INVESTIGATION OF VLF/LF ELECTRIC FIELD VARIATIONS RELATED TO MAGNITUDE MW≥5.5 EARTHQUAKES IN THE MEDITERRANEAN REGION FOR THE YEAR 2023

Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier F. Biagi[3], Patrick H. M. Galopeau[4], Ghulam Jaffer[5], Christoph Schirninger[6], Aleksandra Nina[7], Gordana Jovanovic[8], Giovanni Nico[9], Manfred Stachel[1], Özer Aydogar[1], Cosima Muck[1], Josef Wilfinger[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, [6] Institute for Physics, University of Graz, Graz, Austria, [7] Institute of Physics Belgrade, University of Belgrade, Belgrade, Serbia, [8] Faculty of Science and Mathematics, University of Montenegro, Podgorica, Montenegro, [9] Institute of Applied Mathematics, Italian National Research Council, Bari, Italy

Strong natural hazards together with their societal impact are usually accompanied by multiple physical phenomena which can be an important information source about the underlying processes. In this study we statistically analyze the lithosphere–atmosphere–ionosphere couplings of magnitude Mw5.5+ earthquakes (EQs) in the year 2023 with the aid of sub-ionospheric VLF/LF radio links. The electric field amplitude and phase measurements with a temporal resolution of one second are from the seismo-electromagnetic receiver facility in Graz (GRZ), Austria (Galopeau et al., 2023), which is part of the INFREP network. The spatial extend of the study area has the range [-10°E ≤ longitude ≤ 40°E] and [30°N ≤ latitude ≤ 50°N], in total are 17 EQs according to the United States Geological Survey (USGS) data base, among them the Turkey–Syria EQs (main shocks Mw7.8 and Mw7.5) and the Morocco Mw6.8 EQ. We apply the night-time amplitude method (Hayakawa et al., 2010) for all available paths, of particular importance are the transmitter links TBB (26.70 kHz, Bafa, Turkey), ITS (45.90 kHz, Niscemi, Sicily, Italy), and ICV (20.27 kHz, Tavolara, Italy). Relevant crossings are determined by the size of the Dobrovolsky-Bowman relationship (Dobrovolsky et al., 1979; Bowman et al., 1998). A major finding is the statistically significant electric field variation of the TBB-GRZ link related to the Turkey–Syria EQ sequence. A physical interpretation is based on atmospheric gravity waves (AGWs) which could alter the E-layer in the lower ionosphere during nighttime and modulate the height of the waveguide cavity.

TRANSMITTER LIST & VLF/LF SYSTEM PARAMETERS

Receiver: Graz, IWF, Elettronika [E] and UltraMSK [U] system, geographic location N 47°2'40.38'' E 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	ISR	29.70	2450	Dimona, Israel [U 1s]
16	NRK	37.50	2975	Keflavik, Iceland [U 1s] [U 20s] [E 60s]
17	JJY	40.00	9195	Mount Otakadoya, Honshu, Japan [U 1s]
18	NAU	40.80	7985	Aguada, Puerto Rico, USA [U 1s]
19	ITS	45.90	1105	Niscemi, Sicily, Italy [U 1s] [U 20s]
20	DCF	77.50	580	Mainflingen, Germany [U 1s]
21	RRO	153	790	Brasov, Romania [E 60s]
22	TDF (EU1)	162 (183)	1010 (700)	Allouis, France (Felsberg–Berus, Luxembourg) [E 60s]
23	CH1	198	1900	Berkaoui/Ouargia, Algeria [E 60s]
24	RTL (MCO)	234 (216)	740 (820)	Beidweiler, Luxembourg (Roumoules, Monte Carlo) [E 60s]
25	CZE	270	275	Topolna, Czech Republic [E 60s]

VLF/LF NETWORK, EUROPEAN PATHS, EQ M5.5+

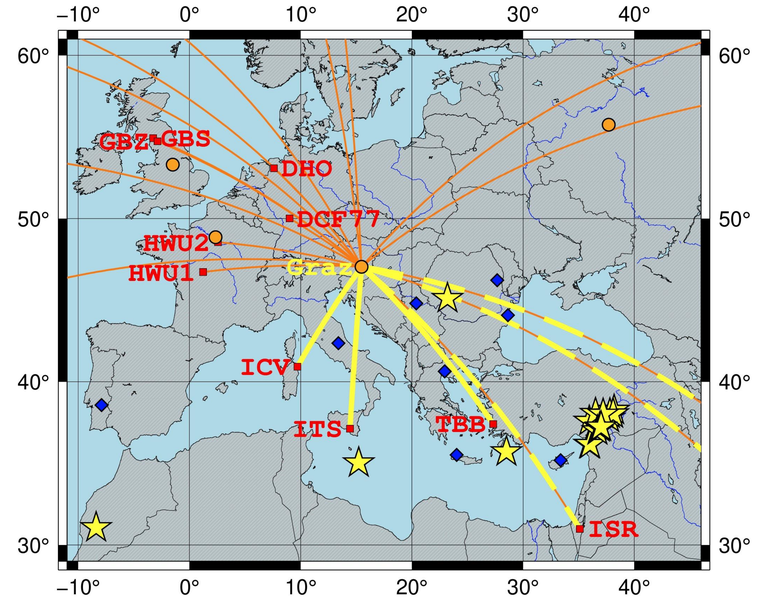


Table 2: Transmitters received at the VLF/LF Graz facility, settings in blue/green/red color [1, 5, 6], major EQs event paths with yellow background.
Figure 1: Great circle paths (orange & yellow lines) between VLF/LF transmitters and the Graz receiver (orange circle, UltraMSK systems [1, 5]), for INFREP (diamonds in blue color) see [6]. Magnitude M5.5+ EQs (17 yellow stars) and the relevant paths related to the Dobrovolsky-Bowman relationship are indicated (yellow lines good S/N, yellow-dotted lines are {VTX, NWC, ISR}-GRZ long distance paths). Credit map: GMT

EARTHQUAKES M ≥ 5.5, 2023, MEDITERRANEAN AREA, DATA PROCESSING & RESULTS

We investigate VLF/LF electric fields from sub-ionospheric VLF/LF propagation paths in the geo. lat/lon range [30° ≤ lat ≤ 50°] / [-10° ≤ long ≤ 40°] in 2023. For this temporal, spatial and magnitude $M_w \geq 5.5$ constraints the USGS EQ database [9] includes 17 EQs, the Dst-index [10] considers external influences. All events (Tab. 1, Fig. 1) are selected, emphasis is according to VLF/LF path crossings and the Dobrovolsky-Bowman relationship [2, 3], i.e., the radius of the effective precursor manifestation zone $\varrho = 10^{(0.43*M)}$ km and log(R) ≈ M/2 km. VLF/LF amplitude nighttime values are used (±2 hours around midnight) [7, 8], with 1 Hz resolution. The data 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 fields and EQs, based on statistics from nighttime electric field amplitude variations with significance level 5%, are achieved for the big Kahramanmaraş EQ sequence and the Lárdos, Greece, event.

Table 1: Results for all M ≥ 5.5 earthquakes (see Figure 1, stars in yellow color), time period 2023, Mediterranean area (2 OK, 2 mixed, 3 NOK).

Selected Earthquakes Magnitude M ≥ 5.5, USGS database, time span 01.01.2023 – 31.12.2023, long/lat range: [-10° – +40°]/[+30° – +50°]							
No.	Date, Time	Lat (°) / Lon (°) / Depth (km)	Mag / ϱ (km)	Location	Main path	Control paths	Result, Annotation
1	2023-01-25 12:37:05	+35.709 / +28.497 / 29.6	5.9 / 344	Lárdos, Greece	TBB–GRZ	11 {ISR,NAA,JJI,ITS,ICV,GWU,GBZ,GBS,DHO,DCF,NRK}–GRZ	OK: Post EQ > Pre EQ values with significance level 5%, min(Dst) = –57 nT
2	2023-02-06 01:17:34	+37.226 / +37.014 / 10.0	7.8 / 2260	Kahramanmaras EQs sequ.	TBB–GRZ	08 {NAA,ITS,ICV,HWU,GWU,GBZ,GBS,DHO}–GRZ	OK: Post EQ > Pre EQ values with significance level 5%
3	2023-02-06 01:26:51	+37.225 / +37.000 / 10.0	6.7 / 760	Nurdağı, Turkey	TBB–GRZ		magnetic storm starts late in the period at 2023-02-15: min(Dst) = –72 nT
4	2023-02-06 01:28:16	+37.189 / +36.893 / 9.80	5.6 / 255	Nurdağı, Turkey	TBB–GRZ		
5	2023-02-06 01:36:27	+36.992 / +36.683 / 10.0	5.4 / 210	Turkey–Syria border	TBB–GRZ		
6	2023-02-06 10:24:49	+38.0101 / +37.196 / 7.43	7.5 / 1679	Kahramanmaras EQs sequ.	TBB–GRZ	08 {NAA,ITS,ICV,HWU,GWU,GBZ,GBS,DHO}–GRZ	
7	2023-02-06 10:26:46	+38.032 / +38.099 / 10.0	6.0 / 380	Çelikhan, Turkey	TBB–GRZ		
8	2023-02-06 10:35:58	+38.025 / +37.802 / 10.0	5.8 / 312	Doğanşehir, Turkey	TBB–GRZ		
9	2023-02-06 10:51:31	+38.248 / +38.185 / 10.0	5.7 / 283	Yeşilyurt, Turkey	TBB–GRZ		
10	2023-02-06 12:02:11	+38.058 / +36.511 / 8.52	6.0 / 380	Göksun, Turkey	TBB–GRZ		
11	2023-02-07 03:13:13	+37.764 / +37.731 / 10.0	5.5 / 232	Gölbaşı, Turkey	TBB–GRZ		
12	2023-02-14 13:16:51	+45.100 / +23.201 / 10.0	5.6 / 255	Leleşti, Romania	TBB–GRZ	14 {ISR,VTX,NWC,NAA,JJI,ITS,ICV,HWU,GWU,GBZ,GBS,DHO,DCF,NRK}–GRZ	Not OK: not significant, all paths out of 5% level, min(Dst) = –72 nT
13	2023-02-20 17:04:30	+36.162 / +36.025 / 16.0	6.3 / 512	Uzunbağ, Turkey	TBB–GRZ	14 {ISR,VTX,NWC,NAA,JJI,ITS,ICV,HWU,GWU,GBZ,GBS,DHO,DCF,NRK}–GRZ	OK/NOK: Mixed results; significant values for the ISR–GRZ path
14	2023-02-20 17:07:36	+36.159 / +35.935 / 10.0	5.5 / 232	Uzunbağ, Turkey	TBB–GRZ		Major magnetic storm at 2023-02-26: min(Dst) = –132 nT
15	2023-04-21 22:19:49	+35.026 / +15.219 / 13.8	5.5 / 232	Birżebbuġa, Malta	ITS–GRZ	08 {TBB,NAA,ICV,GBZ,GBS,DHO,DCF,NRK}–GRZ	OK/NOK: Mixed results; major mag. storm at 2023-04-23: min(Dst) = –213 nT
16	2023-07-25 05:44:51	+37.579 / +35.948 / 13.1	5.5 / 232	Kozan, Turkey	TBB–GRZ	09 {NAA,ITS,ICV,HWU,GBZ,GBS,DHO,DCF,NRK}–GRZ	NOK: Several magnetic storms: min(Dst) = –59 nT
17	2023-09-08 22:11:01	+31.058 / –08.385 / 19.0	6.8 / 839	Al Haouz, Morocco	{ITS,ICV}–GRZ	06 {JJI,HWU,GBZ,GBS,DHO,NRK}–GRZ	NOK: Receiver systematics and out of Dobrovolsky–Bowman area; ICV–Morocco EQ = 1958 km, ITS–Morocco EQ = 2204 km, two major magnetic storms: min(Dst) = –79 nT

REFERENCES

1. Galopeau, P.H.M, et al., *A VLF/LF facility network for preseismic electromagnetic investigations*, Geosci. Instrum. Method. Data Syst., 12, 231–237, 2023. https://doi.org/10.5194/gi-12-231-2023
2. 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
3. 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
4. Hayakawa, M., et al., *A statistical study on the correlation between lower ionospheric perturbations as seen by subionospheric VLF/LF propagation and earthquakes*, JGR Space Physics, 115(A9), 09305, 2010. https://doi.org/10.1029/2009JA015143
5. Schwingenschuh, K., et al., *The Graz seismo-electromagnetic VLF facility*, NHESS, 11, 1121–1127, 2011. https://doi.org/10.5194/nhess-11-1121-2011
6. Biagi, P.F., et al., *The INFREP Network: Present Situation and Recent Results*, OJER, 8, 101-115, 2019. https://doi.org/10.4236/ojer.2019.82007 Website https://infrep.iwf.oeaw.ac.at/
7. Rozhnoi, A., et al., *Middle latitude LF (40 kHz) phase variations associated with earthquakes for quiet and disturbed geomagnetic conditions*, Ph. Chem. Earth, A/B/C, 29, 4-9, 589-598, 2004. https://doi.org/10.1016/j.pce.2003.08.061
8. Rozhnoi, A., et al., *Anomalies in VLF radio signals prior the Abruzzo earthquake (M=6.3) on 6 April 2009*, NHESS, 9, 1727–1732, 2009. https://doi.org/10.5194/nhess-9-1727-2009
9. United States Geological Survey (USGS) earthquake catalog, database and website https://earthquake.usgs.gov/ as of April 2024.
10. World Data Center for Geomagnetism, Kyoto, database https://wdc.kugi.kyoto-u.ac.jp/ as of April 2024.

SUMMARY

VLF/LF electric field variations (nighttime amplitude method; assumed significance level 5%) can be related to the 2023 Turkey–Syria earthquakes (M7.8, M7.5) and the Lárdos, Greece (M5.9) event.

EGU GENERAL ASSEMBLY, 14-19 APRIL 2024, VIENNA, AUSTRIA

IWF — SPACE RESEARCH INSTITUTE, AUSTRIAN ACADEMY OF SCIENCES, HUE@OEAW.AC.AT, EGU24-6001

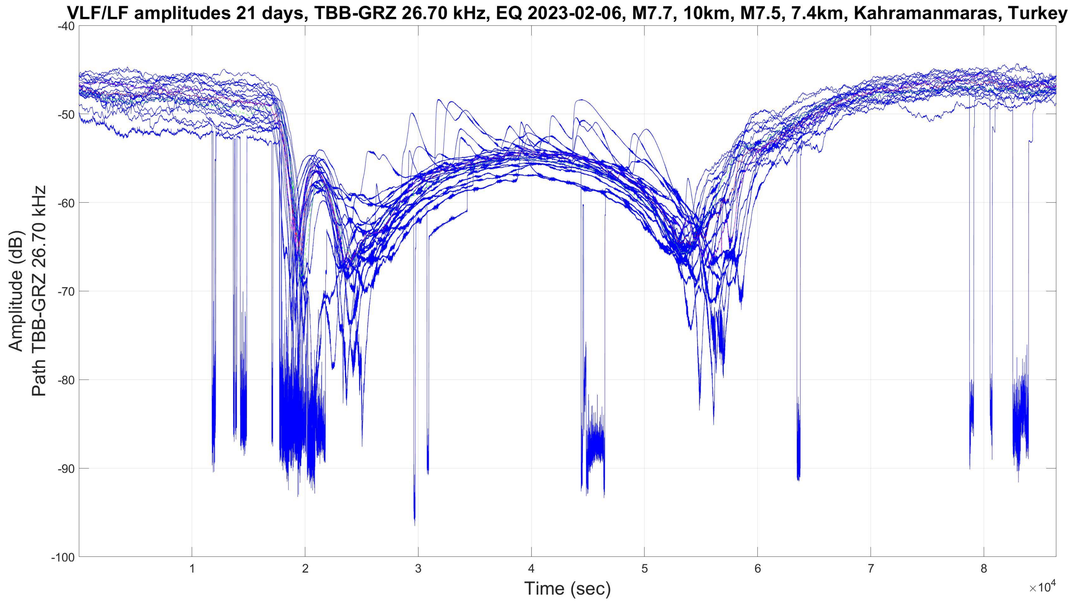
INVESTIGATION OF VLF/LF ELECTRIC FIELD VARIATIONS RELATED TO MAGNITUDE MW≥5.5 EARTHQUAKES IN THE MEDITERRANEAN REGION FOR THE YEAR 2023

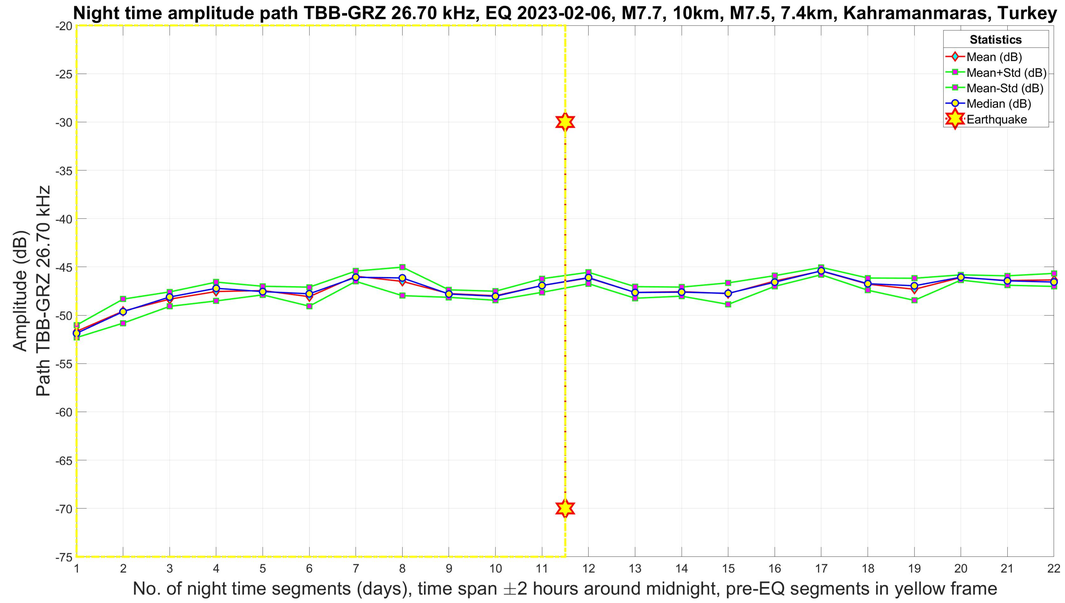
Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier F. Biagi[3], Patrick H. M. Galopeau[4], Ghulam Jaffer[5], Christoph Schirninger[6], Aleksandra Nina[7], Gordana Jovanovic[8], Giovanni Nico[9], Manfred Stachel[1], Özer Aydogar[1], Cosima Muck[1], Josef Wilfinger[1], Irmgard Jernej[1], and Werner Magnes[1]

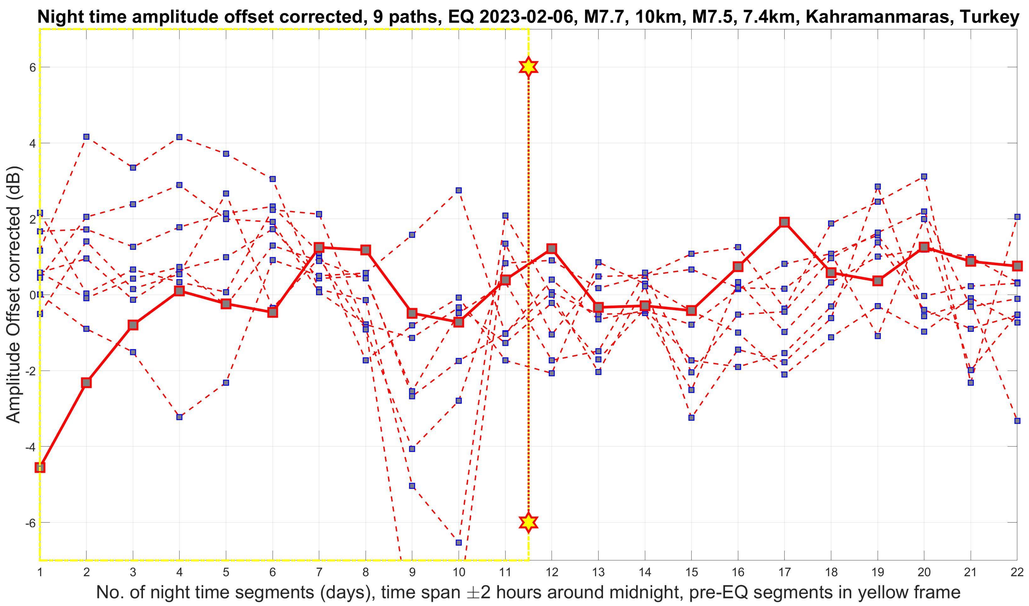
[1] Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [2] Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, [3] Department of Physics, University of Bari, Bari, Italy, [4] LATMOS-CNRS, UVSQ Université Paris-Saclay, Guyancourt, France, [5] SpaSys, SnT – Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg, Luxembourg, [6] Institute for Physics, University of Graz, Graz, Austria, [7] Institute of Physics Belgrade, University of Belgrade, Belgrade, Serbia, [8] Faculty of Science and Mathematics, University of Montenegro, Podgorica, Montenegro, [9] Institute of Applied Mathematics, Italian National Research Council, Bari, Italy

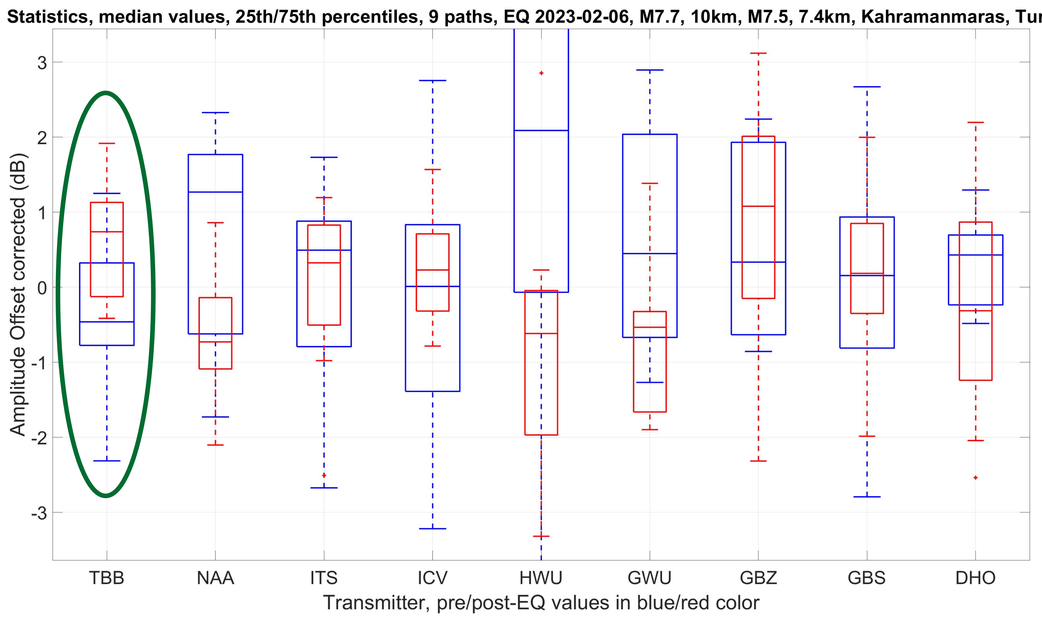
VLF/LF AMPLITUDE MEAS., EARTHQUAKES 2023-02-06, M7.8 10 KM / M7.5 7.4 KM, KAHRAMANMARAŞ EARTHQUAKE SEQUENCE, TURKEY

- Top Left: VLF/LF amplitudes (2023-01-27 to 2023-02-16) 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, for a significance level of 5% only the event path TBB-GRZ shows higher amplitude values after the EQ (nighttime method)









EGU GENERAL ASSEMBLY, 14-19 APRIL 2024, VIENNA, AUSTRIA

IWF — SPACE RESEARCH INSTITUTE, AUSTRIAN ACADEMY OF SCIENCES, HUE@OEAW.AC.AT, EGU24-6001

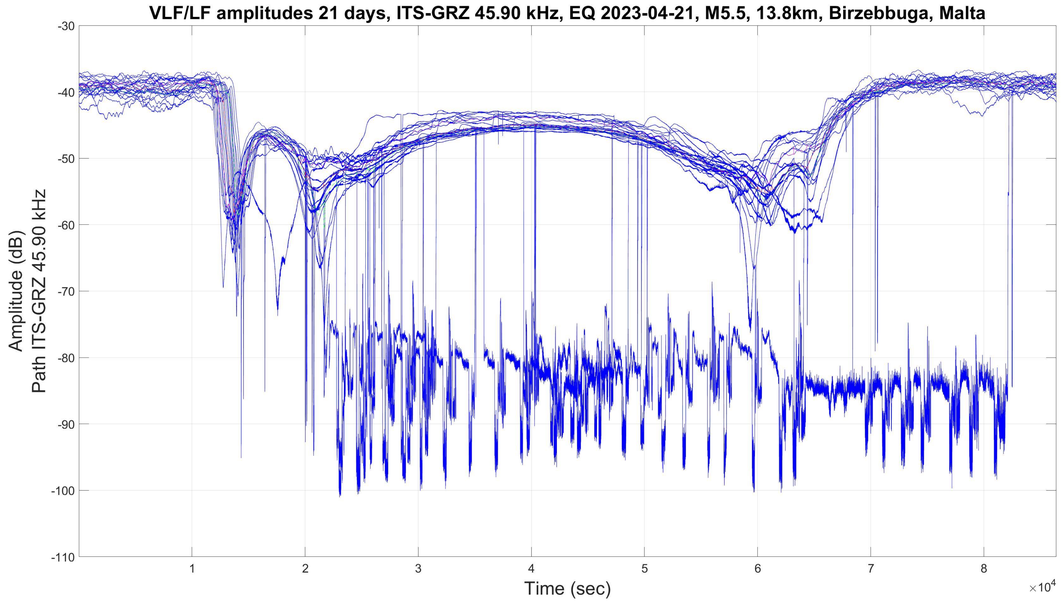
INVESTIGATION OF VLF/LF ELECTRIC FIELD VARIATIONS RELATED TO MAGNITUDE MW≥5.5 EARTHQUAKES IN THE MEDITERRANEAN REGION FOR THE YEAR 2023

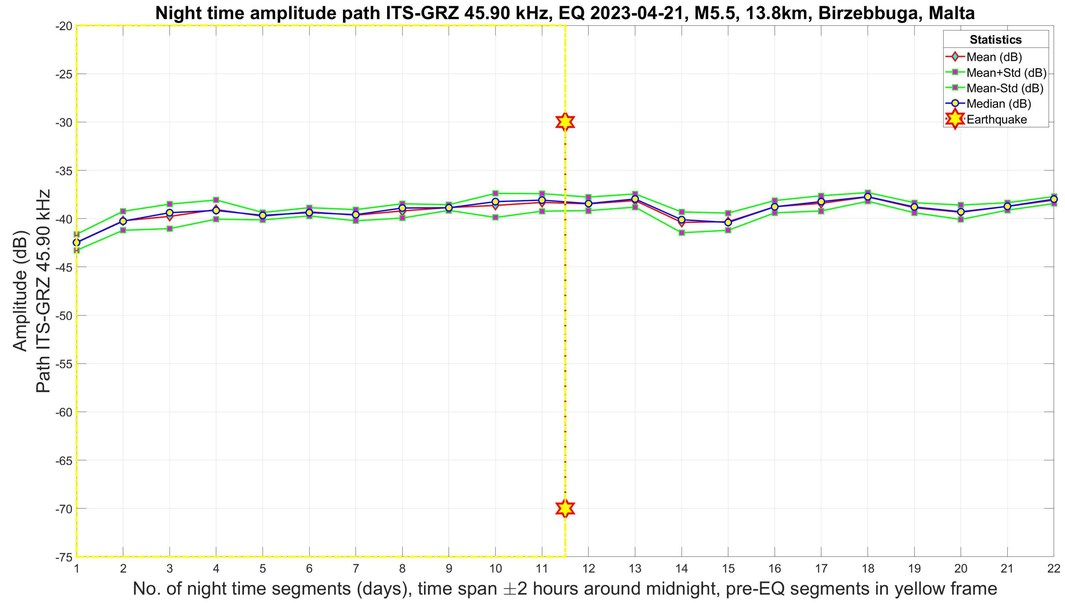
Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier F. Biagi[3], Patrick H. M. Galopeau[4], Ghulam Jaffer[5], Christoph Schirninger[6], Aleksandra Nina[7], Gordana Jovanovic[8], Giovanni Nico[9], Manfred Stachel[1], Özer Aydogar[1], Cosima Muck[1], Josef Wilfinger[1], Irmgard Jernej[1], and Werner Magnes[1]

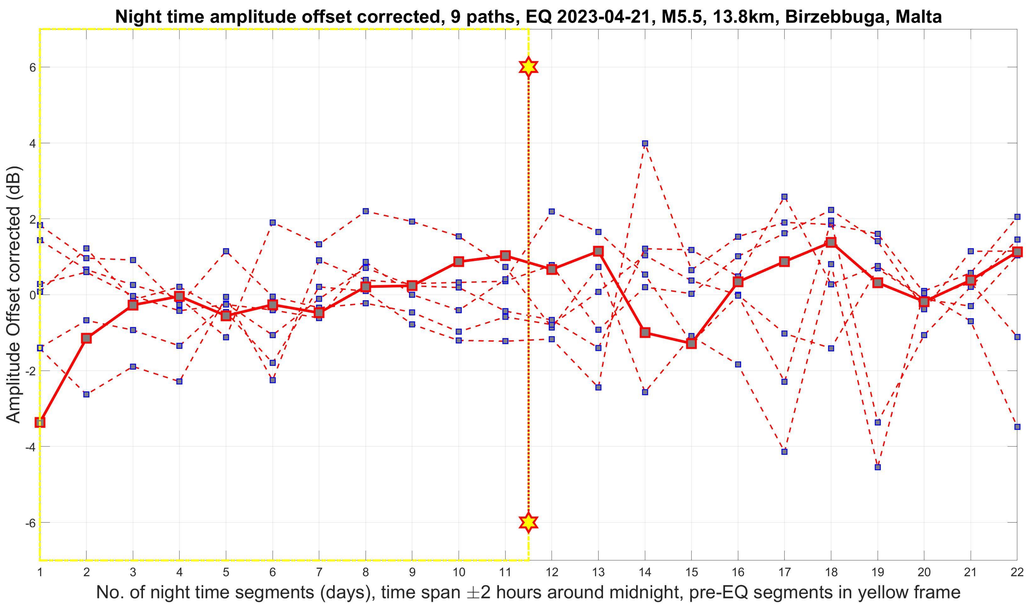
[1] Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [2] Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, [3] Department of Physics, University of Bari, Bari, Italy, [4] LATMOS-CNRS, UVSQ Université Paris-Saclay, Guyancourt, France, [5] SpaSys, SnT – Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg, Luxembourg, [6] Institute for Physics, University of Graz, Graz, Austria, [7] Institute of Physics Belgrade, University of Belgrade, Belgrade, Serbia, [8] Faculty of Science and Mathematics, University of Montenegro, Podgorica, Montenegro, [9] Institute of Applied Mathematics, Italian National Research Council, Bari, Italy

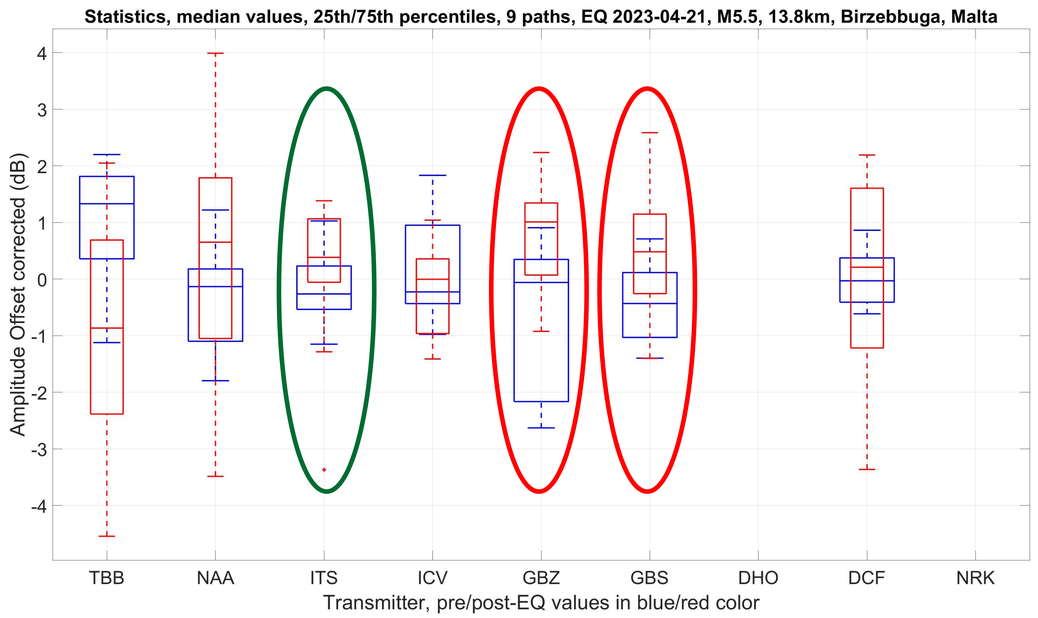
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2023-04-21, M5.5 13.8 KM, BIRŻEBBUĠA, MALTA

- Top Left: VLF/LF amplitudes (2023-04-11 to 2023-05-01) 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 9 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 9 paths (7 continuous), for a sig. level of 5% the event paths ITS-GRZ, GBZ-GRZ, GBS-GRZ show higher amplitude values after the EQ









EGU GENERAL ASSEMBLY, 14-19 APRIL 2024, VIENNA, AUSTRIA

IWF — SPACE RESEARCH INSTITUTE, AUSTRIAN ACADEMY OF SCIENCES, HUE@OEAW.AC.AT, EGU24-6001

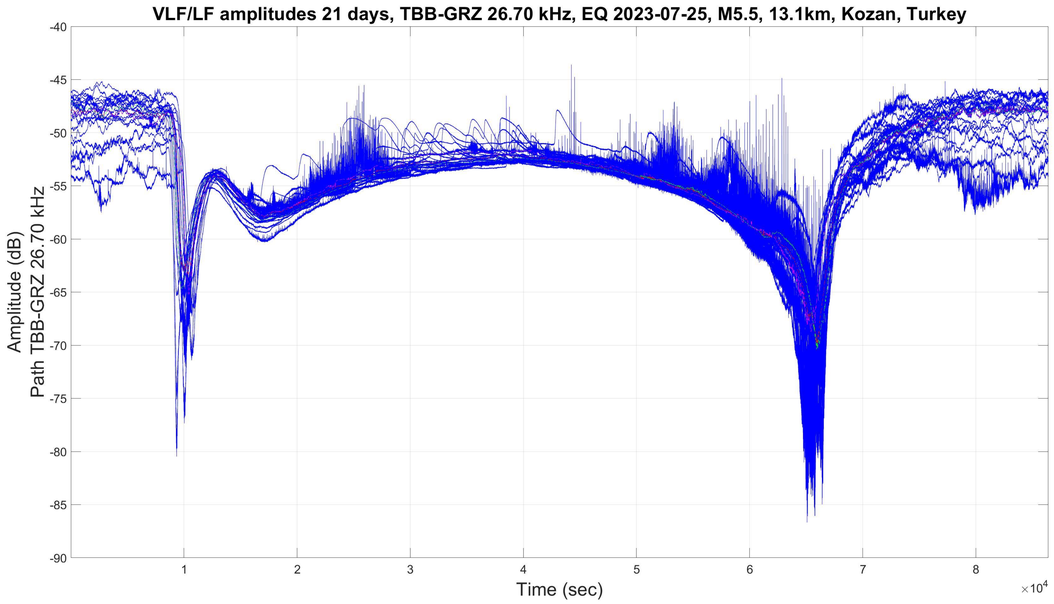
INVESTIGATION OF VLF/LF ELECTRIC FIELD VARIATIONS RELATED TO MAGNITUDE MW≥5.5 EARTHQUAKES IN THE MEDITERRANEAN REGION FOR THE YEAR 2023

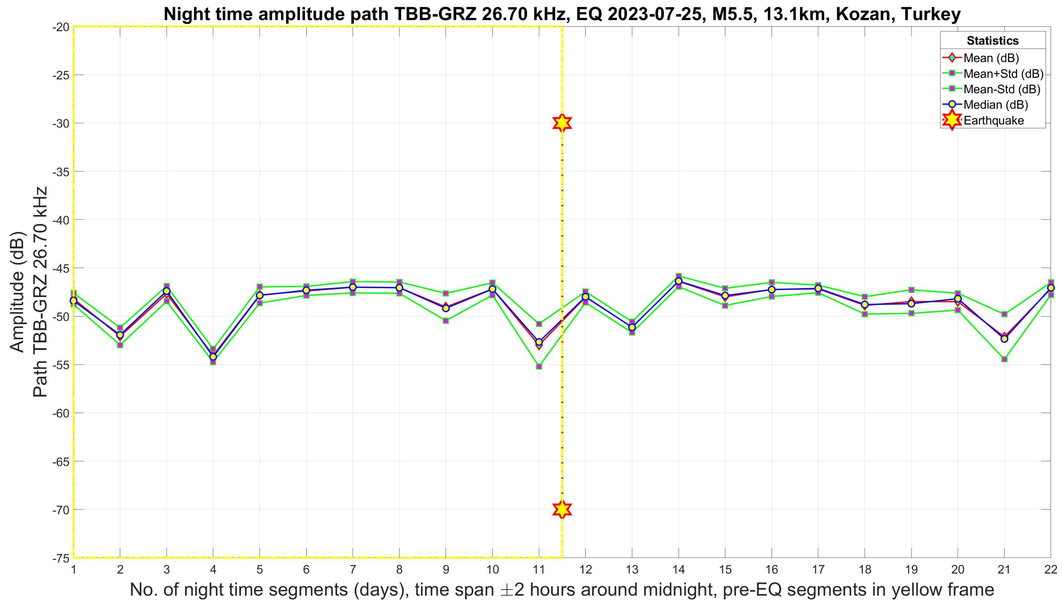
Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier F. Biagi[3], Patrick H. M. Galopeau[4], Ghulam Jaffer[5], Christoph Schirninger[6], Aleksandra Nina[7], Gordana Jovanovic[8], Giovanni Nico[9], Manfred Stachel[1], Özer Aydogar[1], Cosima Muck[1], Josef Wilfinger[1], Irmgard Jernej[1], and Werner Magnes[1]

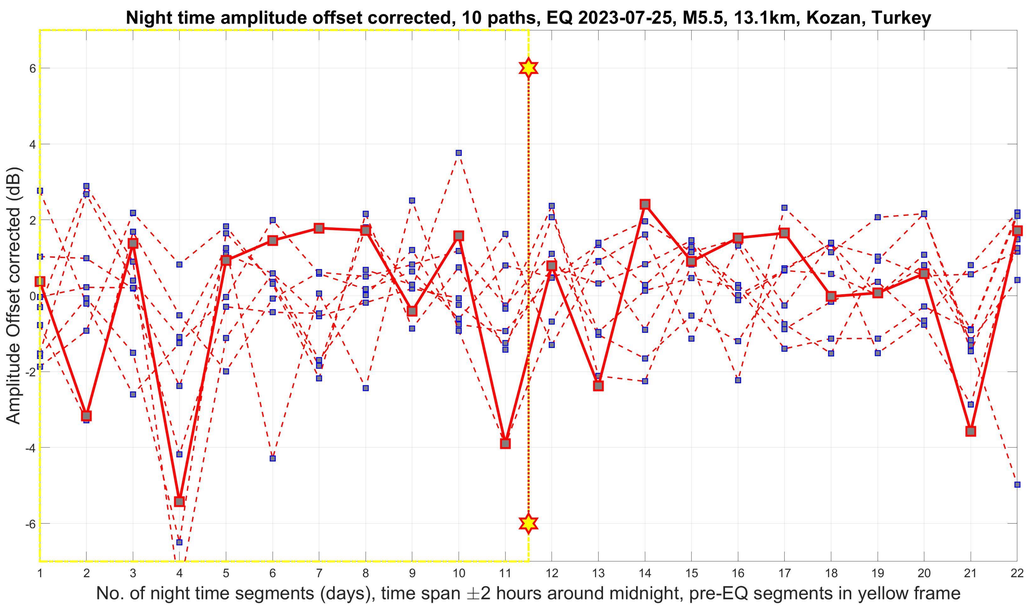
[1] Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [2] Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, [3] Department of Physics, University of Bari, Bari, Italy, [4] LATMOS-CNRS, UVSQ Université Paris-Saclay, Guyancourt, France, [5] SpaSys, SnT – Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg, Luxembourg, [6] Institute for Physics, University of Graz, Graz, Austria, [7] Institute of Physics Belgrade, University of Belgrade, Belgrade, Serbia, [8] Faculty of Science and Mathematics, University of Montenegro, Podgorica, Montenegro, [9] Institute of Applied Mathematics, Italian National Research Council, Bari, Italy

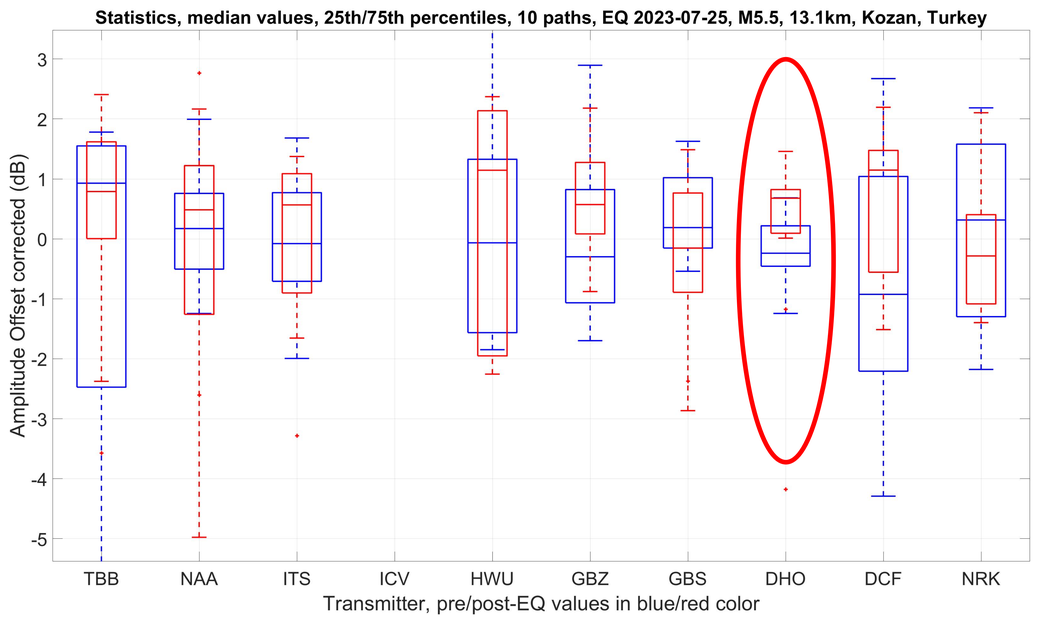
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2023-07-25, M5.5 13.12 KM, KOZAN, TURKEY

- Top Left: VLF/LF amplitudes (2023-07-15 to 2023-08-04) 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 (9 continuous), for a significance level of 5% the control path DHO-GRZ show higher amplitude values after the EQ









EGU GENERAL ASSEMBLY, 14-19 APRIL 2024, VIENNA, AUSTRIA

IWF — SPACE RESEARCH INSTITUTE, AUSTRIAN ACADEMY OF SCIENCES, HUE@OEAW.AC.AT, EGU24-6001

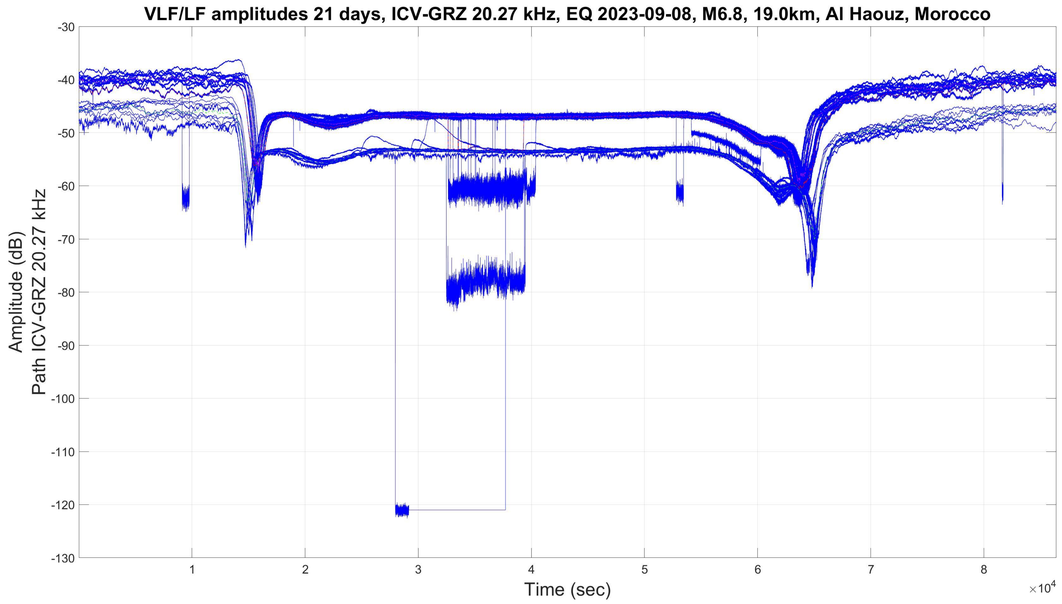
INVESTIGATION OF VLF/LF ELECTRIC FIELD VARIATIONS RELATED TO MAGNITUDE MW≥5.5 EARTHQUAKES IN THE MEDITERRANEAN REGION FOR THE YEAR 2023

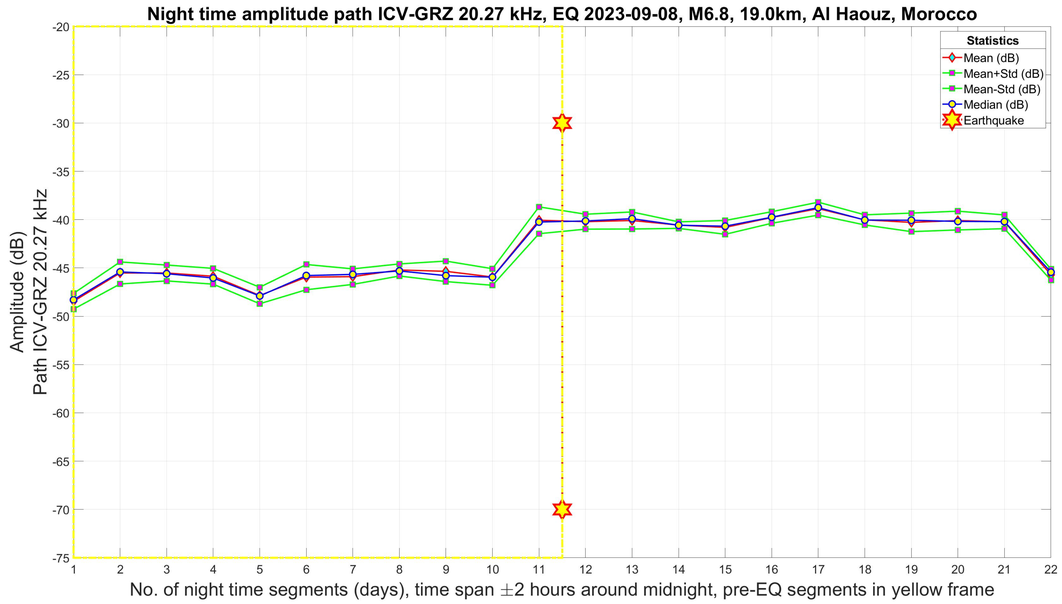
Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier F. Biagi[3], Patrick H. M. Galopeau[4], Ghulam Jaffer[5], Christoph Schirninger[6], Aleksandra Nina[7], Gordana Jovanovic[8], Giovanni Nico[9], Manfred Stachel[1], Özer Aydogar[1], Cosima Muck[1], Josef Wilfinger[1], Irmgard Jernej[1], and Werner Magnes[1]

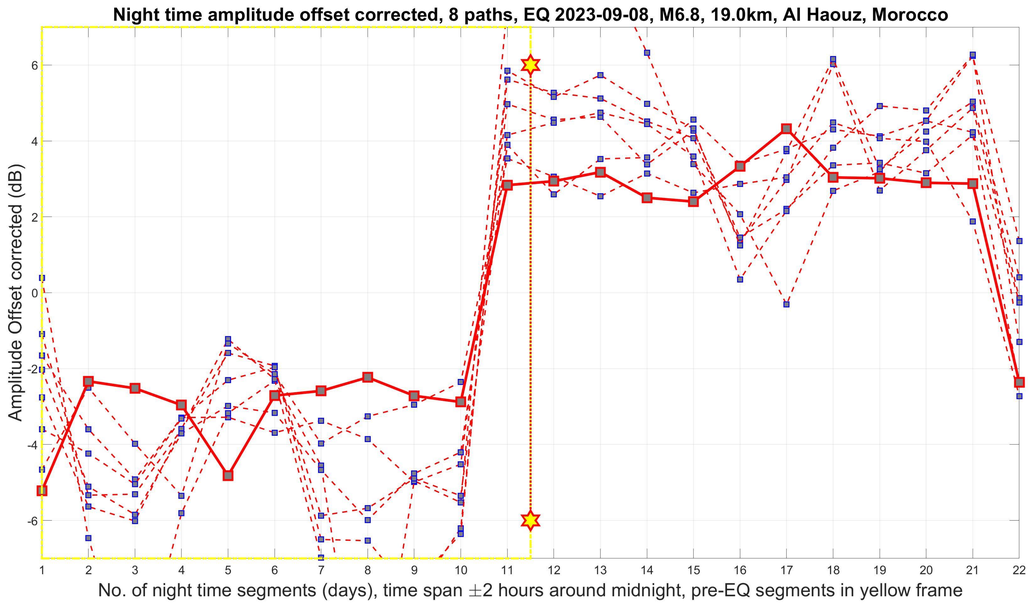
[1] Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [2] Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, [3] Department of Physics, University of Bari, Bari, Italy, [4] LATMOS-CNRS, UVSQ Université Paris-Saclay, Guyancourt, France, [5] SpaSys, SnT – Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg, Luxembourg, [6] Institute for Physics, University of Graz, Graz, Austria, [7] Institute of Physics Belgrade, University of Belgrade, Belgrade, Serbia, [8] Faculty of Science and Mathematics, University of Montenegro, Podgorica, Montenegro, [9] Institute of Applied Mathematics, Italian National Research Council, Bari, Italy

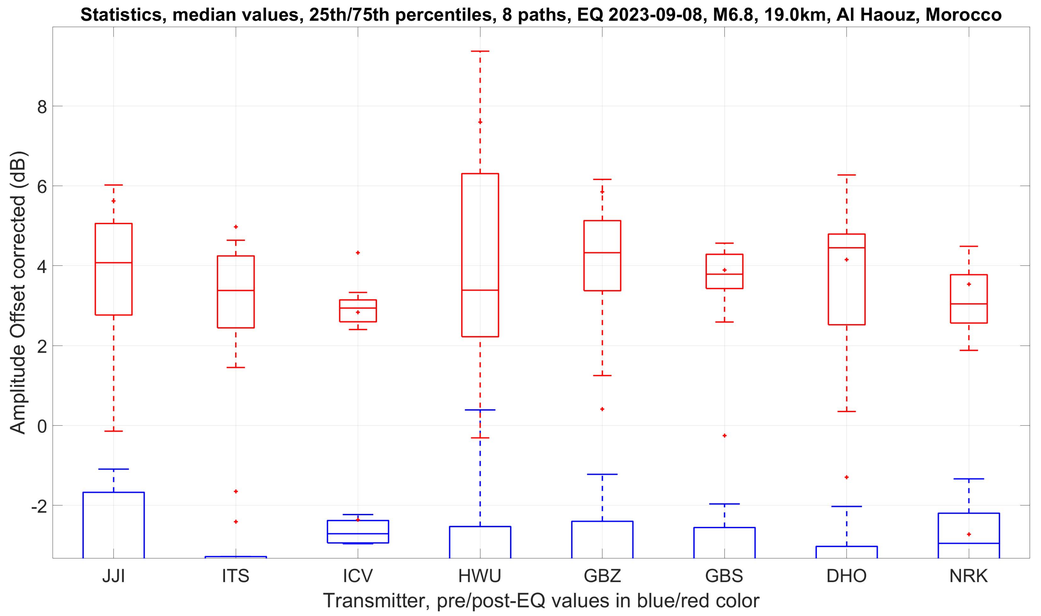
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2023-09-08, M6.8 19 KM, AL HAOUZ, MOROCCO

- Top Left: VLF/LF amplitudes (2023-08-29 to 2023-09-18) for the 20.27 kHz ICV-GRZ path, spikes and transmitter switch off periods are omitted
- Bottom Left: Offset corrected nighttime (± 2h around midnight) amplitude values for the 8 paths
- Top Right: Nighttime amplitude values for the possibly affected ICV-GRZ event path
- Bottom Right: Statistics (box plots) for the offset corrected 8 paths, systematic variation (antenna relocation) and not in the Dobrovolsky-Bowman area, nighttime ampl. method not reliable









EGU GENERAL ASSEMBLY, 14-19 APRIL 2024, VIENNA, AUSTRIA

IWF — SPACE RESEARCH INSTITUTE, AUSTRIAN ACADEMY OF SCIENCES, HUE@OEAW.AC.AT, EGU24-6001

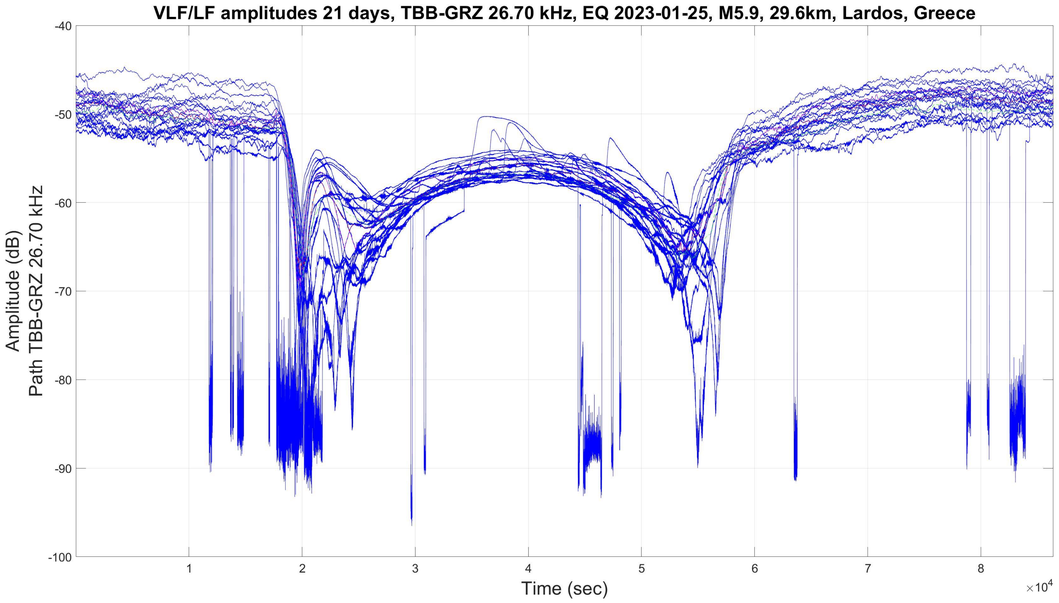
INVESTIGATION OF VLF/LF ELECTRIC FIELD VARIATIONS RELATED TO MAGNITUDE MW≥5.5 EARTHQUAKES IN THE MEDITERRANEAN REGION FOR THE YEAR 2023

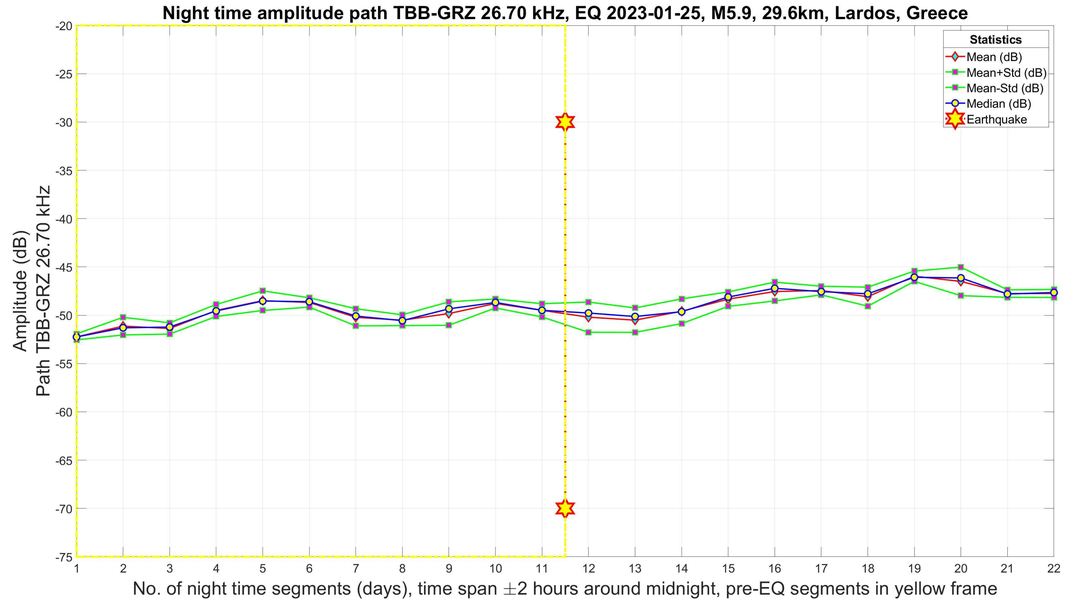
Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier F. Biagi[3], Patrick H. M. Galopeau[4], Ghulam Jaffer[5], Christoph Schirninger[6], Aleksandra Nina[7], Gordana Jovanovic[8], Giovanni Nico[9], Manfred Stachel[1], Özer Aydogar[1], Cosima Muck[1], Josef Wilfinger[1], Irmgard Jernej[1], and Werner Magnes[1]

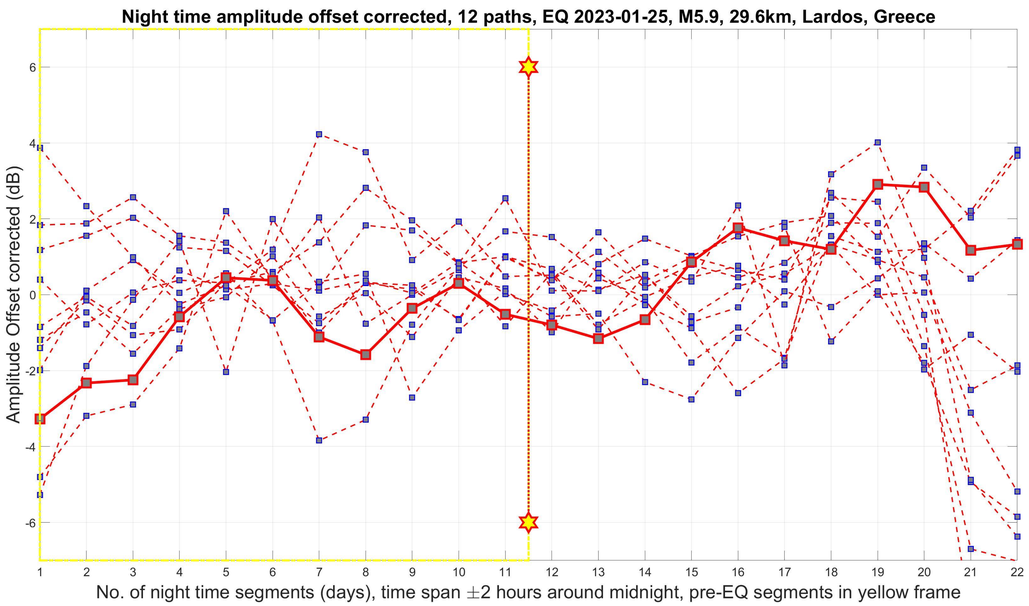
[1] Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [2] Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, [3] Department of Physics, University of Bari, Bari, Italy, [4] LATMOS-CNRS, UVSQ Université Paris-Saclay, Guyancourt, France, [5] SpaSys, SnT – Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg, Luxembourg, [6] Institute for Physics, University of Graz, Graz, Austria, [7] Institute of Physics Belgrade, University of Belgrade, Belgrade, Serbia, [8] Faculty of Science and Mathematics, University of Montenegro, Podgorica, Montenegro, [9] Institute of Applied Mathematics, Italian National Research Council, Bari, Italy

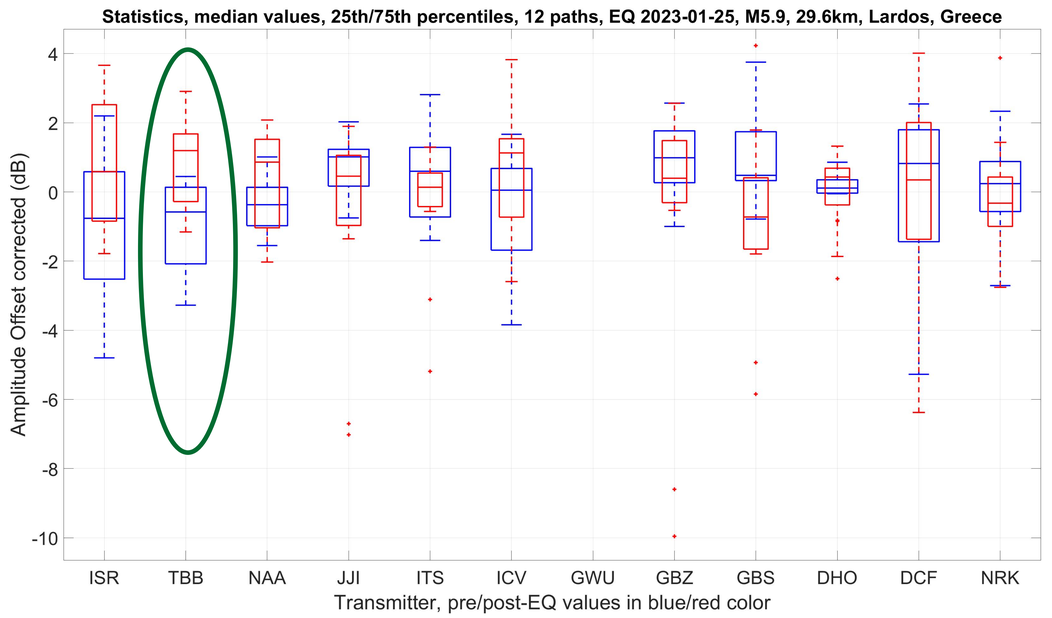
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2023-01-25, M5.9 29.6 KM, LÁRDOS, GREECE

- Top Left: VLF/LF amplitudes (2023-01-15 to 2023-02-04) 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 12 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 12 paths (11 continuous), for sig. level of 5% only the event path TBB-GRZ shows higher amp. values after the EQ (nighttime method)









EGU GENERAL ASSEMBLY, 14-19 APRIL 2024, VIENNA, AUSTRIA

IWF — SPACE RESEARCH INSTITUTE, AUSTRIAN ACADEMY OF SCIENCES, HUE@OEAW.AC.AT, EGU24-6001

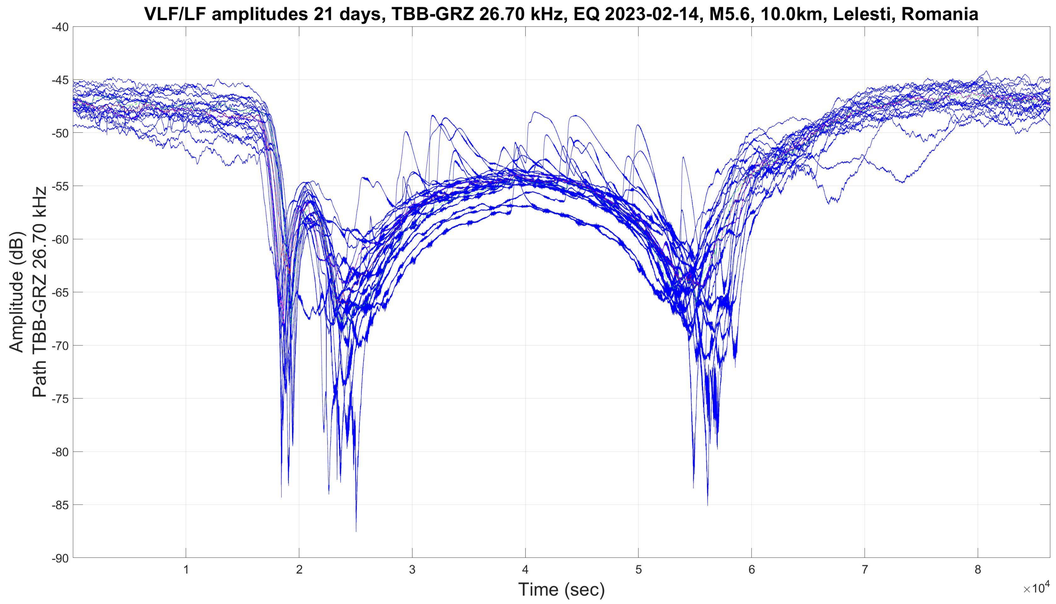
INVESTIGATION OF VLF/LF ELECTRIC FIELD VARIATIONS RELATED TO MAGNITUDE MW≥5.5 EARTHQUAKES IN THE MEDITERRANEAN REGION FOR THE YEAR 2023

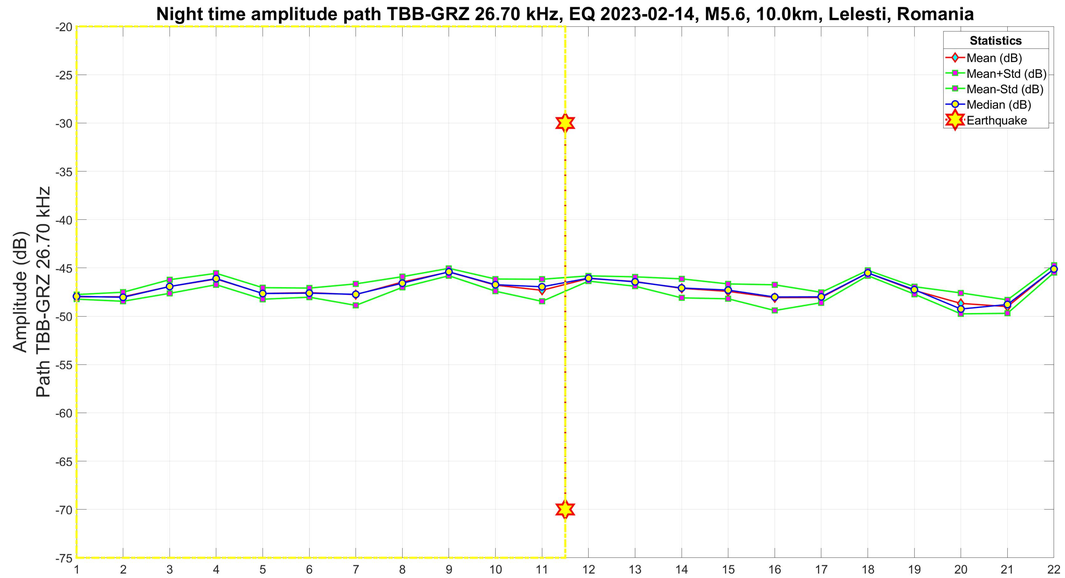
Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier F. Biagi[3], Patrick H. M. Galopeau[4], Ghulam Jaffer[5], Christoph Schirninger[6], Aleksandra Nina[7], Gordana Jovanovic[8], Giovanni Nico[9], Manfred Stachel[1], Özer Aydogar[1], Cosima Muck[1], Josef Wilfinger[1], Irmgard Jernej[1], and Werner Magnes[1]

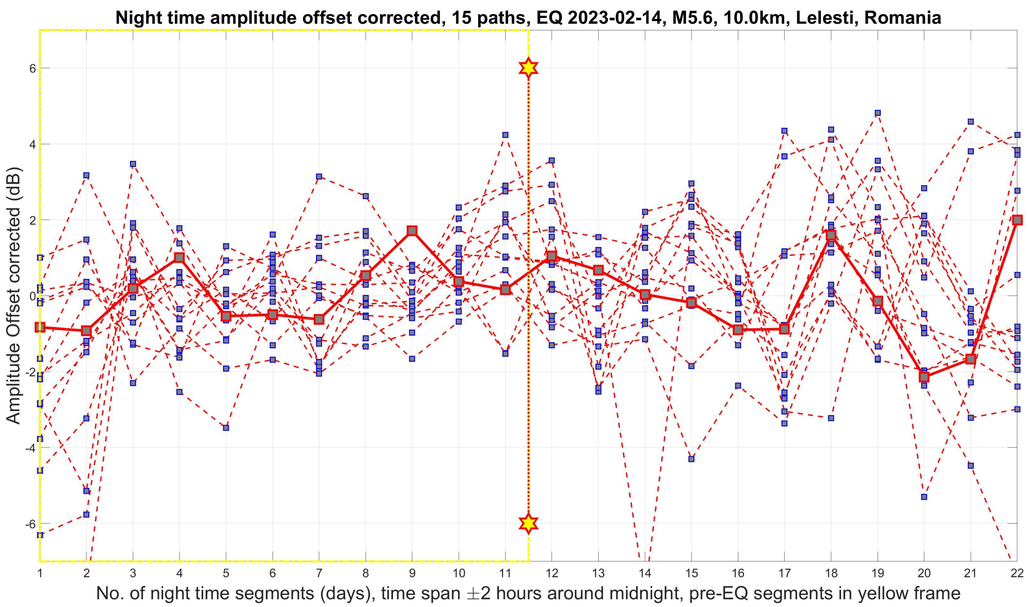
[1] Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [2] Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, [3] Department of Physics, University of Bari, Bari, Italy, [4] LATMOS-CNRS, UVSQ Université Paris-Saclay, Guyancourt, France, [5] SpaSys, SnT – Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg, Luxembourg, [6] Institute for Physics, University of Graz, Graz, Austria, [7] Institute of Physics Belgrade, University of Belgrade, Belgrade, Serbia, [8] Faculty of Science and Mathematics, University of Montenegro, Podgorica, Montenegro, [9] Institute of Applied Mathematics, Italian National Research Council, Bari, Italy

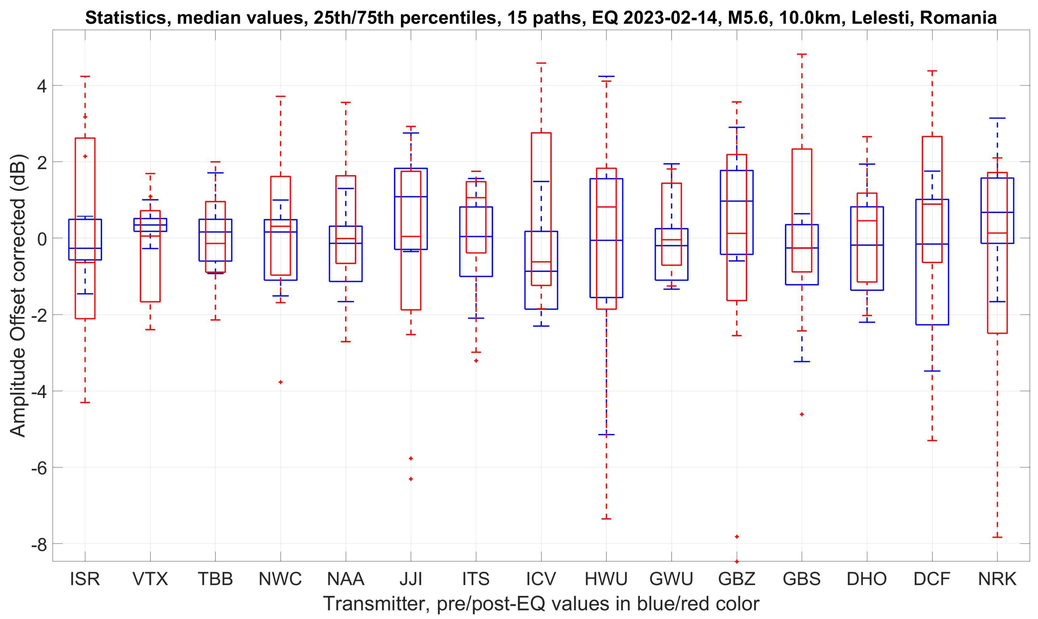
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKE 2023-02-14, M5.6 10 KM, LELEȘTI, ROMANIA

- Top Left: VLF/LF amplitudes (2023-02-04 to 2023-02-24) 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 15 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 15 paths, no significant variations (5% level) according to the nighttime method









IWF — SPACE RESEARCH INSTITUTE, AUSTRIAN ACADEMY OF SCIENCES, HUE@OEAW.AC.AT, EGU24-6001

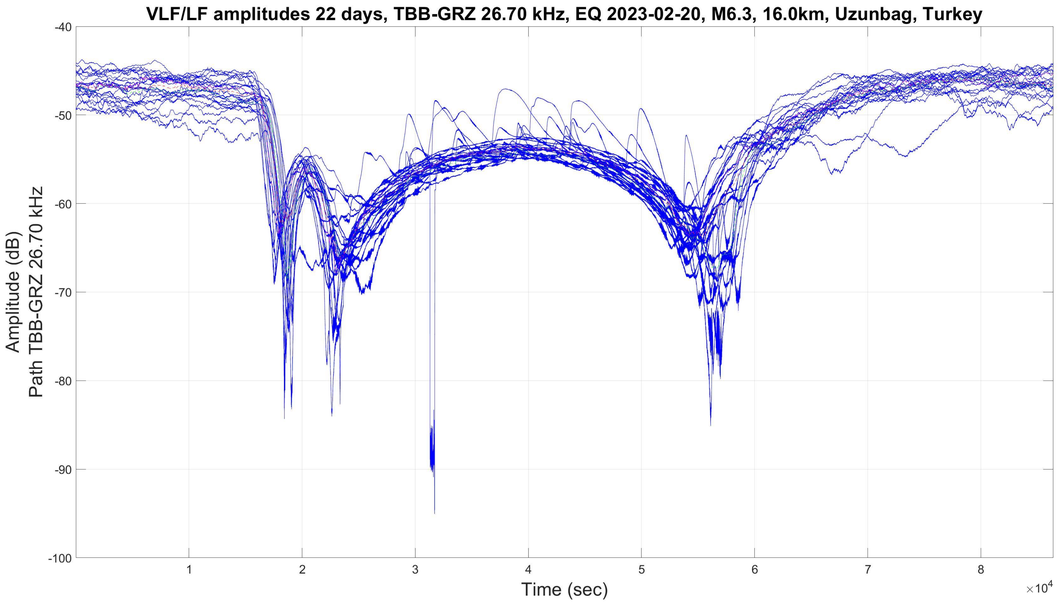
INVESTIGATION OF VLF/LF ELECTRIC FIELD VARIATIONS RELATED TO MAGNITUDE MW≥5.5 EARTHQUAKES IN THE MEDITERRANEAN REGION FOR THE YEAR 2023

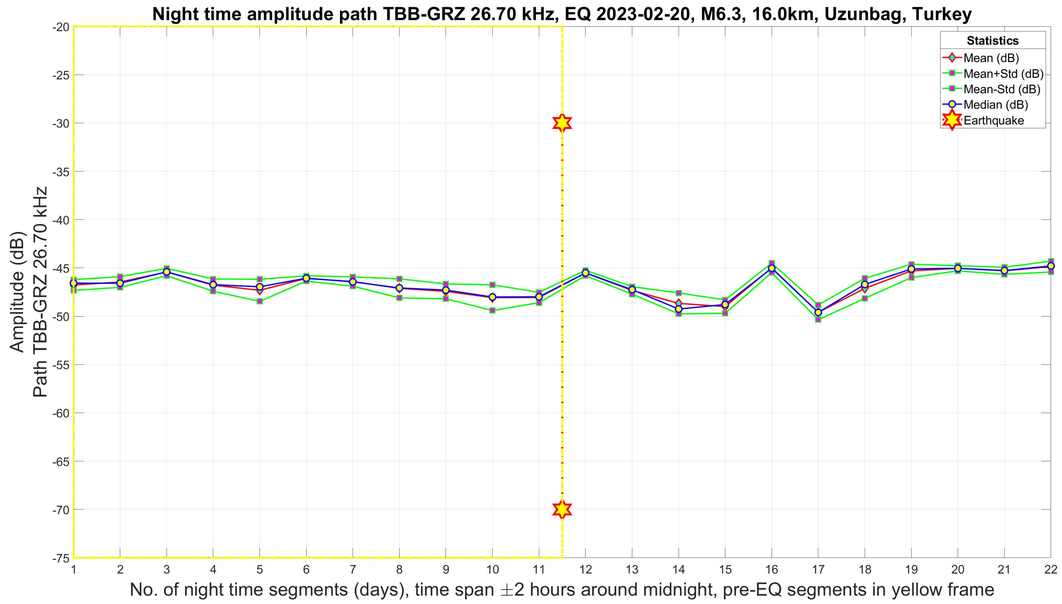
Hans Eichelberger[1], Mohammed Y. Boudjada[1], Konrad Schwingenschuh[1], Bruno P. Besser[1], Daniel Wolbang[1], Maria Solovieva[2], Pier F. Biagi[3], Patrick H. M. Galopeau[4], Ghulam Jaffer[5], Christoph Schirninger[6], Aleksandra Nina[7], Gordana Jovanovic[8], Giovanni Nico[9], Manfred Stachel[1], Özer Aydogar[1], Cosima Muck[1], Josef Wilfinger[1], Irmgard Jernej[1], and Werner Magnes[1]

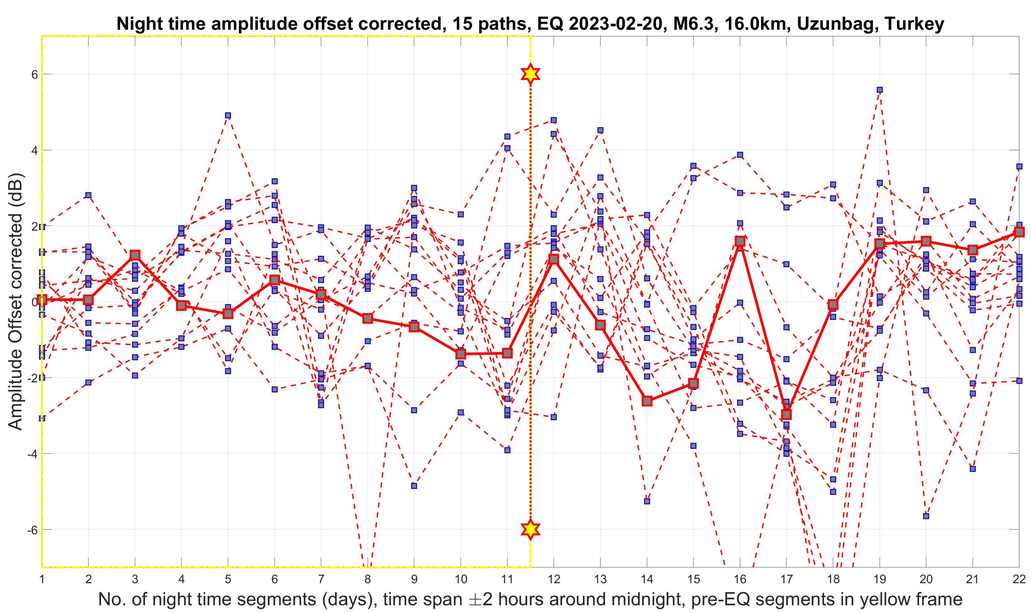
[1] Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [2] Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, [3] Department of Physics, University of Bari, Bari, Italy, [4] LATMOS-CNRS, UVSQ Université Paris-Saclay, Guyancourt, France, [5] SpaSys, SnT – Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg, Luxembourg, [6] Institute for Physics, University of Graz, Graz, Austria, [7] Institute of Physics Belgrade, University of Belgrade, Belgrade, Serbia, [8] Faculty of Science and Mathematics, University of Montenegro, Podgorica, Montenegro, [9] Institute of Applied Mathematics, Italian National Research Council, Bari, Italy

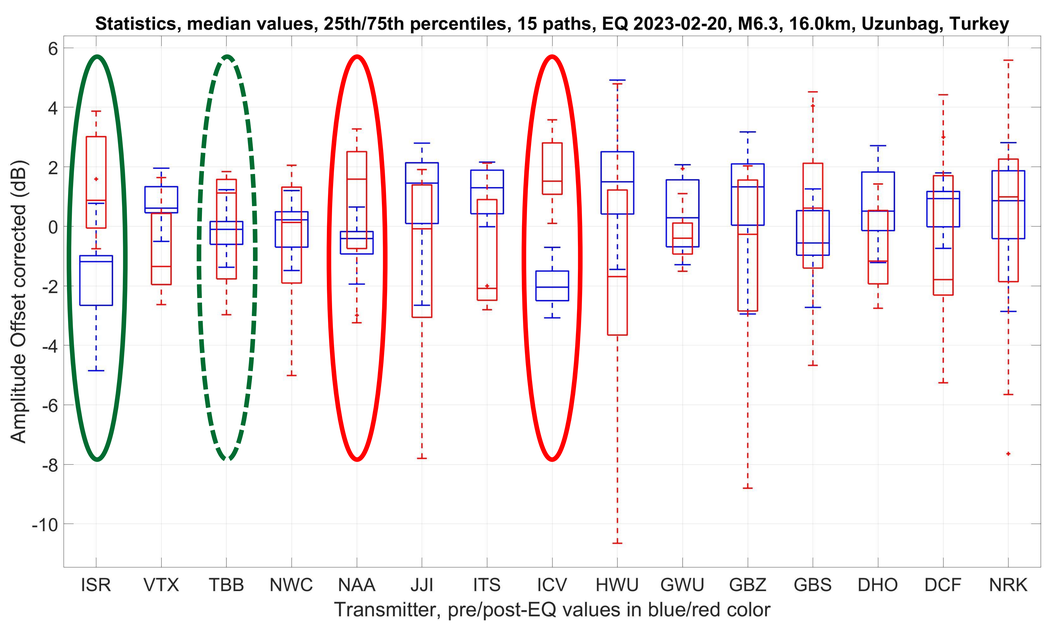
VLF/LF AMPLITUDE MEASUREMENTS, EARTHQUAKES 2023-02-20, M6.3 16 KM & M5.5 10 KM, UZUNBAĞ, TURKEY

- Top Left: VLF/LF amplitudes (2023-02-10 to 2023-03-02) 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 15 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 15 paths, for a sig. level of 5% the paths ISR-GRZ, NAA-GRZ, ICV-GRZ show higher amplitude values after the EQ, TBB-GRZ almost









EGU GENERAL ASSEMBLY, 14-19 APRIL 2024, VIENNA, AUSTRIA

IWF — SPACE RESEARCH INSTITUTE, AUSTRIAN ACADEMY OF SCIENCES, HUE@OEAW.AC.AT, EGU24-6001