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PECULIARITIES OF IONOSPHERIC RESPONSE TO SOLAR ERUPTIVE EVENTS

V. M. ČADEŽ[1] and A. NINA[2]

[1] *Astronomical Observatory, Volgina 7, 11160 Belgrade, Serbia*
E–mail sandrast@ipb.ac.rs

[2] *Institute of Physics, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*
E–mail vcadez@aob.rs

Abstract. Solar eruptive events such as flares and coronal mass ejections (CMEs) affect the terrestrial upper atmosphere, the magnetosphere and ionosphere in particular, through sudden impacts of additional X-ray radiation and by increased intensity of the solar wind. As a consequence, a variety perturbation features occur locally as well as globally in the plasma medium in space around the Earth. We study some of such transient phenomena taking place at low altitudes of the ionosphere (below 90 km) by monitoring and analyzing registered amplitude and phase time variations of VLF radio waves with given frequencies. The main object of this research is gaining an additional insight into the structure and physical properties of the lower ionosphere.

1. INTRODUCTION

The terrestrial atmosphere is a medium of a highly complex nature concerning its numerous physical and chemical processes occurring on different spatial and temporal scales, and being induced by various phenomena such as large scale atmospheric storms, electric discharges in lightnings, atmospheric convective motions, meteorite passages through the atmosphere, and magnetic storms, tectonic motions coming from the interior of the Earth, ocean motions like tsunamis, local effects of the sunrise and sunset, solar eclipses, and a broad set of solar activity features such as CMEs, solar wind, and solar flares of intense electromagnetic radiation. All these features cause atmospheric disturbances ranging from perturbations in the geomagnetic field and excitation of waves and electric currents at very high altitudes (up to several Earth radii) in the plasmasphere, to time-varying atomic processes and formation of nonstationary free-electron layers in the ionosphere at relatively lower altitudes (from 60 km to over 1000 km). All these induced processes are mutually more or less coupled and form a unique dynamic system that became a subject of diverse studies in the fields of theoretical meteorology and aeronomy, as well as in many technical applications related radio-communications and GPS technology among others.

Our research is focussed on processes in the low ionosphere at altitudes below 90 km where the ground emitted very-low-frequency (VLF) radio waves are being deflected from a local free-electron layer and then registered by a world-wide system of receivers (the Atmospheric Weather Electromagnetic System for Observation Modeling and Education - AWESOME) with one of them located in Institute of Physics, Belgrade, Serbia. Time variations of the registered VLF wave amplitude and phase are signatures of induced physical processes at the height of wave-deflection allowing us to estimate both the paths of the electron production kinetics and excitations of hydrodynamic waves.

In this contribution we analyze the low ionospheric reaction to the solar X-flare event from May 5, 2010 that caused a strong transient increase in the ionizing X-ray emission which affected amplitude and phase time variations of the VLF signal emitted by the DHO transmitter (in Germany) at frequency 23.4 kHz and recorded by the AWESOME receiver in Institute of Physics, Belgrade, Serbia.

2. THE RECORDED WAVE AMPLITUDE ANALISIS

The considered solar X-ray burst (May 5, 2010) was recorded by the GOES-15 satellite as a peak in the radiation intensity at 11:52 UT as seen in Fig. 1, the top panel. This X-ray emission rise affects the amplitude $A(t)$ of the recorded VLF wave in a way seen in the lower panel of the same figure. The profile shape of this transient perturbation of the wave amplitude reveals some of the basic physical properties of the lower ionosphere.

First, the time profile of the recorded VLF wave amplitude is Fourier analyzed (Čadež et al. 2009) as:

$$A_F(T) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \mathrm{e}^{-2\pi t/T} \mathrm{A(t)dt} \qquad (1)$$

which gives global and local oscillation spectra of harmonic motions of the lower ionosphere. As seen in Fig. 2, the most pronounced periods are grouped about T = 0.2 s, T = 1 s, T = 10 s, and T = 200-600 related to the class Pc1 pulsations in addition to somewhat less intense Pc2-Pc3 and Pc5 pulsations. Also, low frequency magnetohydrodynamic (MHD) fluctuations were found to exist high in magnetospheric regions both experimentally and in numerical simulations (De Keyser and Čadež, 2001 a, b) as externally driven (by the solar wind) modes with typical periods ranging from couple of seconds to more than 1000 s. These MHD waves can eassily be transmitted to the lower parts of the ionosphere where they show up predominantly as gravito-acoustic modes.

Second, the analysis of the profile $A(t)$, as done in Nina et al. (2011, 2012), allows for modeling the kinetics of electron generation by the X-ray emission:

$$\frac{dN(t,h)}{dt} = K(t,h)I(t) - \alpha_{\mathrm{eff}}(t,h)N^2(t,h) \qquad (2)$$

and, consequently, determination of both the electron density $N(t,h)$ and the effective recombination coefficient $\alpha_{\mathrm{eff}}(t,h)$ in time t and at different heights h as shown in Fig. 3.

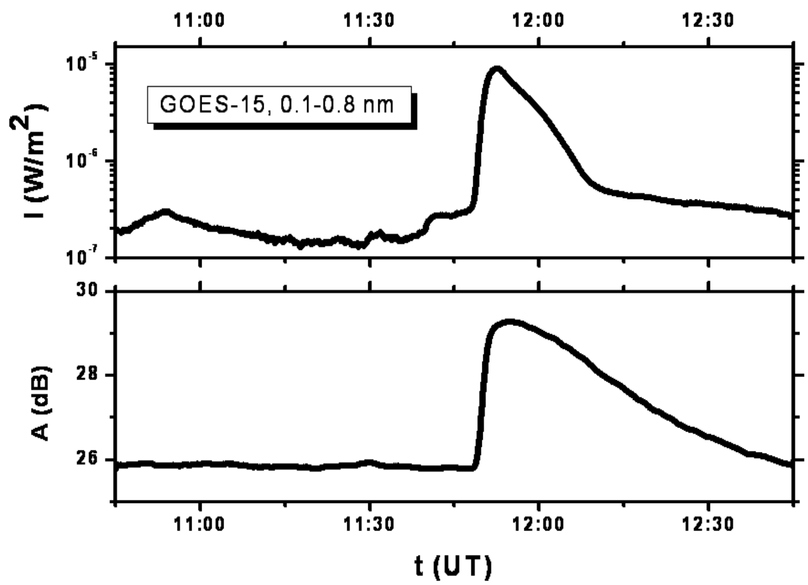

Figure 1: Time variation of the radiation intensity registered by the GOES-15 satellite (top panel) and signal amplitude (expressed in dB) recorded by the AWESOME receiver located in the Institute of Physics in Belgrade.

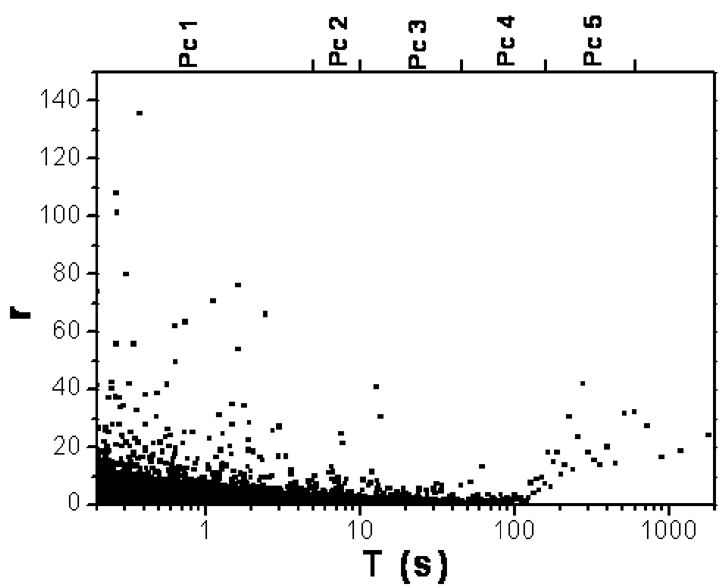

Figure 2: Normalized Fourier transformed VLF signal amplitude vs oscillation period T.

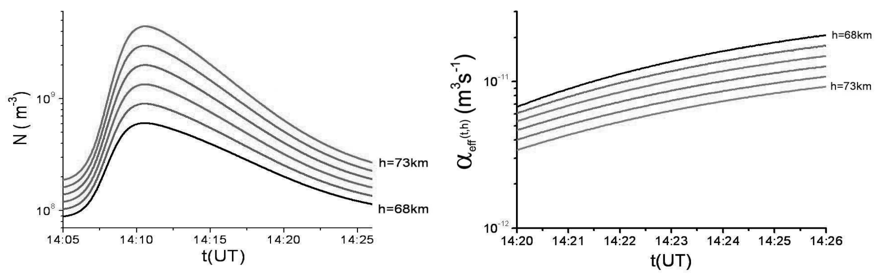

Figure 3: Resulting time distribution of electron concentration $N(t, h)$ (left) and effective recombination coefficient $\alpha_{\rm eff}(t, h)$ (right).

3. CONCLUSION

Solar X-ray bursts are just one of many features that cause disturbances and leave consequences throughout the terrestrial atmosphere. Some of them are recognized as characteristic peculiarities in recorded VLF radio wave amplitude time profiles $A(t)$ typical of the perturbation source and physical properties of the lower ionosphere where the VLF waves are being deflected toward the ground receivers. Analyses of the recorded data on $A(t)$ thus enable us to recover some of physical properties of the low ionosphere such as characteristic wave motions of the local plasma, and kinetics of time evolution of the net free electron production. The monitoring and analysis of the recorded VLF radio waves therefore proves to be a useful tools to study not only the processes and physical properties in the lower ionosphere but also their relations to those elsewhere in the atmosphere. Moreover, these studies are also applicable to space weather research activities as they contribute to a better understanding of global consequences of solar activity induced in the terrestrial environment in general.

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