IONOSPHERIC ANOMALIES OVER BULGARIA DURING TWO GEOMAGNETIC STORMS

R. Bojilova

[1]Geophysical Institute, ul. Acad.G. Bonchev, bl. 3, Sofia 1113, Bulgaria
e-mail: bojilova@geophys.bas.bg

Abstract. This paper considers ionospheric anomalies over the territory of Bulgaria during geomagnetic storms - the storm on 5 April 2010 and the event on 9 March 2012. The response of the ionosphere over Bulgaria is represented by data, collected by the ionospheric station in Sofia at NIGGG- BAS. The values of the Total Electron Content (TEC) have been provided by the Center for Orbit Determination of Europe (CODE). The data for variations on Earth magnetic field are received from INTERMAGNET. It was used the station Panagyurishte (PAG) located on the territory of Bulgaria. The impact of ionospheric anomalies on radio communication on frequencies in shortwave and satellite navigation is also analyzed.

Key words: Geomagnetic storm, TEC, Critical frequency, Ionospheric anomalies.

Introduction

Geomagnetic storms is the common name of the physical processes in the Earth's atmosphere and ionosphere, caused by large increases in plasma streams discharged into interplanetary space during Coronal mass ejections from the sun. Historically, they were first seen as anomalies in the values of Earth's magnetic field, which is one of the visible manifestations, with the help of ground-based measuring devices (magnetometers), of processes that accompany the entering of flows of charged particles (electrons and ions) discharged from solar corona into Earth's atmosphere. Because of the constant Earth magnetic field, the flows of particles penetrate deep into the Earth's atmosphere only in polar regions where the geomagnetic field lines are highly inclined (near vertical). Abnormal changes in the readings of magnetometers are due to the electric currents (generated by streams of charged particles) whose magnetic field is summed with the constant Earth magnetic field. The values of the variations in the magnetic field near the Earth's surface are used to create geomagnetic indices that characterize the intensity of storms. One of the most commonly used is the index Kp, which is obtained by summarizing the variation of a sufficient number of geomagnetic stations. Values of the Kp index vary between 0 and 9. Kp <4 is reported calm state, 4 <= Kp <5 – active state and when Kp>= 5 - geomagnetic storm. The intensity of magnetic storms is denoted by numbers (Scale) from G1 (Kp=5) to G5 (Kp=9). Storms with number G5 are considered extreme (NOAA Space Weather Scales).

Anomalous variations of the Earth's magnetic field are not the only result of the penetration of solar plasma flows into the Earth's atmosphere. Geomagnetic storms are accompanied by the so-called ionospheric storms, which are anomalous variations of the electronic concentration in the ionosphere (increase or decrease). Entering the atmosphere in the polar regions, the flows of charged particles cause further ionization, as well as an increase in the temperature of the neutral air, which changes the general atmospheric circulation at heights above 100 km. A change occurs in the ratio of oxygen to nitrogen and as a consequence the coefficients of recombination in the ionosphere change, which in turn causes anomalies in the electron concentration (Mukhtarov et al., 2013).These anomalies propagate from the polar regions to the equator through the processes of atmospheric dynamic (presence of neutral wind) (Kutiev & Mukhtarov, 2003).

The ability of the ionosphere (the area of the atmosphere, in which free electrons are present in addition to neutral gas molecules) is used to carry out the distant radio connection that are based on the ability of the ionized air to reflect radio waves with a certain frequency transmitted from terrestrial stations. Single and multiple reflection of radio waves from the ionosphere makes possible, under certain conditions, the implementation of communications between widely separated points on Earth with minimal energy consumption.

The ability of the ionosphere to reflect radio waves is directly related to the maximum of electron concentration, formed at altitudes between approximately 200 and 400 kilometers. The height and the value of this maximum vary depending on diurnal and seasonal variations. This two parameters depending also of 11-year solar cycle.

Two variables are used to characterize the possibility of radio communication, their values being derived from the data, gathered by ground- based ionosondes - critical frequency vertical distribution foF2 and maximum applicable frequency in 3000 km distance MUF3000. The critical frequency is actually the maximum applicable frequency for ionospheric radio communication at distances below 100 km.

Total electron content (TEC) is the total amount of free electrons in a vertical column with height limits of the ionosphere (about 1000 km). This ionosphere characteristic is important for determining the so-called ionosphere correction using GNSS (Global Navigation Satellite Systems). Radio waves, used for satellite navigation have a very high frequency and are not reflected by the ionosphere, but as they pass through it, they receive additional delay, which introduces errors in determining the coordinates of the receiver. Knowing the values of TEC allows for correction of the readings (Hansen et al., 1997).

Data

This study uses values of the planetary index of geomagnetic activity Kp, published in NOAA- https://www.ngdc.noaa.gov. Data from the vertical probing of the ionosphere with radio waves (foF2 and MUF3000) are provided by the Ionospheric station at NIGGG-BAS. Data for the variations of the Earth's magnetic field are provided by INTERMAGNET- http://www.intermagnet.org/. To present the magnetic field course, data from the Panagyurishte (PAG) station with coordinates 42.5 ° N, 24.2 E° was taken. The TEC values were obtained by the Center for Orbit Determination of Europe (CODE) - ftp://ftp.unibe.ch/aiub/CODE/. Because the data are in grid with a 2.5° step in latitude and 5° in longitude, the point nearest to Sofia was selected, namely 42.5°N, 25°E.

Experimental results

This work examines two geomagnetic storms - the storm on 5 April 2010 and the other storm on 9 March 2012. Both of them are Severe (G4, Kp =8), according to NOAA Space Weather Scales. The first storm to be explored on April 5, 2010 is a typical storm with a sudden start. The sharp increase of Kp to value (~ 8) occurs at noon (local time) on 5 April of practically calm or slightly disturbed conditions. The subsequent response of Kp is a gradual decrease in value, on 6 April - the index ranges around 5, which is considered a (Minor) disturbed state. Normalization of the geomagnetic activity occurs at 7 April - when the value of Kp is about 4.

The path of the X component of the magnetic field on the graphic (Figure 1), measured at Panagyurishte station, is typical for geomagnetic stations at middle latitudes. During the storm an overall decrease in the value of the X component around 80nT (about 0.34%) is observed. In geomagnetic storms middle latitude stations show effects such as an increase of the equatorial circular current (Dst- variations) and the currents, that are induced in the polar regions (chaotic variations). Anomalies in the ionosphere (ionospheric storm) obviously come with some delay. It is noted that at 5 April the values of foF2 and MUF3000 do not differ significantly from those in the calm state. A significant negative anomaly occurs on 6 April, with a half-day delay from the onset of the storm. This phenomenon is due to the inertia of the ionosphere. The decrease in MUF300 is about 10-12 MHz, which is the narrowing of the range of frequencies at which radio communication is possible at a distance of 3000 km.

TEC anomalies are fundamentally different from the anomalies in the critical frequencies. The sharp rise in TEC values at around 5 TECU at noon by around 15 TECU indicates that the response is entirely positive and the delay to the storm is minimal. The presence of positive and negative phases in TEC response is due to different mechanisms of change of the electron concentration in the areas of the ionosphere (Pancheva et al, 2016).

The other storm, this paper considers, occurred on 9 March 2012. Unlike the first storm examined this one doesn`t have a sudden onset, and its manifestation affects reviewed charts on the previous date as early as 7 March. There is a disturbance at midday (Moderate; G2, Kp = 6), which may indicate an upcoming geomagnetic activity. In the coming days, Kp switches, with a maximum loan amount of 9 March. Then the index becomes 8, which is classified as a severely disturbed state (Severe; G4, Kp = 8). Normalization of geomagnetic activity occurs the next day -10 of March.

For magnetic storm tracking, the same station (PAG) from Mid-Range Geomagnetic Observatories was again selected for this storm. Storm variations in the X-component of the magnetic field are about 140 nT (about 0.6%). The ionospheric storm is expressed by anomalies in foF2 and MUF3000. It can be seen from the graph that the values of the two values for the period 9-10 March 2012 have a very low negative anomaly. Again, the delay in the response is minimal [Kutiev, Mukhtarov, 2001]. The MUF3000 is about 5 MHz. The increase in critical frequencies does not affect radio links. The sudden rise above the TEC by 15 TECU at the end of 7 March shows both the positive response of this magnitude, the first phase of the storm, and the absence of any apparent delay. The second (major phase) of the storm does not produce a visible positive response in the TEC, but in the late hours of 9 and 10 there is a pronounced negative response.

The behavior of the ionosphere over Bulgaria during the geomagnetic storm on 5 April 2010 and 9 March 2012 is shown on Fig. 1 and Fig. 2.

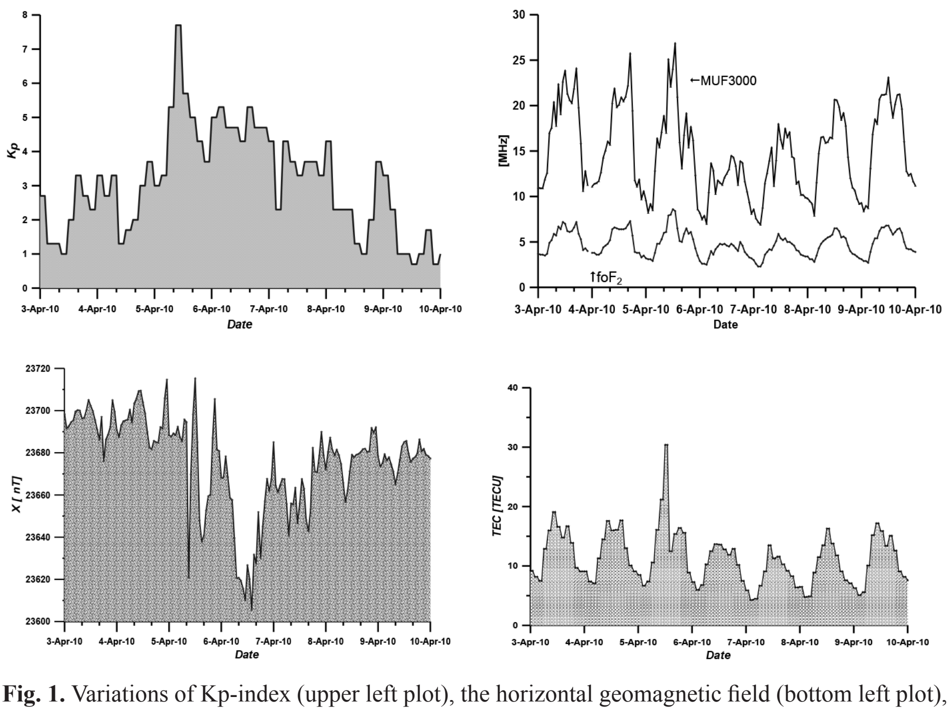

Fig. 1. Variations of Kp-index (upper left plot), the horizontal geomagnetic field (bottom left plot), critical frequencies (upper right plot) and TEC (bottom right plot) during the geomagnetic storm 5 April 2010.

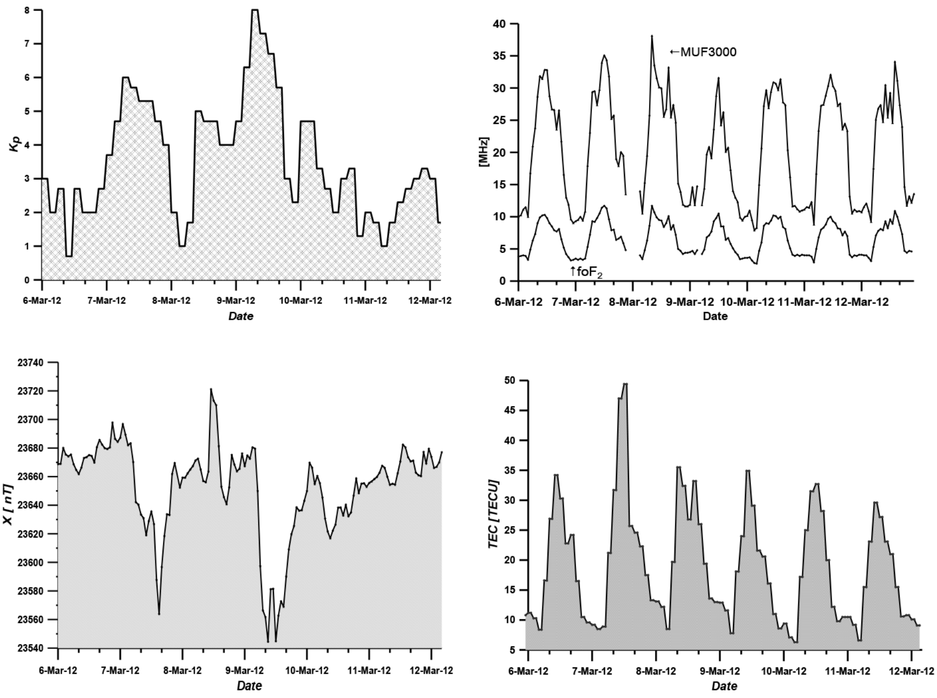

Fig. 2. Variations of Kp-index (upper left plot), the horizontal geomagnetic field (bottom left plot), critical frequencies (upper right plot) and TEC (bottom right plot) during the geomagnetic storm 9 March 2012.

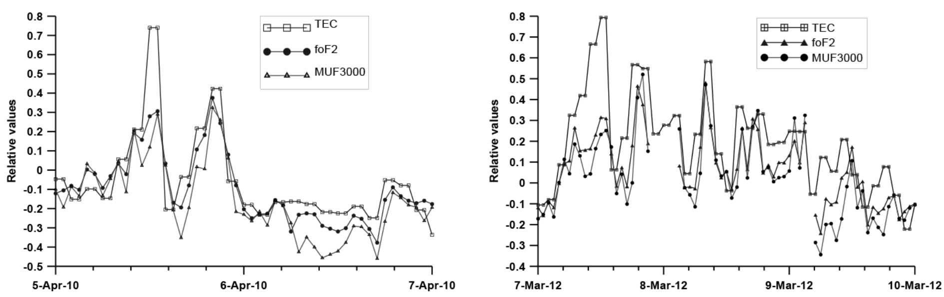

Fig. 3. Relative values of ionospheric quantities during two geomagnetic storms. Upper panel - shows the status of the ionosphere during the storm of April 5, 2010. Bottom panel - shows the status of the ionosphere during the storm of March 9, 2012.

The idea of presenting the relative values (Kutiev & Muhtarov, 2003, Pancheva et al., 2016) of the variables shown in this study is to eliminate the 24-hour diurnal course in each component and to eliminate the impact of different measurement units. As shown in Fig. 3 the relative shift path shows that in TEC the positive response is much stronger than in foF2 and MUF3000. Due to the fact that foF2 and MUF3000 characterize the area of the ionosphere around its maximum, and the TEC is also formed from the upper F-region, this means that the increase in electronic concentration in the initial phase of the storms occurs predominantly at heights above the maximum.

Comments and conclusions

The geomagnetic and ionospheric anomalies during two geomagnetic storms, discussed in this article illustrate their impact on communications and navigation. Changes in the geomagnetic field itself are insignificant. The analysis shows that the horizontal component of the magnetic field varies only around 0.34% - 0.6% and can`t be expected to have a noticeable effect on the navigation compass.

Geomagnetic storms impact is strongest on shortwave radio communications. During extreme events the range of frequencies at which radio communication is possible at a certain distance may be reduced nearly twice. This may lead to disintegration of many of the existing radio communications which are based on ionospheric reflection.

The impact of changes of the electron concentration in the ionosphere during the storm on GNSS navigation has a range of several meters, which is significant for precise positioning.

The correct determination of the ionosphere correction on GNSS receivers is essential to improvement the accuracy of satellite navigation. The determination of this ionospheric correction depends on the precision of the estimated value of TEC, which makes the TEC prediction (especially in the case of geomagnetic anomalies) particularly relevant. Forecasting of TEC in case of geomagnetic anomalies requires the determination on the general patterns of ionosphere response during geomagnetic storms.

The present paper analyzes the ionospheric anomalies over Bulgaria during two geomagnetic storms. This article is part of the empirical analysis that is needed to create a prognostic model for the ionospheric characteristics during anomalies of geomagnetic origin. This method can be used by users work with short wave radio communications and GNSS navigations.

References

Hansen, A. J., T. Walter, and P. Enge. "Ionospheric correction using tomography." Proceedings of Institute of Navigation ION GPS-97, Kansas City (1997): 249-260.

Kutiev, I., P. Muкhtarov. Empirical modeling of global ionospheric fo F2 response to geomagnetic activity, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. A1, 1021, doi: 10.1029/2001JA009134, 2003

Mukhtarov, P., N. Penov, D. Pancheva. N(h) PROFILES DERIVED FROM IONOGRAMS AND THEIR APPLICATION FOR STUDYING MID-LATITUDE IONOSPHERIC RESPONSE TO GEOMAGNETIC STORMS, Comptes rendus de l'Acad´emie bulgare des Sciences, Tome 66, No 9, 2013

NOAA Space Weather Scales, http://www.swpc.noaa.gov/noaa-scales-explanation
Pancheva, D., P. Mukhtarov, B. Andonov. Global structure of ionospheric TEC anomalies driven by geomagnetic storms, Journal of Atmospheric and Solar-Terrestrial Physics 145 (2016) 170–182, www.elsevier.com/locate/jastp

Йоносферни аномалии над България по време на две геомагнитни бури

Р. Божилова

Резюме: В настоящата работа се разглеждат йоносферните аномалии над територията на България по време на геомагнитни бури от слънчев произход – бурята от 5 април 2010 г. и тази от 9 март 2012 г. Реакцията на йоносферата над България е представена чрез данните на Йоносферна станция София при НИГГГ – БАН. Стойностите на Total Electron Content (TEC) са получени от Center for Orbit Determination of Europe (CODE). Данните за вариациите на земното магнитно поле са получени от INTERMAGNET. Разглежда се станция Panagyurishte (PAG), намираща се на територията на България. Анализирано е влиянието на йоносферните аномалии върху радиовръзките на честоти от късовълновия диапазон и спътниковата навигация.