ÖAW — AUSTRIAN ACADEMY OF SCIENCES

CHARACTERIZATION OF SUB-IONOSPHERIC VLF/LF WAVEGUIDES FOR SEISMIC EVENT STUDIES DURING SOLAR MINIMUM

Hans Eichelberger[1], Konrad Schwingenschuh[1], Mohammed Y. Boudjada[1], Bruno P. Besser[1], Daniel Wolbang[1], Alexander Rozhnoi[2], Maria Solovieva[2], Pier Francesco Biagi[3], Manfred Stachel[1], Özer Aydogar[1], Cosima Muck[1], Claudia Grill[1], and Irmgard Jernej[1]

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In this study we present measurements and simulations of mid-latitude sub-ionospheric propagation paths between several VLF/LF transmitters and the Graz seismo-electromagnetic receiver facility (Schwingenschuh etal, 2011) during the current solar minimum condition. The upper D/E-region boundary of the waveguide is stable during the low solar activity in the years 2018 and 2019, i.e. measured VLF/LF amplitude and phase variations are mainly due to natural excitations from the lithosphere, atmosphere, and man-made disturbances. In particular, this period gives a baseline to characterize VLF amplitude and phase modulations in the waveguide cavity related to seismic activity over Europe. In addition, this opportunity let us probe the signal threshold and feed-back into waveguide simulation models. We conclude, proven long-term VLF/LF measurements, the continuous monitoring of the cavity, could be valuable in the assessment of seismic hazard scenarios.

VLF/LF TRANSMITTER - GRZ RECEIVER

Receiver: Graz, IWF, UltraMSK system, N 47°2'40.38'' O 15°28'47.68''				
No. (path)	Acronym	Frequency (kHz)	Distance, Path length (km)	Transmitter
1	JXN	16.40	2160	Aldra, Norway
2	GBS	19.58	1570	Anthorn, UK
3	ICV	20.27	820	Tavolara, Sardinia, Italy
4	HWU	20.90 / 21.75	1080	Le Blanc, St. Assise, France
5	NPM	21.40	12380	Lualualei, Hawaii, USA
6	GBZ	22.10	1540	Skelton, UK
7	DHO	23.40	875	Rhauderfehn, Germany
8	NAA	24.00	6110	Cutler, Maine, USA
9	TBB	26.70	1445	Bafa, Turkey
10	NRK	37.50	2975	Keflavik, Iceland
11	ITS	45.90	1105	Niscemi, Sicily, Italy
12	VTX	19.20 (17.00)	7240	Vijayanarayanam, India

Table 1: List of VLF/LF transmitter to the Graz receiver facility (amplitude and phase measurements). Extended network with the INFREP Elettronika system (Biagi etal, 2019).

SIMULATION SOFTWARE

For propagation studies along the VLF/LF paths we use the Long Wavelength Propagation Capability code (LWPC v2.1) including several options for e.g. ionospheric profile modelling (Ferguson 1998). The profiles are based on Wait's parameters, the reflection height H' (km) and sharpness factor β (1/km), (Wait and Spies, 1964). This (reasonable) two parameter (H', β) approximation for D-region altitudes (50-80 km) gives an electron density $N_e(z)$ (m^{-3}), $N(z)=1.43 \times 10^{13} \exp(-0.15H') \exp((\beta-0.15)(z-H'))$.

An alternative semiempirical model for $N_e(z)$ in the altitude range 60-150 km is given by Friedrich etal (2018).

VLF/LF NETWORK, EUROPEAN AREA

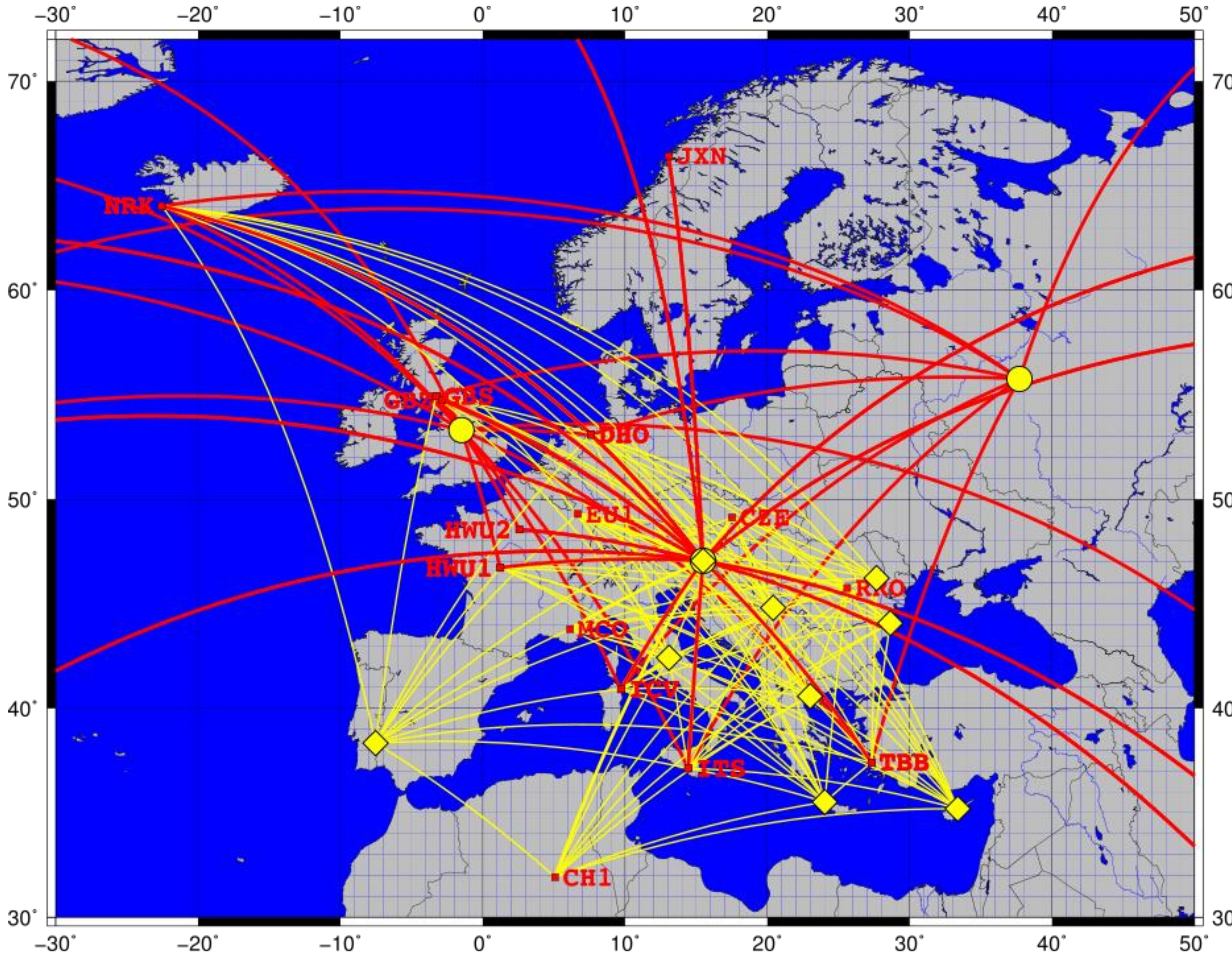

Figure 1: Great circle paths (red color) between VLF/LF transmitter and receiver with three stations (Moscow, Sheffield, Graz; yellow circles) and the INFREP system (paths and diamonds in yellow) over Europe. Credit map software: Generic Mapping Tools (GMT)

The seismic prone areas, Apennine Mountains, Balkan Peninsula, Aegean Sea, and Western Turkey are well covered with the network, see e.g. Boudjada etal (2020). Complementary seismic and volcanic investigations via satellites are carried out by e.g. Schwingenschuh etal (2020).

SIMULATION RESULTS

VLF/LF amplitude and phase measurements and simulations with the LWPC code are in good agreement with each other (shown for 4 links, see next page), even without fine-tuning of the ionospheric parameter H' and β (standard values selected). The simulated paths are scaled and offset trimmed with constant values in order to match the measured values (which are smooth traces due to solar minimum conditions).

The residuals between measurements and simulations are higher during terminator times, modified profiles and narrower time spans (10 min in this simulations) shall improve the performance. A network-wide simulation with many paths requires an automated procedure and carefully tested links at regular times in order to get baseline ionospheric profiles.

CONCLUSIONS & OUTLOOK

- VLF/LF amplitude and phase measurements are in good agreement with simulations, for further improvements matched ionospheric profiles are necessary
- Long-term VLF/LF measurements are a valuable tool for monitoring the sub-ionospheric cavity and characterise induced excitations by natural hazards
- A VLF/LF network as shown in Fig.1 is mandatory in order to sample natural hazard risk areas
- Multiparameter studies and combined investigations further strengthen the conclusions w.r.t. the scienctific goals

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SUMMARY

VLF/LF measurements between several transmitter and receiver facilities in a network are a perfect tool to monitor excitations in the waveguide. Simulations can support the scientific goals, a feed-back into models via ionospheric parameters is necessary.

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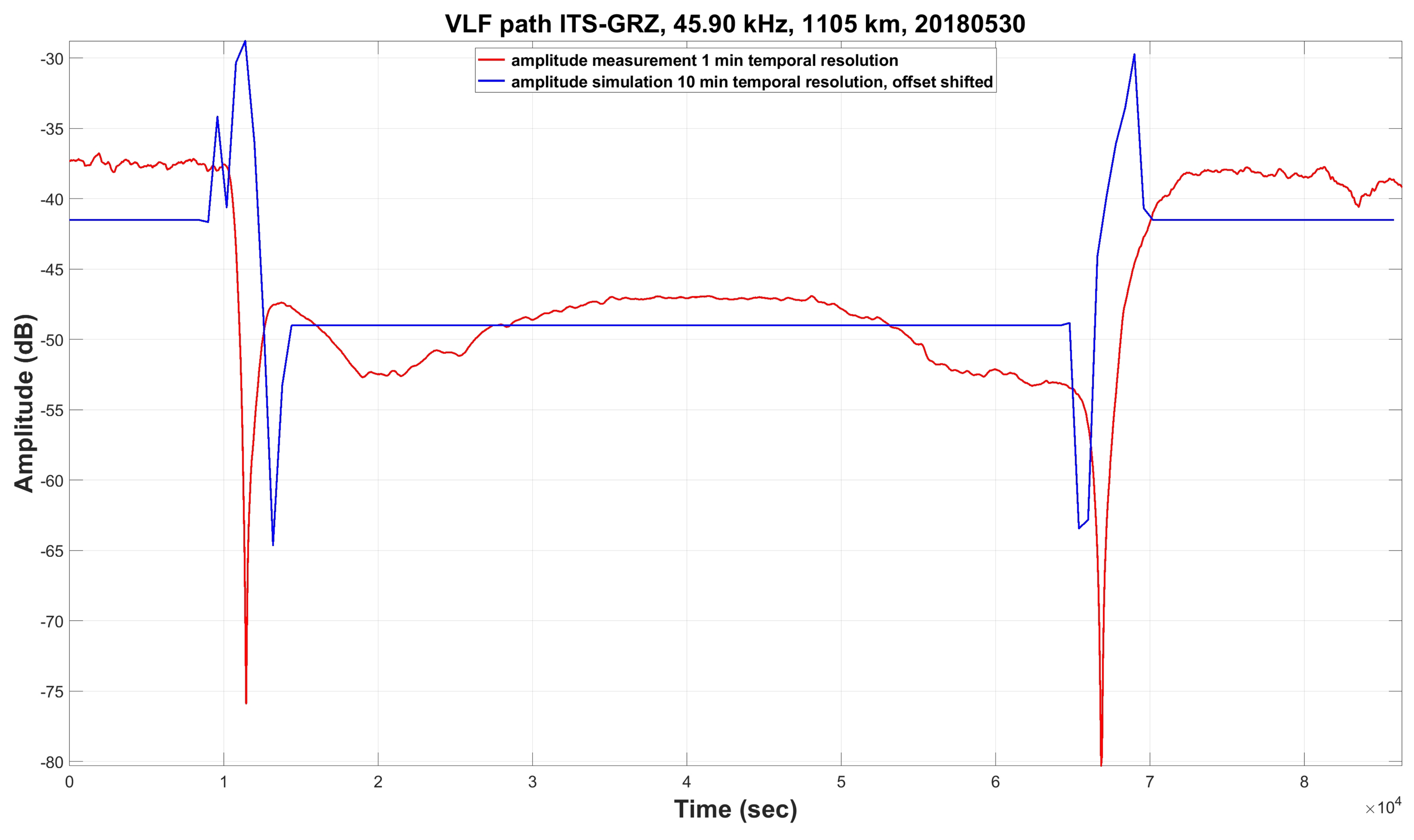
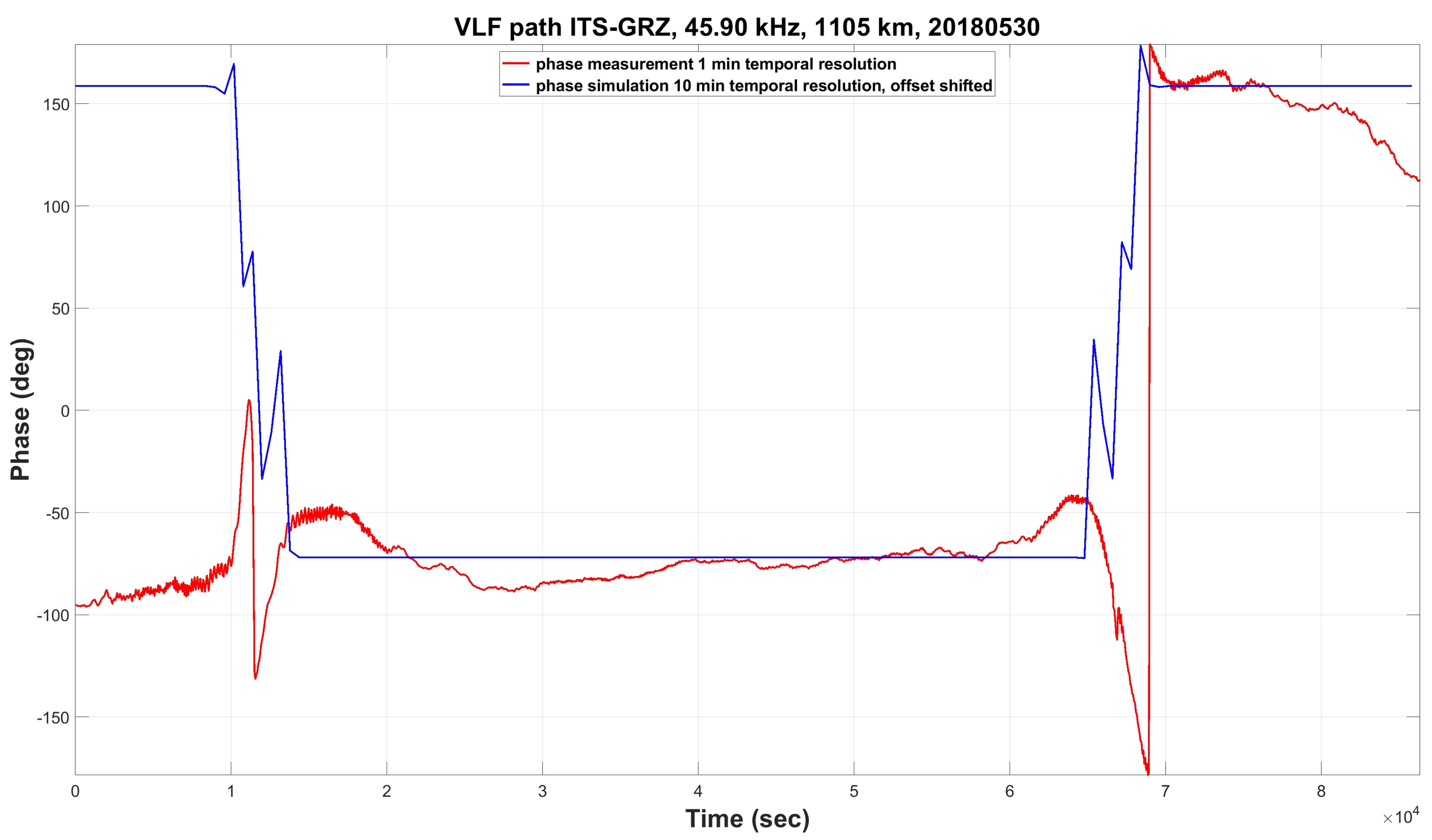
TRANSMITTER ITS – GRZ RECEIVER

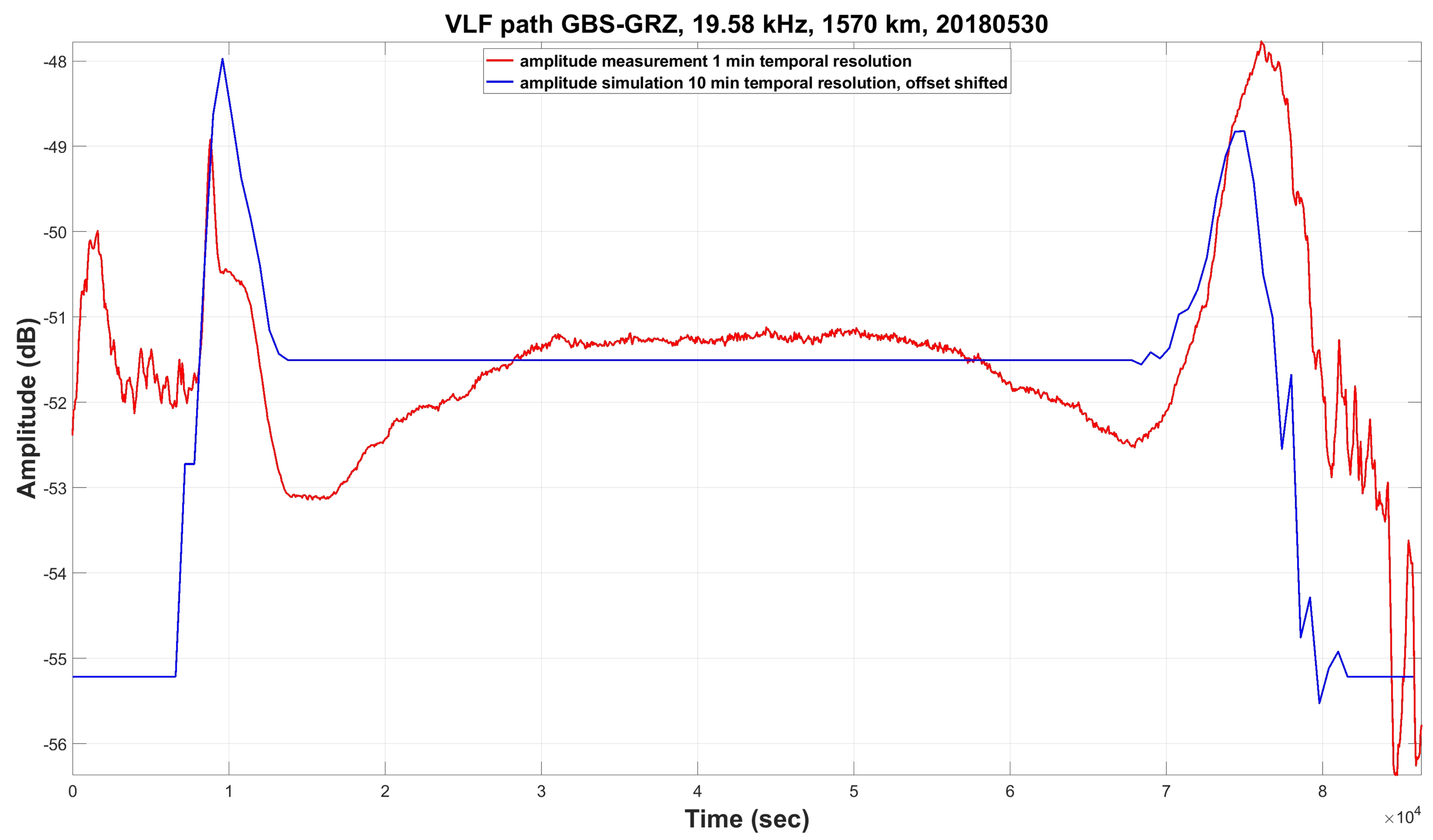
- Top: Amplitude measurements (red) and simulations (blue)
- Bottom: Phase measurements (red) and simulations (blue)
- ITS-GRZ path 45.90 kHz, 1105 km

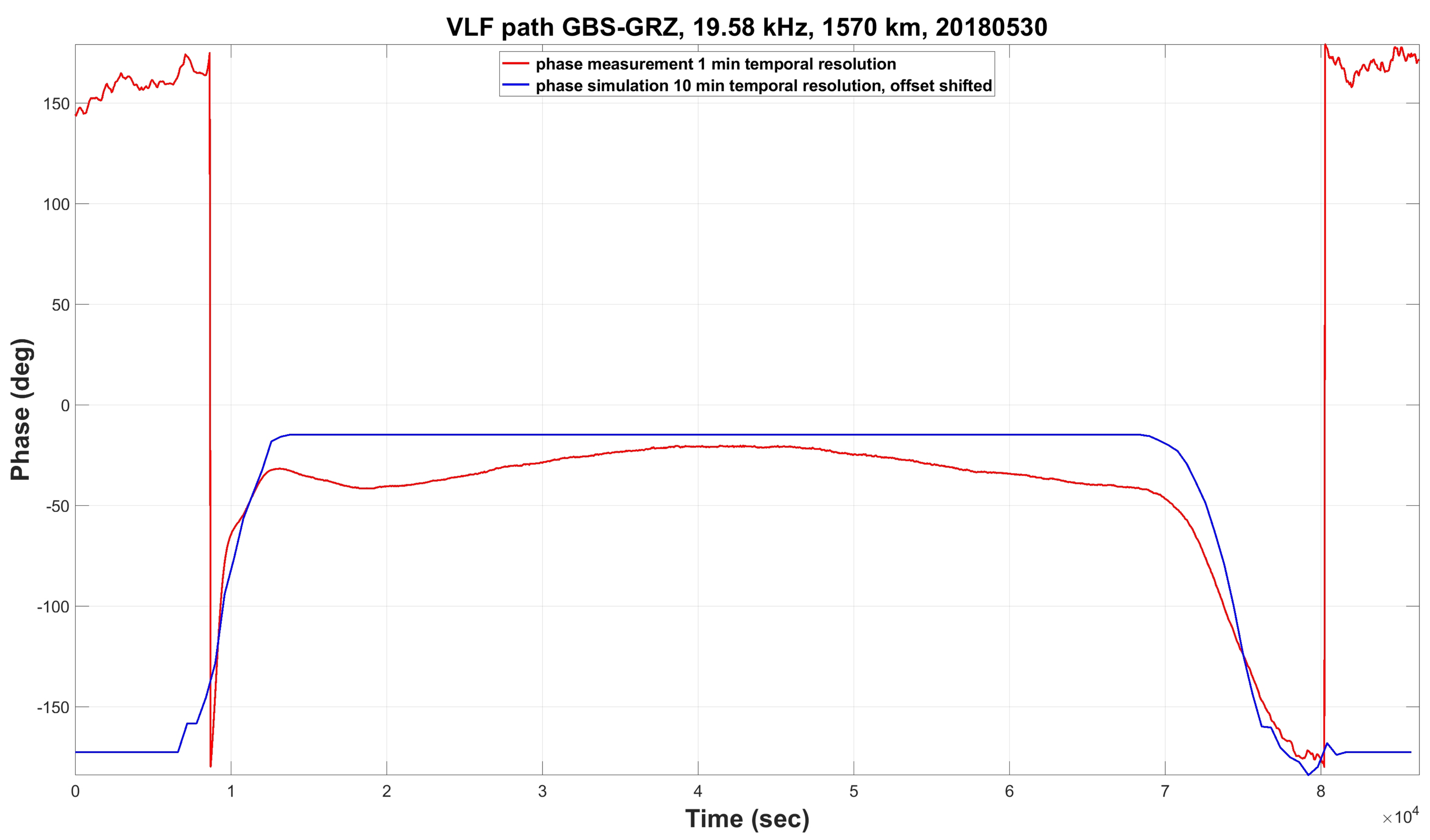




TRANSMITTER GBS - GRZ RECEIVER

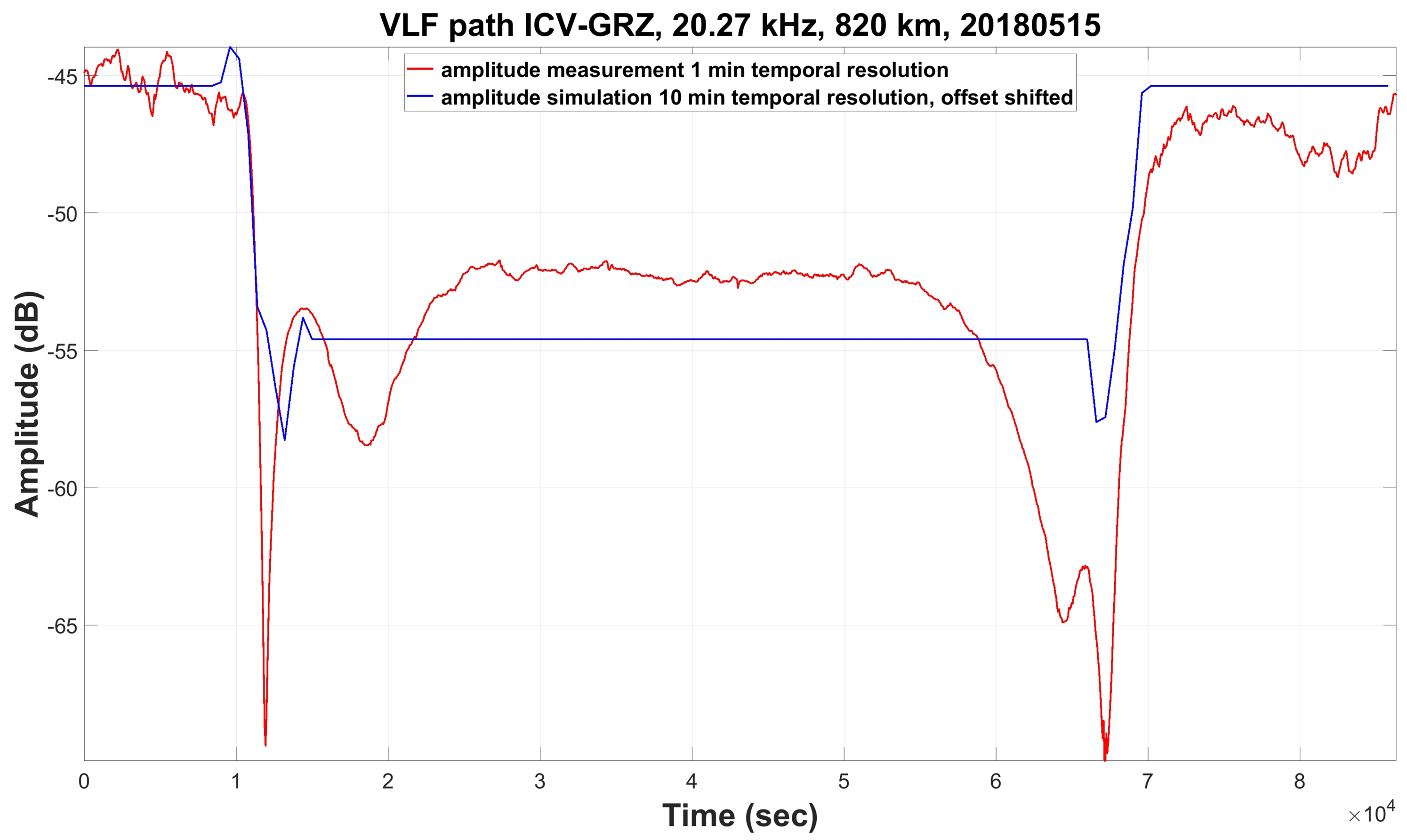
- Top: Amplitude measurements (red) and simulations (blue)
- Bottom: Phase measurements (red) and simulations (blue)
- GBS-GRZ path 19.58 kHz, 1570 km

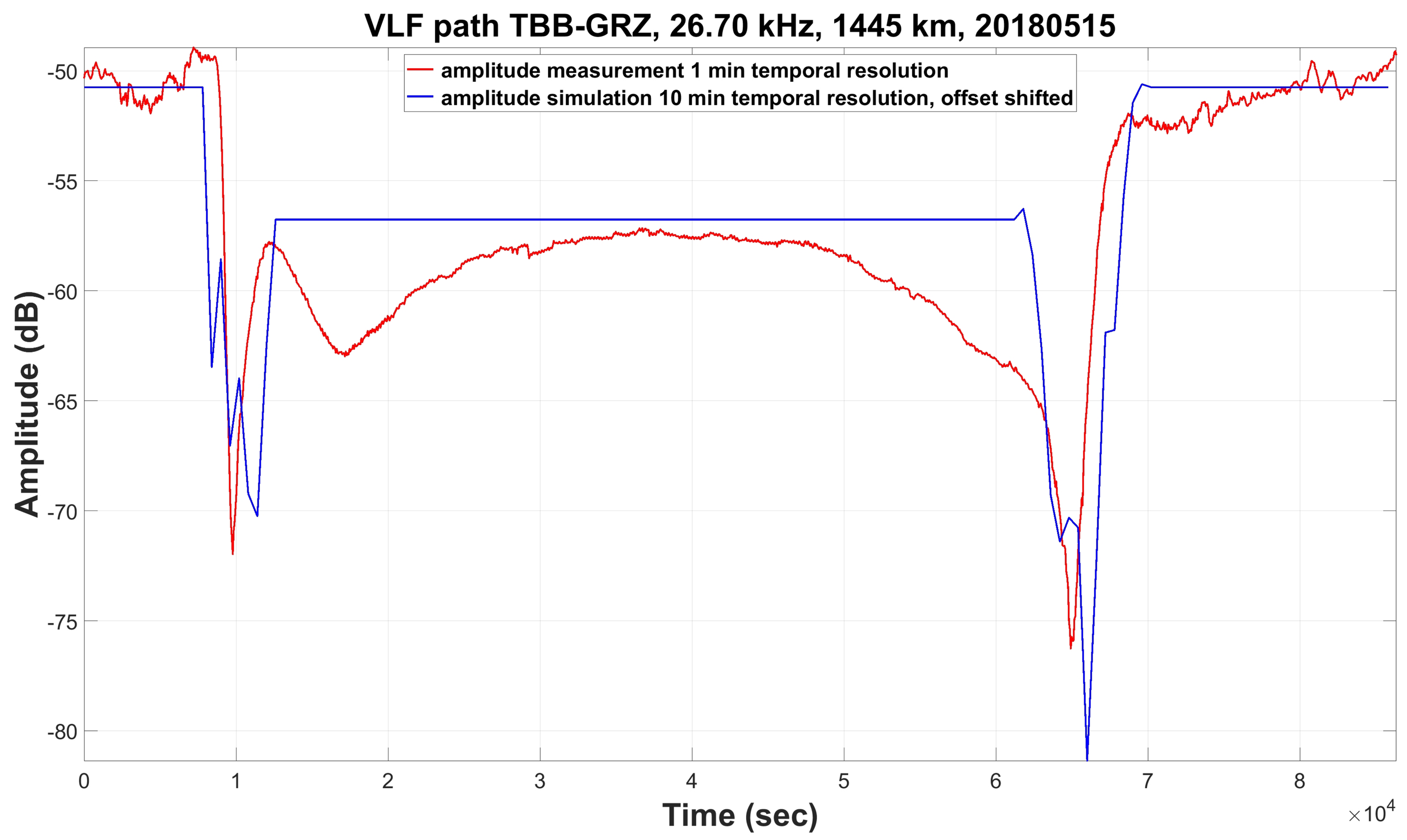




VLF TRANSMITTER - GRZ RECEIVER

- Top: ICV-GRZ path (20.27 kHz, 820 km) amplitude measurements (red) and simulations (blue)
- Bottom: TBB-GRZ path (26.7 kHz, 1445 km) amplitude measurements (red) and simulations (blue)





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