INFLUENCE OF GEOMAGNETIC ACTIVITY ON THE IONOSPHERE CRITICAL FREQUENCIES

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Abstract. The present work investigates the seasonal dependence of the geomagnetic activity influences on the diurnal variability of the maximum electron concentration of the ionosphere over Bulgaria. Data from the ionosonde station Sofia for the period of 1995-2014 are used. The geomagnetic activity is described by the planetary Kp-index. The ionospheric response to the geomagnetic storms is studied by considering the relative deviation of the diurnal variability from its median course for the two ionospheric characteristics foF2 (critical frequency of the ionospheric F-region) and MUF3000 (maximum usable frequency for a distance of 3000 km). It is found that the ionospheric reaction in summer is stronger than that in winter and the time delay of the ionospheric response in winter is longer than that in summer.

Key words: geomagnetic activity, critical frequency, ionospheric response.

Introduction

Ionospheric storm is a common term that describes the entirety of ionospheric variations induced by geomagnetic disturbances. The ionospheric storms primarily occur as a consequence of a sudden input of solar wind energy into the magnetosphere-ionosphere-thermosphere system (Astafyeva et al., 2015). The energy inputs during the geomagnetic disturbances lead to substantial effects in the upper atmosphere and the significant perturbation of the ”quiet-time” ionosphere (Mukhtarov and Bojilova, 2017). Three main mechanisms of storm effects have been suggested to explain the positive and negative phases of ionospheric storms: (i) thermospheric composition changes, (ii) neutral wind perturbations, and (iii) the appearance of electric fields of magnetospheric origin. The negative phase of ionospheric storms is mainly due to the composition changes (Rishbeth, 1991), i.e. the thermosphere becomes richer in molecular nitrogen (N_2) and oxygen (O_2) and poorer in atomic oxygen (O). The molecular species, however, determine the loss rate of ions hence their enhancement leads to an increase of the loss rate. The auroral heating can alter the mean global circulation of the thermosphere. Whereas for quiet conditions there is a general up-welling in the summer hemisphere flow toward the winter hemisphere at higher levels, and down-welling in the winter hemisphere, the storm-time heating adds a polar up-welling and equatorward flow in both hemispheres. The increased equatorward wind at middle latitudes tends to push the ionosphere higher up along magnetic field lines, where the loss rate is lower. The reasons of the positive ionospheric storms are the combined effects of disturbed thermospheric wind and electric fields (Balan et al., 2010 and Tanaka, 1979). Kelley et al. (2004) suggested that, in the presence of day-time ionization an eastward prompt penetration electric field (PPEF) can strengthen the equatorial plasma fountain to a super plasma fountain, which, in turn, can lead to positive ionospheric storms at sub-tropical and mid-latitudes. However, modelling studies later showed that an equatorward neutral wind is required also to produce positive ionospheric storms (Balan et al., 2010).

The present study investigates the seasonal dependence of the geomagnetic activity influences on the diurnal variability of the maximum electron concentration of the ionosphere over Bulgaria. The ionospheric response to the geomagnetic storms is studied by considering the deviation of the diurnal variability from its steady (median) course. It is found that the ionospheric reaction in summer is stronger than that in winter. Using the correlation analysis the seasonal dependence of the ionospheric response time delay for two ionospheric characteristics, foF2 and MUF3000, was determined. It is found that the time delay of the ionospheric response in winter is longer than that in summer.

Data

The geomagnetic activity is described by the planetary Kp-index and the values of the Kp-index are obtained from NOAA website: https://www.ngdc.noaa.gov. The data for foF2 and MUF3000 are taken from the ionosonde station Sofia- SQ143 (42.4°N, 23.2°E) at the NIGGG-BAS for the period of 1995-2014. This study is based on the representation suggested by (Muhtarov et al., 2002 and Mukhtarov et al., 2013) about the reaction of the relative deviation of ionospheric quantities to geomagnetic disturbances in an inertial model, described by a linear differential equation of first order with a given time constant. For this purpose, the Kp-index has been integrated with different time constants from 1 to 72 hours. For each time constant, the cross-correlation function between the integrated Kp-index and the relative deviation of foF2 and MUF3000 is calculated and the time constant with the highest correlation (positive or negative) is selected. It is assumed that this time constant characterizes the real inertness of the ionosphere. In order to get information about the seasonal differences, cross-correlation is calculated for each calendar month. The day and night-time conditions are considered separately.

Experimental results

The results of the cross-correlation analysis between the ionospheric characteristics foF2 and MUF3000 and geomagnetic activity will be illustrated and explained in detail by considering the presented below examples. The obtained results will be used to justify later the development of an empirical model for predicting the ionosphere state over Bulgaria.

Fig. 1 shows the seasonal courses of the negative correlations (left panel) and the optimal time constants (right panel) during daytime conditions for both parameters foF2 (full line) and MUF3000 (dash line). The left panel of Fig. 1 reveals that a significant negative correlation of 28-30% occurs in the summer and equinoctial months for both characteristics foF2 and MUF3000 oppositely to the winter months when the correlation is very small, only 3-8%. The right panel of Fig. 1 shows small time constants of the order of 2-15 hours for the months from February to September (we note that January and December are not shown because the response is always positive).

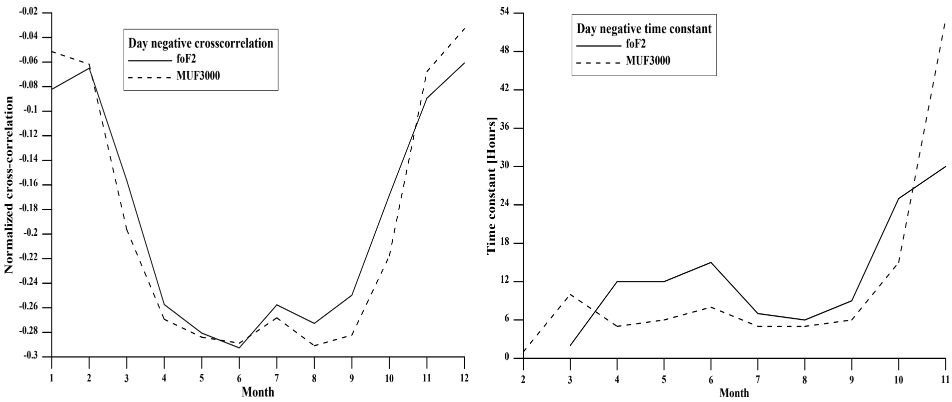

Fig. 1. Seasonal variability of the negative cross-correlation (left panel) and time constant (right panel) during daytime conditions.

Fig. 2 demonstrates the cross-correlation functions for two typical summer months, June and July, for the considered parameters foF2 (left panel) and MUF3000 (right panel) in daytime conditions. The figure shows a good negative cross-correlation during the months under consideration for both parameters, reaching in some cases 30%. The delay corresponding to the maximum negative cross-correlation for daytime conditions in the months June and July, presented in Fig. 2, is around 7 hours.

Fig. 3 is similar to Fig. 1 but for nighttime conditions. Again, we can see well-expressed negative cross-correlations valid for the two quantities foF2 and MUF3000 during the summer months, reaching about 30%. The winter months, shown in Fig. 3, are again characterized by a smaller negative cross-correlation (Fig. 3, left panel). The time constants, shown on the right panel of Fig. 3, demonstrate the smallest values (about 15

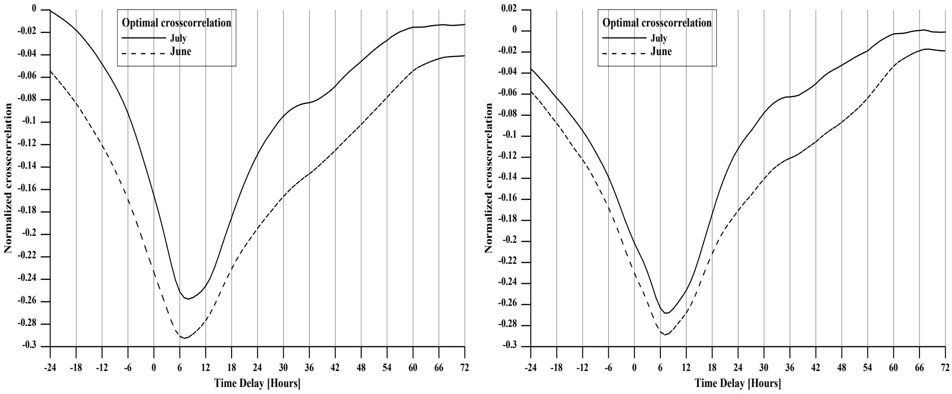

Fig. 2. Optimal negative cross-correlation functions for two months June and July for foF2 (left panel) and MUF3000 (right panel) during daytime conditions.

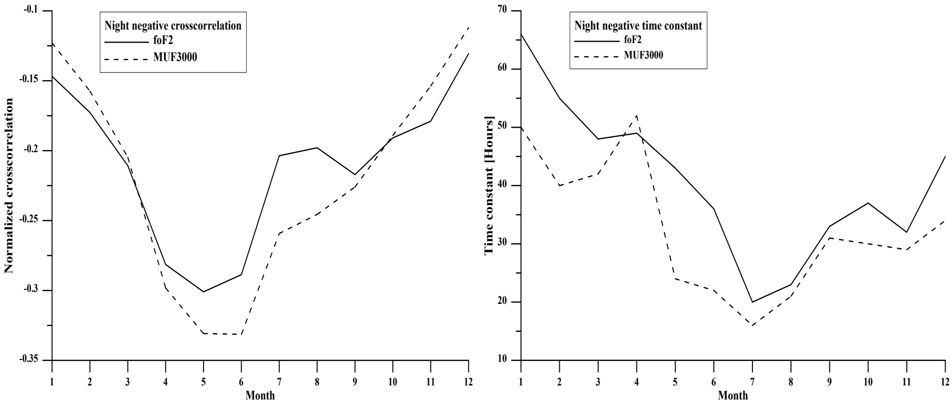

Fig. 3. Seasonal variability of the negative cross-correlation (left panel) and time constant (right panel) during nighttime conditions.

hours) in the summer months again while in the winter months the time constants begin to increase and reach about 66 hours.

Fig. 4 is analogous to Fig. 2 and presents the cross-correlation functions for two typical summer months, June and July, for the considered parameters foF2 (left panel) and MUF3000 (right panel), but this time for nighttime conditions. A good negative cross-correlation during the considered months for both quantities is observed; it reaches almost 30% for foF2 (left panel) and exceeds 32% for MUF3000 (right panel). The delay corresponding to the maximum negative cross-correlation for the nighttime conditions in June and July is presented in Fig. 4 (left and right panel), ranges from 6 to 11 hours.

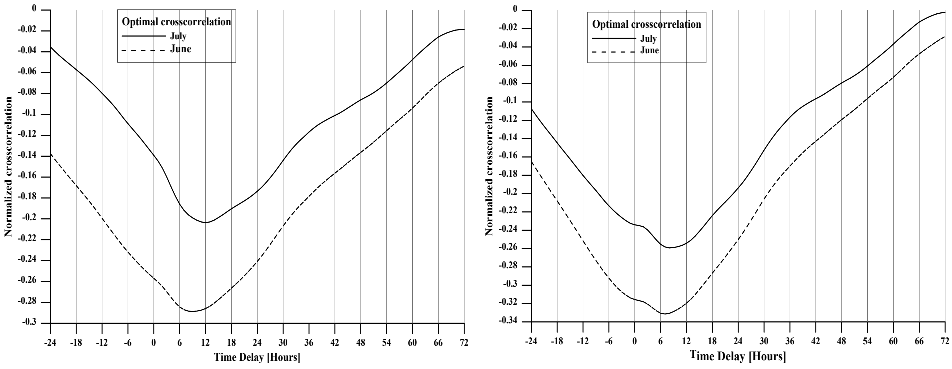

Fig. 4. Optimal negative cross-correlation functions for two months June and July for foF2 (left panel) and MUF3000 (right panel) during nighttime conditions.

Fig. 5 shows the cross-correlation functions in daytime conditions for two typical winter months December and January for the considered parameters foF2 (left panel) and MUF3000 (right panel). The presentation of these months in a separate figure was done because of the positive cross-correlation obtained at the practically zero value of the integrated time constant. The values of the time delay for both critical frequencies are around 2-9 hours for January and 6 and 11 hours for December. The maximum positive cross-correlation for foF2 (left panel) during these winter months is about 24%, whereas for MUF3000 it is approximately 15% (right panel). The delay corresponding to the maximum positive cross-correlation during the daytime conditions in December and January for foF2, presented in Fig. 5 (left panel), is between 3 and 9 hours. The same time delay corresponding to the maximum positive cross-correlation for MUF3000, shown in Fig. 5 (right panel), is about 10-11 hours, which is similar to the summer months presented in Fig. 4.

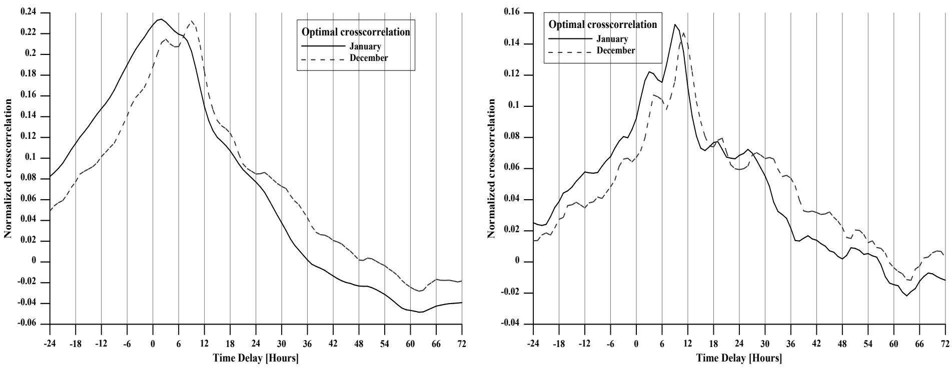

Fig. 5. Optimal positive cross-correlation functions for two winter months December and January for foF2 (left panel) and MUF3000 (right panel) during daytime conditions

Comments and conclusions

This study investigates the seasonal variability of the ionospheric response to geomagnetic activity over ionosonde station Sofia. For this purpose the cross-correlation analysis between the integrated Kp-index and the relative deviation of the parameters foF2 and MUF3000 is performed. It is well known that the values of the cross-correlation function, i.e. the cross-correlation coefficients, to a large extent determine the coefficients of linear regression between the studied quantities, as the negative/positive cross-correlation defines the inverse/direct relationship. The values themselves indicate the strength of the investigated relationship.

The analyses revealed that the negative reaction of the ionospheric parameters to the geomagnetic activity is stronger during summer and equinoctial months than that in winter. This is due to the thermospheric composition changes related to the Joule heating and particle precipitations during the geomagnetic storms which are moved to the middle latitude by the disturbed and ‘quiet-time’ seasonal circulations in summer. The increase in time constants, i.e. the delay of the negative reaction during the winter is caused by the need of extra time for strengthening of the disturbed circulation. Negative nighttime reaction turns out to be more significant than in daytime conditions. A positive reaction practically without delay is observed only in the winter months during daytime conditions.

The results obtained might prove useful in the development of an empirical model for predicting the ionosphere response to geomagnetic storms over Sofia.

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Влияние на геомагнитната активност върху критичните честоти на йоносферата

Р. Божилова

Резюме: В настоящето изследване е представена сезонната зависимост на влиянието на геомагнитната активност върху отклонението от стационарния (среден) денонощен ход на максималната електронна концентрация на йоносферата за България. Използвани са данни от Йоносферна станция София за периода 1995–2014 г, както и индексът, характеризиращ геомагнитната активност Кр, за същия период време. Установява се, че получената реакция се увеличава през летния сезон в сравнение със зимния. Чрез използването на корелационен анализ е определен сезонният ход на времеконстантата на закъснение на реакцията на йоносферата за двете йоносферни характеристики – foF2 и MUF3000. Предложено е обяснение за получените резултати, които показват, че съответната времеконстанта е по-дълга през зимните месеци и ниска през лятото.