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Relationship Between Short-Term Variations in Solar Activity and Critical Frequency of the Ionospheric F2 Layer

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Abstract.

The present work is devoted to the finding of a functional dependence of the critical frequency of the ionospheric F2 layer, denoted by foF2, on the short-term variations in solar activity represented by the solar radio flux F10.7. The foF2 data are obtained from the ionosonde station at Sofia for the period of 1995-2014, while those for F10.7 were taken from the website of NASA https://omniweb.gsfc.nasa.gov/. The examples considered in this work demonstrate the need of pre-processing the selected parameters by introducing a relative deviation from the median value for each of the quantities. The use of a group regression to represent the required relationship is also justified. The result of the regression analysis revealed that the optimal functional dependence between the critical frequency of the F2 layer and F10.7 is close to linear one. These results can be used for building an empirical model that could predict the state of the ionosphere over Bulgaria.

Introduction

Solar radiation has a significant impact on the electron concentration of the ionosphere. The solar activity dependence of the ionosphere is fundamental issue in ionospheric physics, providing information essential for understanding the processes occurring in the ionosphere.

The ionosphere is an open system that strongly couples with the magnetosphere and thermosphere [*Huba et al.*, 2005; *Liu et al.*, 2011]. Various photo-chemical and chemical reactions and dynamical and electro dynamical processes in the system exchange and transport mass, momentum and energy in a complex manner. The regular and irregular variability of the solar activity strongly affects the chemical reactions and physical processes and it further strongly modulates the structure and development of the ionosphere and thermosphere. An essential issue in ionospheric physics is to study ionospheric characteristics and processes under different solar activity conditions. The study of solar activity modulation of the ionosphere will improve our understanding of the ionospheric structure and its development. This is critical in determining ionospheric climatology and long-term trends, and will also deepen our knowledge of chemical and physical processes in the ionosphere and thermosphere [*Schunk and Nagy*, 2009]. On the other hand, the solar activity dependence of the ionosphere is one of the core issues for ionospheric empirical models. Moreover, it is realized that the ionospheric climatology, especially the solar activity effects of the ionosphere, provides an insight into ionospheric weather problems.

Solar activity, as discussed in the scientific community, can have different meanings. First, it refers to the level of solar activity, indicating the intensity of solar electromagnetic ra-diation, particularly notable at wavelengths of solar X-rays and the extreme ultraviolet (EUV) (XUV). Second, refers to solar activity events; e.g. coronal mass ejection and solar proton events. The two meanings have a close relationship as well as distinct differences. Both the variability of solar activity and its relationship with the ionosphere have received a renewed interest recently.

The Earth's upper atmosphere absorbs solar radiation, resulting in heating, dissociation and ionization. The ionosphere is mainly produced via the ionization effect of solar XUV. It is well established that the solar XUV fluctuates regularly and irregularly over timescales from minutes (flares) and roughly 27 days (solar rotation) to decades (11-year solar cycle), with amplitudes varying up to more than 1000 times. The variability of the solar activity initiates large variations in the neutral density and temperature, ion and electron densities and temperatures, neutral winds, and electric fields in the ionosphere [*Rishbeth*, 2006].

The purpose of this study is to find a relationship between the critical frequency of the F2-layer and the solar activity, represented by F10.7. This work presents a regression analysis between the relative deviations from the median value of the considered parameters. The result of the analysis shows that the optimal function describing the relationship between the relative deviations of foF2 and relative F10.7 is close to linear one. In the example shown, the hours at which the geomagnetic activity index Kp is greater than 5 are ignored. In this way the contradiction between variations in solar activity causing usually a positive ionospheric response and the geomagnetic disturbances that most often generate a negative response is significantly reduced. All these results can be used for establishing of an empirical model for forecasting the state of the ionosphere over Bulgaria.

Data and methods

Traditionally, in the ionospheric studies, the daily and seasonal fluctuations of the ionospheric characteristics and its dependence on long-term changes in solar activity are given by the monthly median of hourly values. The advantage of using the median value over the average one is due to the elimination of the extreme values connected with geomagnetic disturbances [*Pancheva and Mukhtarov*, 1996]. For this reason, the median value is used as a characteristic of the calm in the geomagnetic sense conditions of the ionosphere in a given calendar month. Traditionally, as a characteristic of solar activity, the smoothed values of the radiation flux of the Sun with a wavelength of 10.7 cm, F10.7, are used.

The values of the solar radio flux F10.7 are provided from: https://omniweb.gsfc.nasa.gov/. The foF2 values are derived from the ionosonde station Sofia-SQ143 (42.4°N, 23.2°E) that belongs to the National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences.

The use of raw F10.7 data is incorrect when using the relative values of the ionospheric characteristics in which the 11-year variability is filtered out. It is therefore necessary to work with the relative values of F10.7 obtained by the formula:

$$rF10.7(t) = \frac{F10.7(t) - F10.7_m}{F10.7_m}$$

where F10.7m is the average value calculated for a segment of time with a length of 27 days and centered on the current time. Thus the relative F10.7 values contain variations related to the rotational solar period and its harmonics but not variations due to the 11-year cycle of solar activity [*Mukhtarov and Bojilova*, 2017].

Fig. 1 shows a comparison of the raw values of solar radio flux F10.7 (marked in red) and the obtained relative values of the same parameter (blue) according to the formula above for October 2013.

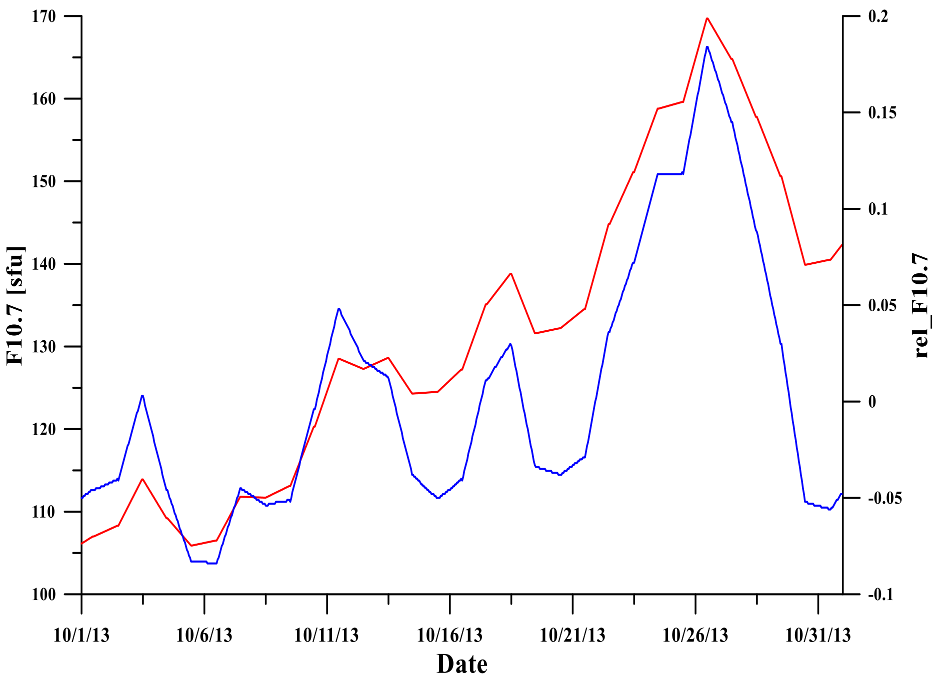

Fig. 1. Comparison between the values of F10.7 (red line) and the calculated relative values (blue line) for October 2013.

Results

To find an optimal functional dependence between the short-term variability of the solar activity and the ionospheric parameters foF2 we perform a regression analysis. The latter is between the relative values of F10.7 and the relative values of foF2. The obtained optimal functional dependence will be later the justification for producing an empirical model for forecasting the ionosphere over Bulgaria.

In this case the group regression analysis is used. For this purpose the range of variation of the „cause "value is divided into intervals, and for each such interval the mean values of the „cause" and the mean value of its corresponding „consequence" values are determined. The functional dependence is obtained by using the least squares method and is calculated on the basis of these group averages. The advantage of this approach in this case is based on the fact that solar and geomagnetic indices have many values under conditions close to calm ones (the modified indices under calm conditions have values close to zero) and only few values under disturbed conditions. If the regressions are calculated based on the regular manner, then the small cases representing the ionospheric response to strong solar variability will be suppressed by prevailing cases of mean solar activity.

Fig. 2 presents the group regression between the relative deviation of foF2 and the relative values of solar activity, marked by rel_F10.7. The error in determining the average of rel_foF2 for a given rel_F10.7 interval is represented by the standard deviation. Fig. 2 also represents the number of values in a given interval of rel_F10.7 shown in red color. The graph clearly shows the predominance of cases of calm in solar activity. The number of cases with extreme elevation is two or more orders of magnitude smaller; this fact clearly confirms the correctness of using the group regression. The graph shows that the optimal function describing the obtained results is close to linear one; the latter provides justification for describing the ionospheric response to solar activity in the generating a model for the prediction of the ionospheric characteristics over Bulgaria.

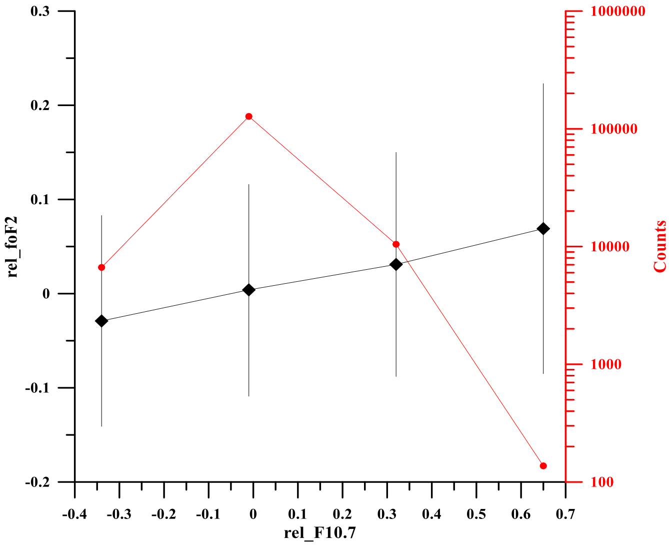

Fig. 2. Group regression between the rel_F10.7 and the relative deviations of the ionospheric characteristic foF2 represented by black color line and the number of hits in the corresponding rel_F10.7 intervals shown in red color.

Conclusions

The group regression analysis revealed that the optimal relationship between the ionospheric critical frequency and the short-term variability of the solar activity over Bulgaria can be described by a linear function. It is important to note that this relationship is found only at times when the geomagnetic activity index Kp is below 5. In this way the contradiction between variations in solar activity that usually cause a positive ionospheric reaction and the geomagnetic disturbances that cause mostly negative response has been reduced. All these results can be used to produce an empirical model for predicting the state of the ionosphere over Bulgaria.

Acknowledgment

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References

Huba, J. D., Joyce, G., Sazykin, S., Wolf, R., & Spiro, R. (2005). Simulation study of penetration electric field effects on the low-to mid-latitude ionosphere, Geophysical Research Letters, 32.

Liu, L., Wan, W., Chen, Y., & Le, H. (2011). Solar activity effects of the ionosphere: A brief review. Chinese Science Bulletin, 56(12), 1202-1211.

Mukhtarov, P., R. Bojilova (2017). Influence of Solar and Geomagnetic Activity on the Ionosphere over Bulgaria, C.R. Acad. Bulg. Sci., 70 (9), 1289-1296.

Pancheva, D. V., & Mukhtarov, P. Y. (1996). A single-station spectral model of the monthly median F-region critical frequency. Annals of Geophysics, 39(4)

Rishbeth, H. (2006). F-region links with the lower atmosphere? J. Atmos. Sol.-Terr. Phys, 68(3-5), 469-478.

Schunk, R., & Nagy, A. (2009). Ionospheres: physics, plasma physics, and chemistry, Cambridge university press.