Ionosphere and Some Practical Applications for Radio Communications

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Abstract. Ionosphere is the part of the earth's atmosphere, in which solar radiation causes ionization of the gases that make up it. Ionization is expressed in the appearance of a certain number of ions and free electrons, the concentration of which depends on height, time of day or night and other factors. Although there is no sharp boundary between any of the layers in the atmosphere, the lower limit of the constituent ionosphere can be viewed as the area located at a height of 50-60 km. For the upper limit of the ionosphere, heights are generally assumed to be around 1000 km. The ionosphere, in turn is divided into several areas that differ in the values of electronic concentration and the physical processes that determine them. Radio signals emitted by terrestrial radio transmitters, due to the electrical conductivity of the ionosphere, may be reflected at significant altitudes and make possible distant (over a thousand kilometers) radio communications. Of particular importance is the study of ionospheric anomalies (so-called ionospheric storms) directly affecting radio communications performed at frequencies of the short wavelength range. Changes in electronic ionosphere concentration during a storm have a strong impact on satellite GNSS navigation. During storm, the accuracy of positioning can reach an error of the order of several meters, which is important for some types of precise positioning. This shows the practical importance of knowing the ionospheric characteristics, which is an important condition for the efficient use of certain types of radio communications

Keywords: Ionosphere, Radio communications, GNSS.

1. INTRODUCTION

In a region extending from a height of about 50 km and over 900 km some of the molecules in the atmosphere are ionized by solar radiation. This region is called the ionosphere. Ionization is a process of decomposition of the gas atoms of negatively charged electrons and positive ions. It is the ions that give their name to the ionosphere, but it is the much lighter and more freely moving electrons which are important in terms of HF (high frequency) radio propagation. The free electrons in the ionosphere cause HF radio waves to be refracted and eventually reflected back to the earth. The higher is the electron density, the higher the frequencies that can be reflected.

During the day there may be four regions present called the D, E, F1 and F2 regions. Their approximate height ranges are:

- D region 50 to 90 km;
- E region 90 to 140 km;
- F1 region 140 to 210 km;
- F2 region over 210 km.

During certain periods the F1 region merges with region F2 in layer F. At night the D, E and F1 regions become very much depleted of free electrons, leaving only the F2 region available for communications. Only the E, F1 and F2 regions refract HF waves. The D region is very important though, because while it does not refract HF radio waves, it does absorb or attenuate them

The F2 region is the most important region for HF radio propagation because:

- it is present 24 hours of the day;
- it is high altitude allows the longest communication paths;
- it reflects the highest frequencies in the HF range (1.5- 30 MHz).

The lifetime of free electrons is greatest in the F2 region which is one reason why it is

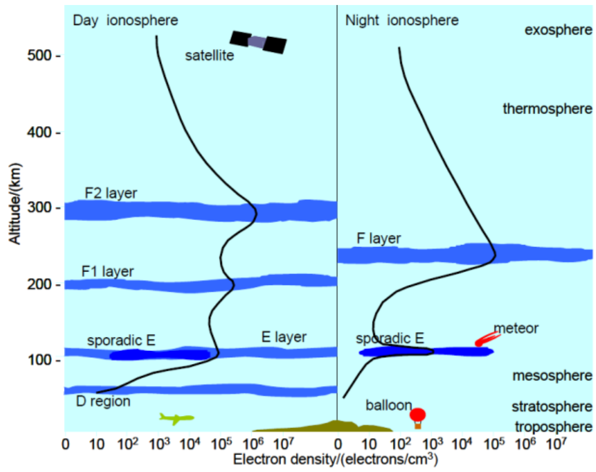

Fig.1. Day and night structure of the ionosphere

present at night. Typical lifetimes of electrons in the E, F1 and F2 regions are 20 seconds, 1 minute and 20 minutes respectively (Australian Government).

Fig. 1 shows the distributions of the electronic concentration relative to the height corresponding to the respective regions in the ionosphere. The left part presents the ionospheric layers during the day and their right course at night.

2. GROUND BASED METHODS FOR IONOSPHERE RESEARCH

One of the based ground ways of sounding the ionosphere with radio waves is the A1 method. The idea of the A1 method is based on the fact that when distributed in ionized environment the radio waves are reflected from an area with a specified value of the electronic concentration, which value depends on frequency of radio waves. Using radio waves with frequencies and measuring the time which is necessary for the radio signals to be returned back gives information on the height distribution of the electron concentration of the ionosphere.

Fig.2. Equipment of ionospheric station - antennas and transceivers

The maximum electron concentration at which occurs the reflection of the radio frequency with maximum usable frequency *foF2* [MHz] is determined by the formula:

$$N_m\left[\frac{el}{cm^3}\right] = 1.24\,10^4 \; foF2^2 \qquad (1)$$

Figure 3 shows a method for vertically sounding the ionosphere. The transmitting antenna emits packets of signals of different frequencies.

These signals, reaching certain altitudes (the so-called ionospheric region) are reflected, and the reflected signal is recorded by a receiving antenna. The pulse delay time determines the so-called virtual frequency *h'* and if necessary, the real height can also be obtained. The virtual height is larger than the actual reflection height. Before reaching the height at which the reflection occurs, the radio wave propagates at a rate less than the the speed of light, depending on the electronic concentration. It is generally accepted to use the so-called “virtual height” which is the product of multiplication of half the delay and the speed of light. The dependence of the virtual height on the frequency is called a ionogram.

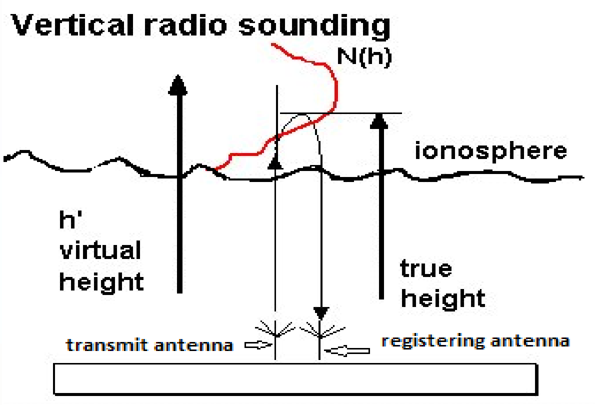

Fig.3. Method A1 for vertically sounding

Figure 3 shows a method for vertically sounding the ionosphere. The transmitting antenna emits packets of signals of different frequencies.

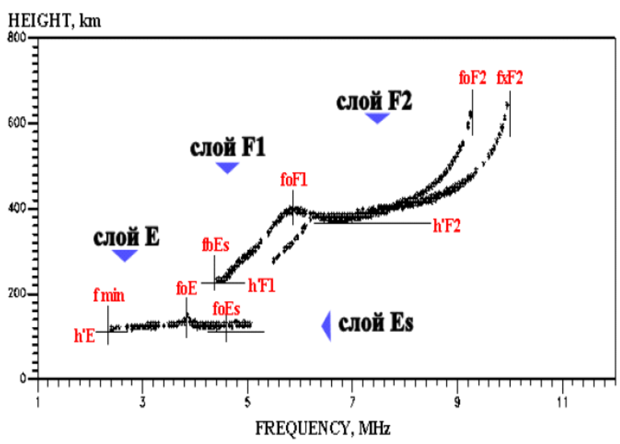

Fig.4. Daily ionogram

Fig. 4 shows a daily ionogram. All characteristics of the ionosphere are shown using the A1 method.

When the electronic concentration at which a reflection occurs for a certain height coincides with one of the maximums of the electronic profile, the delay is greatly increased. This allows the ionogram to determine the corresponding critical frequencies and maximum electronic concentrations. The critical frequency foF2 is the maximum frequency at which the ionosphere can produce a reflection under the given conditions.

3. SLANTED PROPAGATION OF RADIO WAVES

In real radio communications at significant distances, the propagation of radio waves through the ionosphere is carried on in curved lines, which are determined by the electron concentration profile. Fig. 5 shows the passing of MH (medium frequency), HF (high frequency) and VHF (very high frequency) signals through the various layers of the ionosphere.

Critical (maximum) frequencies which are reflected by the ionosphere and can be transmitted are larger than the critical frequency foF2 and depend on the distance of the radio communication. The greater the distance, the more the critical frequency increases. At distances of more than 3000 kilometers, the radio communications is usually the result of multiple reflections of the radio waves from the ionosphere and the Earth’s surface.

Critical frequencies are high in daytime and low in night time, which means that in the daytime the range of the applicable frequencies is larger. But during the night, due to the disappearance of ionization in the D and E regions, there is very little absorption of the radio waves, allowing for remote radio communication with low power of the transmitters (Space Weather Prediction Center).

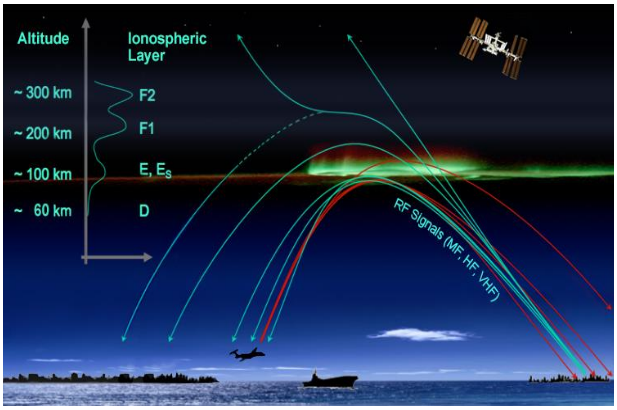

Fig.5. Passing different types of signals through the ionospheric layers.

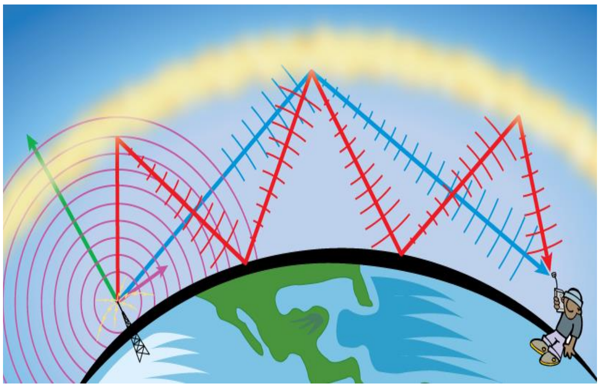

Fig.6. Multiple reflections of radio waves from ionosphere and Earth.

4. EXPERIMENTAL RESULTS

The present work analyzes the seasonal and solar dependencies of the ionospheric characteristics obtained from the Plana station data to NIGGG. The extreme event of October 2003 was followed, as well as the influence of a geomagnetic storm on the critical frequencies of the ionosphere (NOAA Space Weather Scales).

Fig. 7 (upper panel) shows the course of the foF2 critical frequencies for the period 1995-2014 compared to the solar activity course represented by the F10.7. The value-F10.7 is solar radio flux at wavelength 10.7 cm, which presents variations of solar ultraviolet flux. With high solar activity the daytime and night time values of critical frequencies are high especially during the winter period. Night time values are less affected by the solar activity. During the geomagnetic storm (Figure 7 bottom panel), the critical frequencies (daytime and night time) drop strongly and recover with a delay of several days after the storm is over (Kutiev & Muкhtarov, 2003); (Mukhtarov, Penov & Pancheva, 2013).

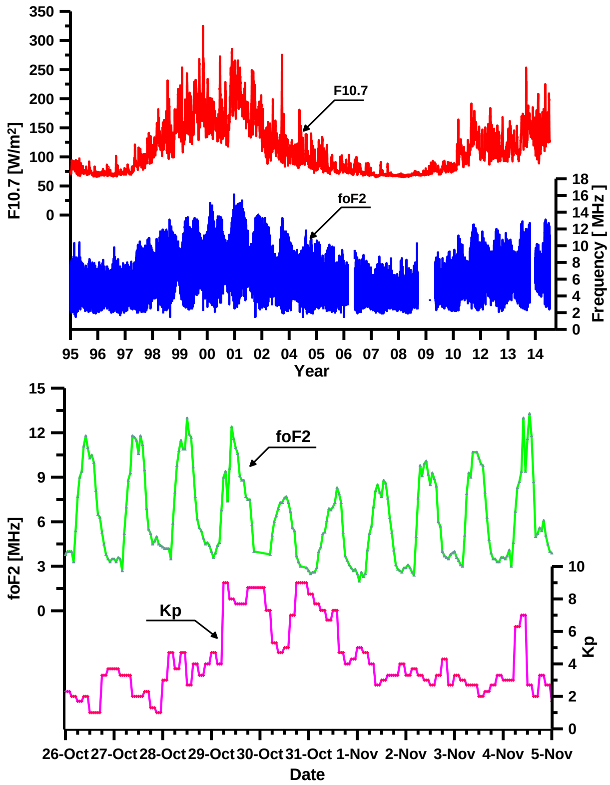

Fig.7. The course of solar activity represented by F10.7 and the foF2 critical frequencies measured at the 1995-2014 Plana Station (upper panel) and the course of the geomagnetic activity index- Kp and the critical frequencies during the "Halloween Storm" geomagnetic storm in October- November 2003 (bottom panel).

The example shown in Fig. 8 illustrates the average monthly diurnal course of foF2 for two years, respectively of high (upper panel) and low (bottom panel) solar activity. Year 2000 is at maximum solar activity and 2008 is minimal. In periods of high solar activity, the foF2 values are significantly higher than those at low solar activity, especially in daytime. With high solar activity present there is a strong seasonal course. Daytime values during the winter are higher than in summer, while in night time the dependency is opposite. At low solar activity, the seasonal course is weak and the difference between critical frequency values during the winter and summer season is significantly lower than in 2000 (a year of high solar activity).

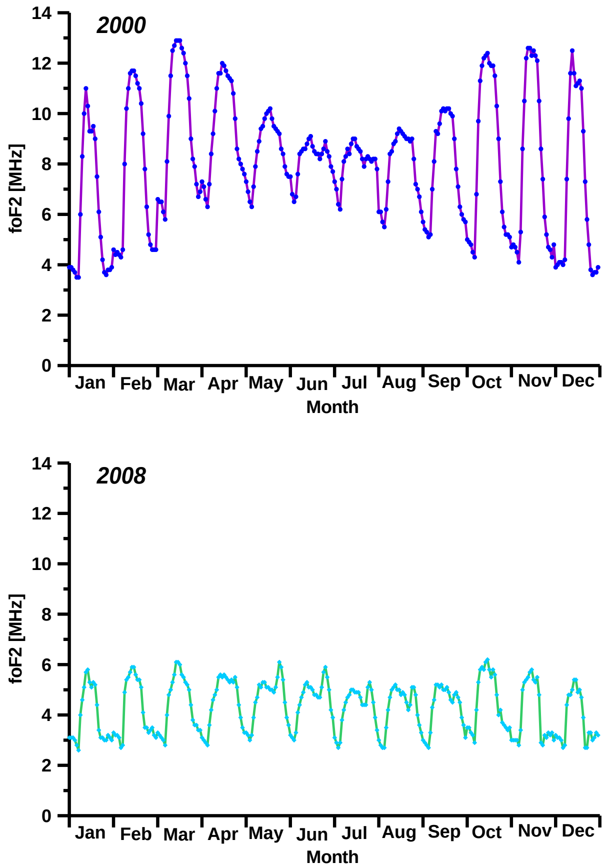

Fig.8. Average monthly diurnal course of foF2 in a year of high solar activity (upper panel) and low solar activity (bottom panel).

5. CONCLUSIONS

In this article considers the layer of the earth's atmosphere, extending at heights of 60 km. up to several thousand kilometers. A method is presented for vertically probing/sounding the ionosphere and an explanation is given for the inclined distribution of the radio waves through it. Examples are presented of the ionospheric characteristics of solar activity for a period of one solar cycle. The average frequency of the critical frequencies - foF2 is monitored under conditions of low and high solar activity. The influence of a geomagnetic storm on the critical frequencies of the ionosphere is analyzed. The change in electronic concentration during a storm worsens the accuracy of the positioning with the error in detecting a location reaching up to several meters. The above not only explains the physics of the ionosphere, but also the practical meaning of knowing its characteristics, which is an important condition for the use of certain types of radio communications.

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