Space Weather of the Heliosphere: Processes and Forecasts
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About Factors of Solar Radiation Affecting the Ionosphere

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Abstract. In this report we present an attempt to find a characteristic set of the space weather parameters allowed to identify the dominant physical connections. This study is based on the data of vertical and oblique sounding of the ionosphere in 2015-2016.

Keywords. (Sun:) solar-terrestrial relations, methods: data analysis

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1. Introduction

Within the framework of space weather studies, research were conducted for a long time to determine the geo-effectiveness of various processes occurring on the Sun and near-Earth space. In most cases, the relationship between changes in near-space parameters measured by artificial satellites and parameters of the upper atmosphere of the Earth is quite clearly expressed. In particular, measurements of ionospheric plasma parameters can serve as a criterion that unequivocally testifies to the degree of geo-efficiency of processes in near-Earth space. The most common methods of ground-based measurements are methods of vertical and oblique sounding of the ionosphere. As one of the parameters of the upper atmosphere of the Earth, it is proposed to consider the time behavior of the critical frequency (f_0F2) of the ionospheric $F2$ layer, measured by vertical sounding of the ionosphere. The behavior of the maximum observed frequency for oblique sounding trajectories (MOF), that is determined in time using ionospheric oblique sounding stations, can be used for analysis, as well.

2. Overview

To increase the sensitivity, to eliminate stationary dependencies (for example, exclude diurnal and seasonal behaviour of f_0F2) we use method to study the disturbances in the data of vertical ionospheric sounding, based on the second order deviation of critical frequency of ionospheric layer $F2$ (Δf_0F2) (Sheiner *et al.* 2002). The data of critical frequency f_0F2 have been determined from uniform ionograms obtained with the modern digital ionosonde CADI. This ionosonde is installed at the NIRFI landfill "Vasilsursk" (near Nizhny Novgorod), and working program of regular observations allowed to obtain ionograms at least once in 15 minutes. The accuracy of determining the critical frequency was less than 50 kHz. The data of maximum applicable frequency for oblique sounding trajectories MOF have been determined using an ionosonde-direction finder with chirp signal on the Cyprus–Nizhny Novgorod chirp-sounding path. This device measures the key characteristics of the ionospheric channel simultaneously in real time over the entire range of transmission frequencies of HF radio signals in all propagation modes (Uryadov *et al.* 2016).

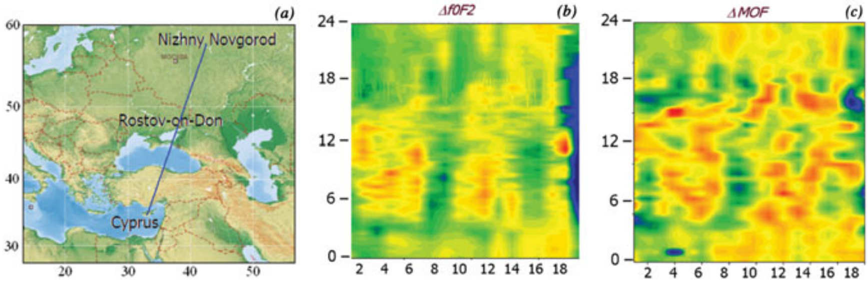

Figure 1. *a)* – The map with the chirp-sounding pass Cyprus–Nizhny Novgorod; *b)* and *c)* – behaviour of differential parameters Δf_0F2 (measured in "Vasilsursk") and ΔMOF, vertical axis – time of the day (UT), horizontal – days of the month.

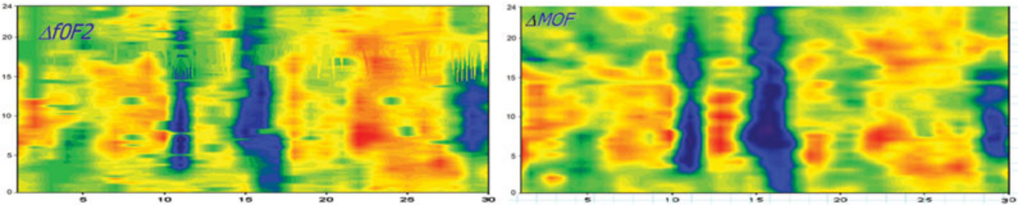

Figure 2. Behaviour of differential parameters Δf_0F2 (measured in Rostov-on-Don) and ΔMOF; vertical axis – time of the day (UT), horizontal – days of the month.

For example, Figure 1 illustrates the chirp-sounding pass Cyprus–Nizhny Novgorod (a) and the behaviour of differential parameters Δf_0F2 (b) and ΔMOF (c) for March 1-18, 2015. We have to add, comparison of two pictures (ΔMOF received using Cyprus-Nizhny Novgorod pass and Δf_0F2 measured in Rostov-on-Don, city located just in the middle of the pass, using vertical sounding of the ionosphere) shows good agreement in behavior (observations in April, 2015, see Figure 2).

To find the most significant parameters of the influence of solar activity on the ionosphere we conducted joint analysis of the data of the GOES satellites and the data of the oblique sounding of the ionosphere on the Cyprus–Nizhny Novgorod pass. Figure 3 presents the results of such analysis. In the bottom panels are graphs of the deviations of the maximum observed frequency (ΔMOF). A significant decrease by a few MHz (blue) of the instantaneous ΔMOF in comparison with the monthly average ΔMOF is clearly correlated with the behavior of the planetary Kp index (Figure 3a). At the same time, we have to mention that the correlation of the ΔMOF behavior with the density of the proton flux and the intensity of X-ray radiation is reliably traced only in the summer observation cycle.

Comparison of ΔMOF behavior with the measured parameters of the near-Earth space obtained on the GOES satellites (Electron Flux, Proton Flux, X-ray) shows a good cross-correlation in most cases when the increase (decrease) of ΔMOF relative to the mean value is caused by the corresponding changes in the parameters measured on the satellites. But sometimes one can see that the changes in the ΔMOF behavior are only partially correlated with the behavior of the characteristics of the near-Earth space measured on the GOES satellites (see Figure 3b). At the same time, joint analysis of the ΔMOF with the data of solar wind proton speed from the ACE RTSW satellite demonstrates the role of high-speed solar wind. Decrease by a few MHz (blue) of the instantaneous ΔMOF may be due to the after-effect of high-speed solar wind passage (Figure 4).

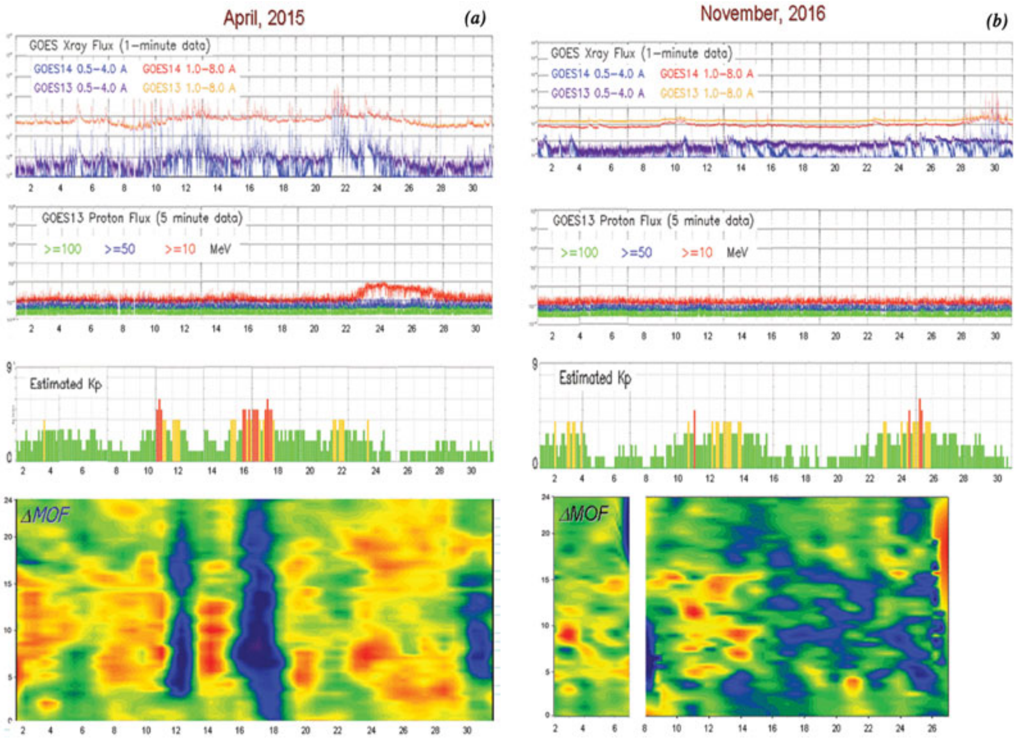

Figure 3. Results of joint analysis of the data of the GOES satellites and the data of the oblique sounding of the ionosphere on the Cyprus-Nizhny Novgorod pass for April 2015 *a)* and November 2016 *b)*, horizontal axis – days of the month; vertical axis for ΔMOF – time of the day (UT).

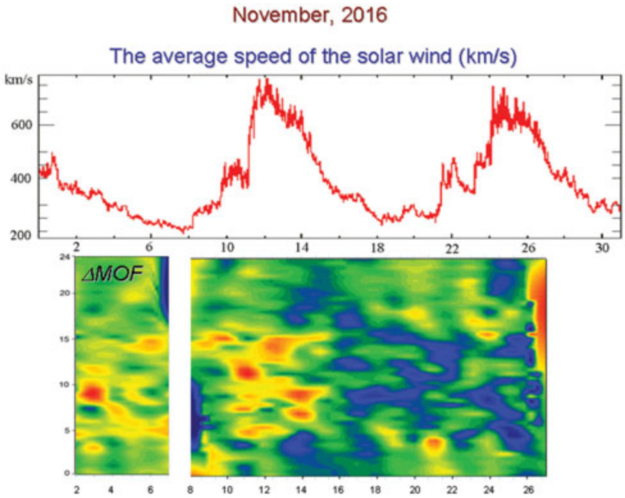

Figure 4. Behaviour of differential parameters ΔMOF and solar wind proton speed on November, 2016. Horizontal axis – days of the month, vertical axis for ΔMOF – time of the day (UT).

Thus, the solar wind proton speed is a very important paremeter that should be used for analysis. And it should be borne in mind that for the preliminary analysis of various processes occurring in the upper atmosphere of the Earth and near-Earth space, it is necessary to use a complete chain describing the processes of solar-terrestrial physics.

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