Publ. Astron. Obs. Belgrade No. 100 (2021), 387 - 390 *Poster*

MONITORING VLF SIGNAL PERTURBATIONS INDUCED BY SOLAR ACTIVITY DURING JANUARY 2005

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Abstract. Simultaneous monitoring of VLF (3-30 kHz) radio signals, transmitted within Earth-Ionosphere waveguide, from USA (NAA/24.0 kHz), GB (GQD/22.1 kHz) and Australia (NWC/19.8 kHz) towards Serbia and registered by narrowband AbsPAL receiving system, stationed at Institute of Physics in Belgrade (44.85N, 20.38E), was carried out. Series of Solar events during January 2005 were surveyed and analyzed. Modeling of related perturbed D region (50-90 km) ionospheric conditions, by means of LWPC program routine, was conducted. Based on the Wait′s model of the lower Ionosphere, electron density height profiles were estimated. Inspected Solar events revealed different effects as observed on monitored VLF signal traces. Main results are presented in this paper.

1. INTRODUCTION

Solar flare events, through emitted X-ray flux during period of solar flare activity, are well known as major source of additional ionization within region of the lower ionosphere (50 - 90 km). Incident radiation changes electron density height profile in this region and affects Very Low Frequency (VLF, 3 - 30 kHz) radio signal propagation within the Earth-ionosphere waveguide (Mitra 1974). Consequently, phase delay and amplitude of VLF signals undergo changes, as well. Absolute Phase and Amplitude Logger (AbsPAL) narrowband system stationed at Institute of Physiscs (44.85N, 20.38E), University of Belgrade, Belgrade, Serbia, was used for monitoring of VLF radio signals analyzed in this paper. VLF signals propagating within transmitted Earth-Ionosphere waveguide, transmitted from Maine (44.63N; 67.28W) USA (NAA/24.0 kHz), Skelton (54.72N; 2.88W) GB (GQD/22.1 kHz) and E. H. Holt (21.8S, 114.16E) Australia (NWC/19.8 kHz) towards Serbia, were simultaneously monitored for period of intense solar flare activity during January 2005. VLF signal propagation parameters changes related to such solar flare activity were studied and related amplitude and phase delay perturbations of observed VLF signals were presented in this paper, for case of NAA/24.0 kHz signal trace, during perturbed day of January 20th, 2005. Some of the recent results of ionospheric D-region monitoring

Table 1: Propagation parameters of monitored VLF signals.

VLF signal code and frequency (kHz)	Transmitter location	Emitted power (kW)	GCP distance to Belgrade (km)
NAA/24.0	Maine, USA	1000	6547
GQD/22.1	Skelton, UK	500	1982
NWC/19.8	E. H. Holt, Australia	1000	11980

by VLF/LF technique by Belgrade VLF group can be found in Srećković et al. 2017, Ilić et al. 2018 and Nina et al. 2019.

2. RESULTS AND DISCUSSION

Main characteristics of monitored VLF signals are given in Table 1. GQD/22.1 kHz signal propagates along WNW-ESE mostly overland path long $\approx$ 2 Mm, NAA/24.0 kHz signal propagates along W-E mostly oversea path long $\approx$ 6.5 Mm while NWC/19.8 kHz signal propagates along SE-NW both overland and oversea path long $\approx$ 12 Mm. Possible GCPs for monitored VLF signals were calculated by Long Wavelength Propagation Capability computer program LWPCv21 (Ferguson J. A. 1998), based on Long Wave Propagation Model developed from Wait's theory (Wait J. R. 1962). Electro-conductivity maps incorporated within prvwPlot subroutine are based on real electro-conductivity data globally measured. In model of Earth-ionosphere waveguide for VLF waves propagation, electron density height profile in the lower ionosphere is characterized by two parameters:β (1/km) - sharpness and H' (km) - reflection height (Wait J. R. and Spies K. P. 1964).

Observed propagation parameters of analyzed NAA/24.0 kHz signal trace during perturbed day of January 20th, 2005 are given in Figure 1. X-ray irradiance diurnal variation on perturbed day January 20th, 2005 is given in black, according to GOES12 one-minute satellite data listings of the X-ray (0.1-0.8 nm) irradiance. NAA signal amplitude variations during perturbed day January 20th, 2005 are given in red, while during quiet day of January 20th, 2007 are given in blue. The dominant feature during perturbed day is X7.1 class flare event recorded at 07:01 UT, which severely affected NAA signal propagation during the entire day, by raising the amplitude signal level during daytime for up to 10 dB as compared to quiet conditions.

The Earth-ionosphere waveguide for monitored VLF signals propagation conditions during perturbed day January 20th, 2005, was modeled for few characteristic times during the flare event duration. Electron density height profile Ne(z)(m^{-3}) for altitude z (km) was calculated, for given pairs of parameters β (1/km) - sharpness and H' - reflection height, using the equation (Wait J. R. and Spies K. P. 1964):

$$N_e(z, H', \beta) = 1.43 \cdot 10^{13} e^{-0.15H'} e^{(\beta-0.15)(z-H')} \quad (1)$$

Propagation paths of monitored VLF signals were simulated by LWPCv21 code for few characteristic states, with goal of obtaining the best fitting pairs of parameters (β/H') estimated to be the closest possible values to real measured VLF signals phase delay and amplitude, at the site of Belgrade receiver. Vertical electron density height profiles through ionospheric D-region were calculated using (1).

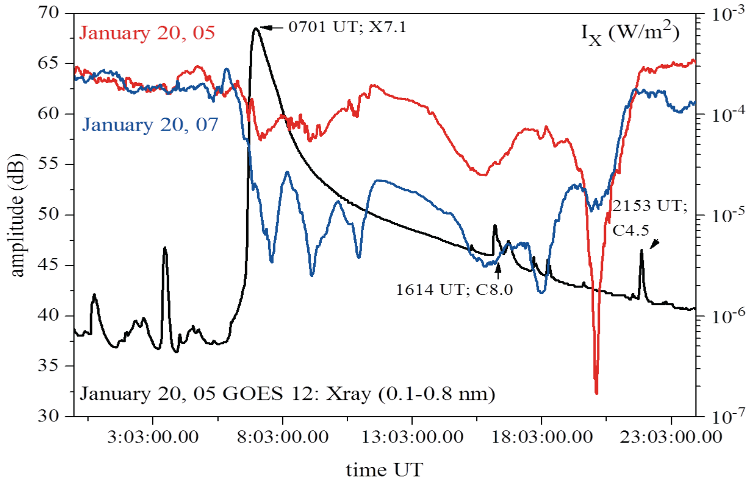

Figure 1: NAA/24.0 kHz signal perturbation

Electron density height profiles Ne(z) in 60 - 90 km altitude range for NAA/24.0 kHz transmitter to receiver distance D (km) along GCP, at midday max time 11:28 UT, during perturbed day of January 20th, 2005 (red) and quiet day of January 20th, 2007 (blue) are given in Figure 2. Solid red and blue lines represent Ne(z) profiles at the place of receiver in Belgrade (Serbia), for perturbed and quiet conditions, respectively. In case of receiver site in Belgrade (Serbia), Ne(z) profiles obtained by modeling vary in several orders of magnitude depending on observed altitude: the differences in calculated Ne(z) vary between about half order of magnitude at the lower boundary of observed altitude range, up to about two orders of magnitude at the upper boundary of observed altitude range, with about one and half orders of magnitude at the 74 km altitude. It should be noted, that results obtained in cases at the altitude boundaries should be taken with caution, due to uncertainties related by calculation method used.

3. CONCLUSIONS

Simultaneous monitoring of NAA/24.0 kHz, GQD/22.1 kHz and NWC/19.8 kHz VLF signals transmitted towards Belgrade AbsPAL receiver (44.85N, 20.38E) was carried out for series of solar X-flare events during January 2005, and inspected Solar events revealed different effects as observed on monitored VLF signal traces. Case of NAA/24.0 kHz signal trace behavior was analyzed and presented in this paper. Perturbations in ionospheric D-region induced by Solar flare activity that took place during perturbed day of January 20th, 2005, severely affected propagation conditions within Earth-ionosphere waveguide of NAA/24.0 kHz signal trace, in way that NAA/24.0 kHz signal amplitude stayed raised during the entire day for up to 10 dB, as compared to quiet conditions. Based on applied modeling method and conducted

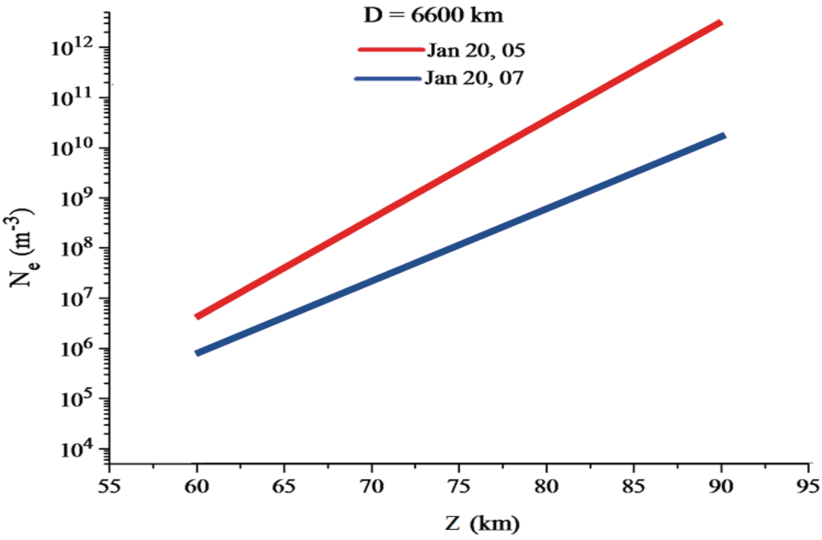

Figure 2: Electron density height profiles Ne(z) in 60 - 90 km altitude range for NAA transmitter to receiver distance D (km) along GCP, at midday max time 11:28 UT

calculations, at the place of Belgrade receiver site, at the altitude of 74 km, registered Solar flare activity induced increase in electron density of about one and half orders of magnitude compared to unperturbed conditions.

Acknowledgments

The thanks are due to Ministry of Education, Science and Technological Development of Republic of Serbia. Authors thank Institute of Physics, University of Belgrade, Belgrade, Serbia for VLF data provided and D. Šulić for instrumental set-up.

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