DYNAMICS OF THE SUBAURORAL IONOSPHERE DURING THE MARCH 29-30, 1979, STORM

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ABSTRACT

The detailed analysis of the dynamics of the subauroral ionosphere structure - ring ionospheric trough (RIT) and Te peak is carried out for the intense March 29-30, 1979, magnetospheric storm on the simultaneous measurements onboard the Intercosmos-19 and Cosmos-900 satellites. It is revealed that the structure is displaced by ~0.7° to the equator when the height of observation increases from ~450 km up to ~950 km. It is revealed also that the changes of the structure position are delayed relative to Kp index changes by 1-1.2 h at heights of the upper ionosphere (~950 km) and by 2.1-2.6 h at heights near the F2-layer maximum (~430 km). The weak dependence of Te peak position on longitude is detected. Taking into account all revealed effects, the precise linear regression equation for the RIT position is evolved: Λ_{RIT} = 57.8 + 0.052 DR. It is characterized by extremely small dispersion (0.2°) and high correlation coefficient (r ~ 0.96).

INTRODUCTION

The intense magnetospheric storm with Kp=7- and Dst = -129 occurred on March 29-30, 1979. During this storm the simultaneous observations onboard the Intercosmos-19 and Cosmos-900 satellites were conducted. They cover all phases of the storm, all longitudes of the Northern and Southern hemispheres, the heights of the upper ionosphere of 400 to1000 km and different sectors of local time. In this paper variations of the nighttime subauroral ionosphere structure – the ring ionospheric trough, RIT, and Te peak associated with it are studied. RIT as structure separated from MIT (main ionospheric trough) was separated earlier [1, 2]. Its dynamics was researched in [2-5], however a lot of the interesting details have remained outside of field of view. Fine effects in the dynamics of RIT and Te peak for the intense storm are considered below, in particular dependencies of the structure position on local time, height and longitude, and also on indexes of magnetic activity Kp, Dst, DR and AE.

DATA

The Intercosmos-19 data for 21.7-22.8 MLT and 0.6-2.1 MLT and the Cosmos-900 data for 2-4.3 MLT and 0.3-2.8 MLT in the Northern and Southern hemispheres correspondingly are used. Thus, in the Southern hemisphere the satellites were practically in the same sector of local time, and, therefore, at the same longitudes, but Intercosmos-19 was at heights about 600 km, and Cosmos-900 at height of ~440 km. In the Northern hemisphere Intercosmos-19 was located at height about 950 km, and Cosmos - 900 at height of ~425 km. In this hemisphere Intercosmos-19 was in the evening sector, and Cosmos - 900 - in the morning sector, therefore the longitudes also differed.

The position of the minimum of the trough in Ne not always precisely coincided with the position of the Te peak maximum, however in general the variations of the trough and Te peak position during the storm were similar. Therefore all obtained results concern the whole structure - trough in Ne and peak in Te, but below for simplicity the variations of Te peak position are only represented. For example, in Fig.1a the latitudinal distributions of Ne and Te typical for the maximum of the storm main phase and for the beginning of the recovery phase are shown. The trough in Ne and peak in Te in these conditions are clearly pronounced. The trough minimum and peak maximum positions coincide within the accuracy of the measurements. A more complex example, with two minima in Ne and two maxima in Te, is shown in Fig.1b. If these minima (maxima) do not greatly differ, the position of the structure was determined by its average position. If the extrema differed strongly (but no more than by 1°), the position was determined by the greater of them. The double peak in Te and trough in Ne are observed during sharp changes of the structure position, and reflects the structure dynamics.

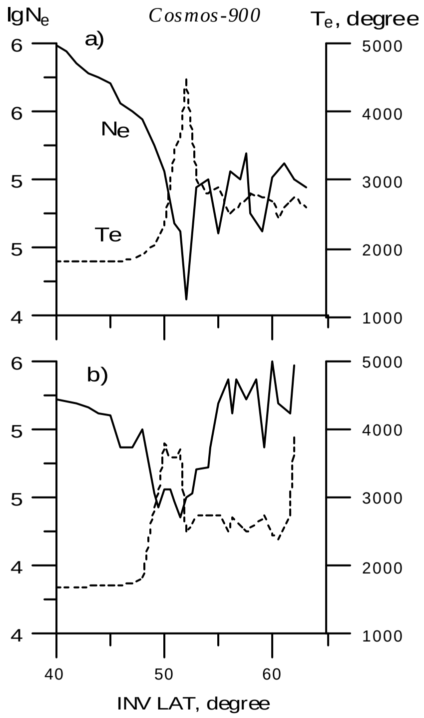

Fig.1. Variations of Ne (continuous curves) and Te (dashed curves), obtained during the March 29-30, 1979, storm as the simple structure - one peak in Te and one minimum in Ne (a), and as the more complex structure - double peak in Te and double trough in Ne (b).

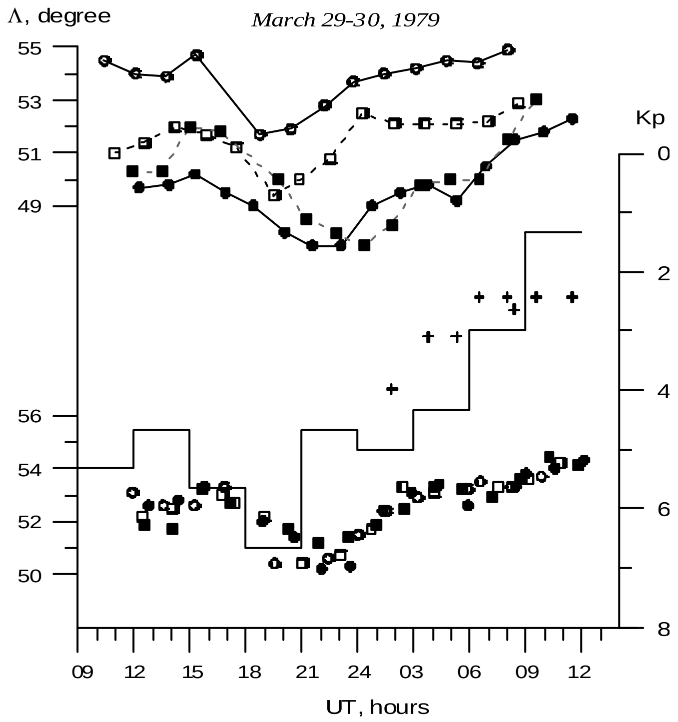

Fig.2. Top: variations of Te peak position during the March 29-30, 1979, storm on Intercosmos-19 data for 21.7-22.8 LT, ~600 km (light circles) and 0.6-2.1 LT, ~950 km (light squares), and also on Cosmos - 900 data for 2-4.3 LT, ~440 km (dark circles) and 0.3-2.8 LT, ~425 km (dark squares) in the Northern and Southern hemispheres correspondingly. Bottom: the same data but reduced to 00 LT and the height of 425 km. The changes of Kp are shown by the solid lines, the MIT position is marked by the crosses.

RESULTS OF OBSERVATIONS

In Fig.2 the variations of the Te peak position with UT for four sectors of local time are shown. Variations of Kp-index are also shown. The March 29-30, 1979 storm started at the recovery phase of the previous storm from rather high level of Kp = 5. Then the short main phase followed with Kp = 7- and then the recovery phase during which Kp-index decreased to 1+.
The observations were made under different conditions, therefore positions of Te peak shown in the top of Fig.2 differ strongly in latitude, the inconjugacy reached 6 to7°. In order to understand the causes of the dispersion, we took into account the most precise formula obtained in [6] for the trough position. It is valid, apparently, both for the plasmapause and for the equatorial border of the auroral diffuse precipitation (BDP): $\Lambda(t) = 0.7\,(t - 0.1t^2 - 0.01t^3)$, where t is LT. With regard to LT, the dispersion of the data diminishes sharply, up to ~2°. The analysis was continued further and it was revealed that the position of a Te peak, averaged for the whole period of observations, depended on height. If one accepts the average position of Te peak at the height of 425 km as a zero, then the following dependence is valid:

Table 1. Dependence of the average Te peak position on altitude (in degrees of the latitude)

Height, km	425	445	600	950
Deviation, degrees	0.0	-0.3	-0.6	-0.8

From Tab.1 the tendency is evident: Te peak is shifted to the equator when the height of observation increases. So, accurate consideration of the dependence on LT allows to separate also a weak dependence on altitude. This dependence is associated, apparently, to the drift across the L-shell owing to the electric field effect [7]. Strong electric fields are regularly observed in the external nighttime plasmasphere [8].
The variations of the Te peak position, reduced to the height of 425 km and 00 LT, according to the revealed regularities, are shown at the bottom of Fig.2. The dispersion on latitude has decreased up to 1-1.5°. Let's compare variations of the Te peak position to the changes of the Kp-index. (The Kp axis in Fig.2 correspond on the latitude to the MIT invariant latitude from the model [9]). The Te peak position (and consequently the trough position too) fits very precisely to the MIT model in the maximum of the storm main phase. In the rest of the time the structure is located much more equatorward of the MIT position at the latitudes of the residual ring current. It is amazing but nobody didn't note such strong contradiction. Thus, the trough observed during the March 29-30, 1979 storm in all sectors of local time is RIT. At MIT latitudes it is possible to detect only the sources of the structure similar to a trough which are shown by crosses in Fig.2.
The position of the Te peak correlates with the Kp-index with some delay which differs for each sector of local time. The assumption was made that the dependence on local time in the case study can be stronger than dependence obtained in [5] by averaging the data for recovery phases of several storms. For the testing of this assumption the correlation of the Te peak position with Kp and DR-indexes for the growth and recovery phases separately was calculated. The correlation coefficients and delay times are shown in Tab.2.

DISCUSSION

From Tab.2 some important conclusions can be deduced. First, the delay of the Te peak response to Kp changes depends, mainly, on height, instead of local time, as it could be assumed. It is clearly seen from the data for the Southern hemisphere where the local times for both satellites are close and the heights differ by ~500 km. The changes of Te peak position at the height of 445 km is delayed relative to changes of its position at height of 950 km for 1 h at the growth phase and for 1.7 h at the recovery phase of the storm. The delay, apparently, is connected to that the dynamics of the Te peak at the high altitudes is controlled, mainly, by the heat source and at the low altitudes by sink of heat. The source is the heat flux which arrives from the magnetosphere. The heat is transferred to the ionosphere as result of the heat conduction. The characteristic time of this process is some minutes [10,11]. The region of the heating is displaced no more than by 1-2° of latitude for 1 h, and because of such slow shifting, the Te peak maximum at the height of ~1000 km follows close to the maximum of the heat stream. The sink of heat is localized, mainly, in the region of the dense plasma near to the F2-layer maximum. The Te growth over 3000° causes at these heights the increase of the recombination coefficient and formation of the trough in Ne [12]. The heat is distributed between particles, therefore, the less is the electron concentration in the trough minimum, the higher is the temperature of every particle. As a result, the maximum of the Te peak at the heights of 425-445 km is collocated with the minimum of the trough, instead of the maximum of the heat flux. The characteristic time of the recombination is 1-2 h [13,14]. When the heat flux position is shifted, the Te peak at high altitudes follows it, but at low altitudes remains still for 1-2 h at the latitudes of the old trough minimum, until the new trough is not formed. This period corresponds approximately to the revealed time delay. The growth of Te means also the increase of the scale height for the electronic gas. Therefore diffusion stream will carry out plasma upwards, and instead of a trough at high altitudes the Ne maximum will be formed. It does occur at altitudes above ~1400 km (see, for example, [15]).
So, the Intercosmos-19 data represent the response of the magnetospheric structure to the magnetic storm, and the Cosmos-900 data include besides the response of the ionosphere. Therefore the analysis of Tab.2 was continued according to the Intercosmos-19 data. From these data it is easy to calculate that the delay between changes of Kp and DR indexes is 2.5-2.6

Table 2. Delay (in hours) of the structure response to the changes of the magnetic activity indexes Kp and DR

Satellite	Hemisphere	Height, km,	LT, h	Growth phase, τ		Recovery phase, τ	
				Kp	DR	Kp	DR
Cosmos-900	Northern	425	~3.0	-2.1	+0.5	-2.6	+0.6
	Southern	445	~1.5	-2.1	+0.5	-2.6	+0.7
Intercosmos-19	Northern	600	~22.0	-1.2	+1.3	-1.0	+2.3
	Southern	950	~1.0	-1.1	+1.7	-0.9	+2.5

h at the growth phase of the storm and 3.3-3.4 h at the recovery phase. Thus, the processes in the magnetosphere which determine these indexes are characterized by different time constants at different storm phases. The planetary Kp-index is calculated from the magnetograms of 12 observatories located in the belt of 62-70° latitudes therefore its increase at the growth phase is connected, mainly, to the intensification of the three-dimensional current system DP_{11}. This current system is created by the currents in the magnetospheric tail, the field-aligned currents of the zone 2 and the western electrojet [16]. The intensity of the currents is the more, the more is the conductivity of the ionosphere and the more is the magnetospheric electric field, as $j \sim \Sigma p E_m$ where Σp is the Pedersen conductivity of the ionosphere. The electric field $E_m \sim V_s B_z$, therefore Kp correlates both with the solar wind velocity V_s (viscous friction) and with B_z IMF (reconnection). The conductivity of the ionosphere under nighttime conditions is determined, mainly, by the auroral electron precipitation from the plasma sheath. The intensification of the precipitation at a substorm is set up for 0.5-1 h [17]. The carriers of the current are the electrons precipitating from the plasma sheath, and ionospheric ones too, therefore the current system DP_{11} is set up approximately for the same time [16]. The growth of the Ey-component of the electric field in the solar wind causes the injection of the energetic ions from the tail of the magnetosphere to the Earth [18]. These ions participate in the formation of the Alfven layer and are the source of the ring current. As the ions are less mobile than the electrons, the formation of the ring current delays relative to the formation of other structures, in this case by ~2.5 h. The changes of the ring current intensity during the storm are determined by the pressure of the magnetospheric plasma, i.e. by the density and energy of the accelerated ions [19]. The indicator of the current intensity is DR-index, and the position of RIT is determined by the position of the maximum of the hot ion precipitation from the ring current. The latter is determined by the position of internal border of the ring current and the position of the plasmapause. Nearly to the plasmapause the interaction of the hot particles of the ring current and cold particles of the plasmasphere take place, which causes the intense ions precipitation [19]. As it is seen from Tab.2, the changes of the RIT position delays behind the variations of Kp-index for 1.1-1.2 h and is ahead of the variations of DR-index for 1.3-1.7 h. Thus, the velocity of the shift of the internal border of the ring current to the Earth is greater than the growth rate of the current intensity. It is apparently associated with that at first the injection of ions from the internal part of the plasma sheath to lower L-shells occurs, and then the increase of the number of the accelerated (more energetic) particles arises from their drift from the external tail.
At the recovery phase the MIT and BDP are shifted to the quiet position practically simultaneously. The time delay of this shifting from changes of the Kp-index is connected to the characteristic lifetime of electrons of the plasma sheath. The ring magnetospheric current decays during the recovery phase, at first fast owing to the decay of the asymmetric part of the current, and then slowly owing to the decay of the symmetric current by the charge exchange of H+ ions with neutral atoms [20]. The maximal rate of the decay takes place at the internal border of the ring current where the ions enter the loss cone by the collisions with dense plasma of the plasmasphere. Therefore RIT will be rather fast (but more slowly than MIT) displaced to the pole. The delay of this shift relative to Kp changes is ~1 h, as it is seen from Tab.2. However the main amount of the ring current ions still long exists at high L-shells, therefore current intensity diminishes more slowly (~ 3.4 h).

Everything considering, the data were again reduced to the heights of Cosmos-900, accepting the common for whole storm value $\tau = -2.5$ h for the Kp-index (then $\tau \sim 0.6$ h for the Dst and DR-indexes). After that the data were averaged over latitude. The obtained approximate curve is shown in Fig.3. Changes of the Kp, DR and Dst indexes taken with the corresponding average time delay are also shown. The best correlation is achieved for DR-index. The correlation coefficient in this case achieves extremely high value r ~ 0.96. The linear regression equation for DR-index is the following:

$$\Lambda_{RIT} = 57.8 + 0.052\ DR \pm 0.2, \quad r \sim 0.96, \quad \tau \sim 0.6\ h$$

The Dst variations are similar to the DR variations for almost the whole period, but strongly differ at the beginning of the period under study, it has reduced the correlation coefficient for Dst to 0.77. At last, correlation with the Kp-index, after the consideration of all dependencies, is also rather high: r ~ 0.89. However this dependence for RIT is three times weaker than for MIT (compare, for example, with [9]):

$$\Lambda_{RIT} = 56.8 - 0.7\ Kp \pm 0.3, \ r \sim 0.89, \ \tau \sim -2.5\ h$$

AE-index of magnetic activity is also involved, but the correlation with it turned out very weak.
At the final stage of the analysis the dependence of the time delay on altitude was taken into account and the search of possible reasons of the residual dispersion was again conducted. Among them were assumed By IMF, longitude and again

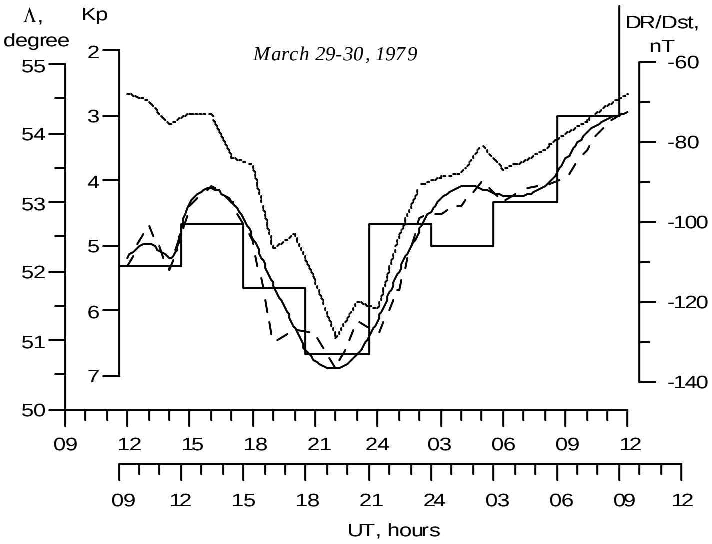

Fig.3. Correlation of the average position of the Te peak (thick line) with Kp (thin line), Dst (thin dotted line) and DR (thick dashed line). All indexes are taken with corresponding delay, in particular the lower X axis relates to the Kp-index. Details see in the text.

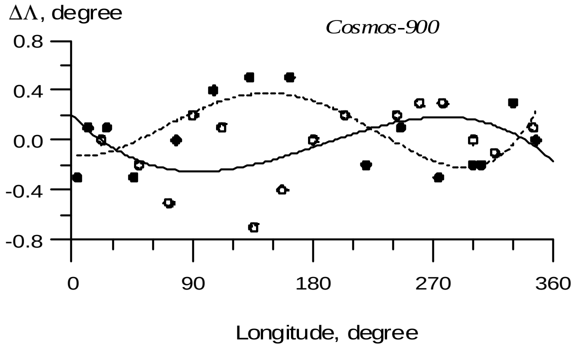

Fig.4. Incojugacy of the position of the subauroral Te peak in the Northern (light circles) and Southern (dark circles) hemispheres obtained on Cosmos-900 data taking into account the dependence on local time, height and time delay (details see in the text). The approximation is shown by the curves.

local time. The detailed analysis has allowed to detect only weak dependence on longitude. In Fig.4 for example the Cosmos-900 data for the Northern and Southern hemispheres as the deviations from the average value (see Fig.3) are shown. As it is seen in Fig.4, the incojugacy of the Te peak positions only in one case exceeds slightly 1°. If one takes into account the longitudinal effect, the difference in the Te peak position in the Northern and Southern hemispheres is practically within 0.2-0.3°. This value, apparently, is the limit of accuracy of the analysis. The longitudinal variations of the Te peak position (and RIT too) in both hemispheres are similar to the variations of the MIT position obtained in [21]. However their amplitude much less and is about 0.5° in both hemispheres. Such value can be detected only by the very accurate analysis.

So, at the fixed altitude incojugacy of Te peaks in the Northern and Southern hemispheres is determined, mainly, by the longitudinal effect and practically does not exceed 1° at some longitudes. At different altitudes the incojugacy can be much greater, as a result of the drift of the structure across the L-shell and the different time delay.

CONCLUSIONS

The analysis of the simultaneous data of the Intercosmos-19 and Cosmos-900 satellites allows to reveal fine effects in behaviour of the structure of the subauroral ionosphere during the strong storm.

1) At the recovery phase of the storm the RIT, in contrast to MIT, is slowly shifted to the characteristic latitudes of the residual ring current (L ~ 3, Λ ~ 55-57°). At the late stage of the recovery phase the RIT can be located by 13-14° equatorward of the MIT and BDP.

2) It is revealed that the structure is displaced by ~0.7 to the equator when the height increases from ~450 km up to ~950 km. This shift is connected, apparently, to the plasma drift across the L-shell under action of the electric field.

3) It is also revealed that the changes of the structure position are delayed relative to changes of the Kp-index for 1-1.2 h at the heights of the upper ionosphere (~950 km) and for 2.1-2.6 h at the heights nearly to the F2-layer maximum (~430 km). The difference in 1-1.5 h is determined by the characteristic time of reconstruction of the dense plasma nearly to the F2-layer maximum.

4) The weak dependence of the Te peak position on longitude is revealed. Thus, incojugacy of the Te peaks in the

Northern and Southern hemispheres at the same height is determined, mainly, by the longitudinal effect and seldom differs more than by 0.5°. It demonstrates a very high symmetry of the processes linking the ring magnetospheric current and the upper ionosphere. Incojugacy of the troughs in the Northern and Southern hemispheres is a little bit greater than for Te peaks, it is connected, apparently, to the effects of the local processes in the ionosphere.

5) A consideration of all revealed regularities has allowed also to determine precisely the RIT position depending on the magnetic activity indexes. The linear regression equation for DR-index is the following: Λ_{RIT} = 57.8 + 0.052 DR, and it is characterized by the extremely small dispersion (0.2°) and very high correlation coefficient (r ~ 0.96).

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