



SYNOPTIC VIEW ON SUB-IONOSPHERIC VLF/LF AMPLITUDE AND PHASE VARIATIONS AT THE GRAZ SEISMO-ELECTROMAGNETIC FACILITY

Hans Eichelberger¹, Konrad Schwingenschuh¹, Mohammed Y. Boudjada¹, Bruno P. Besser¹, Daniel Wolbang¹, Maria Solovieva², Pier Francesco Biagi³, Manfred Stachel¹, Özer Aydogar¹, Martin Pitterle¹, Cosima Muck¹, Claudia Grill¹, and Irmgard Jernej¹

¹Space Research Institute, Austrian Academy of Sciences, Graz, Austria, ²Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, ³Department of Physics, University of Bari, Bari, Italy

This presentation discusses physical processes related to potentially seismic and non-seismic disturbances along VLF/LF paths measured with two different receivers located side by side at the Space Research Institute (IWF) facility in Graz, Austria. At the same time both systems are embedded in international networks which gives the unique opportunity to probe the waveguide cavity over a large area. In general, a variety of VLF/LF amplitude and phase variations are ubiquitous at wide scales throughout the cavity. We analyse such signals observed in the period 2018-2020 (solar minimum, i.e. less external forcing of the upper ionospheric boundary) in the time- and frequency-domain for several paths. In this attempt we aim to single out natural disturbances, characterise the source event, and figure out the lithosphere atmosphere ionosphere coupling mechanism. For known seismic events we consider the so-called Dobrovolsky Bowman relationship (Dobrovolsky et al, 1979; Bowman et al, 1998) allowing to estimate the pre-seismic zone crossed by the VLF/LF paths. The findings open up good prospects for an automated monitoring and characterisation of source phenomena who affect the electric field of VLF/LF sub-ionospheric links.

LIST OF EVENTS & DATA PROCESSING

The period of investigation is 3 years, from Jan. 1, 2018 to Jan. 1, 2021, in the geographical latitude/longitude range $[30^\circ \leq \text{lat} \leq 50^\circ]$ and $[10^\circ \leq \text{long} \leq 40^\circ]$, i.e. roughly a wider Southeast Europe area which is covered by sub-ionospheric VLF/LF propagation paths. For this temporal, spatial, and also moment magnitude $M_w \geq 5.5$ constraints the United States Geological Survey (USGS) earthquake database <https://earthquake.usgs.gov/> (as of April 2021) gives 25 earthquakes. From this list 4 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 $q = 10^{(0.43 \cdot M)}$ km and $\log(R) \approx M/2$ km).

Selected Earthquakes, USGS database, time span 01.01.2018 – 01.01.2021, long/lat range: $[10^\circ\text{--}40^\circ]/[30^\circ\text{--}50^\circ]$				
No.	Date, Time	Long (°) / Lat (°) / Depth (km)	Mag / ρ (km)	Location
1	2020-12-29T11:19:54.762	+45.42 / +16.26 / 10.0	6.4 / 565	Petrinja, Croatia
2	2020-10-30T11:51:27.348	+37.90 / +26.78 / 21.0	7.0 / 1023	Néon Karlovásion, Greece
3	2019-08-08T11:25:31.104	+37.94 / +29.70 / 11.0	5.9 / 344	Baklan, Turkey
4	2019-03-20T06:34:27.835	+37.41 / +29.53 / 8.0	5.7 / 282	Acipayam, Turkey

Table 1: Selected earthquakes (and Figure 1, stars in yellow color).

The VLF/LF amplitude data have 1 Hz temporal resolution and 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.

VLF/LF NETWORK, EUROPEAN AREA

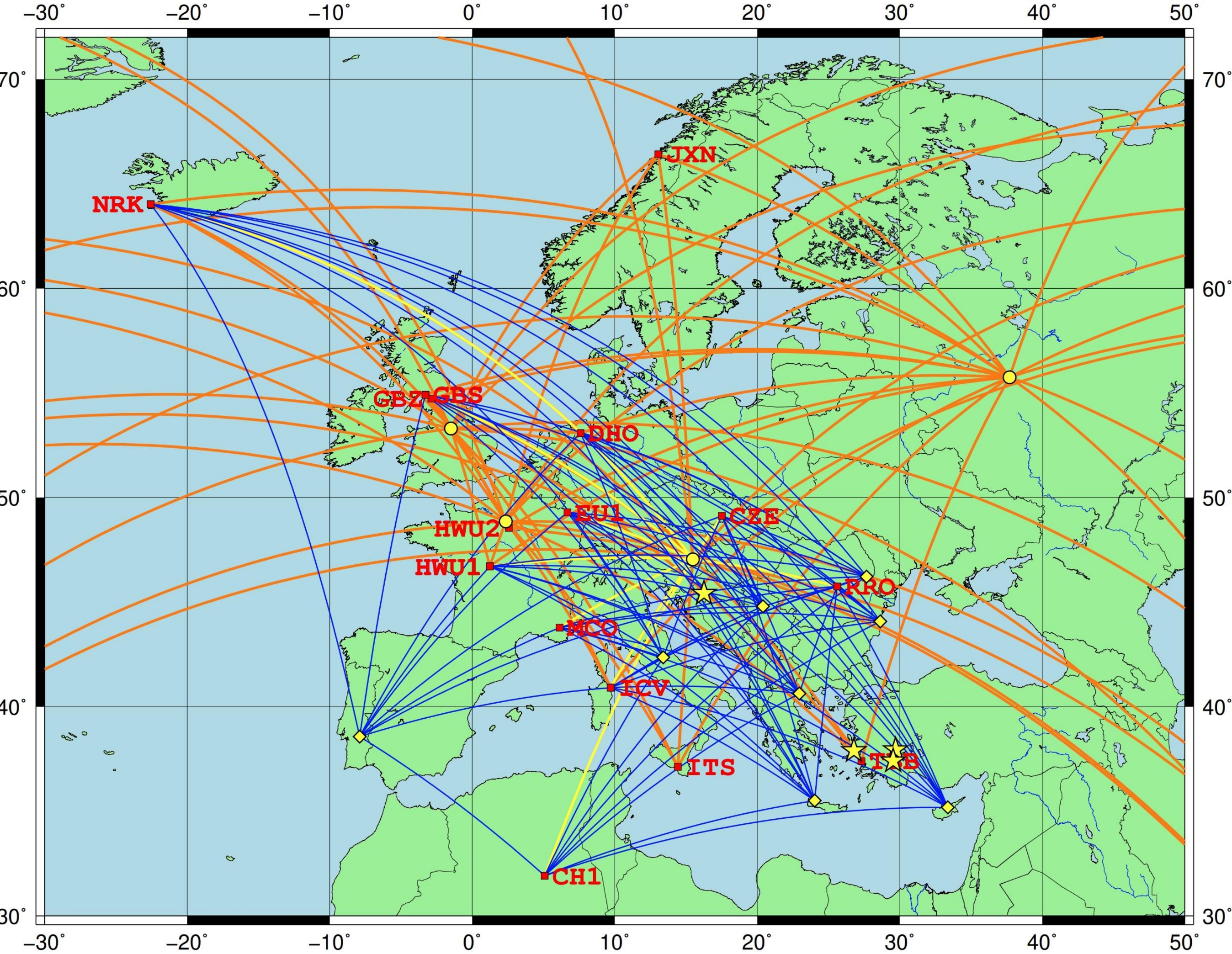


Figure 1: Great circle paths (orange color) between transmitter and receiver for the UltraMSK system with four stations Paris (planned), Moscow, Sheffield, and Graz (yellow circles). INFREP system (paths/diamonds in blue/yellow) over Europe, see (Biagi et al, 2019). Credit map software: Generic Mapping Tools (GMT)

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	Vijayanarayana, 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 and green color, see (Schwingenschuh et al, 2011).

RESULTS

- Sub-ionospheric VLF/LF measurements (in particular during nighttime) are a valuable tool to characterise variations from the lithosphere up to the lower ionosphere
- A network structure is required in order to sample a large area and to distinguish seismic from non-seismic disturbances
- The lithosphere-atmosphere-ionosphere coupling is presumably via atmospheric waves (physical process)
- For robust statistics long term measurements are necessary
- Nighttime VLF/LF amplitudes have lower values before the Petrinja-EQ, Croatia, and show an increase for 8-10 days
- INFREP investigations for the Petrinja-EQs, Croatia, are discussed in (Boudjada et al, 2021)
- For the Turkey and Greece EQs the relevant TBB-GRZ path (16.70 kHz, 1445 km) show different types of modulations, e.g. an increase before the EQ und subsequent attenuation and variations within a constant envelope

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.
- Boudjada, M.Y., et al., *Ray paths of VLF/LF transmitter radio signals in the seismic Adriatic regions*, EGU General Assembly 2021, EGU21-7659, 2021. <https://doi.org/10.5194/egusphere-egu21-7659>
- Biagi, P.F., et al., *The INFREP Network: Present Situation and Recent Results*, Open Journal of Earthquake Research, 8, 101-115, 2019. doi: 10.4236/ojer.2019.82007 <http://www.infrep-network.eu>

SUMMARY

Different types of variations in nighttime VLF/LF amplitude measurements for selected earthquakes are detected. A network is necessary to sample the waveguide over a large area. Further improvements can be achieved in complementary investigations.



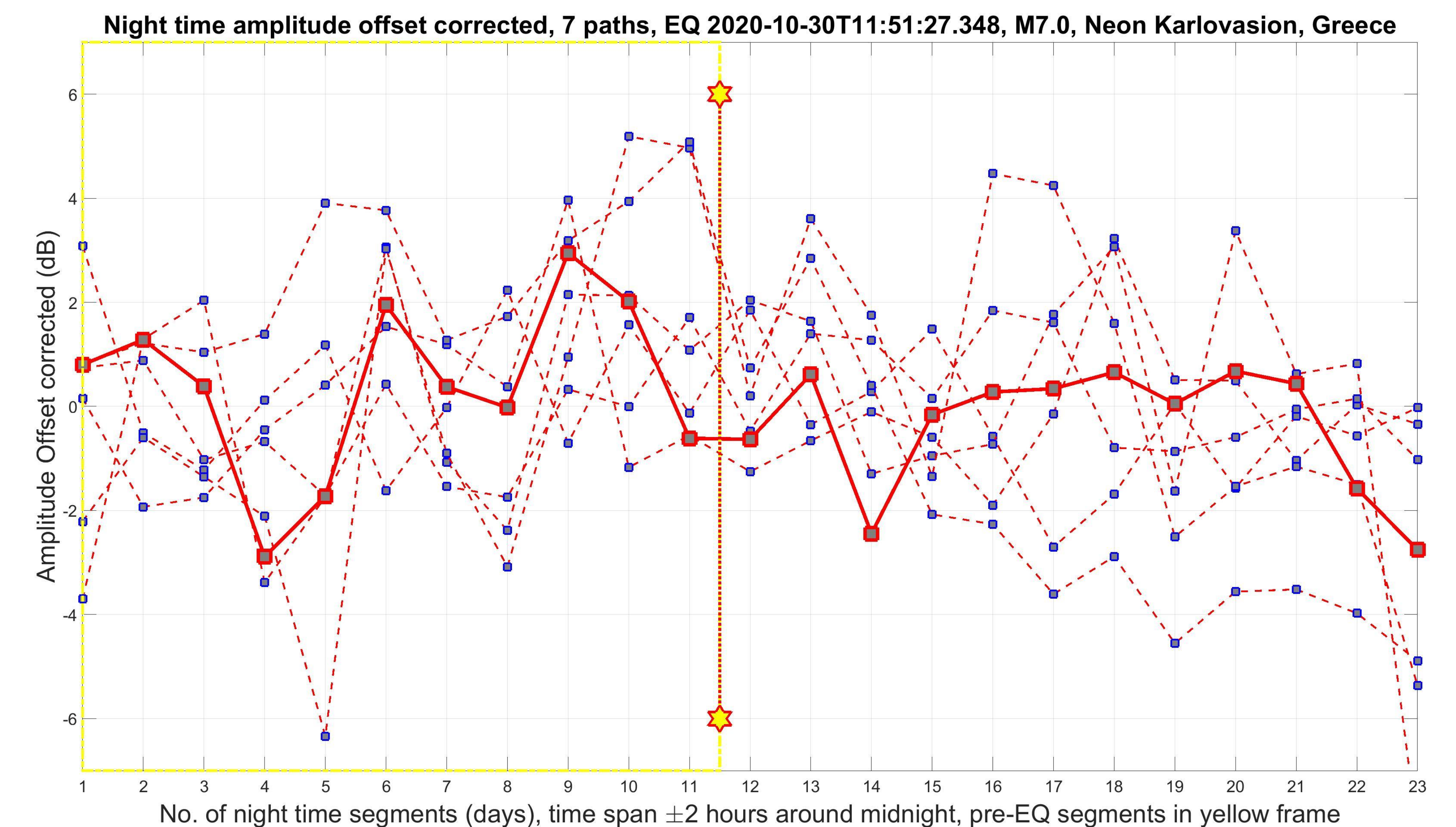
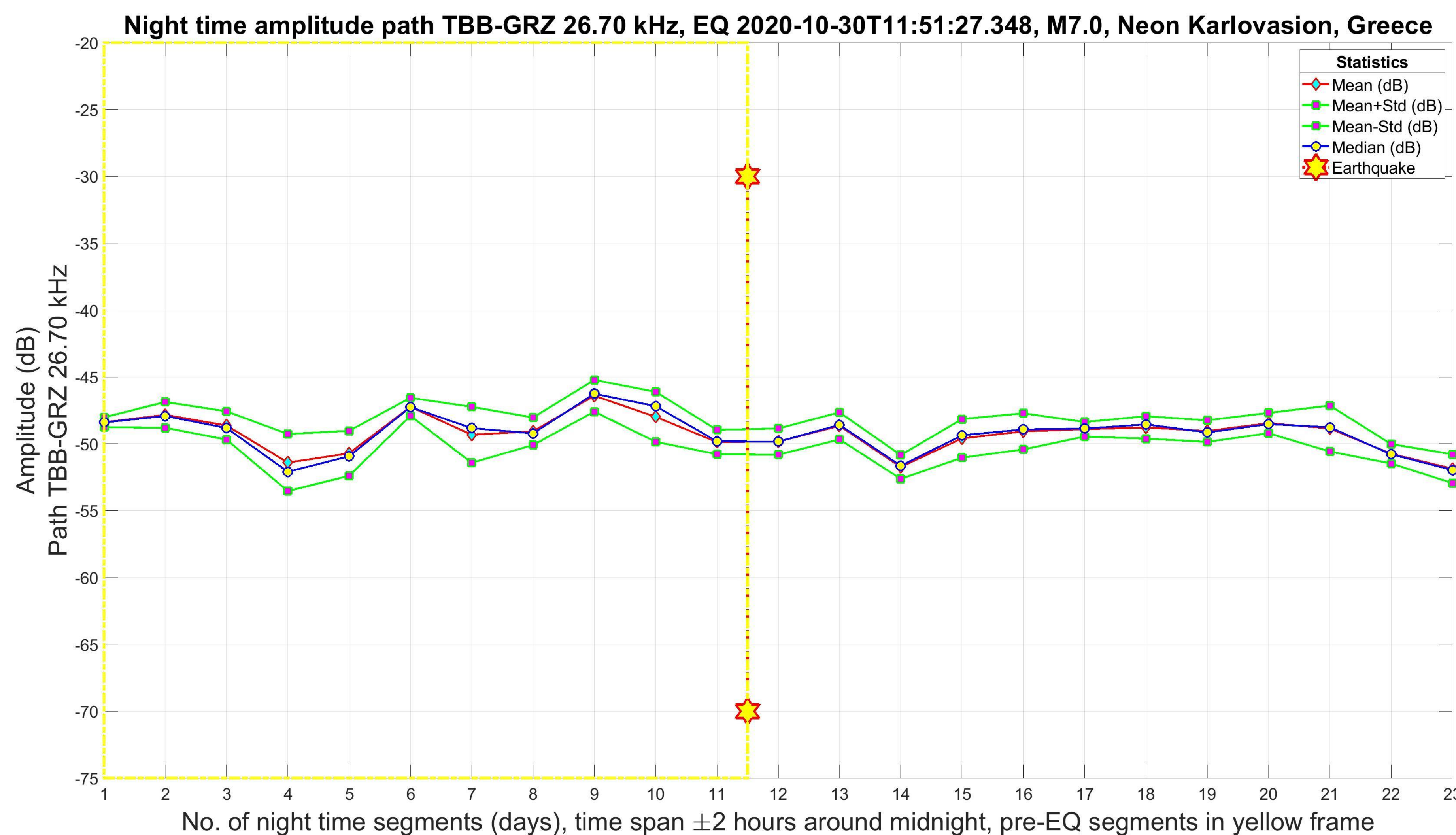
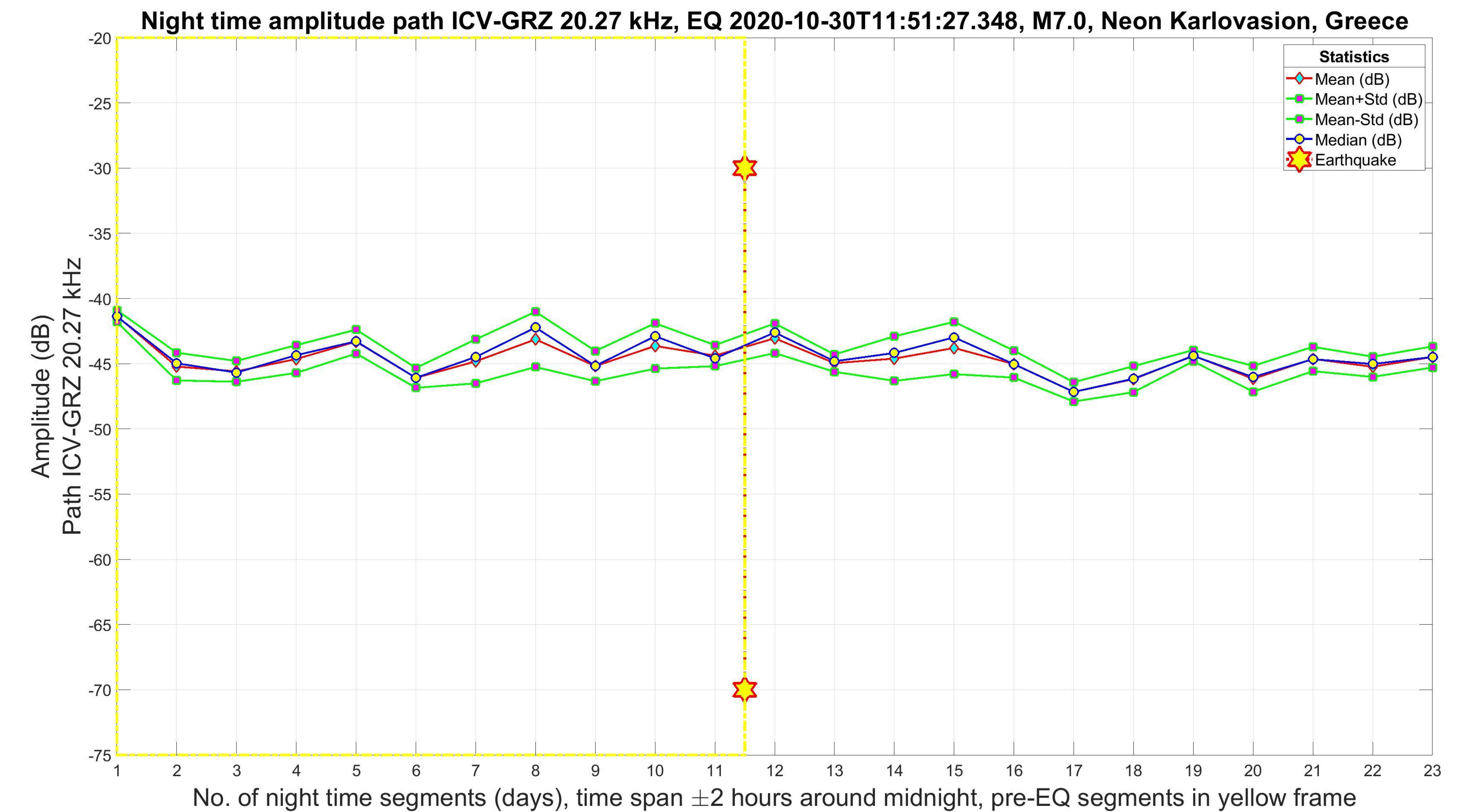
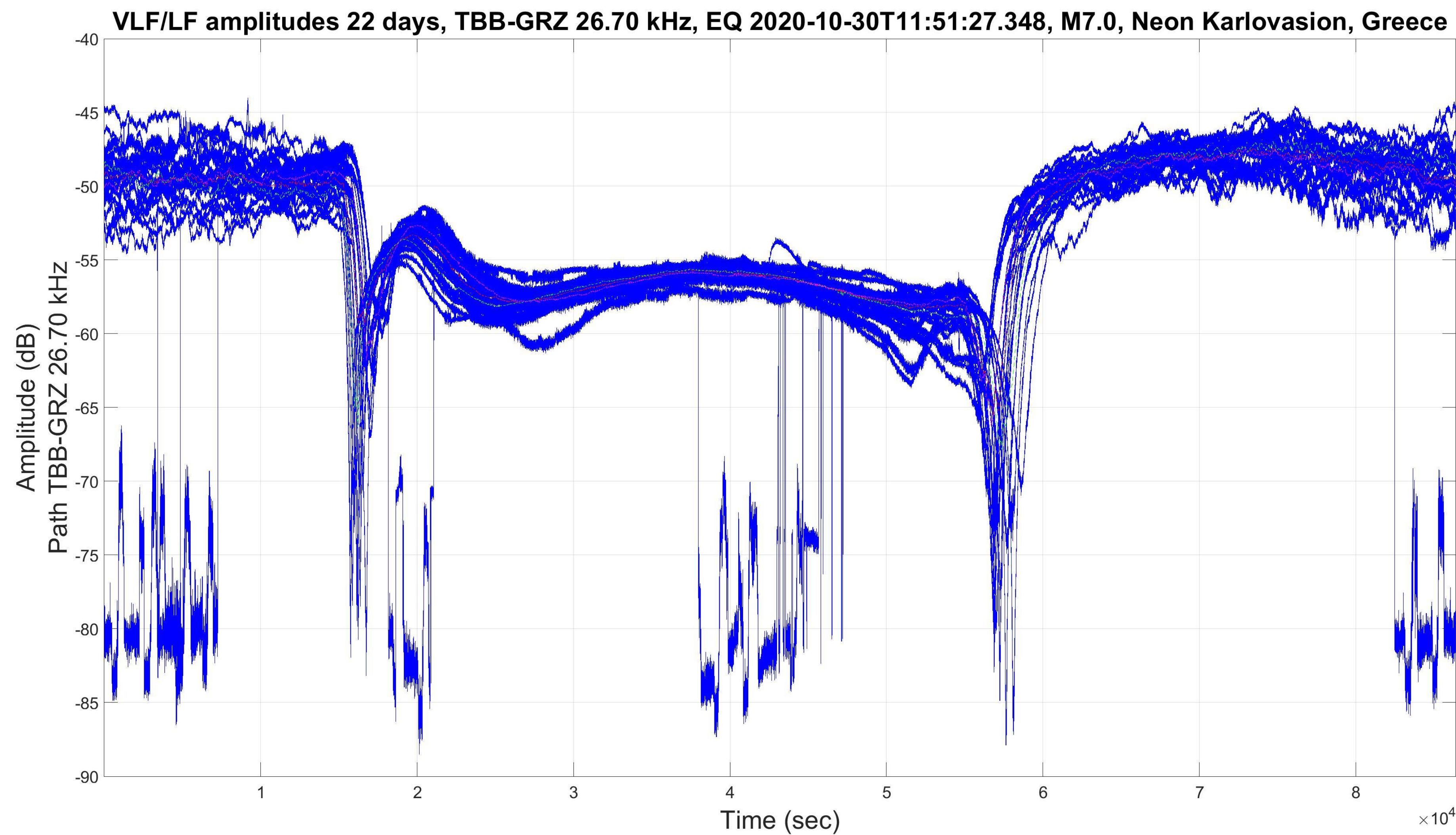
SYNOPTIC VIEW ON SUB-IONOSPHERIC VLF/LF AMPLITUDE AND PHASE VARIATIONS AT THE GRAZ SEISMO-ELECTROMAGNETIC FACILITY

Hans Eichelberger¹, Konrad Schwingenschuh¹, Mohammed Y. Boudjada¹, Bruno P. Besser¹, Daniel Wolbang¹, Maria Solovieva², Pier Francesco Biagi³, Manfred Stachel¹, Özer Aydogar¹, Martin Pitterle¹, Cosima Muck¹, Claudia Grill¹, and Irmgard Jernej¹

¹Space Research Institute, Austrian Academy of Sciences, Graz, Austria, ²Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, ³Department of Physics, University of Bari, Bari, Italy

VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2020-10-30, M7.0, NEON KARLOVASION, GREECE

- Top Left: VLF/LF amplitudes (2020-10-20 to 2020-11-10) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted; C-class solar flare modulation on 2020-10-29
- Bottom Left: Nighttime (± 2 h around midnight) amplitude statistics for the TBB-GRZ path (area crossing given by the Dobrovolsky-Bowman radius), higher fluctuations in the pre-EQ period
- Top Right: Nighttime amplitude statistics for the ICV-GRZ control path (never crossing the Dobrovolsky-Bowman area/radius), fluctuations throughout the whole period
- Bottom Right: Offset corrected nighttime amplitude values for 7 paths (TBB-GRZ in red color), the envelope has a shape like a hump (increase before the EQ and thereafter diminishing values)



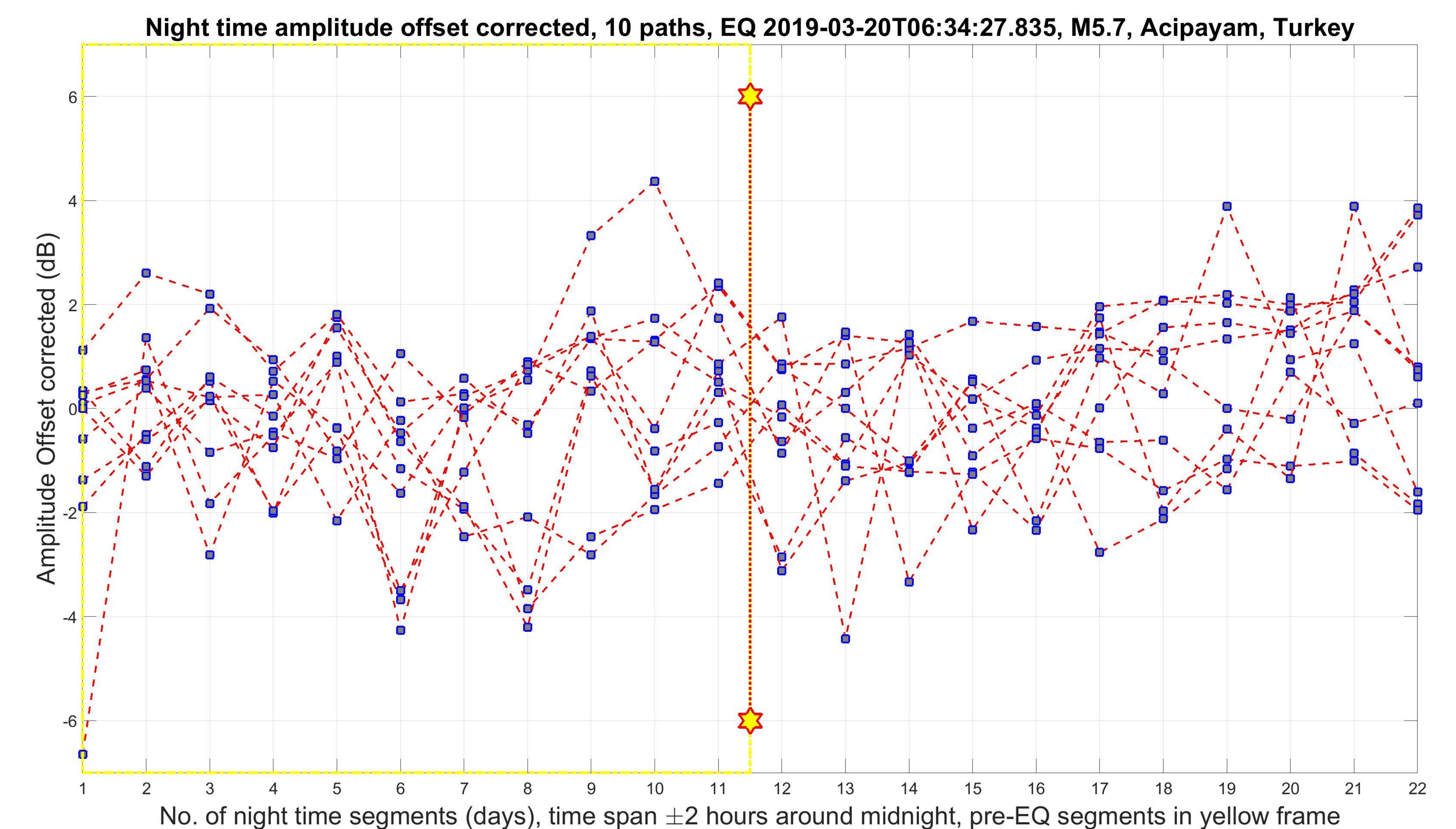
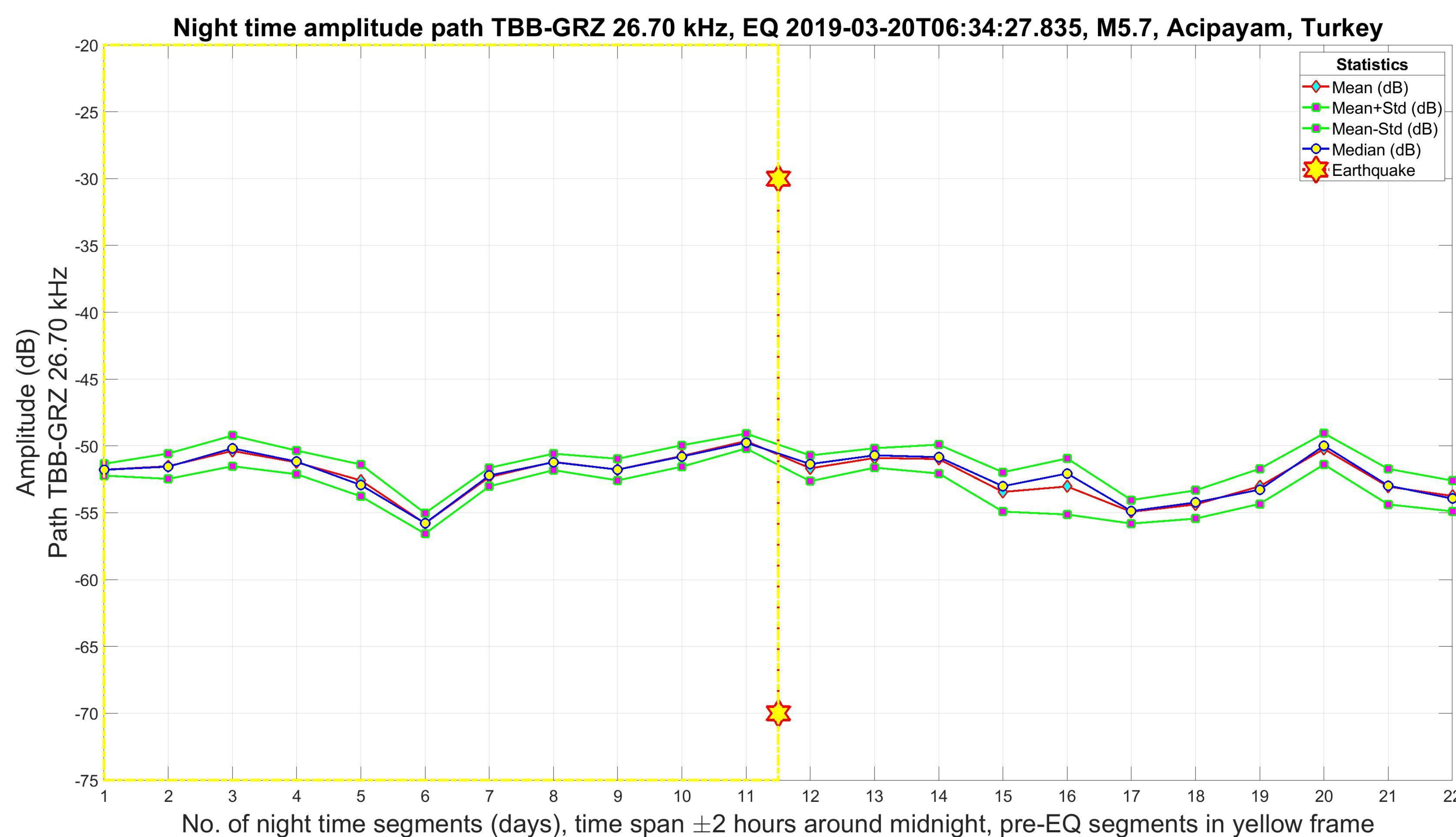
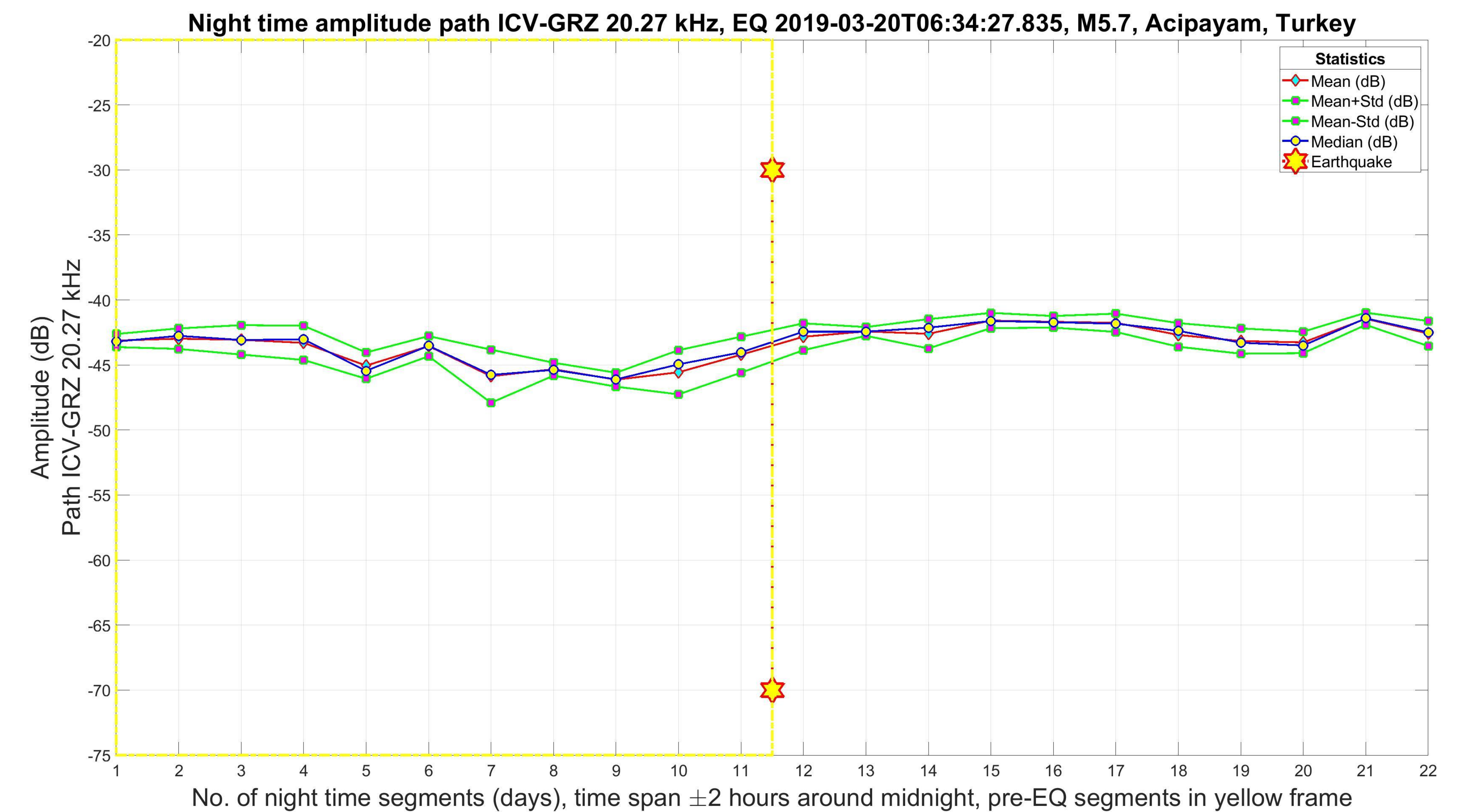
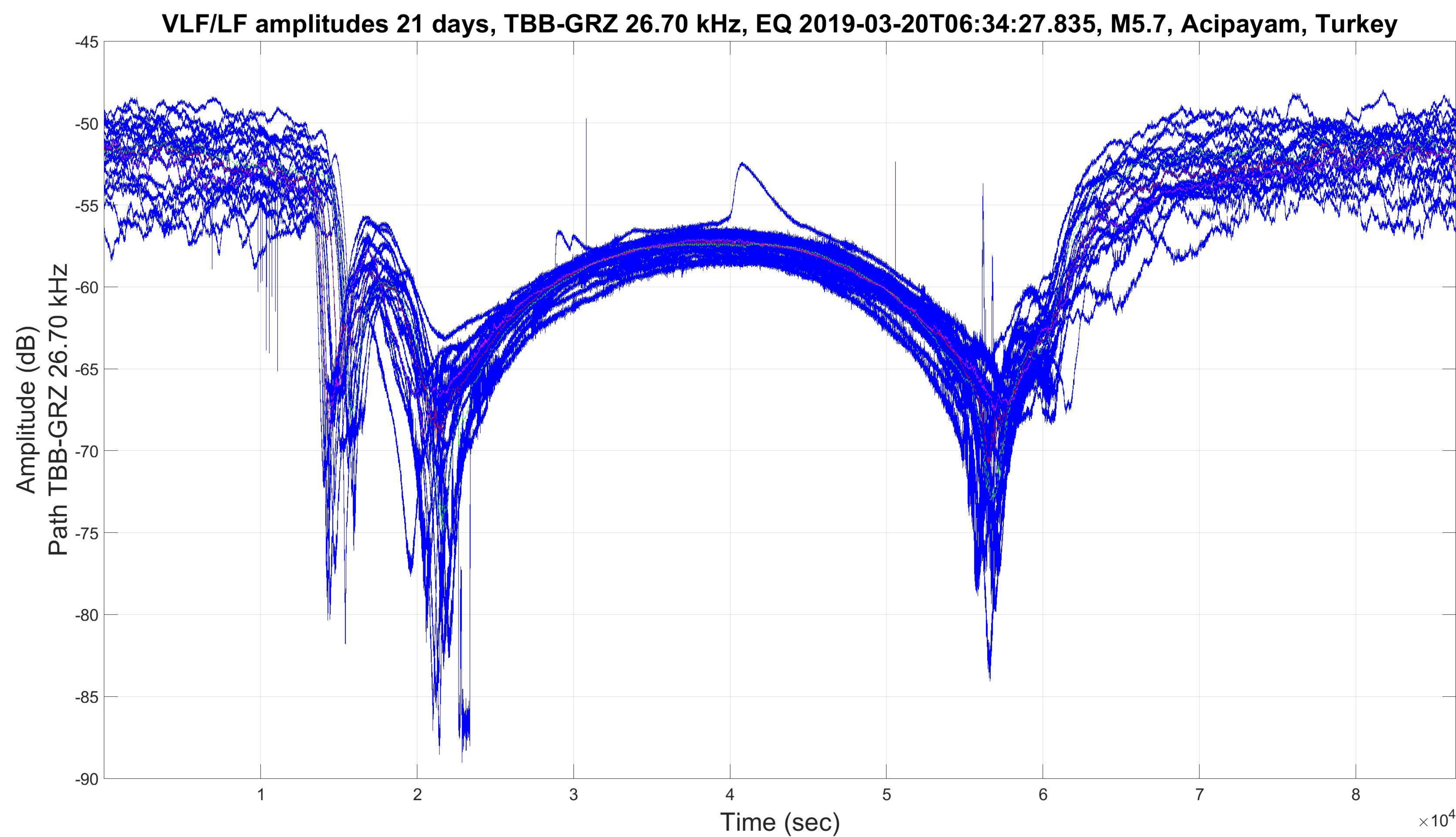
SYNOPTIC VIEW ON SUB-IONOSPHERIC VLF/LF AMPLITUDE AND PHASE VARIATIONS AT THE GRAZ SEISMO-ELECTROMAGNETIC FACILITY

Hans Eichelberger¹, Konrad Schwingenschuh¹, Mohammed Y. Boudjada¹, Bruno P. Besser¹, Daniel Wolbang¹, Maria Solovieva², Pier Francesco Biagi³, Manfred Stachel¹, Özer Aydogar¹, Martin Pitterle¹, Cosima Muck¹, Claudia Grill¹, and Irmgard Jernej¹

¹Space Research Institute, Austrian Academy of Sciences, Graz, Austria, ²Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, ³Department of Physics, University of Bari, Bari, Italy

VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2019-03-20, M5.7, ACIPAYAM, TURKEY

- Top Left: VLF/LF amplitudes (2019-03-10 to 2019-03-30) for the 26.70 kHz TBB-GRZ path, spikes and transmitter switch off periods are omitted; C4-class solar flare modulation on 2019-03-20
- Bottom Left: Nighttime (± 2 h around midnight) amplitude statistics for the TBB-GRZ path (within area given by the Dobrovolsky-Bowman radius), dip in amplitudes 5-7 nights before the EQ
- Top Right: Nighttime amplitude statistics for the ICV-GRZ control path (never crossing the Dobrovolsky-Bowman area/radius), fluctuations before the EQ and amplitude increase
- Bottom Right: Offset corrected nighttime amplitude values for 10 paths, the envelope is nearly constant and the variations are within the boundaries



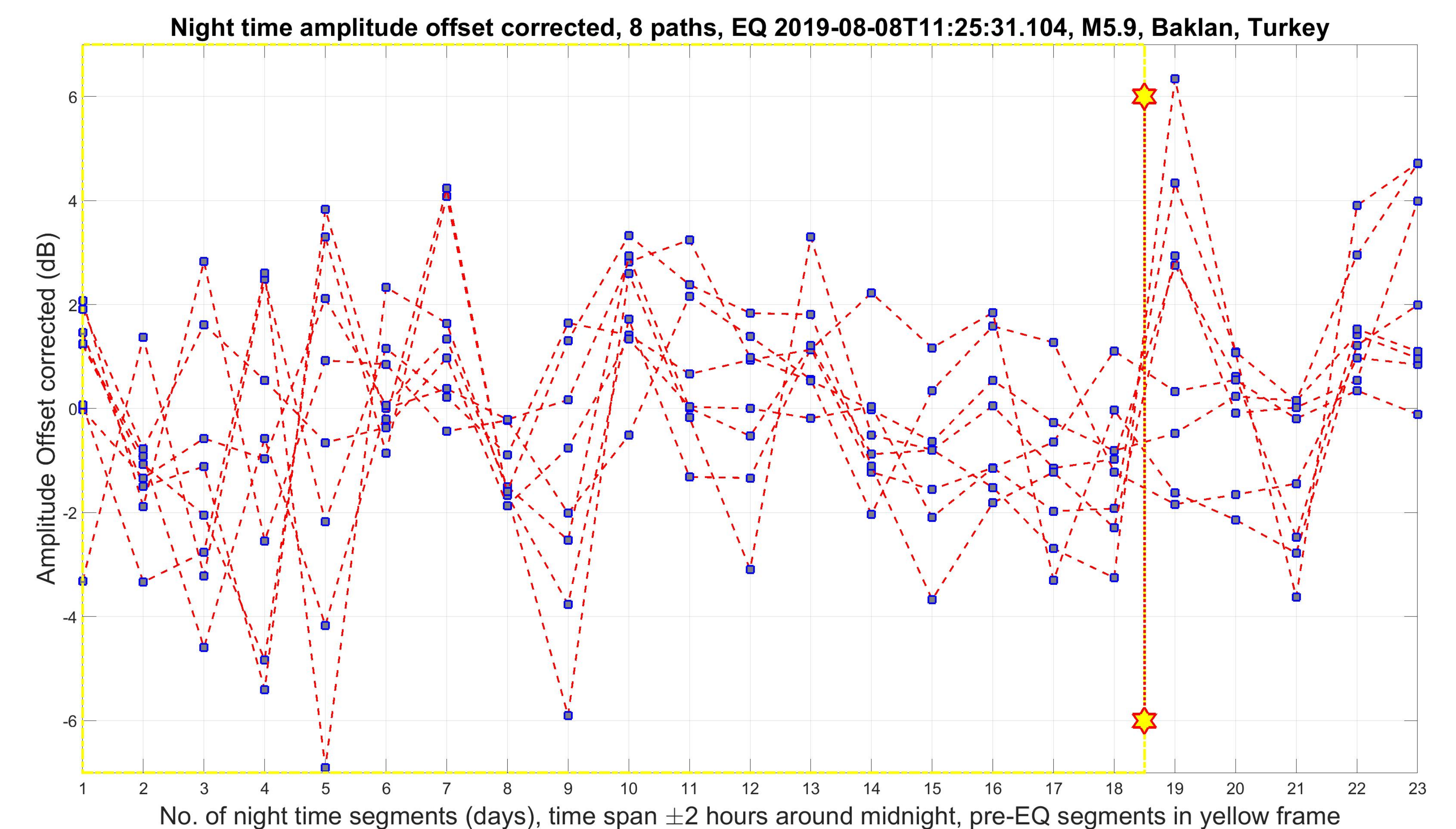
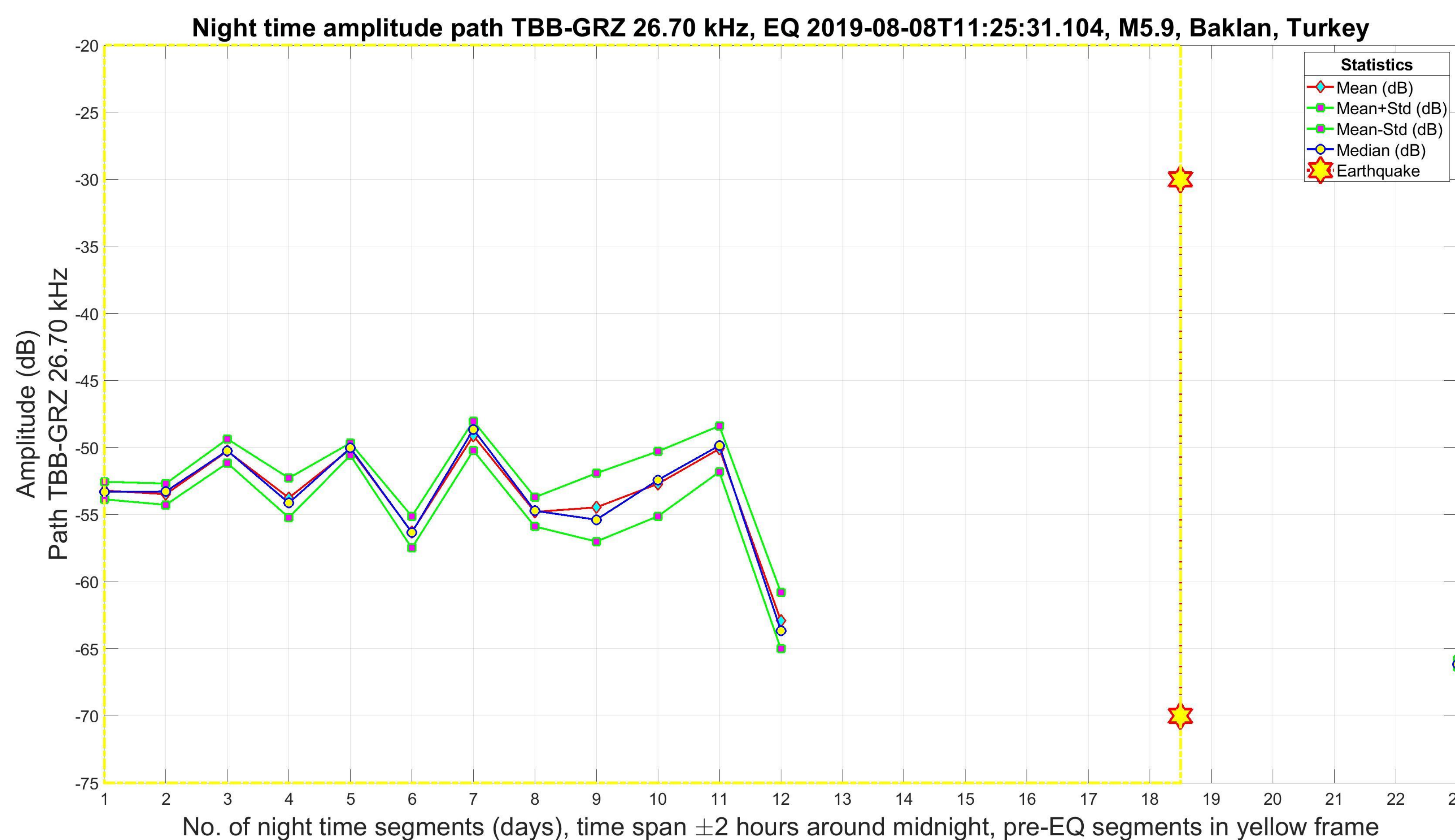
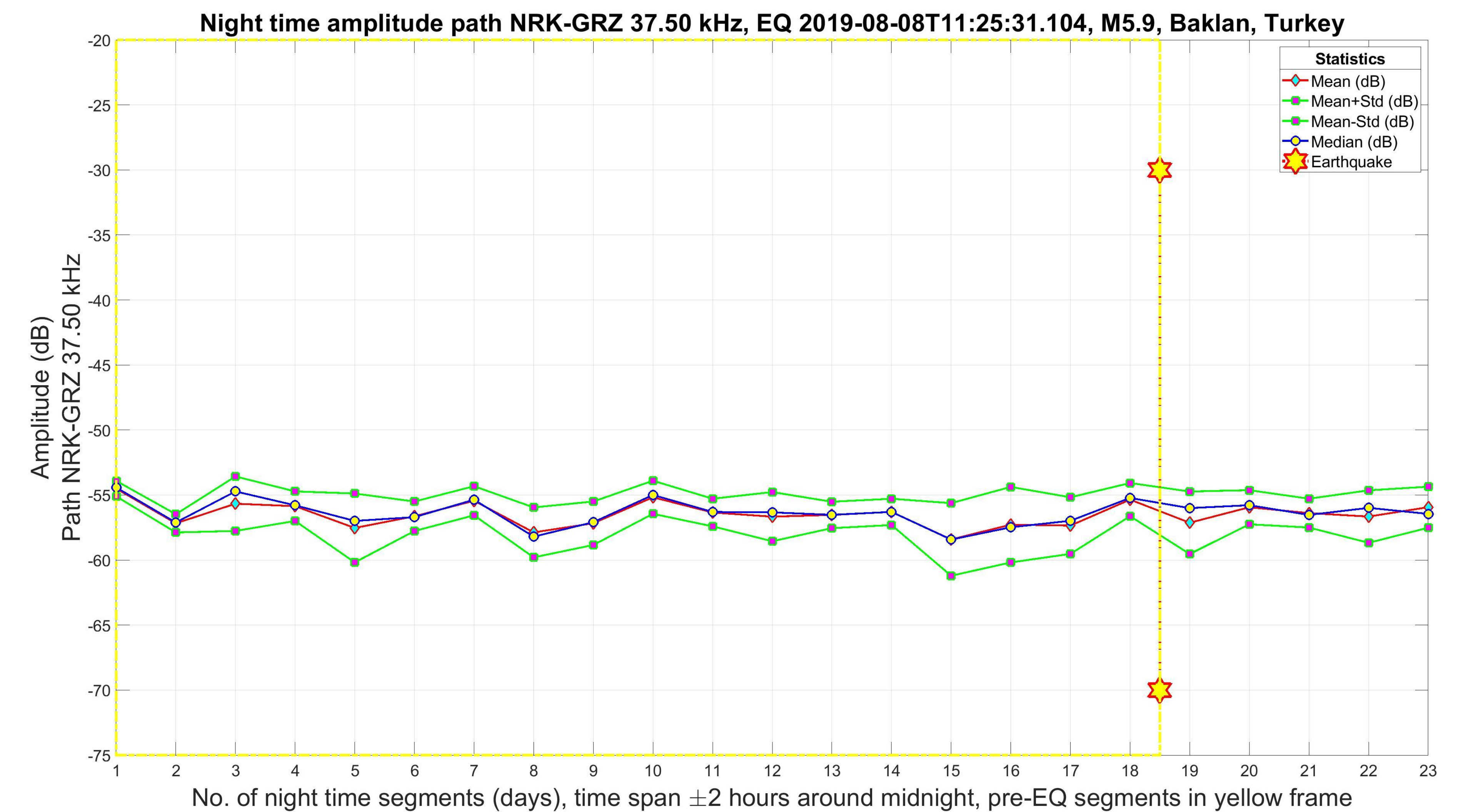
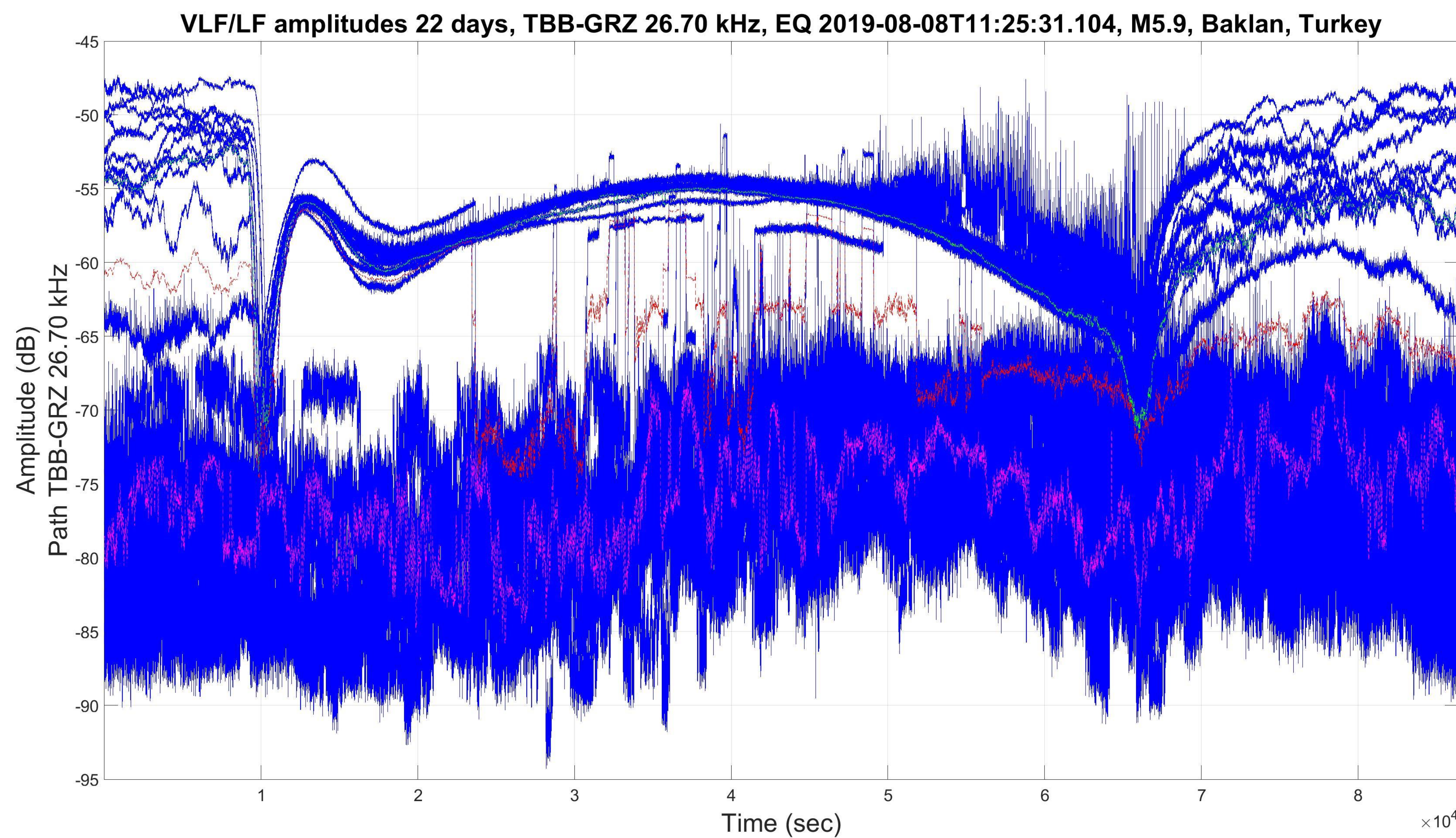
SYNOPTIC VIEW ON SUB-IONOSPHERIC VLF/LF AMPLITUDE AND PHASE VARIATIONS AT THE GRAZ SEISMO-ELECTROMAGNETIC FACILITY

Hans Eichelberger¹, Konrad Schwingenschuh¹, Mohammed Y. Boudjada¹, Bruno P. Besser¹, Daniel Wolbang¹, Maria Solovieva², Pier Francesco Biagi³, Manfred Stachel¹, Özer Aydogar¹, Martin Pitterle¹, Cosima Muck¹, Claudia Grill¹, and Irmgard Jernej¹

¹Space Research Institute, Austrian Academy of Sciences, Graz, Austria, ²Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, ³Department of Physics, University of Bari, Bari, Italy

VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2019-08-08, M5.9, BAKLAN, TURKEY

- Top Left: VLF/LF amplitude measurements (2019-07-22 to 2019-08-12) for the 26.70 kHz TBB-GRZ path, the spikes and transmitter switch off periods during night are omitted for the analysis
- Bottom Left: Nighttime (± 2 h around midnight) amplitude statistics for the TBB-GRZ path (within area given by the Dobrovolsky-Bowman radius), transmitter switch off 1 week before the EQ
- Top Right: Nighttime amplitude statistics for the NRK-GRZ control path (never crossing the Dobrovolsky-Bowman area/radius), fluctuations throughout the whole period
- Bottom Right: Offset corrected nighttime amplitude values for 8 paths, lower fluctuations for several days before the EQ but increase in the post period



SYNOPTIC VIEW ON SUB-IONOSPHERIC VLF/LF AMPLITUDE AND PHASE VARIATIONS AT THE GRAZ SEISMO-ELECTROMAGNETIC FACILITY

Hans Eichelberger¹, Konrad Schwingenschuh¹, Mohammed Y. Boudjada¹, Bruno P. Besser¹, Daniel Wolbang¹, Maria Solovieva², Pier Francesco Biagi³, Manfred Stachel¹, Özer Aydogar¹, Martin Pitterle¹, Cosima Muck¹, Claudia Grill¹, and Irmgard Jernej¹

¹Space Research Institute, Austrian Academy of Sciences, Graz, Austria, ²Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, ³Department of Physics, University of Bari, Bari, Italy

VLF/LF AMPLITUDE MEASUREMENTS FOR THE EARTHQUAKE 2020-12-29, M6.4, PETRINJA, CROATIA

- Top Left: VLF/LF amplitude measurements (2020-12-20 to 2021-01-10) for the 20.27 kHz ICV-GRZ path, the spikes and transmitter switch off periods during night are omitted for the analysis
- Bottom Left: Nighttime (± 2 h around midnight) amplitude statistics for the ICV-GRZ path (within area given by the Dobrovolsky-Bowman radius), wavelike behaviour
- Top Right: Nighttime amplitude statistics for the ITS-GRZ control path (within the Dobrovolsky-Bowman area/radius), pre-EQ dip and increase for 10 days centred around the EQ time
- Bottom Right: Offset corrected nighttime amplitude values for 7 paths, wavelike feature in the envelope, lower values in the pre-EQ period and increase for approx. 8-10 days

