

GEOMAGNETIC CORRELATIONS OF IONOSPHERIC F2 LAYER PEAK ELECTRON DENSITY HEIGHT FOR IONOSPHERIC STATION ROME, ITALY

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Abstract

The basic aim of this research is to present an analysis of the relationship between the average ionospheric response of peak electron density height of the ionospheric F2 region (hmF2) and the geomagnetic activity for ionospheric station Rome, Italy. Significantly long data series for both quantities in the period 2002–2022 (including two solar cycles) were used, and the method for determining the relative deviation of the parameters from quiet (median) conditions was applied. To analyze the influence of geomagnetic activity represented by planetary Kp index on the hmF2, correlation analysis was used. The results show that a) the predominant ionospheric response is positive with a delay of about 1–2 hours; b) the influence of geomagnetic activity on hmF2 is maximal during the equinox months, during the night hours and around local noon. The obtained results of the positive correlation coefficient, indicating the presence of a relationship between hmF2 and Kp index (reaching up to 30%), show that the most significant influence on hmF2 is the vertical upward drift caused by the induced electric fields in the ionosphere from the “perturbed dynamo” and prompt penetration electric fields (PPEF). The choice of the selected ionospheric station Rome is related to the fact that this station is located at the geographic latitude coinciding with the latitude of Sofia, which suggests similar characteristics of the ionosphere for the territory of Bulgaria.

Key words: geomagnetic storm, ionosphere, hmF2

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Introduction. The ionosphere is formed due to photoionization of neutral atmosphere by solar radiation and exhibits latitudinal, longitudinal, altitudinal as well as diurnal and seasonal variations [1]. The behaviour of the ionosphere depends on the geomagnetic field, geomagnetic activity and solar activity [2, 3]. The practical application of shortwave communications and GPS navigation and their relationship to variations in electron density is well known [4].

The peak electron density height of the ionospheric F2 region is an important characteristic of the electron density profile in the Earth's ionosphere. The changes in this quantity will directly affect the selection and design of parameters such as the radio wave radiation elevation and the working frequency band in short wave communication lines, and then affect the distance and efficiency of communication [4, 5]. The calculation of radio path characteristics using meter radio waves in ionospheric reflection requires knowledge of the height of the maximum, its diurnal and seasonal variations, as well as its behaviour during ionospheric anomalies caused by geomagnetic storms [6–8]. The electron density profile in the F region is formed under the action of the Sun's ultraviolet radiation, which ionizes atmospheric oxygen. In the formation of the electron profile, recombination plays an important role, which is mainly determined by the ratio of atomic oxygen and nitrogen. The movements of the ionospheric plasma under the influence of induced electric fields also play a significant role [9, 10]. During ionospheric disturbances caused by geomagnetic storms, a complex set of geophysical processes acts on the ionospheric plasma, related to the change in the recombination coefficient, the creation of additional electric fields, and the drift of the plasma under their influence [3]. These processes cause a change in the entire electron profile of the ionospheric region F, including the height of the maximum electron density.

The aim of the present work is to determine the statistically average response of the height of the maximum of geomagnetic disturbances in mid-latitudes of the European region. For this purpose, data from the Rome, Italy station for the period 2000–2022 were used. This ionospheric station is located at latitude coinciding with the latitude of Bulgaria and the results of the analysis can be used to characterize the main regularities of the ionosphere over Sofia and for verification and improvement of the methodology for predicting the radio path on the territory of Bulgaria [11, 12].

Data. The values of the height of the maximum of the F region, for the ionospheric station Rome, Italy (Station Code RO041, 41.9°N, 12.5°E), subject to this study, are taken from Global Ionosphere Radio Observatory (GIRO) <https://giro.uml.edu/didbase/scaled.php> and are converted into relative values using the formula:

$$(1) \quad rhmF2(t) = \frac{hmF2(t) - hmF2_{med}(UT)}{hmF2_{med}(UT)},$$

where $hmF2(t)$ denotes the $hmF2$ value at the moment t , $hmF2_{med}(UT)$ is the

median $hmF2$ obtained from the $hmF2$ values for universal time UT coinciding with universal time at the moment t during a 27-day period centred on the current day. This characteristic allows determining with sufficient accuracy the type of ionospheric response (positive or negative) in each specific case [13, 14].

The values of the geomagnetic activity index Kp , which are freely available at <https://omniweb.gsfc.nasa.gov/form/dx1.html> have been similarly modified in relative deviations, denoted by rKp :

$$(2) \quad rKp(t) = \frac{Kp(t) - Kp_{mean}(UT)}{Kp_{mean}(UT)},$$

where $Kp(t)$ is the value of Kp at the moment t , and Kp_{mean} is the mean value of Kp for a period of 27 days, centred on the current moment t .

Figure 1 shows an example of how the relative values used in this work de-

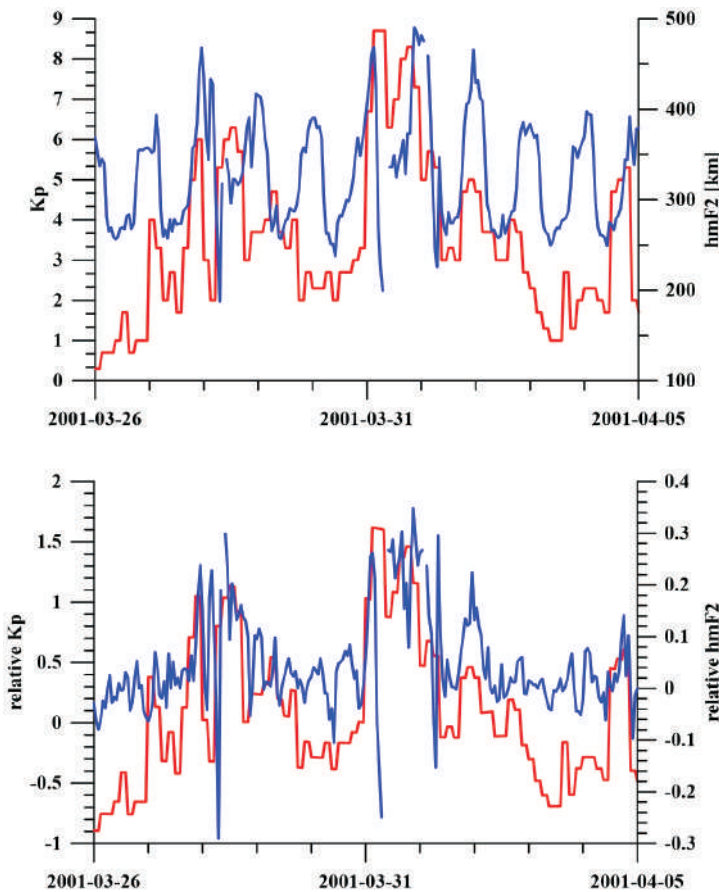


Fig. 1. Geomagnetic storms in March and April 2001 and their impact on Kp and $hmF2$ (top panel) and the corresponding relative values (bottom panel)

scribe the variations of hmF2 and Kp under the conditions of geomagnetic storms in March and April 2001. The normalized cross-correlation function ρ_{xy} , was calculated using the following formula:

$$(3) \quad \rho_{xy}(\tau) = \frac{M[rKp(t) rhmF2(t + \tau)]}{\sigma_{Kp} \sigma_{rhmF2}}.$$

The operator M denotes the mean value in the considered ensemble, σ indicated the corresponding standard deviation, and τ is a time lag.

Results. Figure 2 shows the normalized cross-correlation function between rKp and rhmF2 calculated for all hourly values in the time interval 2000–2022. The cross-correlation is positive and reaches about 25% with a time lag of about 1–2 hours. LIU et al. [15] present a detailed analysis of the response of the electron profile during the storm on 17 March 2015, based on data from a station located at 42.6° N. The results of the analysis show that, compared to quiet conditions, the decrease in electron density is strong at altitudes below 350 km and weakens at altitudes around 400 km, which is one of the reasons for the upward shift of hmF2. In their investigation BALAN et al. [16] considered cases in which the ionospheric density response to geomagnetic disturbances was positive. In these cases, electric fields are excited, causing an upward vertical drift, which also leads to an increase in the height of the maximum.

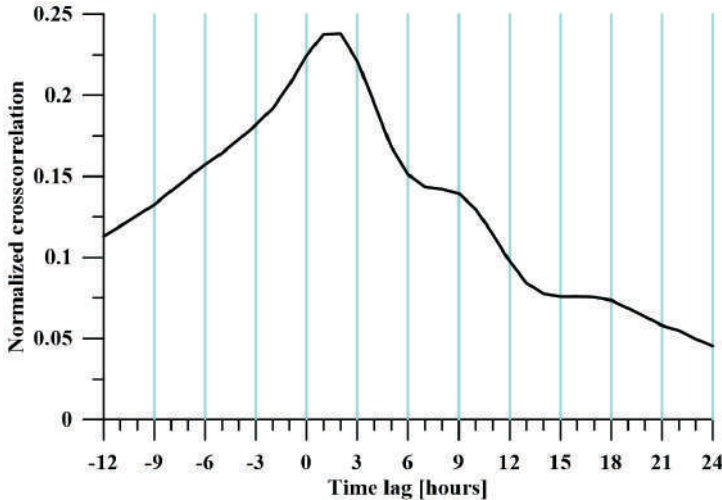


Fig. 2. Normalized cross-correlation function between relative Kp and relative hmF2

In a detailed study of the ionospheric response to several geomagnetic storms recorded in January 2005, BOJILOVA and MUKHTAROV [6] show that the main contribution to the response over Bulgaria to moderate/intense winter geomagnetic storms is associated with significant enhancements of short-period quasi-diurnal oscillations with period of 6–7 hours observed in hmF2.

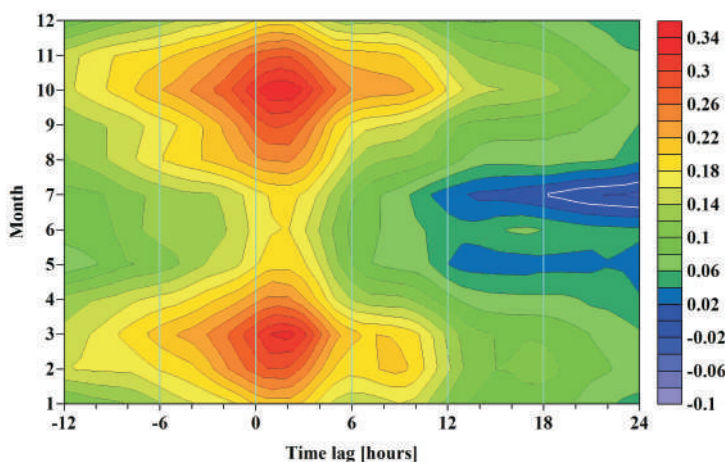


Fig. 3. Dependence of the normalized cross-correlation function on the calendar month

Figure 3 presents the dependence of the cross-correlation function on the calendar month. The cross-correlation and response of hmF2 is strongest around the spring and autumn equinoxes and weakest around the summer and winter solstices. The enhanced response in the equinox months is probably related to the decrease in the meridional circulation of the atmosphere during the transition from winter to summer and from summer to winter. In such conditions, the influence of ionospheric plasma drift under the action of dynamo currents in the tropical region predominates.

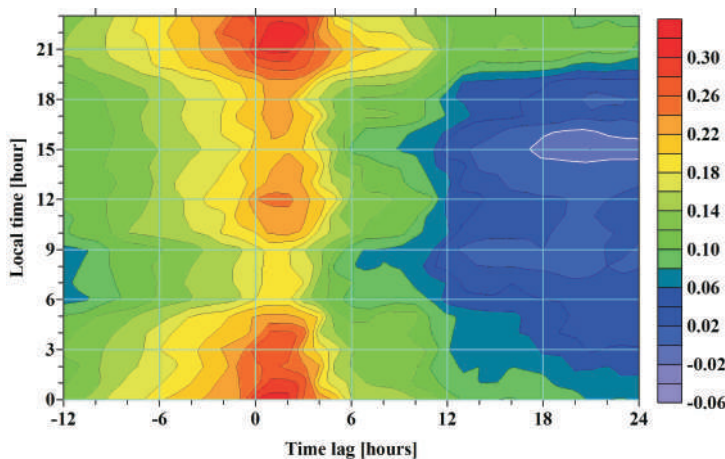


Fig. 4. Dependence of the normalized cross-correlation function on local time

Figure 4 shows the dependence of the cross-correlation function on local time. The positive response is maximized in nighttime conditions and in the hours

around local noon. The strong ionospheric response in nighttime conditions can be explained by the dominance of recombination processes and plasma drift in the absence of direct ionization from the Sun. The enhancement of the response around local noon is most probably due to the influence of prompt penetration electric fields (PPEF) and the vertical drift they cause, which operate in daytime conditions.

Conclusion. The correlation analysis of the influence of geomagnetic activity on the peak electron density height of the ionospheric F2 based on a 22-year data series at the ionospheric station in Rome, Italy, shows that the predominant response is positive with a delay of about 1–2 hours. The influence of geomagnetic activity is maximum during the equinox months, during the night hours, and around local noon. The positive character of the response means that the most significant influence on the hmF2 is the vertical drift directed upwards, caused by the induced electric fields in the ionosphere by the “disturbed dynamo” and prompt penetration electric fields (PPEF). The values of the correlation coefficient reach about 30%, which indicates the good relationship between the studied parameters. The choice of Rome ionospheric station is related to the fact that this station is located at the geographic latitude coinciding with the latitude of Sofia, which suggests similar characteristics of the ionosphere and applicability of the results for the territory of Bulgaria. The presented detailed analysis of the relationship between geomagnetic activity and hmF2 has a practical application in improving and supplementing the methodology for predicting the propagation of radio waves with ionospheric reflection [11, 12].

The present study represents an important contribution to space physics and solar-terrestrial physics, which refers to the processes and anomalies in the Earth’s magnetosphere, thermosphere, and ionosphere that result from changes in the Sun and solar wind [17–20].

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