Geomagnetism and Aeronomy, Vol. 38, No. 3, 1998, pp. 325–333. Translated from Geomagnetizm i Aeronomiya, Vol. 38, No. 3, 1998, pp. 79–91.

Dependence of the Probability of Ionospheric-Trough Observations on the Season, Local Time, Longitude, and Level of Geomagnetic Activity

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Received March 4, 1997; in final form, October 30, 1997

Abstract—A statistical analysis of the probability of observations of different ionospheric troughs is carried out on the basis of a large uniform data set from the *Kosmos-900* satellite (about 3000 revolutions). Variations in the probability of trough occurrence are revealed and investigated as functions of the season, local time, and level of magnetic activity. A longitudinal effect (UT control) is found in the probability of trough observations for the winter daytime and summer nighttime conditions in the northern and southern hemispheres. The probability of trough formation in this conditions is shown to be dependent on the level of magnetic activity and the value of the background density, which is mainly determined by changes in insolation conditions and by the neutral wind. The results of this study are compared with other data, and reasons for discrepancies are found.

INTRODUCTION

It is well known that the probability P of observation of the midlatitude (main, or subauroral) ionospheric trough depends on the season, local time, and level of magnetic activity. In many cases, this dependence can be expressed by a simple qualitative formula: P is maximal in the winter nighttime, increasing with magnetic activity. Thus, in the winter near-midnight conditions, the trough is observed in all experiments, almost always. For other conditions, rare and incomplete statistical studies of the P magnitude [1–6] give widely differing results (see, for example, [1] and [3]). This seems to be related to the fact that the analyses were made by different methods, and limited data sets were used, which were obtained at different altitudes and longitudes in both hemispheres, with low space and time resolutions. In addition, it was shown recently that several types of troughs with different characteristics may exist in both the nighttime and daytime at close latitudes [7, 8]. In such cases, the observed pattern is strongly dependent on the hemisphere and longitude (UT). This paper presents a detailed analysis of the observation probability for different ionospheric troughs, based on a large uniform set of *Kosmos-900* data with due regard for recently found regularities.

SOURCE DATA

For our statistical analysis of the ionospheric-though characteristics, were used about 3000 passages of the *Kosmos-900* satellite over the subauroral ionosphere in both hemispheres, which were more or less uniformly distributed over longitudes. The data were obtained for moderate and high solar activity during the period of 1977–1979. During this time, the nearly circular orbit of the satellite has lowered because of the air drag, from about 550 km to about 350 km. This is close to the altitude of the $F2$-layer maximum, which, according to the *Intercosmos-19* data, varies in the same conditions over the range 350–400 km. In situ measurements of the plasma density N_e and the plasma temperature T_e were made with a time resolution of ≤1 s; thus, the accuracy of recognition of the trough as a structure was determined only by the method of its identification. The trough as a structure of the subauroral ionosphere was recognized by variations in the electron density and temperature according to the following criteria: (1) the presence of a clearly defined N_e minimum near the equatorial boundary of the auroral oval, which is almost always accompanied by a T_e maximum; (2) the presence of a fairly pronounced equatorial wall of the trough; (3) the presence of a steep and strongly nonuniform polar wall of the trough, usually related to a sharp increase in T_e with a similarly nonuniform structure; (4) the recurrence in the appearance of the distinguished feature from orbit to orbit, i.e., a fairly large longitudinal extension of the structure studied. In this context, the accuracy of determination of the equatorial boundary of the auroral oval, as identified in the model [9] on the basis of data for diffuse low-energy electron precipitation, is of little significance, since, at the first stage of the study, even troughs well separated from this boundary were taken into account. As a result of such a procedure, not only the main ionospheric trough (MIT) was among the selected troughs, but also the ring ionospheric trough (RIT) associated with the

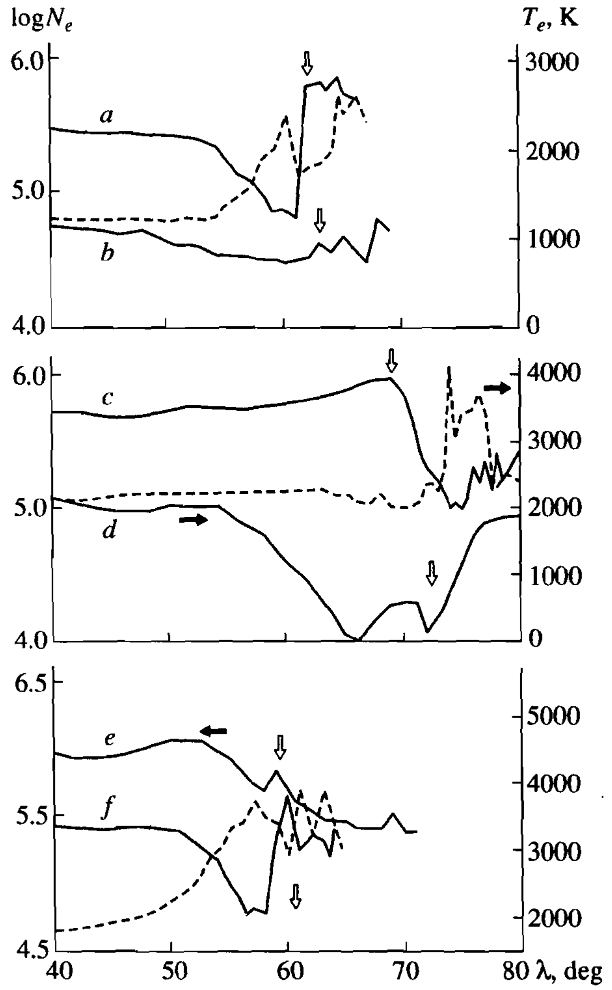

Fig. 1. Examples of well-defined troughs (*a*, *c*, *d*, *f*) and quasi-troughs (b, e) in the winter nighttime (*a*, *b*), winter daytime (c, d) and summer nighttime (*e*,*f*) conditions. Solid curves: latitudinal variations in N_e; dashed curves, in T_e. The light arrow shows the boundary of diffuse auroral precipitations according to the model [9]; the solid arrow at the terminator latitude indicates the shadowed ionosphere. The conditions of observations are listed in the table.

magnetospheric ring current [7], the Muldrew trough associated with the daytime cusp [8], and the high-latitude trough observed around the clock inside the auroral oval and characterized by an extremely nonuniform structure even in the region of the equatorial wall [10]. At the second stage, all troughs other than the MIT were excluded from the analysis or were considered separately, as in the case of the daytime Muldrew's trough.

As an example, Fig. 1*a* shows a clearly pronounced trough observed in the winter nighttime conditions, which completely conforms to the above criteria (the parameters of all the orbits shown in Fig. 1 are listed in table). For comparison, Fig. 1*b* shows a structure that was also observed in the winter nighttime conditions, but could not be confidently identified as a through because all its elements were weakly defined. However, quite pronounced troughs were recorded from the adjacent orbits at the latitudes studied, with a density minimum whose position fairly well corresponds to the conditions under consideration. Such cases of "degenerate trough," or "quasi-trough," will also be taken into account in what follows, because they actually determine the accuracy of the method of trough recognition and, therefore, the accuracy of the performed statistical analysis. Note that in both cases the N_e minimum is accompanied by a well pronounced peak of T_e (for simplicity, the T_e peak is not shown in Fig. 1*b*).

LOCAL-TIME DEPENDENCE OF OBSERVATION PROBABILITY FOR THE WINTER IONOSPHERIC TROUGH

In summer, the trough is observed only during near-midnight hours [2]. In the winter and equinoctial conditions, the trough is frequently detected in the nighttime and much more rarely, in the daytime [1–5]. To quantitatively investigate the local-geomagnetic-time dependence of the probability of trough observations (*P*), we used 1478 cases recorded near (within ±1.5 months) the December solstice in the northern hemisphere and near the June solstice, in the southern hemisphere. Since the trough behavior has specific features in very quiet and in disturbed conditions, we selected data for the K_p range from 1– to 3+. The results of the analysis, consistent with the above criteria, are shown in Fig. 2. It is seen that the trough occurrence probability sharply increases after the sunset, reaching ~100% in the after-midnight hours, and equally sharply decreases after the sunrise, down to ~30% in the afternoon hours. And, vice versa, quasi-troughs are more often observed during the daytime (P = 15–20%), when the trough is poorly marked, and more rarely in the nighttime (P = 3–5%), when the trough is almost always clearly pronounced. Therefore, the number of quasi-troughs may serve as a measure for the degree of trough maturity throughout the day, while the sunrise and the sunset define a sharp boundary between the nighttime and the daytime trough. This is a fairly well-known fact, but a detailed analysis of diurnal variations in the probability of trough observation has not been made. We will perform such an analysis for the winter conditions, in comparison with the most representative data from the satellites *Ariel 3* [1], *ISIS 1*, and *Injun 5* [3] (see Fig. 2).

The data of *ISIS 1* and *Injun 5* were obtained at altitudes *h* < 1500 km; the data of *Ariel 3*, at 500–650 km, i.e., closer to the altitudes of *Kosmos-900*. Nevertheless, as seen from Fig. 2, the former are in better agreement with the data from *Kosmos-900* than the latter. On the other hand, the data from *Ariel 3* are less smoothed, and their relative variations clearly confirm the existence of a sharp boundary between the daytime and nighttime conditions. In addition, they indicate the presence of an evening and a morning peak in the prob-

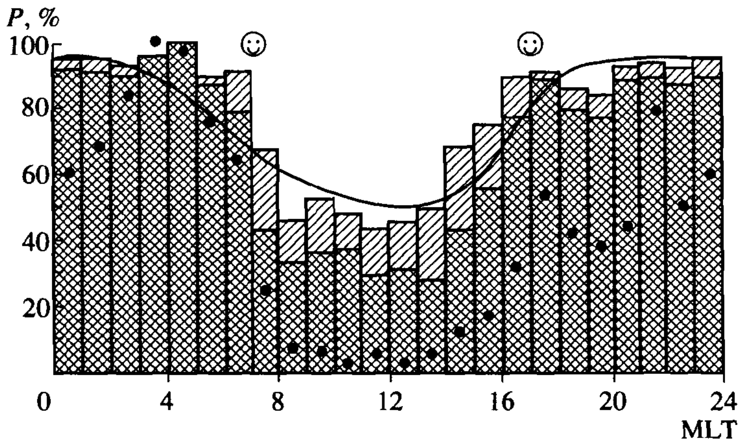

Fig. 2. Dependence of the trough observation probability P on the magnetic local time for the winter quiet conditions (K_p = 1–3+). Dark hatching: well-defined trough; light hatching, quasi-trough; solid circles, *Ariel 3* data [1]; solid curve, *ISIS 1* and *Injun 5* data [3]; open circles, sunrise and sunset.

ability distribution, which have probably been overlooked in earlier studies. However, the evening and the morning peaks of P can also be distinguished from the *AE-C* data [2], in the intervals of 16–18 MLT and 2–4 MLT, respectively, and also from the data of the *Transit* satellite series on the total electron content over Scandinavia [5], at ~17 LT and 2–5 LT, respectively. Investigations of the trough maturity (its depth and width) as a function of local time give rather controversial results, but, in most cases the early evening and early morning hours are again mentioned (see, for example, [6]). Thus, a steady behavior of the winter trough can be noted for the non-illuminated time of the day. The simplest explanation of such a behavior of the winter trough is given in [11]. In that paper, a stagnation mechanism of the trough formation based of the "full-shadow" effect is considered: in the crescent-shaped region between the terminator and the equatorial boundary of the auroral oval, neither solar nor corpuscular ionization sources are present around the clock. The size of this region changes with the Earth's rotation, since the magnetic and the geographic pole do not coincide and the equatorial boundary of the diffuse auroral precipitations can be most closely represented by a circle whose center is offset from the magnetic pole toward the nightside sector by ~5°. Inasmuch as the narrowest crescent is observed during the near-midnight hours, the trough is at this time much less pronounced than in the evening and in the morning. In this case, however, the morning P peak should be attained closer to the sunrise rather than at 3–5 LT, as evidenced by all observations. Some other mechanisms seem to operate in this local-time sector, which make the trough more developed. This may be the neutral wind, which usually attains its maximum equatorward velocity after the midnight and which transfers excited N_2^* molecules from the auroral oval to the trough minimum, causing an additional decrease in N_e [12]. An effect of the downward field-aligned current in the morning sector [13] is also possible. As is known, this current causes a strong depletion in N_e at the ionospheric level [14]. The most pronounced ring trough (RIT), related to the residual ionospheric ring current during the recovery phase of a storm, is normally observed during the morning hours [7]. The presence of the RIT may increase the net probability of trough observation in this local-time sector, since a RIT can in many cases hardly be distinguished from the MIT and since a significant part of the time covered by the *Kosmos-900* dataset belongs to storm periods. Note that it is most difficult to separate the RIT and MIT in the range

Parameters of the *Kosmos-900* satellite orbits presented in Fig. 1

Curve no.	Orbit no.	Date	UT	MLT	λ, deg	h, km	K_p	Hemisphere
a	13023	July 25, 1979	09.13	0.9	220	385	2–	S
b	13098	July 30, 1979	23.22	22.1	4	390	2–	N
c	10098	Jan. 18, 1979	17.11	12.0	290	403	3	N
d	12607	June 28, 1979	16.24	12.0	290	390	1–	S
e	10179	Jan. 24, 1979	09.31	1.2	215	480	3	S
f	10296	Jan. 31, 1979	23.42	21.5	355	487	3–	S

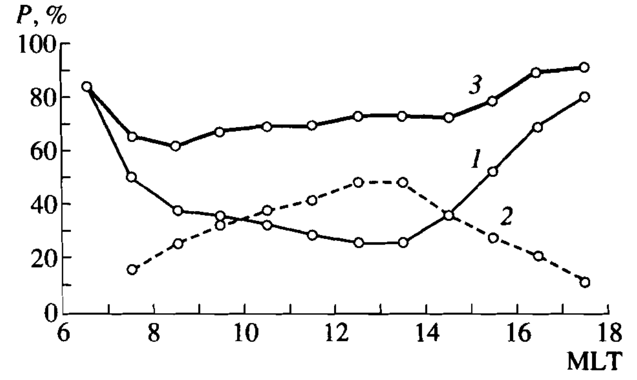

Fig. 3. Variations in the observation probability P for different troughs with magnetic local time in the winter quiet (K_p = 1–3+) conditions, averaged over the longitudes of both hemispheres: (*1*) daytime MIT; (2) Muldrew trough; (*3*) total probability.

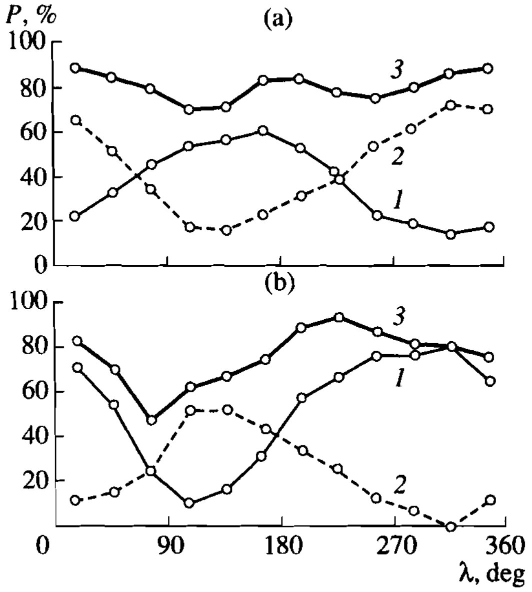

Fig. 4. Variations in the observation probability P for winter troughs with longitude in the northern (a) and the southern (b) hemisphere: (*1*) daytime MIT; (*2*) Muldrew trough; (*3*) total probability; K_p = 1–3+.

K_p = 3–4. Later, at the recovery stage, the equatorial boundary of diffuse auroral precipitations, as well as the MIT, move to higher latitudes (64°–66°), whereas the RIT remains at the latitudes of the residual ring current (55°–57°), which are ~10° equatorward of the auroral oval. Thus, the first criterion for the RIT is not satisfied, and the RIT it is excluded from the analysis.

The sharp increase of the probability P after the sunset ($t \geq 18$ LT) is related to the initiation of the stagnation mechanism in the region where the Earth's rotation velocity and the drift velocity at the equatorial edge of the evening convection cell are mutually compensated [15]. However, the trough that has formed in the evening persists throughout the night and the P value should gradually decrease until the morning without developing a evening peak. Therefore, the evening peak also seems to be related to some additional factors, in particular, with the formation, in the evening local-time sector, of a "polarization jet"—a narrow band of fast westward drift, with a very narrow and deep trough associated with this band (see, for example, [16]). The polarization jet forms during substorms, which often fall in the abovespecified interval K_p = 1–3+. In addition, the trough that has formed during a substorm persists for a long time. We also recall that, in the stagnation region, the trough minimum develops not along the stagnation line, where the drift is zero, but somewhat poleward, i.e., within the westward-drift band [15, 17]. Consequently, the depleted ionization will be carried from the stagnation region not only into the nighttime sector but also into the daytime sector [18]. The data from *Kosmos-900* confirm this suggestion [8]. Therefore, the stagnation region represents the source of the nighttime and, partially, of the daytime trough; thus, the probability of trough observation for this region will be higher than for other times.

A detailed analysis of the *Kosmos-900* data shows that, during the daytime, two troughs actually exist [8]. One of them, being associated with the above-mentioned full-shadow mechanism and closely resembling the nighttime MIT by its characteristics, forms, together with the MIT, a single branch at the shadowed longitudes; this branch is situated positioned near the auroral oval, but equatorward of it. An example of the daytime MIT is shown in Fig. 1d. The second trough, as noted above, is carried from the stagnation region by the westward drift and is sustained in the near-noon hours by strong electric fields and field-aligned currents [8]. This trough is mainly present in the sunlit longitudes and its form is characterized by a very steep equatorial wall and a poorly marked polar wall (see Fig. 1c). The well-defined N_e minimum in this trough is usually accompanied by a clearly shaped peak in T_e. During the near-noon hours, this trough is situated, as a rule, within the auroral oval, but equatorward of the dayside cusp and, at this time, is close in its position to the trough that was first discovered by Muldrew from *Alouette 1* data [19]. That is why it was named the Muldrew trough. Since the Muldrew trough is mainly present at sunlit longitudes, while the dayside MIT, at shadow longitudes, a strong longitudinal effect (or UT control) arises in the P magnitude. And in the case of the Muldrew trough, the P value near the noon will be a maximum, while in the case of the daytime trough, a minimum [8]. The aforesaid is qualitatively illustrated by Figs. 3 and 4.

The variations of P are somewhat different in different hemispheres. For simplicity, in Fig. 3 we present a picture based on 670 cases of trough observation and averaged over both hemispheres. As can be seen from Fig. 3, the Muldrew trough appears at 17–18 LT, is most frequently observed during the afternoon hours, and disappears at 7–8 LT, where it is much less pronounced than in the evening. On the contrary, the daytime MIT is most rarely observed in the afternoon. The observation probability for both troughs (without separation into types) is a minimum in the morning and is ~70% during the near-noon hours of local time.

The regularities found in this study make it possible to understand the reasons for strong discrepancies between different data sets presented in Fig. 2. In case of *Ariel 3*, the data were selected by computer and were limited to a geographic latitude of 70°; for this reason, most of near-noon troughs located at low magnetic activity within the geomagnetic-latitude band 65°–80° were automatically excluded from the analysis. This drastically reduced the P values for the daytime hours—see Fig. 2. The orbits of *ISIS 1* and *Injun 4* had inclinations large enough to allow observation of near-noon troughs, but the authors of [3] failed to separate the two troughs at altitudes $h < 1500$ km; therefore, a summarizing curve for both troughs seems to be presented in their figure for the daytime hours. Finally, the *Kosmos-900* data, shown in Fig. 2, basically represent the main ionospheric trough, according to the selection criteria specified at the first stage. Thus, to analyze both daytime troughs—the daytime MIT and the Muldrew trough—the first selection criterion should be somewhat corrected. Note also that the so-called high-latitude trough also formally meets the first criterion. However, this trough is observed around the clock within the auroral oval, is characterized by an extremely nonuniform structure even at the equatorial wall, and relates to the T_i peak rather than the T_e peak, as all other troughs [10]; consequently, it can relatively easy be separated from others and, for this reason, is not considered here.

LONGITUDE DEPENDENCE OF OBSERVATION PROBABILITY FOR WINTER DAYTIME IONOSPHERIC TROUGHS

The variations of the ionospheric-trough observation probability with longitude in the winter daytime conditions are presented in Fig. 4 separately for the northern (347 cases) and the southern (287 cases) hemisphere. They mainly follow the above-revealed regularity: the daytime MIT is most frequently observed at the longitudes of the deepest shadow, i.e., near 120°–150° in the northern and 270°–300° in the southern hemisphere. Since the deepest shadow is present in the southern hemisphere, the probability of the dayside-MIT observation reaches 70–80% there. Note that the experimental data presented in Fig. 4, refer to a wide range of local times, and the probability for the noon hours will be somewhat lower. The Muldrew trough is more often observed at sunlit longitudes, ~300°–330° in the northern and ~120°–150° in the southern hemisphere; in the former case, P reaches 70–75%. It is not difficult to note that the character of the longitudinal variations of P changes to a virtually inverse one with the change of the hemisphere or the type of trough. Therefore, the total observation probability for both troughs (without separation into types) is less variable with longitude, especially in the northern hemisphere (see Fig. 4).

Thus, the pattern of the winter daytime ionosphere at high latitudes proves to be fairly complicated. Although we managed to reveal some of its important characteristics, there remain significant contradictions. For example, a simulation of two daytime troughs was made in [18] in comparison with ground-based data. In both cases, the initial assumptions were the same (it was surmised that, in the daytime, one trough is carried away by the westward drift, while the other forms in the region of full shadow). Nevertheless, the results obtained in [18] strongly differ from those obtained above both for the sunlit longitudes (where, according to [18], the Sun fills any ionospheric trough) and for the shadowed longitudes (where, as a rule, both troughs are observed). The discrepancies seem to appear because of differences in the conditions of various experiment s, first of all, in the levels of solar ionization. Note in conclusion that a longitude effect is also observed in the position of the trough, but its analysis goes beyond the scope of this study and will be done later.

ANNUAL VARIATIONS IN THE PROBABILITY OF OBSERVATION OF THE IONOSPHERIC TROUGH IN THE NEAR-MIDNIGHT CONDITIONS

Seasonal variations in the ionospheric-trough observation probability for the nighttime conditions were investigated by statistical methods on the basis of data from *Ariel 3* and *AE-C* [2]. However, the annual variations of probability P seem to be completely presented for the first time in Fig. 5. To this end, 1294 cases were used for quiet (K_p = 1–3+), near-midnight (20–04 LT) conditions in both hemispheres. The dark hatching indicates the cases of the well-pronounced MIT and the light hatching, the cases of quasi-troughs. It is seen that the MIT observation probability is very high in winter and reaches 97% in December. In summer, the trough observation probability does not exceed 30% and reduces to 20% in July. Accordingly, the number of quasi-troughs increases from 3–5 to 15–20%. Therefore, a pattern similar to that shown in Fig. 2 is observed: as the illumination of the high-latitude ionosphere increases, the trough is filled by solar ionization, its depth and frequency of occurrence progressively decrease. On average, however, the curve for P in Fig. 5 is shifted as a whole by about 1/3–1/2 month relative to the solstice maximums; thus, the observation probability in September is somewhat less that in March. A similar phase shift (by about 1/2–1 month) is present in the variation of the background density, as one can ascertain by computing the concentration in the trough region according to the IRI model (see Fig. 5). It is clear

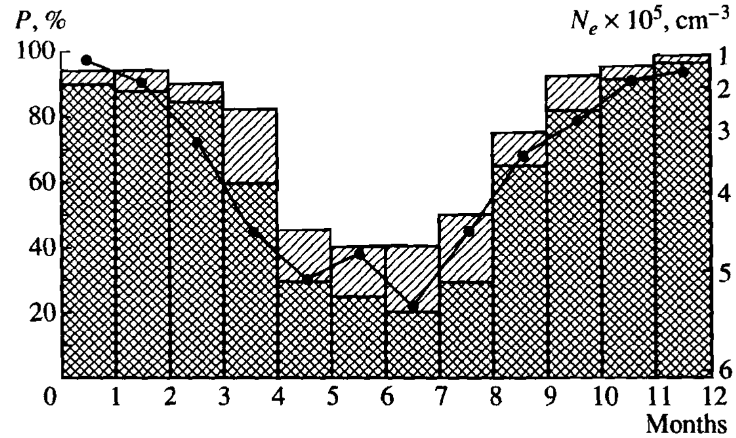

Fig. 5. Annual variations in the observation probability P in near-midnight (20–04 MLT), quiet (K_p = 1–3+) conditions for a trough (dark hatching) and for a quasi-trough (light hatching). The curve represents variations in N_mF2 calculated from the IRI model for an invariant latitude of 60°, 00 LT, and $F_{10.7}$ = 200.

that the lower the background concentration, the easier the trough formation. Furthermore, the lower the background density, the lower the conductivity of the high-latitude ionosphere and the higher the electric field of magnetospheric convection, which produces the trough.

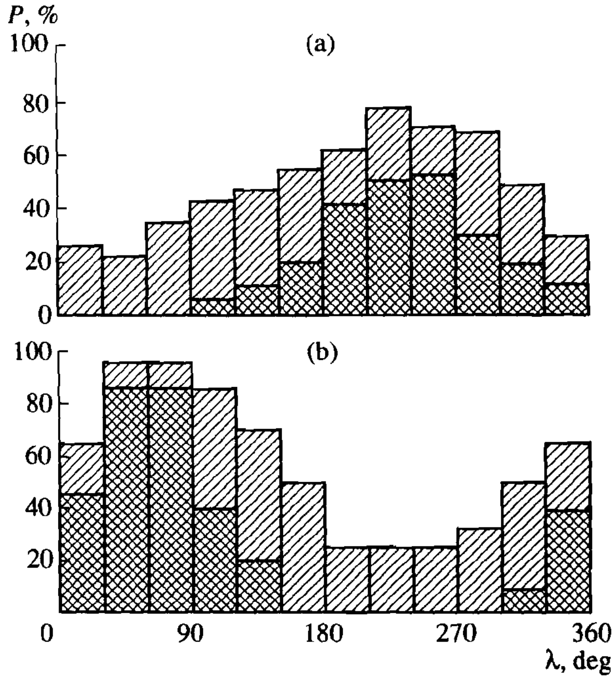

Fig. 6. Dependence of the trough observation probability P on longitude for the summer nighttime (20–04 MLT), quiet (K_p = 1–3+) conditions in the northern (a) and the southern (b) hemisphere. Dark hatching: trough; light hatching: quasi-trough.

LONGITUDE DEPENDENCE OF THE OBSERVATION PROBABILITY FOR THE SUMMER NIGHTTIME IONOSPHERIC TROUGH

Inasmuch the conditions of trough formation depend on the illumination conditions in the high-latitude ionosphere, which are strongly longitude-dependent during summer nights and winter days, the summer trough-observation probability will also depend on longitude. Figure 6 presents the longitudinal variations of P for the nighttime (20–04 LT) summer conditions, near (within ~1.5 months) the June solstice in the northern hemisphere and near the December solstice in the southern hemisphere. For the northern hemisphere, 258 cases were used; for the southern hemisphere, 185 cases. The trough, as should be expected, forms in the shadow region and is almost never observed at the sunlit longitudes, where it may persist relatively long only in a degenerated form, i.e., as a quasi-trough. For comparison, we present examples of a mature trough and a quasi-trough in Figs. 1f and 1e, respectively.

From the comparison of Figs. 4 and 6, it can be seen that the P maxima and minima for the main ionospheric trough exchange their places with the change of the hemisphere and season (time of day). This can be explained by the fact that, near the winter noon, at high latitudes the Sun shines "directly," and near the summer midnight, from the opposite side of the Earth—through the polar cap. This correspondence is, however, not complete, because in the winter daytime conditions, at longitudes that are far away from the Sun, the polar night takes place around the clock, whereas in the summer nighttime conditions, the shadow is observed only several hours even at the longitudes most distant from the Sun. For this reason, the MIT forms, on average, more frequently in the winter daytime (P ~ 35%) than in the summer nighttime (P ~ 25%). Nevertheless, in the southern hemisphere at longitudes of 60°–90°, near the midnight, the summer trough forms almost always, although it is not as pronounced as in winter.

It was shown above that the process of trough formation is also influenced by variations in the background density. This also completely applies to the summer nighttime conditions considered here. In this case, the background variations of the electron density in the trough region are mainly determined by the action of solar ionization and of the neutral wind [20, 21]. So far as the lowest background density is observed in the southern hemisphere at longitudes 30°–90°, the trough appears in this region most frequently. Therefore, the trough as a structure is formed under the action of the electric field of magnetospheric convection, and the variations of its characteristics with season, local time and longitude are mainly governed by solar ionization and the neutral wind. This is true for the winter daytime and summer nighttime conditions considered above.

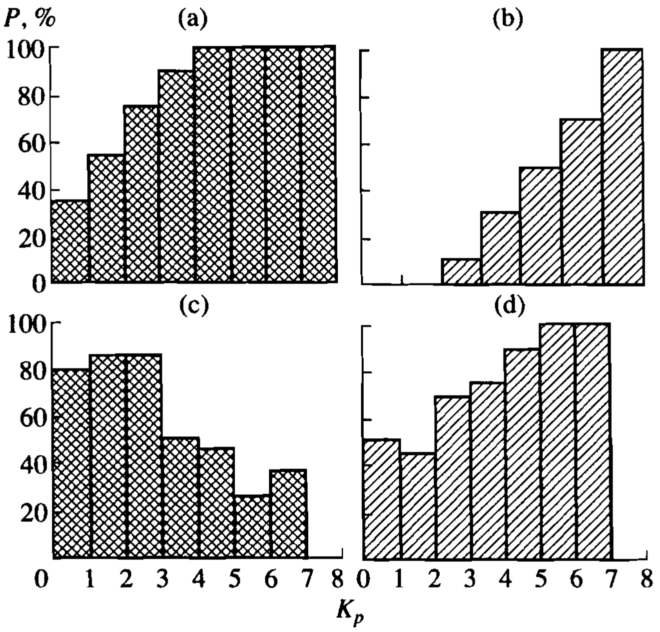

Fig. 7. Dependence of the trough observation probability P on the K_p-index for illuminated longitudinal sectors in the northern and the southern hemisphere (light hatching) and for shadowed longitudinal sectors (dark hatching) in the summer nighttime (a, b) and winter daytime (c, d) conditions.

MAGNETIC-ACTIVITY DEPENDENCE OF THE OBSERVATION PROBABILITY FOR IONOSPHERIC TROUGHS

The dependence of the probability P on the magnetic-activity level has been studied both for separate storms and statistically (see, for example, [1, 6]). The results of these studies are usually represented in a very general form: the trough-formation probability increases with magnetic activity. Let us consider how this rule can be expressed quantitatively for the winter daytime and summer nighttime conditions. As far as the pattern strongly depends on the illumination conditions, we consider separately the longitudes with the deepest shadow and the sunlit longitudes. Figs. 7a and 7b show the dependence of P on the K_p index for the summer nighttime conditions. Totally, 120 cases were considered for shadowed longitudes and 40 cases, for sunlit longitudes of both hemispheres. As seen from Fig. 7a, in the summer nighttime conditions, the trough always appears at the longitudes of the deepest shadow even at $K_p \sim 5$, i.e., during a moderate storm. At the sunlit longitudes (Fig. 7b), a well-pronounced trough appears only for $K_p > 3$ and is always observed only at very strong disturbances. Thus, during a very strong storm, the trough will be always observed even in the local summer conditions. Note, however, that, under the conditions considered, the *Kosmos-900* satellite has recorded only several cases of very strong disturbances; hence, the accuracy of the determination of P decreases with the increase of K_p. A different pattern is observed in the winter daytime conditions, where different troughs are, as a rule, present in different longitudinal sectors. For this reason, Figs. 7c and 7d illustrate separately, as functions of K_p, the occurrence probabilities of the daytime MIT, for the sunlit longitudes in the region of the deepest shadow and in the Muldrew trough in both hemispheres. To this end, 180 and 125 cases were considered, respectively, for the 08–16 MLT interval. Very strong disturbances did not occur in the longitude sectors considered, and the plot is thus limited by the value of $K_p = 7$; its accuracy at the end of the K_p range is poor. In addition, the identification of different troughs in the daytime conditions is even more difficult because, in many cases, the variations of the ionospheric parameters become very complicated as the level of disturbances rises. Thus, even for a sufficiently large set of *Kosmos-900* data, only a tendency in the behavior of daytime troughs proves to be revealed. Nevertheless, it is fairly pronounced: the probability of observation increases with K_p for the Muldrew trough and decreases for the daytime MIT.

Differences in the behavior of the trough in various conditions can simply be explained. In the summer nighttime conditions, with the increase of K_p, the trough moves into the region of a deeper shadow, where the enhanced electric field of magnetospheric convection forms a deeper trough. In the winter daytime conditions, as the equatorial boundary of diffuse auroral precipitations moves toward lower latitudes, the shadow region shrinks and the daytime MIT is gradually filled by ionization. At the same time, the formation probability of the Muldrew trough, which seems to be produced by electric fields and field-aligned currents, increases with the enhancement of both these factors, during a disturbance. Therefore, in the winter daytime conditions, during a strong magnetic storm, the observations will mainly reveal the Muldrew trough.

DISCUSSION OF THE RESULTS

Three different types of troughs may be observed with different probability, in the high-latitude ionosphere under the nighttime and daytime conditions. The high-latitude trough, as evidenced by the data from the *OGO 6* satellite [10], exists in winter within the auroral oval around the clock. The RIT is observed at the latitudes of the residual ring current mainly in the morning hours, during the recovery phase of a storm [7]. However, the observation probability for the MIT in the winter nighttime conditions is very high even without allowances for the RIT, reaching 97–98%. In the daytime (winter) conditions, two troughs (daytime MIT and Muldrew trough) can be observed with an equal probability, but, as a rule, in different longitudinal sectors. In this case, the total observation probability for both troughs (if they are not separated) reaches at the noon an unexpectedly high value of 70–80%. If the daytime troughs are not separated, they will be observed in combination, within a very wide (up to 15° in the morning hours) latitude band, even at a fixed value of K_p. Both these features lead to significant discrepancies between the data of different experiments. The trough observation probability P in the winter daytime and summer nighttime conditions exhibits strong variations, depending on three factors—the level of magnetic activity, the conditions of illumination, and the background density in the trough region. The variations of the background density are determined, in turn, by solar ionization, as well as by the neutral wind and the thermospheric composition. All this leads to diurnal, seasonal, and longitudinal variations in P. The observation probability of the MIT is mainly governed by the competition between the magnetic activity and the solar ionization: P increases with the rise of the disturbance level and decreases with the rise of illumination. Ultimately, in quiet conditions, the summer nighttime MIT is observed only within the shadow and at the minimum of background ionization, whereas it appears even at sunlit longitudes during a strong magnetic storm. On the contrary, the probability of observation of the winter daytime MIT decreases with the increase of magnetic activity, because in this case, the MIT moves to lower latitudes, where the illumination sharply increases. Note that the replacement of the conditions (summer nighttime by winter daytime) and the hemisphere (northern by southern), in fact, results in the mutual replacement of the illuminated and the shadowed longitudinal sector. In addition, in the winter daytime conditions, the Muldrew trough appears at illuminated longitudes. Thus, the picture of the high-latitude ionosphere changes dramatically with the change of the hemisphere (under the same set of geophysical conditions). The asymmetry of the hemispheres manifests itself, in particular, in differences of the characters of variations of the ionospheric-trough position, form, and observation probability with longitude, local time, and season. If "snapshots" of the ionosphere are considered the asymmetry of hemispheres also manifests itself as the UT control of the high-latitude ionosphere. The asymmetry of hemispheres is determined by the difference between the geographic and the geomagnetic pole, by the changes of the magnetic-field parameters (inclination and declination), as well as by the auroral-oval offset with respect to the magnetic pole in the direction of the night sector.

CONCLUSIONS

The detailed analysis of the large uniform set of *Kosmos-900* data makes it possible to perform a comprehensive investigation of the observation probability of different ionospheric troughs under various conditions. Not only are the obtained conclusions in good agreement with the results of other observations, but they also allow one to explain their mutual contradictions. The main result of the present analysis is a fairly comprehensive pattern of the dependence of the ionospheric-trough formation on various factors. Its particular aspects are as follows:

(1) The trough is a steady ($P \sim 90$–95%) characteristic of the winter nighttime subauroral ionosphere. In the winter daytime and summer nighttime conditions, the probability P reduces to ~30% and strongly depends on the illumination conditions. In the summer daytime conditions, there are virtually no observations of a well-defined trough.

(2) In the winter daytime and summer nighttime conditions, the illumination of the high-latitude ionosphere and the level of background ionization are functions of longitude in the geomagnetic coordinate system. Therefore, in the summer nighttime conditions, the trough is observed only in the shadowed region and at the minimum background ionization, whereas in the winter daytime conditions, the daytime MIT is observed in the shadowed region and the Muldrew trough is observed at the illuminated longitudes. At noon, the MIT is observed rarely, while the Muldrew trough is the most frequently observed. Since the observation probabilities for both troughs as functions of local time and longitude are virtually in antiphase, their total probability depends weakly on longitude and time, reaching ~80% in the northern hemisphere at noon. All this governs the UT control of the high-latitude ionosphere, which is associated with a strong asymmetry between the hemispheres. The UT control also manifests itself in longitudinal variations of the position of the trough minimum.

(3) In the summer nighttime conditions, the probability of trough observation increases with the magnetic activity: in the shadowed region, the trough is always present at $K_p \sim 5$, whereas at the illuminated longitudes a well-defined trough starts to appear only at $K_p \sim 4$. In the winter daytime conditions, the probability of the MIT appearance (in the shadowed region) decreases with the increase of magnetic activity, while the probability of observation of the Muldrew trough increases.

(4) The sunrise and sunset clearly divide the winter trough into the nighttime ($P \sim 95\%$) and the daytime ($P \sim 30\%$) trough. After the sunset (at 17–19 LT) and during the morning hours (at 3–5 LT), the probability P exhibits peaks, which may be associated with various reasons.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research, project no. 97-05-64085.

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