

Ray paths of VLF/LF transmitter radio signals in the seismic Adriatic regions

M.Y. Boudjada¹, H.U. Eichelberger¹, P.F. Biagi², K. Schwingenschuh¹, G. Nico³, M. Solovieva⁴, A. Ermini⁵, I.A. Moldovan⁶, M.E. Contadakis⁷, A. Nova⁸, K. Katzis⁹, M. Bezzeghoud¹⁰, H. Lammer¹, P.H.M. Galopeau¹¹, B. Besser¹, and Ö. Aydogar¹

- ⁰¹ Space Research Institute, Austrian Academy of Sciences, Graz, Austria;
- ⁰² Department of Physics, University of Bari, Bari, Italy
- ⁰³ Institute for Applied Mathematics (IAC), National Research Council of Italy (CNR), Bari, Italy;
- ⁰⁴ Institute of the Earth Physics, RAS, Moscow, Russia;
- ⁰⁵ Department of Industrial Engineering, University of Tor Vergata, Rome, Italy;
- ⁰⁶ National Institute of Earth's Physics, Seismological Department, Bucharest, Romania;
- ⁰⁷ Department of Surveying & Geodesy, University of Thessaloniki, Thessaloniki, Greece;
- ⁰⁸ Institute of Physics Belgrade, University of Belgrade, Belgrade, Serbia;
- ⁰⁹ Department of Computer Science and Engineering, European University Cyprus, Nicosia, Cyprus;
- ¹⁰ Geophysical Centre of Évora and Physics Department, ECT, University of Évora, Évora, Portugal;
- ¹¹ LATMOS-CNRS, Université Versailles Saint-Quentin-en-Yvelines, Guyancourt, France



Abstract

We analyze the radio wave propagations of VLF/LF transmitter signals along sub-ionospheric paths using two different reception systems localized side by side at the Space Research Institute (IWF) of the Austrian Academy of Sciences (ÖAW) in Graz (Austria). Those systems allow the simultaneous detection of more than fifteen transmitter signals emitting in the northern (i.e. France, Germany and United Kingdom) and southern (i.e. Italy and Turkey) parts of Europe. In this work, we investigate the transmitter radio wave propagations associated with two earthquakes (EQs) which occurred, at two occasions, in nearly the same Croatian regions (Geo. Long.=16°E; Geo. Lat.=45°N). The first and second EQs happened, respectively, on March 22 and December 29, 2020, with magnitudes M_w equal to 5.4 and 6.4. The use of two complementary reception systems, i.e. INFREP (Biagi et al., *Open Journal of Earthquake Research*, 8, 2019) and UltraMSK (Schwingenschuh et al., *Nat. Hazards Earth Syst. Sci.*, 11, 2011), and the proximity to the epicenters lead us to characterize the behavior of the transmitter signal amplitudes particularly above the Croatian seismic regions. We analyze the amplitude variation for a given transmitter frequency starting few weeks before the earthquakes occurrences. We discuss the observed anomalies in the transmitter signals which may be considered as precursors due to the ionospheric disturbances of the transmitter ray paths above the earthquakes preparation zones.

→ Earthquakes Events

Event1
2020-03-22 05:24
45.87N 16.02E 10 6.4
CROATIA

M5.4 2020/03/22 - 05:24:02 UTC Lat 45.87 Lon 16.02 Depth 10.0 km

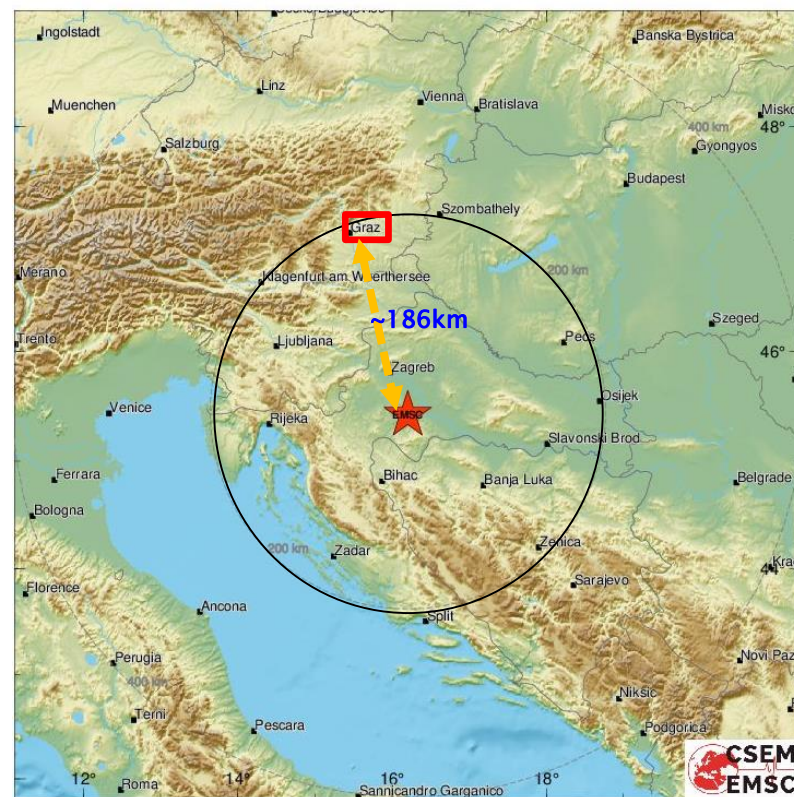
7 km NE of Zagreb, Croatia (pop: 699,000 local time: 06:24 2020/03/22)
 5 km S of Kasina, Croatia (pop: 1,500 local time: 06:24 2020/03/22)



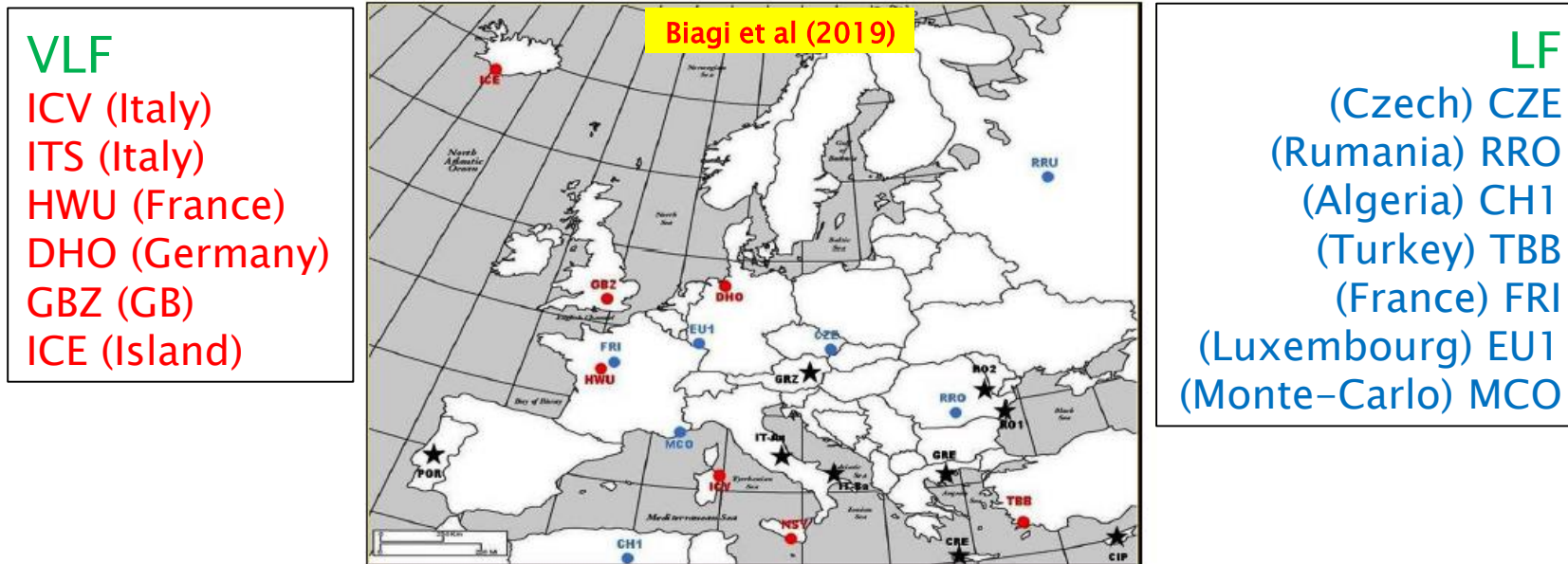
Event2
2020-12-29 11:19:54.6
45.46N 16.31E 10 6.4
CROATIA

M6.4 2021/12/29 - 11:19:54 UTC Lat 45.42 Lon 16.21 Depth 10.0 km

47 km SSE of Zagreb, Croatia (pop: 698,000 local time: 12:19 2020/12/29)
 14 km WSW of Sisak, Croatia (pop: 35,700 local time: 12:19 2020/12/29)



→ VLF and LT Transmitters in Europe



- Two VLF/LF reception systems
- Ultra-MSK VLF Schwingenschuh et al (2011)
 - Elettronika VLF/LF Biagi et al (2011)

➔ Methodology and VLF/LF signal analysis

1. Diurnal variations of transmitter signal amplitudes

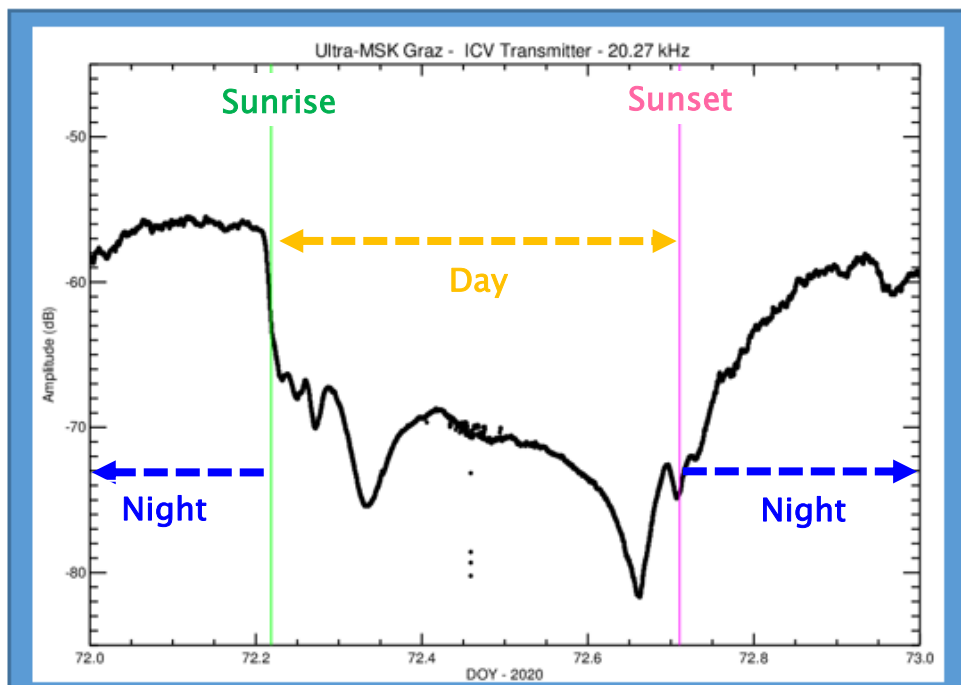
2. 50 days before EQs occurrences

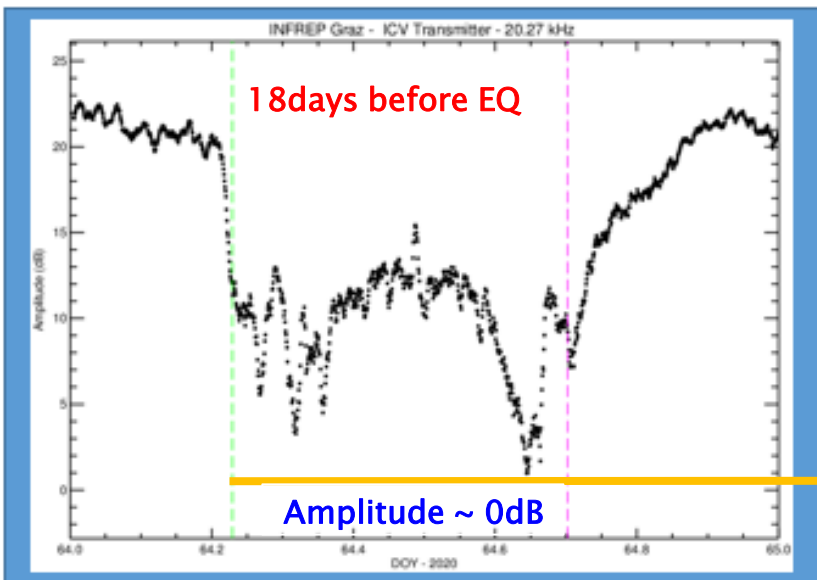
➤ **Event1**: from 13 Feb. to 24 March 2020

➤ **Event2**: from 21 Nov. to 31 Dec. 2020

3. Terminator Times (TTs): Sunrise and Sunset

Hayakawa et al (1996)

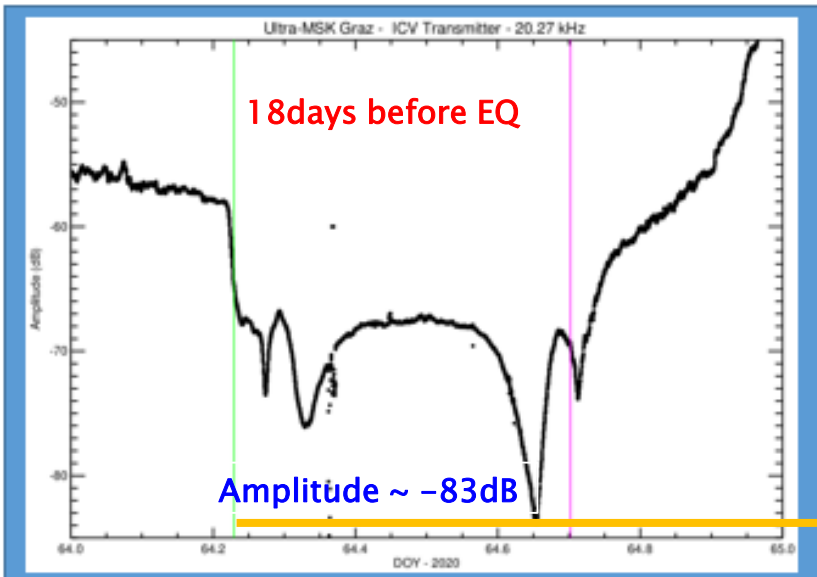
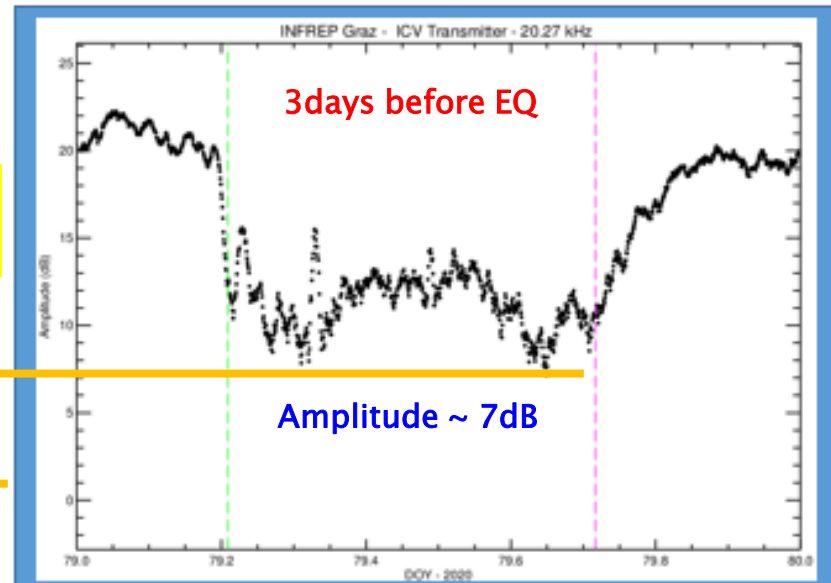




Event1

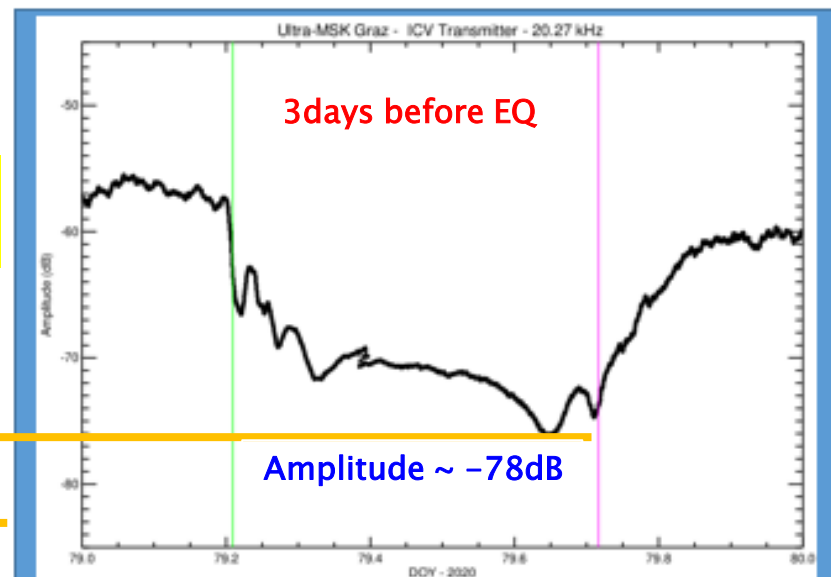
INFREP
VLF-ICV
(One Day)

~ 7dB

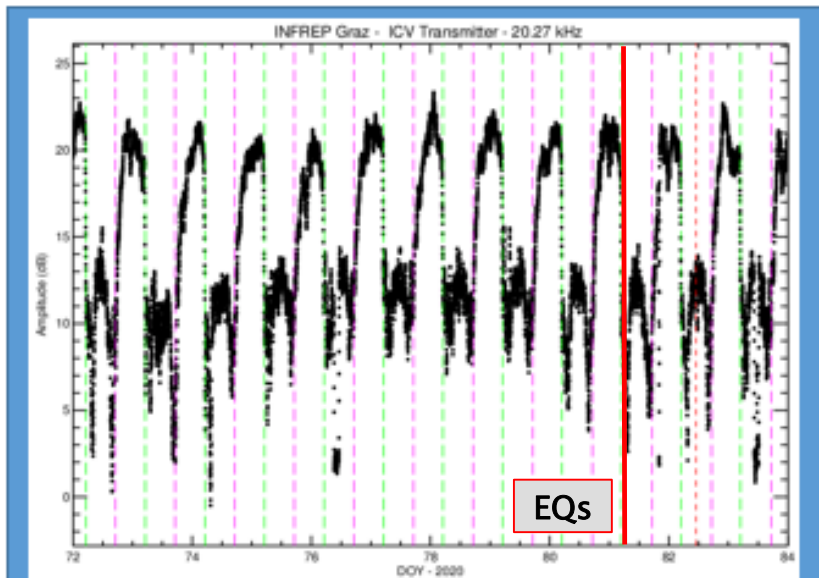


Utra-MSK
VLF-ICV
(One Day)

~ 5dB



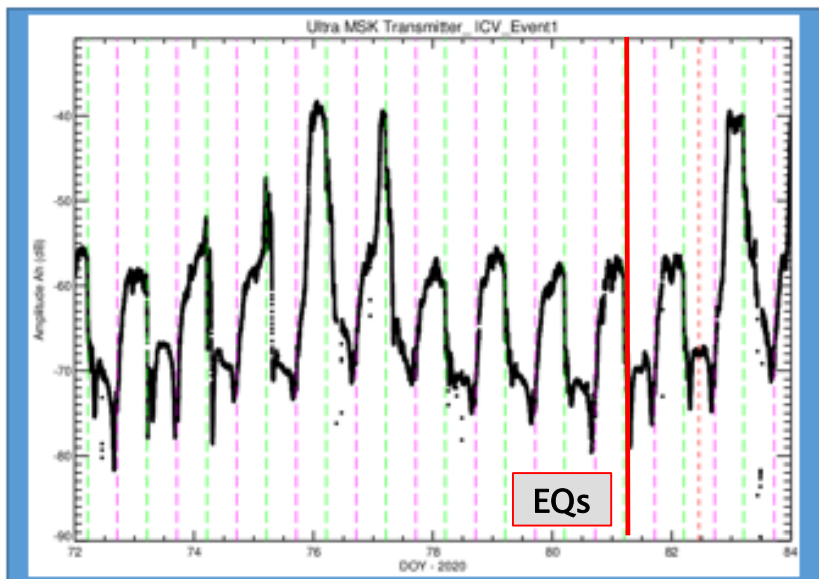
INFREP
VLF-ICV
(14 Days)

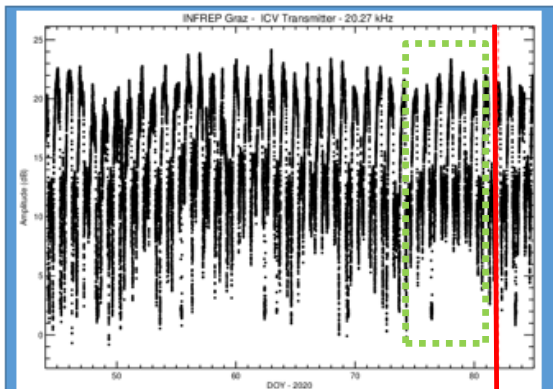


Event1

1. EQs vertical red lines
2. 10 days before EQs occurrence
3. Increase of TT signal amplitudes
4. Recover of TT amplitudes after EQs

Ultra-MSK
VLF-ICV
(14 Days)



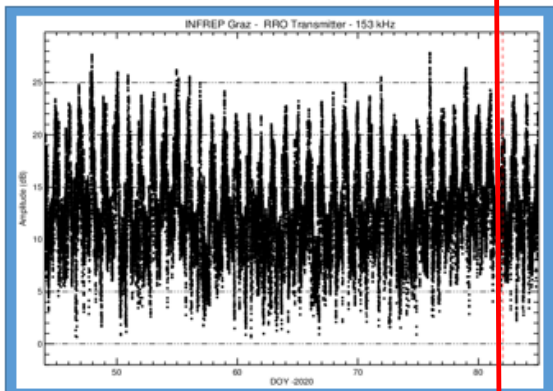
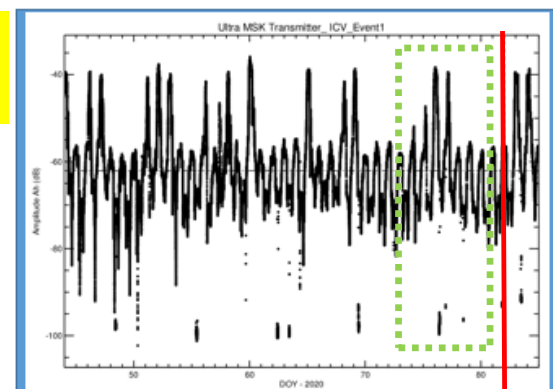


**INFREP
VLF-ICV
(50days)**

Event1

**Ultra-MSK
VLF-ICV
(50days)**

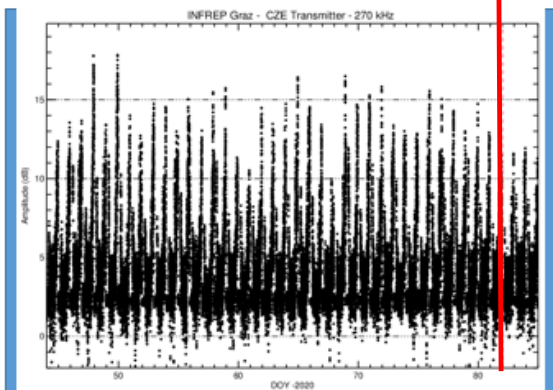
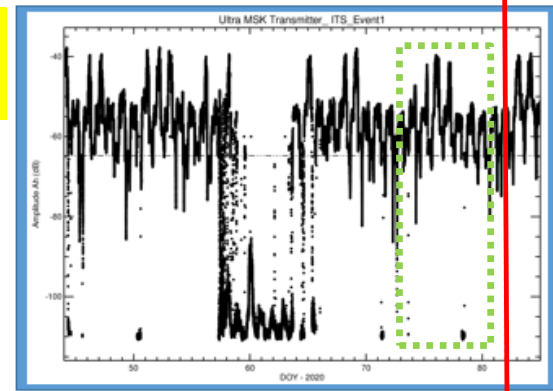
1. EQs Vertical red lines
2. Green boxes increase in TT amplitudes



**INFREP
LF-RRO
(50days)**

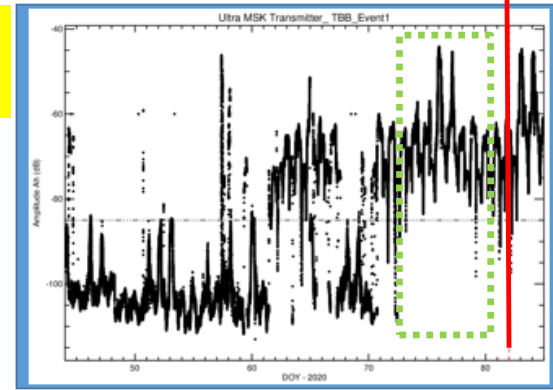
**Ultra-MSK
VLF-ITS
(50days)**

3. Signal increase
 - VLF/ICV transmitter
 - VLF/ITS transmitter
 - VLF/TBB transmitter



**INFREP
LF-CZE
(50days)**

**Ultra-MSK
VLF-TBB
(50days)**



Event2

INFREP
VLF-ICV
(50days)

Ultra-MSK
VLF-ICV
(50days)

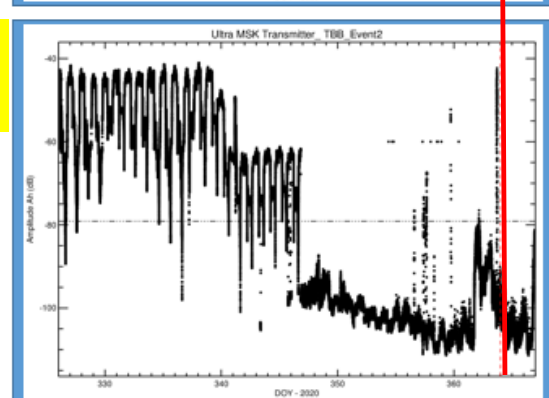
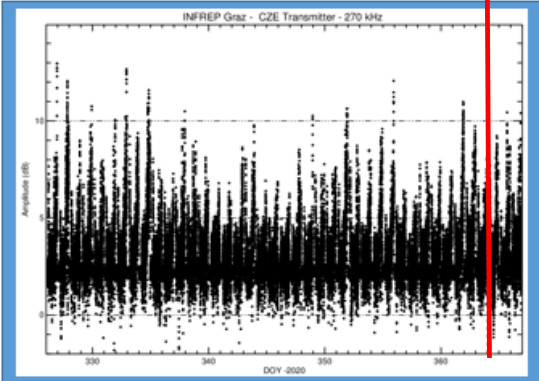
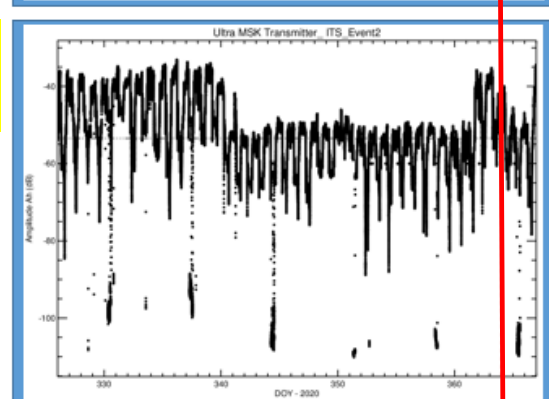
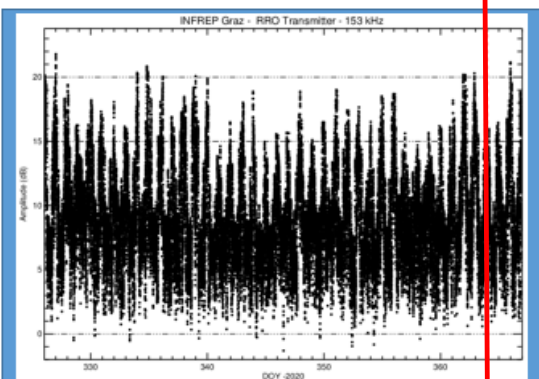
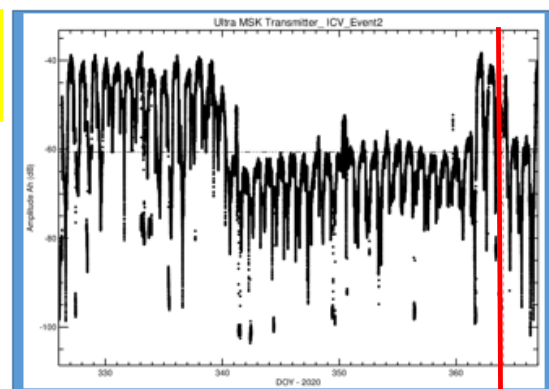
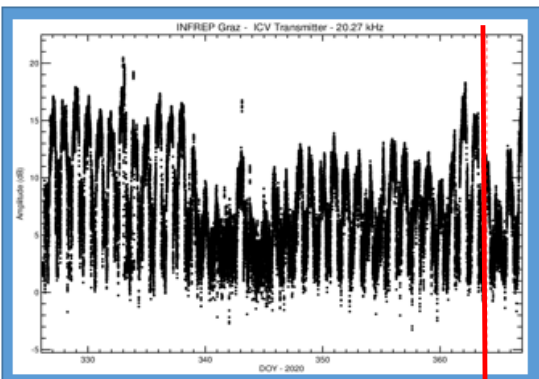
1. Vertical red line = EQs day
2. No 'anomalies' in TT amplitudes

INFREP
LF-RRO
(50days)

Ultra-MSK
VLF-ITS
(50days)

INFREP
LF-CZE
(50days)

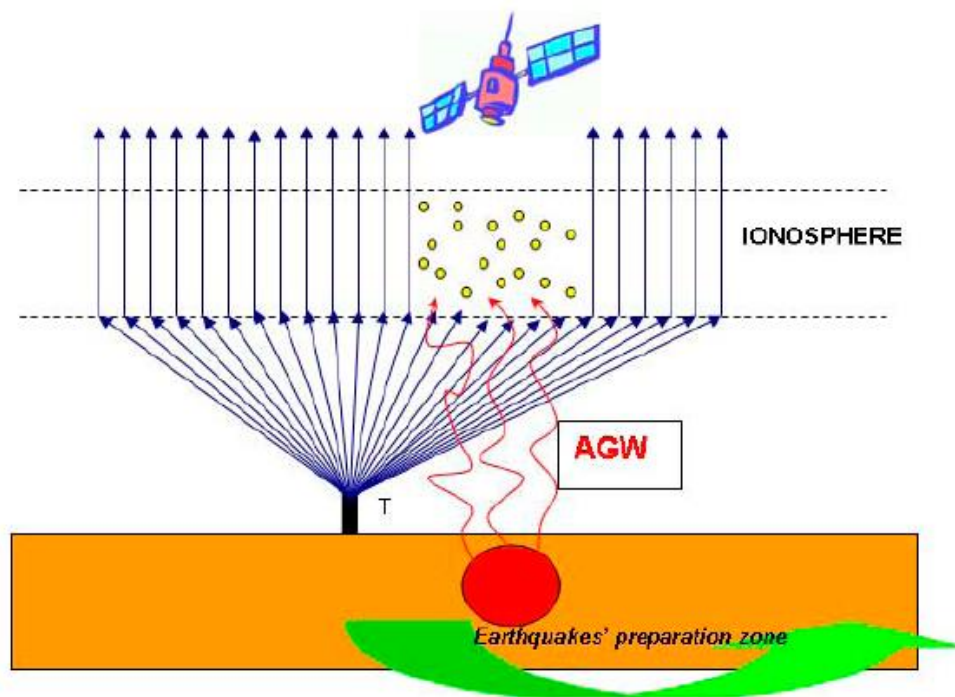
Ultra-MSK
VLF-TBB
(50days)

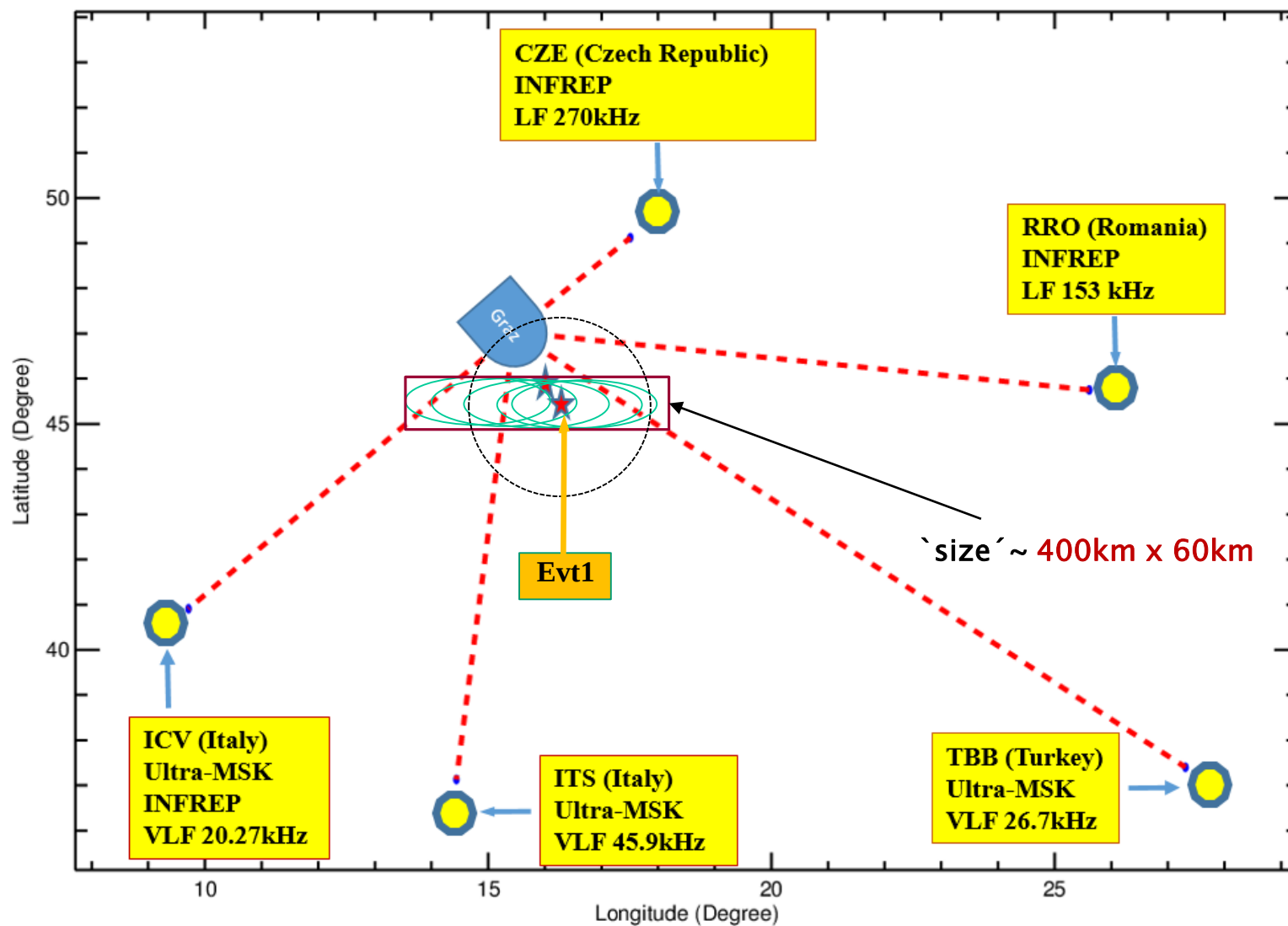


→ Physical Model

Physical mechanism at the origin of TT amplitude variations **Molchanov et al (2006)**

1. Phase1: Increase of strain energy in the preparation seismic region
2. Phase2: Come up of atmospheric gravity waves (AGW) above the preparation zone
3. Phase3: Arise of ionospheric turbulence linked to AGW





Summary

1. Two seismic events have been investigated which occurred in Croatia on 22nd March 2020 (**Event1**) and 29th Dec. 2020 (**Event2**)
2. Distances to Graz (Austria) were, respectively, of about 136km and 186km for Event1 and Event2
3. **Terminator Times (TTs)** method has been used to study the amplitude signal variation at sunset and sunrise
4. From this preliminary study, we find precursor signals:
 - Increase of TT amplitude signals **only for Event1**
 - Enhancement **only** in the case of **VLF** transmitters: ICV (Italy), ITS (Italy) and TBB (Turkey)
 - No effect on **LF** transmitters: RRO (Rumania) and CZE (Czech Republic)
5. Probable physical mechanism is related to **AGWs linked to preparation zone** appearing about 10 days before earthquake occurrence.
6. Such AGWs generate **disturbances in the ionospheric region** above the pre-seismic region
7. Ionospheric disturbance region characteristics are:
 - 'Source size' of about **400kmx60km**
 - **Extended in longitudinal** directions and narrow in latitudinal ones
 - Elongated more on west-side of the EQs region

Thank You