SUB-IONOSPHERIC VLF/LF WAVEGUIDE VARIATIONS RELATED TO MAGNITUDE M>5 EARTHQUAKES IN THE EASTERN MEDITERRANEAN AREA

Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier Francesco Biagi[3], Patrick Galopeau[4], Ghulam Jaffer[5], Özer Aydogar[1], Christoph Schirninger[1], Cosima Muck[1], Irmgard Jernej[1], and Werner Magnes[1]

[1] Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [2] Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, [3] Department of Physics, University of Bari, Bari, Italy, [4] LATMOS-CNRS, UVSQ Université Paris-Saclay, Guyancourt, France, [5] SpaSys, SnT – Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg, Luxembourg

In this study we examine earthquakes with magnitude M ≥ 5 in the year 2022 where the epicenters are crossed by sub-ionospheric narrowband VLF/LF radio links. The study regions are Italy, Aegean area, and the Balkan Peninsula. Ideal suited for this task are paths from the transmitters TBB (26.70 kHz, Bafa, Turkey), ITS (45.90 kHz, Niscemi, Sicily, Italy), and ICV (20.27 kHz, Tavolara, Italy) to the seismo-electromagnetic receiver facility GRZ (Graz, Austria). The receiver is part of a wider network, this gives the opportunity to have multiple simultaneous crossings of an earthquake event. We investigate electric field amplitude variations in the time span a few days around the main shock, in particular we apply the so-called night-time amplitude method. All electric field data sets have 1 sec temporal resolution. A crucial point is a certain threshold magnitude to obtain statistically significant results, but to firm up the results additional complementary investigations are necessary. In summary, VLF/LF investigations of strong earthquakes show the complex interplay between the lithospheric events and electric field amplitude waveguide variations, multi-parametric observations in a network could be a tool to derive robust results.

VLF/LF NETWORK, SOUTH EUROPEAN PATHS

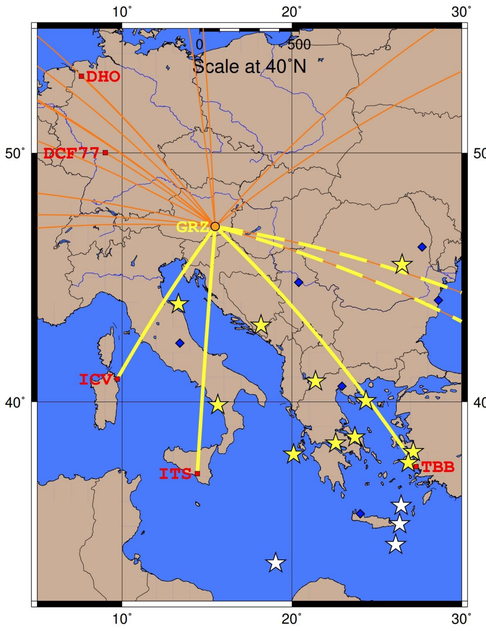

Figure 1: Great circle paths (orange & yellow lines) between VLF/LF transmitter and Graz receiver (orange circle, UltraMSK system [3]), for the INFREP system (diamonds in blue color) see [4]. Magnitude M>5 earthquakes (15 white & yellow stars) and the relevant paths (ITS-GRZ, TBB-GRZ, and ICV-GRZ) related to Dobrovolsky-Bowman relationship are indicated (yellow lines good S/N, yellow-dotted lines are VTX-GRZ and NWC-GRZ long distance paths). Credit map: GMT

TRANSMITTER, VLF/LF SYSTEM PARAMETERS

Receiver: Graz, IWF, Elettronika [E] and UltraMSK [U] system, N 47°2'40.38'' O 15°28'47.68''				
No.	Acronym	Frequency (kHz)	GCP (km)	Transmitter, Systems [U 1sec], [U 20sec], [E 60 sec]
1	JXN	16.40	2160	Aldra, Norway [U 1s] [U 20s]
2	GWU	18.30	980	Le Blanc, Rosnay, St. Assise, France [U 1s]
3	VTX	19.20 (17.00)	7240	Vijayanarayanam, India [U 1s] [U 20s]
4	GBS	19.58	1570	Anthorn, UK [U 1s] [U 20s]
5	NWC	19.80	12390	Exmouth, Western Australia [U 1s]
6	ICV	20.27	820	Tavolara, Sardinia, Italy [U 1s] [U 20s] [E 60s]
7	HWU	20.90 / 21.75	1080	Le Blanc, St. Assise, France [U 1s] [U 20s] [E 60s]
8	NPM	21.40	12380	Lualualei, Hawaii, USA [U 1s] [U 20s]
9	GBZ	22.10	1540	Skelton, UK [U 1s] [U 20s] [E 60s]
10	JJI	22.20	9140	Ebino, Kyushu, Japan [U 1s]
11	DHO	23.40	875	Rhauderfehn, Germany [U 1s] [U 20s] [E 60s]
12	NAA	24.00	6110	Cutler, Maine, USA [U 1s] [U 20s]
13	NLM	25.20	7820	LaMoure, North Dakota, USA [U 1s]
14	TBB	26.70	1445	Bafa, Turkey [U 1s] [U 20s]
15	NRK	37.50	2975	Keflavik, Iceland [U 1s] [U 20s] [E 60s]
16	JJY	40.00	9195	Mount Otakadoya, Honshu, Japan [U 1s]
17	NAU	40.80	7985	Aguada, Puerto Rico, USA [U 1s]
18	ITS	45.90	1105	Niscemi, Sicily, Italy [U 1s] [U 20s]
19	DCF	77.50	580	Mainflingen, Germany [U 1s]
20	RRO	153	790	Brasov, Romania [E 60s]
21	TDF (EU1)	162 (183)	1010 (700)	Allouis, France (Felsberg–Berus, Luxembourg) [E 60s]
22	CH1	198	1900	Berkaoui/Ouargia, Algeria [E 60s]
23	RTL (MCO)	234 (216)	740 (820)	Beidweiler, Luxembourg (Roumoules, Monte Carlo) [E 60s]
24	CZE	270	275	Topolna, Czech Republic [E 60s]

Table 2: Transmitter received at the VLF/LF Graz facility, current settings in blue/green color, see [3, 4], event paths in yellow color.

EARTHQUAKES M ≥ 5, 2022, EASTERN MEDITERRANEAN AREA, DATA PROCESSING & RESULTS

We investigate VLF/LF electric fields from sub-ionospheric VLF/LF propagation paths in the geographic lat/lon range [30° ≤ lat ≤ 50°] / [10° ≤ long ≤ 30°], i.e., an Eastern Mediterranean area, in the year 2022. For this temporal, spatial and moment magnitude M_w ≥ 5 the USGS earthquake database [7] gives 15 EQs. All events (Tab. 1, Fig. 1) are selected, emphasis is according to VLF/LF path crossings and the size of the Dobrovolsky-Bowman relationship [1, 2] (the radius of the effective precursor manifestation zone ϱ = $10^{(0.43*M)}$ km and log(R) ≈ M/2 km). Four events are out of a crossing area (Fig. 1, white stars and Tab. 1, no. 12-15). The VLF/LF amplitude data have 1 Hz temporal resolution, nighttime values are used (±2 hours around midnight), see [5, 6]. The values are smoothed with a low-pass filter, the residuals are below 1 dB. Positive results (green color in Tab. 1), i.e., the link between measured VLF/LF electric field and EQ, based on statistics from nighttime electric field amplitude variations with significance level 5%, are mainly achieved for M ≥ 5.5 earthquakes.

Selected Earthquakes Magnitude M ≥ 5, USGS database, time span 01.01.2022 – 31.12.2022, long/lat range: [10°–30°]/[30°–50°]							
No.	Date, Time	Lat (°) / Lon (°) / Depth (km)	Mag / ϱ (km)	Location	Main path	Control paths	Result, Annotation
1	2022-01-09 21:43:47	+40.827 / +21.392 / 13.4	5.5 / 232	Flórina, Greece	TBB–GRZ	6 {NAA,ICV,GWU,GBZ,GBS,NRK}–GRZ	Not OK: not significant, all paths out of 5% level
2	2022-01-16 11:48:05	+40.041 / +24.361 / 7.0	5.5 / 232	Karyes, Greece	TBB–GRZ	8 {NAA,JJI,ICV,GWU,GBZ,GBS,DHO,NRK}–GRZ	Not OK: not significant, except ICV
3	2022-04-22 21:07:48	+43.074 / +18.180 / 10.0	5.7 / 282	Ljubinje, Bos. & Herzeg.	ITS–GRZ	9 {TBB,NAA,JJI,ICV,HWU,GBZ,DHO,DCF,NRK}–GRZ	OK: Post EQ > Pre EQ values with significance level 5%
4	2022-08-14 03:24:22	+37.995 / +27.151 / 11.7	5.0 / 141	Özdere, Turkey	TBB–GRZ	8 {NAA,ITS,HWU,GBZ,GBS,DHO,DCF,NRK}–GRZ	Not OK: not significant
5	2022-08-31 10:10:11	+37.553 / +26.852 / 10.9	5.4 / 210	Megálo Chorió, Greece	TBB–GRZ	9 {NAA,JJI,ITS,HWU,GBZ,GBS,DHO,DCF,NRK}–GRZ	Not OK: not significant, except NAA, GBZ, DHO
6	2022-09-08 07:36:23	+37.894 / +20.099 / 10.5	5.5 / 232	Lixouri, Greece	{TBB,ITS}–GRZ	6 {NAA,HWU,GBZ,GBS,DHO,NRK}–GRZ	OK / not OK: Post EQ > Pre EQ values with sig. level 5%,
7	2022-10-08 22:02:28	+38.339 / +22.579 / 19.8	5.3 / 190	Antikyra, Greece	TBB–GRZ	9 {NAA,JXN,JJI,ITS,ICV,GBZ,GBS,DHO,NRK}–GRZ	OK: Post EQ > Pre EQ values with significance level 5%
8	2022-10-31 21:42:50	+39.877 / +15.640 / 271	5.5 / 232	Tortora Marina, Italy	ITS–GRZ	9 {TBB,NAA,JJI,ICV,GWU,GBZ,GBS,DHO,NRK}–GRZ	Not OK: not significant, except GBS
9	2022-11-03 04:50:25	+45.512 / +26.490 / 153	5.1 / 156	Gura Teghii, Romania	TBB–GRZ	9 {NAA,JJI,ITS,ICV,GWU,GBZ,GBS,DHO,NRK}–GRZ	Not OK: not significant, except GBS; out of Dob–Bow area
10	2022-11-09 06:07:26	+43.932 / +13.315 / 8.0	5.6 / 256	Central Italy, Italy	{ITS,ICV}–GRZ	9 {TBB,NAA,JJI,HWU,GWU,GBZ,GBS,DHO,NRK}–GRZ	Not OK: not significant, except TBB; ITS, ICV close to OK
11	2022-12-28 12:24:20	+38.581 / +23.709 / 10.3	5.0 / 141	Psachná, Greece	TBB–GRZ	9 {NAA,JJI,IST,ICV,GWU,GBZ,GBS,DHO,NRK}–GRZ	Not OK: not significant, except NAA, GBS, NRK
12	2022-08-12 21:31:50	+33.524 / +19.044 / 18.2	5.2 / 172	Tukrah, Libya	{TBB,ITS}–GRZ	7 {NAA,JJI,HWU,GBZ,GBS,DHO,NRK}–GRZ	No crossing link, not in Dobrovolsky–Bowman area
13	2022-09-03 04:13:10	+35.097 / +26.347 / 8.8	5.3 / 190	Palekastro, Greece	TBB–GRZ	10 {NAA,JXN,JJI,ITS,HWU,GBZ,GBS,DHO,DCF,NRK}–GRZ	No crossing link, not in Dobrovolsky–Bowman area
14	2022-10-02 04:04:01	+34.266 / +26.114 / 10.0	5.4 / 210	Ierápetra, Greece	TBB–GRZ	10 {NAA,JXN,JJI,ITS,ICV,GBZ,GBS,DHO,DCF,NRK}–GRZ	No crossing link, not in Dobrovolsky–Bowman area
15	2022-11-20 23:24:58	+35.836 / +26.412 / 63.0	5.5 / 232	Crete, Greece	TBB–GRZ		Receiver out of service during the EQ epoch

Table 1: Results for all M ≥ 5 earthquakes (see Figure 1, stars in yellow and white color), time period 2022, Eastern Mediterranean area.

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7. United States Geological Survey (USGS) earthquake catalog, database and website https://earthquake.usgs.gov/ as of April 2023.

SUMMARY

VLF/LF electric field variations (nighttime amplitude method; assumed significance level 5%) could be related to M ≥ 5.5 (threshold) earthquakes. Multi-parametric observations shall complement the VLF/LF method to achieve robust results.

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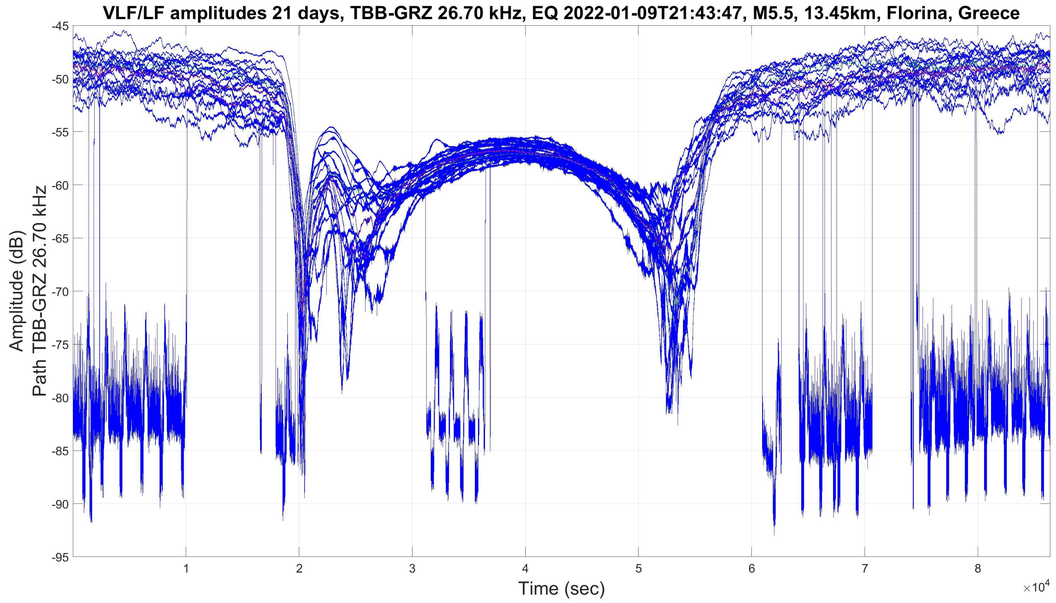
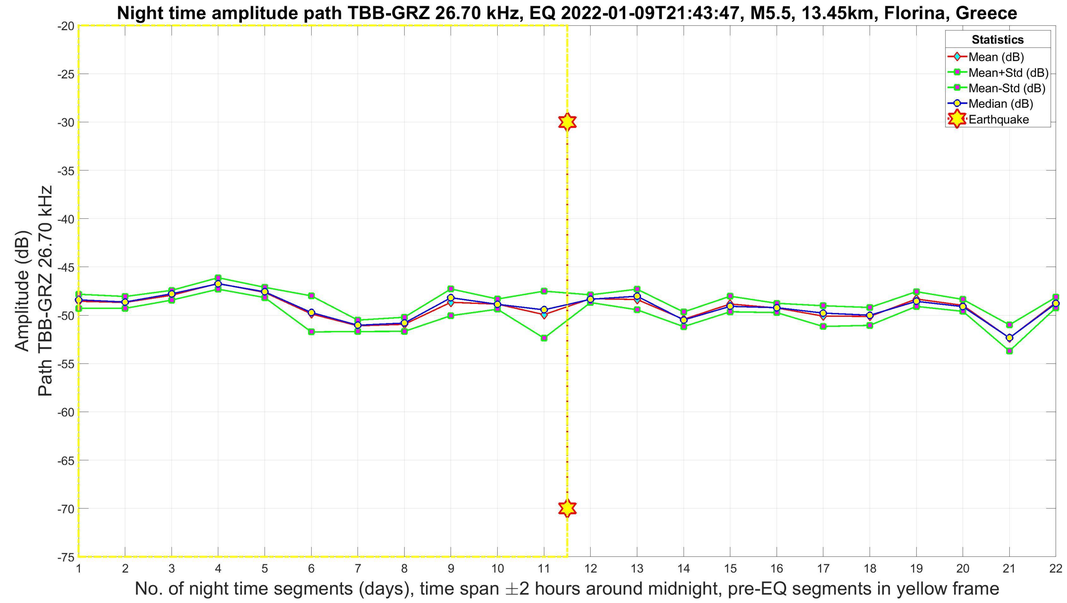
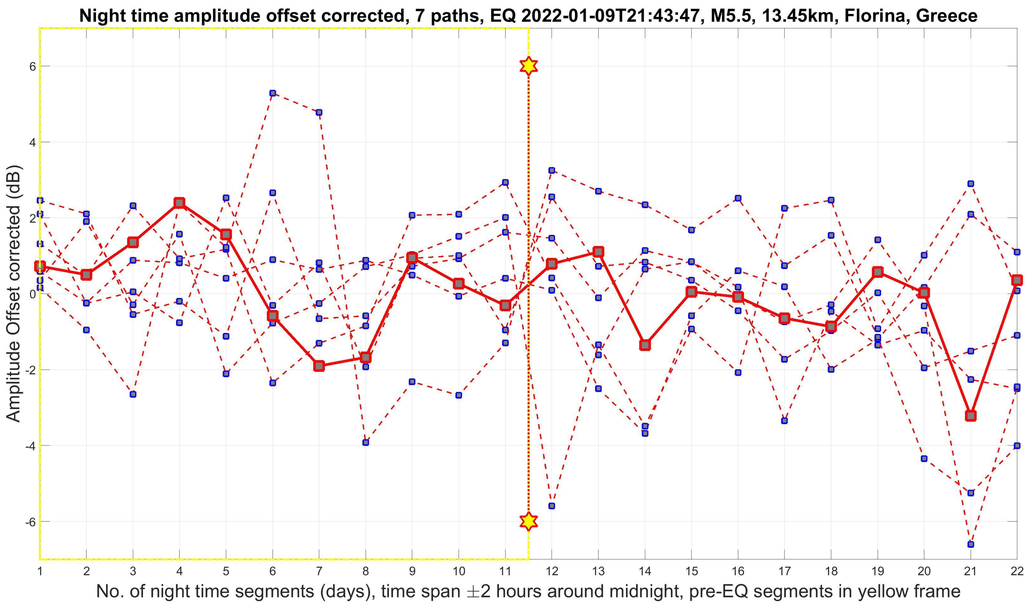
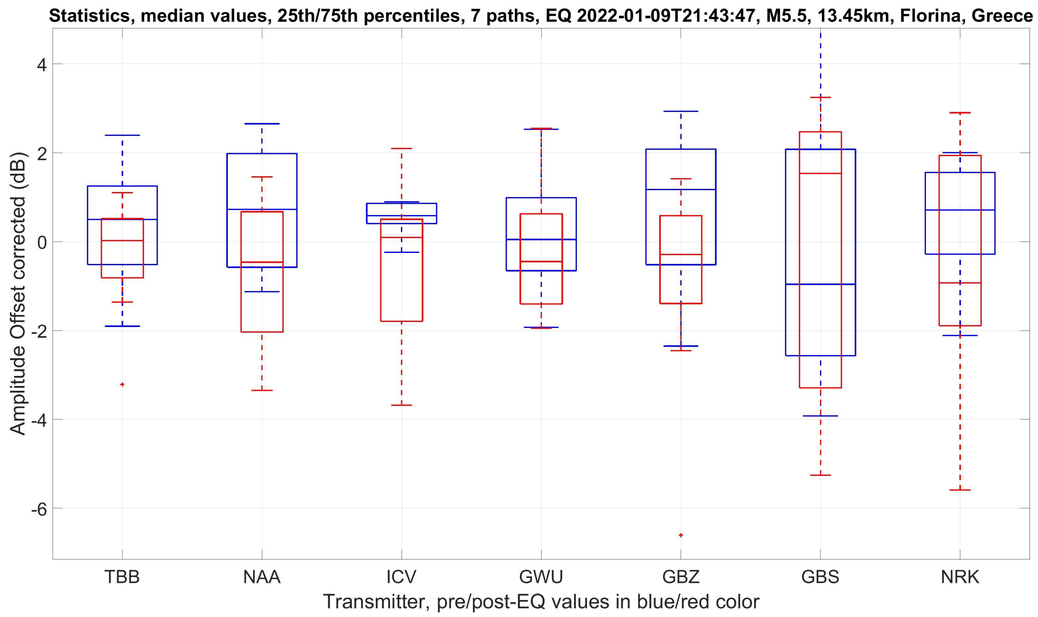
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-01-09, M5.5, 13.45 KM, FLÓRINA, GREECE

- Top Left: VLF/LF amplitudes (2021-12-30 to 2022-01-19) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 7 paths
- Top Right: Nighttime amplitude values for the affected TBB-GRZ event path (crossing the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected 7 paths, no significant variations (5% level) according to the nighttime method









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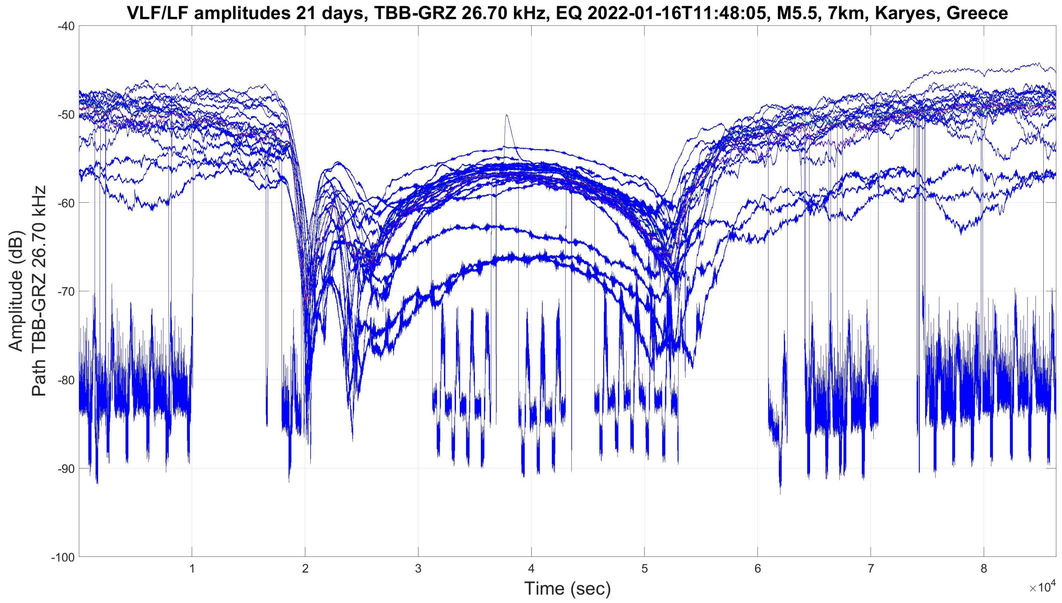
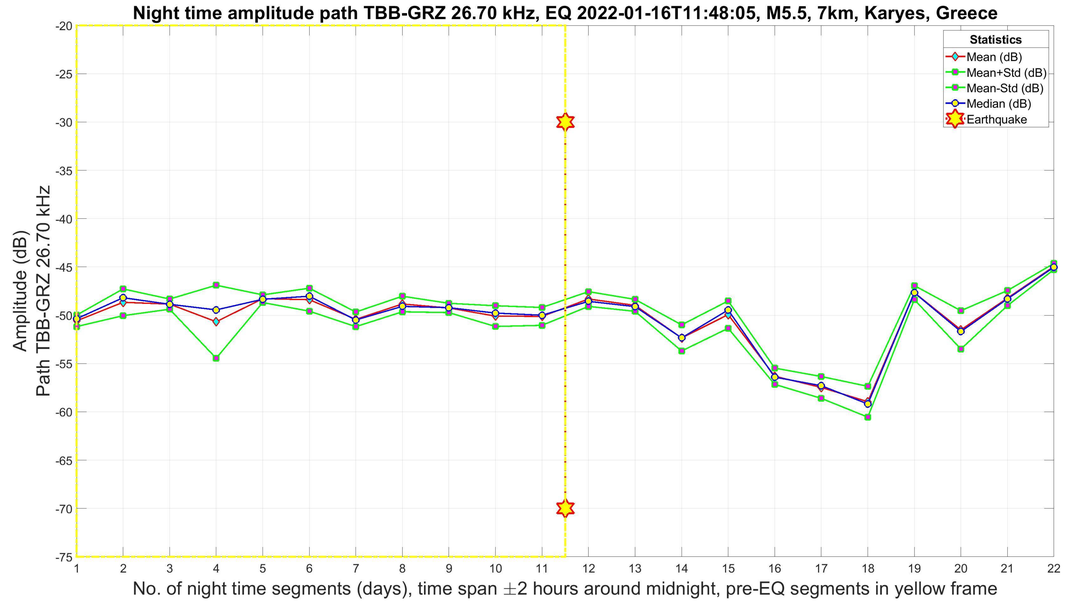
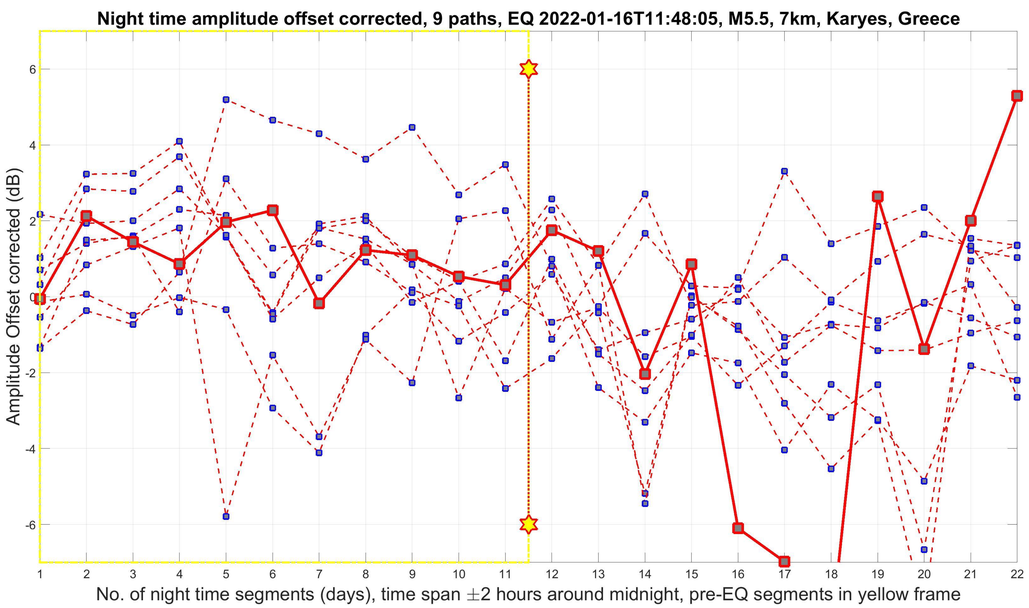
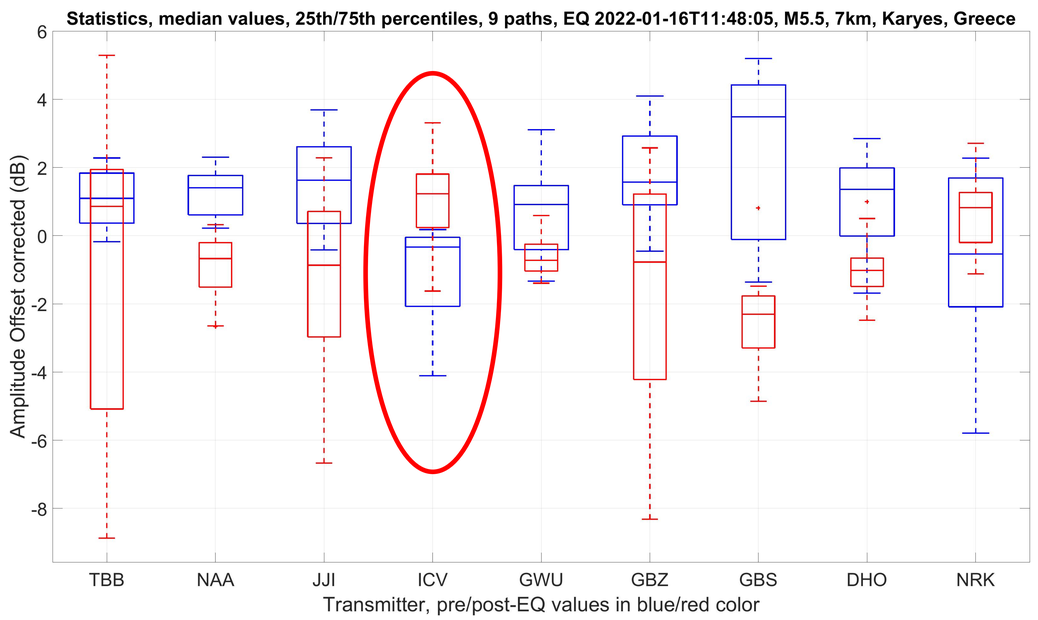
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-01-16, M5.5, 7 KM, KARYES, GREECE

- Top Left: VLF/LF amplitudes (2022-01-06 to 2022-01-26) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted, variations in the electric fields (power issue)
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 9 paths
- Top Right: Nighttime amplitude values for the affected TBB-GRZ event path (crossing the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected 9 paths, for a significance level of 5% only ICV-GRZ shows higher amplitude values after the EQ (nighttime method)









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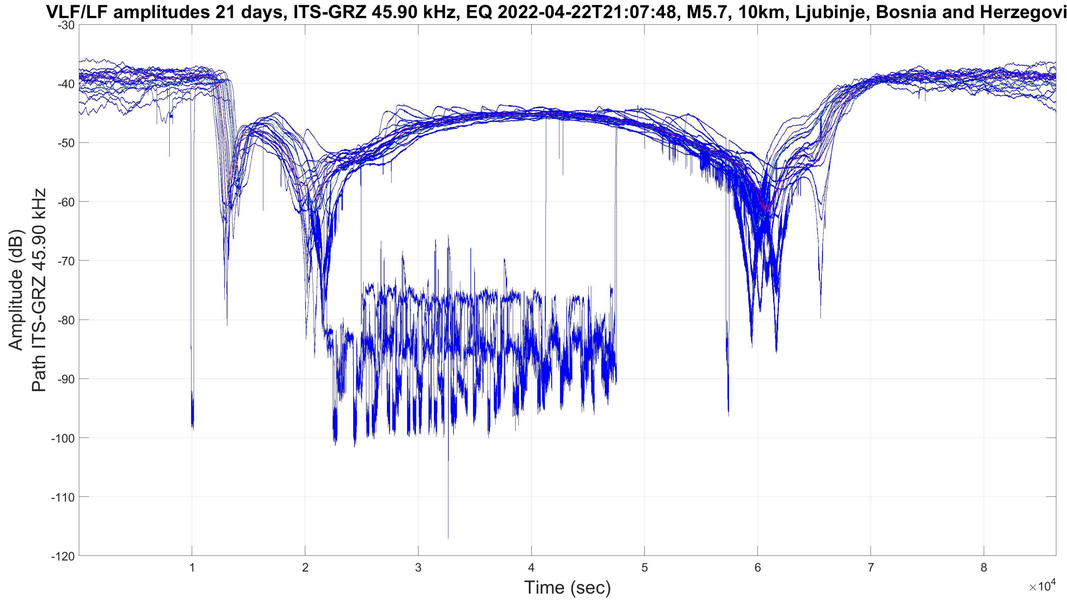
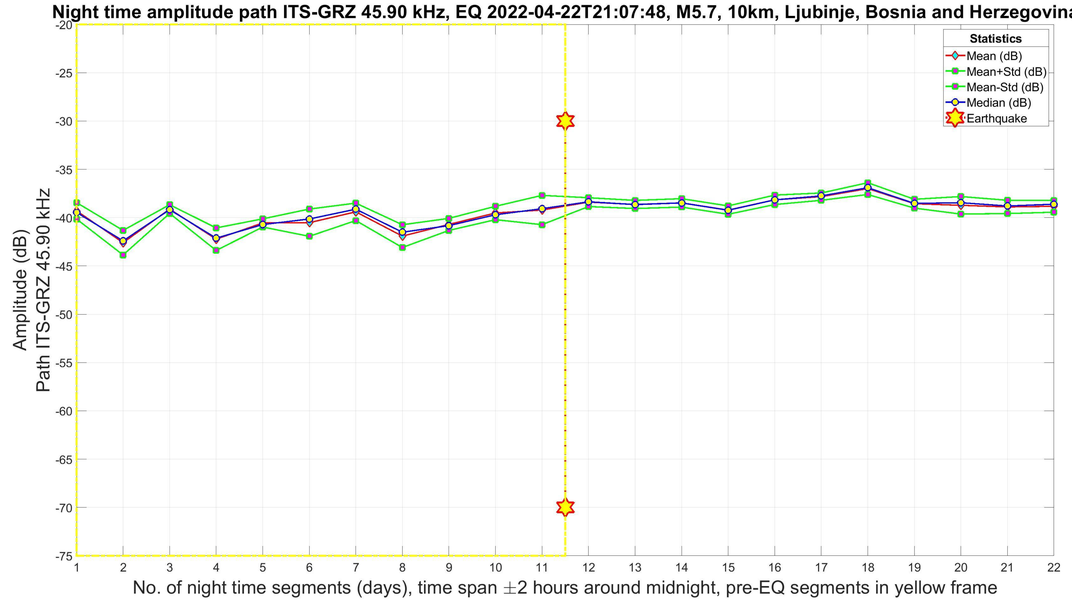
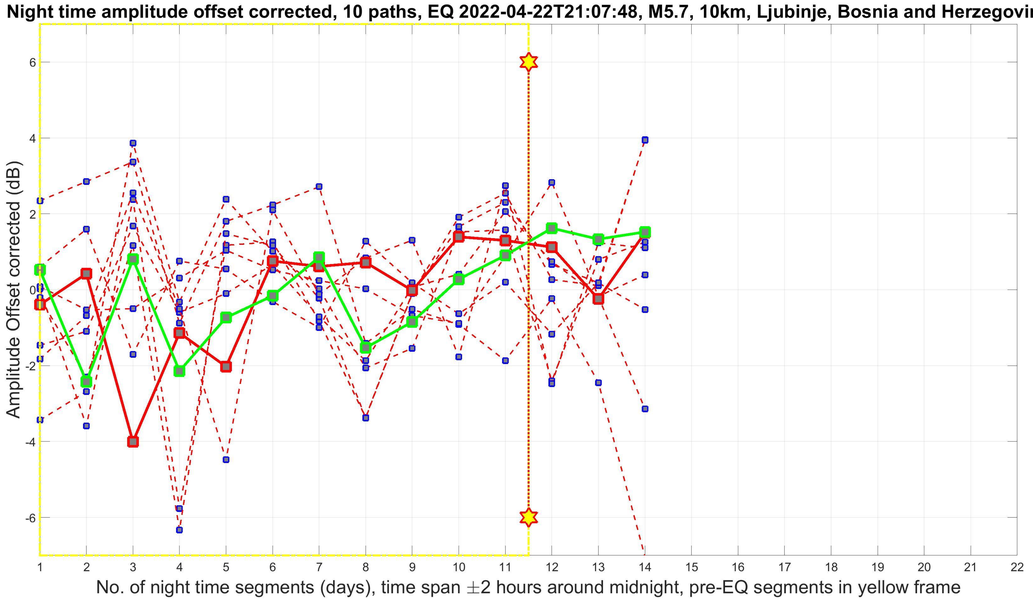
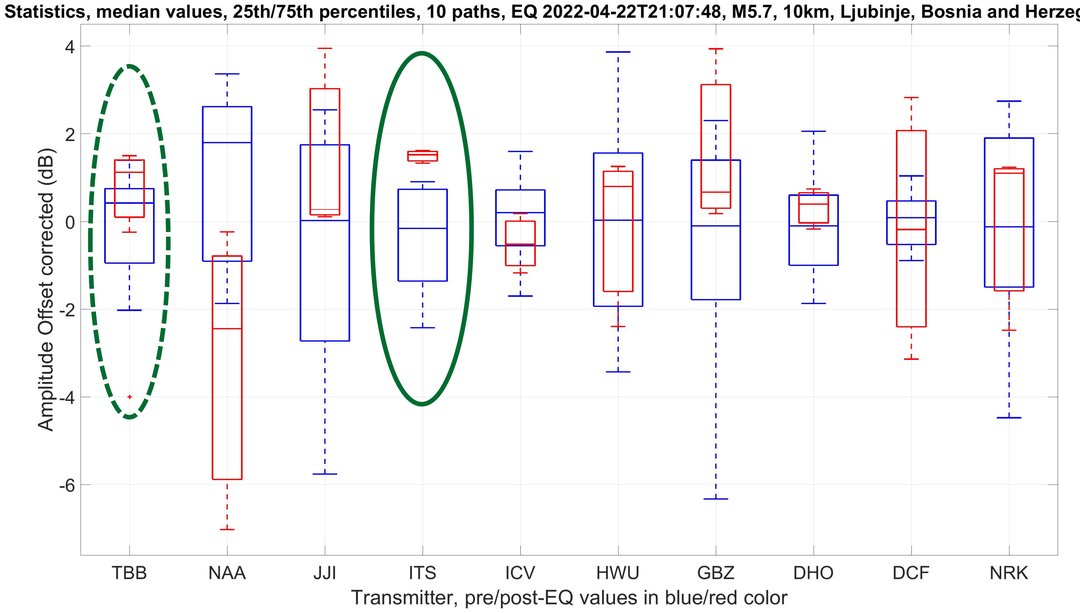
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-04-22, M5.7, 10 KM, LJUBINJE, BOSNIA AND HERZEGOVINA

- Top Left: VLF/LF amplitudes (2022-04-12 to 2022-05-02) for the 45.90 kHz ITS-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 10 paths
- Top Right: Nighttime amplitude values for the affected ITS-GRZ event path (crossing the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected 10 paths, for a significance level of 5% only the event path ITS-GRZ shows higher amplitude values after the EQ (nighttime method)









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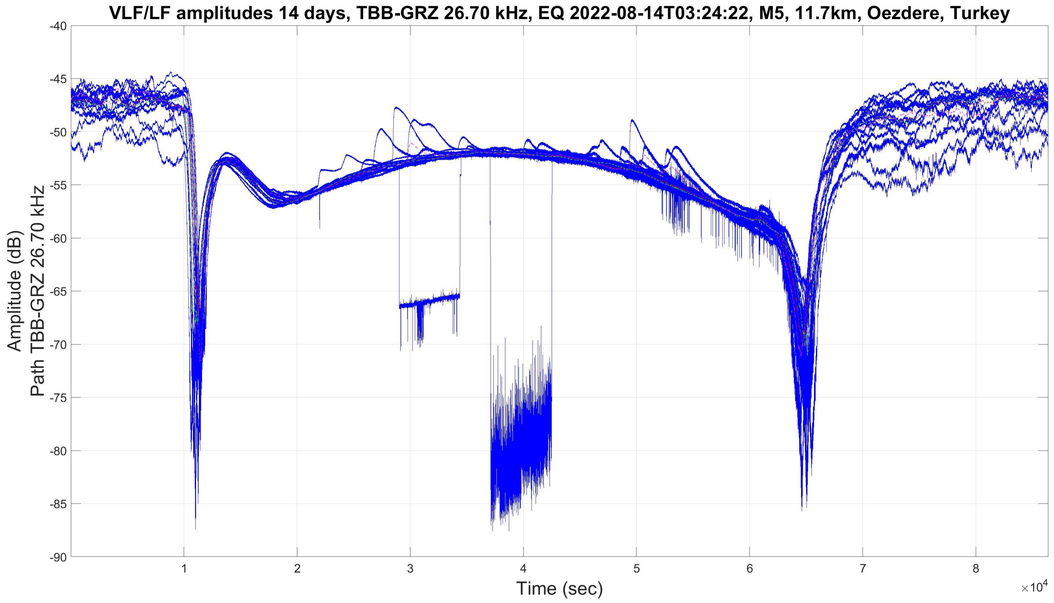
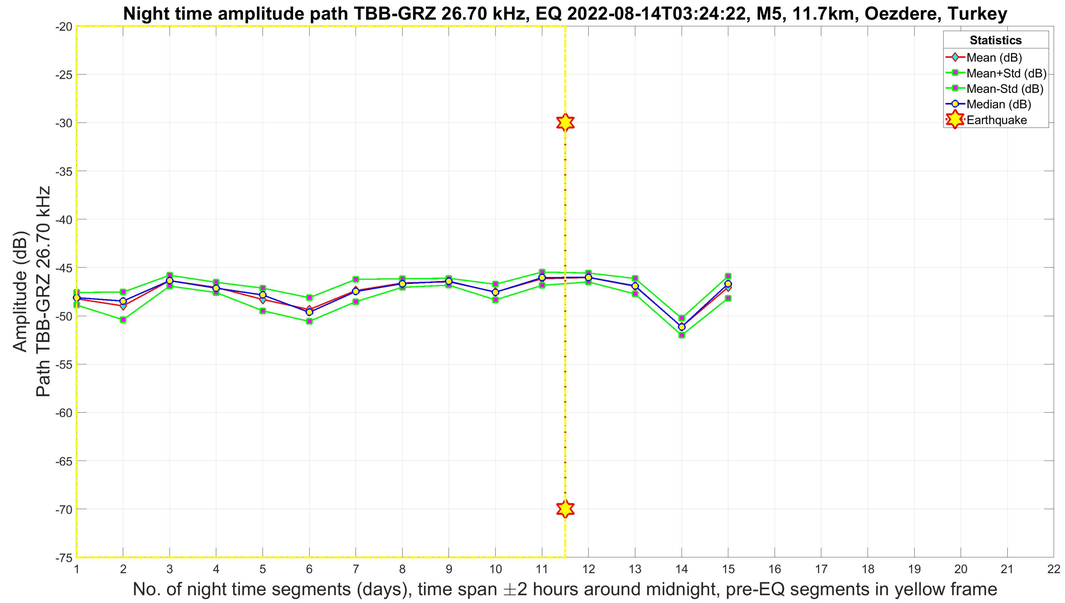
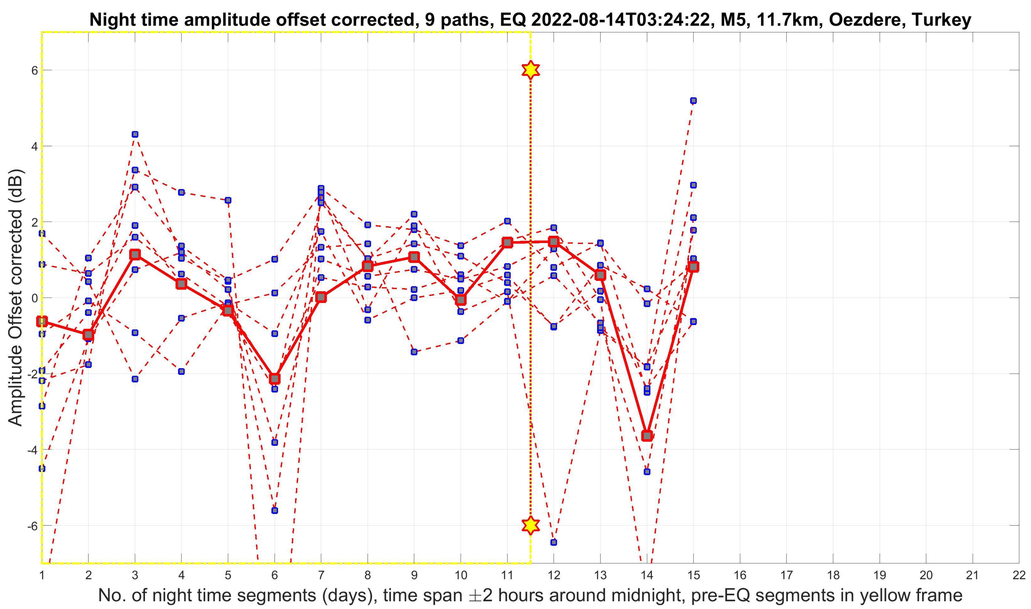
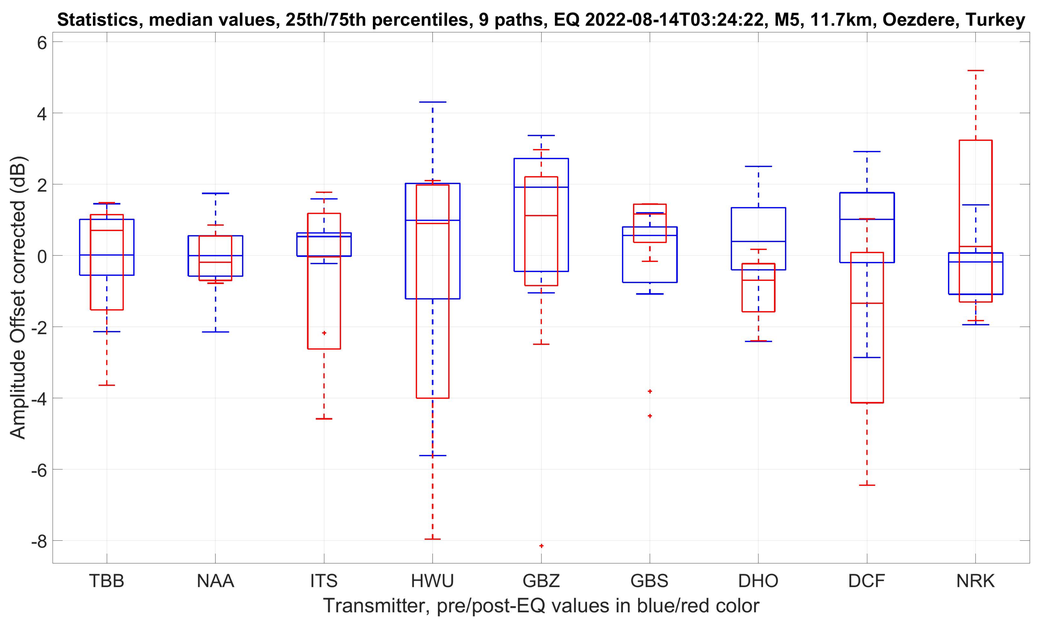
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-08-14, M5.0, 11.7 KM, ÖZDERE, TURKEY

- Top Left: VLF/LF amplitudes (2022-08-04 to 2022-08-17) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 9 paths
- Top Right: Nighttime amplitude values for the affected TBB-GRZ event path (crossing the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected 9 paths, no significant variations (5% level) according to the nighttime method









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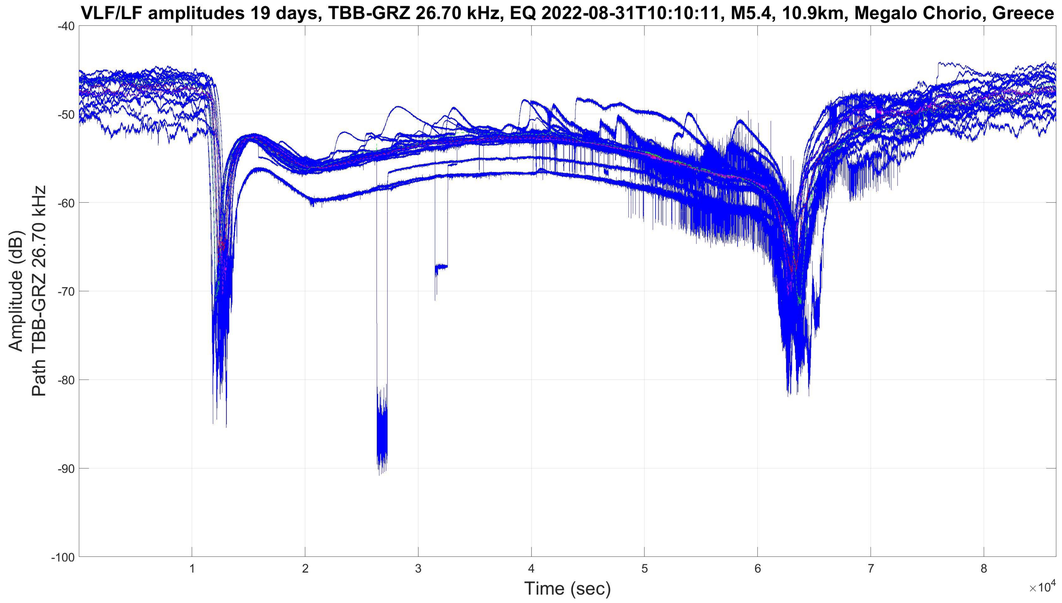
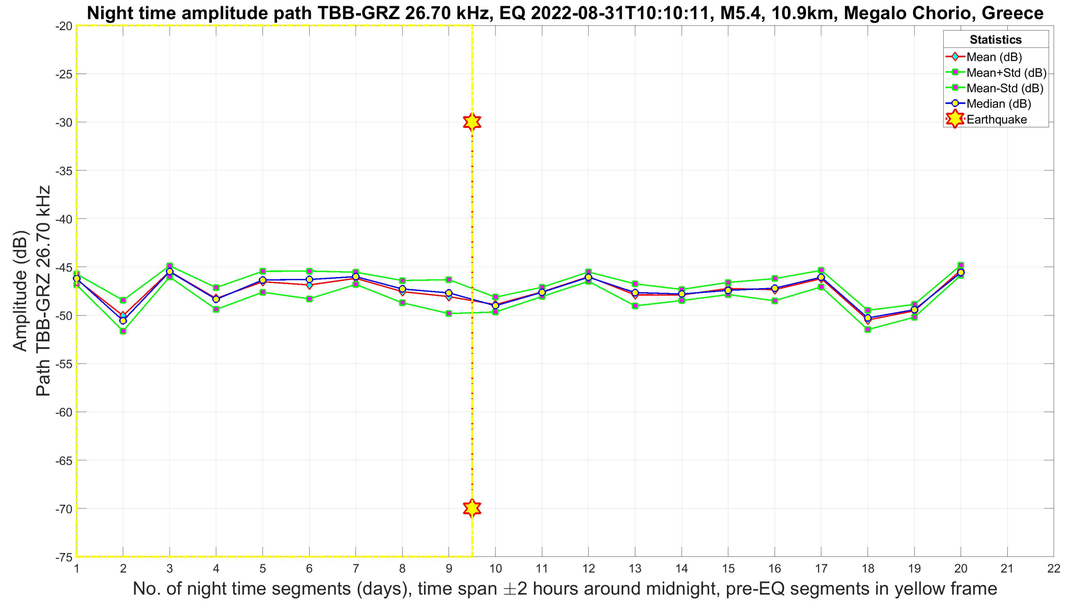
Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier Francesco Biagi[3], Patrick Galopeau[4], Ghulam Jaffer[5], Özer Aydogar[1], Christoph Schirninger[1], Cosima Muck[1], Irmgard Jernej[1], and Werner Magnes[1]

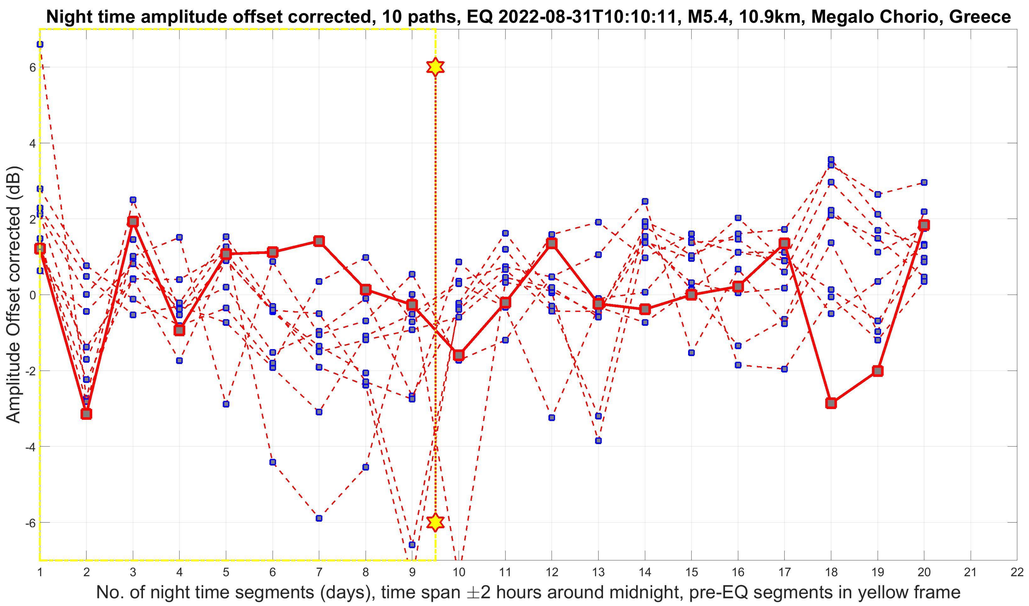
[1] Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [2] Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, [3] Department of Physics, University of Bari, Bari, Italy, [4] LATMOS-CNRS, UVSQ Université Paris-Saclay, Guyancourt, France, [5] SpaSys, SnT – Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg, Luxembourg

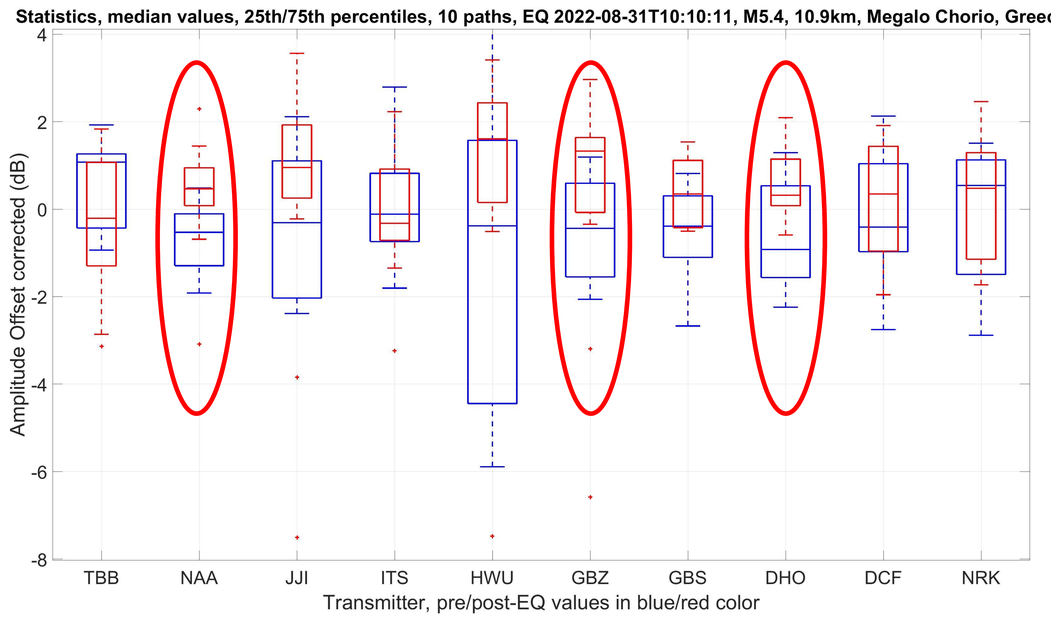
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-08-31, M5.4, 10.9 KM, MEGÁLO CHORIÓ, GREECE

- Top Left: VLF/LF amplitudes (2022-08-23 to 2022-09-10) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted, variations in the electric field values
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 10 paths
- Top Right: Nighttime amplitude values for the affected TBB-GRZ event path (crossing the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected 10 paths, for a significance level of 5%, NAA-GRZ, GBZ-GRZ and DHO-GRZ show higher amplitude values after the EQ









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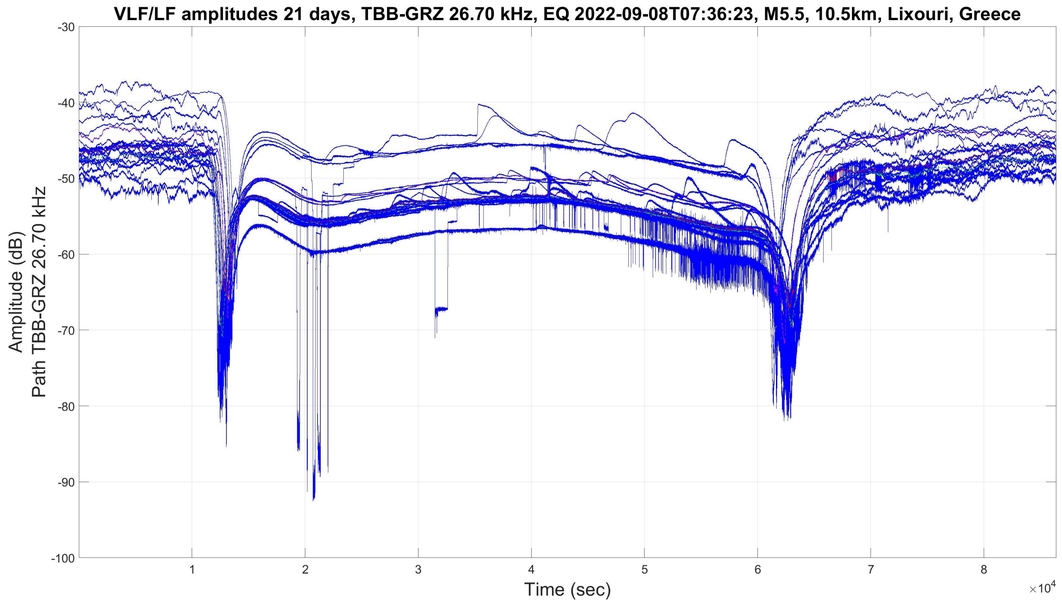
SUB-IONOSPHERIC VLF/LF WAVEGUIDE VARIATIONS RELATED TO MAGNITUDE M>5 EARTHQUAKES IN THE EASTERN MEDITERRANEAN AREA

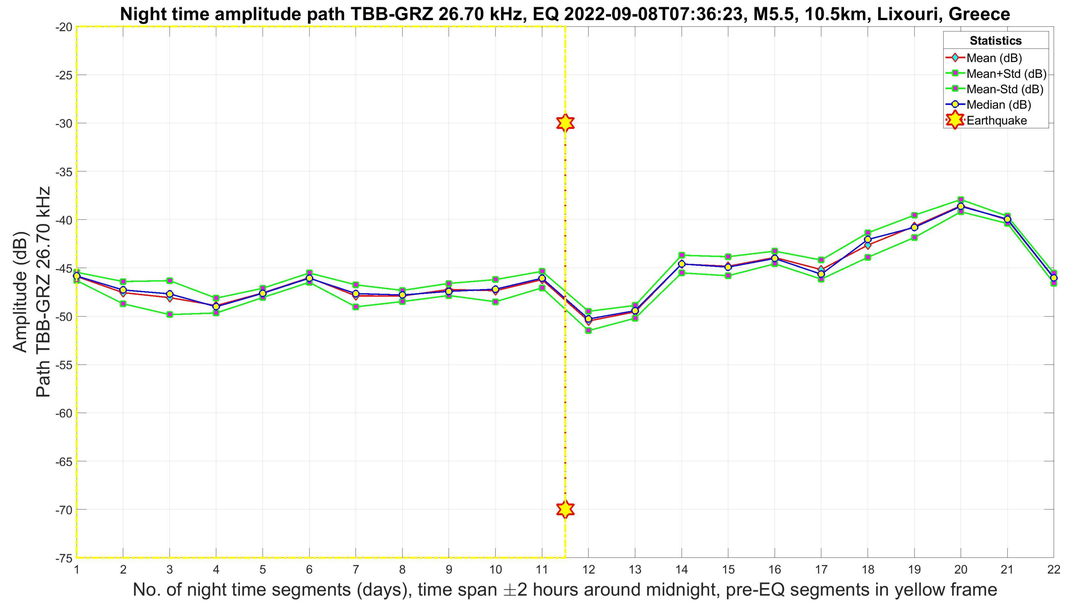
Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier Francesco Biagi[3], Patrick Galopeau[4], Ghulam Jaffer[5], Özer Aydogar[1], Christoph Schirninger[1], Cosima Muck[1], Irmgard Jernej[1], and Werner Magnes[1]

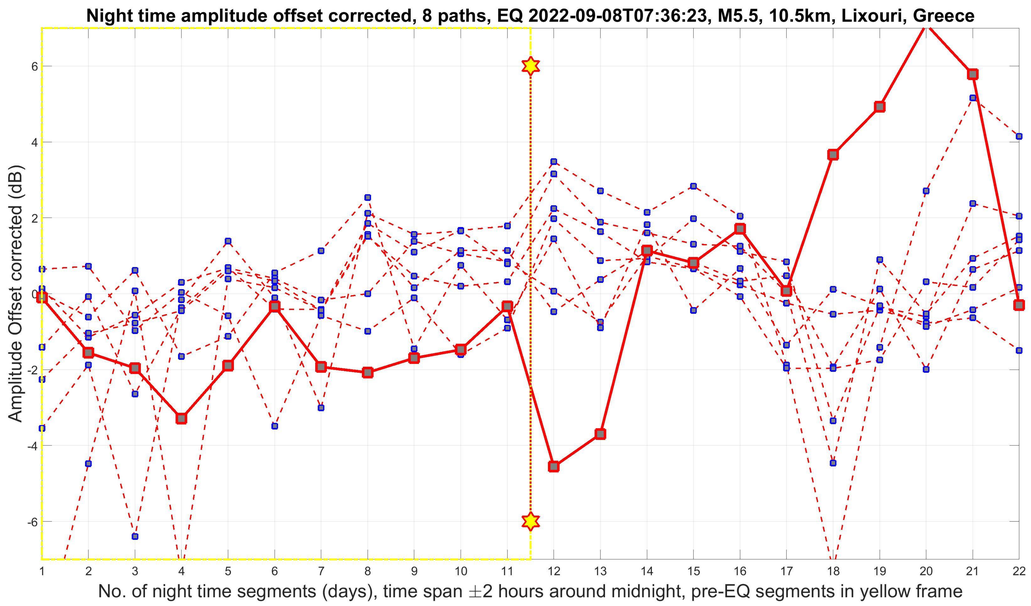
[1] Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [2] Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, [3] Department of Physics, University of Bari, Bari, Italy, [4] LATMOS-CNRS, UVSQ Université Paris-Saclay, Guyancourt, France, [5] SpaSys, SnT – Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg, Luxembourg

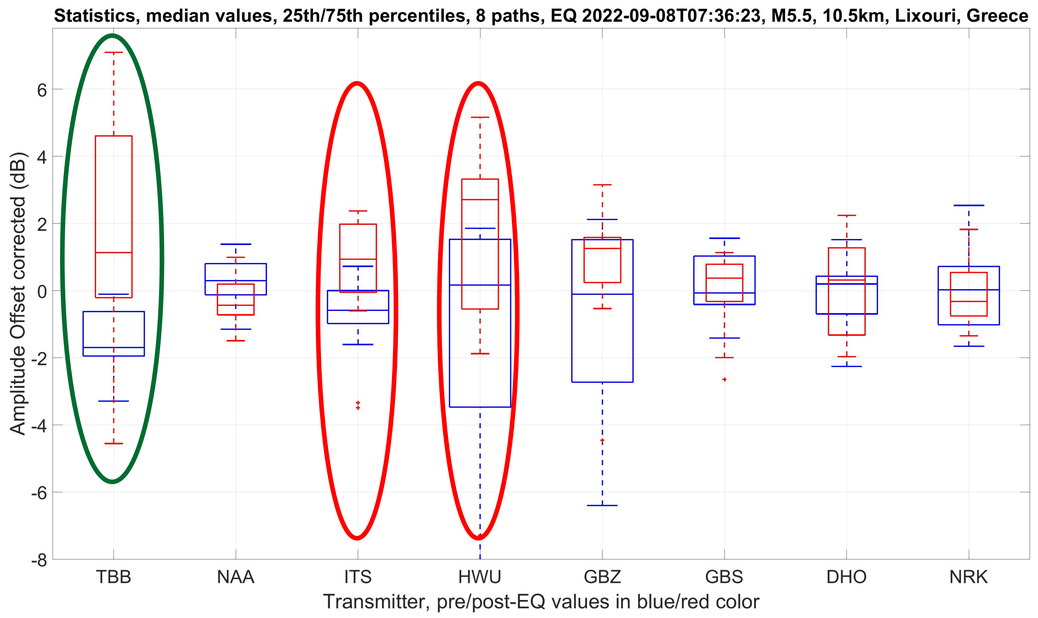
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-09-08, M5.5, 10.5 KM, LIXOURI, GREECE

- Top Left: VLF/LF amplitudes (2022-08-29 to 2022-09-18) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted, variations in the electric field values
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 8 paths
- Top Right: Nighttime amplitude values for the affected TBB-GRZ event path (crossing the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected 8 paths, for a significance level of 5% the event paths TBB-GRZ, ITS-GRZ, HWU-GRZ show higher amplitude values after the EQ









SUB-IONOSPHERIC VLF/LF WAVEGUIDE VARIATIONS RELATED TO MAGNITUDE M>5 EARTHQUAKES IN THE EASTERN MEDITERRANEAN AREA

Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier Francesco Biagi[3], Patrick Galopeau[4], Ghulam Jaffer[5], Özer Aydogar[1], Christoph Schirninger[1], Cosima Muck[1], Irmgard Jernej[1], and Werner Magnes[1]

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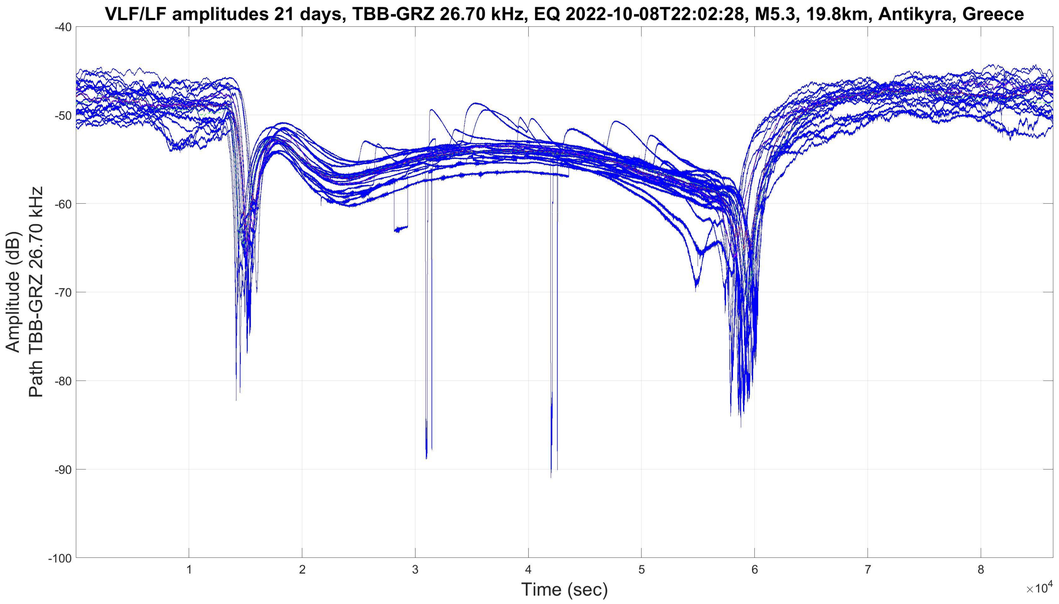
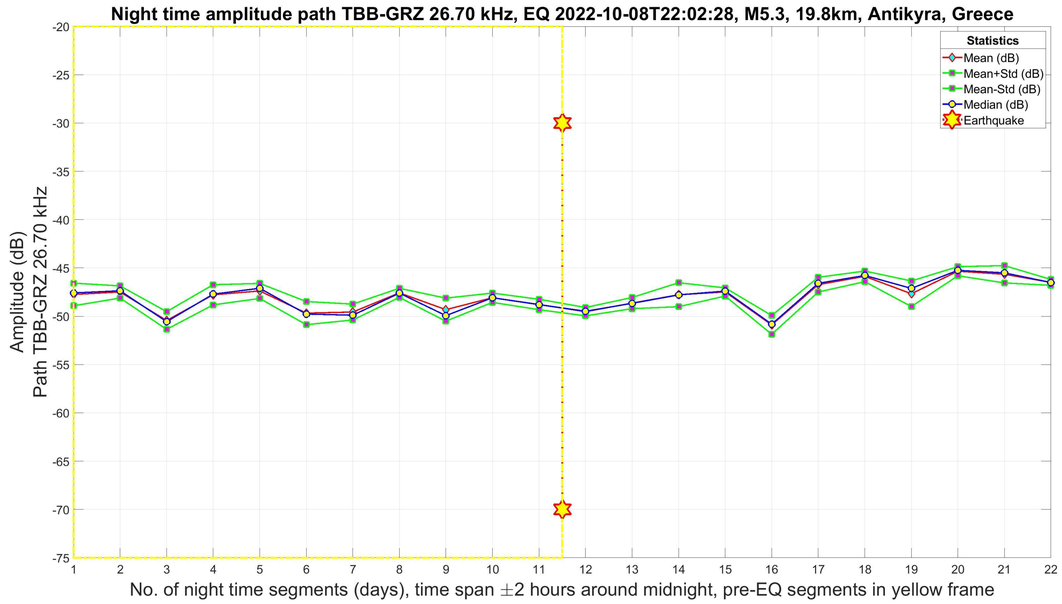
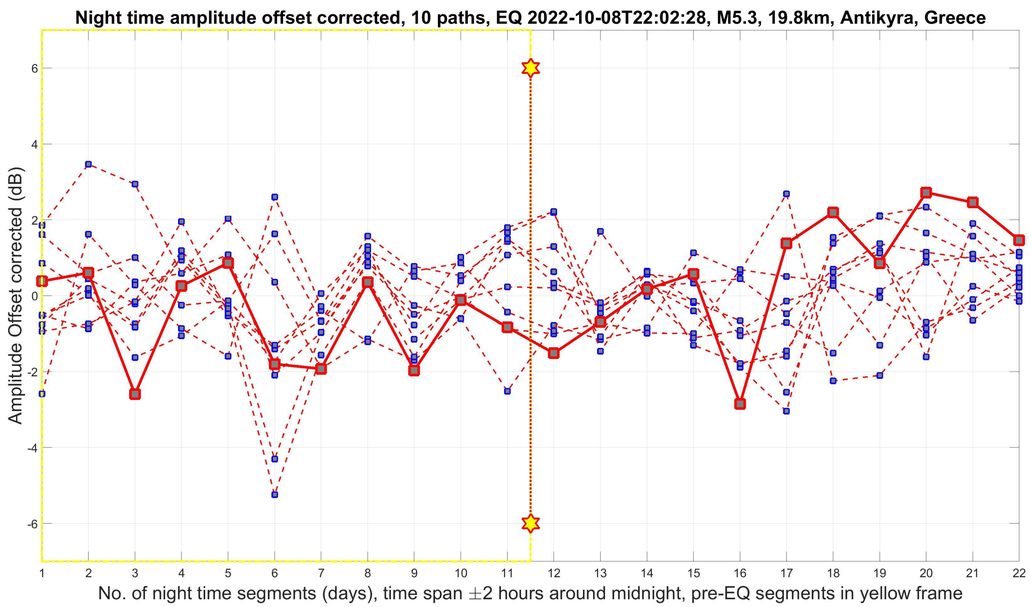
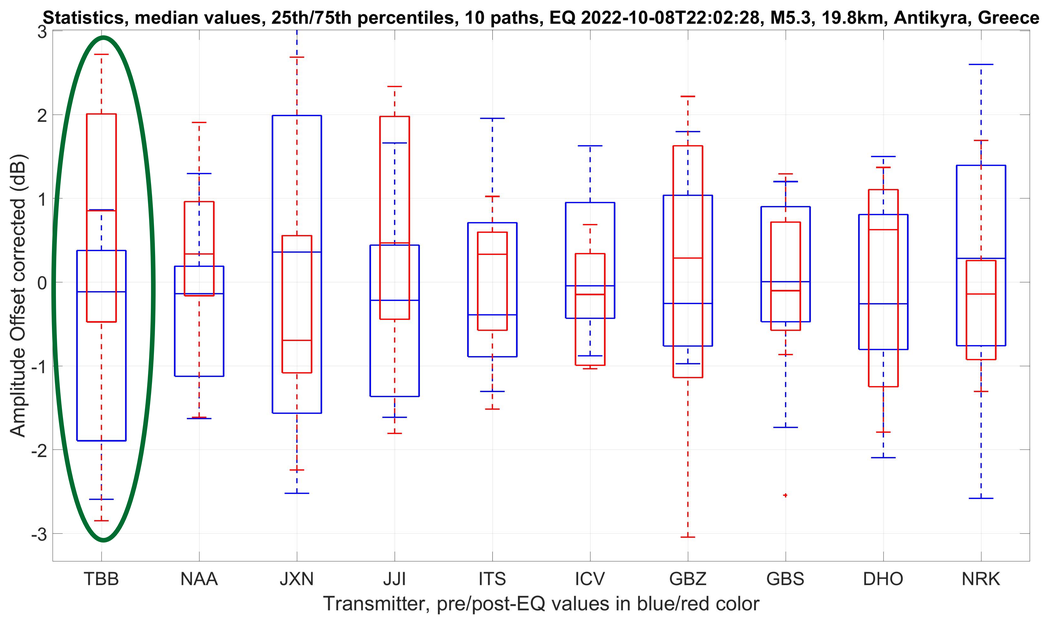
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-10-08, M5.3, 19.8 KM, ANTIKYRA, GREECE

- Top Left: VLF/LF amplitudes (2022-09-28 to 2022-10-18) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 10 paths
- Top Right: Nighttime amplitude values for the affected TBB-GRZ event path (crossing the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected 10 paths, for a significance level of 5% only the event path TBB-GRZ shows higher amplitude values after the EQ (nighttime method)









SUB-IONOSPHERIC VLF/LF WAVEGUIDE VARIATIONS RELATED TO MAGNITUDE M>5 EARTHQUAKES IN THE EASTERN MEDITERRANEAN AREA

Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier Francesco Biagi[3], Patrick Galopeau[4], Ghulam Jaffer[5], Özer Aydogar[1], Christoph Schirninger[1], Cosima Muck[1], Irmgard Jernej[1], and Werner Magnes[1]

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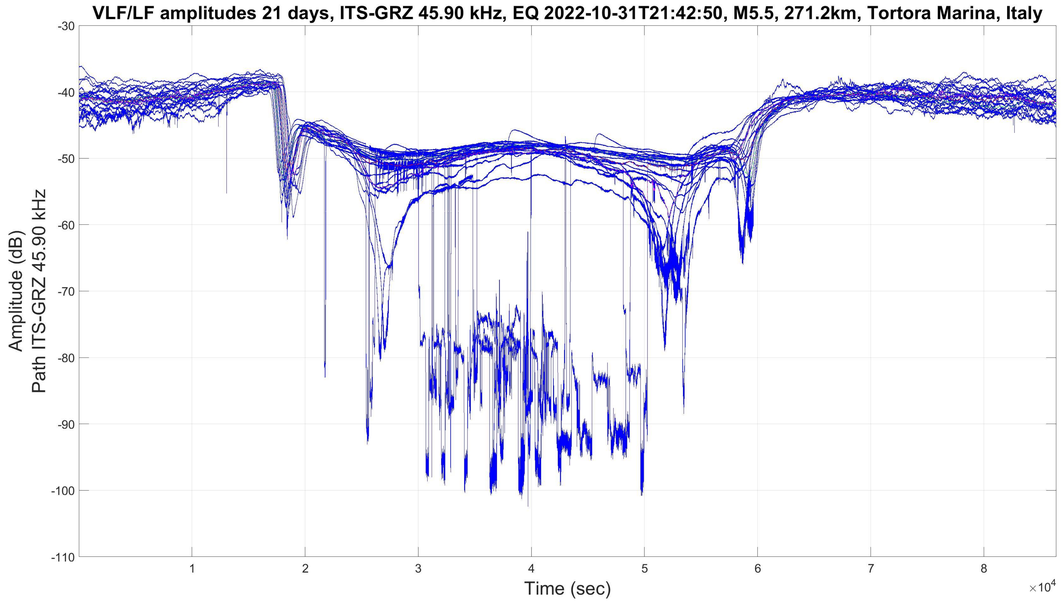
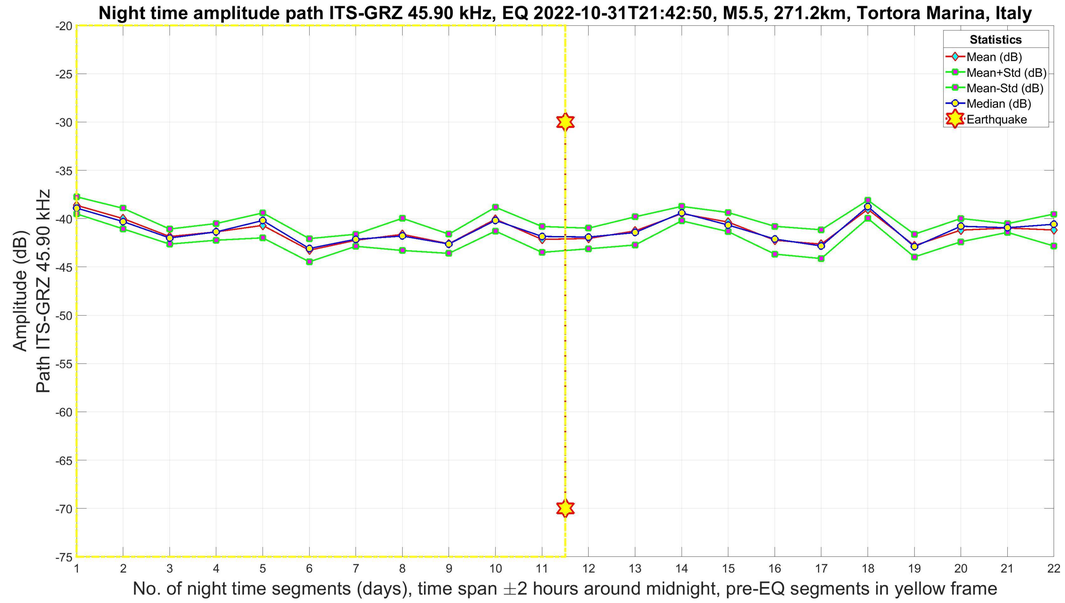
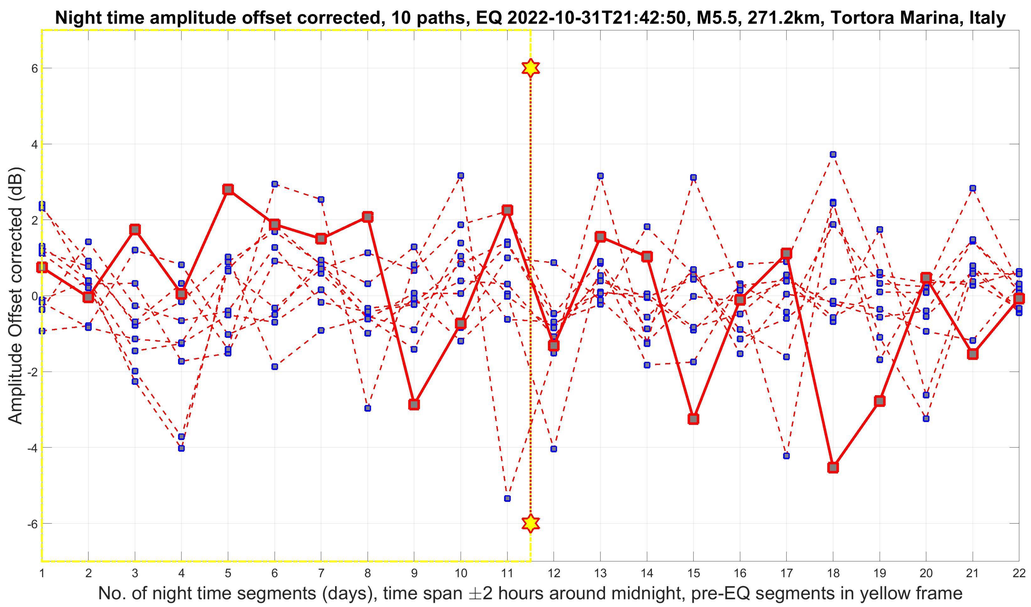
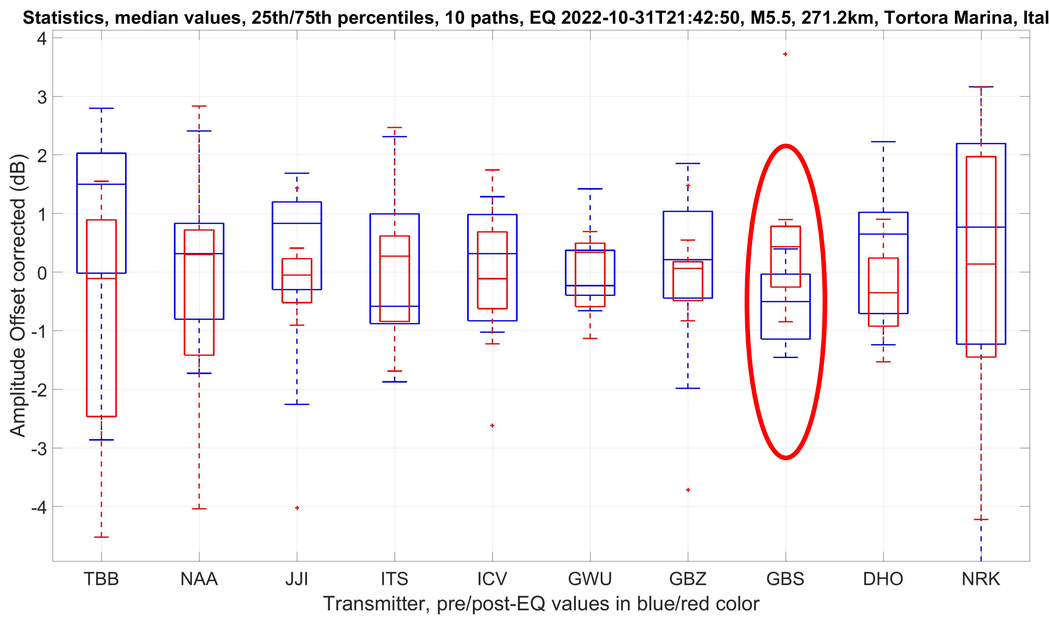
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-10-31, M5.5, 271.2 KM, TORTORA MARINA, ITALY

- Top Left: VLF/LF amplitudes (2022-10-21 to 2022-11-10) for the 45.90 kHz ITS-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 10 paths
- Top Right: Nighttime amplitude values for the affected TBB-GRZ event path (crossing the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected 10 paths, for a significance level of 5% the path GBS-GRZ shows higher amplitude values after the EQ (nighttime method)









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SUB-IONOSPHERIC VLF/LF WAVEGUIDE VARIATIONS RELATED TO MAGNITUDE M>5 EARTHQUAKES IN THE EASTERN MEDITERRANEAN AREA

Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier Francesco Biagi[3], Patrick Galopeau[4], Ghulam Jaffer[5], Özer Aydogar[1], Christoph Schirninger[1], Cosima Muck[1], Irmgard Jernej[1], and Werner Magnes[1]

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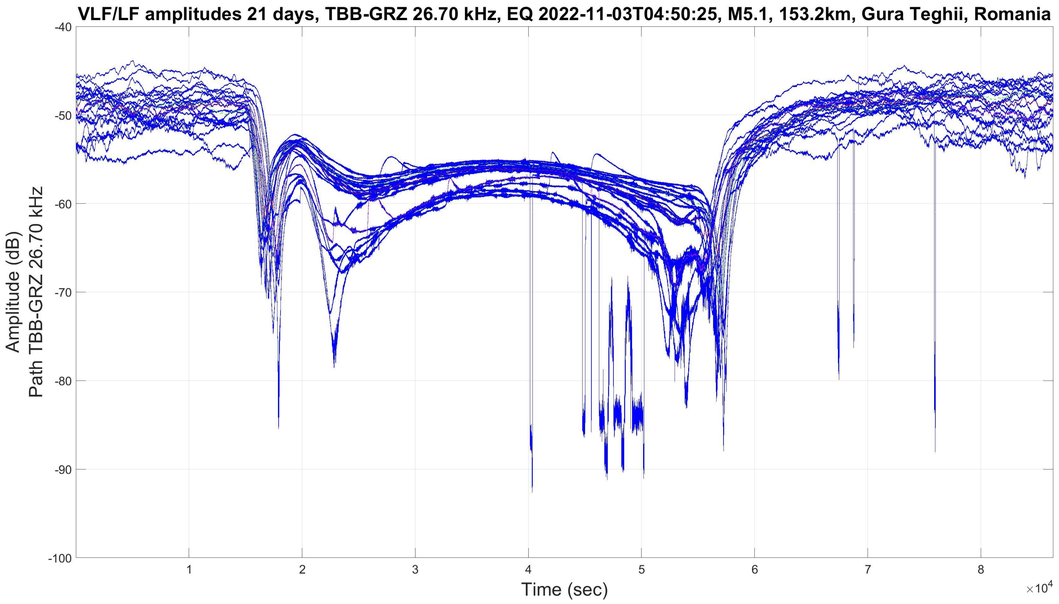
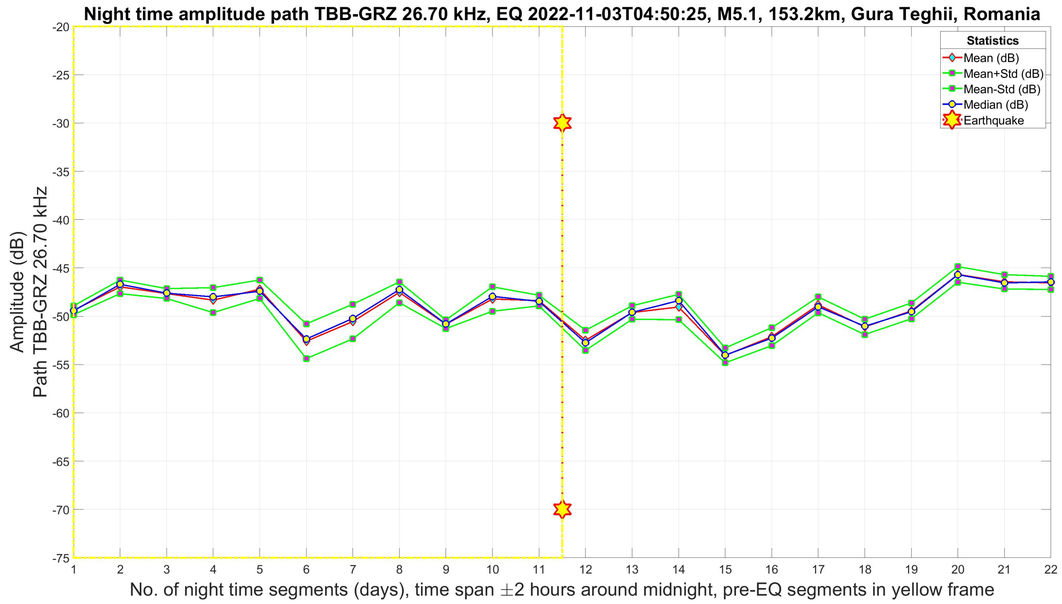
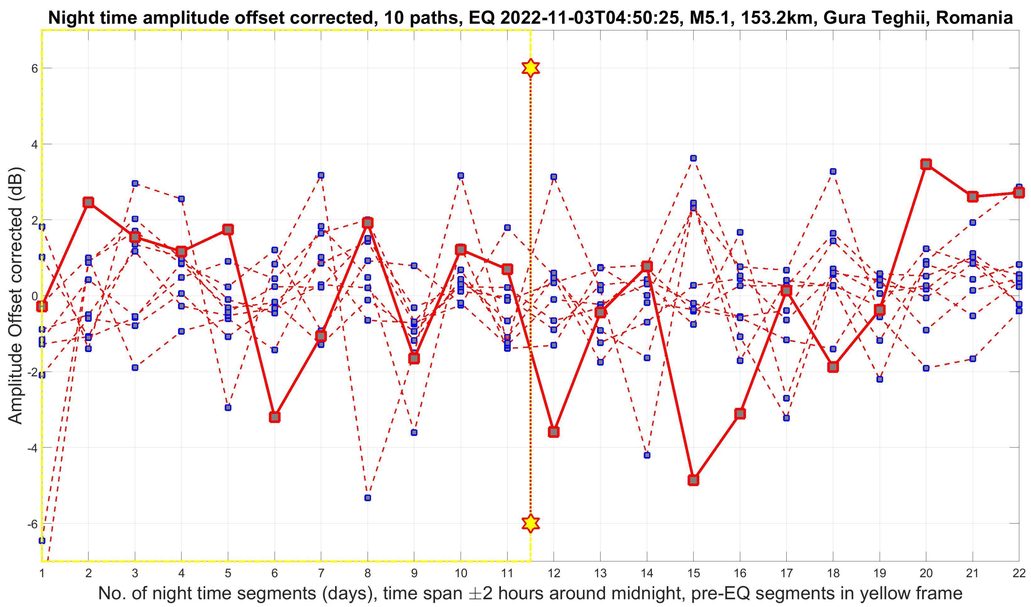
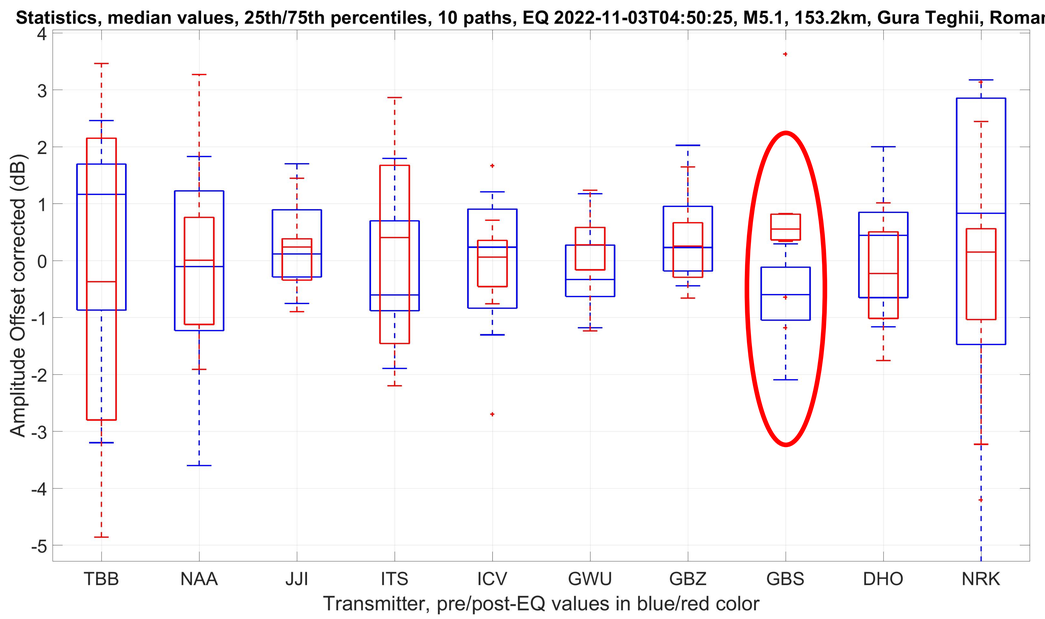
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-11-03, M5.1, 153.2 KM, GURA THEGII, ROMANIA

- Top Left: VLF/LF amplitudes (2022-10-21 to 2022-11-10) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 10 paths
- Top Right: Nighttime amplitude values for the TBB-GRZ path (no crossing of the Dobrovolsky-Bowman area/radius), VTX-GRZ and NWC-GRZ are long distance links
- Bottom Right: Statistics (box plots) for the offset corrected 10 paths, for a significance level of 5% the path GBS-GRZ shows higher amplitude values after the EQ (nighttime method)









SUB-IONOSPHERIC VLF/LF WAVEGUIDE VARIATIONS RELATED TO MAGNITUDE M>5 EARTHQUAKES IN THE EASTERN MEDITERRANEAN AREA

Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier Francesco Biagi[3], Patrick Galopeau[4], Ghulam Jaffer[5], Özer Aydogar[1], Christoph Schirninger[1], Cosima Muck[1], Irmgard Jernej[1], and Werner Magnes[1]

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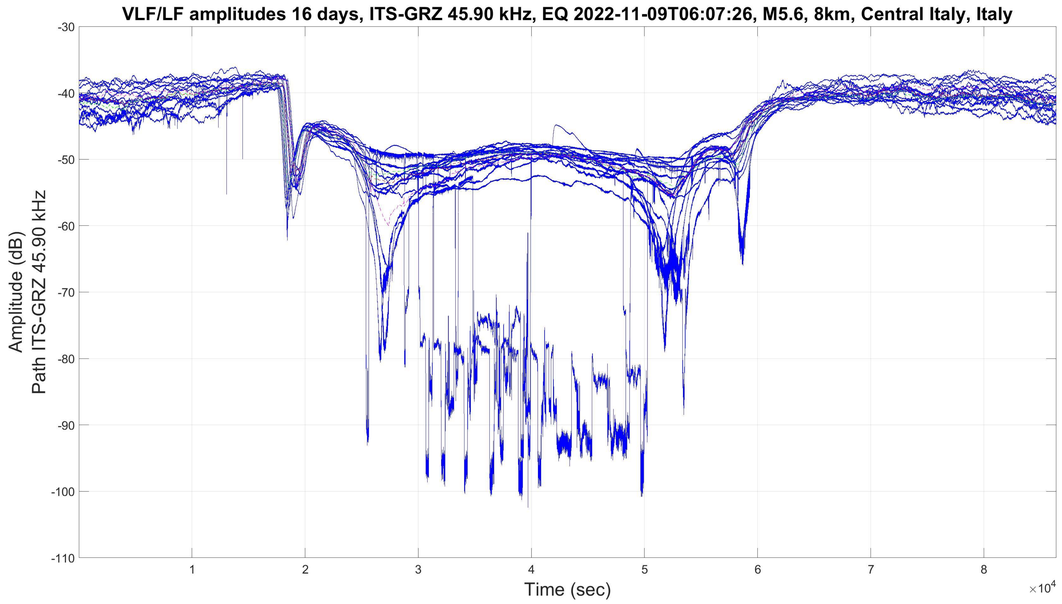
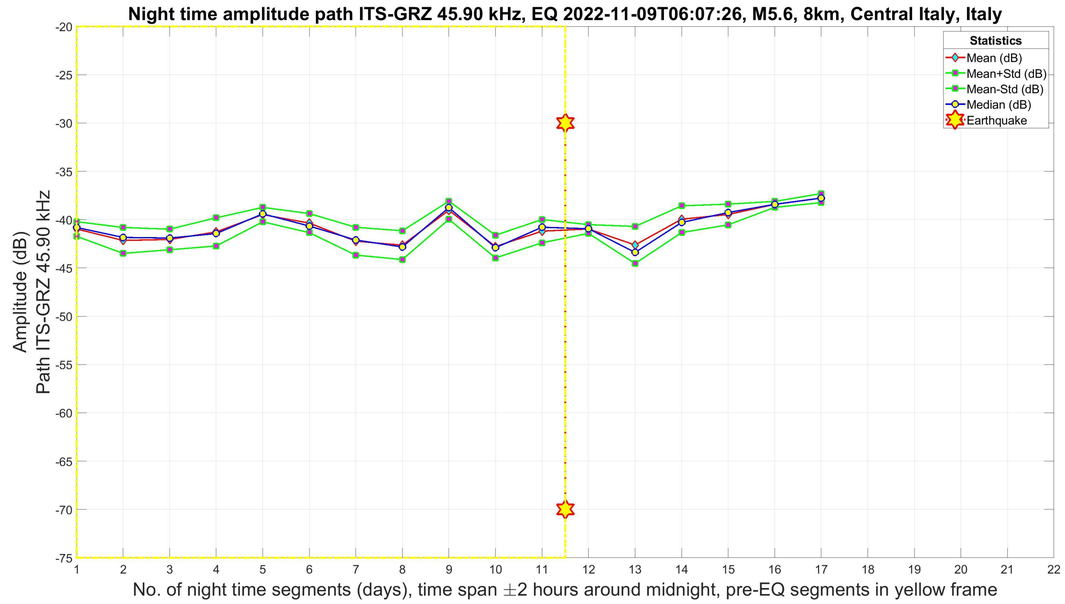
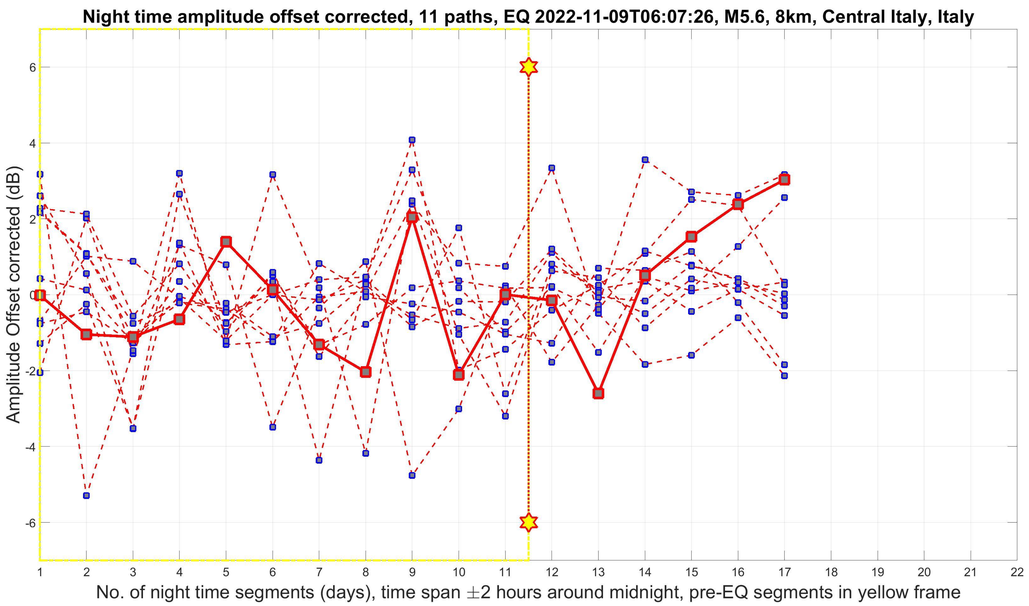
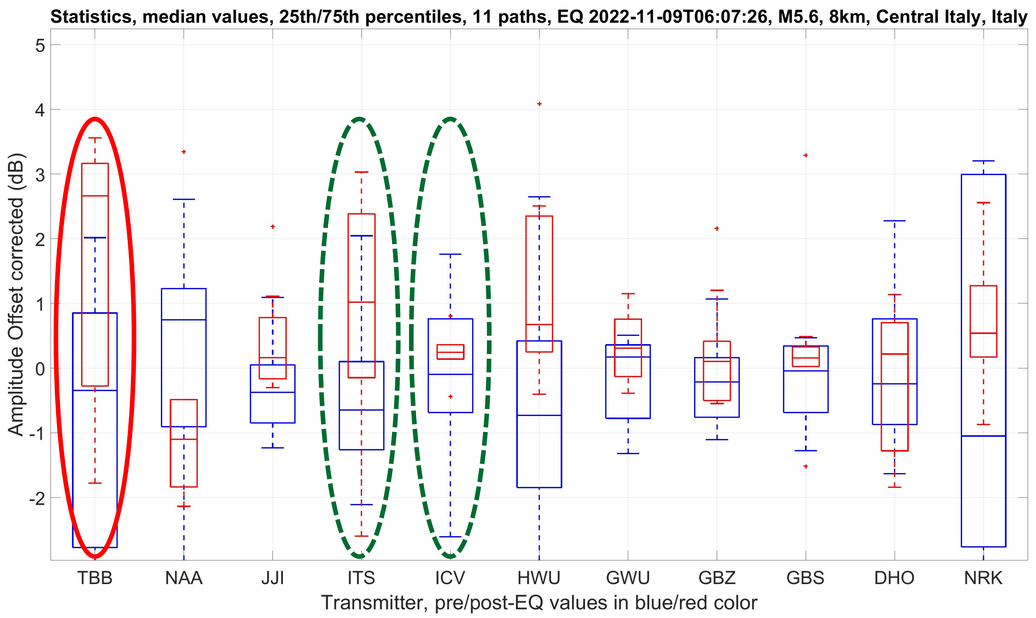
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-11-09, M5.6, 8 KM, CENTRAL ITALY, ITALY

- Top Left: VLF/LF amplitudes (2022-10-30 to 2022-11-14) for the 45.90 kHz ITS-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 11 paths
- Top Right: Nighttime amplitude values for the affected ITS-GRZ (and ICV-GRZ, not shown) event path (crossing the Dobrovolsky-Bowman area/radius; EQ in the wedge of the two links)
- Bottom Right: Statistics (box plots) for the offset corrected 11 paths, for a significance level of 5% the path TBB-GRZ shows higher amplitude values after the EQ (nighttime method)









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SUB-IONOSPHERIC VLF/LF WAVEGUIDE VARIATIONS RELATED TO MAGNITUDE M>5 EARTHQUAKES IN THE EASTERN MEDITERRANEAN AREA

Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier Francesco Biagi[3], Patrick Galopeau[4], Ghulam Jaffer[5], Özer Aydogar[1], Christoph Schirninger[1], Cosima Muck[1], Irmgard Jernej[1], and Werner Magnes[1]

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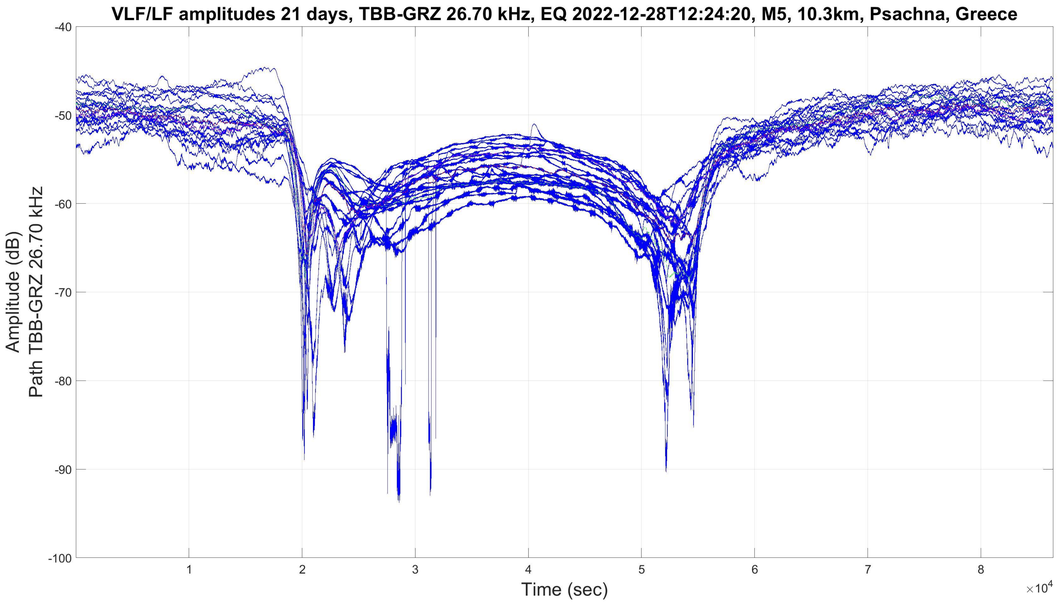
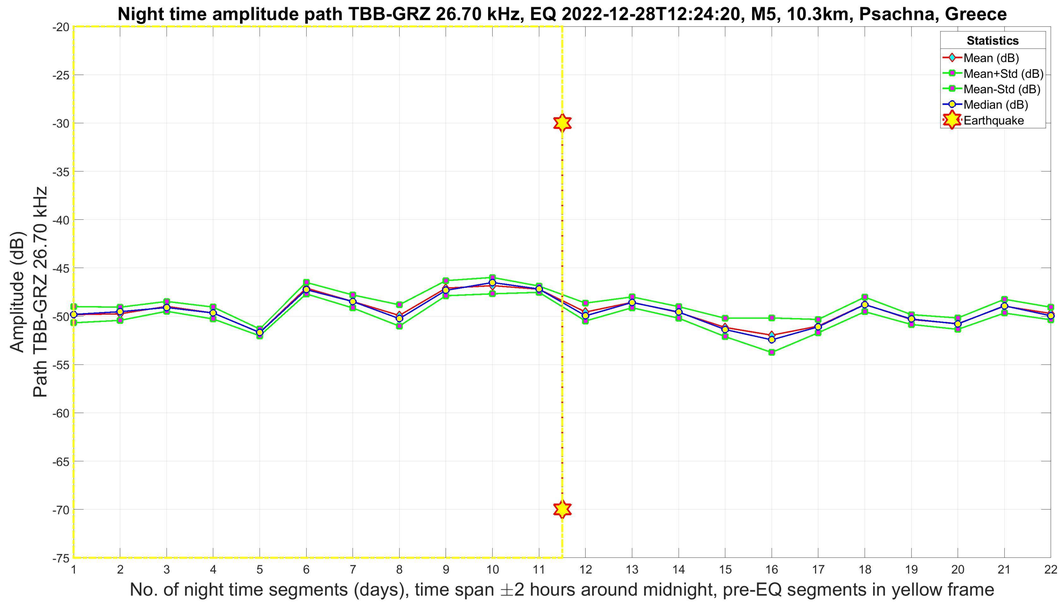
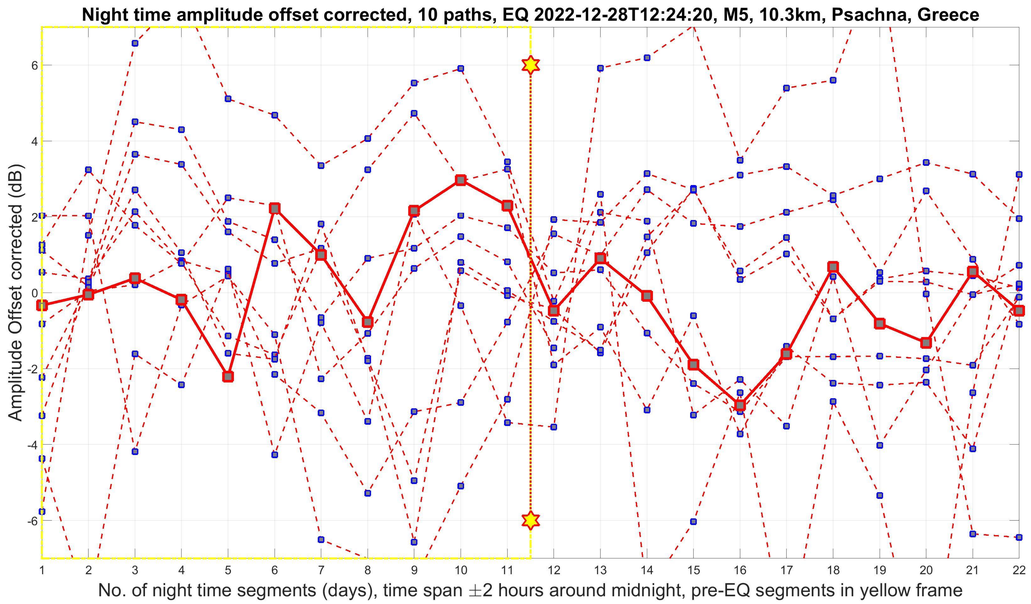
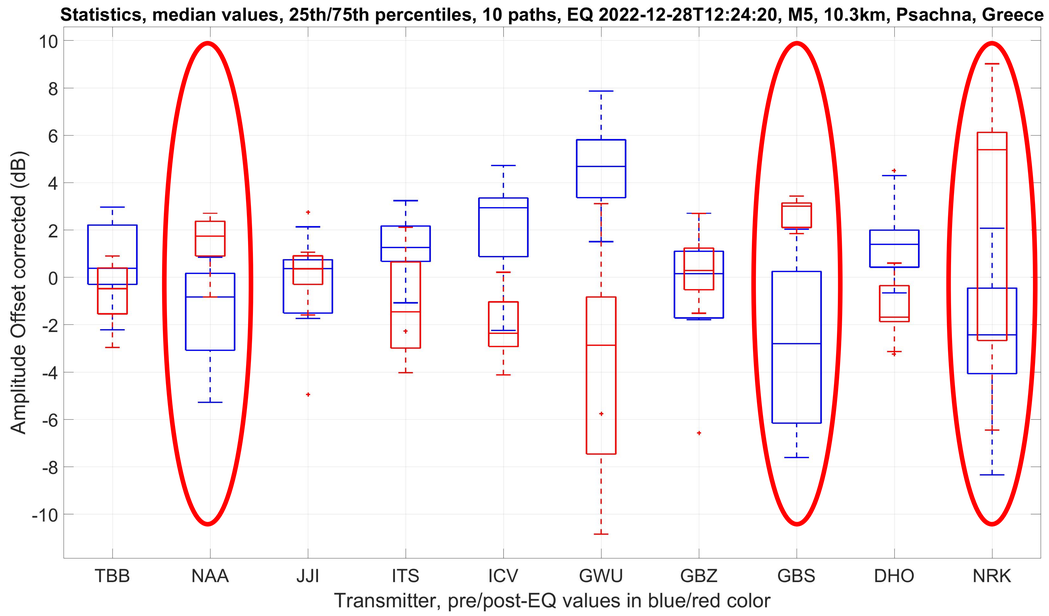
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-11-09, M5.0, 10.3 KM, PSACHNÁ, GREECE

- Top Left: VLF/LF amplitudes (2022-12-18 to 2023-01-07) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 10 paths, in general high variations
- Top Right: Nighttime amplitude values for the affected TBB-GRZ event path (crossing the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected 10 paths, for a significance level of 5% the paths NAA-GRZ, GBS-GRZ, and NRK-GRZ show higher amplitude values after the EQ









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SUB-IONOSPHERIC VLF/LF WAVEGUIDE VARIATIONS RELATED TO MAGNITUDE M>5 EARTHQUAKES IN THE EASTERN MEDITERRANEAN AREA

Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier Francesco Biagi[3], Patrick Galopeau[4], Ghulam Jaffer[5], Özer Aydogar[1], Christoph Schirninger[1], Cosima Muck[1], Irmgard Jernej[1], and Werner Magnes[1]

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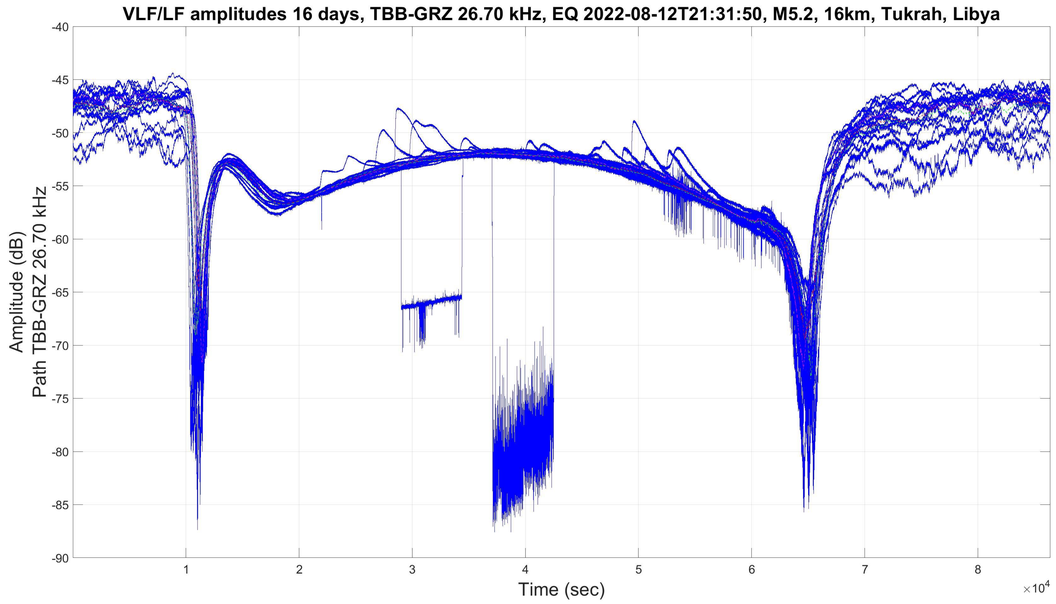
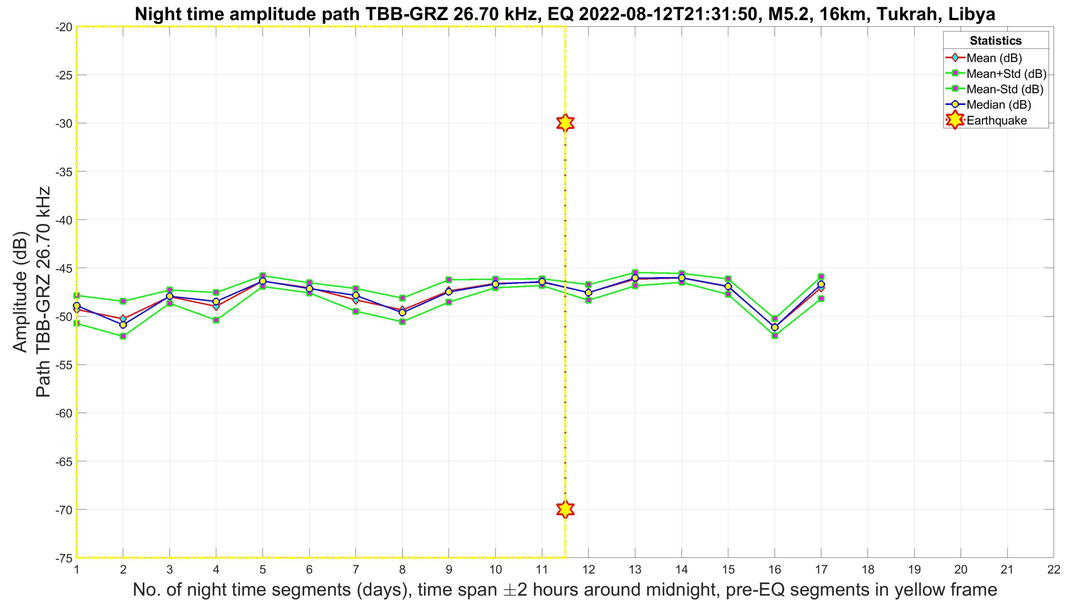
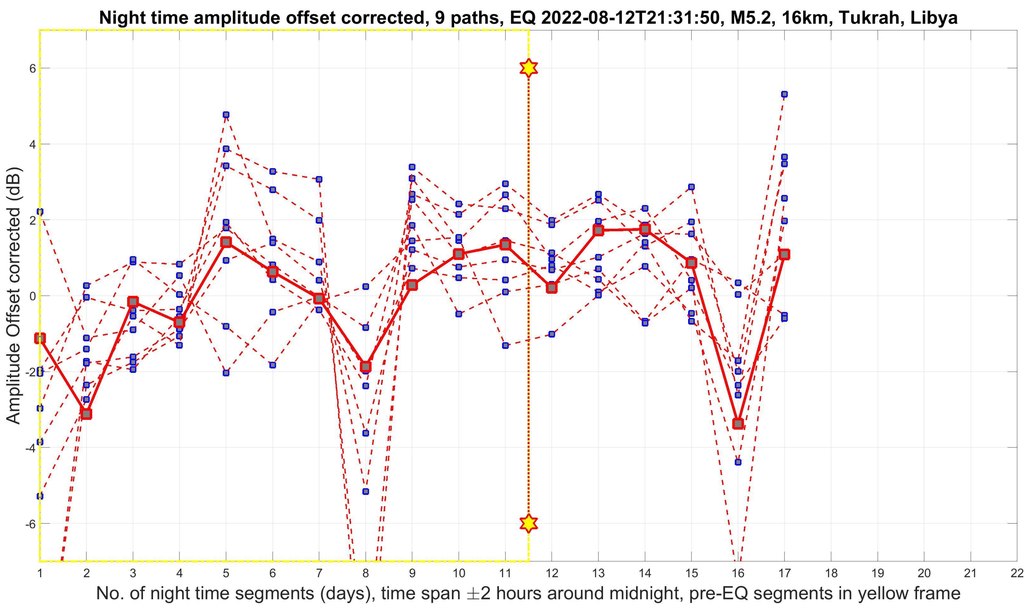
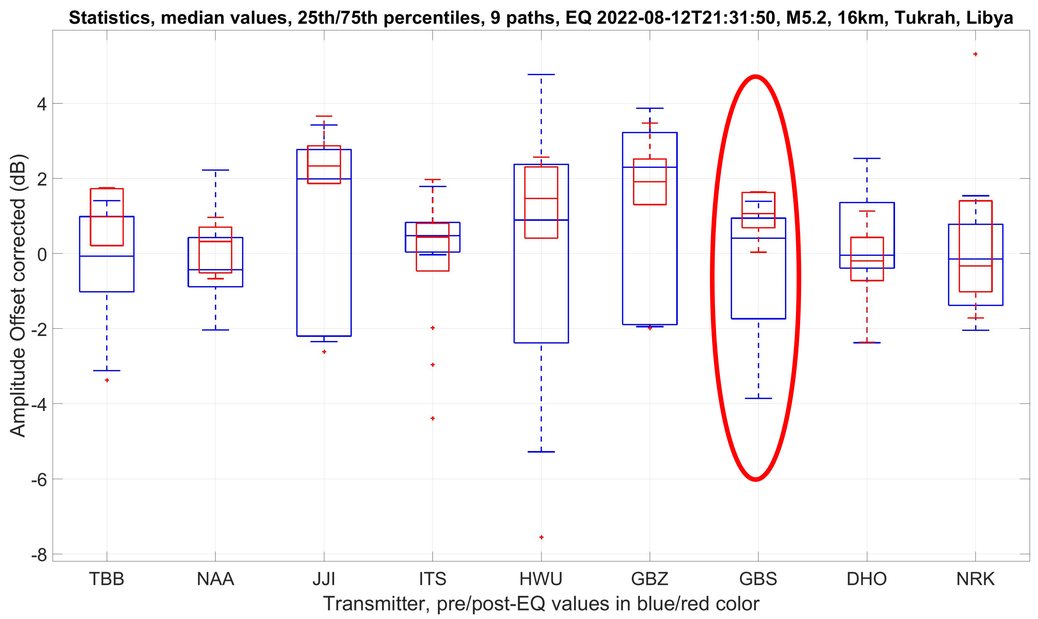
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-08-12, M5.2, 16 KM, TUKRAH, LIBYA

- Top Left: VLF/LF amplitudes (2022-08-02 to 2022-08-17) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 9 paths
- Top Right: Nighttime amplitude values for the TBB-GRZ path (no crossing of the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected 9 paths, for a significance level of 5% the path GBS-GRZ shows higher amplitude values after the EQ (nighttime method)









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APRIL 2023

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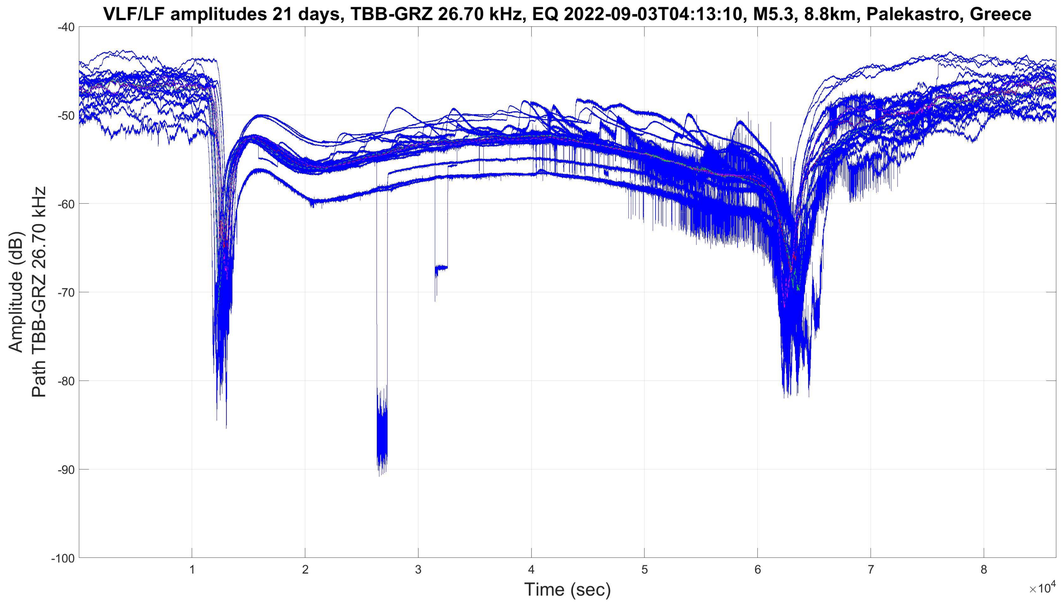
SUB-IONOSPHERIC VLF/LF WAVEGUIDE VARIATIONS RELATED TO MAGNITUDE M>5 EARTHQUAKES IN THE EASTERN MEDITERRANEAN AREA

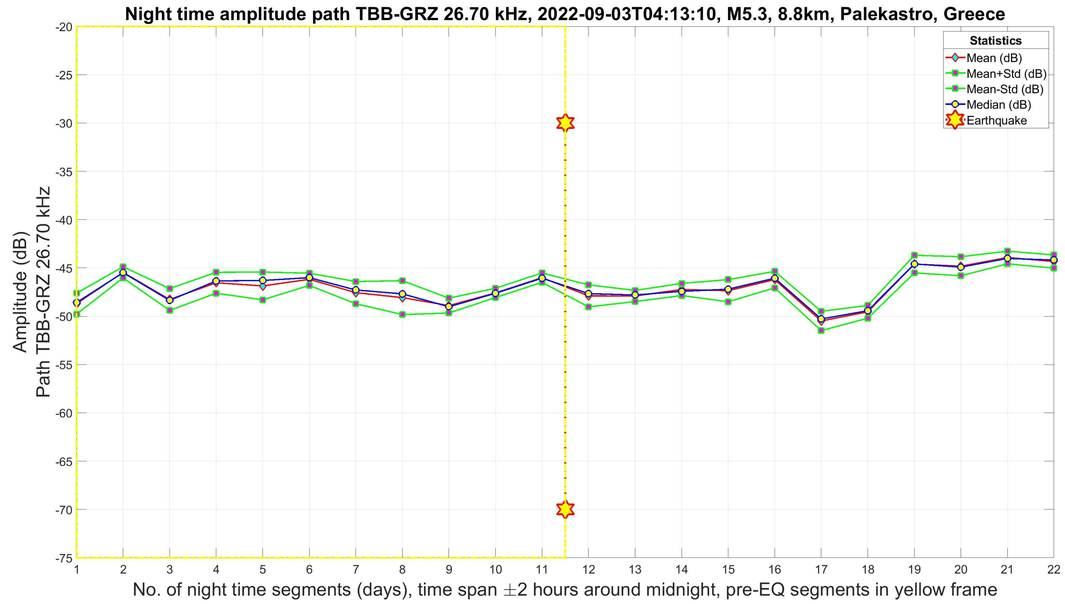
Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier Francesco Biagi[3], Patrick Galopeau[4], Ghulam Jaffer[5], Özer Aydogar[1], Christoph Schirninger[1], Cosima Muck[1], Irmgard Jernej[1], and Werner Magnes[1]

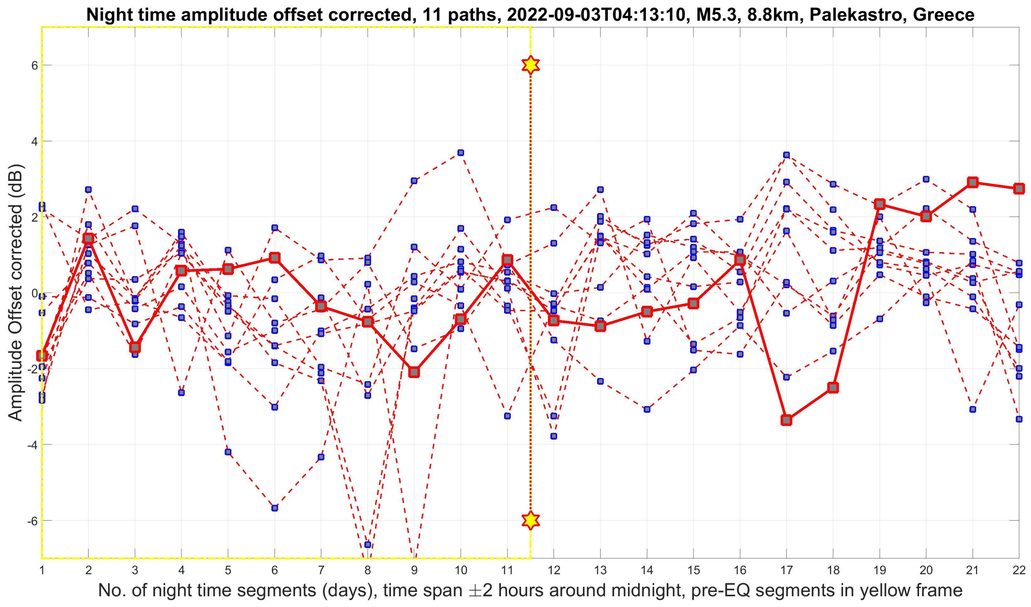
[1] Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [2] Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, [3] Department of Physics, University of Bari, Bari, Italy, [4] LATMOS-CNRS, UVSQ Université Paris-Saclay, Guyancourt, France, [5] SpaSys, SnT – Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg, Luxembourg

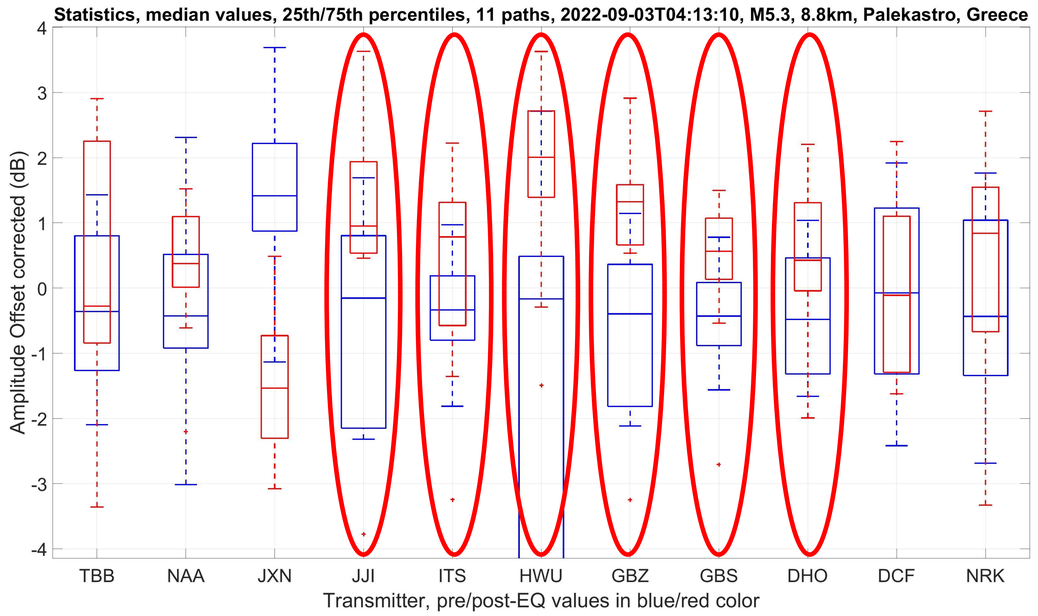
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-09-03, M5.3, 8.8 KM, PALEKASTRO, GREECE

- Top Left: VLF/LF amplitudes (2022-08-24 to 2022-09-13) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted, variations in the electric field values
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 11 paths
- Top Right: Nighttime amplitude values for the TBB-GRZ path (no crossing of the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected 11 paths, for a significance level of 5% 6 paths show higher amplitude values after the EQ (nighttime method)









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Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier Francesco Biagi[3], Patrick Galopeau[4], Ghulam Jaffer[5], Özer Aydogar[1], Christoph Schirninger[1], Cosima Muck[1], Irmgard Jernej[1], and Werner Magnes[1]

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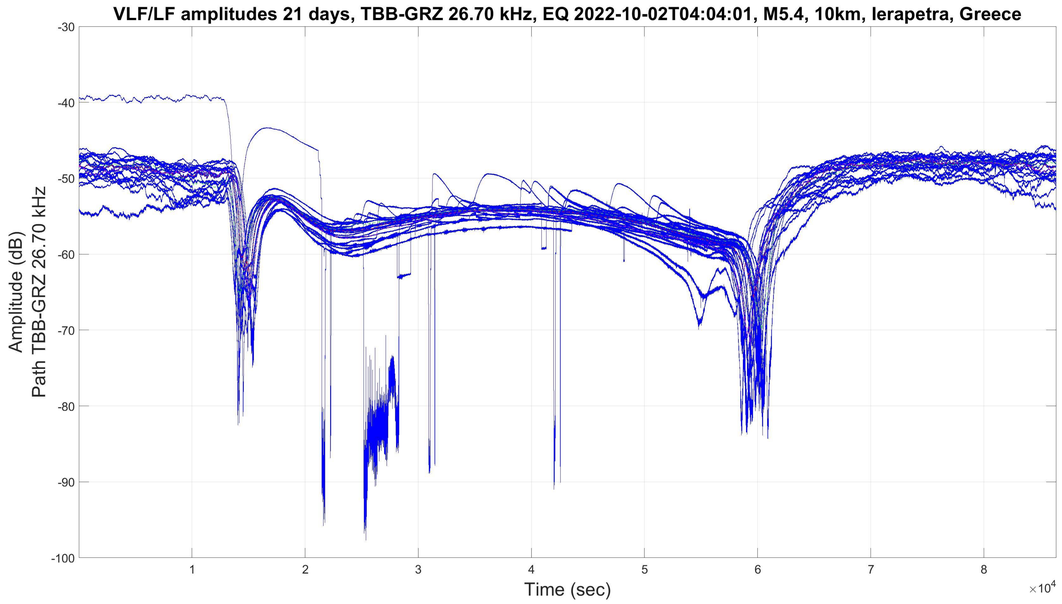
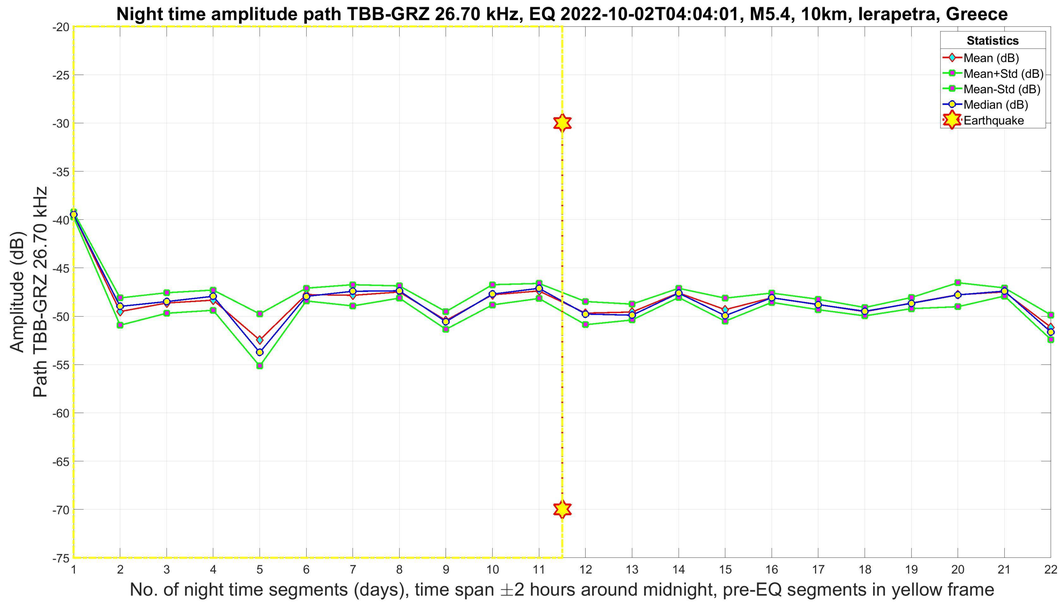
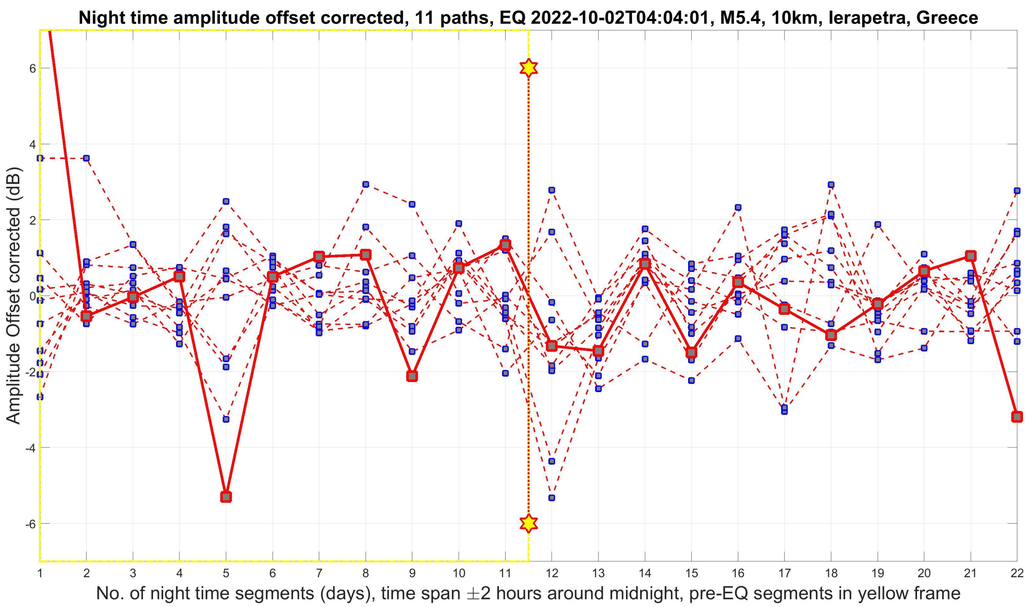
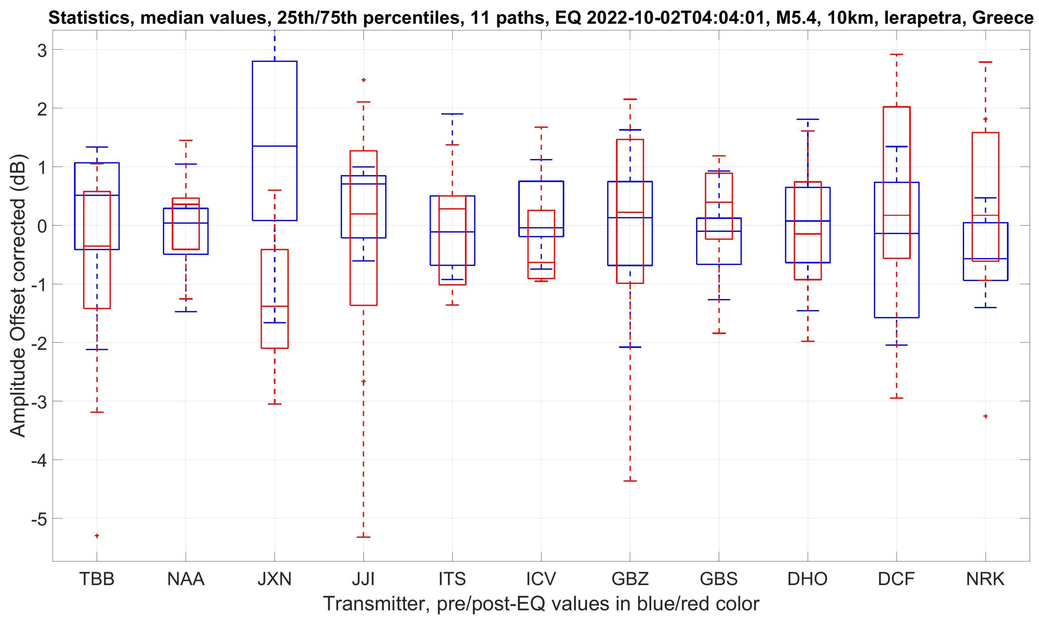
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2022-10-02, M5.4, 10 KM, IERÁPETRA, GREECE

- Top Left: VLF/LF amplitudes (2022-09-22 to 2022-10-12) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 11 paths
- Top Right: Nighttime amplitude values for the TBB-GRZ path (no crossing of the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected 11 paths, no significant variations (5% level) according to the nighttime method









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