Japan - 2017-09-20 16:37:16 UTC. 37.982°N 144.669°E 10.0 km depth – 92 hours before the earthquake.

**RDF Spectrogram.** Dynamic spectrogram (SELF-VLF band) realized through the RDF electromagnetic monitoring system. The colors inside the spectrogram indicate the azimuthal direction of the electromagnetic signals captured by the monitoring station. The intensity of the electromagnetic signals is indicated by an increase in color saturation: the higher the color saturation, the greater the intensity of the radio signal and vice versa. The time (UTC) of the recording is visible at the bottom; on the right side of the spectrogram are indicated the emission frequency and the intensity (in decibel) of the radio signals. At the top, proceeding from left to right are visible: the spectrogram summary data, the colorimetric scale in relation to the geographic azimuth and a "total intensity" scale synchronized with the spectrogram registration. Electromagnetic signals related to seismic events are those included within the dashed white line.

**Time interval:** 92 hours and 23 minutes before the earthquake.

**Distance:** 9,906 km

**Azimuthal correlation of the seismic event.** In the image shows the seismic epicenter (indicated by the yellow icon) correlated with the azimuthal electromagnetic data captured by the RDF station. The colored lines originate from the geographic site where the RDF station is installed (Lariano, Rome, Italy) and are intended to indicate which association exists between azimuthal direction of the electromagnetic signals captured by the RDF receiver (colors present in the spectrogram) and the real azimuthal direction. The red line has been inserted to make more evident the azimuth angle of the seismic epicenter than the colorimetric scale used in the spectrogram (in this case, the color is very close to yellow).

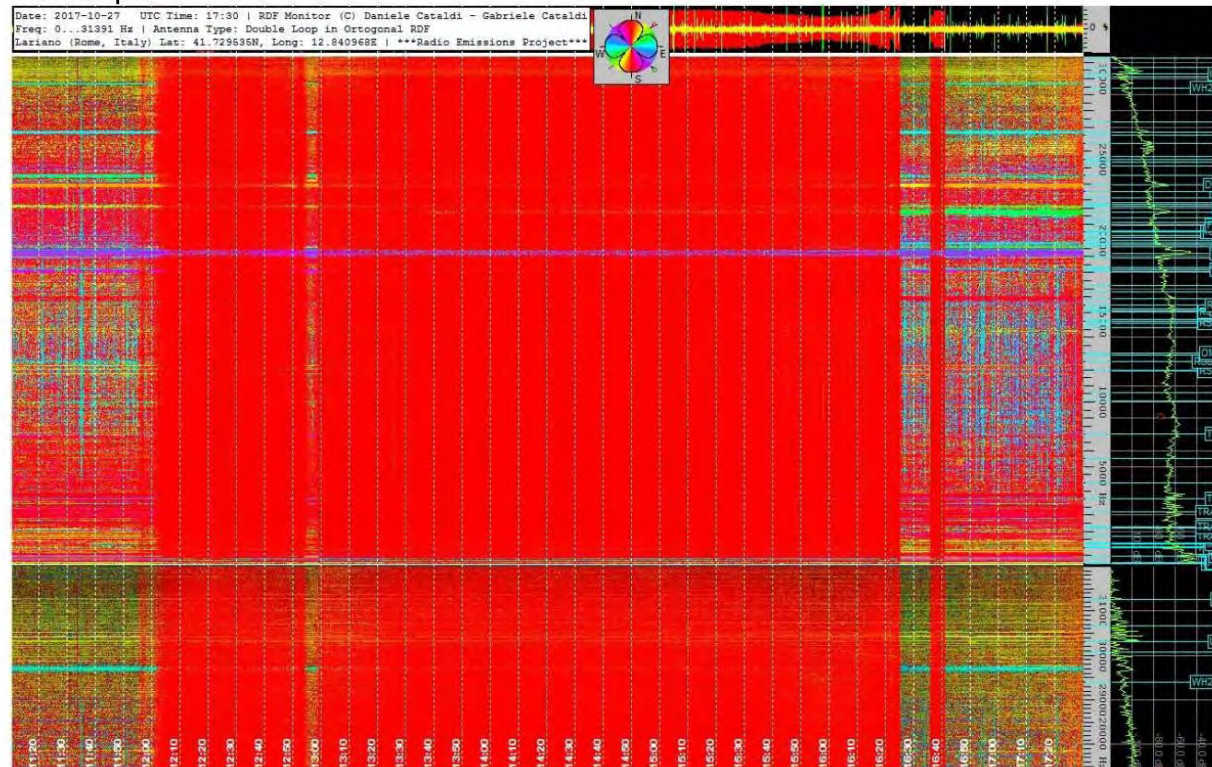
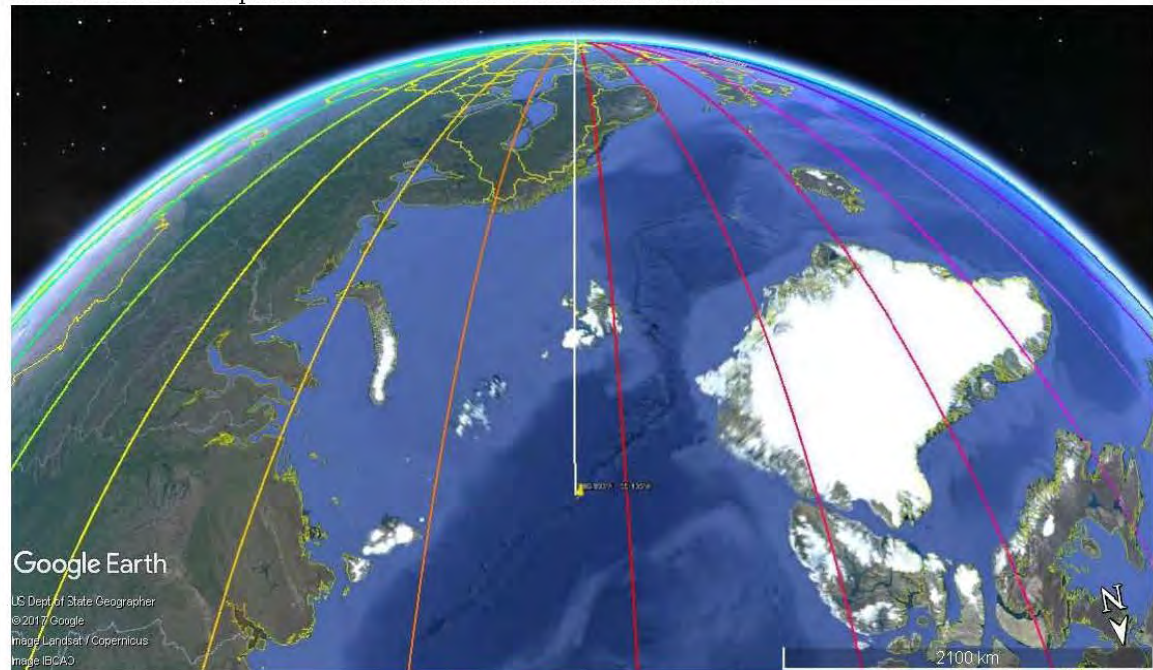
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**Info sheet no.3**

M 6.0 - North of Franz Josef Land - 2017-10-28 19:11:01 UTC

86.893°N 55.135°E and 10.0km depth - Time Difference: 26h and 29'. Distance: 5,187km

**RDF Graph****Localization of earthquake in relation to an RFD colorimetric scale**

M 6.0 - North of Franz Josef Land - 2017-10-28 19:11:01 UTC. 86.893°N 55.135°E 10.0 km depth – 31 hours before the earthquake.

**Time interval:** 26 hours and 29 minutes before the earthquake.

**Distance:** 5,187 km



**RDF Spectrogram.** Dynamic spectrogram (SELF-VLF band) realized through the RDF electromagnetic monitoring system. The colors inside the spectrogram indicate the azimuthal direction of the electromagnetic signals captured by the monitoring station. The intensity of the electromagnetic signals is indicated by an increase in color saturation: the higher the color saturation, the greater the intensity of the radio signal and vice versa. The time (UTC) of the recording is visible at the bottom and on the right side of the spectrogram the emission frequency and the intensity (in decibel) of the radio signals are shown. At the top, proceeding from left to right are visible: the spectrogram summary data, the colorimetric scale in relation to the geographic azimuth and a "total intensity" scale synchronized with the spectrogram registration. Electromagnetic signals related to seismic events are those included within the dashed white line.

**Azimuthal correlation of the seismic event.** In the image above is visible the seismic epicenter (indicated by the yellow icon) correlated with the azimuthal electromagnetic data captured by the RDF station. The colored lines originate from the geographic site where the RDF station is installed (Lariano, Rome, Italy) and are intended to indicate which association exists between azimuthal direction of the electromagnetic signals captured by the RDF receiver (colors present in the spectrogram) and the real azimuthal direction. The white line has been inserted to emphasise the azimuth angle of the seismic epicenter than the colorimetric scale used in the spectrogram (in this case, the color is very close to red).