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RESEARCH OF THE IMPACT OF STRONG SOLAR FLARES ON THE LOWER IONOSPHERE BY VLF/LF RADIO WAVES AND SATELLITE OBSERVATIONS

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Abstract. Solar flare X-ray energy can cause strong enhancements in the electron density in the Earth's atmosphere. This intense solar radiation and activity can cause sudden ionospheric disturbances and further create potential natural disasters. The focus of this work is on the study of these changes induced by strong solar X-ray flares using Very Low Frequency (VLF, 3-30 kHz) and Low Frequency (LF, 30-300 kHz) radio signal. All data were recorded by Belgrade stations system. The model computation is applied to obtain the ionosphere parameters induced by intense solar radiation.

1. INTRODUCTION

Methods of investigation of the Earth's atmosphere are diverse and numerous. Depending on the ionospheric composition, ionospheric altitudes, preferred technics, geographical locations, for its investigation scientists usually use rockets, satellites, balloons, digisonde, GPS, different ground based measurements such as radars, radio measurements, optical instruments, etc. (see Mitra, 1974; Nina et al., 2011; Šulić & Srećković, 2014 and references therein). At the altitude region 60–90 km called D-region measurements are mostly based on radio wave propagation technique (Šulić et al., 2016). 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 under these extreme conditions (Srećković et al., 2017, Ilić et al. 2018; Nina et al. 2015, 2019). The intense solar radiation and activity can cause sudden ionospheric disturbances (SIDs) and further create ground telecommunication interferences, blackouts as well as natural disasters like forest fires (see e.g. Radovanović et al. 2017).

2. RESULTS AND DISCUSSION

In this research we focus our attention to the analysis of amplitude and phase data, acquired by monitored VLF/LF radio signals emitted by worldwide distributed transmitters and satellite data during SIDs.

Figure 1: The geographic position of Belgrade system of VLF/LF receivers and the surrounding transmitters.

2. 1. MONITORING

All the data were recorded at a Belgrade site (44.85^0 N, 20.38^0 E) 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]. The details and description of the Belgrade site are provided in Šulić & Srećković (2014). Locations of some transmitters and the receiving site are presented in Fig.1. The analysis and comparison of VLF/LF 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 [2]. The GOES satellites record the X-ray fluxes in two wavelength bands: 0.1-0.8 nm, referred to as "long" or "XL" and 0.05-0.4 nm, referred to as "short" or "XS". The most important data in our work are data of intensity of X-ray flux in the band 0.1-0.8 nm. Solar flares are destructive explosions in the solar chromosphere which release radiation across entire electromagnetic spectrum accompanied by the energetic particles (Srećković & Nina 2019). Fig. 2 shows an image of the 10 solar flares that occurred on 8 March 2011. As presented in Fig. 3, the phase (φ) and amplitude (A) variations of the

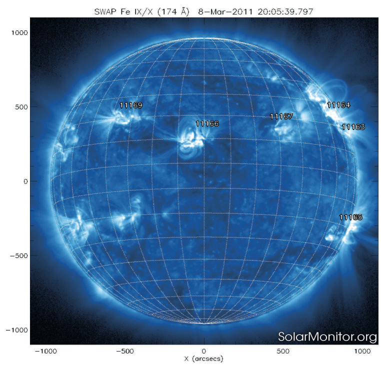

Figure 2: The solar corona in extreme ultraviolet light (17.1-nm band) at 20:08 UTC on 8 March 2011 (https://solarmonitor.org).

[1] http://solar-center.stanford.edu/SID/AWESOME/
[2] https://www.ngdc.noaa.gov/stp/satellite/goes/dataaccess.html

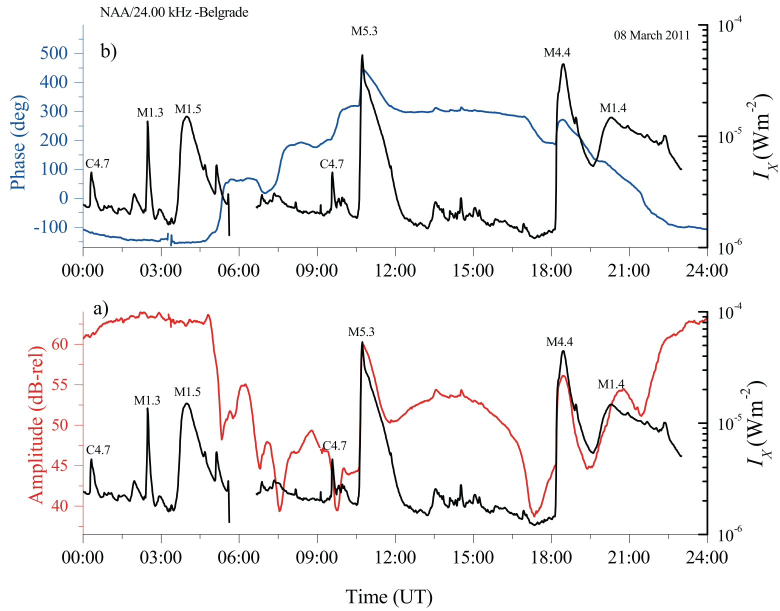

Figure 3: Amplitude a) and phase b) of NAA/24.00 kHz radio signal recorded at Belgrade against universal time on 08 March 2011. X-ray flux is presented on right axes of panel a) and b).

NAA/24.00 kHz radio signal on 8 March 2011 follow the intensity of X-ray flux quite closely at daytime during development of these solar flares (C4.7 to M5.3).

2. 2. STATISTICAL RESULTS

Simultaneous observations of amplitude and phase of VLF/LF radio signals during solar flares could be applied for calculation of ionospheric parameters. Therefore, the perturbation of amplitude and phase was estimated as a difference between values of the perturbed amplitude induced by flare and amplitude in the normal ionospheric condition. During the occurrence of solar flares, classified as a minor and small flare up to the C3 class, the amplitude of the signal does not have significant perturbations. A solar flare in the range from C3 to X classes induced a noticeable increase of the amplitude (see Fig. 3 and Fig. 4). In the presence of ionospheric disturbances, a standard numerical procedure for the calculation of electron density 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 Nina et al. (2012).

On the base of statistical analysis of events (ranging from C3.6 to X2.2 class) we present results (ionospheric parameters) of simulations on Fig. 4 together with changes of amplitude, phase and X-ray flux. Changes of amplitude and phase are proportional to the increase of the X-ray irradiance. Using Fig. 4 we can approximately estimate the values of electron density and ionospheric parameters for larger solar X-ray flares just knowing the class of solar flare.

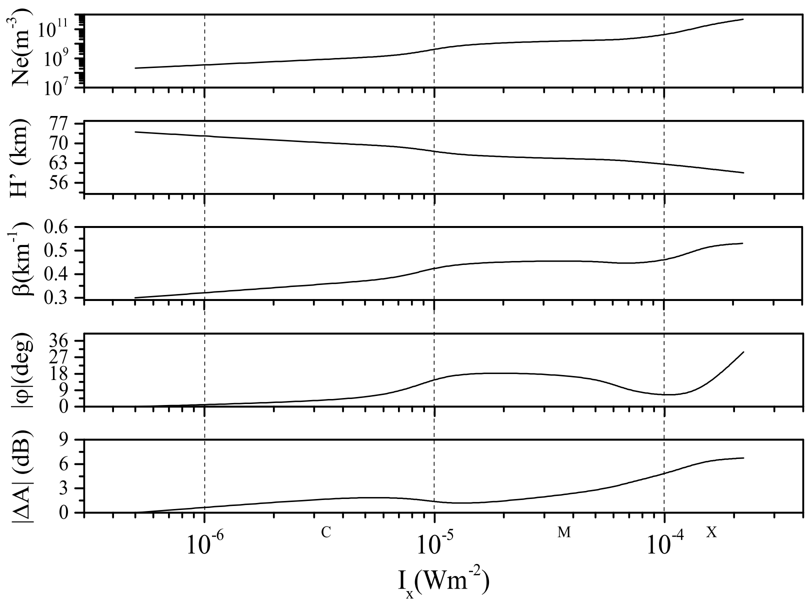

Figure 4: SID VLF signatures and calculated data by LWPC code as a function of intensity of X-ray flux during solar flare events, ranging from class C3 to X2, observed at Belgrade.

3. CONCLUSIONS

In this paper we present our study of effect during the enhancements of X-ray flux due to the solar flares, on the propagating VLF and LF radio signals. The model computation is applied to determine structures of the perturbed D-region, during occurrences of solar flares. It can be concluded that the solar explosive events lead to an increased rate of electrons production and electron density can increase depending on flare intensity up to few orders of magnitude. The results confirmed the successful utilization of used technique for detecting/analysing space weather phenomena such as solar explosive events.

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