Modeling the atmosphere under the influence of intense solar X-ray radiation

V. A. Srećković[1], D. M. Šulić[2] and V. Vujčić[3]

[1]Institute of Physics Belgrade, University of Belgrade, P.O.Box 57, Pregrevica 118, Belgrade, Serbia

[2]Faculty of Ecology and Environmental Protection, University Union—Nikola Tesla

[3]Astronomical Observatory, Volgina 7, Belgrade, Serbia

The perturbations in the D-region induced by solar flares were studied using monitored amplitude and phase data from VLF radio waves (3– 30 kHz and 30–300 kHz) transmitters. All data were recorded by system at Belgrade stations (44.85^{0}N, 20.38^0 E).

Statistical results show that the magnitude of the VLF perturbations is in correlation with intensity of X-ray

Fig. 1 Great Circle Paths (GCPs) of subionospherically propagating VLF radio signals recorded at Belgrade site.

VLF Station

The Belgrade station is simultaneous monitoring the properties of subionospheric propagating waves that reveal changes of the electrical properties of the ionospheric D-region during various stellar activities (Šulić & Srećković 2014). The cosmic disturbances, γ, X and UV radiation, cause numerous complicated physical, chemical and dynamical phenomena in the D-region and may directly affect human activities. We show that the VLF technique is well suited to search for stellar events, and to provide a diagnostic of high-energy astrophysical phenomena.

Solar Flares:

Strong solar flares penetrate to lower ionospheric region, cause transient changes. Study the influence of solar flares on the terrestrial ionospheric D-region by analyzing the amplitude and phase time variations of VLF radio waves emitted by transmitters (all over the world) and recorded by the receivers in Belgrade in real time (see e.g. Šulić et al. 2016). VLF and LF radio signals propagate inside the waveguide formed by the lower ionosphere and the Earth's surface. A range of dynamic phenomena occurs in D-region, and some of them are: diurnal effect (day/night), a seasonal effect (summer/winter), strong relationship with solar activity (11-year- sunspot level and solar flares), effects of lightning induced electron precipitation and red sprites.
All these phenomena are followed by changes in electron density of D-region, which affects the subionospheric VLF/LF propagation as an anomaly in amplitude and/or phase.

Results and Discussion:

Amplitude and phase perturbations on VLF radio signal induced by solar flares.

Data points of the observed GQD/22.10 kHz are shown in Figure 2—amplitude and phase perturbations as a function of solar X-ray intensity. The range of size in amplitude and phase perturbations varies for different X-ray solar flares.

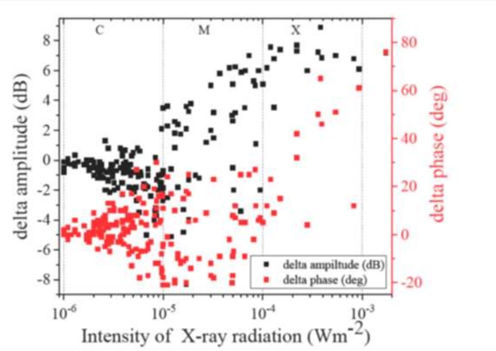

Figure 3. (left) Observed amplitude perturbations on GQD/22.10 kHz radio signals due to solar X-ray flares, measured at Belgrade station during period (2003–2017) as a function of X-ray flux. **(right)** Observed phase perturbations under same conditions. Two hundred events of solar X-ray flares were examined.

Modeling:

Figure 3a presents simultaneous variations of X-ray flux, amplitude and phase of GQD radio signal against universal time during five successive flares on 10 Jun 2014. From the Figures 3 one can see that VLF and X-ray flux peaks happened simultaneously i.e. intense radiation instantly disturbed ionosphere creating SIDs and resulting in perturbed VLF signal. Figure 3b shows calculated values of time dependent effective reflection height H' and the sharpness β (with the time resolution of one minute) for the time period 08:00 to 14:30 UT during occurrences of five solar flare on 10 Jun 2014.

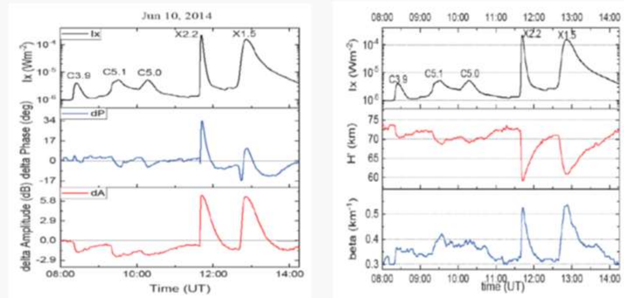

Fig. 3 a) Variation of X-ray irradiance, phase increase, amplitude increase on GQD/22.10 kHz radio signal recorded at Belgrade against universal time on 10 Jun 2014. b) Ix, beta, H'

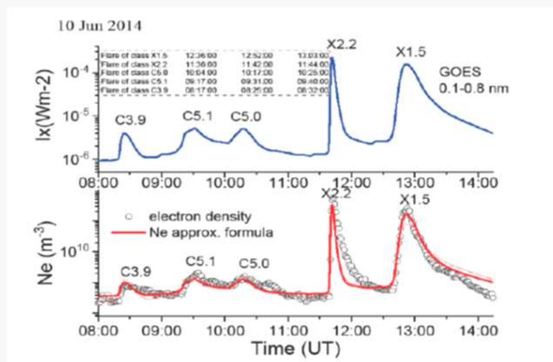

Fig. 4 Variation of X-ray flux, as measured by GOES-15 satellite, and the corresponding electron density evaluated at reference height 74 km versus universal time UT during five successive flares on 10 Jun 2014. The red line presents results obtained using simple approximative Equation (1). With circles are presented Ne obtained by the mentioned above method.

$$\log Ne(h, Ix) = a_1(h) + a_2(h) \cdot \log Ix + a_3(h) \cdot (\log Ix)^2$$

Height (km)	$a_1(h)$	$a_2(h)$	$a_3(h)$
50	10.3249	0.97123	0.06168
55	12.94731	1.65399	0.11341
60	15.56972	2.33674	0.16513
65	18.19213	3.0195	0.21686
70	20.81454	3.70226	0.26858
75	23.43695	4.38501	0.32031
80	26.05936	5.06777	0.37203

It can be noticed that the intense solar radiation namely solar extreme events lead to an increased electron production rate and can increase electron density up to a few orders of magnitude, depending on the flare intensity with distortion of the amplitude and phase VLF signal. Also, we give a simple approximative formula for altitude electron density profile as a function of X-ray flux which is valid for nonperturbed and also for perturbed D-region (see Sreckovic et al. 2021).

References:

Srećković, V. A., Šulić, D. M., Ignjatović, L., & Vujčić, V. (2021). Low Ionosphere under Influence of Strong Solar Radiation: Diagnostics and Modeling. Applied Sciences, 11(16), 7194.

Šulić, D. M., V. A. Srećković, and A. A. Mihajlov. "A study of VLF signals variations associated with the changes of ionization level in the D-region in consequence of solar conditions." Advances in Space Research 57.4 (2016): 1029-1043.

Šulić, D. M., and V. A. Srećković. "A Comparative Study of Measured Amplitude and Phase Perturbations of VLF and LF Radio Signals Induced by Solar Flares." Serbian Astronomical Journal 188 (2014): 45-54.