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THE EFFECTS OF SOLAR ACTIVITY ON THE TERRESTRIAL LOWER IONOSPHERE

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Abstract. The perturbations in the terrestrial D-region induced by solar flare X-ray energy 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 system of stations (44.85^0 N, 20.38^0 E). The focus of this contribution is on the study of perturbed amplitude on VLF/LF signal caused by strong solar flares. The results show that the magnitude of the VLF perturbations is in correlation with intensity of X-ray. The model computation and simulation are applied to acquire the electron density enhancement induced by intense solar radiation.

1. INTRODUCTION

The plasma in the ionospheric D-region (50 km $\leq$ h $\leq$ 90 km) is a very sensitive medium to external perturbation like moderate solar influence, stellar explosive radiation, etc. (Šulić & Srećković (2014) and Nina et al. (2011)). Processes like solar emission in far-UV and extreme-UV regions (Srećković et al. (2014); Mihajlov et al. (2013)) strongly affect the Earth's atmosphere. This intense solar radiation and activity can cause sudden ionospheric disturbances (SIDs) and further create ground telecommunication interferences, blackouts and minor radiation storms (see Radovanović et al. (2017)).

Solar flares that can be detected with VLF/LF radios waves are generally caused by X-ray flares and have various flux levels associated with them. Lower ionosphere monitoring by the mean of the radio technique can play a important role for a better understanding of space weather conditions Mitra (1974).

2. RESULTS

In this paper we confine our attention to the analysis of the amplitude and phase data of Very Low Frequency (VLF, 3 - 30 kHz) and Low Frequency (LF, 30 - 300 kHz) radio signals emitted by worldwide transmitters during SIDs.

The data were recorded at the Belgrade site with 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) (Šulić & Srećković (2014)). These data are digitized and saved in two different resolutions - high resolution (50 Hz) and low resolution (1 Hz). 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 the solar X-ray flux is taken from the online database of the GOES satellites.

2.1. Signal Monitoring

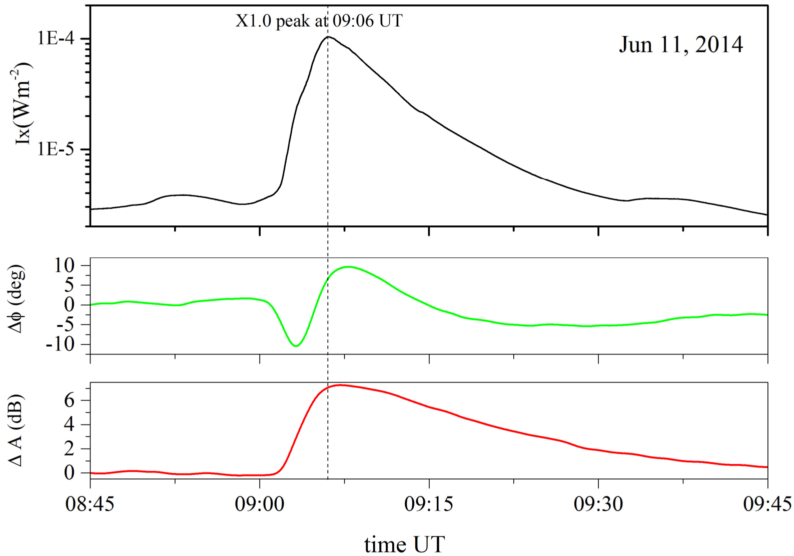

Figure 1: Simultaneous variation of the X-ray flux, phase and amplitude in the GQD/22.10 kHz radio signal (in universal time) recorded at Belgrade on 11 Jun 2014.

Simultaneous observations of amplitude (A) and phase (ϕ) in VLF/LF signals during solar flares could be applied for investigations of the perturbed ionospheric plasma. Therefore, the perturbation of the amplitude was estimated as a difference between values of the amplitude induced by some disturbance and amplitude in the normal ionospheric condition: $\Delta A = A_{\mathrm{per}} - A_{\mathrm{nor}}$. In subscript 'per' means the perturbed and 'nor' means normal condition. Similarly, the perturbation of phase was estimated as $\Delta\phi = \phi_{\mathrm{per}}\text{-}\phi_{\mathrm{nor}}$.

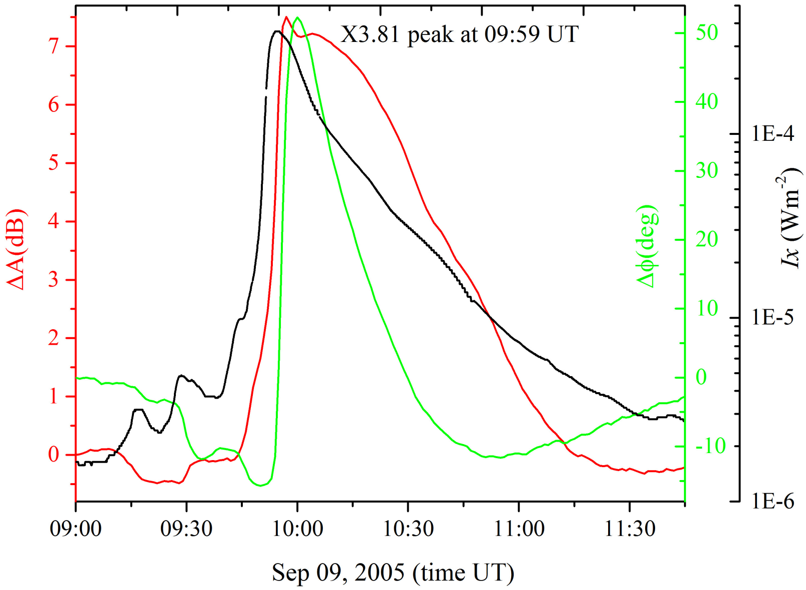

Figure 2: Simultaneous variation of the X-ray flux, phase and amplitude in the GQD/22.10 kHz radio signal (in universal time) recorded at Belgrade on 09 September 2005.

During the occurrence of solar flares, classified as a minor and small flare up to the C3 class, the amplitude of the VLF/LF signals does not have significant changes. 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 (Šilić & Srećković 2014, Srećković et al. 2017).

2.2. Perturbations on VLF/LF Signal Induced by Strong Solar Flares

For studding SID we have selected strong solar flare event whose occurrence was in time interval of few hours around local noon at Belgrade. The selected events are X1.0 class solar flare recorded on 11 Jun 2014 and X3.81 class solar flare recorded on 09 September 2005. Our data are presented in Figs.1 and 2. Perturbations of the GQD/22.10 kHz radio signal are presented as temporal changes of ΔA and $\Delta\phi$ during solar flare event. Fig 3. presents calculated electron density at height h = 74 km during flare occurrences, as a function of the maximal intensity of X-ray flux. Electron density is calculated (as in Srećković et al. 2017) on the basis of VLF/LF propagation data recorded at Belgrade for one year. From the figures we conclude that changes of the phase and amplitude of radio signals during X class solar flares exhibit as well-defined enhancements that follow the development of the maximum in X-ray radiation. Also, after occurrences of such

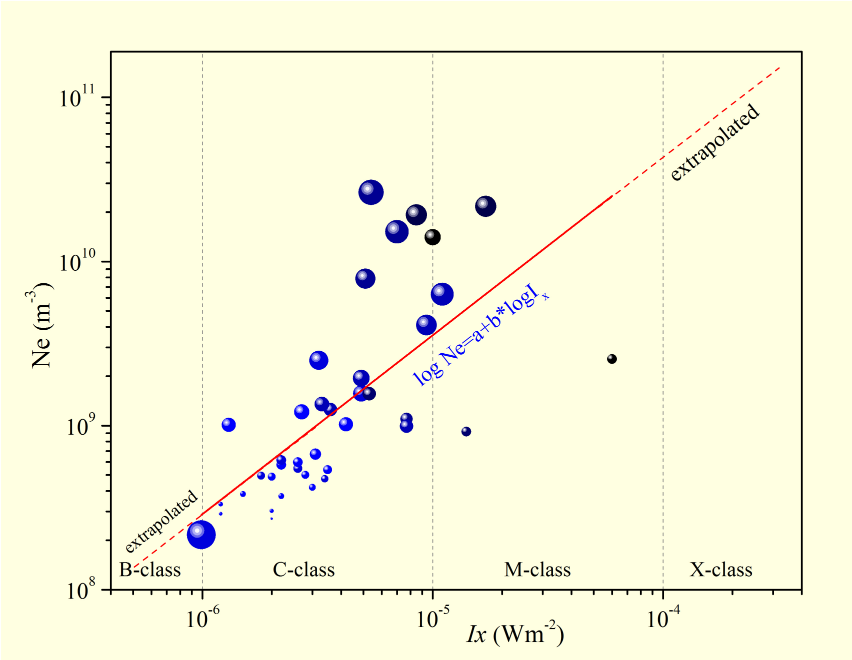

Figure 3: Values of electron density at height h = 74 km during flare occurrences, against maximum intensity of X-ray flux. Electron density is calculated on the basis of VLF/LF propagation data recorded at Belgrade for one year. The size of the point is proportional to the amplitude change while the color depends on the phase change (the darker color indicates a larger phase change). The red line indicates linear fit and red dashed line extrapolation to stronger/weaker solar flares.

strong solar flares the amplitude recovers bit slower than the phase. Using linear fits and extrapolations we can estimate the values of electron density even for larger solar X-ray flares (right dashed area) on the base of statistical analysis.

2.3. Perturbations on VLF/LF Signal Induced by Weak Solar Flares

Using linear fits and extrapolations we can estimate also the values of electron density even for week solar X-ray flares i.e. B-class on the base of statistical analysis. In Fig 3. is presented electron density at height h = 74 km during flare occurrences, as a function of maximal intensity of X-ray flux. The red line indicates linear fit and left red dashed line extrapolation to weaker solar flares.

3. CONCLUSIONS

In this work the effects during the enhancements of X-ray flux due to solar flares, on the propagating radio signal have been studied. The presented examples (Figs. 1, 2 and 3) are used to qualitatively describe consequences of SIDs, during occurrences of strong and weak solar flares.

Finally, we can point out the most important conclusion of this study: the successful use of applied technique for detecting space weather phenomena such as solar explosive events as well as for describing and further modeling the ionospheric plasma which is important as the part of electric terrestrial-conductor environment.

Acknowledgments

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