ON THE CAUSES OF DAY-TO-DAY VARIATIONS IN THE MID-LATITUDE IONOSPHERIC F2 REGION ELECTRON DENSITY

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ABSTRACT

The data on ionospheric total electron content and the peak density of the mid-latitude F2 layer (N_mF2) have been used to study most probable causes of significant day-to-day variations in the ionospheric parameters. The considerable deviation of the parameters under study from their mean values is shown to be not only strong storm time phenomena and they often occur during the periods when the meridional wind component of the thermospheric wind is close to zero. On isolated days, the wind is possible in the both southward and northward directions, which can change the processes dominating in the ionospheric F2 region. Another mechanism for the significant variations can be 2- to 6-mode tidal variations.

INTRODUCTION

At present, important advances have been made in modeling ionospheric F2-region electron density N_e variations, however the significant day-to-day variability has not found a satisfactory explanation [1, 2]. To solve this problem, the study of basic physical processes occurring during magnetic storms is conducted [1, 3], first of all, during strong magnetic storms. However, significant deviations in ionospheric parametrs from their typical (median) values are observed not only during strong magnetic storms. Hence, an approach which adheres to the most typical N_e features without division the ionospheric conditions into quiet and disturbed should be adopted. The conditions under which, first of all, significant N_e deveations from the median occur or the conditions for the rapid transition from one type of deviation to another happen, are the subject of inquiry in such an approach. The aim of this work is to study the features and possible causes of the day-to-day variability in the midlatitude ionospheric F2-region electron number density during quiet and disturbed conditions.

DATA AND ANALYSIS METHOD

The changes in N_e were estimated in terms of the total electron content N_0 and the critical F2-region frequency f_0F2 or in terms of deviations in f_0F2 from the moving monthly median, δf_0F2. The data on N_0 were collected at the Kharkiv V. Karazin National University Radiophysical Observatory from 150 MHz and 400 MHz navigation sattelite receivers during the 1998–1999-yr period. The N_0 calculations were made using the technique of [4] that on average yields the more reliable results than other techniques. The data on f_0F2 were gathered by the ionosonde technique at Moscow [5] and at several sites in the West Siberia in the 44.4 – 58.4 geomagnetic latitude interval. The joint use of data on f_0F2 and N_0 enables the variations in ionospheric features to be determined at different heights. The simultaneous N_0 and f_0F2 data for our region were unavailable, and therefore we had to use the data from [6] to establish some properties. We use the data on both f_0F2 (Boulder: 42.4 N, 109.2 W) and N_0 collected at three site, the subionospheric points for two of which (Boulder: 42.4 N, 109.2 W and Bozeman: 37.5 N, 104.2 W) are close to the site where f_0F2 were determined. The main attention has been paid to the diurnal variations in f_0F2 and N_0 during daytime conditions. The analysis of F2 region lag properties and of the relation features between variations in f_0F2 and N_0, and solar and geomagnetic activity levels has been done.

RESULTS AND DISCUSSION

To make estimates of the F2 region lag properties, the correlation coefficients r_{ij} were calculated between the day-to-day variations in $\delta f_0F2(t_i)$ and $\delta f_0F2(t_j)$ for various t_i and t_j instants of local time. A major amount of the calculations

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were performed using the data collected at Moscow over the 1969 – 1987-yr period. The results of the calculations for nighttime conditions on the whole agree with those expected: the r_{ij} values gradually decrease with increasing $t_i - t_j$ time interval. On transition to the daytime conditions, a more noticeable decrease in r_{ij} occur, especially for winter minimum solar activity conditions. Only under these conditions can the correlation coefficients r_{ij} again appreciably increase ($r_{ij} > 0.5$) with a further time interval $t_i - t_j$ increase, which indicates a sufficiently close relation between the F2 region states during two consecutive nights in the absence of relation between daytime and nighttime values. One of the displays of this statistical pattern is a significant disturbance in the nighttime F2 region in 1 – 2 days after the magnetic storm termination [7]. The principle role apparently plays the exchange of plasma between the F2 region and the protonosphere: the protonosphere depletion during magnetic storm results in a significant decrease in the fluxes from the protonosphere after magnetic storms, which maintain the nighttime F2 region under other conditions.

Under daytime conditions, other F2-region features become essential or even predominant against the background of a gradual decrease in r_{ij}. Specifically, during summer, changes in δf_0F2 within dawn and sunset hours are sufficiently closely related to each other ($r_{ij} > 0.6$, $p < 0.05$), while their association with the δf_0F2 near noon variations is weakened or disrupted. This feature is displayed more clearly at the solar activity minimum and is obviously a reflection of the processes resulting in the well-known phenomenon of season anomaly due to changes in the neutral atmosphere composition at the F2 region peak. As solar activity increases, this phenomenon spans the majority of sunlit part of the day that results in a smoother change in r_{ij} under the influence of one dominating mechanism.

Yet more substantial features have been revealed for the afternoon winter conditions when the r_{ij} value can significantly decrease and even change the sign over time intervals of $t_i - t_j \sim 2 - 3$ hr. It is important that such a feature arises during both higher and lower geomagnetic activity levels, and thus it is a permanent feature of daytime winter conditions during both magnetic storm time intervals and beyond.

The correlation analysis of relation between f_0F2 variations and solar and geomagnetic activity indices has also revealed that only during winter conditions the most rapid developments in the character of relation between the parameters involved occur, often during a few hours.

The calculations making use of the data on N_0 confirmed the revealed pattern. On the whole, for the 1998–1999-yr interval, a few tens of latitudinal N_0 dependences were obtained for various seasons, times of day, and for quiet and disturbed days. The solar activity level also varied widely: from a moderate level at the beginning of 1998 (daily Wolf sunspot number R~50) to a high level (R~150). Comparisons of the N_0-data with the N_0-values computed over 40 to 60 degrees north latitude using the model of [8] (analogous to the IRI model) has displayed that during winter day conditions, including quiet conditions, the discrepancy between the model and measured N_0-values is often more significant (sometimes almost of 2 times) than during disturbed intervals in other seasons and times of the day.

Thus, it can be assumed that the principle cause of the day-to-day F2 region parameter variability is processes with time scales of unities of hours that are due to a rapid change in a dominating mechanism for external influence on the F2 region. Consider possible circumstances determining such variability.

1. For treating one of the possible mechanisms, the correlation coefficients between F2-region parameters and solar (r_F) and geomagnetic (r_{Ap}) activities have proved to be sufficiently informative. At Eastern Europe longitudes (Moscow), the r_F and r_{Ap} diurnal variations are on the whole similar (see Fig. 1): maximum values occur during afternoon, and minimum values during after midnight hours, with the positive values predominant in r_F and negative in r_{Ap}. Such

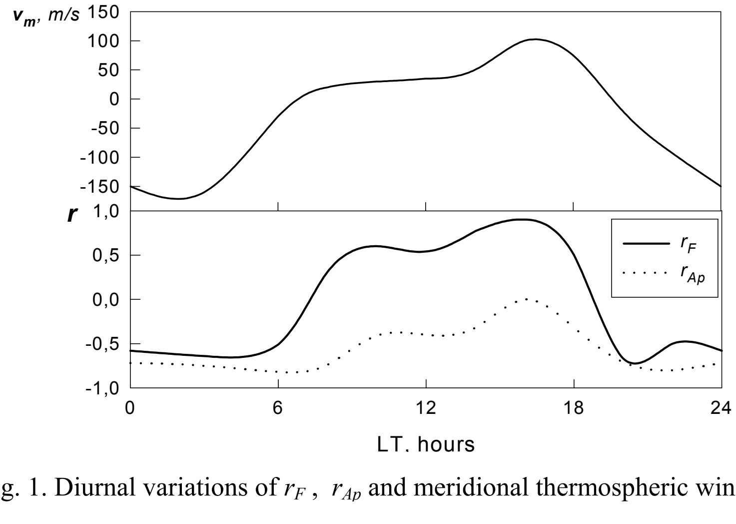

Fig. 1. Diurnal variations of r_F , r_{Ap} and meridional thermospheric wind in winter [10]

changes could be mainly regarded as a result of the well-known ionospheric storm features: the positive phase is maximal during sunset hours, and the negative during the second half of the night [9]. At the same time, such a feature distinctively develops also during the intervals when significant magnetic storms do not occur.

A weak effect that geomagnetic disturbances have on f_0F2-values near 16:00 LT results in the fact that day-to-day f_0F2-variations most exactly follow the changes in UV solar emissions just at these hours, e.g., in a 27-day solar rotation period dependence [7] while at near noon hours 27-day variations in f_0F2 can be absent.

Despite of significant similarity in the diurnal variations, the instants when r_F and r_{Ap} change the sign do not usually coincide, and the correlation coefficients have different signs over the winter ~08:00–10:00 LT and ~ 18:00–20:00 LT intervals. Note that exactly during these hours usually occur maximal day-to-day f_0F2-variability.

It is easy to notice that the r_{Ap}-variations, and especially r_F-variations, reproduce typical diurnal variations in the meridional component of neutral wind velocity at the F2-region heights (see Fig. 1). Correspondingly, the maximal f_0F2-variability occur at the hours when the wind velocity is on the average close to zero, and on specific days it can be directed either towards south or north even under similar level of geomagnetic activity. In summer, the wind velocity is close to zero during daytime hours [10, 11], which is associated with significant day-to-day f_0F2-variability also occurring during these hours. Since diurnal variations in r_F and r_{Ap} proved to be similar even for significantly different mean levels of geomagnetic activity during different months, it is possible reach a conclusion that the competition between the midlatitude and high-latitude heat sources display in arbitrary geophysical conditions and does not allow the ionospheric conditions to be divided into quiet and disturbed.

At American sector longitudes, the features of the diurnal r_F- and r_{Ap}-variations mentioned above are observed only in summer, whereas in winter, at least under low solar activity level, the r_{Ap}-variations fluctuate about the zero level with the predominance of positive values during the second half of the day and during isolated hours at night. A similar tendency for the relation between the geomagnetic activity level and N_0 is still more pronounced. The positive relation of both the f_0F2 and N_0 with the A_p-index increases during the intervals of increased relation with the solar activity level. Consequently, the positive phase of two ionospheric storms following each other in 1 – 2 weeks more distinctly develops during a higher solar activity level. Specifically, during two magnetic storms of similar level that occurred during the discussed above interval (December 1974), an increase in N_0 on December 9 ($F_{10.7} = 70$) did not exceed 25%, whereas on 17 December ($F_{10.7} = 88$) it was ~ 60%; the positive phase in f_0F2 in the first case was absent and attained ~30% in the second. A similar feature has been revealed also for other magnetic storms, when variations in N_0 are more pronounced than in f_0F2. Such a difference indicates that the principle effect occur above the F2-region peak, which makes the main contribution to N_0.

To explain such features, it is necessary to assume that during daytime conditions northward winds in the American sector are significantly higher than in the European sector. The "switching-on" of the auroral source of heating due to an increase in geomagnetic activity level results in a decrease in this velocity with a simultaneous F2-region raise along the magnetic lines, but it is not accompanied by the southward wind shift. The latter resists a change in the thermosphere composition, and correspondingly, the development of the negative phase of the ionospheric

Provided the UV radiation flux is greater, the background northward wind velocity in the absence of magnetic storm can rise, and conditions for the prolonged preservation of the positive ionospheric storm phase are more favorable. Thus, a moderate geomagnetic disturbance, which has commenced against the background of high northward wind, can be one of the principal factors resulting in the appearance of long duration positive storm effects in the F2 region [12]. On the contrary, a gentle northward breeze can change its direction southward due to the auroral sources, and this results in the transition from the positive to the negative phase of the ionospheric storm.

Hence, one of the basic sources for the ionospheric parameter day-to-day variability can be regular daily, seasonal, and caused by solar heating rearrangements in thermospheric dynamics regimes. The change in the relative role of processes resulting from the ionizing radiations and the processes acting in the auroral oval can be their cause. The latter act virtually continuously, except for winter afternoon hours, during any magnetic activity level, which indicate that the conception of "quiet ionosphere" is arbitrary.

2. As was mentioned before, the ionospheric storm positive phase occurs most often during evening hours, and the negative during morning. At the same time, the estimates of positive and negative δf_0F2 values made during many months exhibit maximum values soon after sunrise and further they gradually decrease during the entire day. In the

evening, after sunset, a new increase in a disturbance level can happen, which persists until the end of night. Such a situation is more typical of high solar and geomagnetic activity levels, although they can occur and under another conditions. Thus, an example of similar changes in f_0F2 disturbance was observed in April 1973, when the monthly index $A_p = 30$, which is comparable in value to the changes in the magnetic field during a moderate magnetic storm, and the solar activity level was sufficiently low, $F_{10.7} = 106$. Under a low geomagnetic activity , a few small amplitude maxima and minima in δf_0F2 during the sunlit intervals usually occur. As during higher geomagnetic activity, the first increase in δf_0F2 also commence after sunrise, and the following maxima are often, but not always, have a value smaller than the first. Provided quiet conditions maintain during a few successive days, a similar structure can also repeat during a few successive days without essential changes, and a geomagnetic disturbance commencement can result in a transition to semidiurnal variations. The verification of this pattern made using the data from Western Siberia has revealed that the amplitude of the morning disturbance decreases, or at least it does not increase, with increasing latitude. Hence, the disturbance generated in the auroral zone cannot be a cause of such disturbances. Their possible cause can be the m = 2 – 6 thermospheric tide modes.

CONCLUSIONS

1. The magnetic storm effects cannot explain all observed day-to-day features of F2 region parameters. One of the main causes of theses variations can be seasonal and diurnal dynamic features of the thermosphere, as well as the features caused by solar heating of the thermosphere at the F2 region altitudes. Significant variations in the day-to-day electron density even in the absence of strong magnetic storms can occur, first of all, against background neutral wind speeds close to zero. Moderate magnetic disturbances that commence against the background of significant northward winds increase the probability of ionospheric disturbance positive phase occurrence.
2. The m = 2 – 6 thermospheric tide modes can become a cause of an additional F2-region parameter day-to-day variability, especially during the first half of day. During quiet conditions, the higher order mode prevail, in proceeding to disturbed conditions, the suppression of some modes occur and the amplification of others.

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