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Analysis of VLF/LF transmitter signals during the minimum of solar activity in the year 2018

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We report on VLF/LF transmitter signals observed in the year 2018 during the minimum of solar activity. Those signals were recorded in Graz (Austria) using INFREP (Biagi et al., Nat. Hazards Earth Syst. Sci., 11, 2011) and UltraMSK (Schwingenschuh et al., Nat. Hazards Earth Syst. Sci., 11, 2011) systems. This leads us to record fourteen transmitter signals in the frequency range between 19 kHz and up to 270 kHz. Six transmitter channels are common to both systems and are localized in Great-Britain (Anthorn, GBZ, 19.58kHz), Italy (Tavolara, ICV, 20.27kHz), Germany (Rhauderfehn, 23.4kHz,) and Island (Keflavik, NRK, 37.5kHz). Others are mainly LF broadcasting transmitters from Romania (Brasov, 153kHz), Luxembourg (Felsberg-Berus, 183kHz), Algeria (Berkaoui, 198kHz), Monte-Carlo (Roumoules, 216kHz) and Tchecki (Lualualei, 270kHz). In the year 2018, the solar activity decreased reaching its minimum in the end of 2019. We emphasize in this work on three aspects: (a) C-flares related to the solar activity, (b) Kp-index linked to the geomagnetic activity, and (c) seismic events in the southern part of Europe, i.e. Greece and Italy. The dominant patterns observed on almost all transmitters are due to the solar flares. Geomagnetic activity is found to depend on the seasonal effect and mainly observed few weeks before and after the summer solstice in the northern hemisphere. Few earthquakes occurred in the southern part of Europe, in Greece (6 events) and in Italy (2 events) with a magnitude of 5.5 Mw and depths less than 10 km. We discuss the disturbances of VLF/LF transmitter signals prior to EQs occurrences, and their links to external effects. Our results are compared to recent investigations of Zhang et al. (Radio Sci., 52, 2017) and Rozhnoi et al. (Ann. Geophys., 37, 2019) concerning, respectively, the spatial distribution of VLF transmitter signals recorded by Demeter satellite, and the solar X-flare effects on VLF/LF transmitter signals.

The observed channels recorded @ Graz_Station (+15.46E; 47.03N)

	System	Code	Freq. (Hz)	Long.	Lat.	Location
1	INFREP/ULTRA	GBZ	019580	-3.28E	54.91N	UK, Anthorn
2	INFREP/ULTRA	ICV	020270	09.71E	40.91N	Italy, Tavolara
3	ULTRA	NPM	021400	-158.13E	21.42N	USA, Lualualei
4	INFREP	HWU	021750	01.24E	46.71N	France, Le Blanc
5	INFREP/ULTRA	DHO	023400	07.60E	53.08N	Germany, Rhaderfehn
6	ULTRA	NAA	024000	-67.28E	44.65N	USA, Cutler
7	ULTRA	TBB	026700	27.31E	37.40N	Turkey, Bafa
8	INFREP/ULTRA	NRK	037500	-22.56E	64.02N	Island, Keflavik
9	ULTRA	ITS	045900	14.43E	37.12N	Italy, Niscemi
10	INFREP	RRO	153000	25.61E	45.75N	Romania, Brasov
11	INFREP	EU1	183000	06.68E	49.28N	Luxembourg, Felsberg-Berus
12	INFREP	CH1	198000	05.08E	31.92N	Algeria, Berkaoui/Ouargia
13	INFREP	MCO	216000	06.13E	43.78N	Roumoules, Monte-Carlo
14	INFREP	CZE	270000	17.51E	49.12N	Czechia, Lualualei

Selected Seismic Events

Date	Time	Mag.	Lat.	Long.	Depth (km)	Location
02.01.2018	04:24	5.1	41.22N	22.86E	06	Greece
16.05.2018	22:30	5.0	36.46N	22.96E	10	Southern Greece
25.06.2018	05:14	5.5	36.72N	21.37E	10	Southern Greece
16.08.2018	18:19	5.3	41.89N	14.82E	10	Southern Italy
31.08.2018	07:12	5.1	39.28N	21.62E	12	Greece
17.09.2018	00:24	5.0	34.33N	26.50E	10	Crete, Greece
27.09.2018	10:21	5.2	36.74N	21.33E	10	Southern Greece
26.12.2018	02:19	5.0	37.53N	15.20E	10	Sicily, Italy

Solar Activity: C-Flare Occurrence

Date	Detection of C-Flares			
	GBZ	ICV	DHO	NRK
04.02.2018	Y	Y	N	Y
07.02.2018	N	N	N	N
12.02.2018	Y	N	N	Y
02.03.2018	N	N	N	N
30.03.2018	N	N	N	N
23.05.2018	Y	Y	Y	Y
28.05.2018	Y	Y	Y	Y
06.06.2018	Y	Y	N	Y
21.06.2018	Y	Y	Y	Y
05.07.2018	Y	Y	N	Y

Geomagnetic Activity: Kp-Index

Date	Kp-index	Detection of C-Flares			
		GBZ	ICV	DHO	NRK
14.01.2018	4.5	N	N	N	N
15.01.2018	4.7	Y	N	N	N
27.02.2018	5.0	N	N	Y	N
18.03.2018	6.0	N	Y	N	N
20.04.2018	6.0	N	N	Y	N
05.05.2018	5.7	N	N	N	N
06.05.2018	5.7	N	N	Y	N
01.06.2018	4.7	Y	Y	Y	Y
25.06.2018	4.9	N	N	N	N
26.06.2018	4.7	Y	Y	Y	Y
26.08.2018	7.2	N	N	N	N
11.09.2018	6.0	N	N	N	N
07.10.2018	5.1	N	N	N	N
05.11.2018	5.5	N	N	N	N

Main Outcomes

- **Seismic events**
 1. **Eight EQs occurred in Greece (6) and in Italy (2) with a magnitude more than 5 Mw and a depth in the order of 10 km**
 2. **Only ICV transmitter exhibits drop amplitude signal before EQs occurrence**
 3. **Decrease of ICV signal is observed for 3 events (25/06;16/08;26/12)**
- **Solar activity**
 1. **C-flares only occur in the first semester of 2018**
 2. **C-flares were simultaneously recorded (all transmitters) at three occasions (23/05; 28/05;21/05)**
 3. **More than five C-flares were observed in signals of GBZ (6/10), ICV(5/10) and NRK (6/10) transmitters**
 4. **Only two flares associated to DHO transmitter signal**
- **Geomagnetic activity**
 1. **Kp-index ~ 6.0 during the year 2018**
 2. **Only DHO transmitter signal exhibits a dependence on geomagnetic activity**