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STRONG SOLAR X-RAY FLARES: INFLUENCE ON THE IONOSPHERE

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Abstract. The perturbations in the D-region induced by solar flares were studied using monitored amplitude and phase data from Very Low Frequency (VLF, 3 - 30 kHz) and Low frequency (LF, 30 - 300 kHz) radio waves. All data were recorded by Belgrade stations system (44.85^0 N, 20.38^0 E). The focus of this work is on the study of perturbed amplitude on VLF/LF signal caused by strong solar flares. Results show that the magnitude of the VLF perturbations is in correlation with intensity of X-ray. The model computations applied to obtain the electron density enhancement induced by intense solar radiation.

1. INTRODUCTION

The monitoring of the lower ionosphere layers by the mean of the VLF/LF technique can play an important role for a better understanding of space weather conditions. It is now recognized that the plasma in the ionospheric D-region ($50 \leq h \leq 90$ km) is a very sensitive medium to external forcing like moderate solar influence, stellar explosive radiation, energetic particle intrusion (Šulić & Srećković 2014, Nina et al. 2011). Processes like solar emission in far-UV and EUV regions (Srećković et al. 2014) strongly affect the Earths atmosphere (Mitra, 1974). This intense solar radiation and activity can cause sudden ionospheric disturbances (SIDs) and further create ground telecommunication interferences, blackouts as well as natural disasters (Šulić et al. 2016).

2. RESULTS AND DISCUSSION

In this contribution we focus our attention to the analysis of amplitude and phase data, acquired by monitoring Very Low Frequency (VLF, 3 - 30 kHz) and Low Frequency (LF, 30 - 300 kHz) radio signals emitted by worldwide transmitters during SIDs. All the data were recorded at a Belgrade site by two receiver systems: Absolute Phase and Amplitude Logger (AbsPAL) system (Šulić et al. 2016) and Atmospheric Weather Electromagnetic System for Observation Modeling and Education (AWESOME)[1].

[1] http://solar-center.stanford.edu/SID/AWESOME/

The analysis and comparison of VLF data has been carried out together with the examination of the corresponding solar X-ray fluxes. The intensity of solar X-ray flux is recorded by the GOES satellites (Geostationary Operational Environmental Satellite)[2].

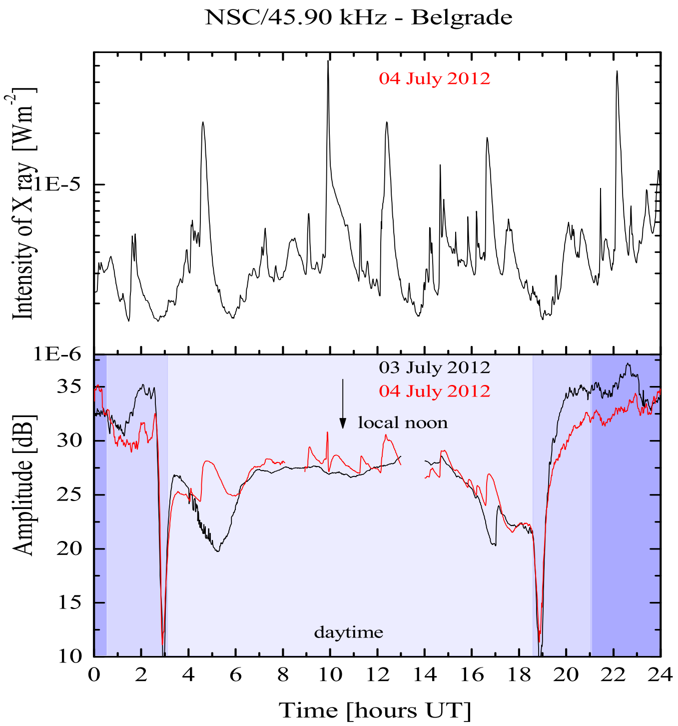

Figure 1: Variation of X-ray irradiance (panel 1), and amplitude (panel 2) on NSC/45.90 kHz radio signal recorded at Belgrade against universal time on 03 (normal day) and 04 July 2012.

Simultaneous observations of amplitude (A) and phase (ϕ) in VLF/LF radio signals during solar flares could be applied for calculation of electron density profile. Therefore, the perturbation of amplitude was estimated as a difference between values of the perturbed amplitude induced by flare and amplitude in the normal ionospheric condition: $\Delta A = A_{per}$ - A_{nor}, where "per" means the perturbed and "nor" means normal condition. In the same way the perturbation of phase was estimated as: $\Delta\phi = \phi_{per}$ - ϕ_{nor}. During the occurrence of solar flares, classified as a minor and small flare up to the C3 class, the amplitude of the signal GQD/22.10 kHz and NSC/45.90 kHz does not have significant perturbations. A solar flare in the range from C3 to M3 classes induced an increase of the amplitude, which corresponds nearly proportional to the logarithm of the X-ray irradiance maximum (Šulić & Srećković, 2014). A numerical procedure for the calculation electron density from the Waits parame-

[2]https://satdat.ngdc.noaa.gov/sem/goes/data

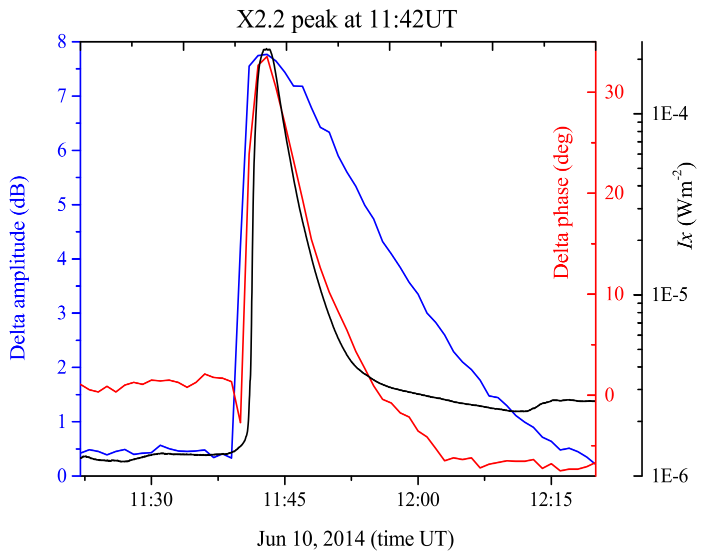

Figure 2: Variation of X-ray irradiance, phase increase and amplitude increase on GQD/22.10 kHz radio signal recorded at Belgrade against universal time on 10 Jun 2014.

ters is based on comparison of the recorded changes of amplitude and phase with the corresponding values obtained in simulations using the Long-Wave Propagation Capability (LWPC) numerical software package (Ferguson, 1998) as explained in (Šulić et al. 2014).

2. 1. AMPLITUDE PERTURBATIONS ON VLF/LF RADIO SIGNAL INDUCED BY SMALL AND MEDIUM CLASS SOLAR FLARES.

Fig.1 shows time variation of X ray irradiance and measured amplitudes on NSC/45.90 kHz radio signal for 03 and 04 July 2012 for time interval of 24 hours. Measured data for 03 July 2012 are given as reference level for normal ionospheric condition. Results show that the magnitude of the VLF perturbations is in correlation with intensity of solar X-ray.

2. 2. AMPLITUDE PERTURBATIONS ON VLF/LF RADIO SIGNAL INDUCED BY STRONG SOLAR FLARES.

For studding SID VLF/LF signatures we have selected solar flare events whose occurrences where in time intervals of few hours around local noon at Belgrade. All selected events (X2.2 class and X3.81 class) were recorded under similar solar zenith angles. Our results are presented on Figs. 2 and 3. Perturbations of the GQD/22.10 kHz radio signal are presented as temporal changes of ΔA and $\Delta\phi$ during solar flare event. From the figures we conclude:

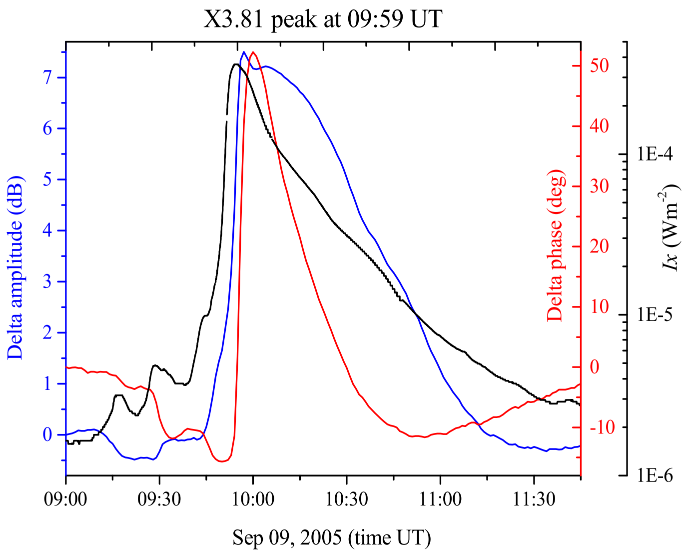

Figure 3: Variation of X-ray irradiance, phase increase and amplitude increase on GQD/22.10 kHz radio signal recorded at Belgrade against universal time on 9 September 2005.

- Changes of amplitude on radio signals during X class solar flares perform as well defined enhancement that follow the development of the maximum in X-ray radiation.
- During X2.2, and X3.81 class solar flare event electron density changes for three order of value at reference height $h = 74$ km in according to ambient value.

3. CONCLUSIONS

In this contribution the effect during the enhancements of X-ray flux due to the solar flares, on the propagating radio signal have been studied. The obtained results confirmed the successful use of applied technique for detecting space weather phenomena such as solar explosive events as well for describing and modeling the ionospheric electron density which are important as the part of electric terrestrial-conductor environment.

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