Wavelet analysis applied to temporal data sets in order to reveal possible pre-seismic radio anomalies and comparison with the trend of the raw data

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OUTLINE

✓The INFREP network

✓Radio precursors of EQs

✓Dodecanese islands earthquake (January 30, 2020)

✓Analysis of VLF signals to detect anomalies:

- Wavelet spectrum
- Perceptually Important Points (PIP) technique

✓Results

The INFREP RADIO NETWORK

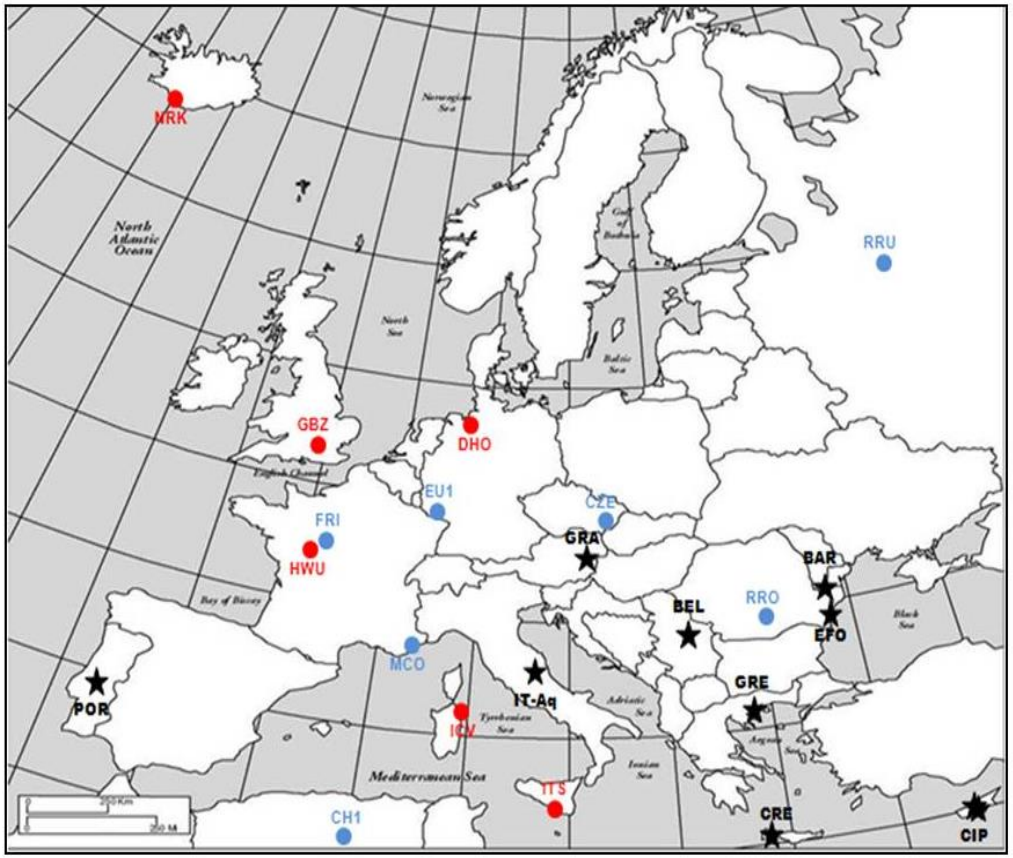
The INFREP network (www.infrep-network.eu) consists of radio receivers able to measure the electric field intensity from various broadcasting stations existing in Europe. Currently, nine receivers have been installed.

The radio receivers measure the intensity of 10 radio signals in the bands VLF (20-80 kHz) and LF (150-300 kHz), with 1 minute sampling rate.

Generally, each receiver collects 5 VLF and 5 LF signals; in any case, the selection of the signals to collect is based on the quality of local reception.

The INFREP RADIO NETWORK

star = receiver
circle = transmitter
VLF (red) and LF (blue)



Labels and frequencies of the VLF-LF transmitters

VLF	Frequency (kHz)	LF	Frequency (kHz)
GBZ	19.58	RRO	153
ICV	20.27	FRI	162
HWU	21.75	EU1	183
DHO	23.4	CH1	198
TBB	26.7	MCO	216
ICE	37.5	RRU	261
NSY	45.9	CZE	270

Radio precursors

The VLF signals propagate in the earth-ionosphere wave-guide as channeled wave.

The LF signals are characterized by a ground-wave and a sky-wave propagation mode. The first one generates a signal that propagates in the channel ground-troposphere, while the second one generates a signal which propagates using the lower ionosphere as a reflector.

The ground wave and sky wave propagation mode is able also to simulate the propagation of VLF signals.

Radio precursors

In the last 20 years, a research into the interaction between seismic activity and disturbances in radiobroadcasts has been carried out. Pre-seismic disturbances in VLF radio signals have been presented mainly by Japanese and Russian researchers; pre-seismic disturbances on LF radio broadcasts were proposed mainly by Italian researchers. We call these disturbances radio precursors.

Variations of parameters in the ground, atmosphere and ionosphere generate variations in the propagation medium of the radio-waves and so disturbances in their propagation can occur.

The radio precursors confirm the existence of a lithosphere-atmosphere-ionosphere coupling.

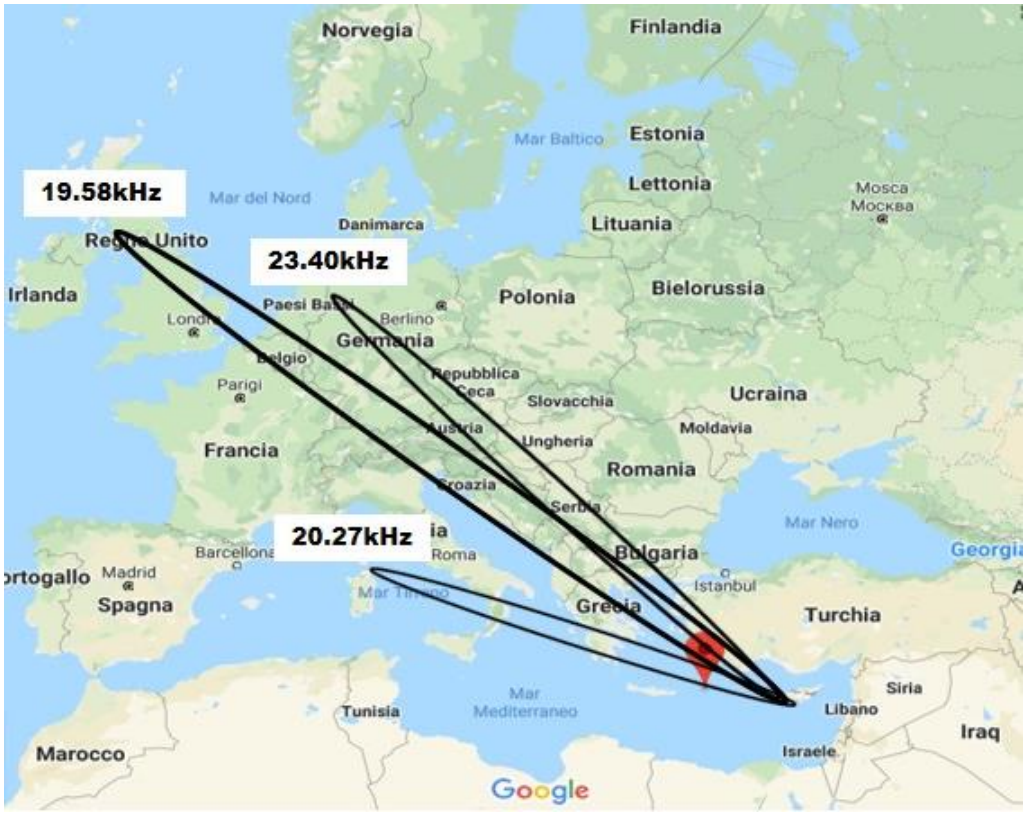
Radio precursors

In order to reveal possible radio precursors, the data had to be analyzed for discovering "anomalies", which differs from normal variations of the data trends.

Generally, due to the absence of solar radiation, the VLF/LF radio signals are less disturbed during the night than during the day. So in INFREP, the analysis of the radio data is performed only on the night-time data for all VLF/LF radio bands, between 21.00 to 24.00 (UTC). Each day is therefore represented by 3 hours, that is, taking into account the 1 min sampling rate used, 180 data (minutes).

Dodecanese islands earthquake (January 30, 2020)

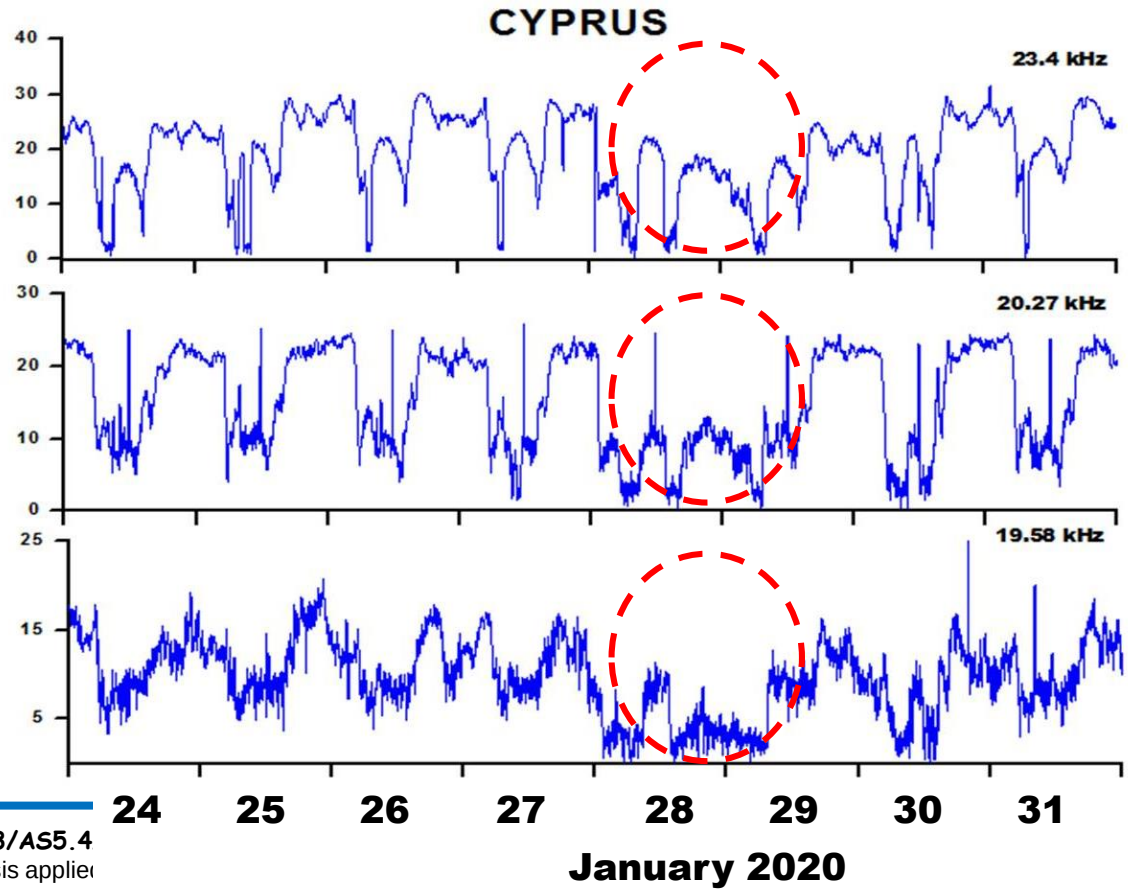
On January 30, 2020 an earthquake with Mw=6.0 occurred in Dodecanese Islands This event occurred in the "sensitive" zone of the Cyprus receiver of INFREP network as it is shown in the map where the red symbol indicates the location of the earthquake and the ellipses represent the 5th Fresnel zones related to the Cyprus receiver of the 19.58kHz, 20.27kHz and 23.40kHz transmitters.



Dodecanese islands earthquake (January 30, 2020)

Anomalies (night time decrease of the intensity) appeared in the trends of the previous three VLF radio signals collected by the receiver.

Trends of the other signals collected by this receiver do not show similar decreases ➔ the receiver is working properly



Dodecanese islands earthquake (January 30, 2020)

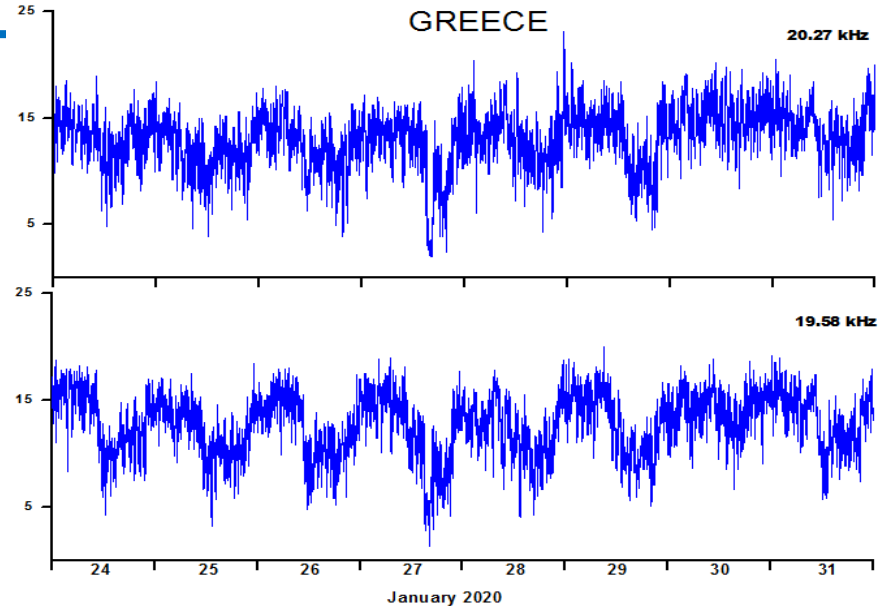
In order to corroborate the possibility that the previous decreases could be preseismic anomalies related to the Dodecanese earthquake, the data collected in the same period by the GRE, CRE, GRA and BAR receiver have been examined and anomalies were not observed (shown in next two slides).

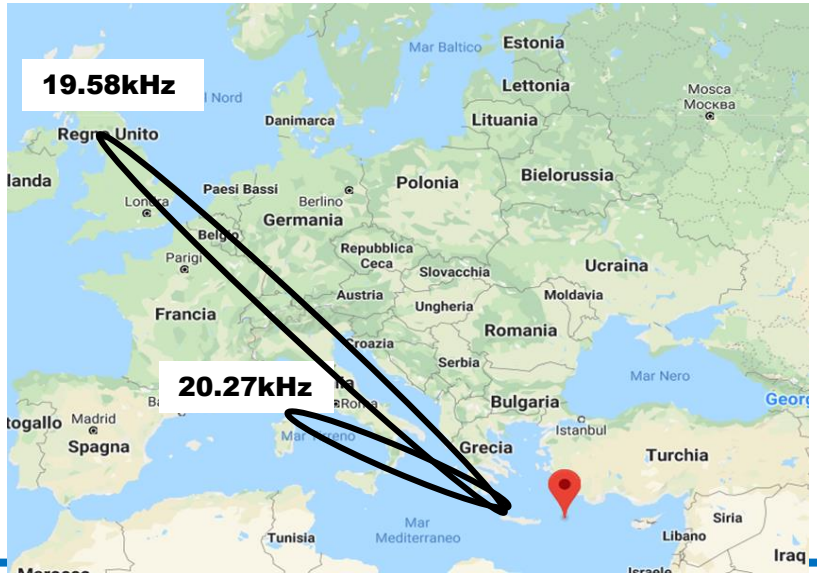
Hence, the occurrence of disturbances in the atmosphere of the EQ epicentral area seems to be the cause of the observed anomalies in the VLF signals.

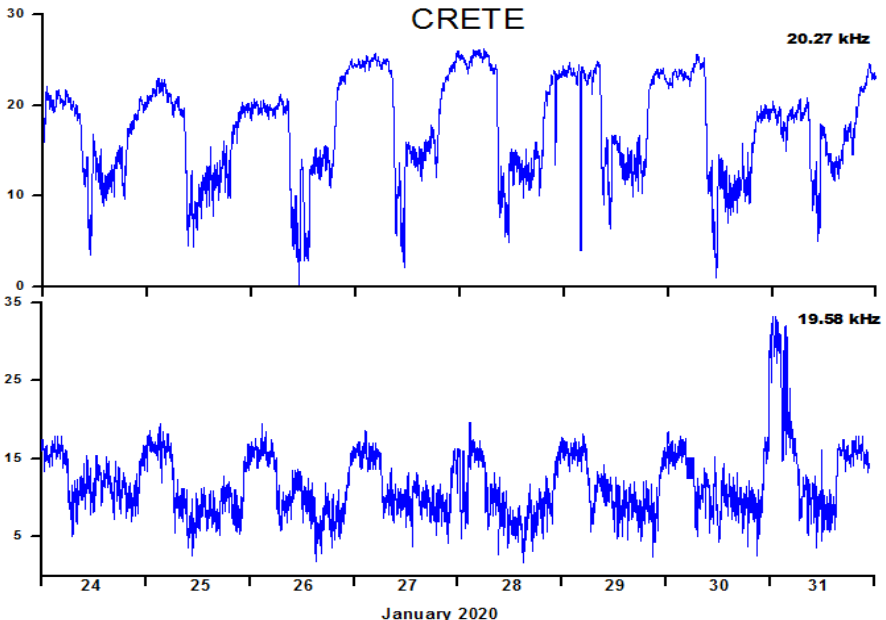
Dodecanese islands earthquake (January 30, 2020)

In order to identify radio precursors it is very important to take into account that, as well as the preparatory phase of earthquakes, other causes can produce disturbances in VLF/LF radio propagation: solar flares, anomalous geomagnetic activity and adverse meteorological conditions mainly around the receiver location. These effects can produce radio anomalies very similar to the pre-seismic ones; so, before to claim radio precursors it is necessary to check these effects.

Dodecanese islands earthquake (January 30, 2020)







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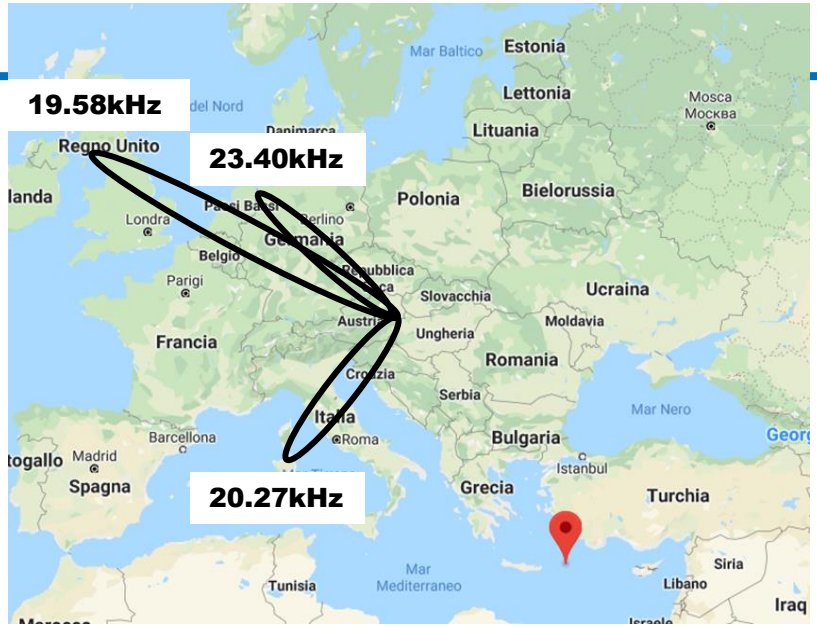
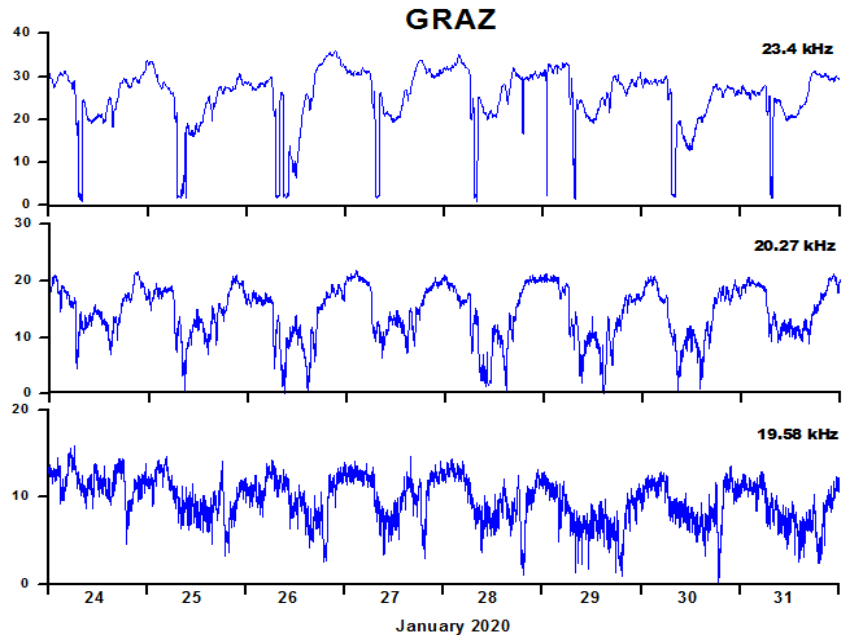
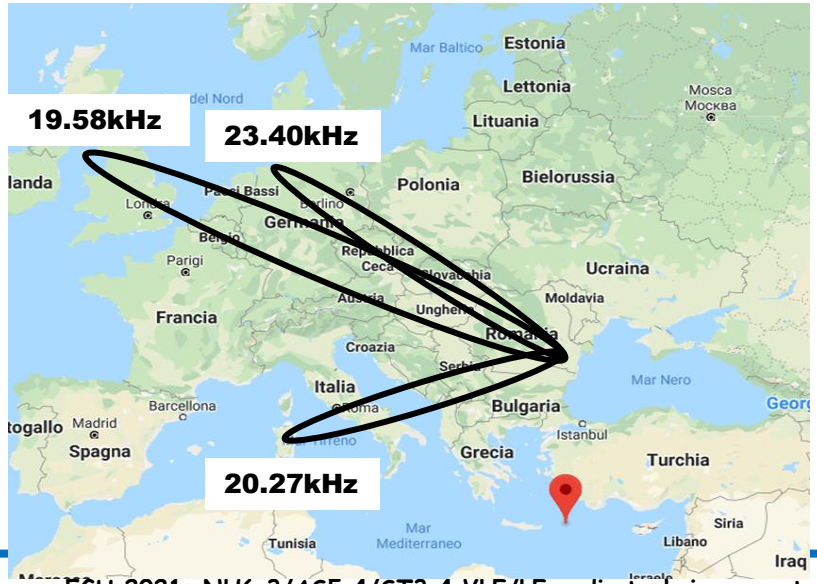
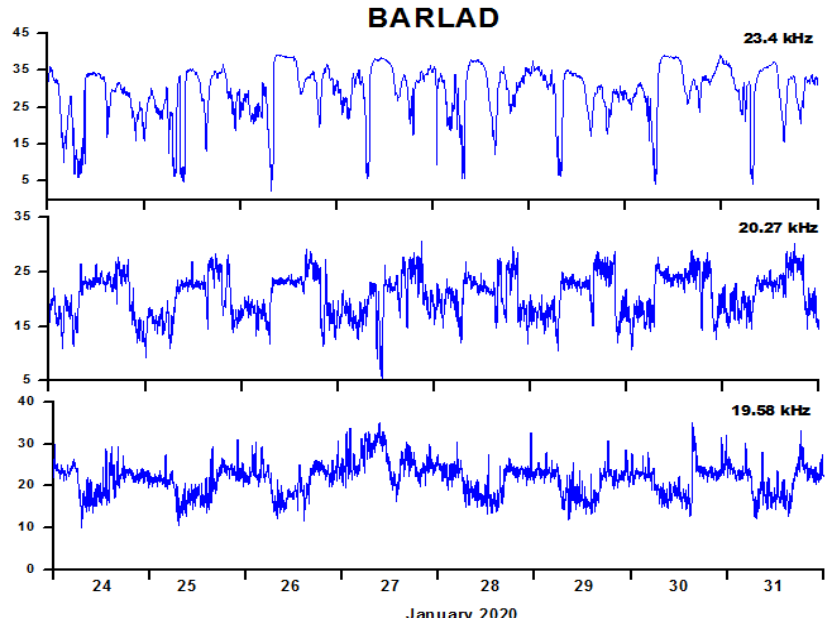








Analysis of anomalies

No anomalous geomagnetic activity or adverse meteorological conditions appeared at the end of January 2020, so the possibility that the anomaly revealed in the radio signals collected by the Cyprus receiver is a precursor of the Dodecannese earthquake is convincing.

Note that this anomaly is by the standards pointed out for the radio precursors, i.e:

a) a precursor time within ten days

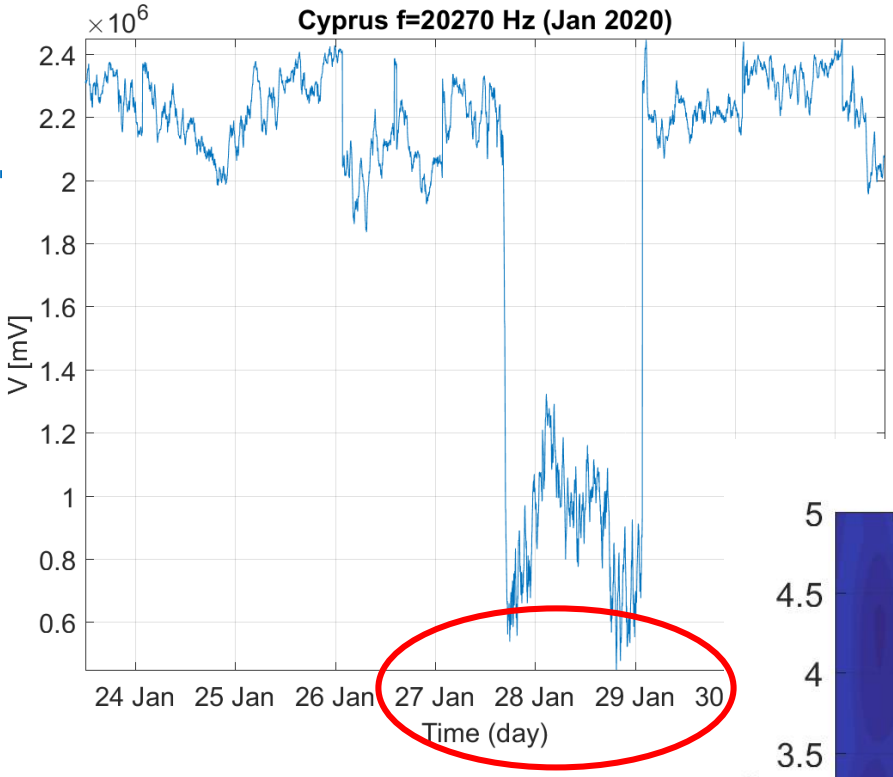
b) a value of Mw equal or greater than 6.0

c) the epicentre located inside the 5th Fresnel zone of the radio signal near the receiver (most sensitive zone).

Analysis of anomalies

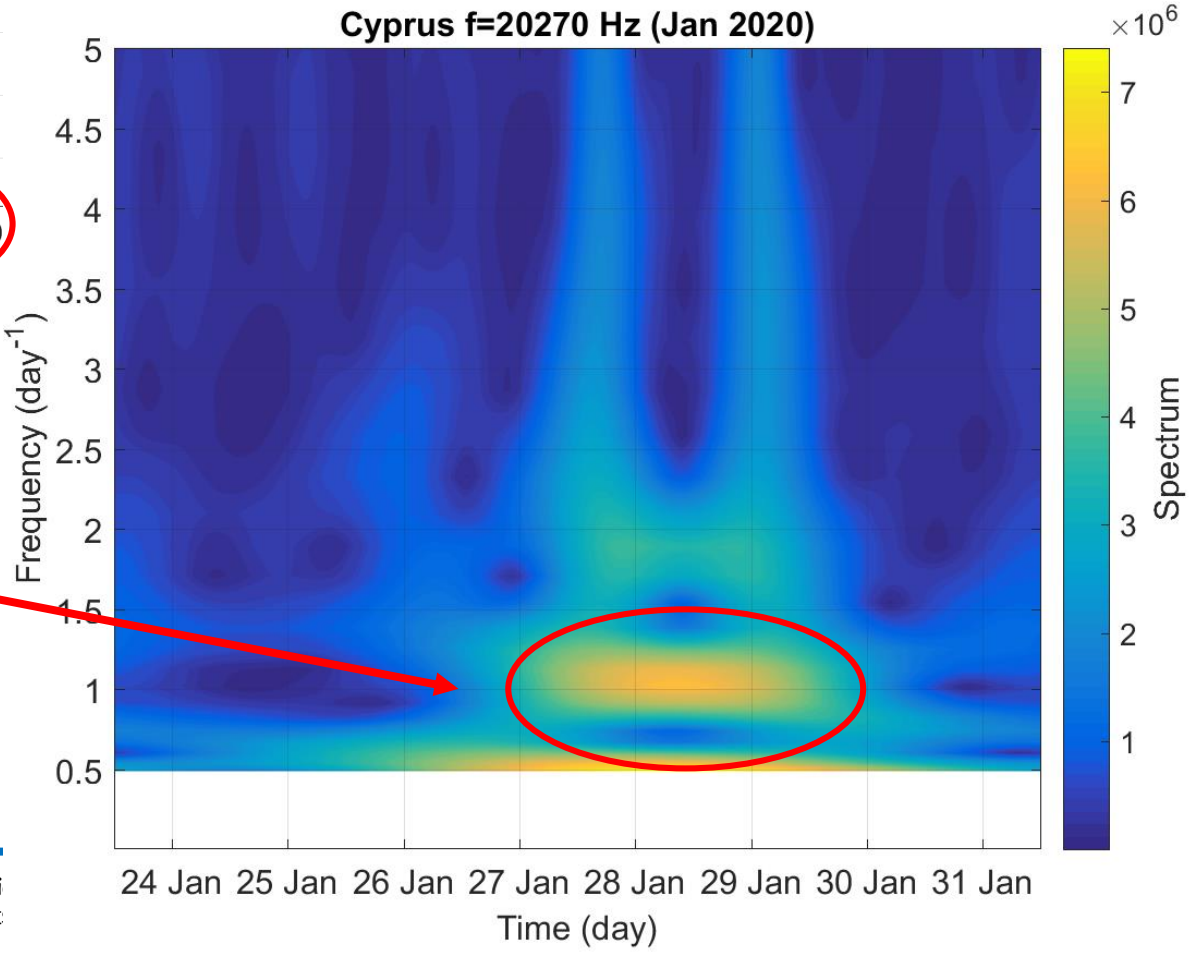
For the analysis of the data sets the Wavelet power spectrum is used. A power spectrum is a two dimensions plot that, once properly normalized with respect to the power of the white noise, gives information on the strength and precise time of occurrence of the various Fourier components which are present in the original time series.

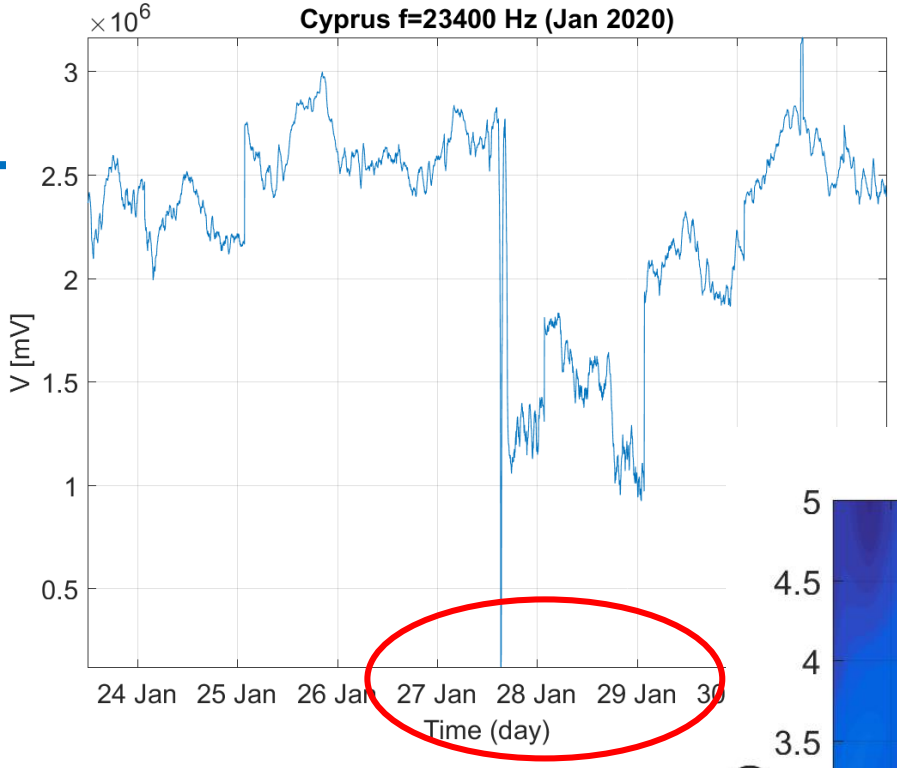
The Perceptually Important Points (PIP) technique is also applied to the analysis of time series of VLF to dynamically segment the time series into subsequences of unequal length, preserving the shape of the data.



Wavelet power spectrum at the top a normal situation; at the bottom an anomaly appears

An anomaly is observed when the EQ occurs





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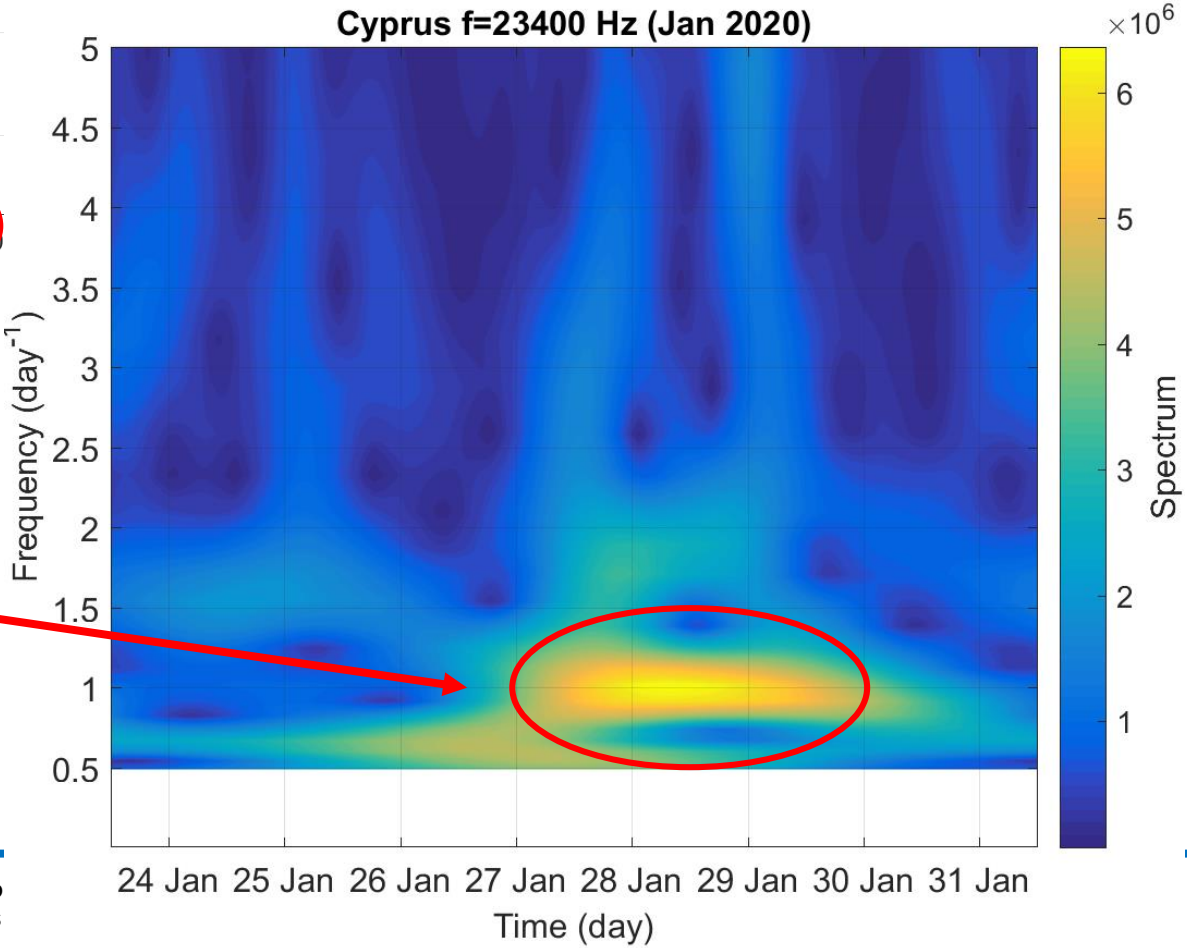
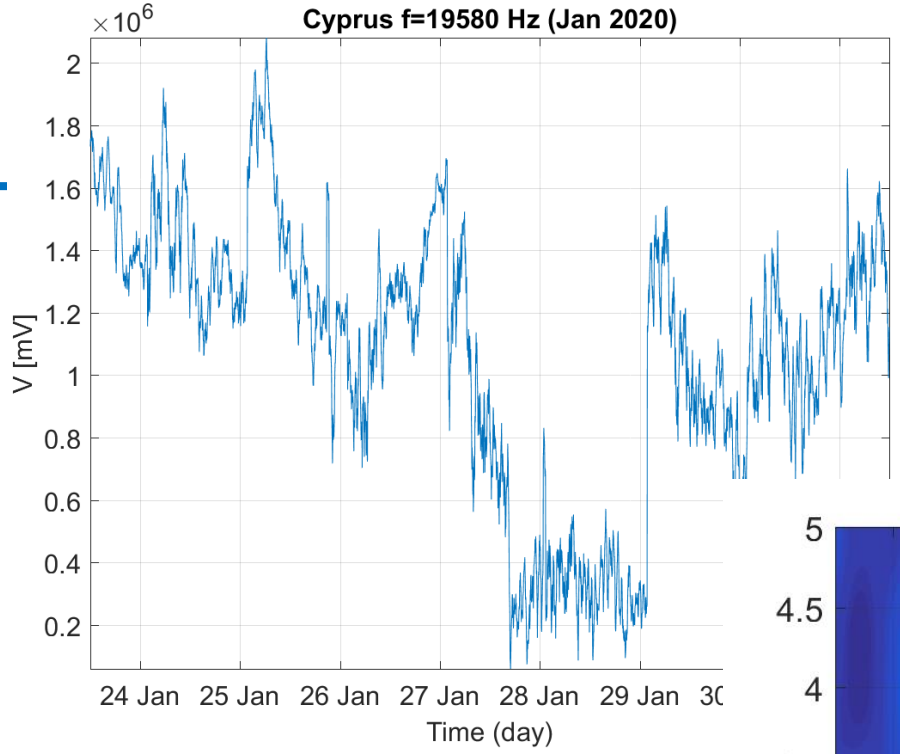
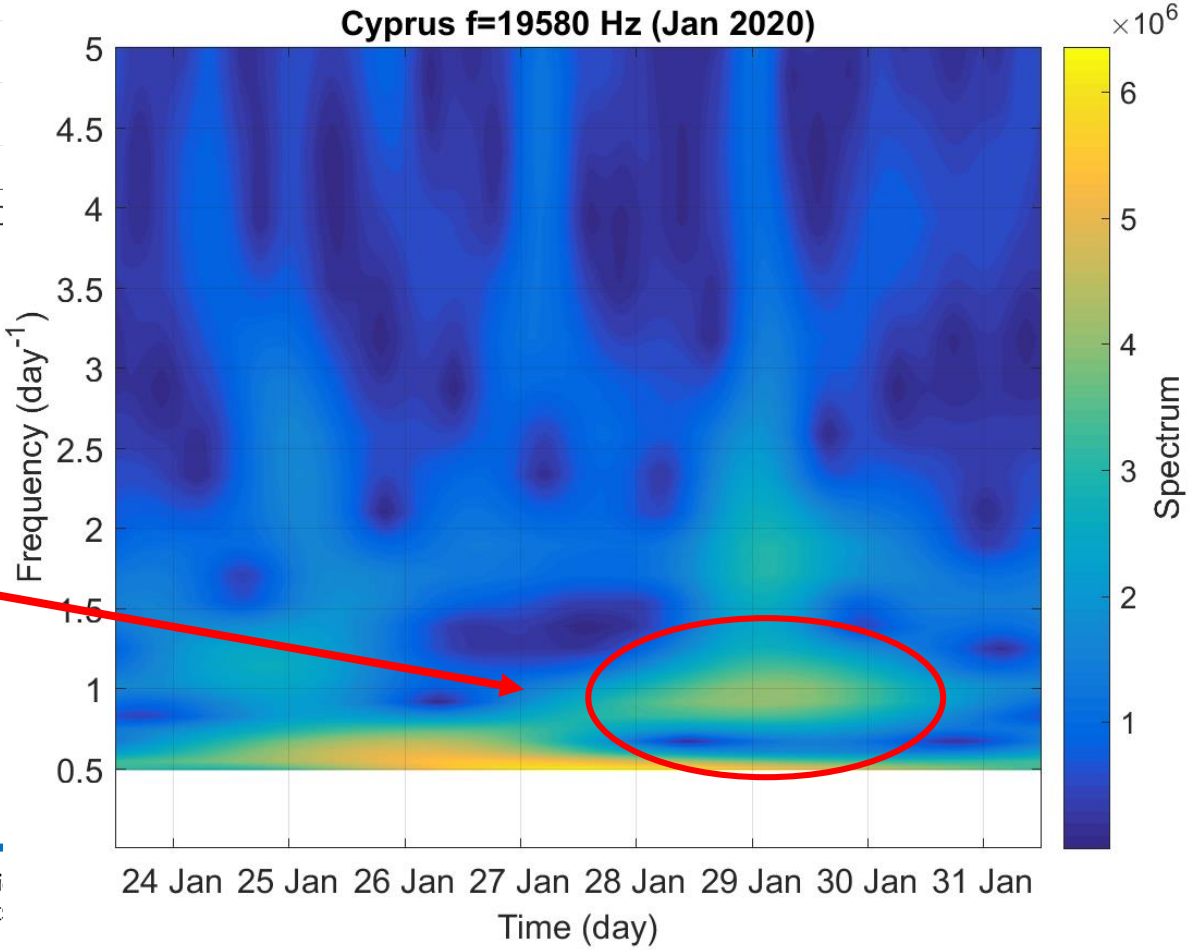
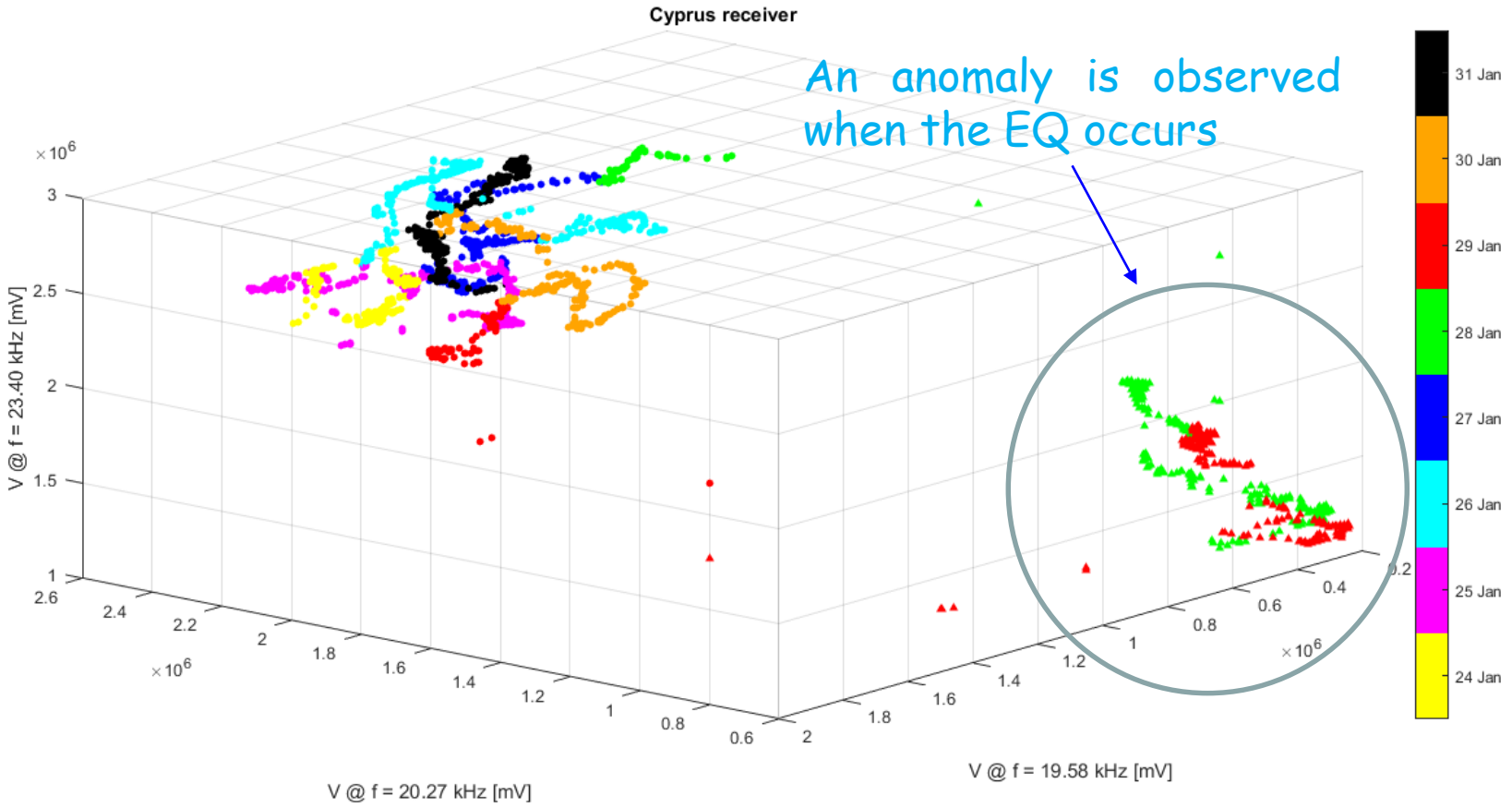






The anomaly is less evident

The automatic detection of anomalies has been also studied using the Perceptually Important Points (PIP) technique applied to the analysis of time series of VLF to dynamically segment the time series into subsequences of unequal length, preserving the shape of the data.



(from M. Monaco et al., accepted to the conference IEEE IGARSS 2021)

Conclusions

Results from the analysis of three VLF signals acquired from the INFREP network have been presented and anomalies have been found in correspondence of the Dodecanese islands EQ (January 20, 2020).

The radio signals confirm their validity as earthquakes precursors.

The importance of using the data of a radio network clearly stands out from this presentation.

In any case in order to produce an earthquake forecast statistically significant one parameter is not sufficient. Only the simultaneous use of several different parameters could be successfull.