Publ. Astron. Obs. Belgrade No. 80 (2006), 191 - 195 *Contributed paper*

SPACE WEATHER SIGNATURES ON VLF RADIO WAVES RECORDED IN BELGRADE

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Abstract. VLF (Very-Low-Frequency, 3-30 kHz) radio waves emitted from four single frequency transmitters located in Australia, USA, UK and Italy, have been permanently monitored in Belgrade by an AbsPAL receiver since August 2003. The collected data comprise a digitalized VLF wave amplitude and phase both recorded at 0.1 s time intervals for each of the four transmitters. Peculiarities, showing up in profiles of their time dependence curves, reveal effects of phenomena such as solar flares and magnetospheric electron precipitations among others. These features of solar activity may significantly influence the electron density distribution in the ionospheric D-region and consequently the characteristics of received radio signals. This work gives some insight into solar activity and space weather in general in their signatures in VLF signal recordings as well. Two examples show how sudden changes in the ionizing solar X-ray intensity in the ionosphere caused by a flare and solar eclipse, effect VLF signals recorded by the Belgrade receiver.

1. INTRODUCTION

The term 'weather' is now related not only to the dynamical processes in the lower part of the terrestrial atmosphere but it may also include developments in the space surrounding the Earth in which case we are talking about 'the space weather'. Just as it effects the weather on Earth, the Sun is also responsible for what is going on in our space environment. The Sun emits into space electromagnetic radiation as well as streams and clouds of mass particles. The intensities of these emissions depend on the stage of solar activity and may vary from relatively low level fluxes up to disruption of colossal energy involvement. No wander that such events influence the environmental conditions on Earth and are now a subject of systematic and permanent monitoring by instruments at ground and space orbiting laboratories. One of the main tasks concerning the space weather activities is therefore a prediction of expected consequences of solar activity on proper functioning of modern human technological society. Now, a world-wide network of activities enables a continuous collection and analysis of solar activity data providing a reliable daily space weather forecasting.

Among the most typical solar phenomena affecting the Earth and its surrounding geospace are the solar wind, coronal mass ejections (CMEs) and solar flares. The solar wind is an everlasting flow of particles and magnetic field from the Sun into the outer space. At the orbit of the Earth, the average values of the solar wind velocity, particle density, and magnetic field strength are 468 km/s, 8.7 protons/cm^3, and 6.6 nT, respectively. Besides emitting a continuous stream of solar wind plasma, the Sun periodically releases billions of tons of matter, a substantial fraction of the total corona, in sudden eruptions called a coronal mass ejection or CME. The ejected material expands away from the Sun at speeds as high as 2000 km/s. Another phenomenon with explosive mass and energy release are solar flares. They are the most energetic explosions in the solar system, can last a few hours with temperatures reaching 5 million K, and the ejected particle streams and emitted intense electromagnetic radiation may seriously affect the Earth. The intense radiation from a solar flare travels to Earth in 8 minutes and some of immediate results are:

- The upper part of the atmosphere becomes more ionized and it expands.
- Satellite orbits around the Earth can be disturbed by the expanding atmosphere.
- Satellites electronic components can be damaged.
- Long-distance radio signals can be disrupted by the resulting change in the ionosphere.

For more details on the related subjects see Thomson and Clilverd (2001), Hargreaves (1992) and Ratcilffe (1972).

2. IONOSPHERE

The ionosphere is the upper part of the Earth atmosphere that is partially ionized by the solar radiation. This region where motions of free electrons have strong effects on ionization-recombination processes in the ambient medium, extends from about 50 km to several hundreds of kilometers above the surface of the Earth. The ionospheric plasma is globally electro-neutral and its electrical properties significantly influence conditions for radio-wave propagation. In particular, the concentration of free electrons in the lower part of the ionosphere, in the so called D-region, determines how the ground emitted radio-waves will propagate between different points on the globe following multiple reflections between the ground and wave reflection points in the D-layer. Therefore, any variation in solar activity that result into changes of the electron concentration distribution in the ionosphere will alter locations of reflection

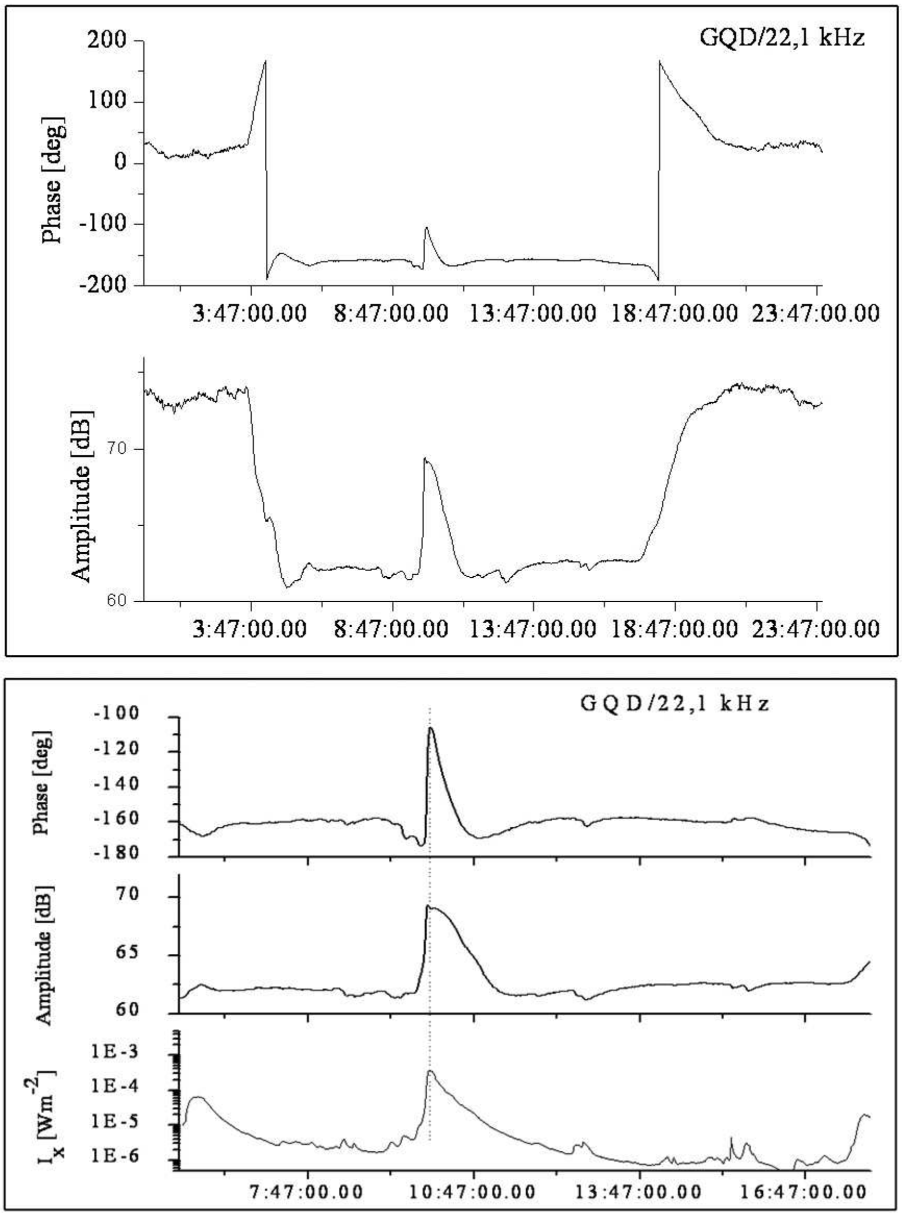

Figure 1: Solar flare on September 09, 2005: Phase and amplitude time dependences of a VLF signal at 22.1 kHz emitted from Scotland as recorded in Belgrade (left). Enlarged data from the plot at left with the solar radiation flux added. The flare had its maximum at about 09:59:00 UT

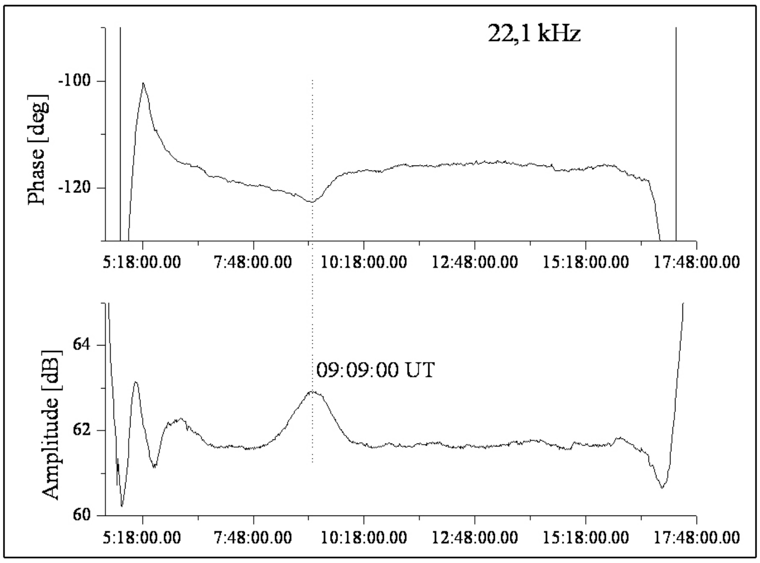

Figure 2: Solar partial eclipse on October 03, 2005: Phase and amplitude time dependences of a VLF signal at 22.1 kHz emitted from Scotland as recorded in Belgrade.

points in the D-layer and consequently the radio-wave trajectories. As a consequence, a received radio signal will vary in its intensity and phase depending on changes occurring in the geometry and physical conditions along its trajectory between the place of the emitter and the receiver.

3. BELGRADE VLF RECORDINGS

The Belgrade Station is AbsPAL (Absolute Phase and Amplitude Logger) receiver, installed in the Institute of Physics (44°38'N 20°46'E), the University of Belgrade, Belgrade, Serbia and Montenegro, in August 2003. This facility is developed by the Radio and Space Physics Group of Otago University, New Zealand. The system consists of a VLF and GPS antennas, VLF pre-amp, feed cables, service unit, and DSP computer card. The AbsPAL VLF receiver can log up to six transmitters at the time, logging phase and amplitude (PAL) with time resolutions ranging from 50 ms to 60 s. More details on this instrument and discussions of the obtained data can be found in Grubor et al. (2005).

In this paper, we present the effects of two solar phenomena on VLF 22.1 kHz waves transmitted from Scotland, UK, and recorded at the Belgrade Station some 2000 km away. First, it was a strong flare occurring on September 09, 2005 with its maximum intensity at about 09:59:00 UT and whose presence is seen as a perturbation peak on curves in Fig. 1. The second phenomenon was a partial solar eclipse on October 03, 2005 which crossed the same 22.1 kHz wave trajectory Scotland-Belgrade at about 09:09:00 UT as registered in Fig. 2.

A flare and eclipse produce opposite effects on electron concentration distribution in the ionosphere. During a flare event, the ionizing solar radiation is largely increased which results in higher electron concentrations and lowering of the wave reflection points in the D-layer. A solar eclipse causes a reversed effect of a reduced ionizing radiation resulting in lower electron densities and higher locations of radio-wave reflection points in the D-layer.

4. SUMMARY

We summarize our presentation as follows:

- The use of VLF transmissions propagating inside the earth-ionosphere waveguide is a well developed technique for probing physical conditions inside the ionospheric D-region.
- For daytime propagation conditions, the D-region is particularly stable, with wave reflection points occurring at 70-75 km. The electron density variation is strongly dominated by changes in the ionizing Lyman-α radiation flux with solar zenith angle.
- Additional perturbations are driven by solar flares and total solar eclipses. Variations in the D-region lead to changes in propagation conditions for VLF waves within the waveguide.
- Recorded data at the Belgrade station are used to study global and local conditions in the D-region in order to make relevant models.

Acknowledgements. This work has been supported by the Ministry of Science and Environmental Protection of the Republic of Serbia through:

- Project No. 1466 Radiative and Transport Properties of Nonlinear Laboratory and Ionospheric Plasma, D. Šulić and D. Grubor.
- Project No. 1951, Solar Spectral Irradiance Variation, V. M. Čadež.

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