



IONOSPHERIC PERTURBATIONS RELATED TO SEISMICITY AND VOLCANIC ERUPTIONS INFERRED FROM VLF/LF ELECTRIC FIELD MEASUREMENTS

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In this study we investigate electric field perturbations from sub-ionospheric VLF/LF paths which cross seismic and volcanic active areas. We use waveguide cavity radio links from the transmitters TBB (26.70 kHz, Bafa, Turkey) and ITS (45.90 kHz, Niscemi, Sicily, Italy) to the seismo-electromagnetic receiver facility GRZ (Graz, Austria). The continuous real-time amplitude and phase measurements have a temporal resolution of 1 sec, events are analyzed for the period 2020-2021. Of high interest in this time span are paroxysms of the stratovolcano Mt. Etna, Sicily, Italy. We show electric field amplitude variations which could be related to atmospheric waves, occurred at the active crater and propagated up to the lower ionosphere. This corresponds to vertical coupling processes from the ground to the E-region, the upper waveguide boundary during night-time. Ionospheric variations possibly related to earthquakes are discussed for events along the TBB-GRZ path, assumed is an area given by the so-called effective precursor manifestation zone [1,2]. The findings indicate statistical relations between electric field amplitude variations of the ITS-GRZ path in the VLF/LF sub-ionospheric waveguide and high volcanic activity of Etna. For earthquakes multi-parametric observations shall be taken into account to diagnose physical processes related to the events. In summary, VLF/LF investigations in a network together with automated data processing can be an essential component of natural hazards characterization.

VLF/LF NETWORK, EUROPEAN AREA

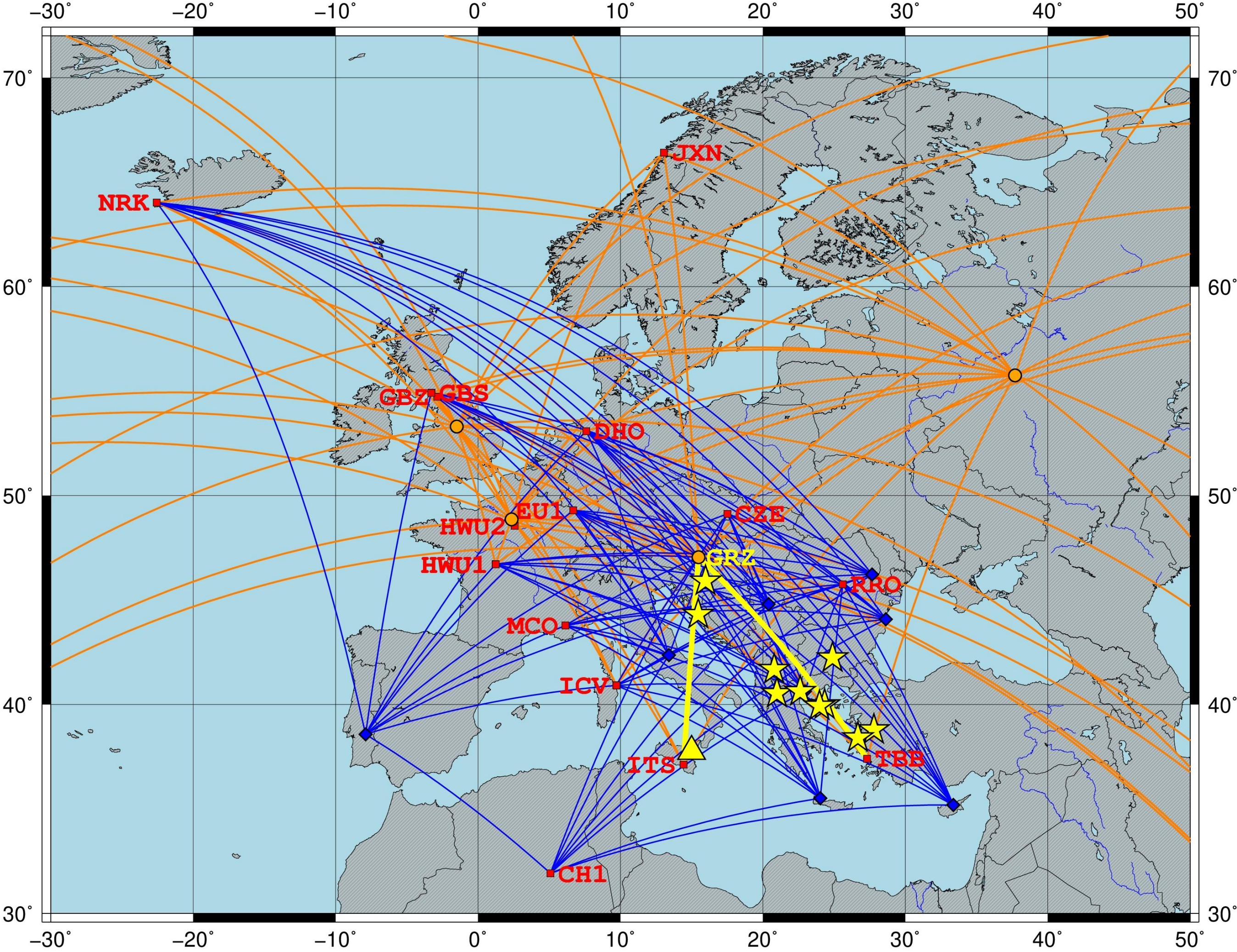


Figure 1: Great circle paths (orange color) between transmitter and receiver for the UltraMSK system with four sites: Paris (planned), Moscow, Sheffield, Graz (orange circles). INFREP system (paths and diamonds in blue color), see [5]. Earthquakes (yellow stars) and volcano Mt. Etna (yellow triangle) paths (ITS-GRZ, TBB-GRZ) near to the events in yellow color. Credit map software: GMT

TRANSMITTER, VLF/LF SYSTEM PARAMETERS

Receiver: Graz, IWF, Elektronika [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], event paths in yellow color.

REFERENCES

- Dobrovolsky, I.P., Zubkov, S.I., and Miachkin, V.I., *Estimation of the size of earthquake preparation zones*, PAGEOPH 117, 1025–1044, 1979. <https://doi.org/10.1007/BF00876083>
- Bowman, D.D., Ouillon, G., Sammis, C.G., Sornette, A., and Sornette, D., *An observational test of the critical earthquake concept*, JGR Solid Earth, 103, B10, 24359–24372, 1998. <https://doi.org/10.1029/98JB00792>
- Schwingenschuh, K., et al., *The Graz seismo-electromagnetic VLF facility*, NHESS, 11, 1121–1127, <https://doi.org/10.5194/nhess-11-1121-2011>, 2011.
- Marchese, F., et al., *Mt. Etna Paroxysms of February–April 2021 Monitored and Quantified through a Multi-Platform Satellite Observing System*, Remote Sensing, 13, 16, 3074, 2021. <https://doi.org/10.3390/rs13163074>
- Biagi, P.F., et al., *The INFREP Network: Present Situation and Recent Results*, OJER, 8, 101–115, 2019. doi: 10.4236/ojer.2019.82007 www.infrep-network.eu
- United States Geological Survey (USGS) earthquake database, <https://earthquake.usgs.gov/> as of May 2022.

SUMMARY

Paroxysms of the volcano Mt. Etna, Italy, can be characterized via VLF/LF measurements (path ITS-GRZ) during nighttime. Magnitude $M > 5.0+$ earthquakes along the path TBB-GRZ can cause larger VLF/LF amplitude values after the EQ than before (nighttime amplitude method; assumed significance level 5%).

EARTHQUAKE EVENTS, MT. ETNA PAROXYSMS/ERUPTIONS, DATA PROCESSING & RESULTS

For the biennial period 2020-2021 we consider the geogr. latitude/longitude range $[30^\circ \leq \text{lat} \leq 50^\circ] / [10^\circ \leq \text{long} \leq 40^\circ]$, i.e., a wider Southeast Europe area which is covered by sub-ionospheric VLF/LF propagation paths. For this temporal, spatial, and moment magnitude $M_w \geq 4.5$ constraints the USGS earthquake database [6] gives 301 EQs. From this list 10 events (Tab. 1) are selected according to VLF/LF path crossings and the size of the Dobrovolsky-Bowman relationship (the radius of the effective precursor manifestation zone $\rho = 10^{(0.43 \cdot M)}$ km and $\log(R) \approx M/2$ km). The VLF/LF amplitude data have 1 Hz temporal resolution, nighttime values are used (± 2 hours around midnight). The values are smoothed with a low pass filter, the residuals are below 1 dB. Phase data are avoided due to higher variations on all paths.

Selected Earthquakes, USGS database, time span 01.01.2020 – 31.12.2021, long/lat range: [10°–40°]/[30°–50°]							
No.	Date, Time	Long (°) / Lat (°) / Depth (km)	Mag / ρ (km)	Location	Main path	Control paths	Result
1	2020-03-22 05:24:03	+45.91 / +15.97 / 10.0	5.3 / 190	Gornja Bistra, Croatia	{TBB,ITS}–GRZ	6 {ITS,ICV,HWU,GBZ,GBS,NRK}–GRZ	OK: Post EQ > Pre EQ values with significance level 5%
2	2020-11-11 03:54:14	+41.68 / +20.80 / 10.0	5.0 / 141	Vrutok, North Macedonia	TBB–GRZ	7 {NAA,ITS,HWU,GBZ,GBS,DHO,NRK}–GRZ	OK: Post EQ > Pre EQ values with significance level 5%
3	2020-09-26 22:50:25	+39.99 / +24.34 / 10.4	5.4 / 210	Karyes, Greece	TBB–GRZ	5 {ITS,ICV,GBZ,GBS,DHO}–GRZ	Not OK: Post EQ > Pre EQ for GBS with significance level 5%
4	2020-06-26 07:21:12	+38.79 / +27.79 / 10.0	5.2 / 172	Gölmarmara, Turkey	TBB–GRZ	6 {NAA,ITS,HWU,GBZ,GBS,DHO}–GRZ	Not OK: not significant, magnitude to low
5	2020-05-01 11:01:39	+42.23 / +24.89 / 10.0	4.5 / 86	Rakovski, Bulgaria	TBB–GRZ	7 {NAA,ITS,HWU,GBZ,DHO,DCF,NRK}–GRZ	OK / not OK: more paths show significance
6	2020-11-01 13:15:41	+44.31 / +15.46 / 10.0	4.6 / 95	Starigrad, Croatia	{TBB,ITS}–GRZ	7 {ITS,ICV,HWU,GBZ,GBS,DHO,NRK}–GRZ	Not OK: not significant, magnitude to low
7	2021-05-11 21:31:01	+40.53 / +20.99 / 10.0	4.8 / 116	Bilisht, Albania	TBB–GRZ	4 {ITS,ICV,HWU,NRK}–GRZ	Not OK: Post EQ > Pre EQ for NRK with significance level 5%
8	2020-08-10 02:07:53	+40.61 / +22.61 / 10.0	4.5 / 86	Trikala, Greece	TBB–GRZ	5 {ITS,HWU,GBZ,GBS,DHO}–GRZ	Not OK: not significant, magnitude to low
9	2020-07-16 18:09:26	+38.40 / +26.67 / 10.0	4.5 / 86	Rakova, Turkey	TBB–GRZ	5 {ITS,HWU,GBS,DHO,DCF}–GRZ	Not OK: not significant, magnitude to low
10	2020-11-05 22:16:37	+39.24 / +23.80 / 10.0	4.9 / 128	Sykia, Greece	TBB–GRZ	8 {NAA,ITS,ICV,HWU,GBZ,GBS,DHO,NRK}–GRZ	Not OK: Post EQ > Pre EQ for ITS with significance level 5%
Selected paroxysmal periods, Mt. Etna, Sicily, Italy							
No.	Date, Time	Total No. of Paroxysms	Main path	Result			
1	2021-02-16 to 2021-02-19	3	ITS–GRZ	OK: VLF/LF amplitude variations during night time (ionospheric E region) correspond with local measured tremor amplitudes (eruptions) of Mt. Etna			
2	2021-07-01 to 2021-07-04	2	ITS–GRZ	OK: VLF/LF amplitude variations during night time (ionospheric E region) correspond with local measured tremor amplitudes (eruptions) of Mt. Etna			

Table 1: Top - Selected earthquakes (and Figure 1, stars in yellow color), Bottom – Selected paroxysms/eruptions, e.g. [4], of Mt. Etna, Italy.



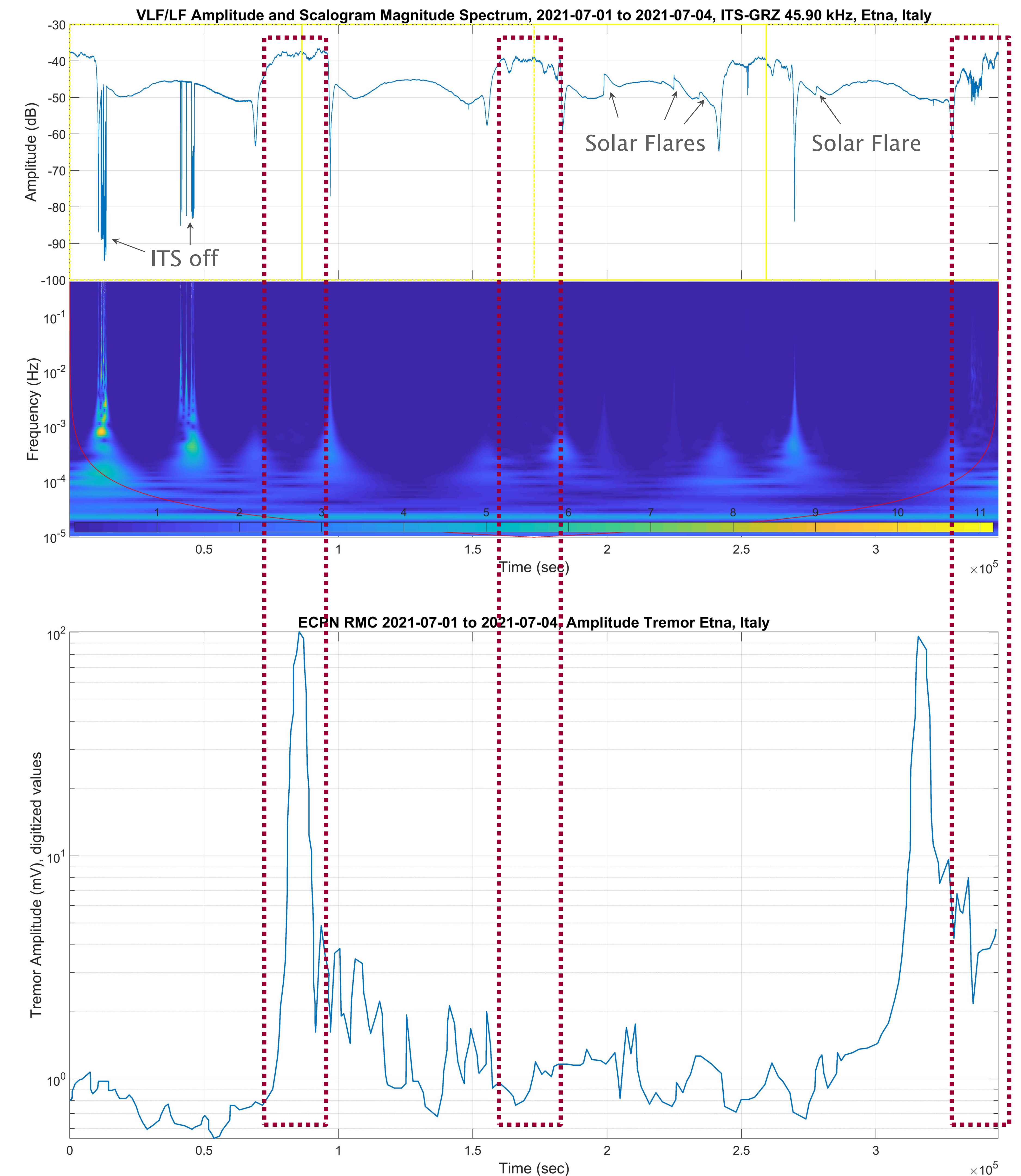
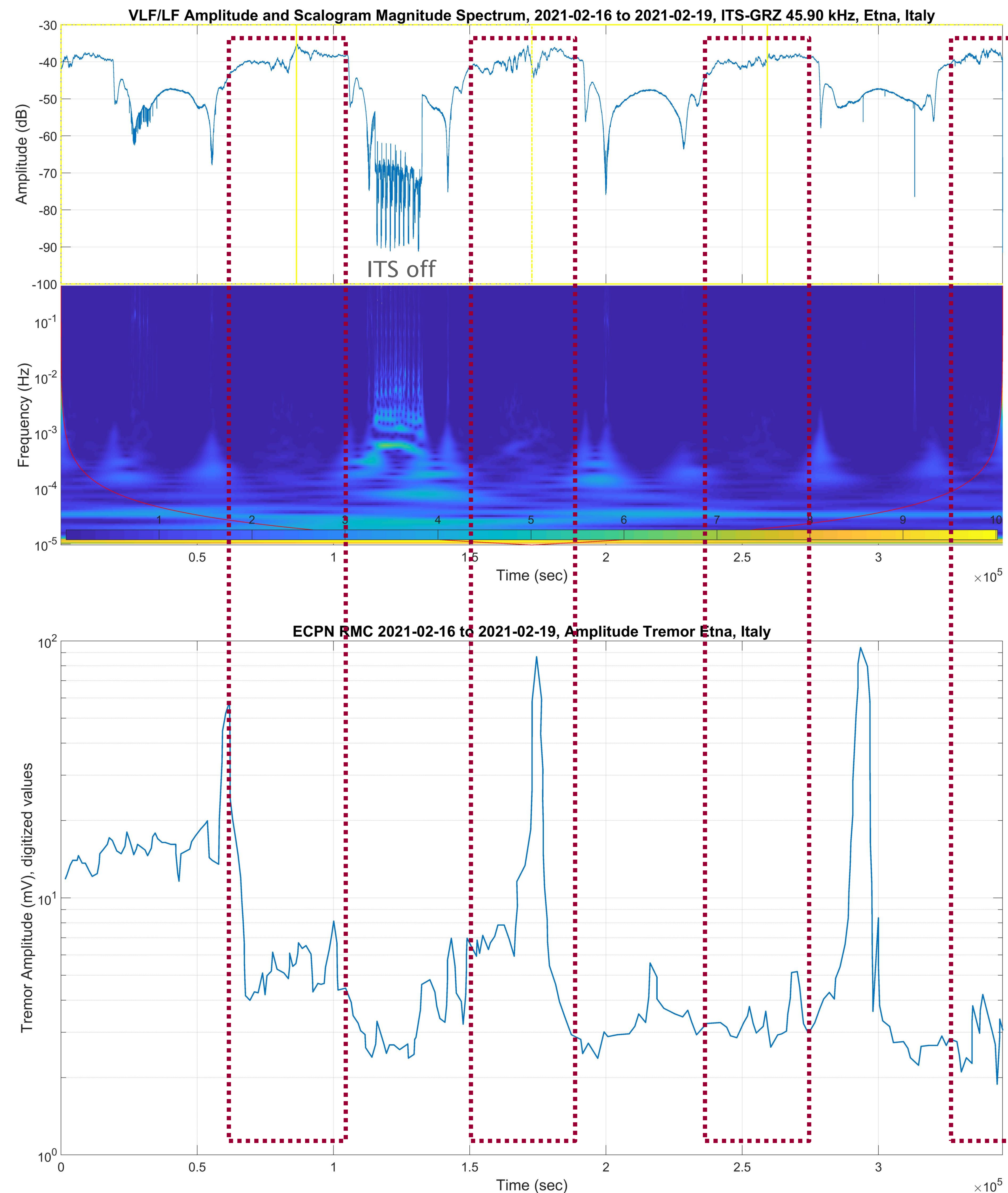
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VLF/LF AMPLITUDE MEASUREMENTS ALONG THE PATH ITS-GRZ, VOLCANIC ERUPTIONS OF MT. ETNA, ITALY

- Top Left: VLF/LF amplitudes and spectra (2021-02-16 to 2021-02-19) for the 45.90 kHz ITS-GRZ path, nighttime electric field variations (max. 8 dB) due to paroxysms of Mt. Etna
- Bottom Left: Tremor measurements (2021-02-16 to 2021-02-19) at Mt. Etna, ECPN (INGV, Osservatorio Etneo) digitized values
- Top Right: VLF/LF amplitudes and spectra (2021-07-01 to 2021-07-04) for the 45.90 kHz ITS-GRZ path, nighttime electric field variations (max. 12 dB) due to eruptions of Mt. Etna
- Bottom Right: Tremor measurements (2021-07-01 to 2021-07-04) at Mt. Etna, ECPN (INGV, Osservatorio Etneo) digitized values



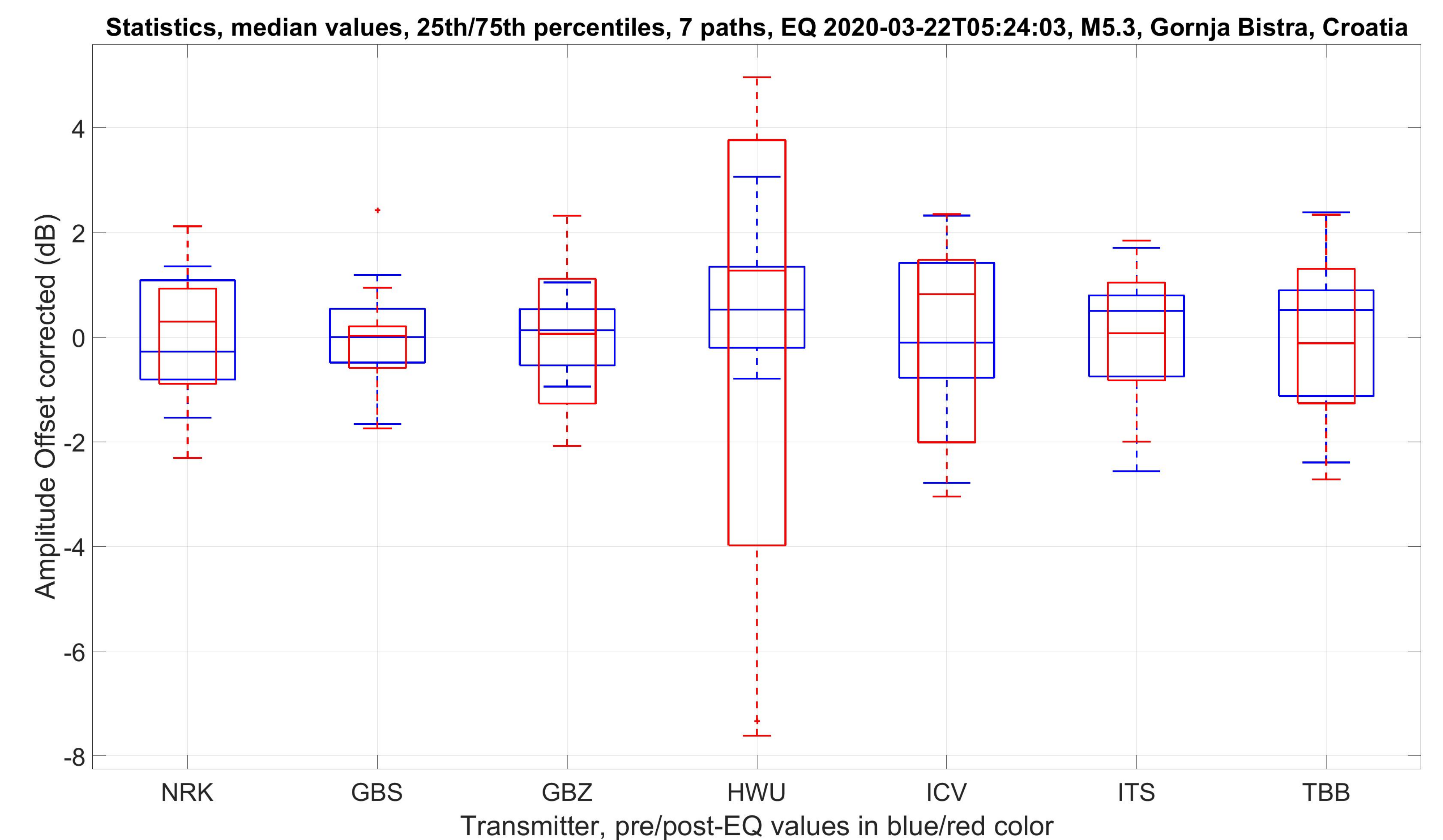
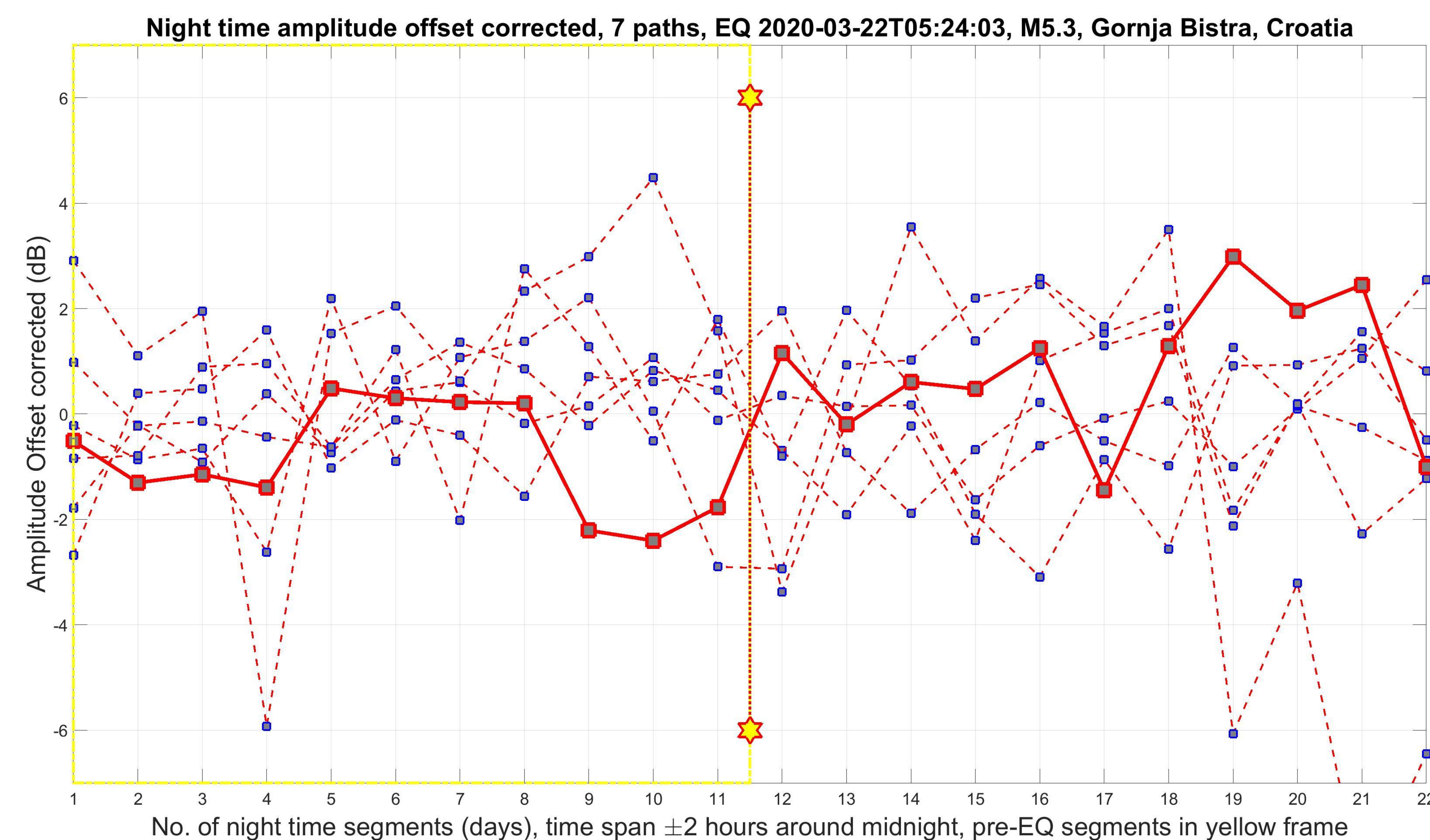
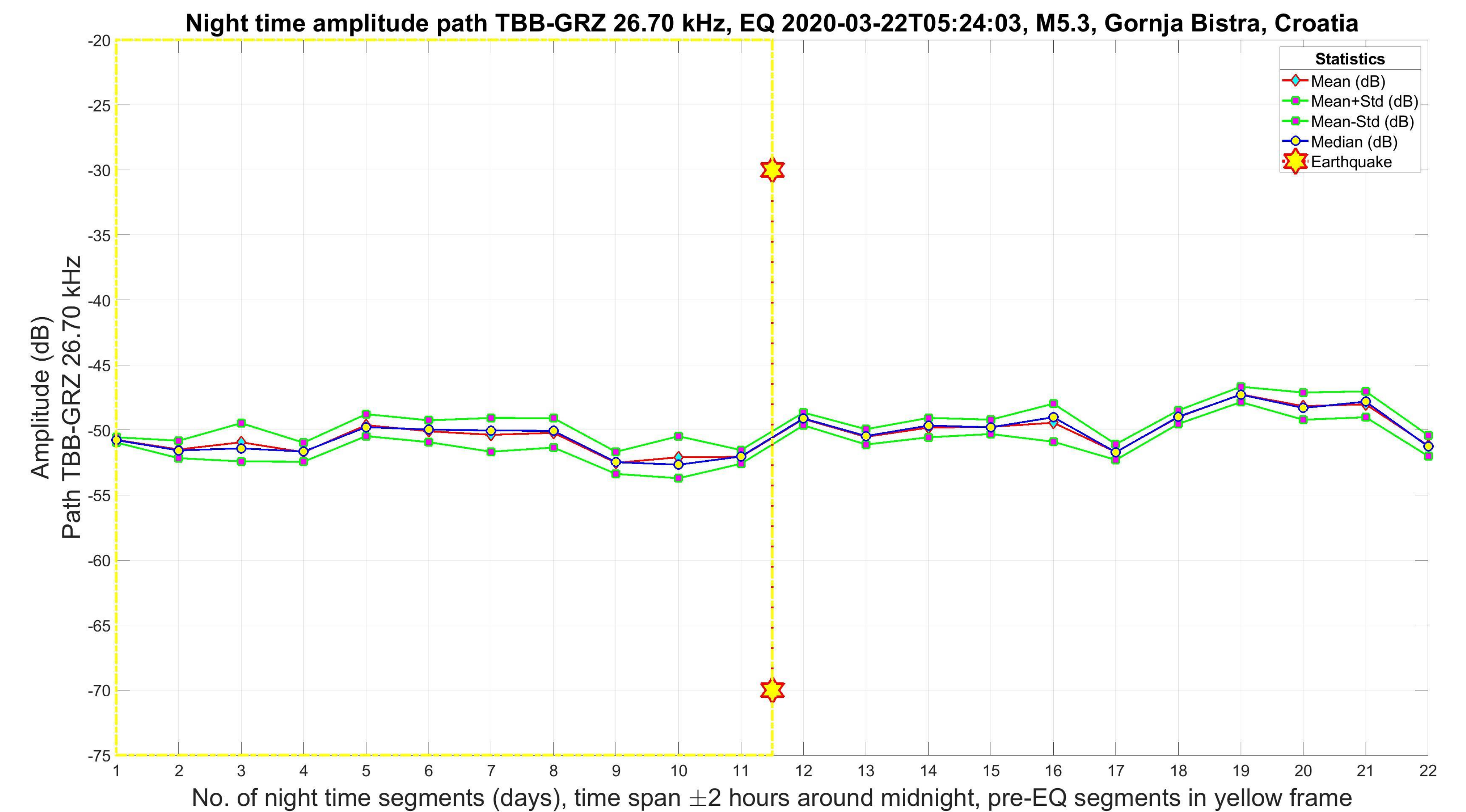
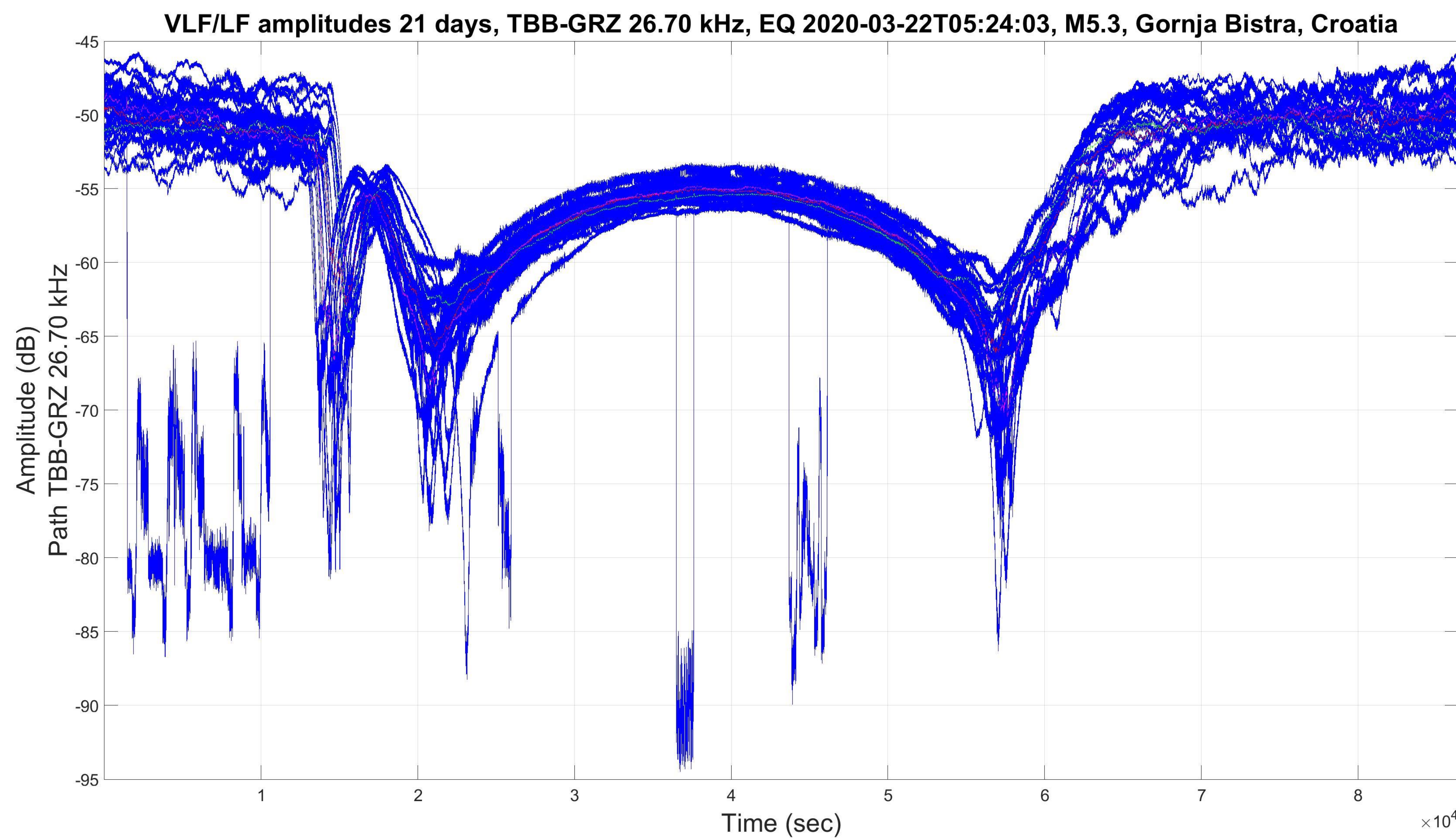
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VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2020-03-22, M5.3, GORNJA BISTRA, CROATIA

- Top Left: VLF/LF amplitudes (2020-03-12 to 2020-04-01) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2 h 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, **for a significance level of 5% only the event path TBB-GRZ shows higher amplitude values after the EQ (nighttime method)**



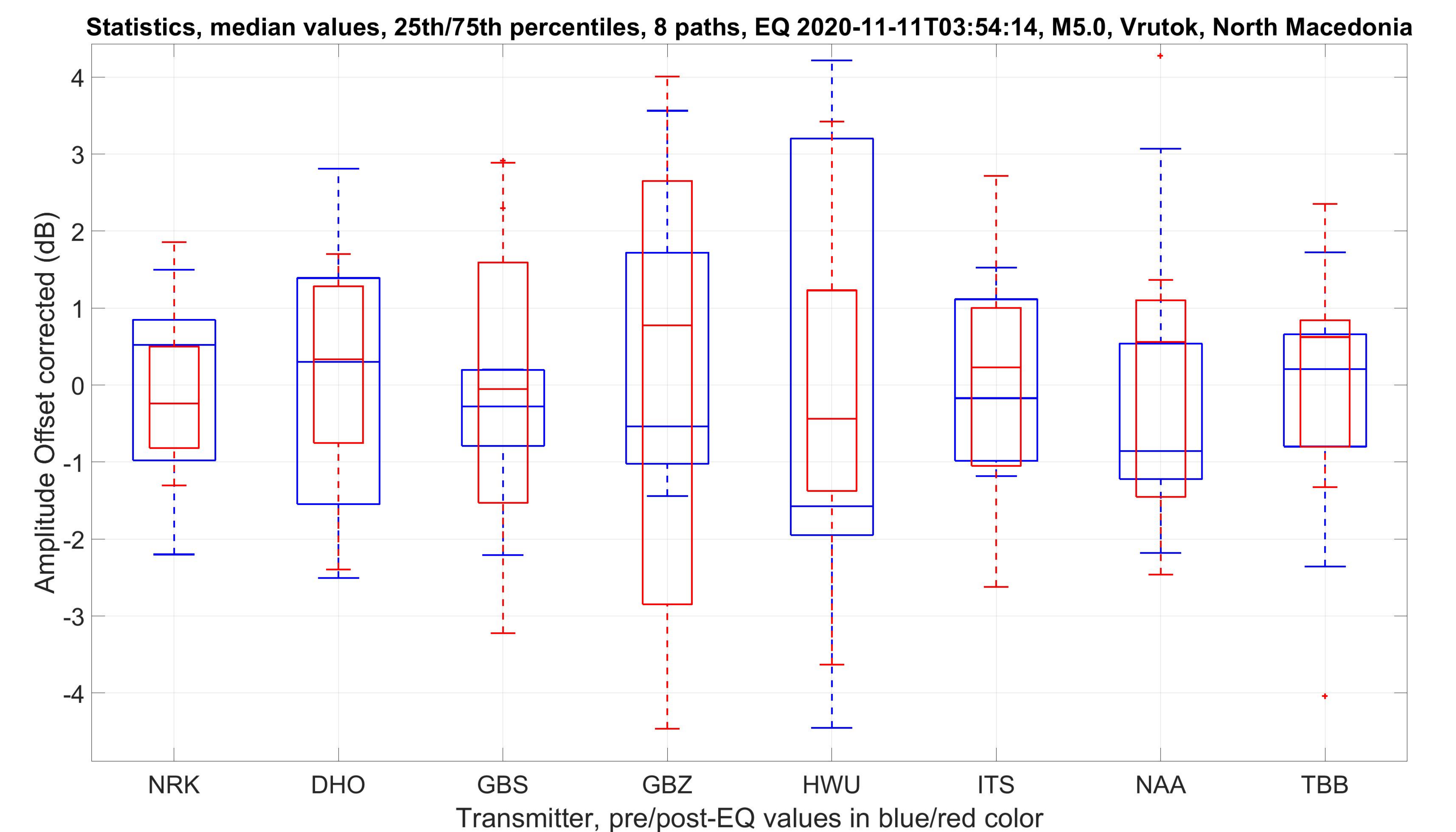
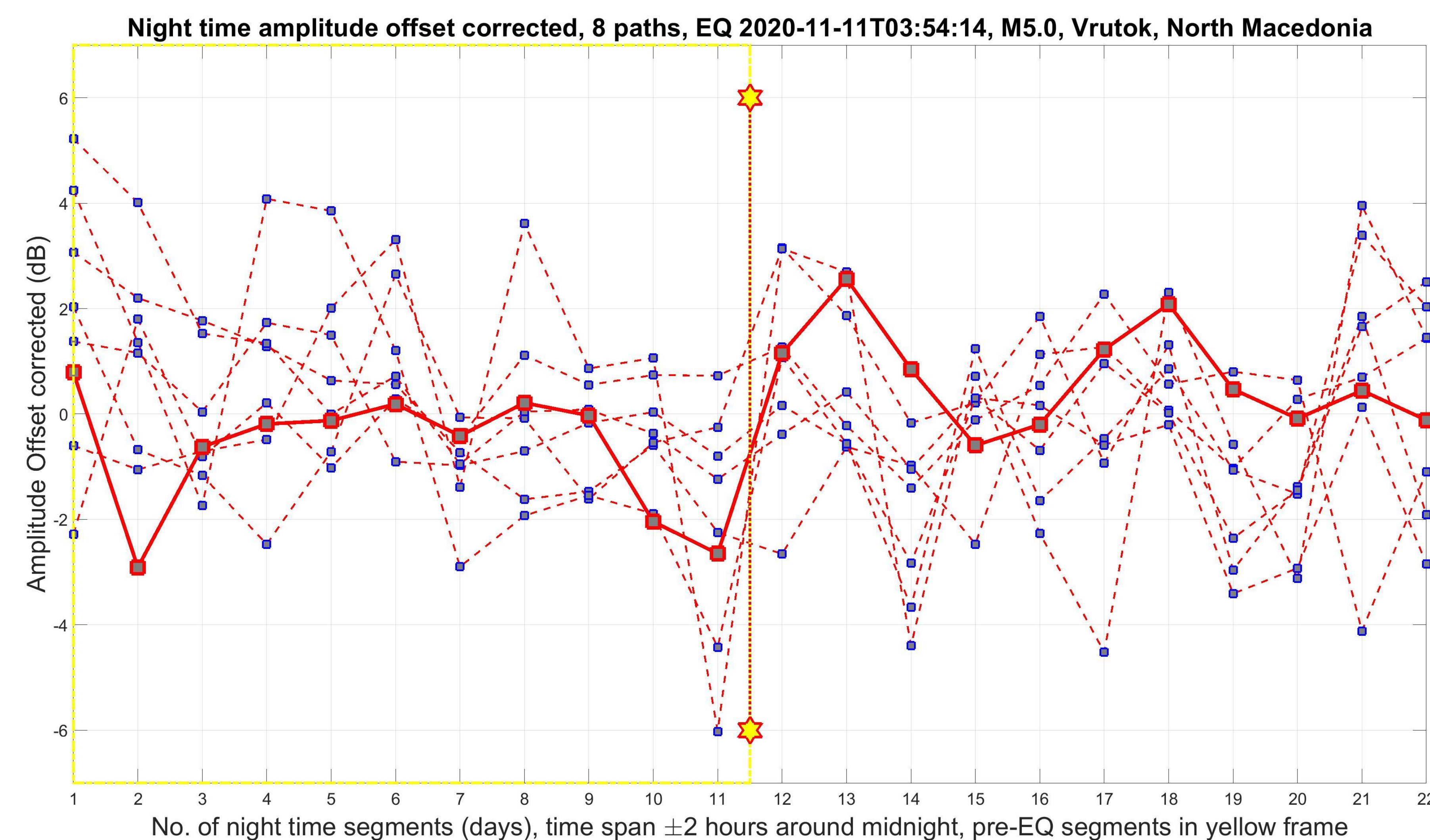
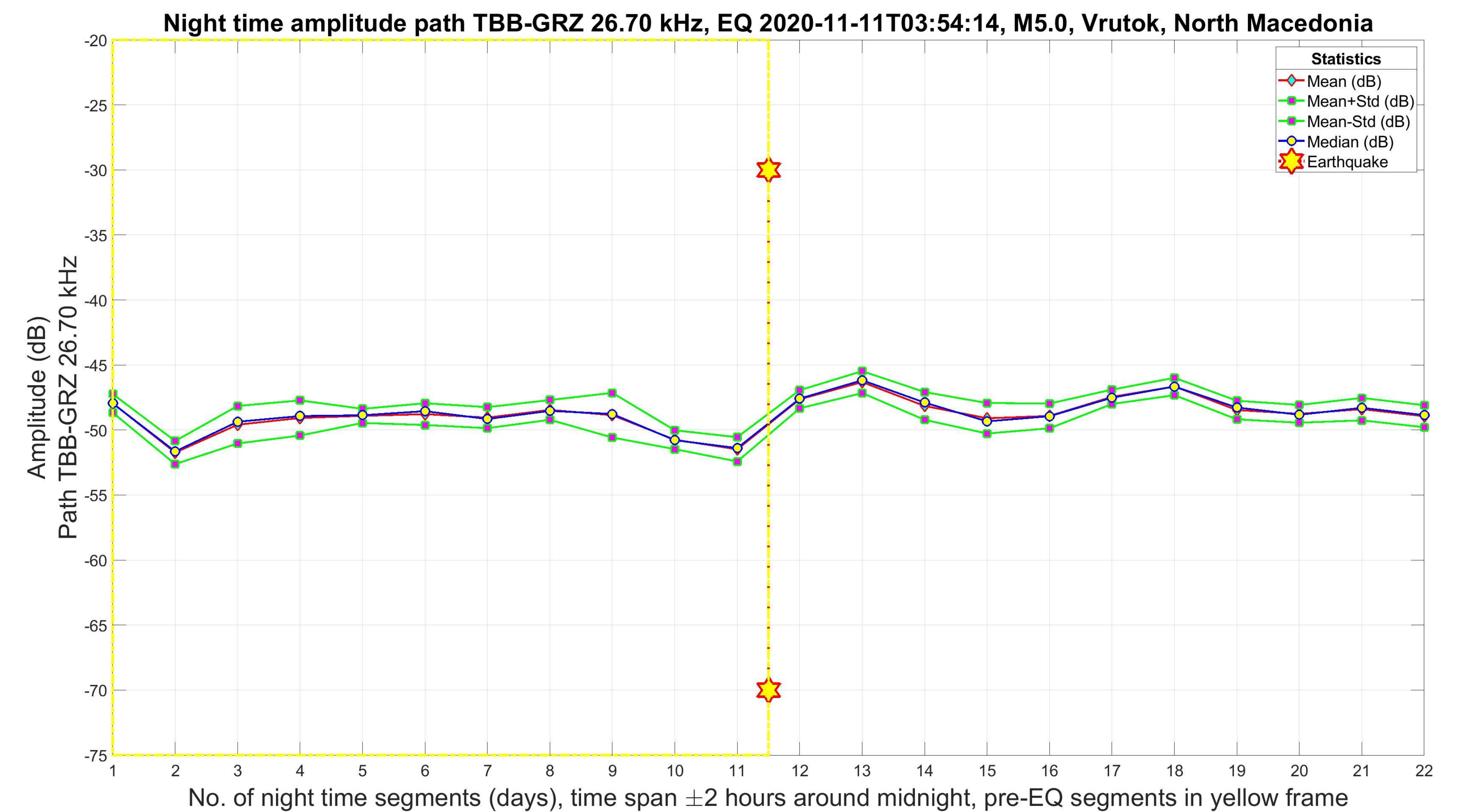
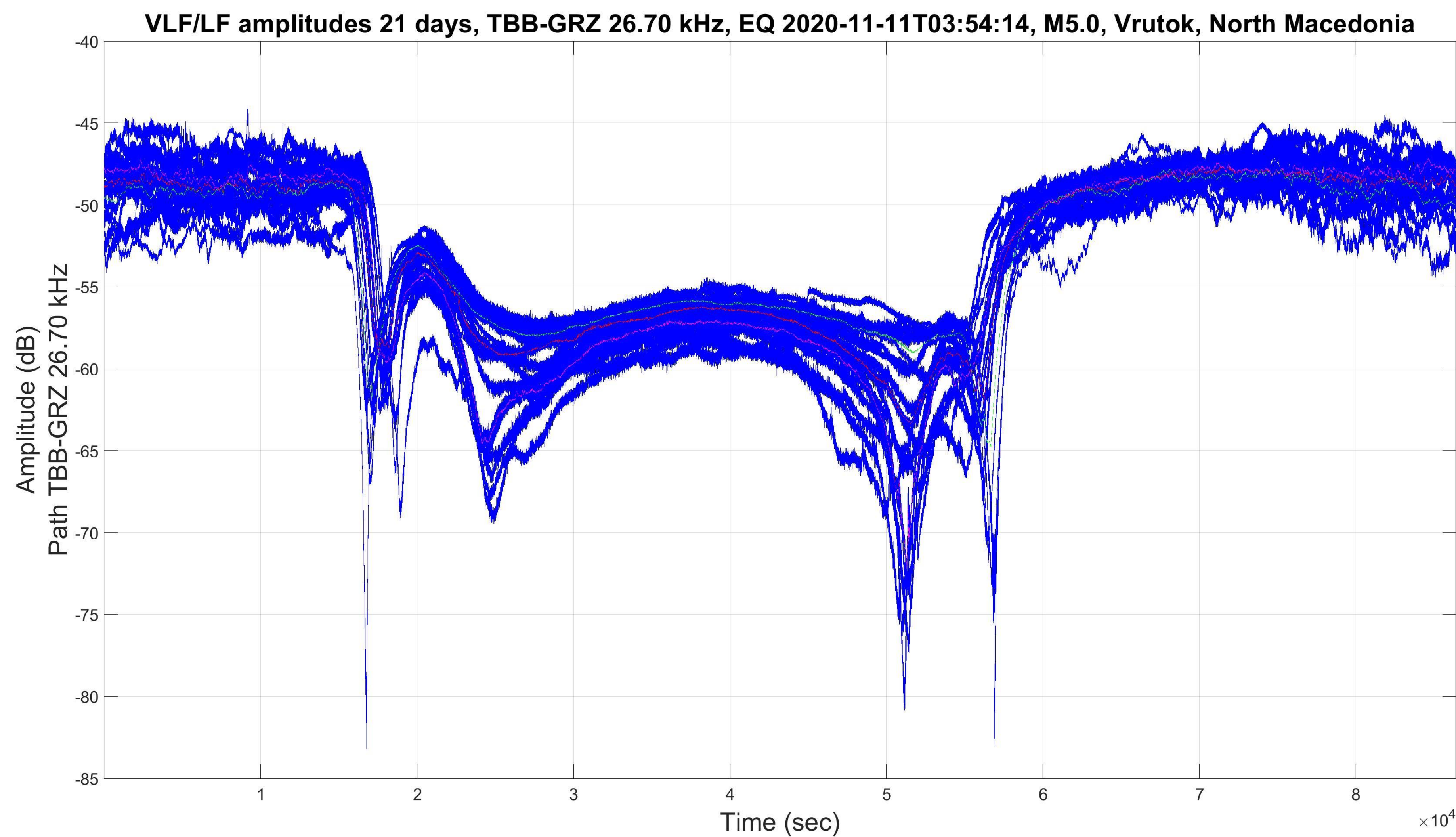
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VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2020-11-11, M5.0, VRUTOK, NORTH MACEDONIA

- Top Left: VLF/LF amplitudes (2020-11-01 to 2020-11-21) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2 h around midnight) amplitude values for the 8 paths
- Top Right: Nighttime amplitude statistics for the affected TBB-GRZ event path (within area given by the Dobrovolsky-Bowman radius)
- Bottom Right: Statistics (box plots) for the offset corrected nighttime amplitude values, 8 paths, **for a significance level of 5% only TBB-GRZ shows higher amplitude values after the earthquake**



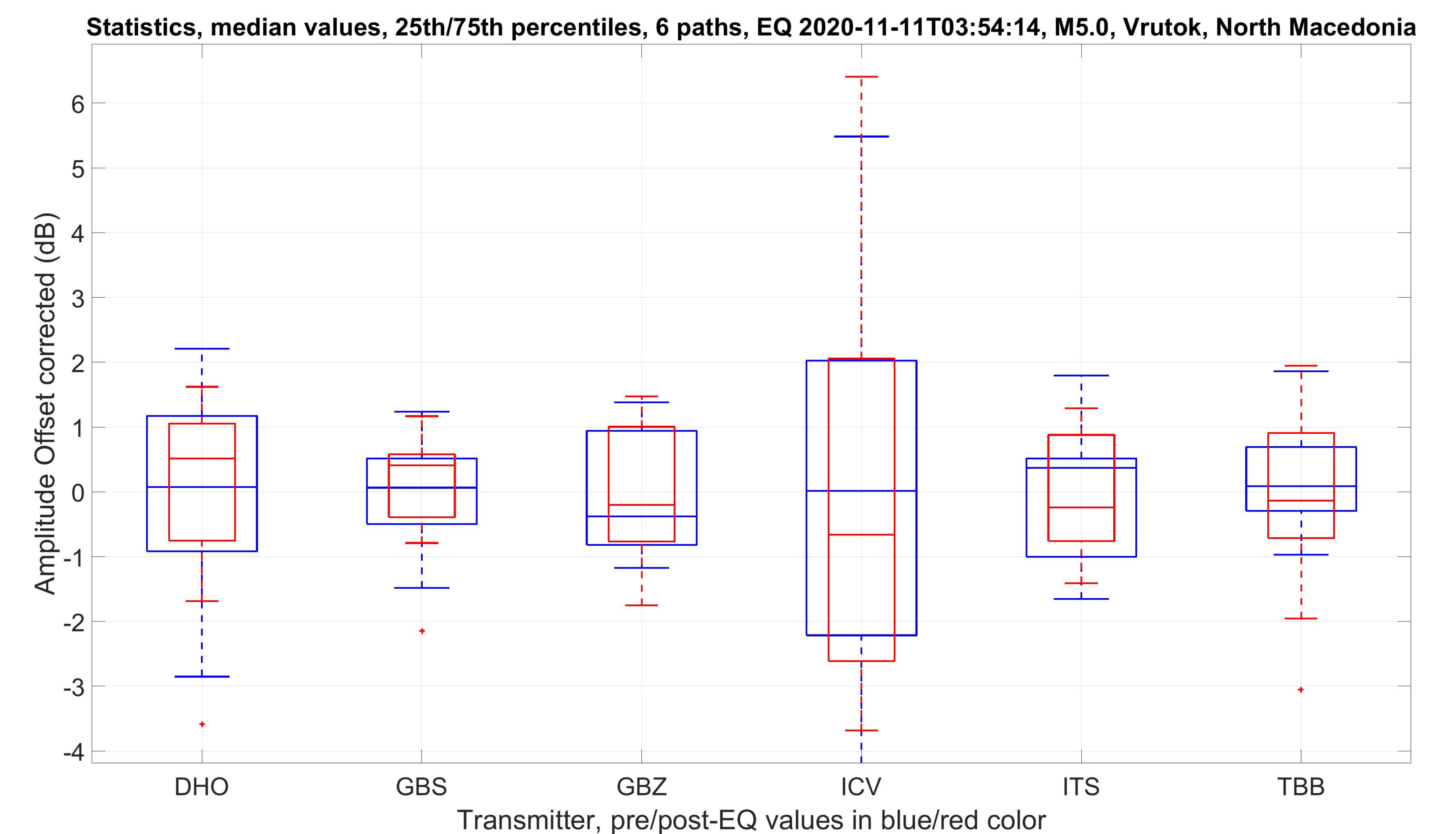
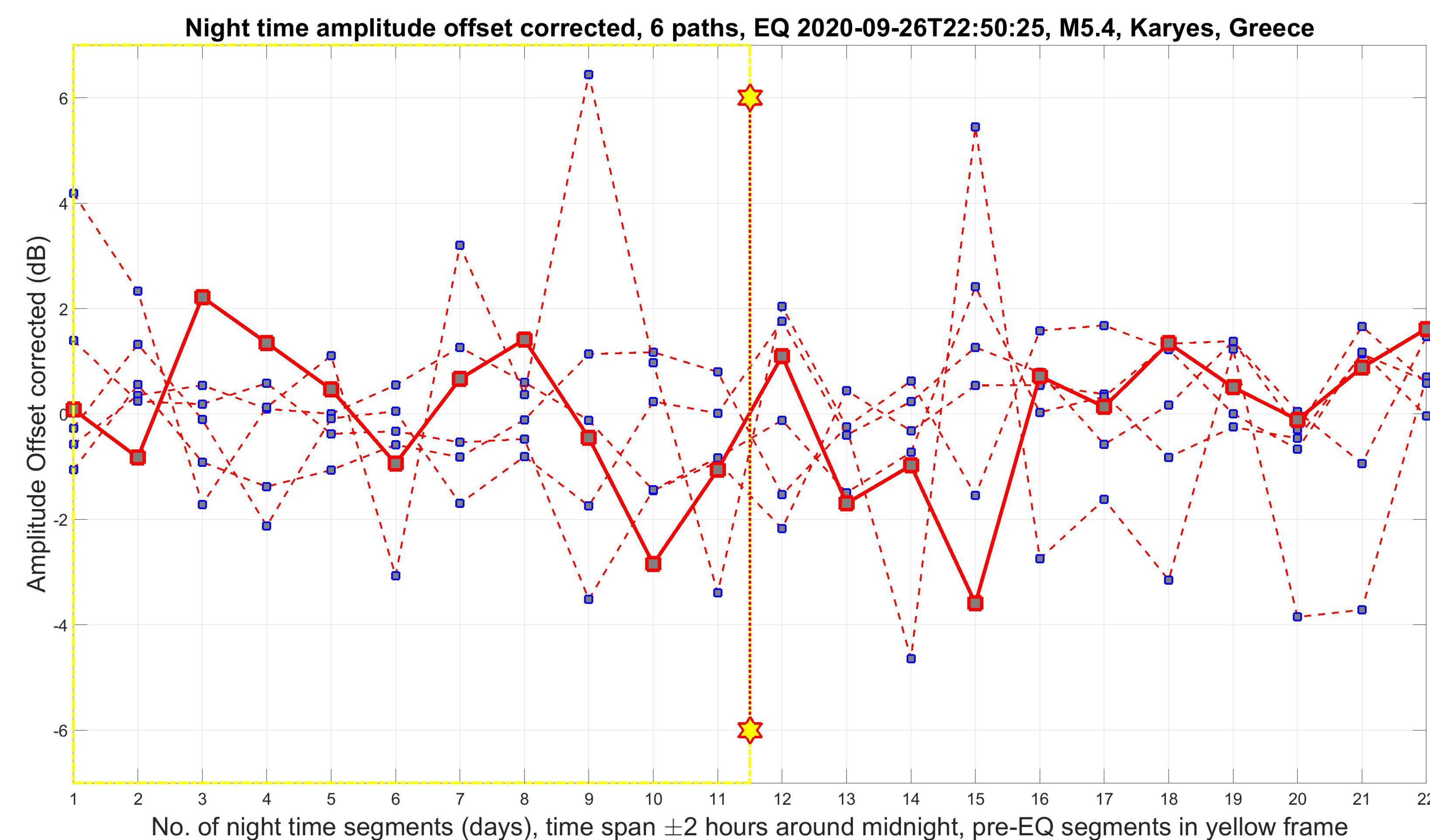
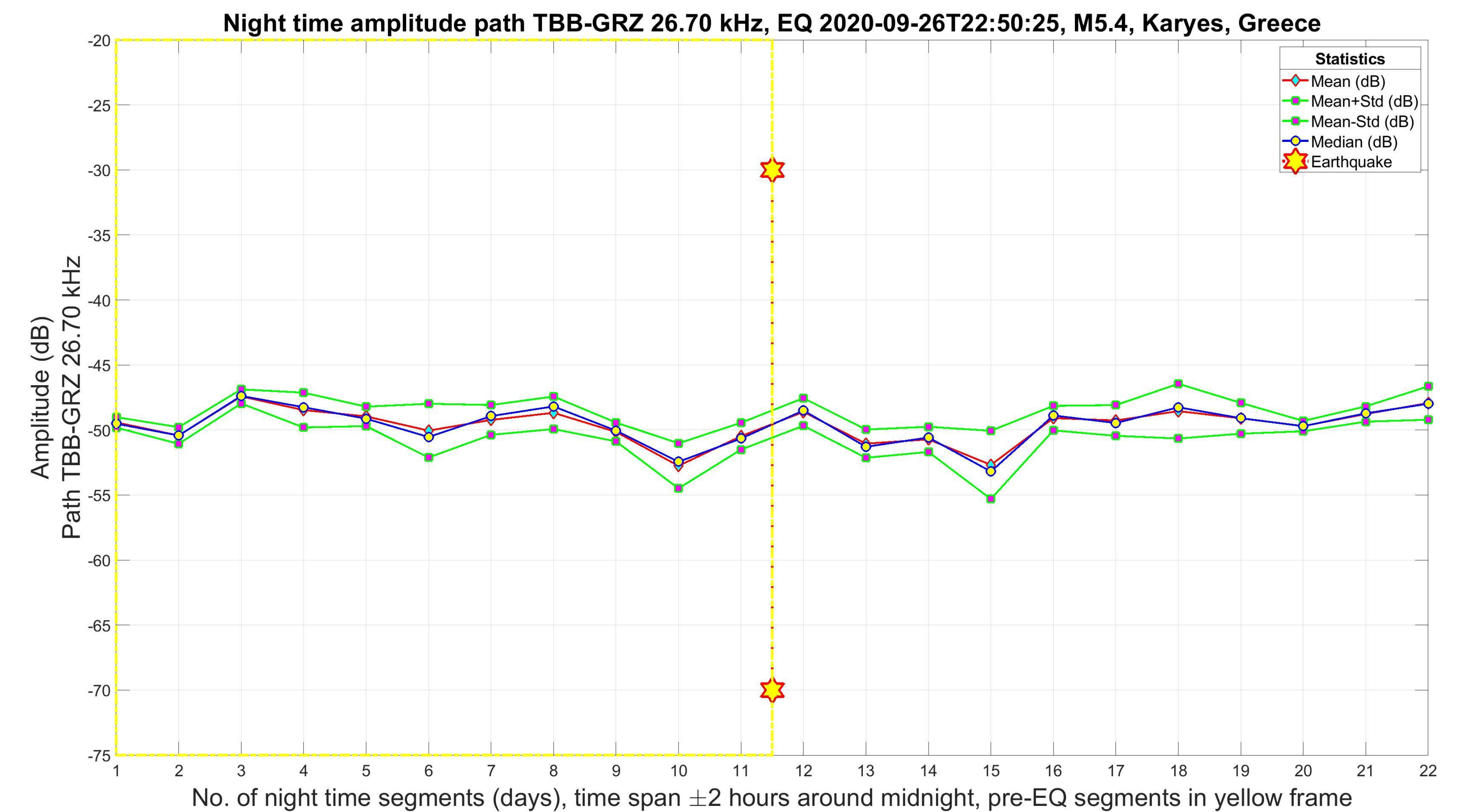
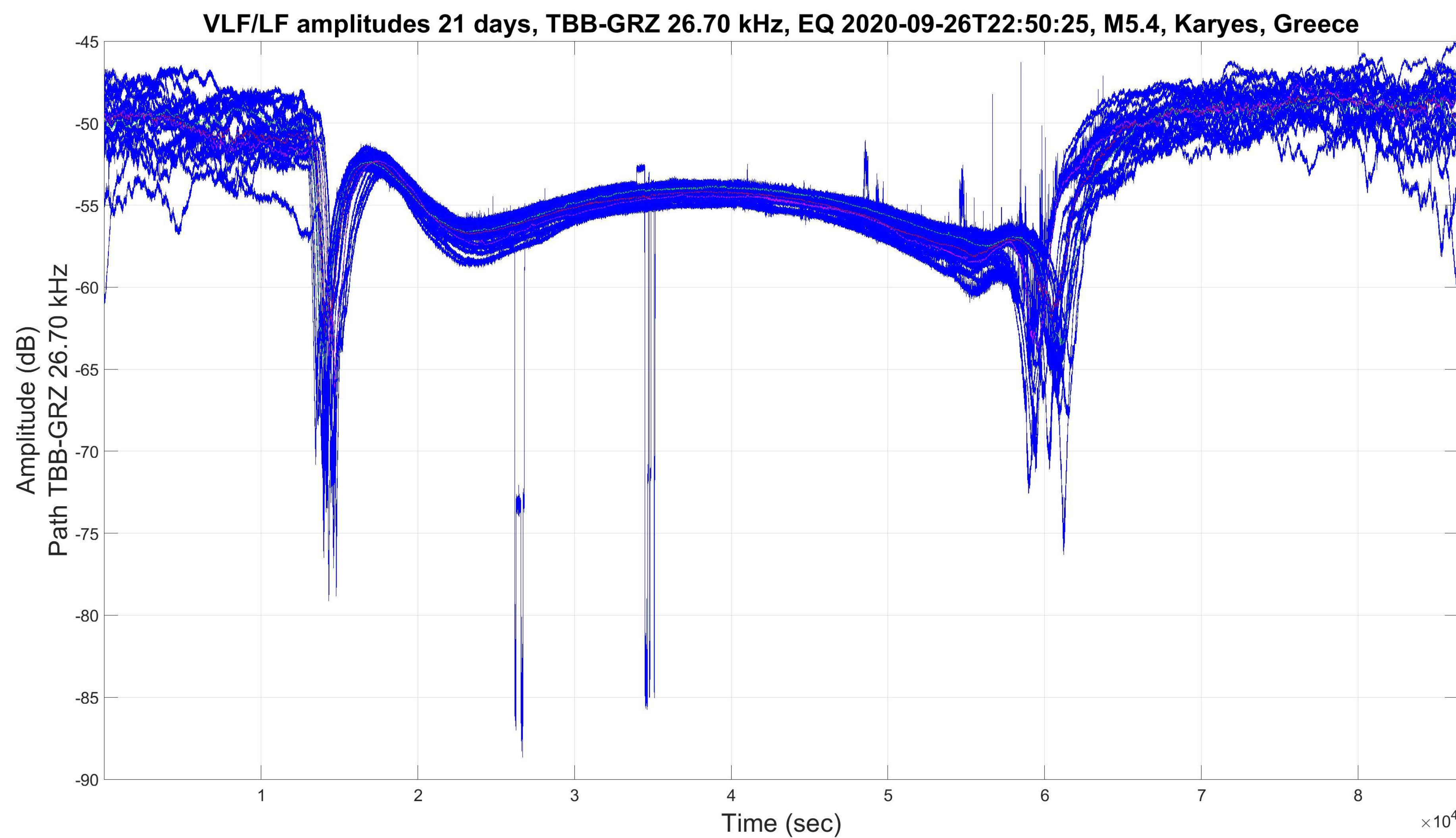
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VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2020-09-26, M5.4, KARYES, GREECE

- Top Left: VLF/LF amplitude measurements (2020-09-16 to 2020-10-06) for the 26.70 kHz TBB-GRZ path, the spikes and transmitter switch off periods during night are omitted for the analysis
- Bottom Left: Offset corrected nighttime (± 2 h around midnight) amplitude values for the 6 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 nighttime amplitude values, 6 paths, only a control path (GBS-GRZ) shows variations with a significance level of 5%



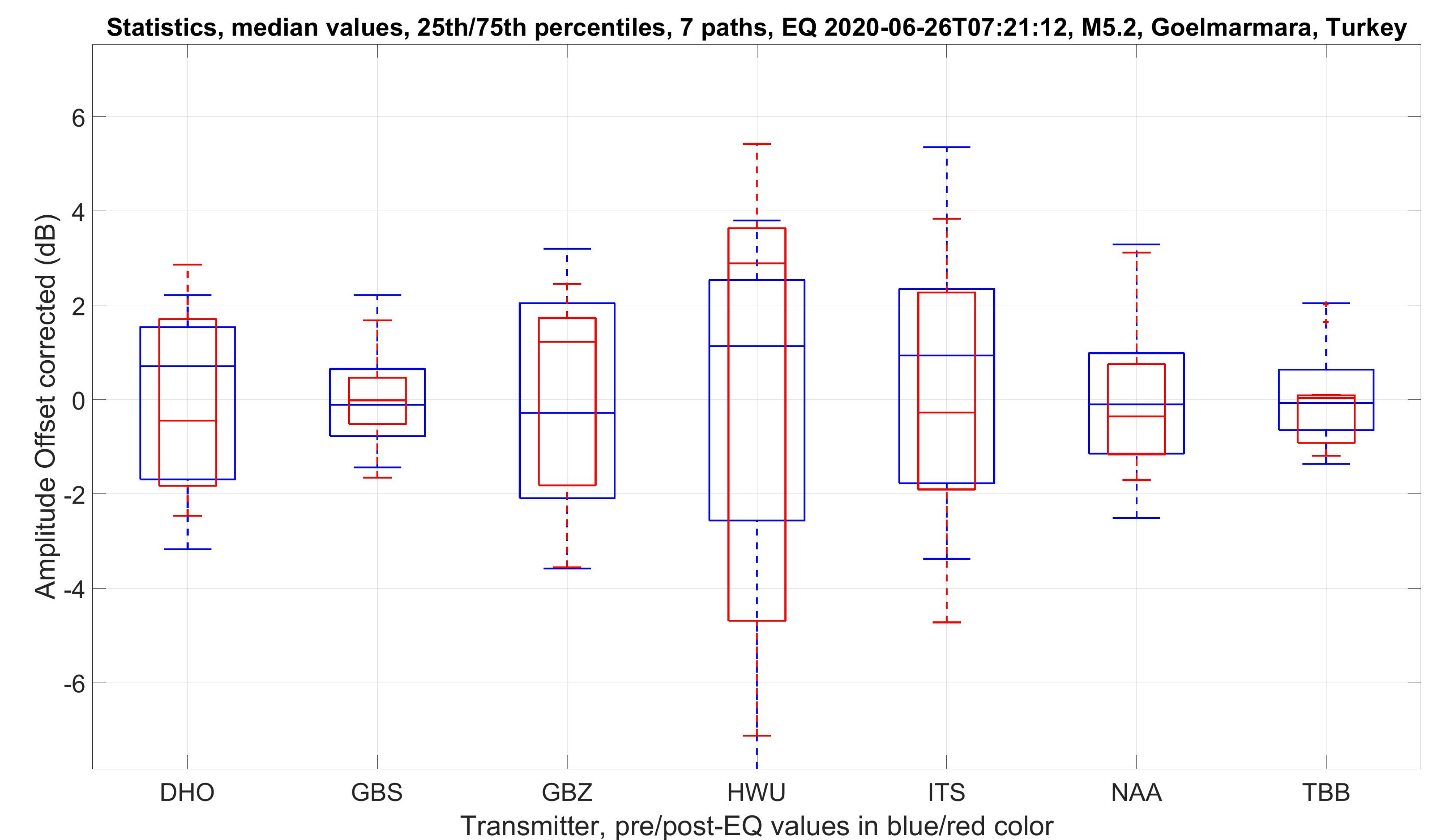
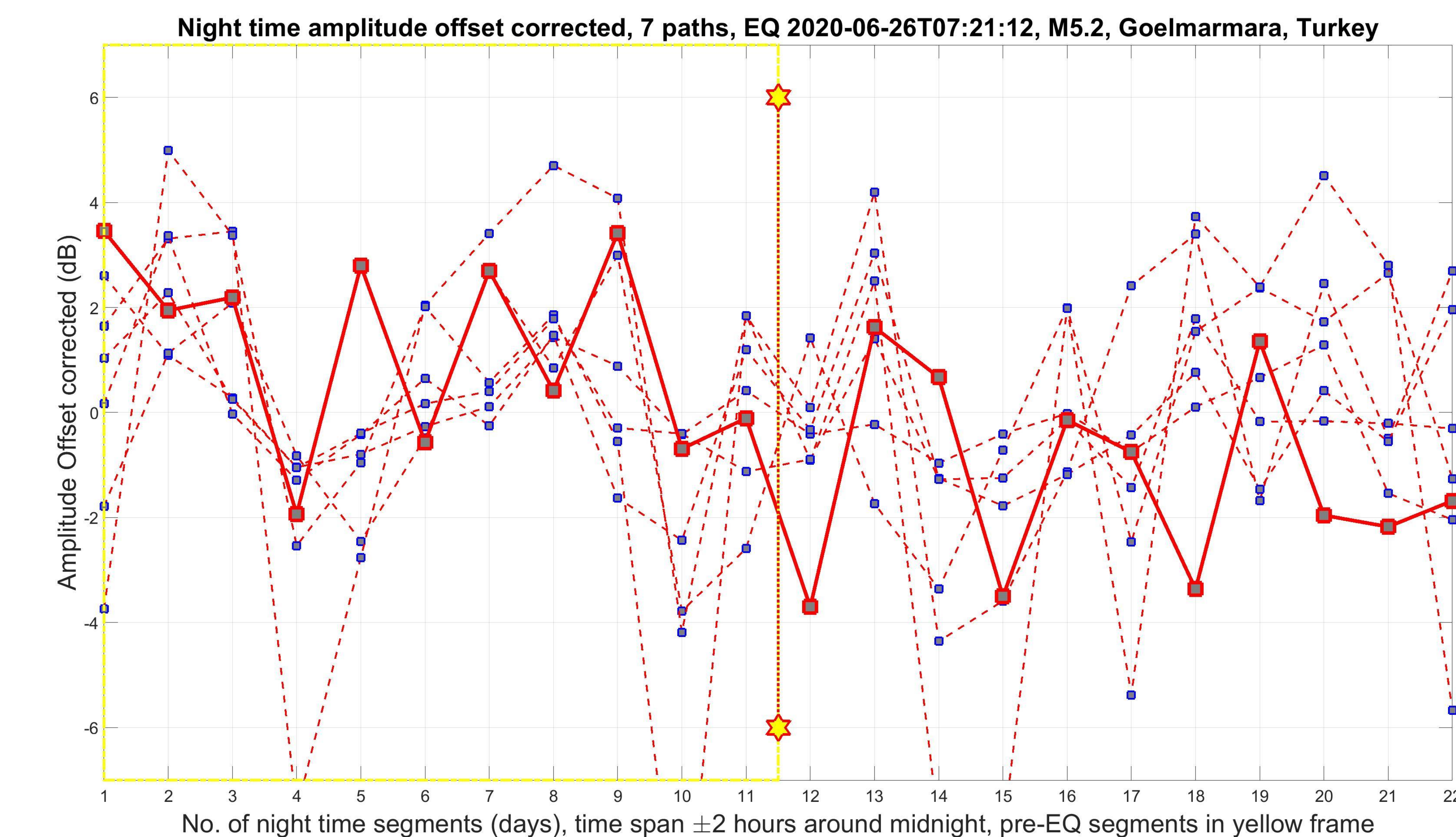
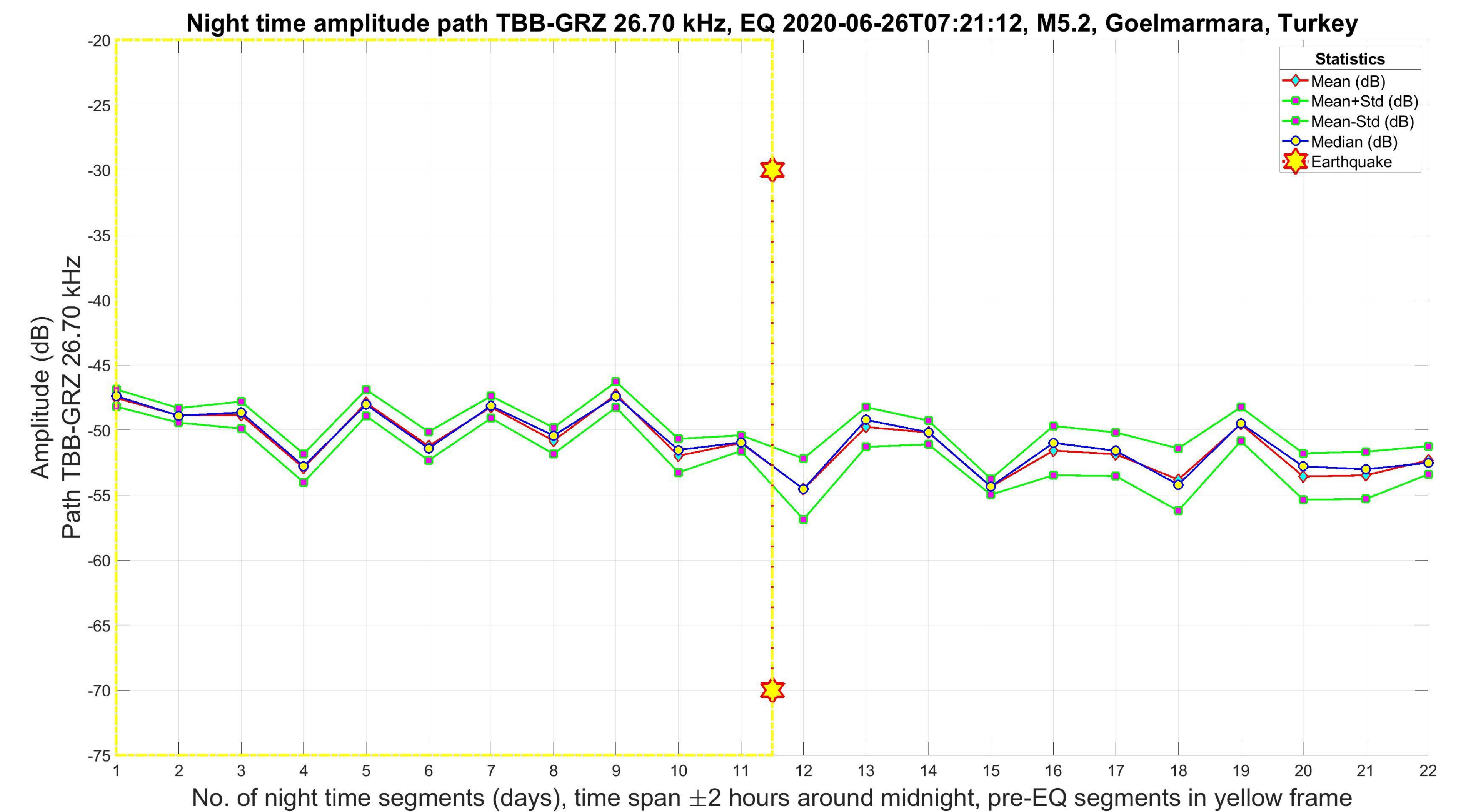
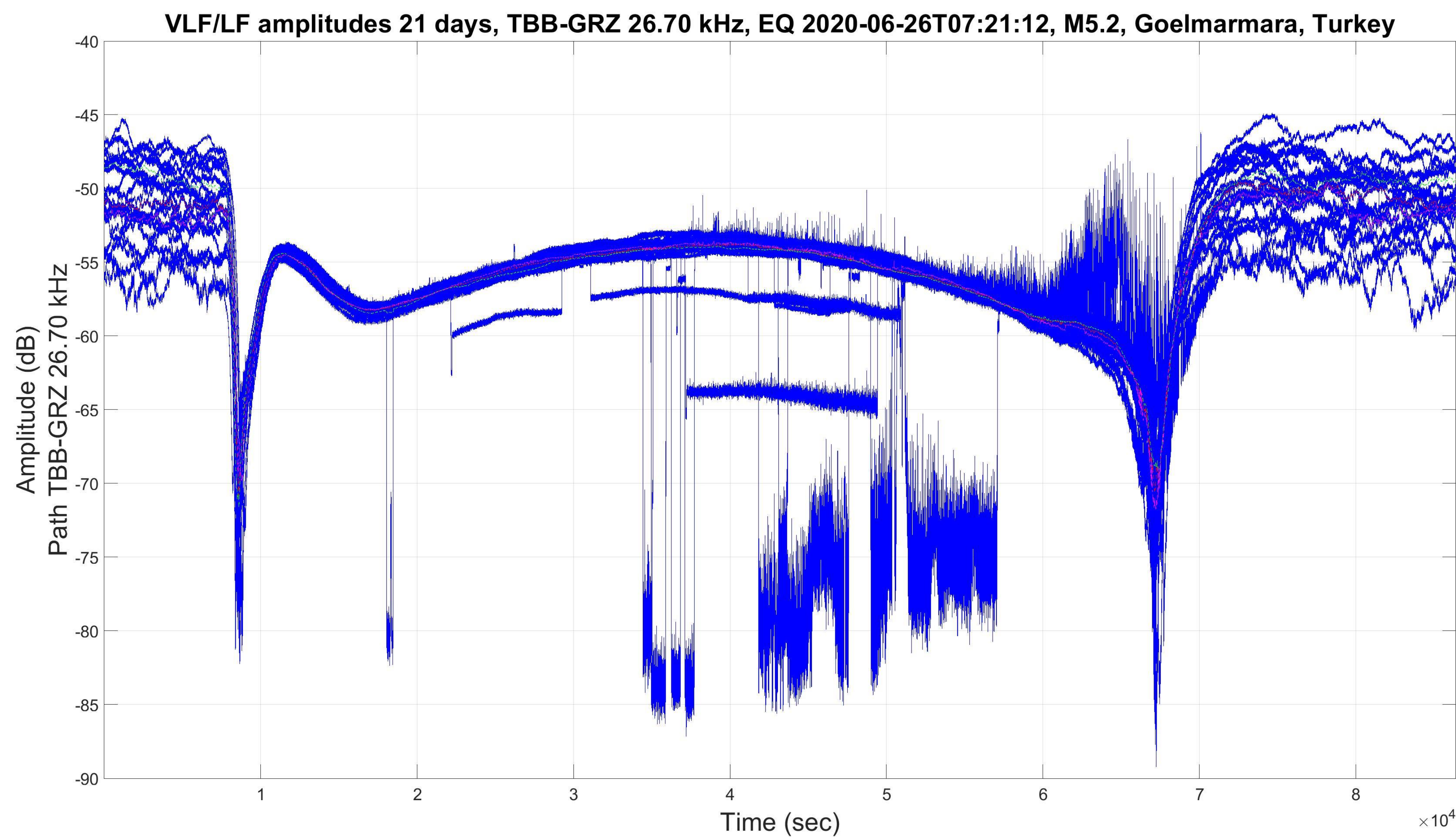
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VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2020-06-26, M5.2, GÖLMARMARA, TURKEY

- Top Left: VLF/LF amplitude measurements (2020-06-16 to 2020-07-06) for the 26.70 kHz TBB-GRZ path
- Bottom Left: Offset corrected nighttime (± 2 h around midnight) amplitude values for 7 paths
- Top Right: Nighttime amplitude values for the affected TBB-GRZ event path (within the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected nighttime amplitude values, 7 paths, significance criteria 5% not achieved



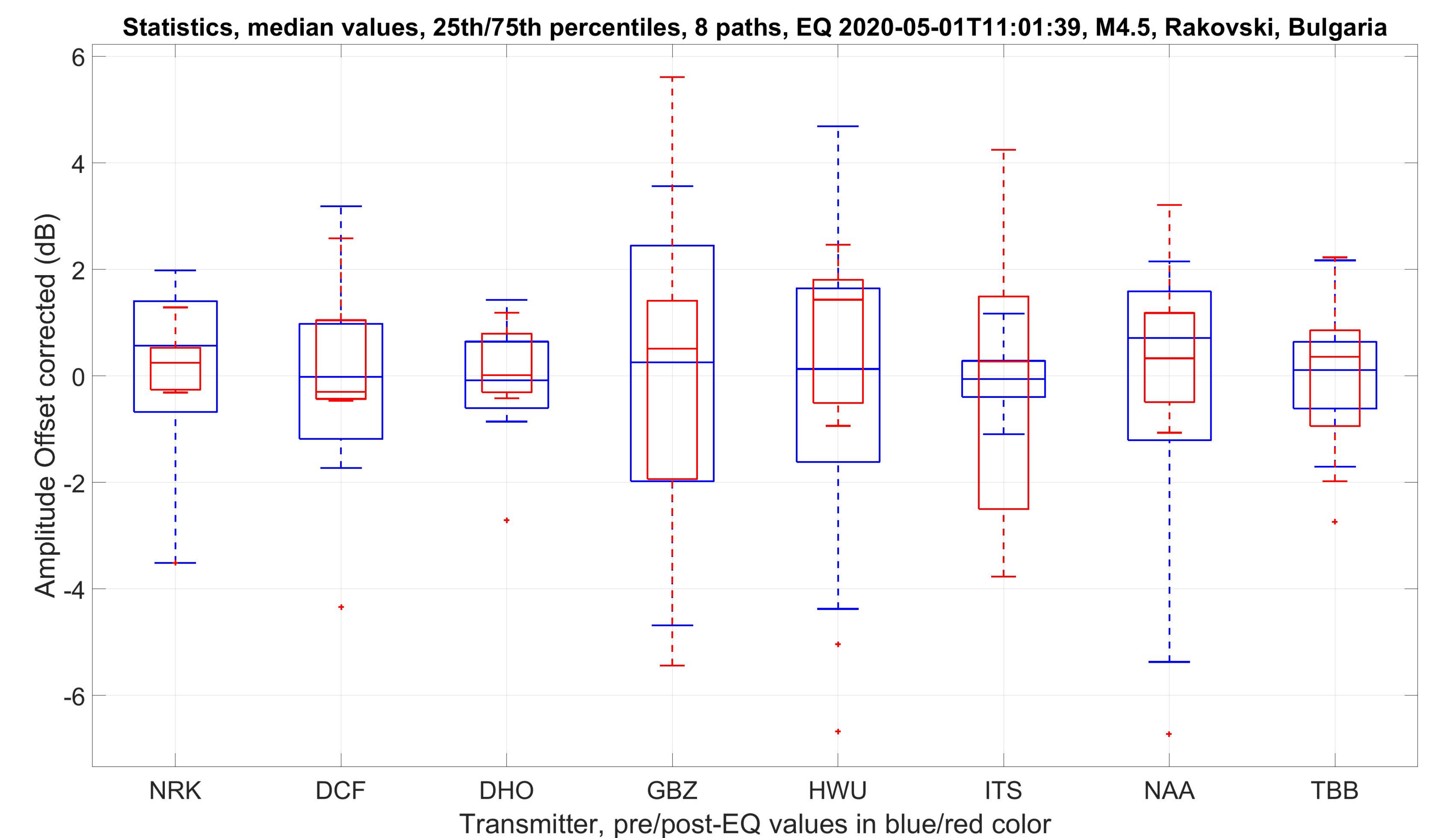
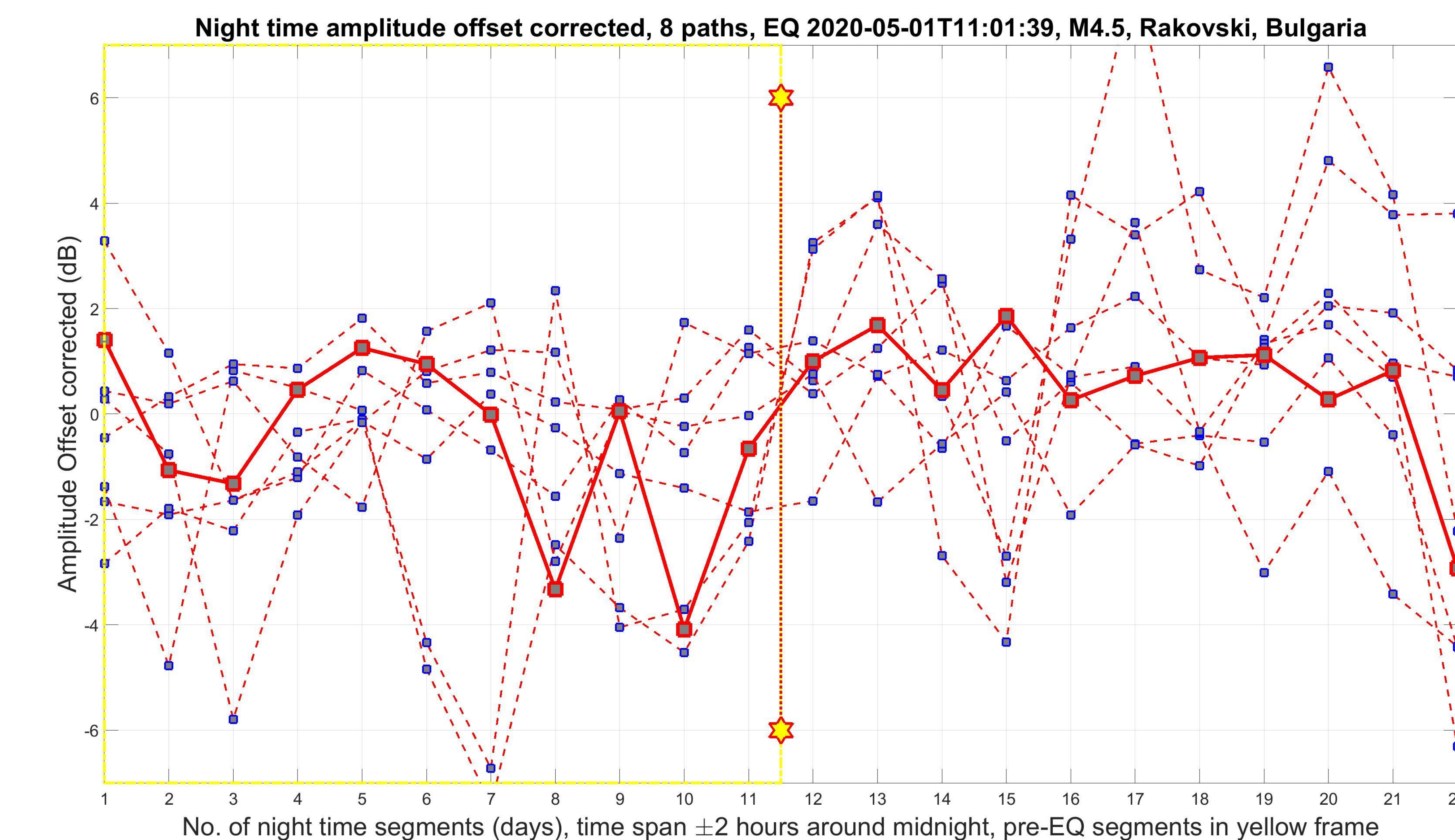
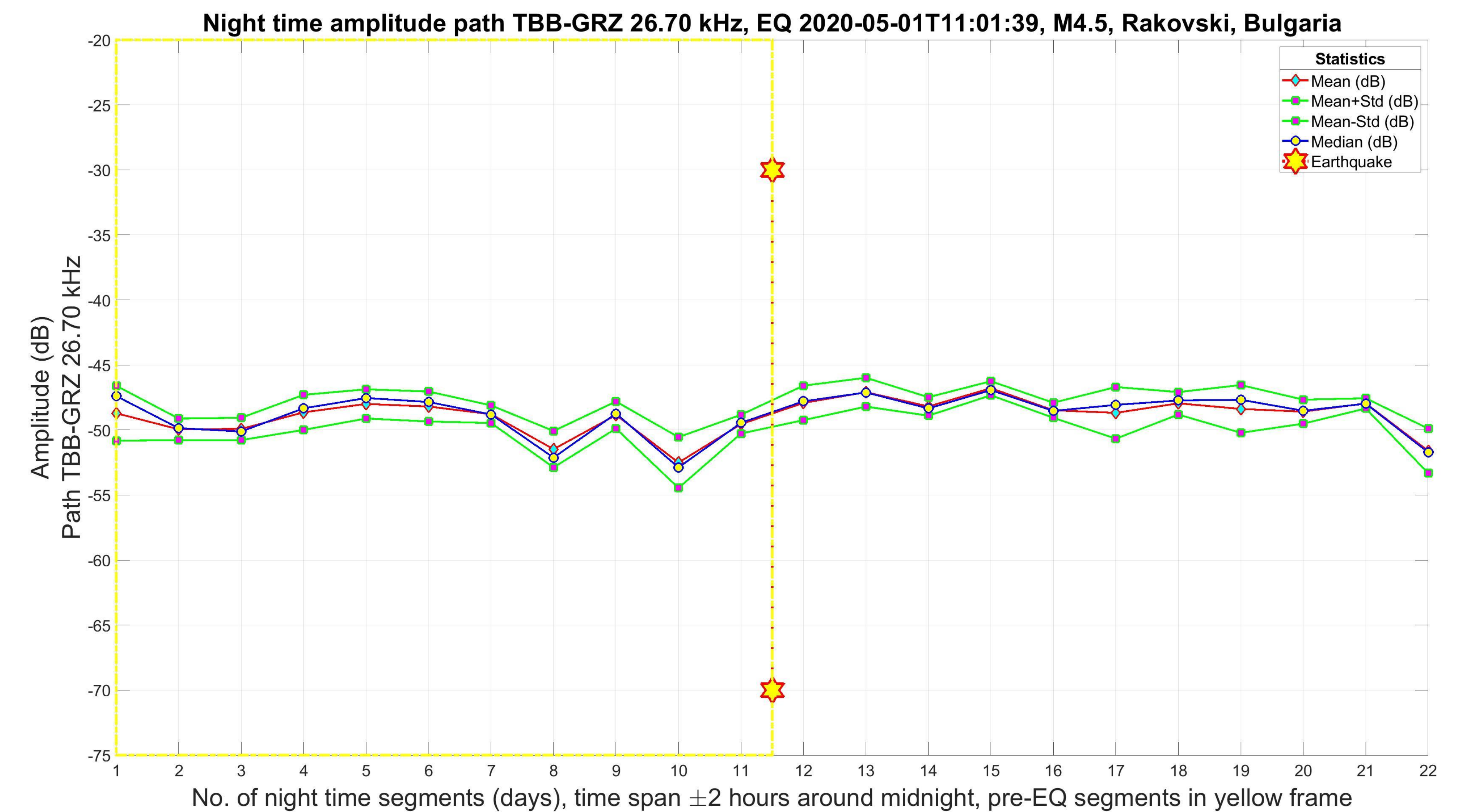
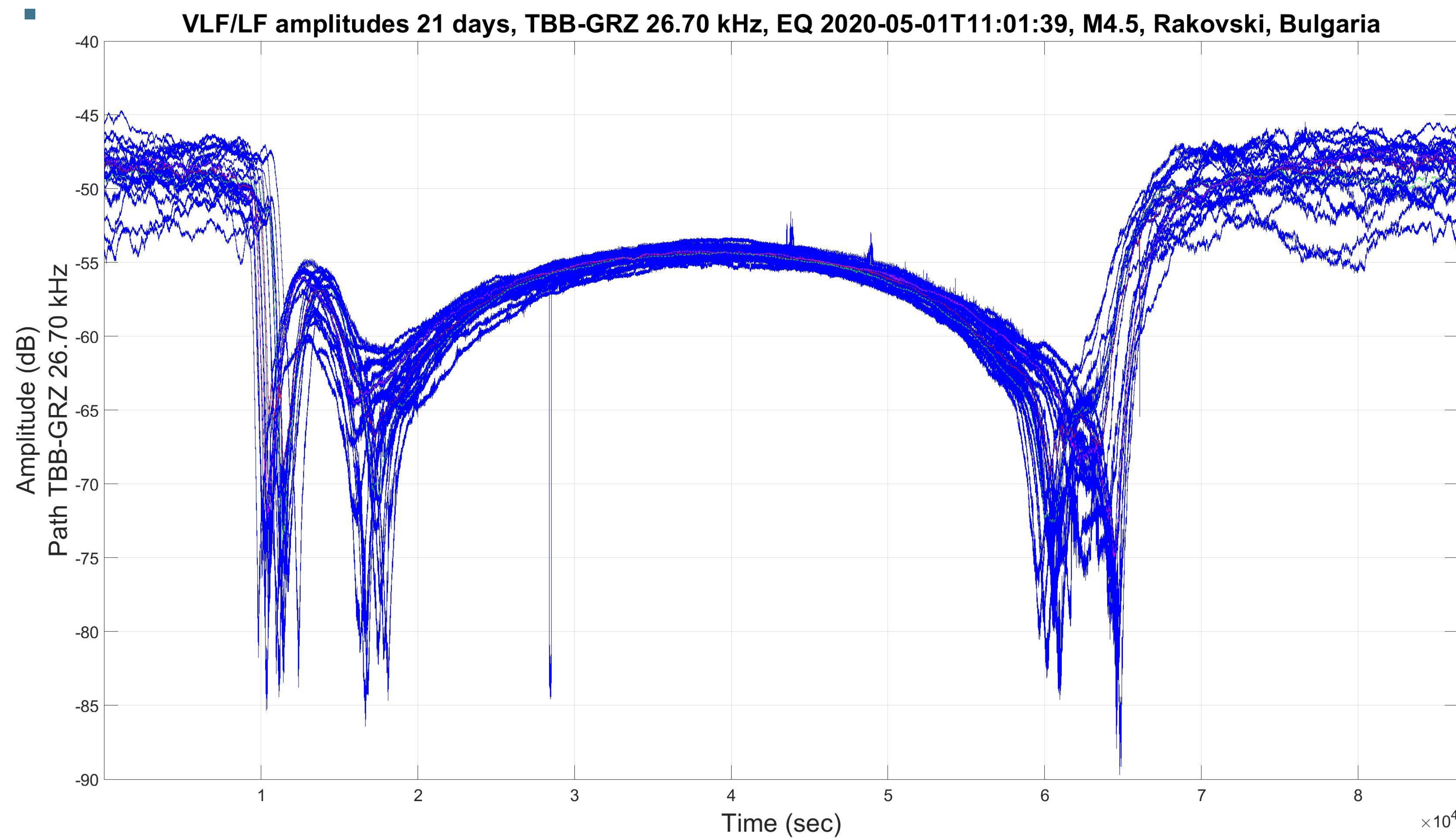
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VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2020-05-01, M4.5, RAKOVSKI, BULGARIA

- Top Left: VLF/LF amplitude measurements (2020-04-21 to 2020-05-11) for the 26.70 kHz TBB-GRZ path
- Bottom Left: Offset corrected nighttime (± 2 h around midnight) amplitude values, 8 paths
- Top Right: Nighttime amplitude values for the affected TBB-GRZ event path (within the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected nighttime amplitude values, 8 paths, four path ({TBB, ITS, HWU, GBZ}-GRZ) show variations with a significance level of 5%



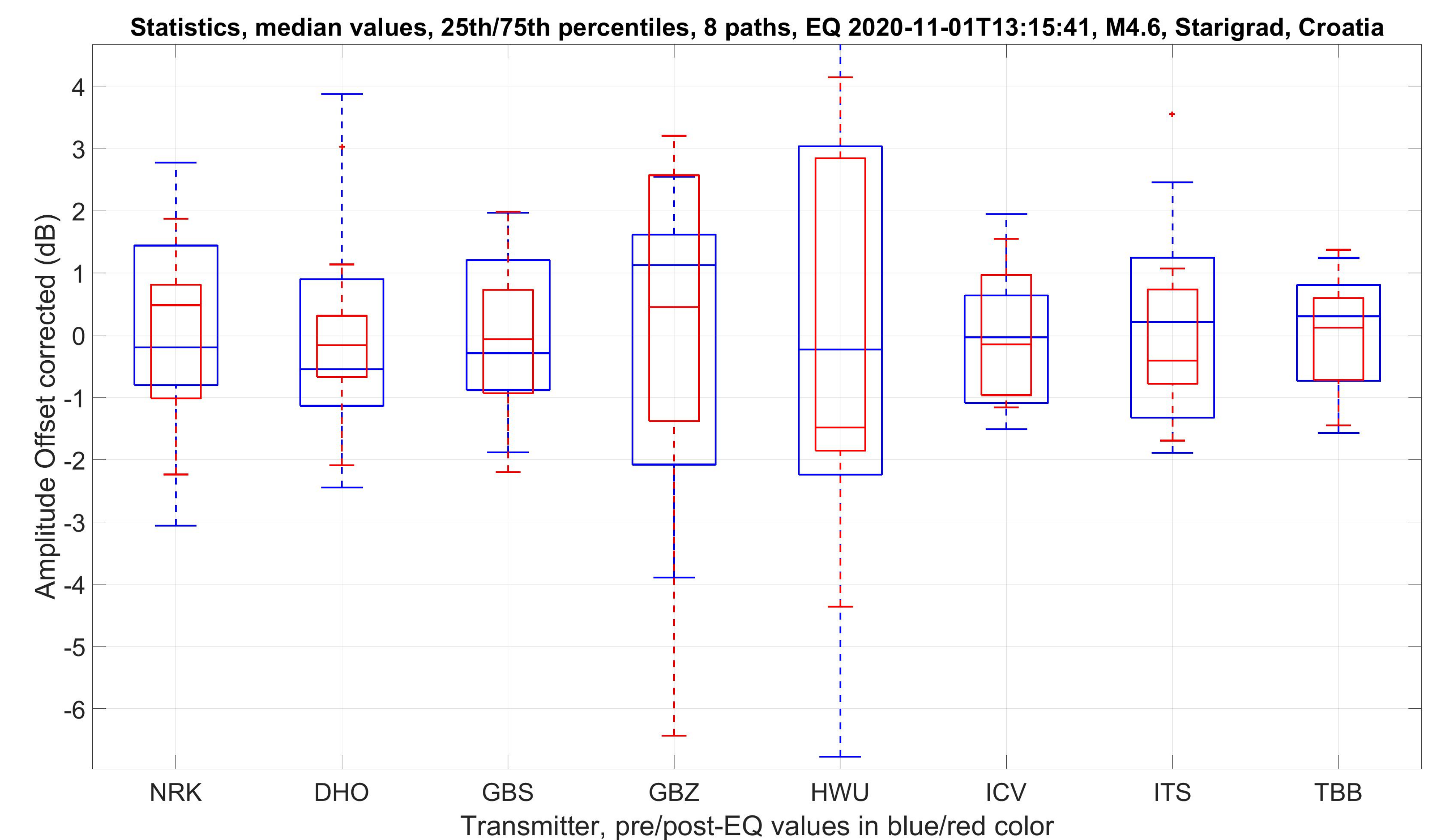
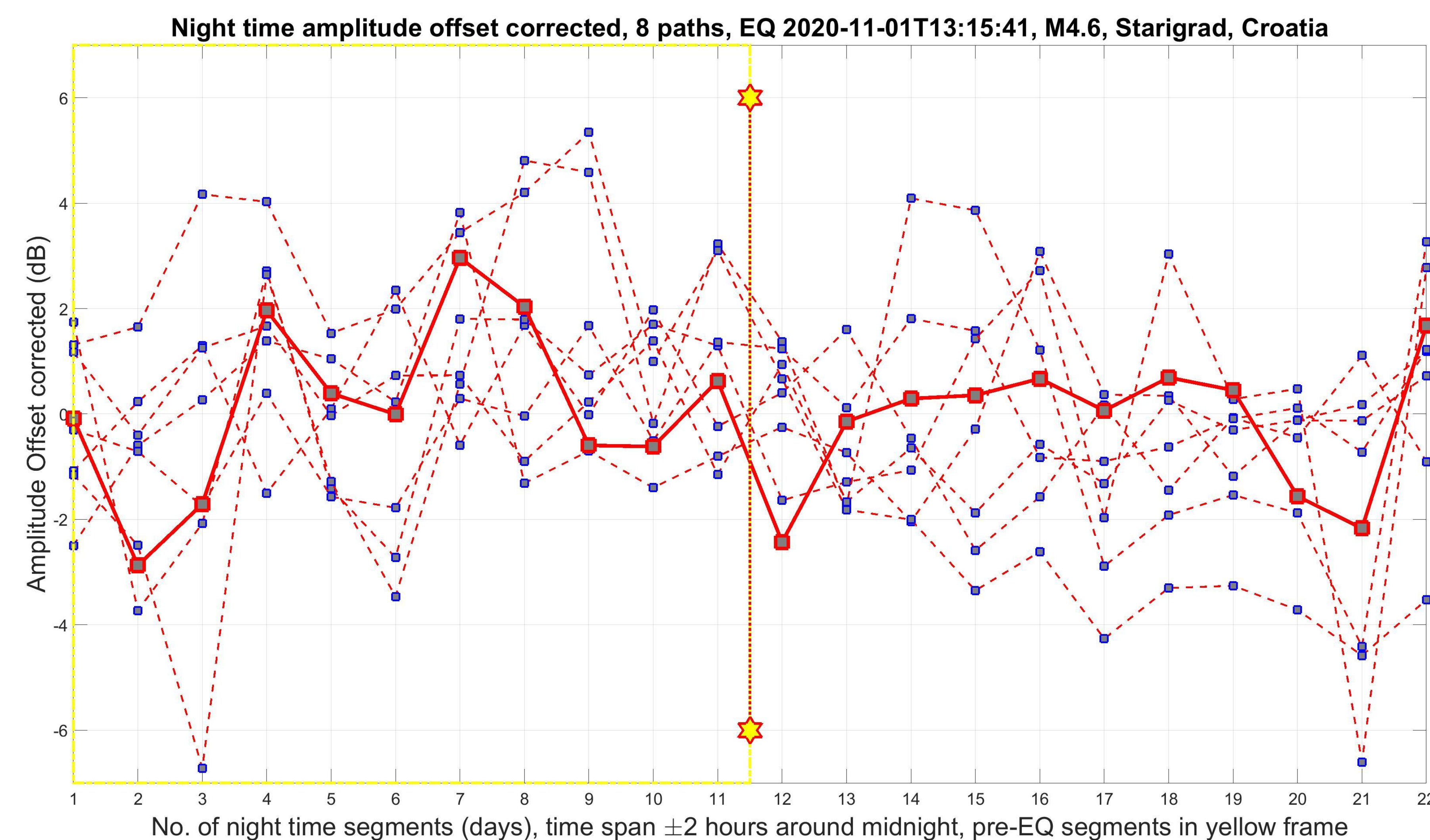
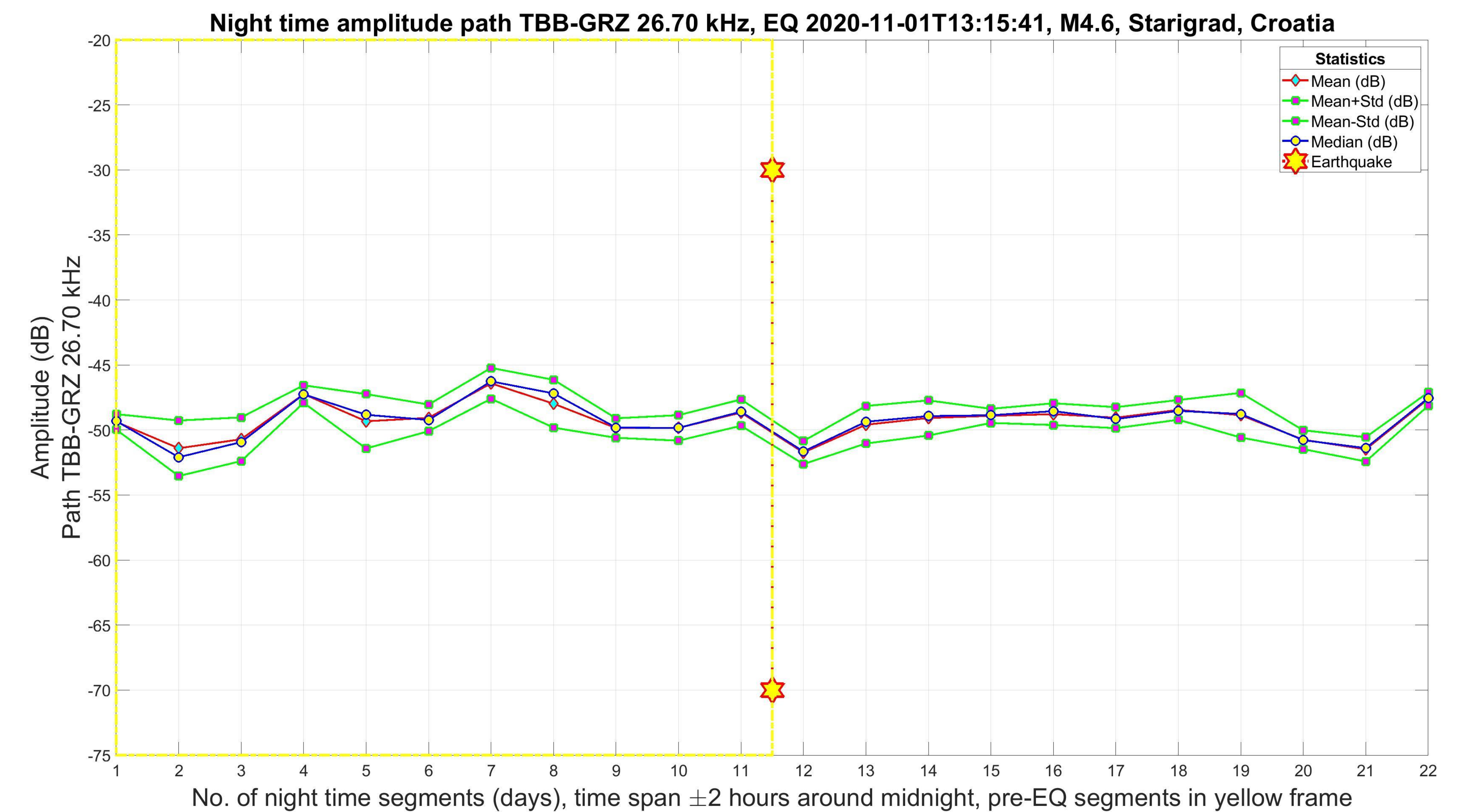
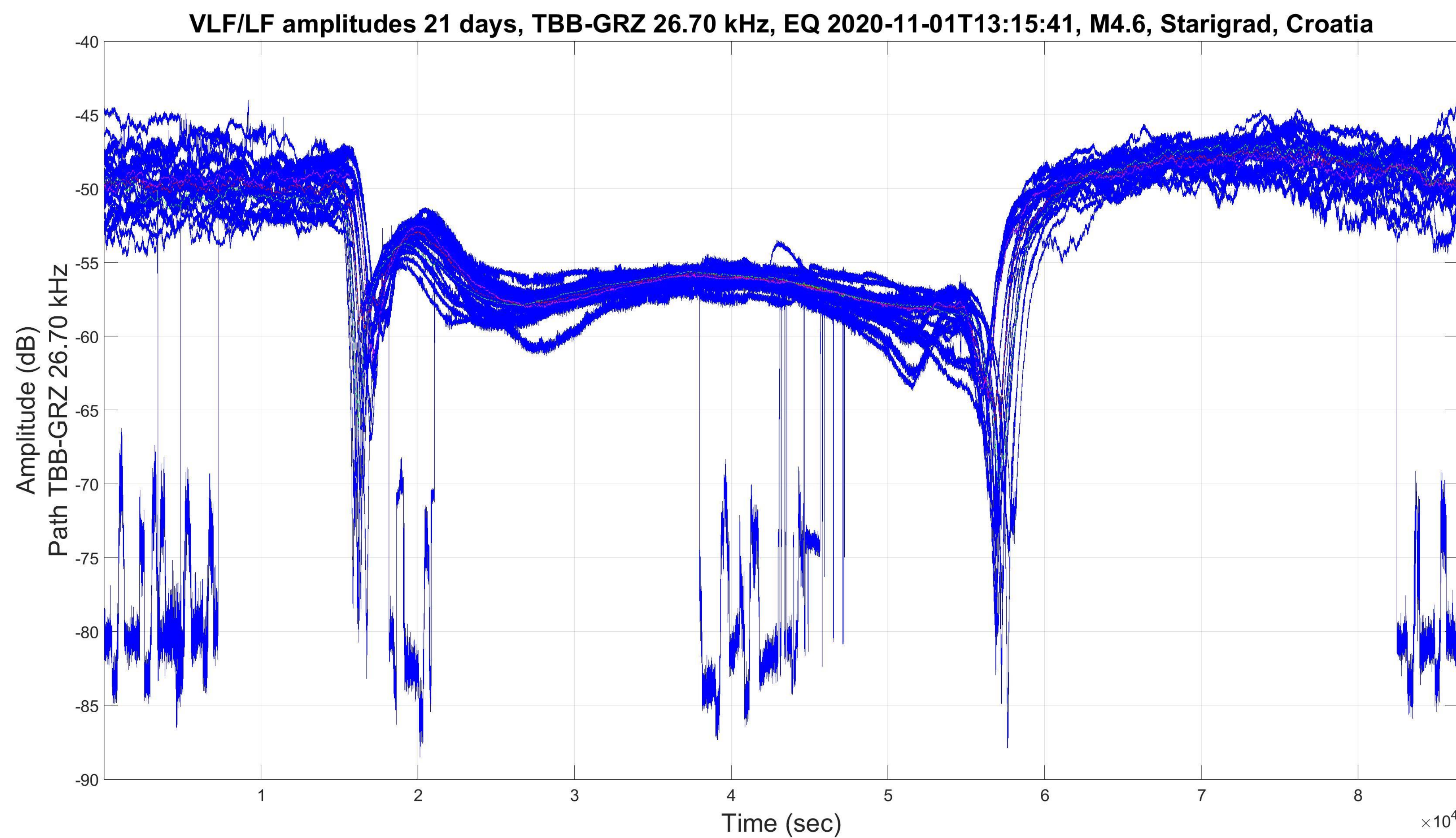
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VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2020-11-01, M4.6, STARIGRAD, CROATIA

- Top Left: VLF/LF amplitude measurements (2020-10-22 to 2020-11-11) for the 26.70 kHz TBB-GRZ path, the spikes and transmitter switch off periods during night are omitted for the analysis
- Bottom Left: Offset corrected nighttime (± 2 h around midnight) amplitude values for 8 paths
- Top Right: Nighttime amplitude values for the affected TBB-GRZ path (within the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected nighttime amplitude values, 8 paths, significance criteria 5% not achieved



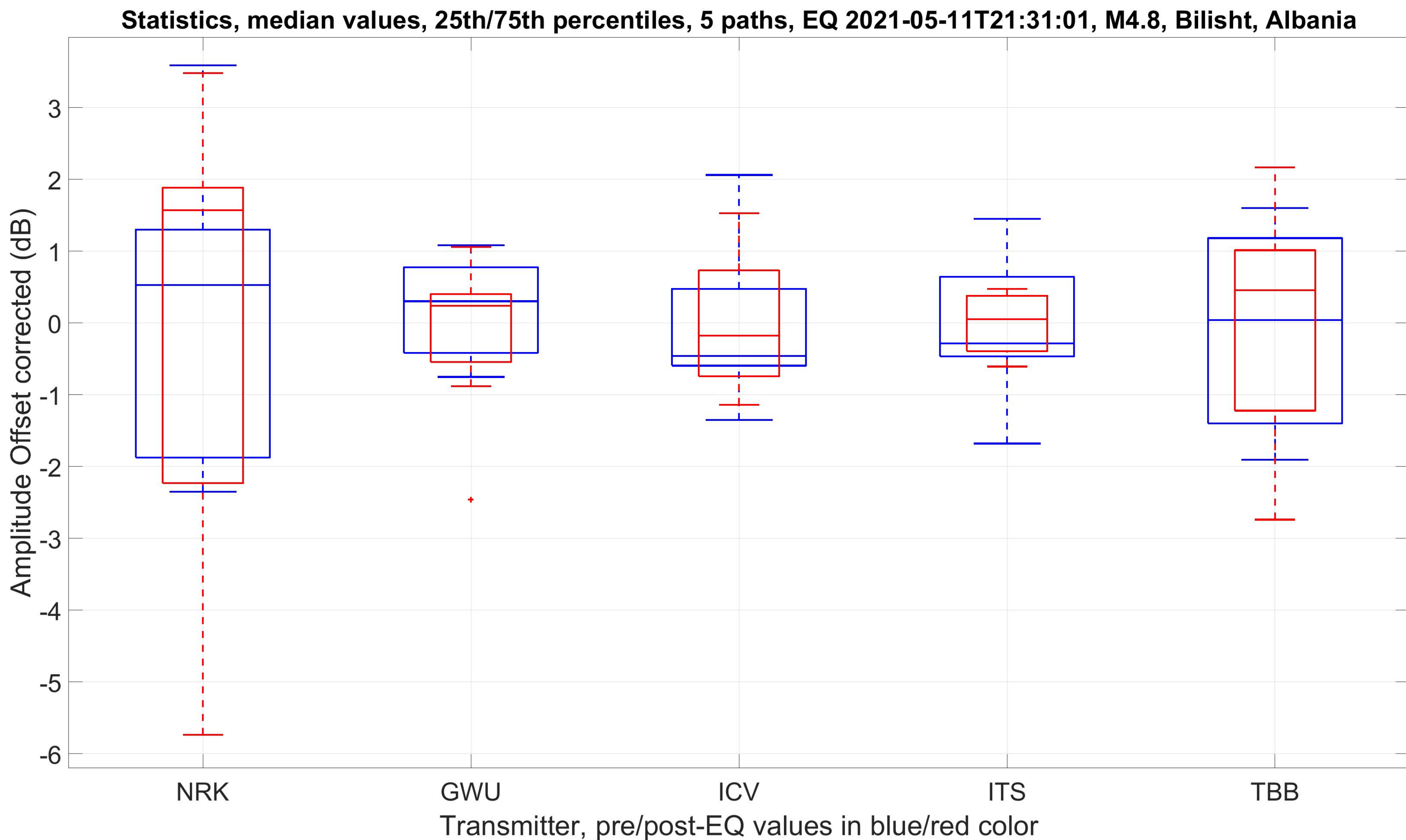
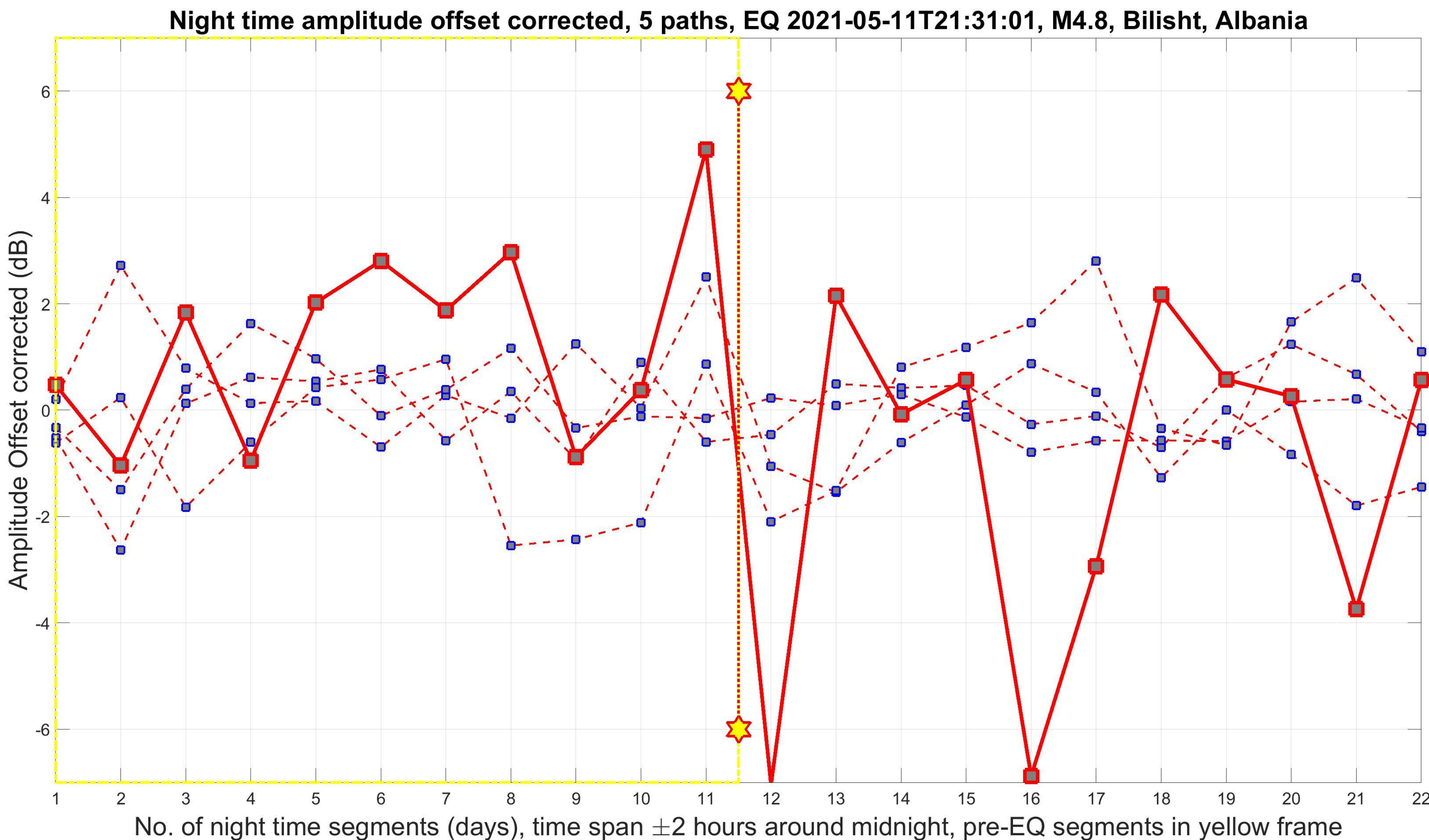
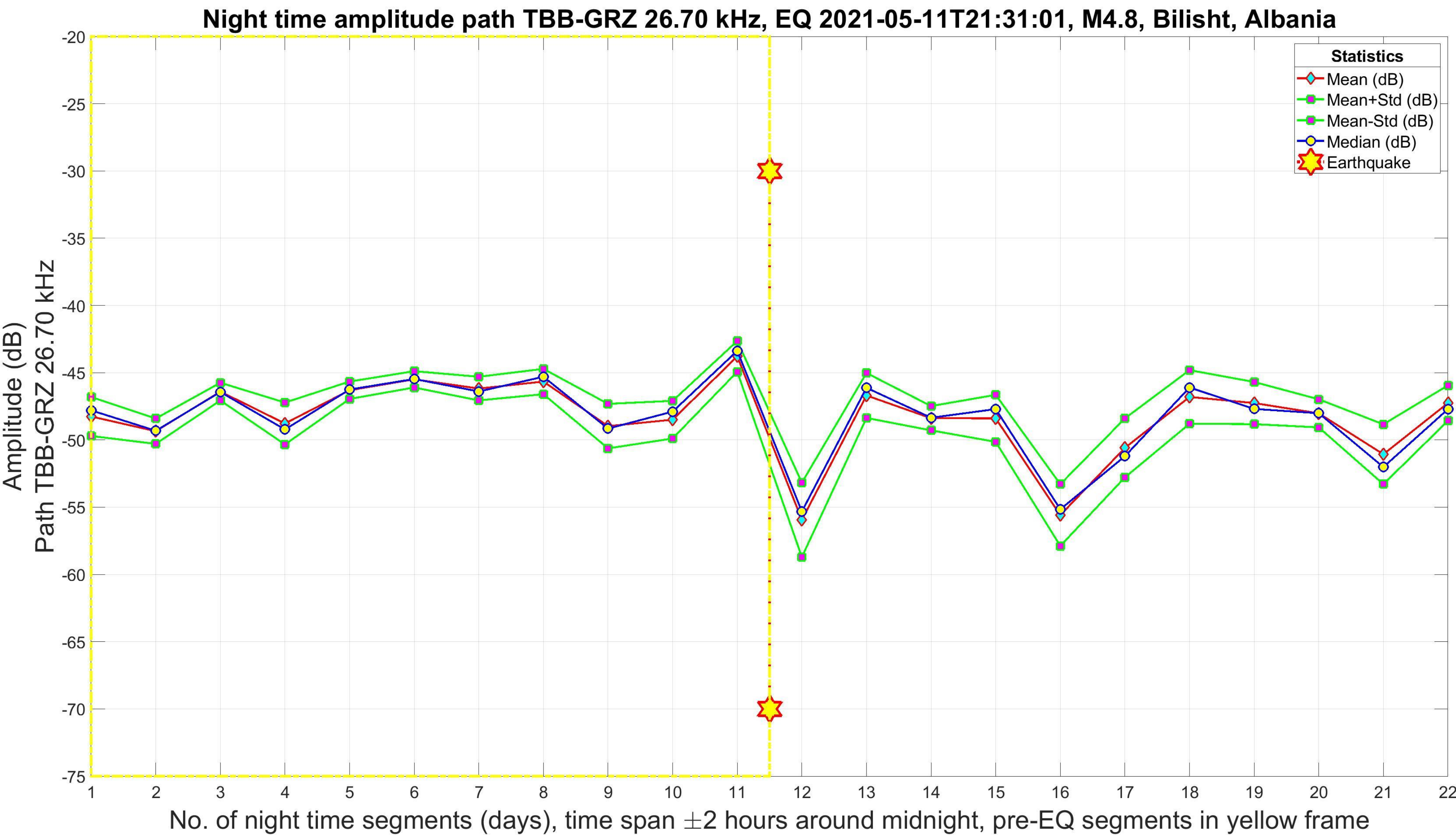
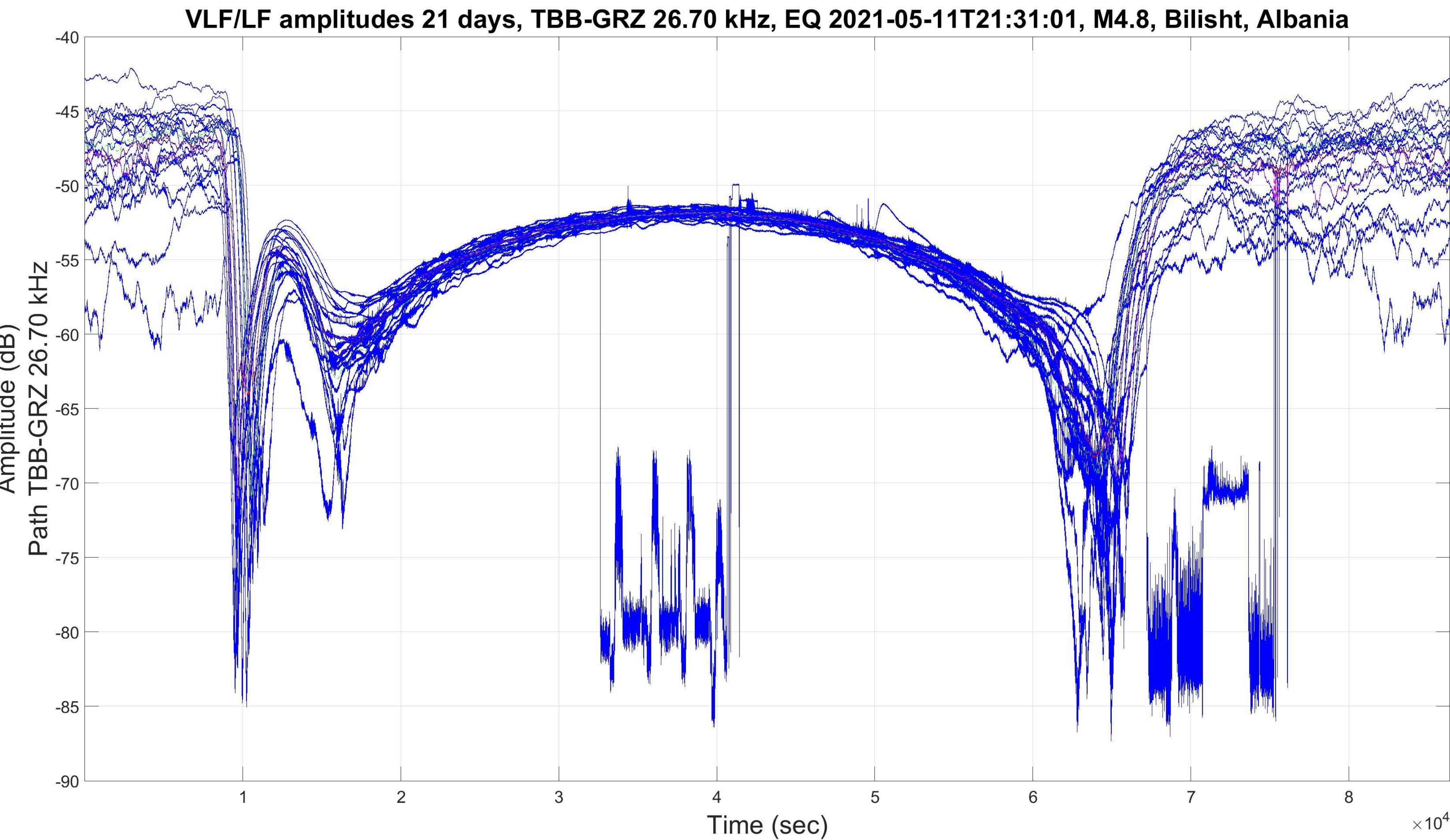
IONOSPHERIC PERTURBATIONS RELATED TO SEISMICITY AND VOLCANIC ERUPTIONS INFERRED FROM VLF/LF ELECTRIC FIELD MEASUREMENTS

Hans Eichelberger¹, Konrad Schwingenschuh¹, Mohammed Y. Boudjada¹, Bruno P. Besser¹, Daniel Wolbang¹, Maria Solovieva², Pier Francesco Biagi³, Manfred Stachel¹, Özer Aydogar¹, Christoph Schirninger¹, Cosima Muck¹, Claudia Grill¹, and Irmgard Jernej¹

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VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2021-05-11, M4.8, BILISHT, ALBANIA

- Top Left: VLF/LF amplitude measurements (2021-05-01 to 2021-05-21) for the 26.70 kHz TBB-GRZ path, the spikes and transmitter switch off periods during night are omitted for the analysis
- Bottom Left: Offset corrected nighttime (± 2 h around midnight) amplitude values for 5 paths
- Top Right: Nighttime amplitude values for the TBB-GRZ event path (within the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected nighttime amplitude values, 5 paths, only a control path (NRK-GRZ) shows variations with a significance level of 5%



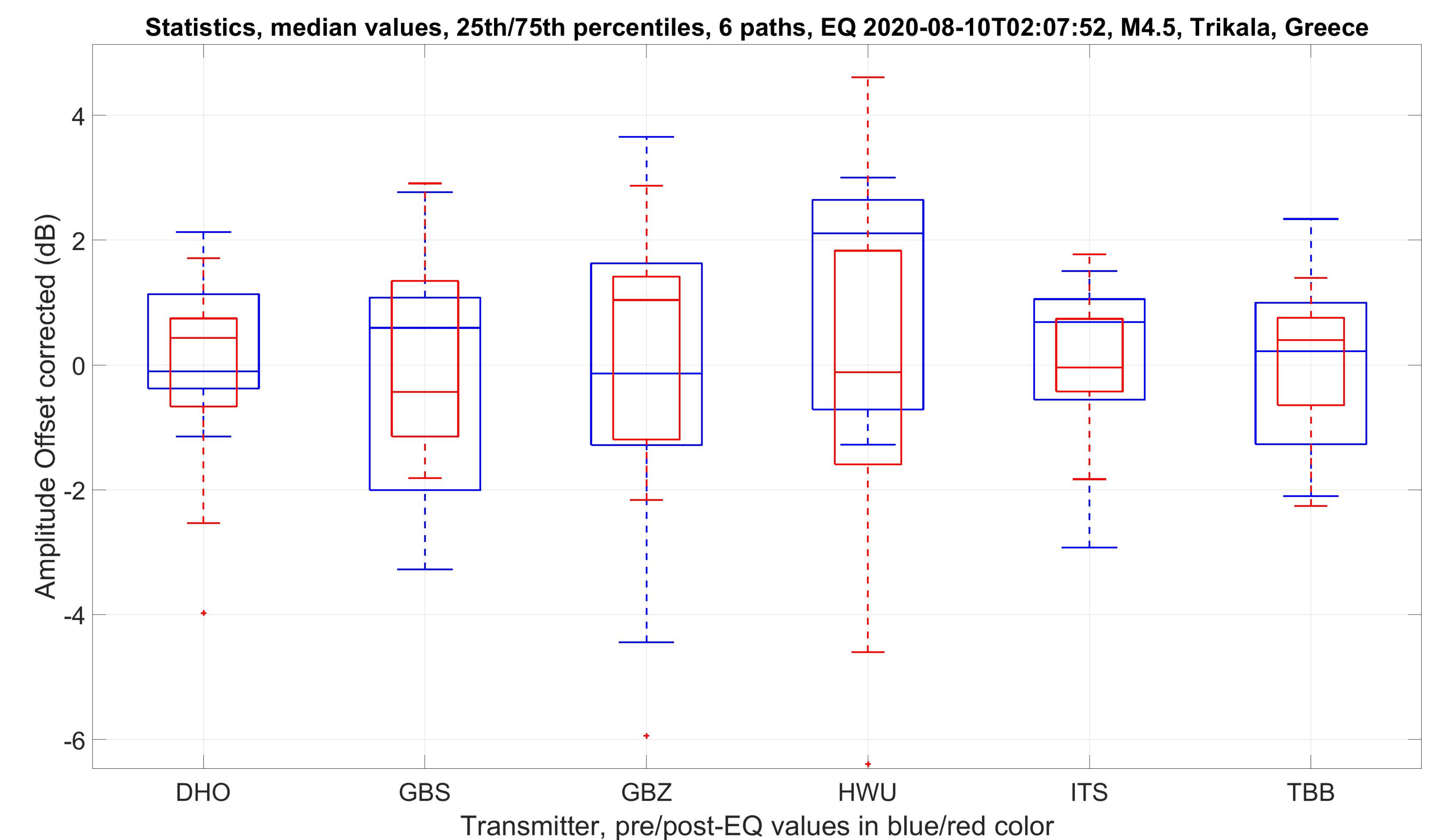
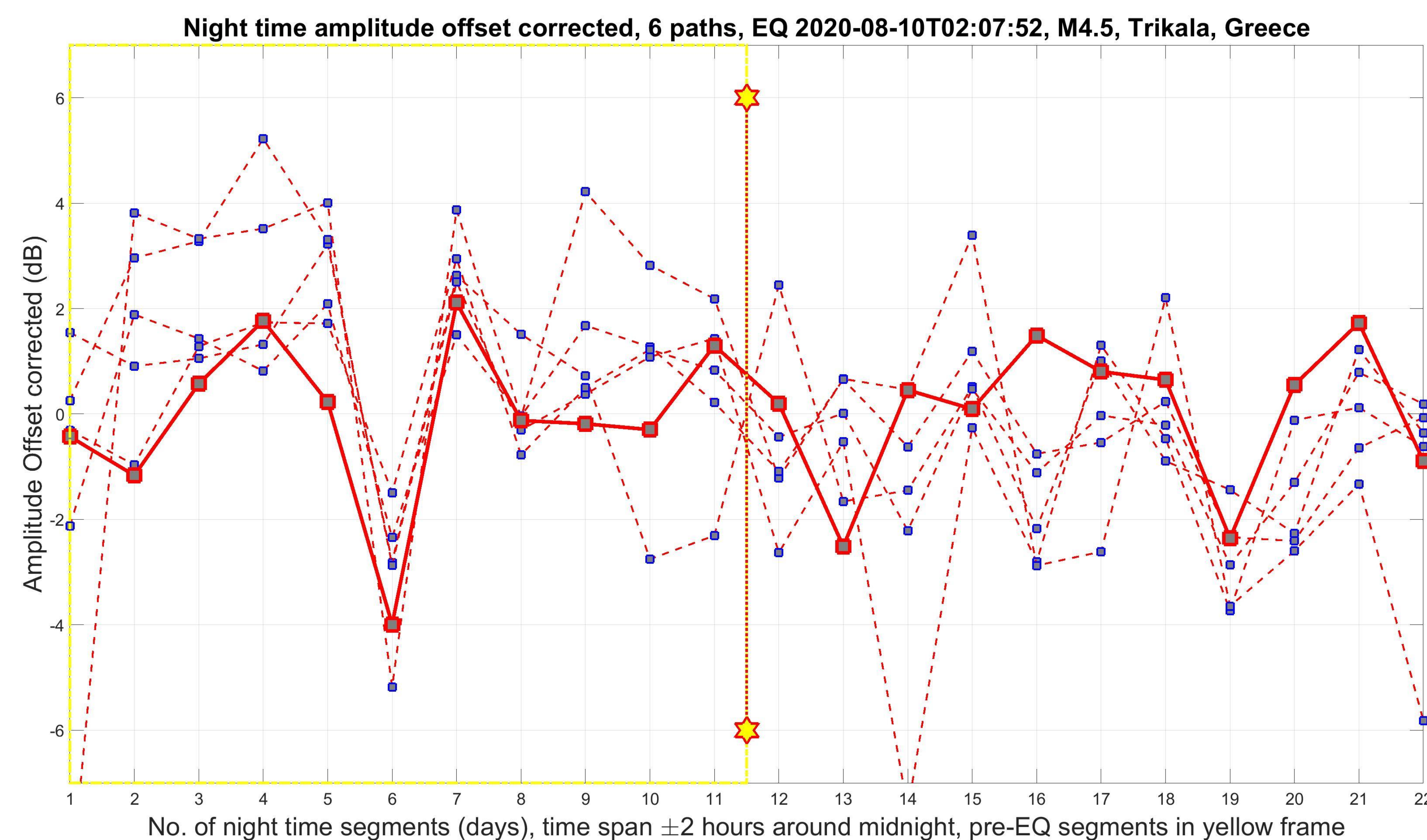
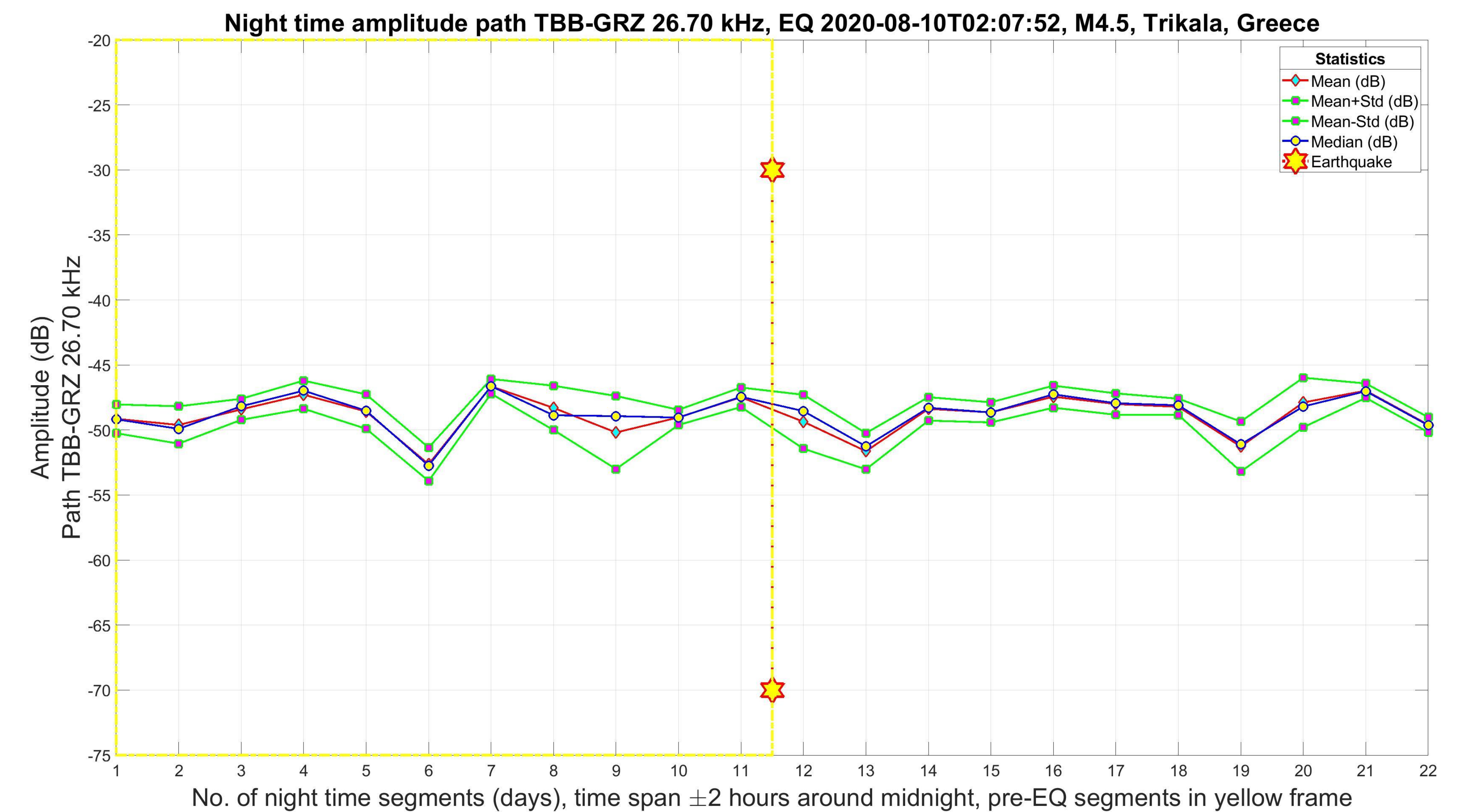
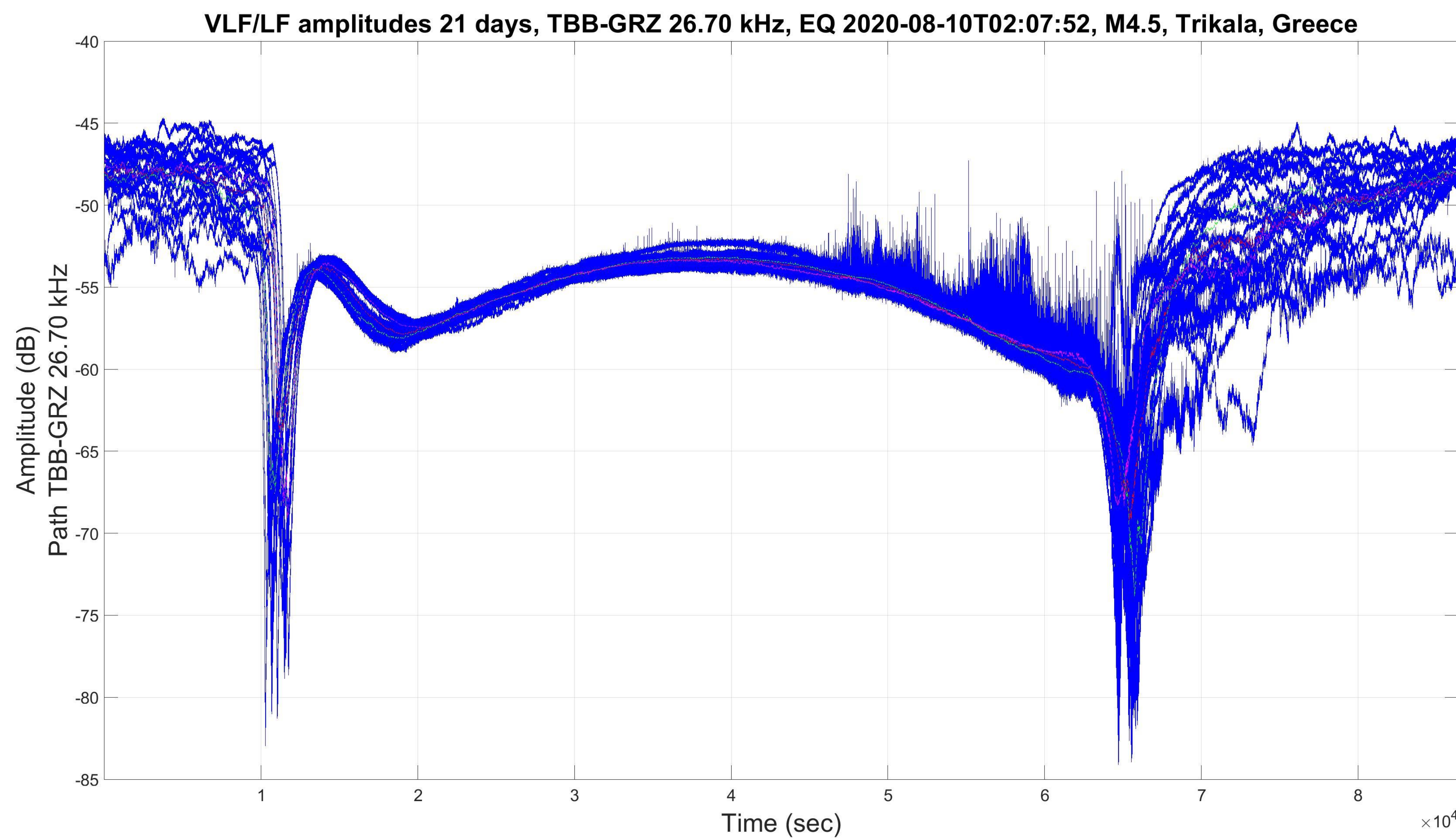
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Hans Eichelberger¹, Konrad Schwingenschuh¹, Mohammed Y. Boudjada¹, Bruno P. Besser¹, Daniel Wolbang¹, Maria Solovieva², Pier Francesco Biagi³, Manfred Stachel¹, Özer Aydogar¹, Christoph Schirninger¹, Cosima Muck¹, Claudia Grill¹, and Irmgard Jernej¹

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VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2020-08-10, M4.5, TRIKALA, GREECE

- Top Left: VLF/LF amplitude measurements (2020-07-31 to 2020-08-20) for the 26.70 kHz TBB-GRZ path
- Bottom Left: Offset corrected nighttime (± 2 h around midnight) amplitude values for 6 paths
- Top Right: Nighttime amplitude values for the affected TBB-GRZ event path (within the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected nighttime amplitude values, 6 paths, significance criteria 5% not achieved



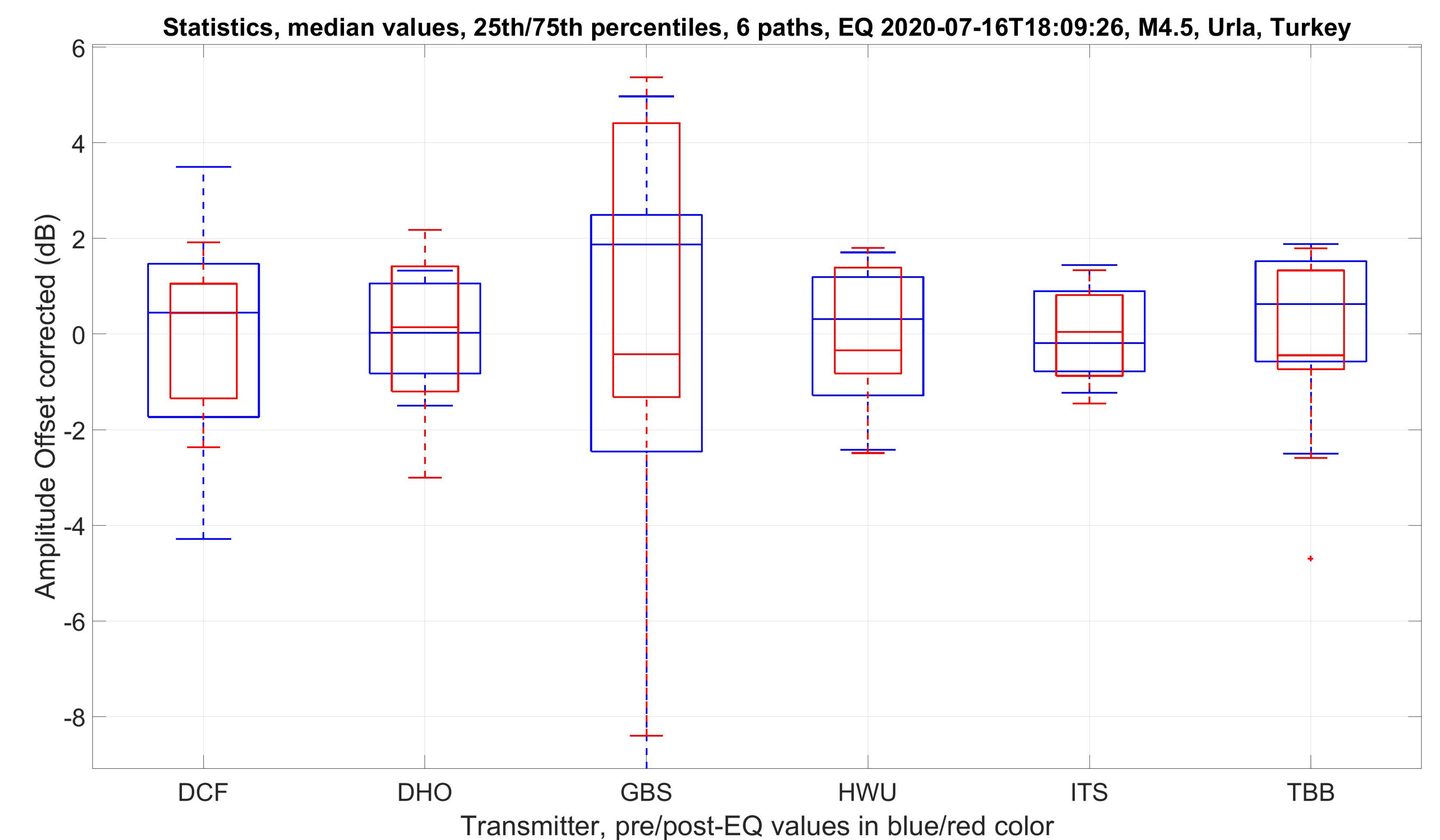
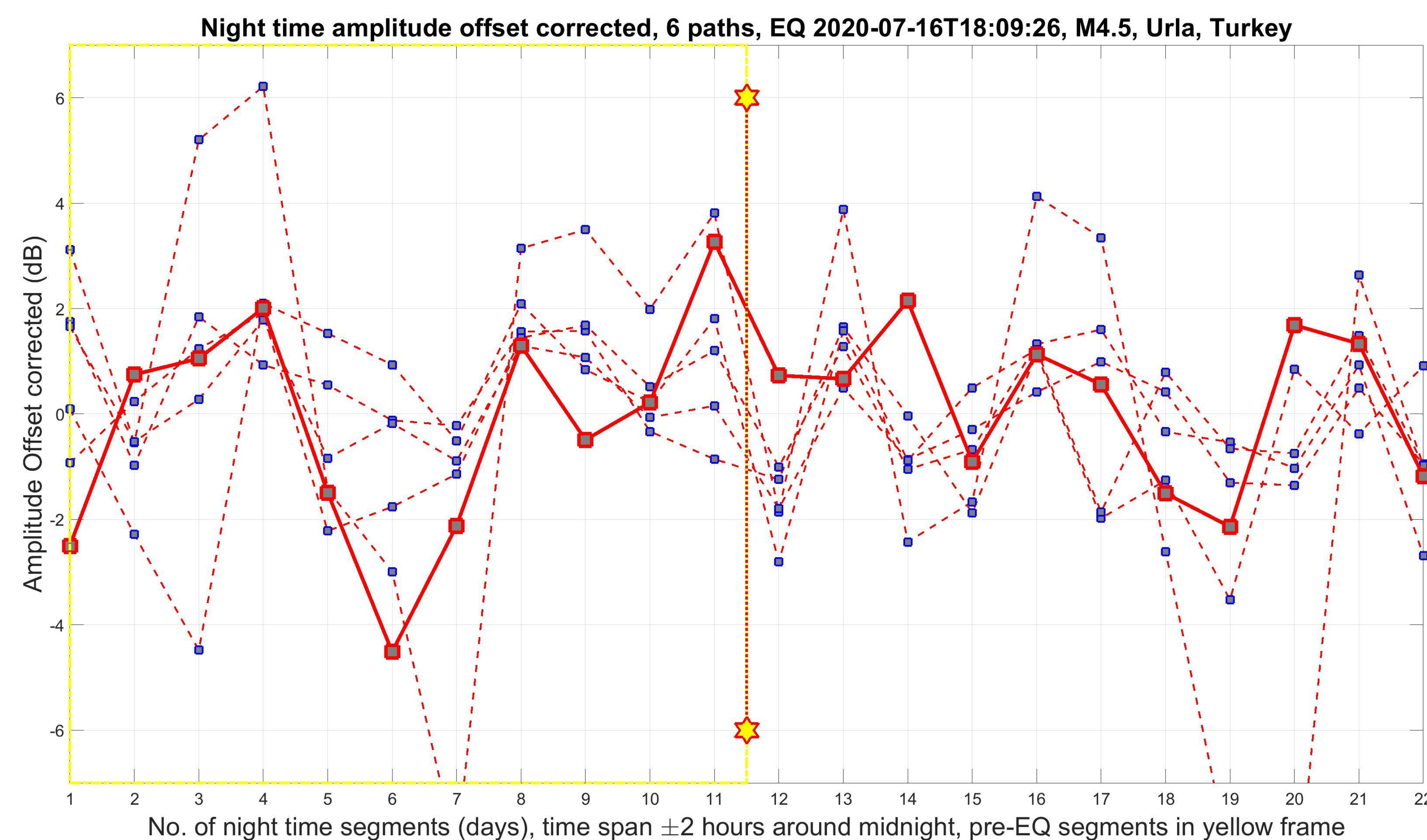
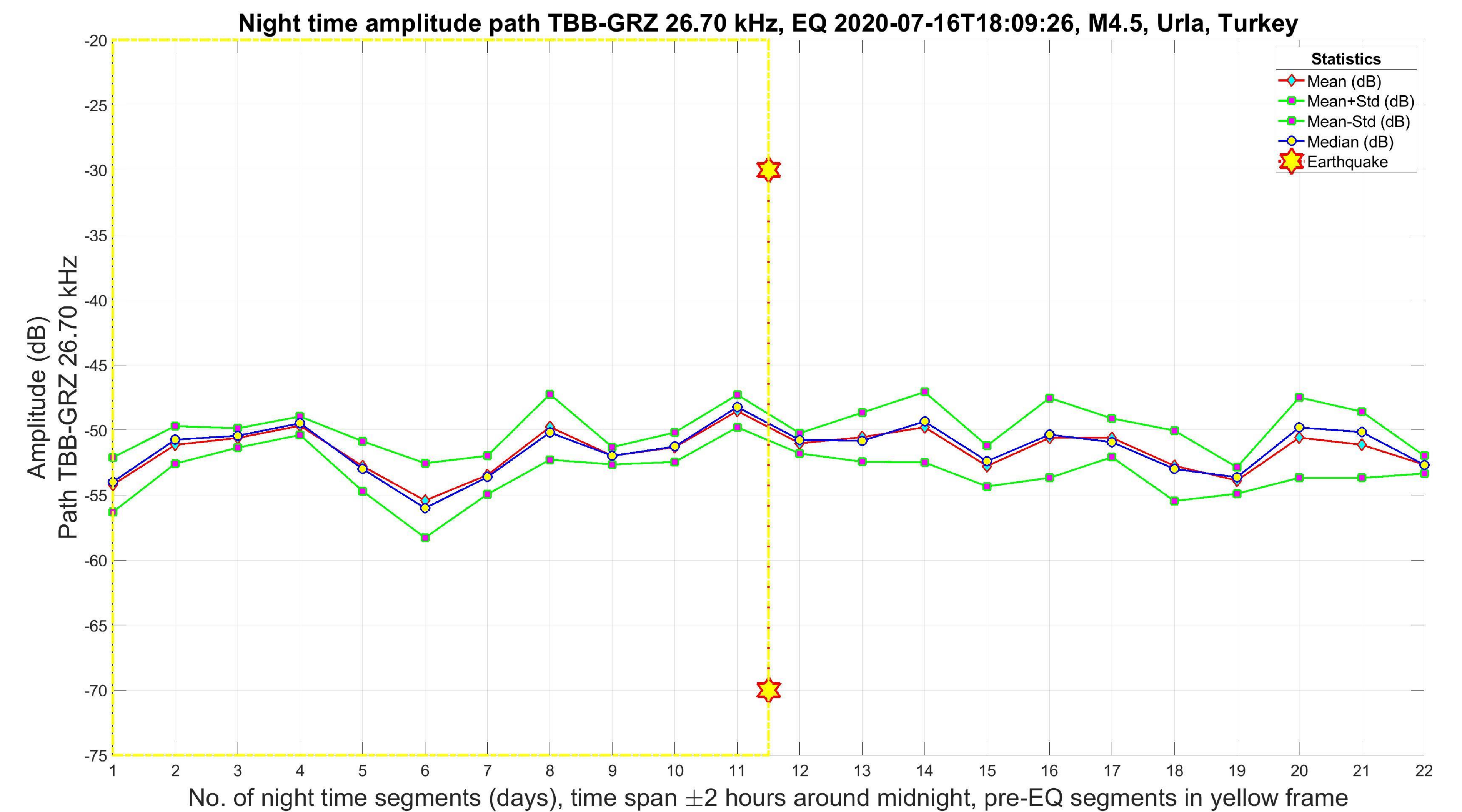
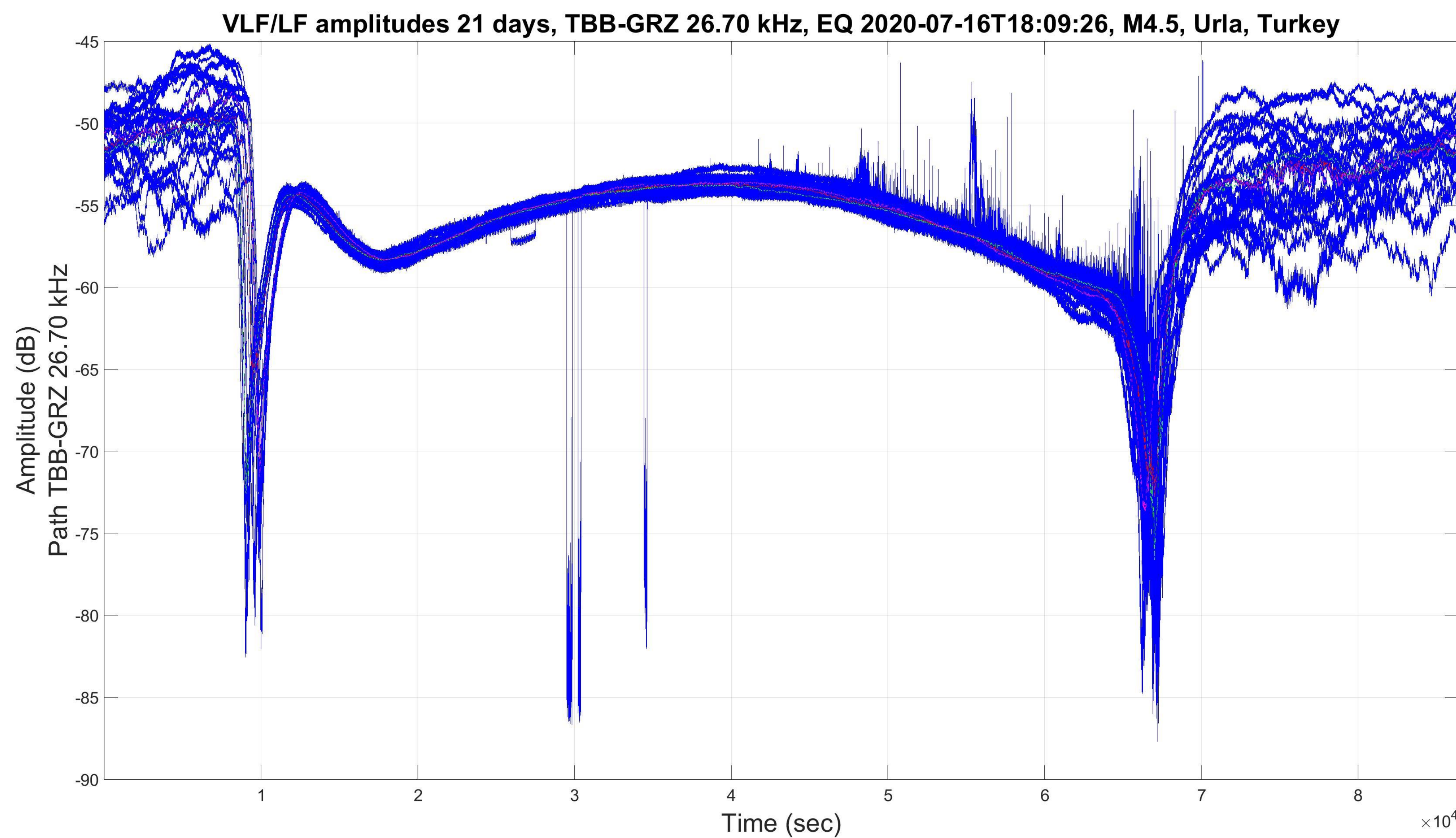
IONOSPHERIC PERTURBATIONS RELATED TO SEISMICITY AND VOLCANIC ERUPTIONS INFERRED FROM VLF/LF ELECTRIC FIELD MEASUREMENTS

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VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2020-07-16, M4.5, URLA, TURKEY

- Top Left: VLF/LF amplitude measurements (2020-07-06 to 2020-07-26) for the 26.70 kHz TBB-GRZ path
- Bottom Left: Offset corrected nighttime (± 2 h around midnight) amplitude values for 6 paths
- Top Right: Nighttime amplitude values for the TBB-GRZ event path (within the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for the offset corrected nighttime amplitude values, 6 paths, significance criteria 5% not achieved



IONOSPHERIC PERTURBATIONS RELATED TO SEISMICITY AND VOLCANIC ERUPTIONS INFERRED FROM VLF/LF ELECTRIC FIELD MEASUREMENTS

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VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2020-11-05, M4.9, SYKIA, GREECE

- Top Left: VLF/LF amplitude measurements (2020-10-26 to 2020-11-15) for the 26.70 kHz TBB-GRZ path, the spikes and transmitter switch off periods during night are omitted for the analysis
- Bottom Left: Offset corrected nighttime (± 2 h around midnight) amplitude values for 9 paths
- Top Right: Nighttime amplitude values for the affected TBB-GRZ event path (within the Dobrovolsky-Bowman area/radius)
- Bottom Right: Statistics (box plots) for offset corrected nighttime amplitude values, 9 paths, only one control path (ITS-GRZ) shows variations with a significance level of 5%

