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INVESTIGATION OF PRE-EARTHQUAKE IONOSPHERIC ANOMALIES BEFORE ALBANIA 2019 EARTHQUAKE USING THE ROMANIAN RECEIVERS OF THE VLF/LF INFREP AND GNSS GLOBAL EUROPEAN NETWORKS

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Session NH4.5
Short-term Earthquakes Forecast (StEF) and multi-parametric time-Dependent Assessment of Seismic Hazard

Co-sponsored by EMSEV and JpGU
Convener: Valerio Tramutoli | Pier Francesco Biagi, Nicola Genzano, Dimitar Ouzounov, Xuhui Shen
Chat Fri, 08 May, 14:00–15:45

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Abstract

The last two decades a significant effort has been invested in order to understand and interpret the link between seismic activity and ionospheric perturbations. Since not any individual seismo-ionospheric precursor can be used as an accurate stand alone for earthquake prediction it is required to integrate different kinds of precursors and analysis techniques.

To this context, the aim of this study is to investigate pre-earthquake ionospheric anomalies that occurred prior to large 6.4 Mw earthquake in Albania (26th November 2019), following a multi-instrument and multi-technique approach, using sub-ionospheric radio VLF/LF signals obtained from the Romanian receivers of the INFREP European network and Total Electron Content (TEC) observations from GNSS global network.

To identify possible ionospheric anomalies before the earthquakes we applied the terminator time and nighttime fluctuation methods on the amplitude of subionospheric LF radio signals and spectral analysis on diurnal TEC variations several days prior the seismic event. It was found that sunrise terminator times are delayed approximately 20-40 min few days before and during the earthquake day. Intensified wave-like TEC oscillations with periods around 20 min were also revealed up to 5 days prior to the earthquake shocks in all cases that could be interpreted as possible ionospheric precursors of the impending earthquakes.

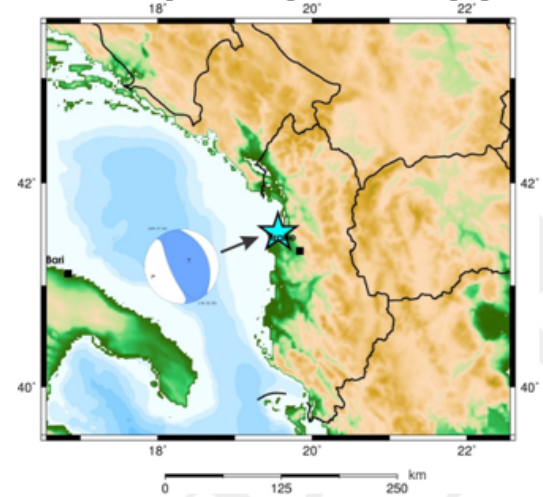
Seismic context

On November 26, 2019, at 02:54 GMT, a strong earthquake of magnitude 6.4 occurred in Albania.

Earthquake parameters (after EMSC)

Date	Hour (GMT)	Lat (°N)	Long (°E)	Depth (km)	M_w
26 Nov 2019	02 : 54 : 11.6	41.38	19.47	10	6.4

The epicenter is located 30 km northwest of Tirana (375,000 inhabitants), 7 km north of Durres (123,000 inhabitants) and 9 km northwest of Shijak (14,200 inhabitants). The quake occurred in a region with a high rate of seismic activity. The strongest earthquake in the area, was a magnitude 6.9 Mw earthquake, occurred on April 15, 1979, 70 km NNE from the earthquake of November 26, 2019 and killed 100 people in Montenegro, 35 in Albania and left 100,000 people homeless. An earthquake with a magnitude of Mw 6.7, recorded on November 30, 1967, 80 km east of the event of November 26, 2019, caused 19 casualties and significant damage in the surrounding region.



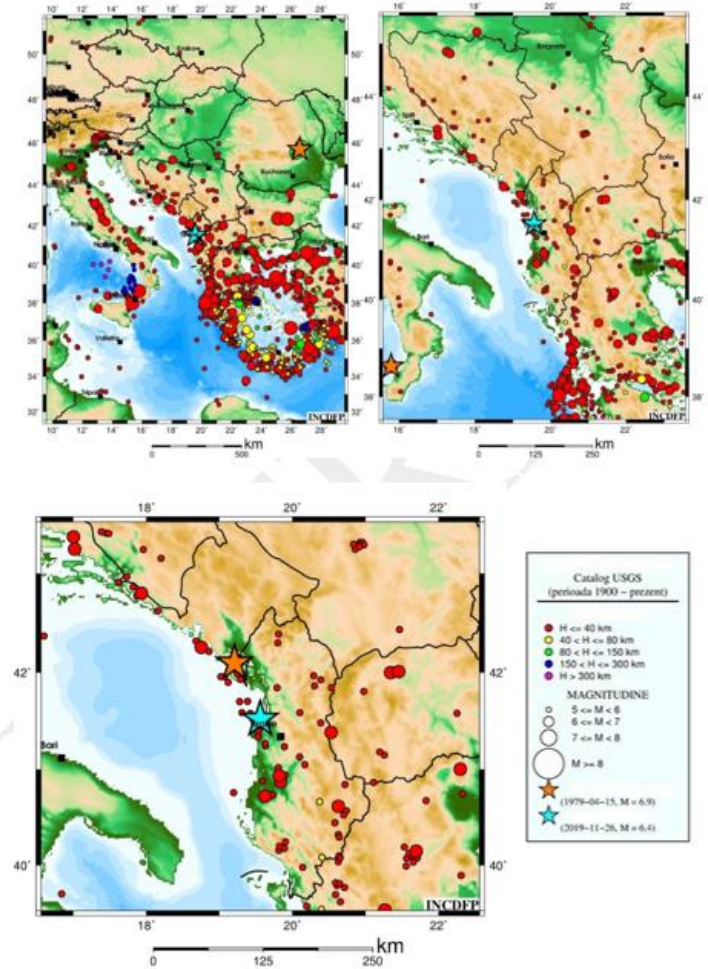
Location of the event and its focal mechanism (according to USGS).

Events with magnitude Mw ≥ 6, recorded in the area over the last 60 years

Date	Hour	Long (°E)	Lat (°N)	Depth(km)	M_w
2019-11-26	**02:54:12.758**	**19.5591**	**41.5205**	**20**	**6.4**
1996-09-05	20:44:09.290	17.936	42.803	10	6.0
1995-05-13	08:47:12.730	21.695	40.149	14	6.6
1990-12-21	06:57:42.990	22.3	41.004	13	6.1
1979-05-24	17:23:18.200	18.752	42.255	8	6.2
1979-04-15	**06:19:44.100**	**19.209**	**42.096**	**10**	**6.9**
1967-11-30	07:23:52.000	20.532	41.386	20	6.7
1967-05-01	07:09:03.000	21.267	39.528	25	6.2
1963-07-26	04:17:17.000	21.345	41.998	15	6.0
1963-07-26	04:17:00.000	21.455	42.008	5	6.1
1962-03-18	15:30:34.000	19.626	40.723	26	6.1
1962-01-11	05:05:03.000	17.006	43.369	15	6.2
1962-01-07	10:03:13.000	17.019	43.247	15	6.2
1960-05-26	05:10:16.000	20.629	40.619	20	6.2
1959-10-07	08:30:45.000	19.84	40.875	20	6.0
1959-09-01	11:37:45.000	19.82	40.935	20	6.2

The earthquake of November 26, 2019 in Albania, with a magnitude of Mw 6.4 occurred as a result of a fault fault near the converging boundary between the African and Eurasian plates. The solutions of the focal mechanism indicate an inverse fault at a shallow depth. The orientation of the fault line is NW - SE and is consistent with the tectonics of the region. At the location of the event the two tectonic plates converge at a rate of 73 mm / year. The tectonics of the Mediterranean Sea in the

region of convergence between Africa and Eurasia is complex and involves the movements of numerous microplates and structures on a regional scale.



Seismicity in the region.

Surface effects of the earthquake

The quake was located 30 km northwest of Tirana (USGS) and was felt throughout the Balkans, but also in Puglia, in southern Italy. In the epicentral area the earthquake had macroseismic intensity VIII MMI (USGS). According to the latest estimates, at least 30 people have died, and the search continues, with many more people missing. Most of the victims were recorded in the coastal area of Dures and in the nearest epicenter, Thumanë. More than 600 people were injured and another 1,200 were evacuated to Thumanë, Tirana, Durrës, Krujë and Lezhë. Hundreds of buildings in these cities have partially or completely collapsed.
Romania sent the rescue-search team RO-USAR of the IGSU special unit within the Ministry of Interior (52 firefighters accredited by the UN for international missions and 12 tons of materials and equipment) in support of the Albanian authorities, according to the Union Civil Protection Mechanism European. Romanian specialists are working in the Durres area with teams from Greece, Croatia and Turkey, to try to find survivors after the disaster.

- http://www.emsc-csem.org/
- http://www.gdasc.org/
- http://earthquake.usgs.gov/
- https://www.mai.gov.ro/echipa-ro-usar-a-inceput-operatiunile-de-salvare
- http://www.infp.ro/index.php

During the studied period (November 2019), the seismic regime in Europe was moderate to high, see next table.

Date	Time UTC	Latitude	Longitude	Depth	M Type	M	Region Name
2019-12-20	6:11:49	59.62	-30.41	10	mb	5	REYKJANES RIDGE
2019-12-10	21:58:29	35.38	26.5	54	Mw	5.4	CRETE
2019-11-27	14:45:27	41.56	19.35	40	Mw	5.3	ADRIATIC SEA
2019-11-27	**7:23:40**	**35.66**	**23.16**	**67**	**Mw**	**6**	**CRETE**
2019-11-26	9:19:26	43.2	17.96	10	Mw	5.4	BOSNIA AND HERZE
2019-11-26	6:08:22	41.58	19.33	10	Mw	5.4	ADRIATIC SEA
2019-11-26	3:03:00	41.47	19.53	10	mb	5.3	ALBANIA
2019-11-26	2:59:24	41.4	19.54	10	mb	5.1	ALBANIA
2019-11-26	**2:54:11**	**41.38**	**19.47**	**10**	**Mw**	**6.4**	**ALBANIA**
2019-11-17	8:39:09	32.66	-4.24	10	Mw	5.1	MOROCCO
2019-11-07	22:47:04	37.72	47.6	10	Mw	5.9	NWIRAN

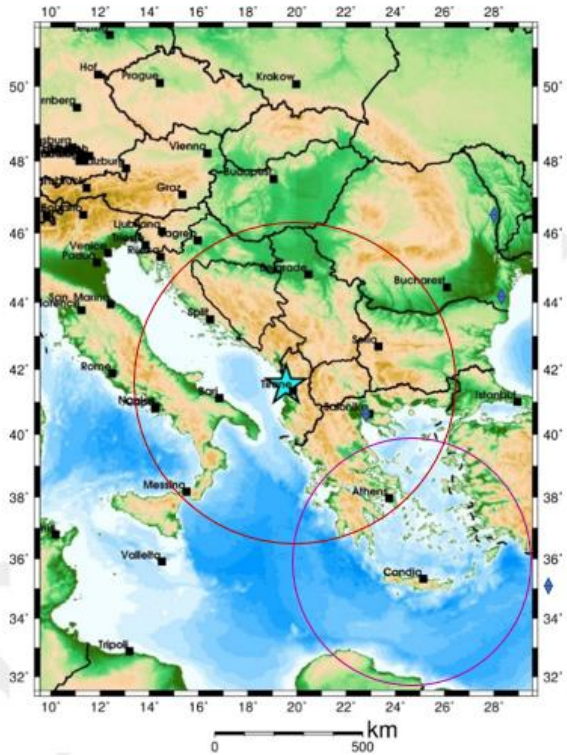
The influence of the solar activity was low during the months of November, excepting 21, 22 and 24 of November

Date	Kp	Kp	Kp	Kp	Kp	Kp	Kp	Kp	ΣKp
2019 11 21	0	0	1	3	3	3	2	3	15
2019 11 22	4	1	2	5	4	3	3	2	20
2019 11 23	1	1	-3	1	-5	-1	1	2	-4
2019 11 24	2	2	3	4	5	2	1	1	18

INFREP Receivers

http://www.infrep-network.eu/index.php/the-network

In this paper we have used the data and the charts from four **INFREP** receivers (Romania : Eforie Nord and Barlad) , Cyprus (Nicosia) and Greece (Thessalonika) offered on the **INFREP** site for **INFREP** participants.



Receivers and Albania earthquake

The preparation zone after Dobrovolski, is between 550 and 1000 km radius. In all maps we have represented only the Dobrovolski preparation area.

Preparation zone

Mw	Dob	H&G	M&M	Fried
6.4	550	700	900	1000
6.0	375	500	550	700

Romania receivers

Romania – Barlad receiver

VLF and LF frequencies monitored by Barlad receiver

LF frequencies monitored by Barlad receiver:

153KHz (RRO-Romania), 162 KHz (FRI – France) , 183 KHz (EU1 – Germany), 198 KHz (CH1 - Algeria), 216 KHz (MCO – France) and 270 KHz (CZE). **Only 198 KHz (Algeria transmitter) is crossing Albania. No paths over Crete.**

VLF frequencies monitored by Barlad receiver:

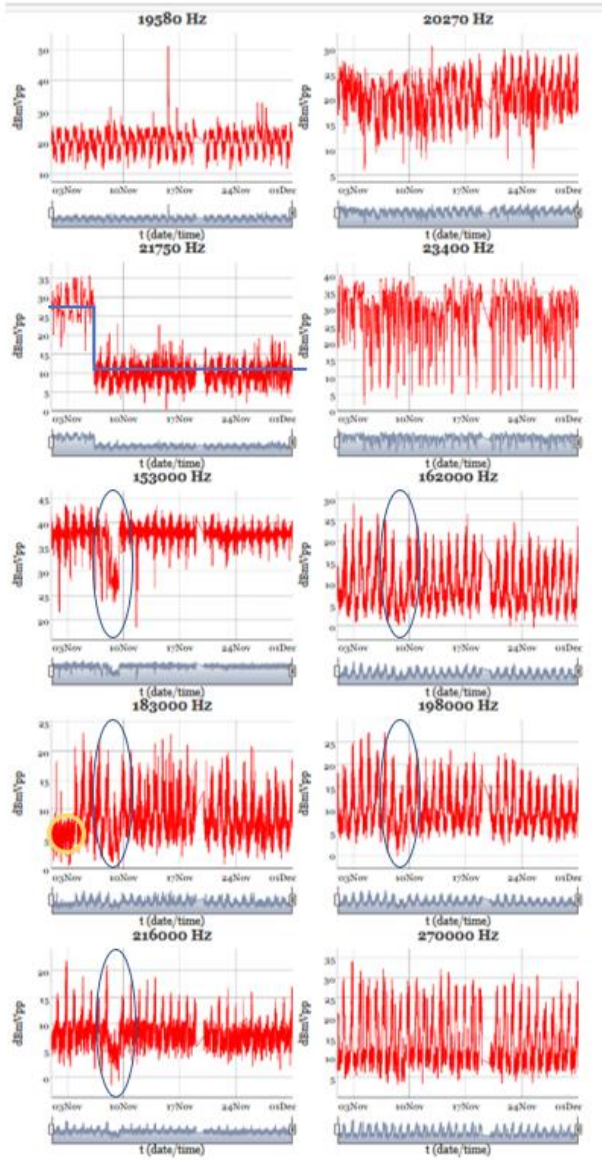
19580 GBZ UK, 20270 ICV IT, 21750 HWU FR, 23400 DHO, Germany. Only **20270 ICV (Italy transmitter) is crossing Albania. No paths over Crete.**

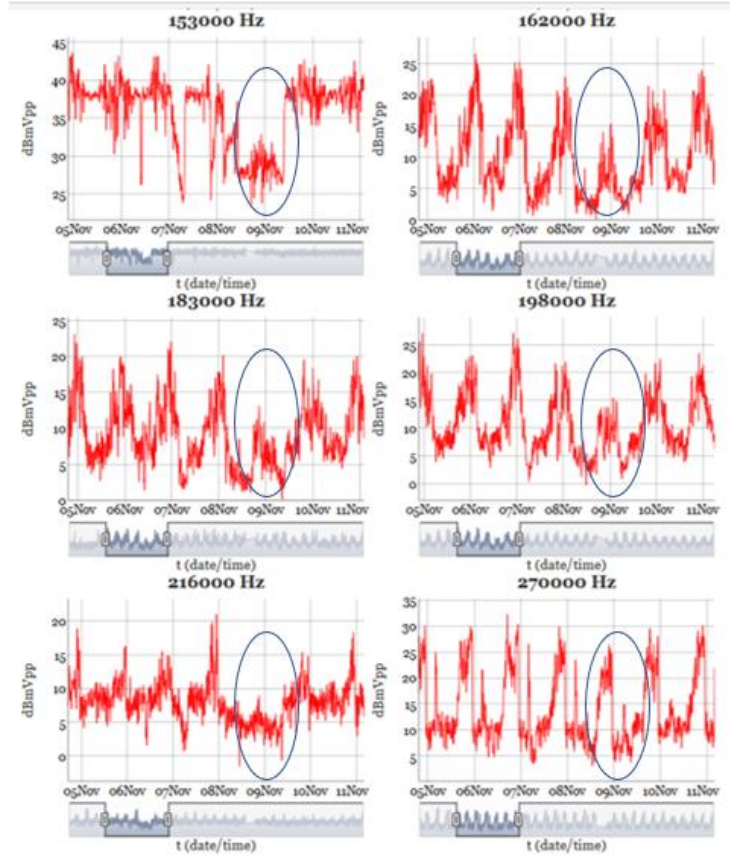
Local seismicity (Barlad deppression) was very low during that time. A local seismic sequence, with earthquakes from 2.0 to 3.5 was recorded in Barlad area only after 25th of December 2020.

Vrancea seismicity for November and December 2019

Date	Time UTC	Latitude	Longitude	Depth	ML
2019-12-30	14:12:37	45.69	26.73	110	3.5
2019-12-19	23:42:40	45.62	26.49	113	3.5
2019-12-12	2:11:45	45.55	26.39	119	3.6
2019-12-09	8:32:41	45.5	26.45	116	3.8
2019-12-01	19:55:37	45.46	26.36	121	3.6
2019-11-24	19:07:06	45.69	26.64	131	3.6
2019-11-10	11:53:58	45.54	26.35	147	3.6
2019-11-05	7:18:34	45.42	26.27	126	3.6

Local meteorological conditions were stable, with temperatures ranking from 7 to 20 degrees, no rain.

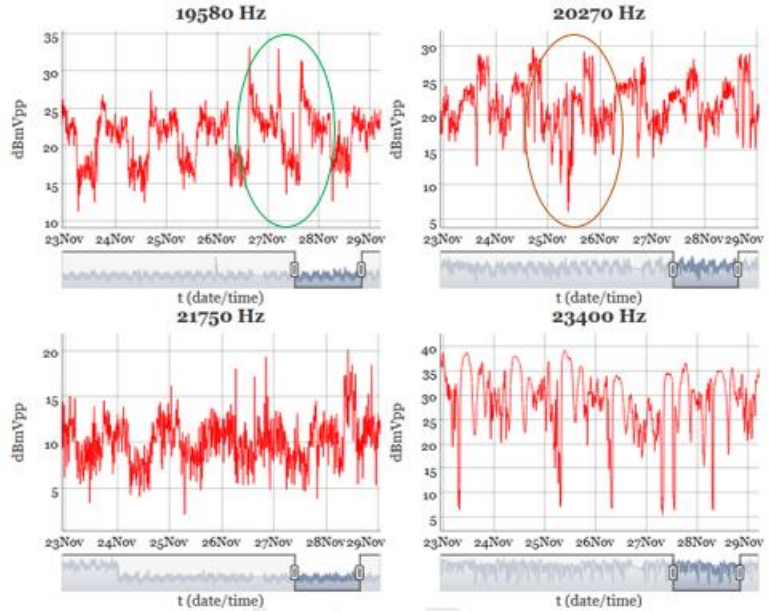




Lower of the signal during the night of 8 to 9th of November 2019, on all LF paths. The anomaly is not present on other INFREP receivers during that time, so maybe the anomaly is a local one.

On VLF recordings (19580 GBZ UK, 20270 ICV IT, 21750 HWU FR, 23400 DHO, Germany), there cannot be seen such annomalies.

It seems that the propagation conditions for LF radio waves was perturbed by a local cause from the lower ionoshpere or from the atmosphere.

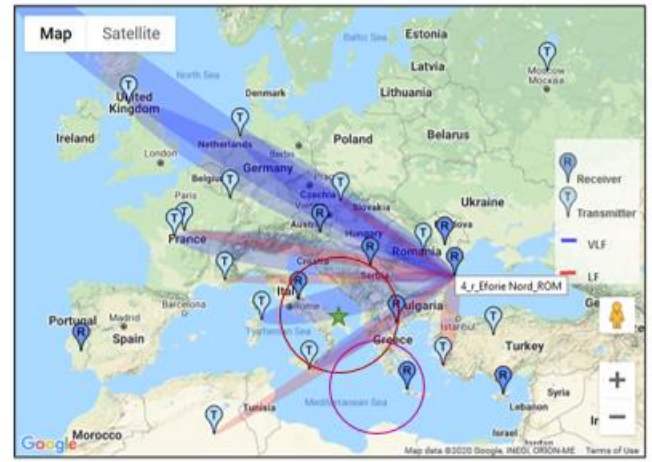


On 19580 UK (not crossing Albania) an anomaly (green) on 27 and 28 of November, after the earthquake.

On 20270 ICV (the only VLF crossing Albania) an anomaly (orange) on 25th, before the earthquake. Pick to pick value of 20 dBmVpp (at 9:00), the average on daytime data beeing less than 10 dBnVpp.

No visible annomalies on the other VLFs'.

Romania – Eforie Nord receiver



VLF and LF frequencies monitored by Barlad receiver

Unfortunately, the receiver experienced some errors between 16 and 21st of November, so we can study only 5 days before the earthquake.

LF frequencies monitored by Eforie Nord receiver:

162 KHz (FRI – France) , 198 KHz (CH1 - Algeria), 216 KHz (MCO – France) and 270 KHz (CZE).

VLF frequencies monitored by Eforie Nord receiver:

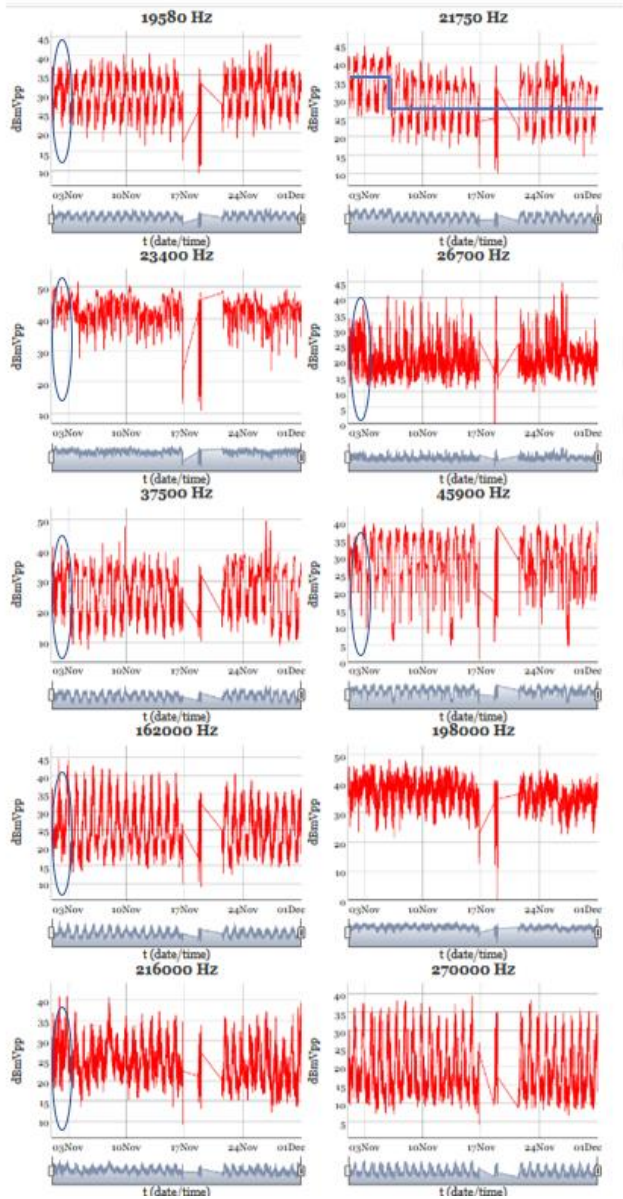
19580 Hz GBZ UK, 21750Hz HWU FR, 23400 Hz DHO, Germany, 26700 Hz TBB Turkey, 37500 Hz NRK Iceland, and 45900 Hz ITS Sicily, IT.

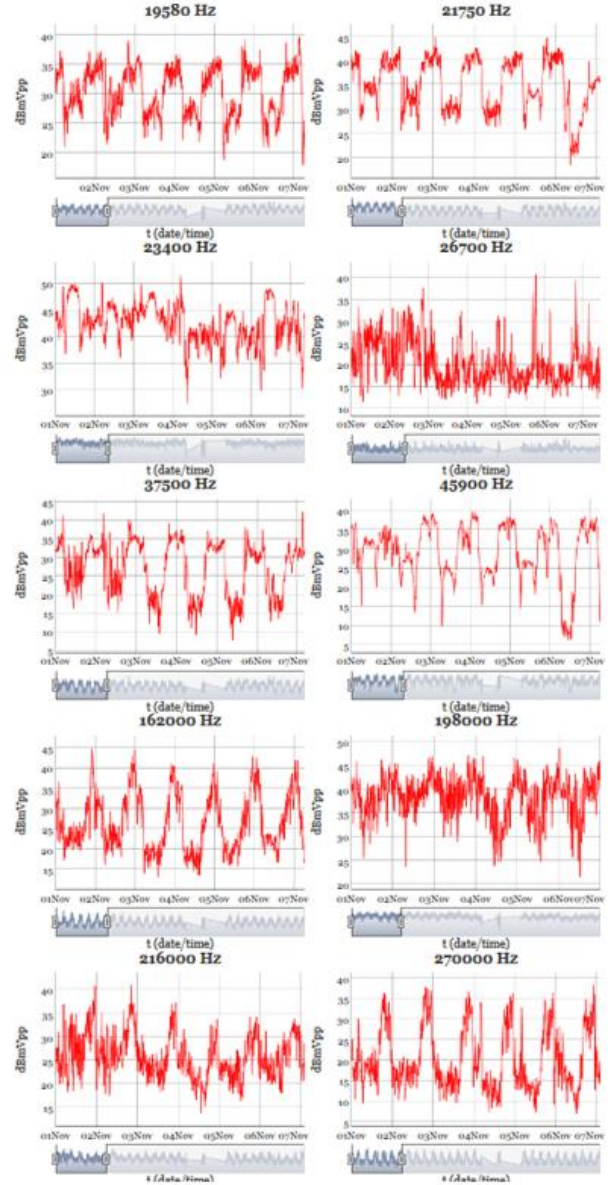
Only 45900 ITS IT and 198000 CH1 Algeria are crossing over Albania, but FRI 162KHz, HWU 21750Hz, MCO 216KHz, and others might be crossing over the preparation zone. No paths over Crete.

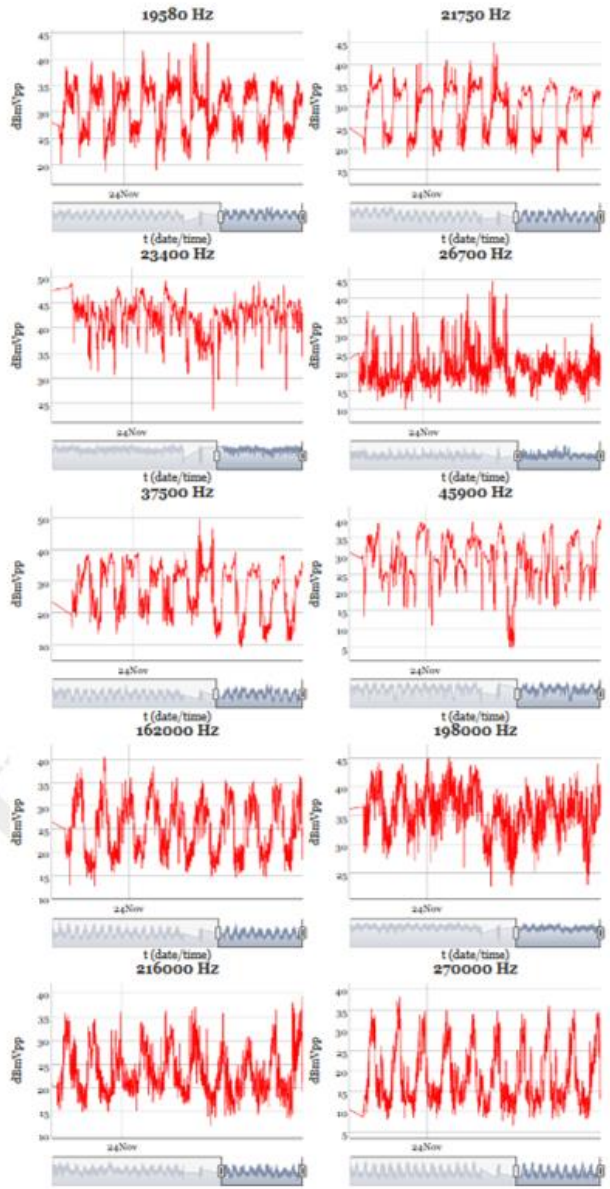
The signal is perturbed in the first two days, on all frequencies, maybe bacause something local, affecting the receiver site, but not of tectonic cause, because the only earthquake recorded in the vicinity of the site, was one month later ML4.1:

Seismicity in the Black Sea

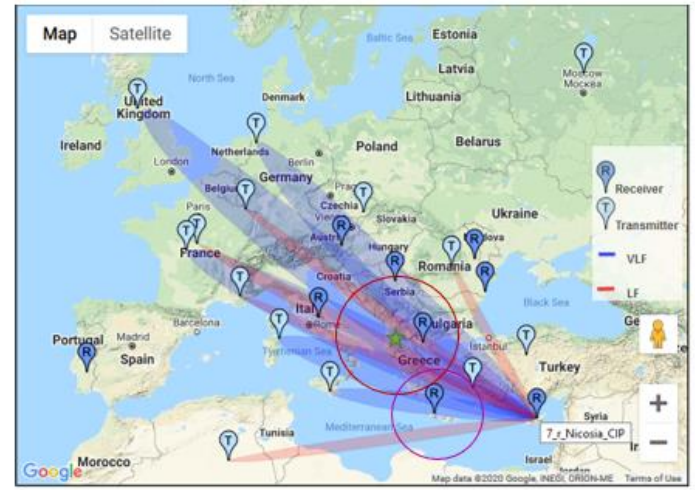
Date	Time UTC	Latitude	Longitude	Depth	ML
2019-12-04	9:43:27	44.04	30.42	80	4.1


19580 Hz
21750 Hz
23400 Hz
26700 Hz
37500 Hz
45900 Hz
162000 Hz
198000 Hz
216000 Hz
270000 Hz
dBmVpp
t (date/time)
03Nov
10Nov
17Nov
24Nov
01Dec


19580 Hz
21750 Hz
23400 Hz
26700 Hz
37500 Hz
45900 Hz
162000 Hz
198000 Hz
216000 Hz
270000 Hz
dBmVpp
t (date/time)
01Nov
02Nov
03Nov
04Nov
05Nov
06Nov
07Nov



Cyprus Nicosia receiver

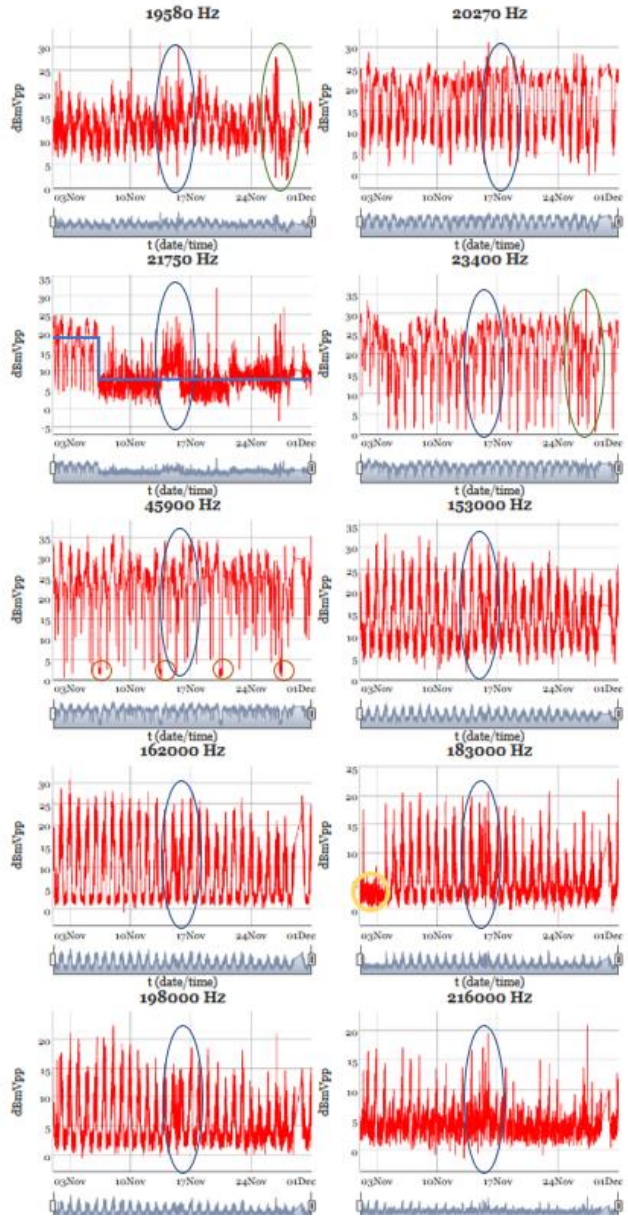


All paths recorded by Cypus are crossing over Albania, excepting ICV 20270 and ITS 45900 from Italy on VLF and CH1 198K from Algeria and RRO 153K from Romania on LF. All VLF are crossing the preparation zone of Albania earthquake. CH1 might be influenced by Crete earthquake.

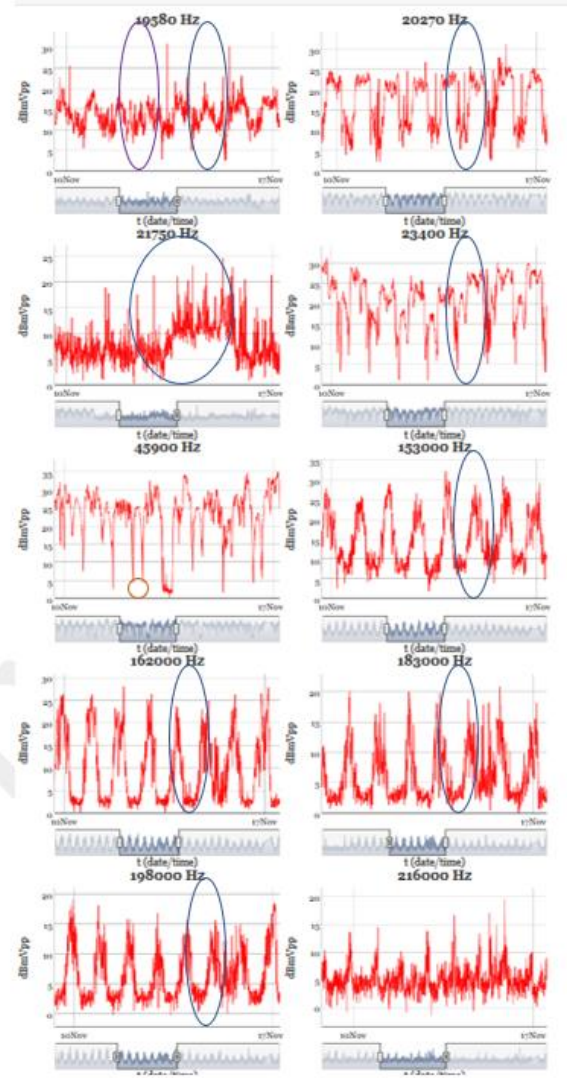
No local earthquakes with M>4.0 in Cyprus during the study period.

Seismicity in the region

Date	Time UTC	Latitude	Longitude	Depth	Mb	Region Name
2019-12-28	1:48:38	35.67	32.09	70	4.3	CYPRUS REGION
2019-11-01	10:17:04	36.5	31.44	91	4	WESTERN TURKEY

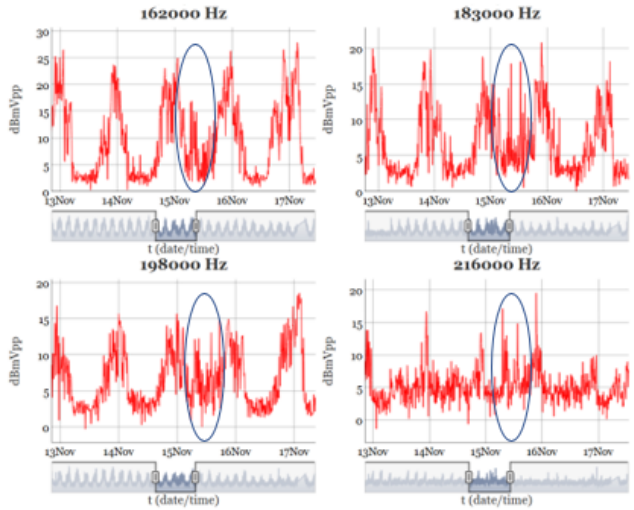


15 November on almost all propagation paths – blue and 13 th of November on 19580 and 45900 – violet and yellow. On 21750 from 13th to 15th.

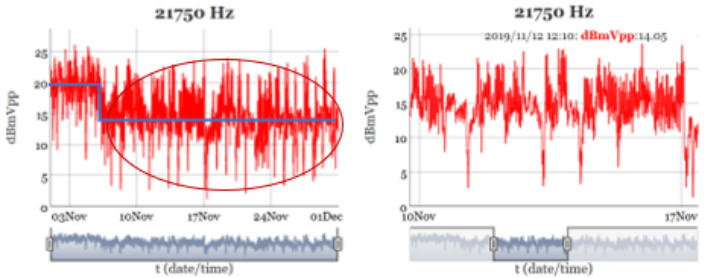


Observations:

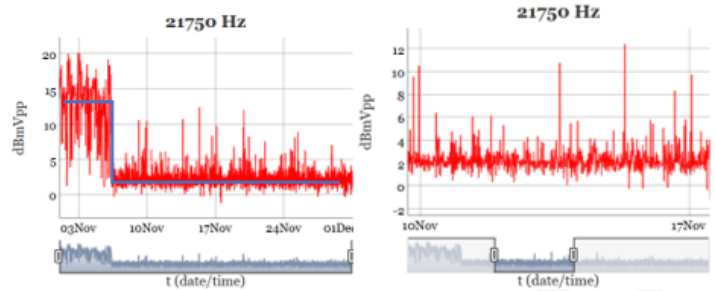
1. On 15th very noisy signal during day time on all paths from LF transmitters to Cyprus receiver, but no decrease of the signal like in Romania, Barlad, on 9th of November (6 days before, also on LF).



2. Starting with 6th of November the signal coming from HWU – France - 21750 Hz, was perturbed, but even so, between 13th to 16th the amplitude of the signal increased. The same behaviour was observed on all receivers that are monitoring HWU France, even on the path Evora (Portugal) – HWU (France), that is not crossing Albania seismic zone. No increase of the signal during 13-15th of November.



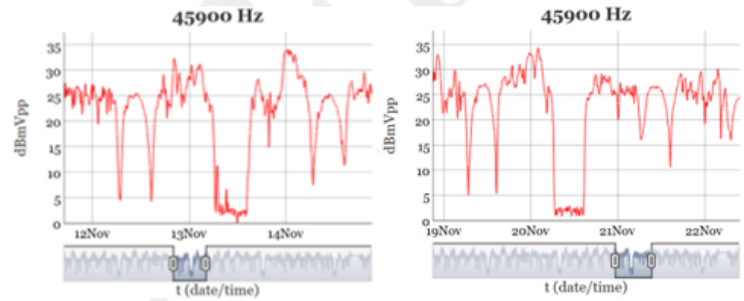
Also on the path Graz (Austria) – HWU (France) the same behavior can be observed, as for Evor – HWU (no crossing of the seismogenic zone). A sudden decrease of the signal in the morning of the 6th of November, but no increase between 13 and 15.



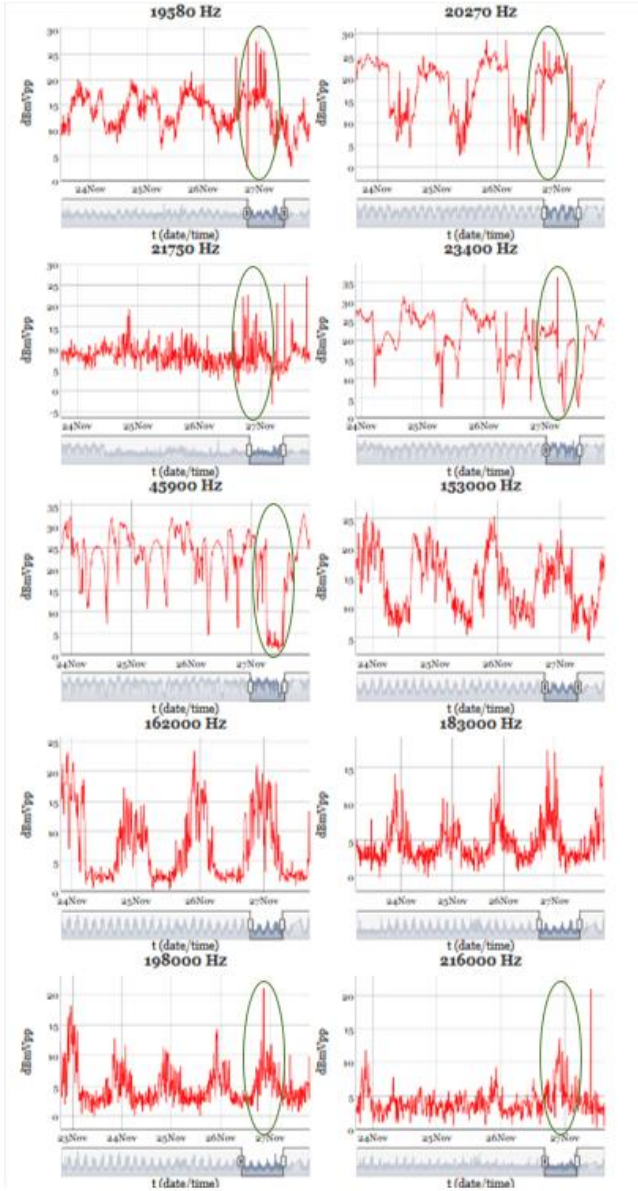
The sharp decrease is observed on all receivers that are monitoring 21750Hz, but no increase between 13 and 15 November.

That means that the anomaly starting on 6th of November is due to a decrease in the emmiting power of the transmitter, but the increase between 13 and 15 of November has to be disscussed more. The increase in the signal appears only on the paths HWU (frequency 21750 Hz) monitored by Cyprus receiver. Maybe the anomalies from 13 – 15 November are related to local phenomena from Nicosia and are not related to Albania Earthquake from 26th November.

3. On 45900 ITS Niscemi, the signal is very low during day time (6AM – 4PM) every 7 days: 6, 13, 20, 27th of November (Wednesday)
4. On 183000 Hz there is a loss of the signal at the beginning of the month. It was observed on all receivers that are monitoring 183000



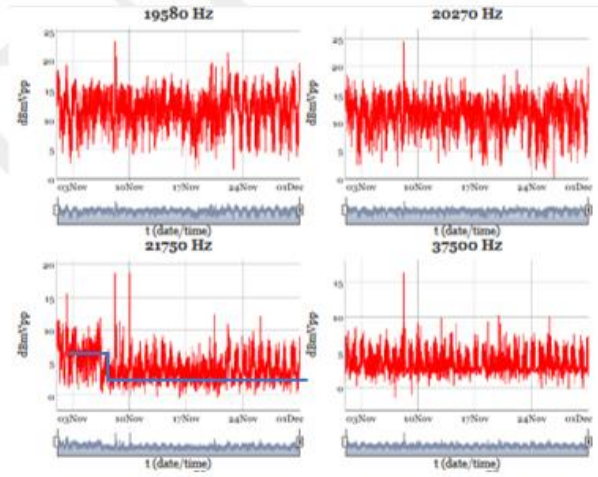
5. 183000 was not functioning until 3rd of November. Anomaly observed on all receivers.
6. On Cyprus receiver, there is another anomaly after the Albania earthquake in the evening of 26th and the morning of 27th of November.

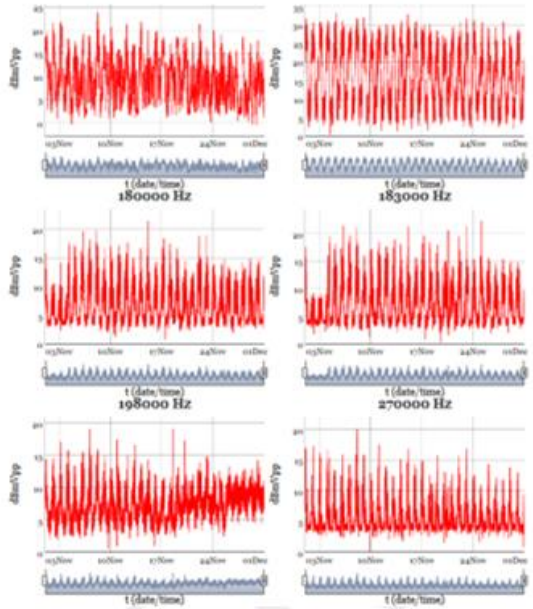


Greece – Thessaloniki receiver

All VLF paths are crossing over Albania. Only two LF paths do not cross it, but the preparation zone is large enough to affect the receiver site in Thessalonica: 153KHz Brasov and 180KHz Turkey.

No local earthquakes with M>4.0 in Greece, Thesaloniki zone during the study period. Only in Crete, but no path is influenced by Crete earthquake.



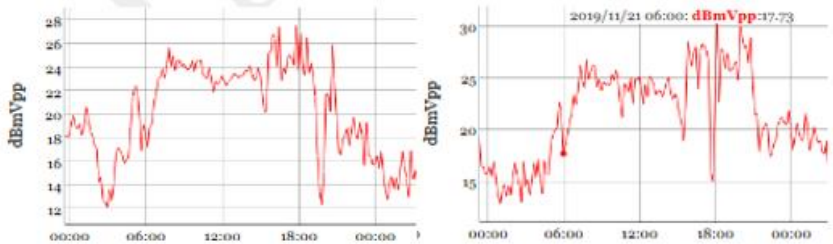


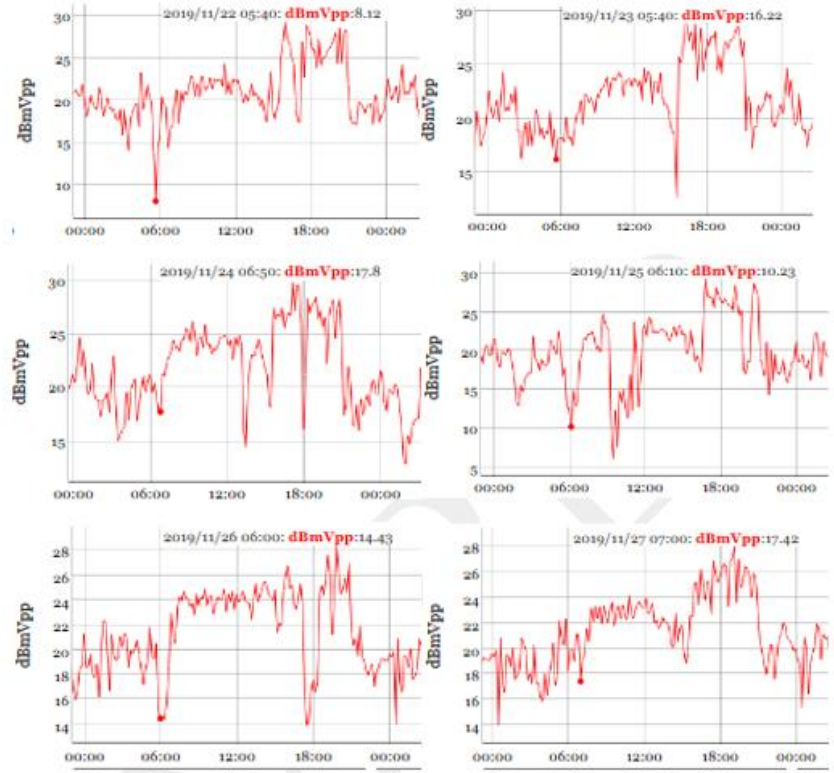
Terminator time

To identify possible ionospheric anomalies before the earthquakes we applied the terminator time method on the amplitude of subionospheric LF and VLF radio signals .
It was found that sunrise terminator times are delayed more th half hour (40-60 min) few days before and during the earthquake day.

Romania Receiver -Barlad (20 – 27 november 2020)
Only 198 KHz (Algeria transmitter) and 20270 ICV (Italy transmitter) are crossing Albania

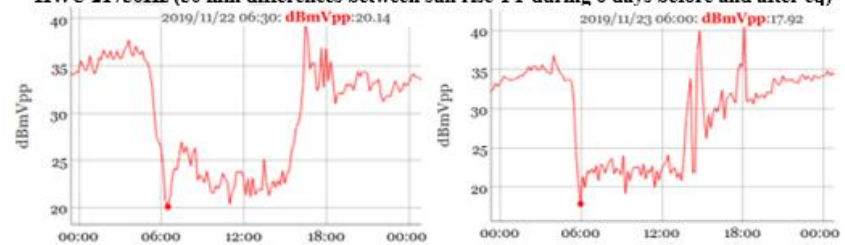
ICV 20270Hz (70 min differences between sun rise TT during 6 days before and after eq)

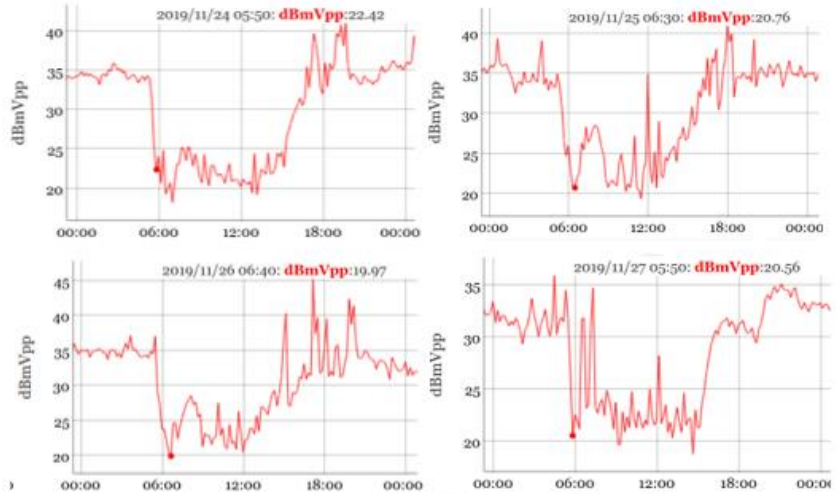




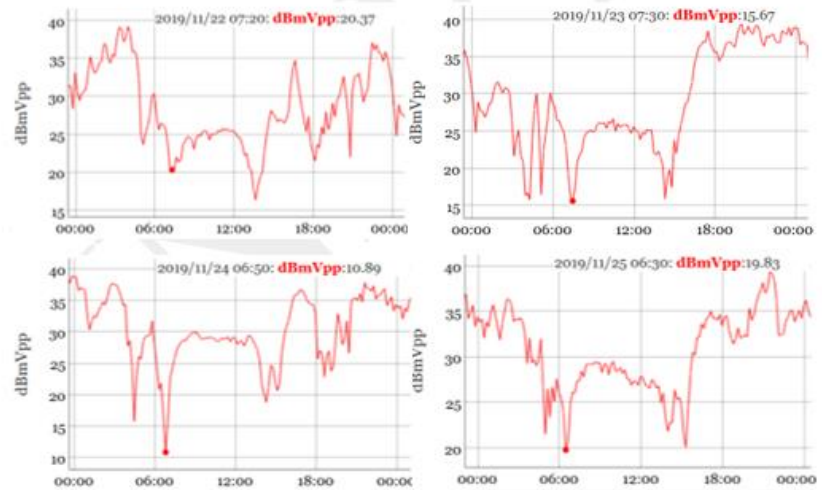
Romania Receiver -Eforie Nord (22 – 27 november 2020)
Only 45900 ITS IT and 198000 CH1 Algeria are crossing over Albania, but FRI 162KHz, HWU 21750Hz, MCO 216KHz are crossing over the preparation zone

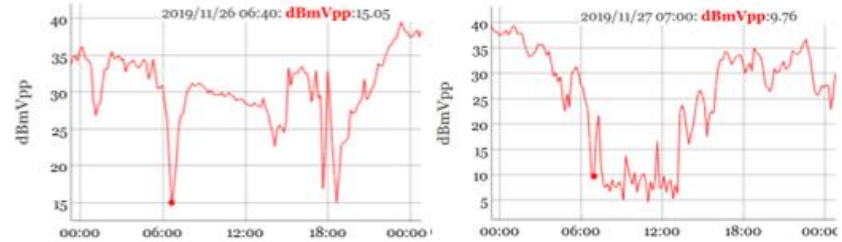
HWU 21750Hz (50 min differences between sun rise TT during 6 days before and after eq)





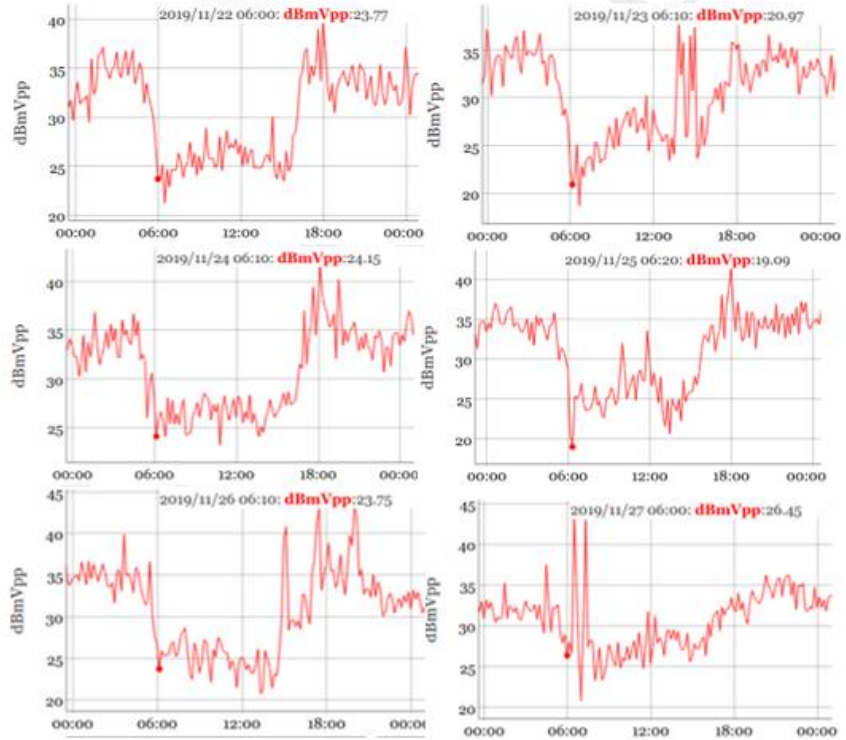
ITS 45900 Hz (60 min differences between sun rise TT during 6 days before and after eq)





GBZ 19580 Hz (refference – not crossing over Albania)
(only 10 min differences between sun rise TT during 6 days before and after eq)

19580 Hz



Spectral analysis on GNSS-derived Total Electron Content (TEC)

Data and Methodology

We apply Spectral Analysis on TEC measurements obtained from regional and global GNSS networks (IGEWE GNSS network in Albania, Hellenic GNSS permanent network, EUREF, IGS). In particular, the difference of slant TEC measurement between two successive satellite epochs is firstly estimated and spectral analysis is then applied on differential slant TEC data by assessing the period and amplitude of differential TEC fluctuations for a period up to 5 days prior to the examined Mw6.4 earthquake on 26 November 2019 in Albania (Muslim et al., 2013). In Figure 1, the GNSS stations employed for the TEC derivation are shown along with the earthquake epicenter and preparation area. It should be mentioned that quiet geomagnetic conditions were prevailing during November 2019, as observed by using the geomagnetic bulletins provided by the National Geophysical Data Center (NGDC) (https://www.ngdc.noaa.gov/) as well as through the geomagnetic index Dst (http://wdc.kugi.kyoto-u.ac.jp/dstdir/index.html), where a Dst index of -50 or deeper denotes a geomagnetic storm-level disturbance. Thus, any TEC anomalies prior to the earthquake are not associated with geomagnetic storms.

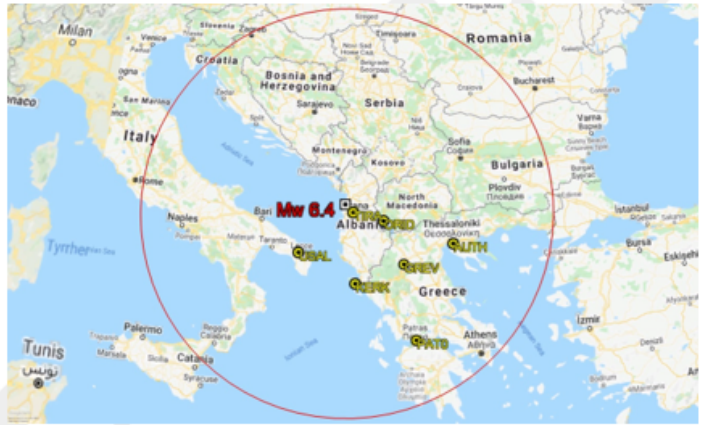


Figure 1. Map showing: a) the preparation area (red circle) and epicenter (white square dot) of Tirana earthquake on 26 November 2019 and b) the GNSS stations (yellow dots) used in this study.

Careful consideration of TEC spectrograms one day before and during the earthquake day on 26 November 2019 demonstrates intensified TEC fluctuations with periods around 20 minutes occurring around 1:00 to 2:30 UT inside the earthquake preparation zone. Such fluctuations are observed mainly from GNSS satellites paths crossing over regions located close to the epicenter (e.g satellite21 in Figure 2). These TEC wave-like perturbations are detected from all 7 GNSS receivers one day and few hours prior to the earthquake as seen in Figures 2, 4, 5. Unlike these days, no such TEC anomalies were detected during 22 October 2019, which is considered as a quiet day in regard to seismic activity (Figure 3) and taking also in mind the quiet geomagnetic conditions dominating during the 1-month pre-earthquake period we can conclude that the observed TEC perturbations prior to the earthquake are most probably related to the impending earthquake. Furthermore, the enhanced TEC fluctuations which are found to occur around sunrise and sunset are excluded from the analysis as they are induced by solar terminator transition. It has been shown that solar terminator comprises a source of TEC waves with periods from 5 min to 1 h which present large regularity (Somsikov 1991, Karpov and Bessarab 2008).

Results

In this investigation, possible ionospheric precursors of the Mw6.4 seismic event on 26 November 2019 in Tirana were identified one day and few hours before the event, by performing Spectral Analysis on GNSS derived TEC observations. This method is capable of discriminating the ionospheric TEC perturbations related to the earthquakes from those induced by the solar terminator transition or geomagnetic storms. As it is known, geomagnetically induced TEC anomalies have periods greater than 60 min, while the observed earthquake related TEC anomalies have periods around 20 min.

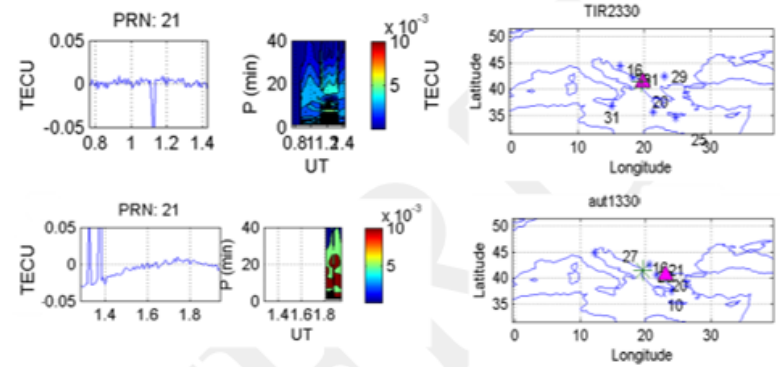


Figure 2. Snapshots of TEC fluctuations (period T up to 40 min) obtained from measurements of several satellites (PRN 21) passing over the area of interest during 1-2 UT on 26 Nov 2019 (Day of year 330). The power spectra of amplitude are also shown. Maps show the number and position of satellite ionospheric pierce points (IPPs) (blue asterisks), GNSS receivers (TIR2, AUT1) location (pink triangles) and earthquake epicenter (green asterisk).

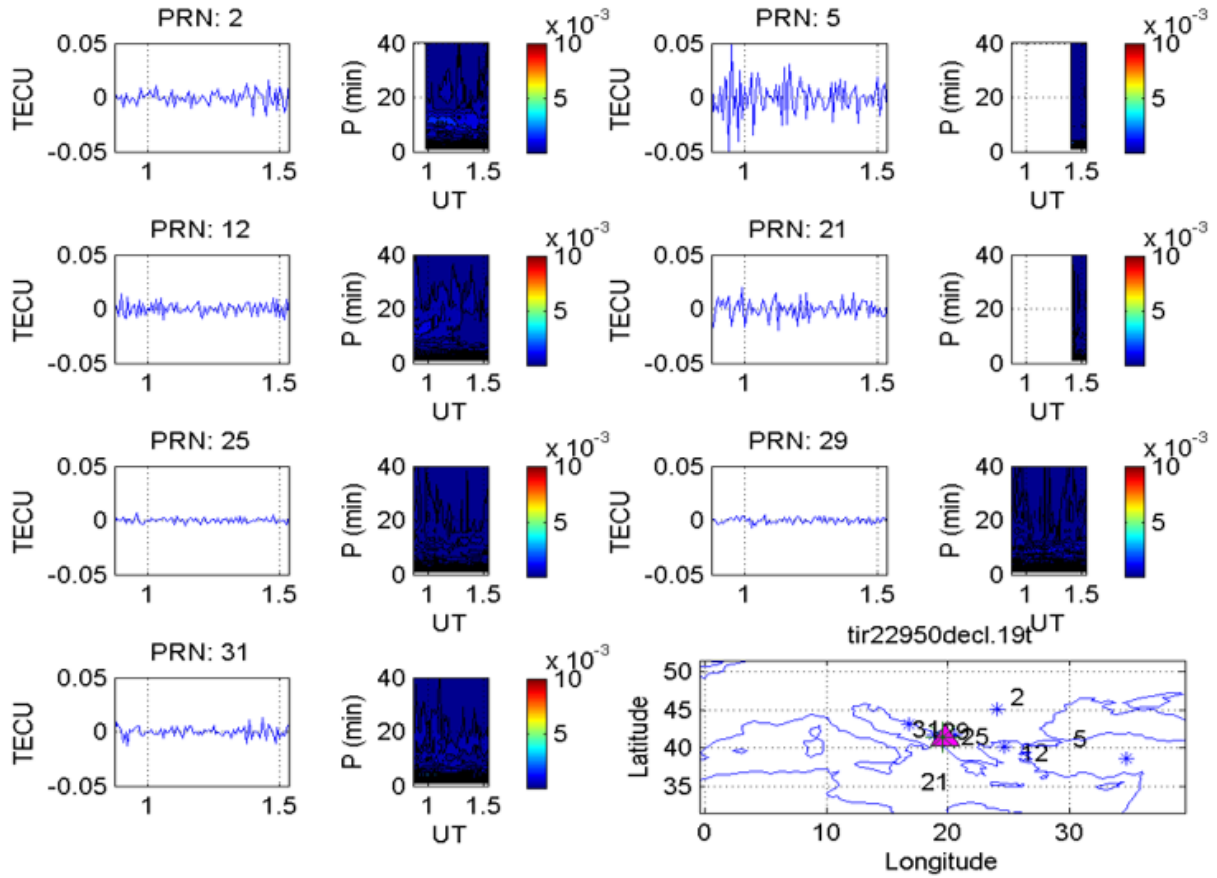


Figure 3. Snapshots of TEC fluctuations (period T up to 40 min) obtained from measurements of several satellites (PRNs) passing over the area of interest during 1-2 UT on seismically quiet day 22 Oct 2019 (Day of year 295). The power spectra of amplitude are also shown. Maps show the number and position of satellite ionospheric pierce points (IPPs) (blue asterisks), GNSS receivers (TIR2) location (pink triangle) and earthquake epicenter (green asterisk).

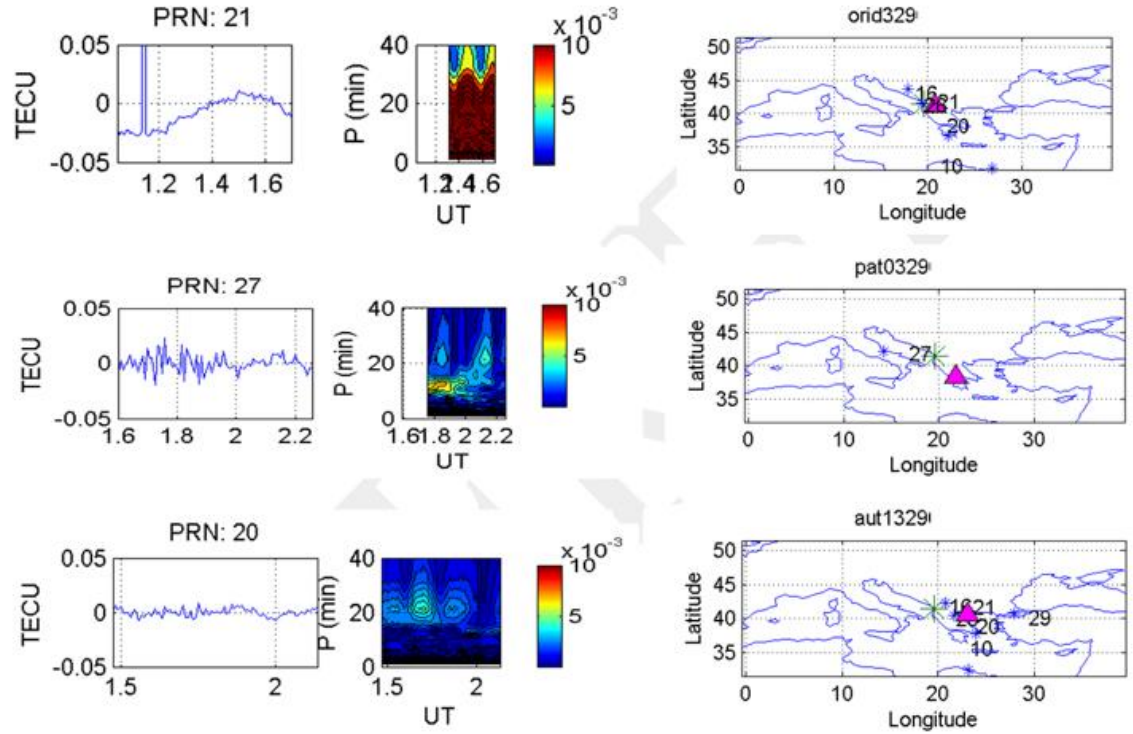


Figure 5. Snapshots of TEC fluctuations (period T up to 40 min) obtained from measurements of several satellites (PRNs) passing over the area of interest during 1:30-2:30 UT on 25 Nov 2019 (Day of year 329). The power spectra of amplitude are also shown. Maps show the number and position of satellite ionospheric pierce points (IPPs) (blue asterisks), GNSS receivers (ORID, PAT0, AUT1) location (pink triangles) and earthquake epicenter (green asterisk).

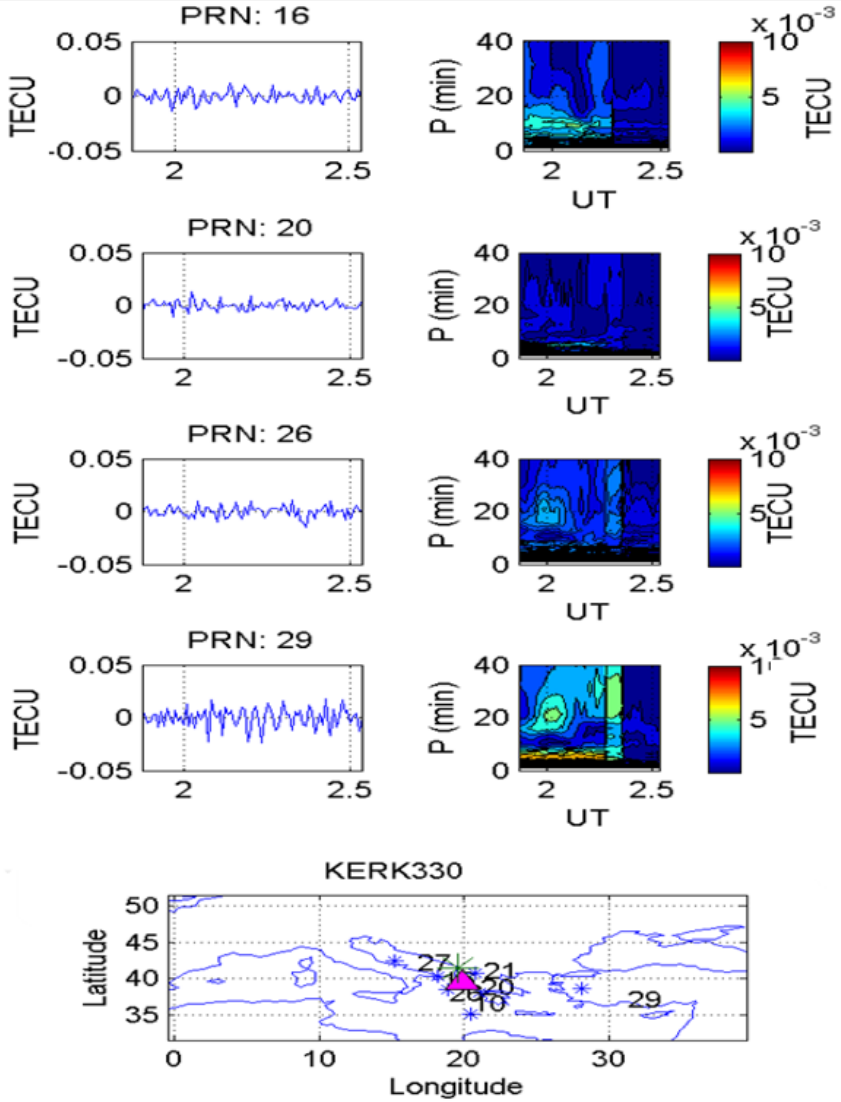


Figure 4. Snapshots of TEC fluctuations (period T up to 40 min) obtained from measurements of several satellites (PRNs) passing over the area of interest during 2:00-2:30 UT on 26 Nov 2019 (Day of year 330). The power spectra of amplitude are also shown. Maps show the number and position of satellite ionospheric pierce points (IPPs) (blue asterisks), GNSS receiver (KERK) location (pink triangle) and earthquake epicenter (green asterisk).

Conclusions

All VLF/LF data were represented using the INFREP application (http://www.infrep-network.eu/index.php/the-network), that is offering to the users a very usefull tool to primary process the network data, and give a general image of observed anomalies and cross - correlate different path Ri-Ti and seismic sources.

The observed anomalies in radio propagation were considered local anomalies with no correlation with the Albania earthquake. Only on SRTT the anomalies were observed only on paths that are crossing albania or the preparation area of the earthquake.

By performing Spectral Analysis on GNSS derived TEC observations, possible ionospheric precursors of the Mw6.4 seismic event on 26 November 2019 in Tirana were identified one day and few hours before the event. The observed earthquake related TEC anomalies have periods around 20 min.

Selective bibliography

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Karpov IV, Bessarab FS (2008) Model studying the effect of the solar terminator on the thermospheric parameters. Geomagn Aeron 48:209–219.