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DYNAMICS OF THE IONIZATION TROUGHS IN THE NIGHT-TIME SUBAURORAL F-REGION DURING GEOMAGNETIC STORMS

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ABSTRACT

On the basis of analysis of the Cosmos-900 satellite data for near-midnight and after-midnight hours, indicators of geomagnetic activity for the mid-latitude ionization trough movement during storms are found which are more adequate than Kp. They are (1) the magnetic field of the disturbed ring current, DR, for the storm initial and main phases and (2) an effective, i.e. averaged, index Kp* for the recovery phase. It is found that during the recovery phase, two troughs, the mid-latitude and the ring ionization troughs, can exist simultaneously, and are distinctly spaced in latitude. DR is the indicator of magnetic activity for the ring ionization trough. It is found also that when only one trough is observed during the recovery phase, this trough is not necessarily the mid-latitude trough. The empirical formulae for the position of these troughs are presented.

INTRODUCTION

F-layer ionization troughs are frequently observed in the night-time subauroral ionosphere. Similarly with /1/, we define the mid-latitude ionization trough (MIT) as the region of low plasma density that occurs near the equatorward diffuse auroral boundary, i.e., the 1 keV electron precipitation boundary. There have been several empirical formulae, derived from a variety of data sets, for the invariant latitude of this trough minimum Φ(MIT) in which Kp-index was used as an indicator of magnetic activity effects (see, e.g., the review /1/). For magnetic storm periods, these formulae are rather qualitative, and their discrepancy with observed data can exceed 5°Φ (e.g., /1/). One of the goals of this paper is to search a more adequate indicator of magnetic activity for MIT than Kp.

We define the ring ionization trough (RIT) as the region of low plasma density at F-region altitudes during the storm recovery phase which seems to be associated with the region where dissipation of energy from the disturbed ring current into the ionosphere is maximum and where the stable auroral red (SAR) arcs occur. The existence of the F-layer ionization trough and the increase of the electron temperature in the SAR region has been known for a long time (e.g. /2/)

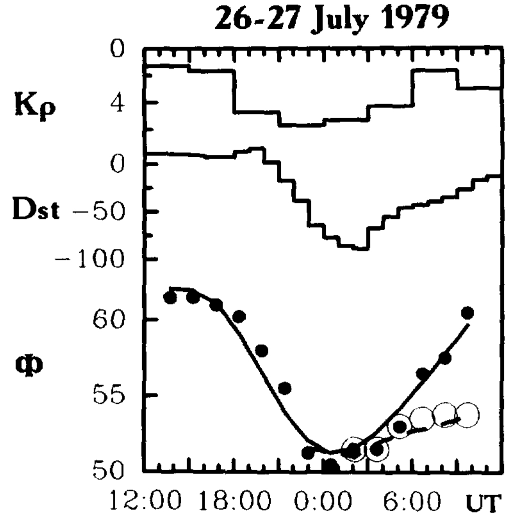

Fig 1.

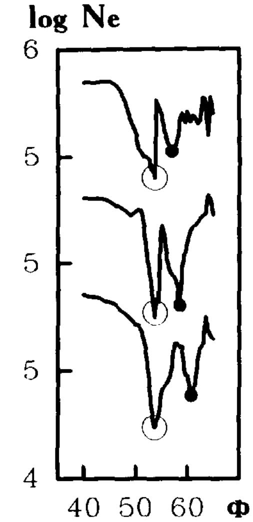

Fig 2.

Fig.1. Invariant latitudes of the mid-latitude trough minimum (dots) and of the ring trough minimum (circles) derived from data of Cosmos-900 consecutive passes through the subauroral F-region at mid-night during the 26-27 July, 1979 storms.

Fig.2. Electron density versus invariant latitude obtained from the three last (at fig.1) passes of Cosmos-900 on 27 July,1979.

peaks were observed at the troughs. Therefore the dots and circles in the figures 1 and 2 are also locations of the Te peaks.Two Te peaks correspond to two troughs spaced in latitude. Kp and Dst variations during this same time period are also shown in fig.1. It is seen that Kp is regularly ahead of Φ(MIT) changes by approximately 2-3 hours. This outstripping may be taken into account by introducing a certain effective index Kp* which is an averaged value of Kp over the preceding 4 hours and the current hour. Empirical formulae and their correlation coefficients R for this storm:

$$\Phi(MIT) = 65.4 - 2.52 \cdot Kp^{*} \pm 1.2 ; \qquad R=0.95 \qquad (1)$$

$$\Phi(MIT) = 62.7 - 1.73\, Kp \pm 2.9 ; \qquad R=0.70 \qquad (2)$$

show that Kp* is indeed a more adequate indicator of magnetic activity for MIT than Kp. Values of Φ(MIT) , derived from the formula (1), are shown in fig.1 by a solid line. The equatorward diffuse auroral boundary seems also to correlate with Kp* better than with Kp /3/. Therefore the definition of MIT that has been given in the Introduction is valid at this stage. Formula (1) was derived considering the entire storm period. Analysis of troughs' dynamics during individual phases of a magnetic storm may reveal other appropriate indicators of magnetic activity.

The Storm Initial and Main Phases.

In fig.1, the intervals 18-20 UT and 21-03 UT are seen to correspond approximately to the initial and main phases of the magnetic storm. The rapid movement of the trough to the lower latitudes began about 19 UT, i.e., before the main phase, and seemed to be associated with an increase in the southern component of the interplanetary magnetic field (B_s). For this initial period of the storm, Dst is not valid as an indicator of magnetic activity. The initial phase is caused by an increase in the solar wind pressure $P_s \sim n_s V_s^2$, where n_s is a density and V_s is a velocity of the solar wind (see e.g. /4/). Enhanced values of Kp during the 18-21 UT interval seem to be also associated with P_s. This increase in P_s is not a direct cause of the trough movement to the equator. Therefore at the initial period of the storm, the MIT movement to the equator lags behind Kp and outstrips

Dst. It seems that this effect may be taken into account by using the magnetic field of the disturbed ring current DR:

$$DR = Dst - 0.02\cdot(n_s V_s^2)^{0.5} + 20, \quad (3)$$

where DR and Dst are in nT, V_s is in km/s, n_s is in cm^{-3} and the values of the constants are taken from /4/. The empirical formula for the 18-03 UT interval (the storm initial and main phases) is

$$\Phi(MIT) = 68.5 - (20 - 4.2\cdot DR - 0.01\cdot DR^2)^{0.5} \pm 1.5 \; ; \qquad R=0.95. \quad (4)$$

Thus, the movement of the mid-latitude trough to the equator was found to depend on DR. It seems to be valid also for the equatorward diffuse auroral boundary.

The Storm Recovery Phase.

During this period, the MIT moves to higher latitudes, and formula (1) describes this movement fairly exactly. This movement seems to result from the magnetospheric convection electric field decrease and from depletion of the 1 keV magnetospheric electrons, whose lifetime increases with the L-shell number.

Fig.1 shows that after 06 UT, RIT begins to separate from MIT, and RIT moves to higher latitudes very slowly. Existence of the RIT, as isolated from the MIT trough, is more clearly seen in fig.2. Dots and circles in this figure are the same as in fig.1 for the three last values of the troughs locations. From the data on the ring trough during the storm recovery phase, the following empirical formula was derived:

$$\Phi(RIT) = 55 + 0.041\cdot DR \pm 0.6 \; ; \qquad R = 0.99. \quad (5)$$

The dashed line in fig.1 is calculated using this formula. From the formula (5) it follows that during the storm recovery phase, RIT may move to higher latitudes but no farther than to 55°Φ, i.e. RIT never reaches 65°Φ which is typical for MIT under quiet conditions. Average location of the inner plasmapause for multiple-plateau density profiles in the magnetospheric equatorial plane is also 55°Φ (see the review /5/). The Te peak has been associated observationally with the plasmapause (see e.g. /6/) as well as with the ring current. The important role of Coulomb collisions between ring-current relatively hot ($E \leq 17$ keV) O^+ ions and thermal electrons at high altitudes in the Te peak and SAR-arcs formation has been described in /7/. This process seems to be the main cause of the Te peak formation in the RIT region. This Te peak, by means of vibrationally excited species, such as N_2^* and O_2^*, can cause increase in the recombination coefficient and, as a consequence, the F2 layer electron density depletion (see e.g. /1/), i.e. the RIT formation at the heights below 500 km. The other cause of the F2 layer depletion can be precipitation of the relatively hot O^+ ions from the ring current by means of the thermosphere heating and of the neutral molecular/atomic ratio increase /8/. These two processes seem to be the main causes of the RIT formation. Therefore the RIT definition presented in the Introduction is warranted at this step.

Fig.2 shows that both troughs are deep for this storm. Analysis of other storms in the Cosmos-900 data shows that during the magnetic storm recovery phase, at post-midnight hours, RIT is often deep while MIT is not clearly distinguished. Therefore, if preliminary separation of the troughs into MIT and RIT have not been carried out, then RIT may often be taken for MIT, and it will not be possible to derive the correct dependence of Φ(MIT) on geomagnetic activity.

The formulae presented in this section are derived for one specific storm period. In deciding on an adequate index of geomagnetic activity for the troughs, statistical analysis of the data is necessary, at least over periods of several storms. As a first step, such analysis is presented below of data referring to the storm main phase.

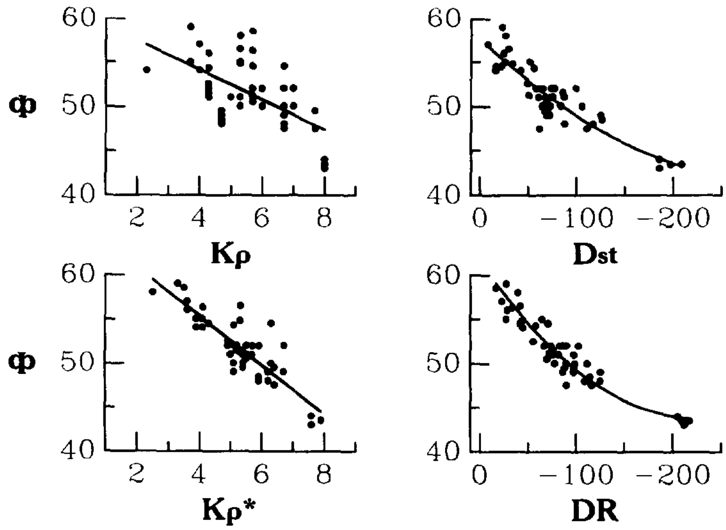

Fig.3.Invariant latitude of the mid-latitude trough Φ (MIT) at the main phase of the magnetic storm versus: Kp; Kp* (average over the current hour and the preceding 4 hours Kp value); Dst; DR (the ring current magnetic field). Dots are data from Cosmos-900 at heights of 380÷480 km in the interval 23-04 MLT in local winter and equinoxes over 9 magnetic storm period.

THE STORM MAIN PHASE

Φ(MIT) data obtained from Cosmos-900 in the subauroral ionosphere, during local winter and equinoxes, at heights 380-480 km, in the local time interval 23-04 MLT and within the period 1978-1979 were analyzed during the main phases of nine storms. For all nine storms, during periods of Dst monotonous decrease, only one trough was observed. According to the definition given in the Introduction, this trough is the MIT. In fig.3, the mid-latitude trough location Φ(MIT) is shown in comparison with Kp, Kp^*, Dst and DR. Using data shown in fig.3, the following empirical formulae were derived:

$$\Phi(MIT) = 60.9 - 1.7\,Kp \pm 3.0\,; \qquad R = 0.59 \qquad (6)$$

$$\Phi(MIT) = 66.5 - 2.8\cdot Kp^* \pm 1.8\,; \qquad R = 0.88 \qquad (7)$$

$$\Phi(MIT) = 63 - (4.1\text{-}2.0\,Dst - 0.001\,Dst^2)^{0.5} \pm 1.5\,; \qquad R = 0.91 \qquad (8)$$

$$\Phi(MIT) = 69.5 - (20\text{-}4.7\,DR - 0.008\,DR^2)^{0.5} \pm 1.4\,; \qquad R = 0.93. \qquad (9)$$

The values of the coefficients in these formulae do not strongly differ from those for the specific storm analyzed previously. But the correlation between Φ(MIT) and Kp* became appreciably worse. This is explained by different time delays in the trough equatorward movement with respect to Kp growth for different storms, which is not taken into account in the Kp* definition. Dst and DR are more adequate indices of magnetic activity for the trough during the storm main phase. Correlation between Dst and Φ(MIT) near the storm maximum was noticed in /9/. But as stated in the previous section, Dst was shown to be a poor indicator for the beginning of the trough fast movement to lower latitudes. This is reflected also in a too low value of Φ(MIT)=61° at Dst=0, given by formula (8). It is well known that the trough mean position under quiet conditions is about 65°Φ. Formulae (7) and (9) correctly represent this fact. Thus, formula (9) is the best fit to the trough movement over the entire period covering the storm initial and main phases.

SUMMARY

Our analysis of the Cosmos-900 data at heights of 380-480 km in the near-midnight and post-midnight local time sectors has shown that DR is the indicator of magnetic activity for the ionization trough movement to the lower latitudes during the storm initial and main phases. An empirical formula (9) can be used to obtain features of this movement. During the storm recovery phase, two troughs can exist, for which velocities of movement to the higher latitudes are appreciably different. Therefore two indicators, DR and Kp*, and two empirical formulas, (1) and (5), can be used during the storm recovery phase in order to obtain features of these movements. In conclusion, the relative depths of these two troughs can vary considerably. Their separate analysis is a necessary step in searching for regularities in the subauroral ionosphere dynamics during storms.

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