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CLASSIFICATION OF IONOSPHERIC DISTURBANCES AT MIDDLE LATITUDES BASED ON LONG-TERM OBSERVATIONS

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Abstract. The foundations of ionospheric disturbances classification caused by Solar-geomagnetic activity on critical frequencies of the F2 are developed. To study the variation of ionospheric layer F2 critical frequency the data for the full cycle of Solar activity from 1975 to 1986 at the ionospheric observatory Moscow (55°45' N, 37°37' W) were used. The level of Solar activity was estimated by the values of the index F10.7. Geomagnetic disturbance was determined by indices Kp*10, Dst and AE. According to established classification the index of ionospheric activity is introduced.

1. Introduction

Investigation of ionospheric disturbances, depending on the level of heliogeophysical activity is the present-day geophysical problem. One of the effective tools for diagnosing the state of ionosphere are critical frequencies, since they contain information about the electrons and ions concentration in the ionosphere. Among the studies that analyze the critical frequencies behavior in the different Solar and magnetospheric activity conditions should be mark out work on the classification of ionospheric disturbance and the creation of ionospheric weather index [Kutiev and Muchtarov, 2001; Bremer et al., 2006; Gulyaeva et al., 2008] . This problem is most topical because of universal index performance will allow to realize the operational control of ionospheric disturbances and forecast the state of the ionosphere under varying heliogeophysical conditions.

This paper analyzes the critical frequency of ionospheric F2 layer over the station in Moscow a year minimum (1975) and maximum (1982) of Solar activity. This study main purpose is creation of a method for ionospheric mid-latitude disturbances classification and subsequent development of ionospheric activity index on the basis of the established classes. The advantage of this method is to use "cleaned" data of critical frequencies which include only ionospheric disturbances and it does not contain long-term variations (such as annual, seasonal variation, variation related to the Sun rotation, etc.). Also from consideration the daily variation of the critical frequency is excluded. However the proposed classification takes into account the level of ionospheric disturbances associated with the year cycle of Solar activity and global geomagnetic disturbances. The provided classes thereupon can be considered universal.

2. Experimental data and their processing

The study of ionospheric F2 layer critical frequency variations have been carried out on data for the full cycle of Solar activity from 1975 to 1986 obtained at the ionospheric station Moscow (55° 45' N, 37° 37' W) at 1 hour resolution. Omissions of critical frequencies were filled by cubic interpolation. To determine the level of Solar activity index F10.7 is used. The level of geomagnetic disturbance was defined by indices Kp*10, Dst and AE with 1 hour resolution.

In order to identify ionospheric disturbances which are not directly related to seasonal and diurnal variations the input data of the critical frequency was cleared. For that the cleaning method of critical frequencies was developed based on spectral analysis and Fourier transform. The analysis was performed for time intervals up to a month.

At the first stage of cleaning were made critical frequency spectra based on fast Fourier transform. In the second stage was carried out a removing a number of harmonics with periods of 24 hours, 12 hours and more than 24 hours out of the critical frequency signal. For this purpose has been made the decomposition of original signal into its spectral components using the method of harmonic analysis, described in detail in [Yanovski, 1978, P. 389-393]. The final stage of cleaning was performed signal convolution – the sum of the remaining harmonics. As a result we obtain new values of "cleared" critical frequency (CCF) which contains only the variations directly related to ionospheric disturbances. Fig. 1 shows the spectra example of such CCF for January 1972.

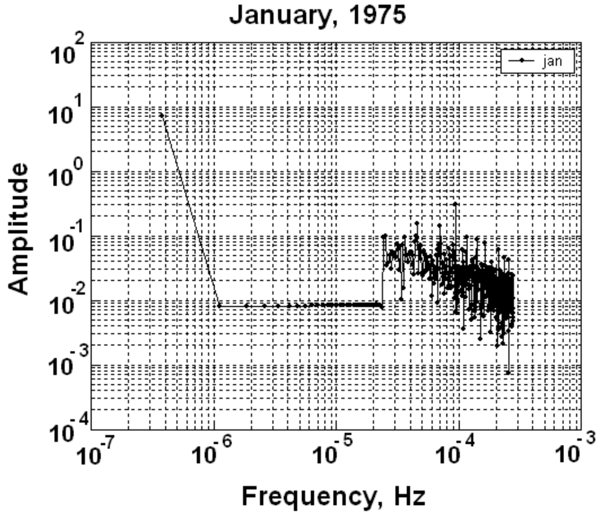

Fig. 1. Example spectrum of "cleared" critical frequencies for the Moscow station in January 1975

3. Ionospheric disturbances relationship with the Solar-geomagnetic activity

CCF comparing with F10.7 and Kp*10 indices which characterize the level of Solar and geomagnetic activity in the given month shows that most cases have characteristic jumps of CCF variations with increasing index Kp*10. This suggests a connection between these variations and geomagnetic disturbances. It was also found markedly increasing of CCF variations amplitude during Solar maximum indicating a significant effect of Solar radiation on the variation. Fig. 2 shows examples of CCF amplitude increasing with extension of index Kp*10 values for the February 1975 and April 1982. Arrows indicate jumps in CCF variations and corresponding jumps in the index Kp*10.

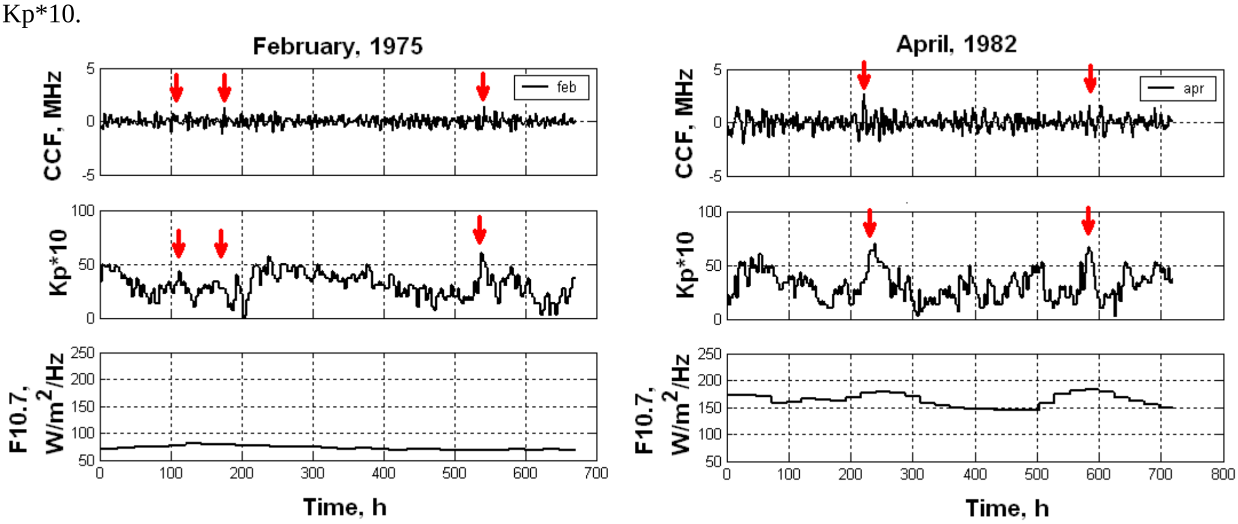

Fig. 2. Examples of CCF increasing amplitude with increasing values of index Kp*10 for the February 1975 and April 1982; arrows marks jumps in CCF variations and corresponding jumps in the index Kp*10.

Thus, the study of CCF variations can give an overall picture of ionospheric state depending on the level of Solar activity and global geomagnetic disturbances. According to the results ionospheric state is directly characterized by the CCF deviation amplitudes from the zero average. However such variations using is difficult to analyze because they have short periods and very noisy background values.

4. Classification of ionospheric disturbances and ionospheric activity index IAI

To characterize the ionospheric disturbances related to the direct influence of Solar and geomagnetic activity, the ionospheric activity index (IAI) based on CCF variations is developed.

In the first stage of index development were studied CCF deviations above average in the minimum and maximum Solar activity years taking into account the values of Dst index. It allows us to identify the main classes of ionospheric disturbances.

The first disturbance class. This class corresponds to the quiet state of the ionosphere. In the year of Solar activity minimum (1975) for each month were considered international undisturbed days within Kp index values were near zero (Q-days). Each month has 5 such days [http://wdc.kugi.kyoto-u.ac.jp/qddays/index.html]. During this period the average positive and negative CCF deviations from the zero level were 0.75 Hz and -0.7 Hz respectively. The minimum value of Dst index in the considered undisturbed 60 days during the year of minimum Solar activity was –25 nT.

The second disturbance class. This class corresponds to the state of the ionosphere with small disturbance. In the years of minimum Solar activity were considered international disturbed days (D-days). Average positive and negative CCF deviations from the zero level in these days were 0.8 Hz and -0.75 Hz respectively. The minimum value of Dst index in the studied disturbed days was -110 nT.

The third disturbance class. This class corresponds to increased ionospheric disturbance. For each month of maximum Solar activity year (1982) examined international undisturbed days (Q-days). Average positive and negative CCF deviations from the zero level were 1.2 Hz and -1.2 Hz respectively. The minimum value of Dst index in the studied days was – 83 nT. Note that the level of global geomagnetic disturbances measured by the value of Dst is lower than in the second class. However during the ionospheric disturbances classification it should consider not only the level of geomagnetic activity but also the overall Solar activity level. It is known that during Solar maximum the radio emission flow is greatly increased which leads to ionospheric ionization increase and hence to increase of critical frequencies variation amplitudes.

The fourth disturbance class. It corresponds to a high ionospheric disturbance. Here we used to consider international disturbed days in the year of Solar activity maximum. Average positive and negative values of CCF deviations from the zero level were 1.5 Hz and -1.5 Hz respectively. The minimum value of Dst index during considered period was -325 nT. Note that for a significant increase in the geomagnetic disturbance compared to the second and third classes, the mean CCF amplitude increased slightly. This may be due to an absence of direct connection between midlatitude ionosphere and magnetospheric currents.

The fifth disturbance class. It corresponds to the state of ionosphere with extreme disturbance. This class includes events with CCF deviation amplitudes from the zero level more than 1.5 Hz or less -1.5 Hz.

Selected ionospheric disturbances classes were form the basis for the index of ionospheric activity IAI. These index values take into account both positive and negative CCF variations within each of five disturbance classes. In Table 1 to each of disturbance class values conferred values of index IAI.

Table 1.

Ionospheric disturbance class	Intervals of CCF values	Values of ionospheric activity index IAI
Class 1	$-0.7 < CCF < 0.75$	0
Class 2	$0.75 \le CCF < 0.8$ $-0.75 < CCF \le -0.7$	1 –1
Class 3	$0.8 \le CCF < 1.2$ $-1.2 < CCF \le -0.75$	2 –2
Class 4	$1.2 \le CCF < 1.5$ $-1.5 < CCF \le -1.2$	3 –3
Class 5	$CCF \ge 1.5$ $CCF \le -1.5$	4 –4

IAI index values were computed for all seasons in years of minimum and maximum Solar activity and compared with the global geomagnetic disturbances characterized by Dst index and disturbances in the auroral region characterized by index AE. The top panel of Fig. 3 shows examples of IAI variations for April 1975 and June 1982, the middle panel shows the corresponding change in the index Dst, the bottom panel – the variation of AE index. Gray color indicates increased values of index IAI observed within the intense magnetic storms and auroral disturbances.

Comparison of IAI index values with values of indices Dst and AE (see Fig. 3) shows high negative values of IAI in times of geomagnetic disturbances. For two geomagnetic disturbances in April 1975 the maximum negative value of IAI = -2 is marked. Note what during this period there is activity burst in the auroral region – AE index value are more than 1000 nT. In June 1982 there are several geomagnetic storms of low intensity. During the first storm the maximum negative value of index IAI = -4 is marked which corresponds to a class of extreme ionospheric disturbance. Note that in this period took place a sequence of intense auroral substorms and each of them has exceeded values of index AE – up 1000 nT. For second magnetic storm minimal value of index IAI = -3 is marked. Within this interval the activity in auroral region is also high – index AE ~ 700 nT.

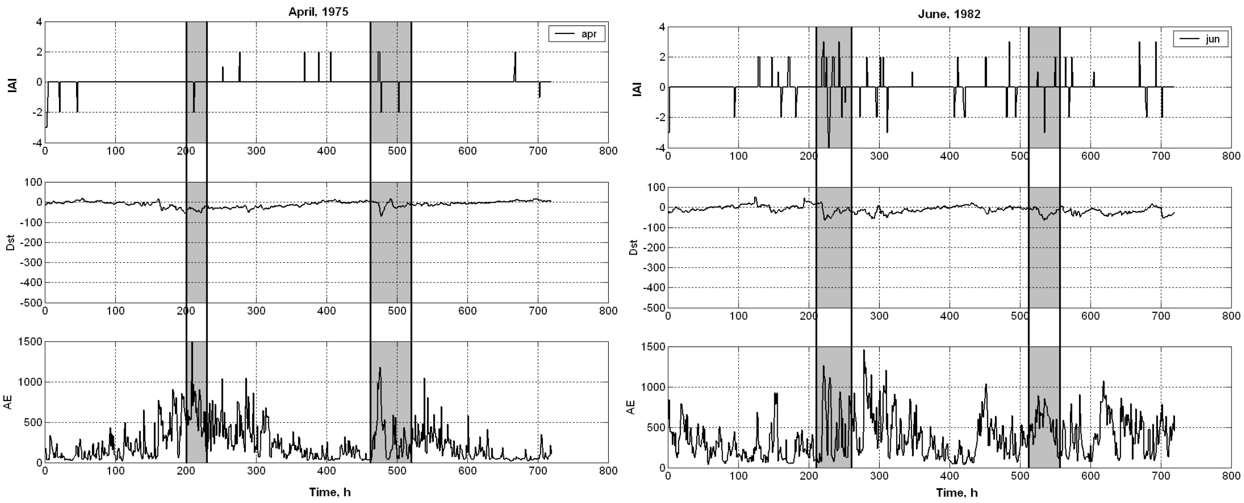

Fig. 3. Examples of index IAI variations for April IAI 1975 and June 1982 (top panel); synchronized variation of index Dst (middle panel); synchronized variations of index AE (lower panel). Gray color indicates increased values of index IAI observed within the intense magnetic storms and auroral disturbances

Thus during the development of magnetic storms which are accompanied by intense substorms in the auroral region, high negative values of index IAI are observed and it is evidence of mid-latitude ionospheric concentration decreasing within these periods.

5. Conclusions

In the present study the "cleared" critical frequencies (CCF) values of the ionospheric F2 layer are analyzed over the station Moscow in minimum (1975) and maximum (1982) Solar activity years. Comparison of CCF variations for each season for two years with index Kp*10 variations shows their co-ordination. It observed simultaneous increase CCF and Kp*10 in minimum as with in maximum Solar activity year. This means that CCF variations adequately reflect the state of midlatitude ionosphere in various heliogeophysical conditions.

The study of average values of CCF variations in international undisturbed and disturbed days for 1975 and 1982 allowed picking out five classes of ionospheric disturbances which correspond to the quiet state of ionosphere, the state of the ionosphere with a small, increased, high and extreme disturbance. On the basis of this classes created an index of ionospheric activity IAI which ranges from 0 to ± 4 depending on the level of ionospheric disturbance.

Analysis of received IAI index values for minimum and maximum Solar activity years shows that the increase in the absolute index values is usually accompanied by increase in global geomagnetic and/or auroral disturbances. This demonstrates the validity of developed index to characterize the ionospheric activity independently of the season. In addition by the sign of IAI index can judge the drop or increase concentration of ionospheric layer F2 since the index values correspond to real variations of the critical frequency midlatitude ionosphere.

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