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Two Types of Daytime Winter Ionospheric Trough as Revealed by *Kosmos-900* Data at Heights 350–550 km

A. T. Karpachev* and V. V. Afonin**

**Institute of Terrestrial Magnetism, Ionosphere, and Radiowave Propagation, Russian Academy of Sciences, Troitsk, Moscow oblast' 142092, Russia*

***Space Research Institute, Russian Academy of Sciences, Profsoyuznaya ul. 84/32, Moscow, 117810 Russia*

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Abstract—An extensive set of *Kosmos-900* satellite data for heights of 350–550 km is used to study the causes of the large spread in latitude of the ionospheric-trough position under daytime winter conditions. It is shown that two types of trough actually exist at daytime. The daytime main ionospheric trough (MIT) is essentially similar in shape to the nighttime MIT. Since this trough is observed equatorward of the auroral oval normally in the shadow region, it is recorded more rarely in the northern hemisphere and at noon. The second trough has a characteristic shape with a steep equatorial wall and a poorly developed polar wall. It is mainly observed at sunlit longitudes and is therefore recorded more frequently at noon and in the northern hemisphere. The second trough lies at a higher latitude than the first one and is found in the auroral-oval region but equatorward of the cusp at near-noon hours. The daytime MIT results from the decay of ionization in the total-shadow region, where there are no ionization sources throughout the day. The second trough, along with the nighttime MIT, forms in the stagnation region in the evening sector, but apparently in the band of the westward drift, and is supported at daytime by strong electric fields and field-aligned currents.

INTRODUCTION

The main (MIT) or, alternatively, mid-latitude ionospheric trough (MLIT) was actually revealed by *Alouette 1* data as a nighttime phenomenon [1]. In the course of time, it emerged that the trough could also be observed at daytime (see, e.g., [2]). However, only few attempts were made to determine the trough position for all hours of local time [3–6]. This is not accidental and is attributable to certain difficulties involved in interpreting the data, among which are the following: the daytime trough lies at a very high latitude, and it cannot be observed by all methods (see [5, 6]); the daytime trough is less pronounced than the nighttime one [3]; the trough at daytime is observed much more rarely than at nighttime [3, 5]; the scatter of data in latitude at daytime is very large, which may be due to the presence of not one but two troughs [3] and a strong dependence of the positions of auroral structures on solar-wind and IMF parameters [7]. A large scatter of data is also observed for night hours; the mean statistical deviation in latitude is 2°–3°, while the mean trough position for midnight determined in various experiments may differ by 5°–6° (see, e.g., [8, 9]). The spread in the nighttime-trough positions is determined by many factors, and some of them have recently been eliminated. In particular, large variations of the trough position with longitude were distinguished [10], the effective K_p index for determining the trough position which takes into account the delay of trough response to a magnetic disturbance [11, 12] was introduced, an index for determining the trough position during strong storms which is more suitable than K_p (*DR* index) was introduced [13], and the MLIT was separated into the MIT controlled by K_p and the RIT (ring ionospheric trough) associated with the ring magnetospheric current [12]. This all allowed us to sharply decrease the scatter of data (down to 1°–1.3°) and to construct a much more complete and accurate model of the nighttime trough for winter and equinox conditions [12, 14]. The method of data analysis we developed allows a similar study of the causes of the large spread in ionospheric-trough position to be carried out for daytime conditions.

OBSERVATIONAL DATA

In this study, we use direct *Kosmos-900* satellite measurements of N_e and T_e for the period of mean and high solar activity (1977–1979). In this time, the height of the satellite's circular orbit decreased from ~550 to ~350 km due to braking. The data set includes about 3000 satellite passes over the high-latitude ionosphere of both hemispheres. The data cover the entire range of longitudes, all hours of magnetic local time (MLT), the range K_p = 0–8, and refer to winter conditions. The discreteness of the N_e and T_e measurements was so high that the error in the position of the trough minimum is determined only by the data reduction technique and does not exceed 0.5°. Below, the trough position as determined from *Kosmos-900* is compared with data from other experiments in terms of the invariant latitude Φ.

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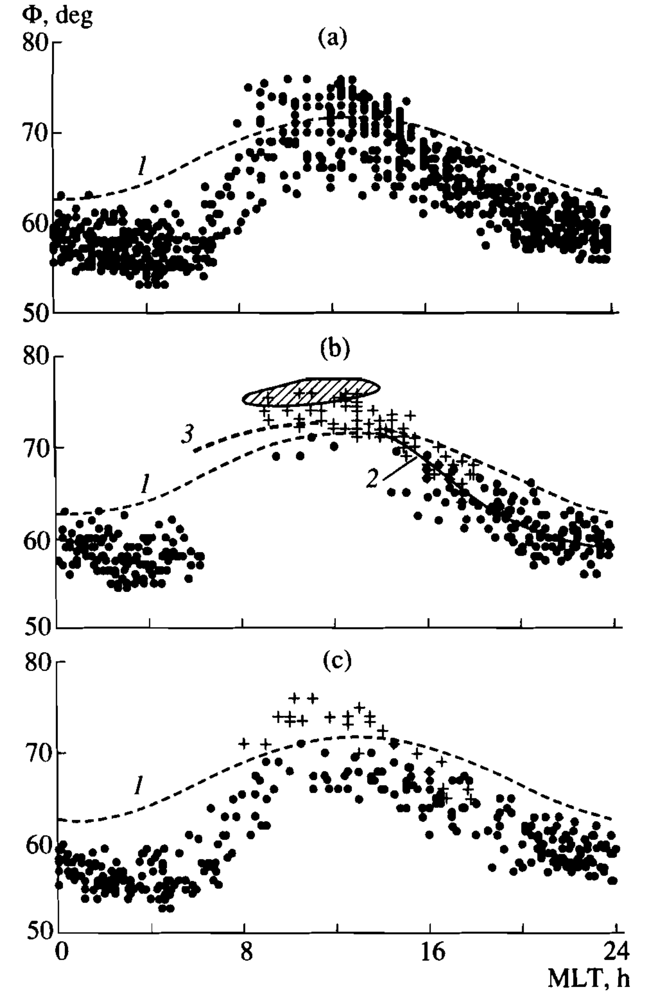

Fig. 1. Variations of the ionospheric-trough positions with magnetic local time for K_p = 2–4 (the mean is K_p = 3): (a) for all longitudes of both hemispheres; (b) only for the most illuminated longitudes; (c) only for the region of the deepest shadow. (*1*) The position of the equatorial boundary of the auroral oval according to the model [20], (*2*) the position of the trough minimum as deduced from *Alouette 1* data in the evening sector [1], (*3*) the position of the maximum of the field-aligned current in the prenoon sector [37]; the crosses in Fig. 1b and Fig. 1c mark the positions of Muldrew's trough. In Fig. 1b, the region of soft-electron precipitations near the cusp [21] is hatched.

As an example, Fig. 1a shows the trough position for quiet-time and weakly disturbed conditions: K_p = 2–4. The data were reduced to the mean K_p = 3 with allowance for a 2.3° shift per unit K_p. (For the remaining intervals of K_p, the pattern is similar.) Note that, since the number of daytime observations (due to the peculiarities of the *Kosmos-900* operation program) and the probability of occurrence of a trough at daytime are smaller than those at nighttime, the nighttime data set is much larger than the daytime one. The ring trough, which was recorded particularly frequently in the range K_p = 2–4 at latitudes 55°–58° Φ [11, 13], was excluded from the nighttime data in Fig. 1a. In this case, the scatter of data at nighttime is therefore 6°–8° (the rms deviation is ~20.0°). The scatter at daytime is almost twice as large and reaches 15° at 8–9 MLT. This scatter cannot be reduced appreciably by substituting B_z or B_zV_s, where V_s is the solar-wind velocity, for the K_p index. This is contrary to our expectations, because the main ionospheric trough is closely associated with the equatorial boundary of the auroral oval, whose position is determined by variations in B_z and V_s with a fairly high correlation coefficient [7]. Thus, it should probably be assumed that there are several structures at daytime, most likely two different troughs attributable to different formation mechanisms.

A detailed analysis of the entire daytime data set does reveal two types of trough. One of them essentially matches in shape the classical nighttime main ionospheric trough, because it is characterized by a steep polar wall, a deep minimum, and a distinct equatorial wall (Fig. 2d). Since this trough is observed mainly in the shadow, it is recorded at noon most rarely. Variations in the probability of occurrence of a trough with local time are shown in Fig. 3 separately for the northern and southern hemispheres. The trough of the first type is always observed several degrees below the equatorial auroral diffuse precipitation boundary (DPB), i.e., equatorward of the auroral oval. As this trough essentially matches the nighttime MIT both in shape and in position (with respect to the auroral oval), we retain for it the established definition—the daytime main ionospheric trough, though it may be caused by other factors than the nighttime MIT.

The other daytime trough differs markedly from the classical MIT both in position and, particularly, in shape. It is characterized by a very steep equatorial wall, a well-defined minimum, and, as a rule, an indistinct polar wall (Figs. 2a, 2b). At evening hours (16–18 MLT), it has the largest depth and is observed at higher latitudes than the MIT, so its minimum at this time is located very close to or even inside the auroral oval (Fig. 2a). By contrast, the trough of the second type is mainly observed at sunlit longitudes and, consequently, is recorded most frequently at noon. It is at this time that the trough assumes its characteristic shape with a well developed equatorial wall and an indistinct polar wall (Fig. 2b). At noon, the trough can be deep inside the auroral oval (Fig. 2b). As one approaches the morning hours, it becomes progressively less developed. Variations in the probability of occurrence of this trough with local time are also shown in Fig. 3. We see that the trough of the second type appears at 17–18 MLT, is observed most frequently at afternoon hours, and disappears in the morning, at 7–8 MLT. It is more frequently observed in the northern hemisphere than in the southern one. For the daytime MIT, an opposite tendency can be noted (Fig. 3): it is recorded much more frequently in the southern hemisphere.

As one passes from evening hours to noon, the two branches of the trough become increasingly separated. Therefore, even at near-noon hours all variants can be observed: the troughs are recorded separately, but they are separated much more strongly in latitude; both troughs (and the corresponding peaks of T_e) are observed simultaneously; the troughs merge into one with a wide bottom, in which, however, two local minima are frequently recorded—near its polar wall and at some distance from it. The last variant is probably shown in Fig. 2d, and the case of observation of both daytime troughs simultaneously is shown in Fig. 2c. This case is realized at transitional longitudes with a shallow shadow, where the equatorial wall of the trough of the second type has not yet been completely destroyed and, consequently, the daytime MIT is not developed. This all will occur only in the region of total shadow, and only a weak minimum near the polar wall (and close to the DPB) will then be left from the trough of the second type (Fig. 2d). Thus, at the longitudes of a deep shadow, the daytime MIT usually masks the second trough, and it is observed rarely. At morning hours, if both troughs are observed simultaneously, they are clearly distinguished because of their even larger separation in latitude than that at noon. However, since the trough of the second type is indistinct in the morning, in the data analysis it is revealed rarely and more likely at transitional longitudes, where it is preserved longer, than at sunlit ones.

For completeness, it should be noted that yet another trough, the so-called high-latitude trough, is commonly observed in the auroral oval closer to its polar edge. It was also detected by the *Alouette 1* satellite and was studied most extensively using *OGO 6* satellite data [15]. It differs from the troughs under consideration by a characteristic, very nonuniform structure even in the region of the equatorial wall, because it is always formed deep inside the auroral oval, in the band of strong precipitations of particles and nonuniform electric fields. The study of the parameters of the high-latitude trough is beyond the scope of this paper; however, we had to distinguish it by using *Kosmos-900* data in order to exclude it from the analysis. Thus, apart from the high-latitude trough, not one but two types of ionospheric trough are observed under daytime winter conditions. Though it was evident from the outset that the structures so widely separated in latitude cannot be associated with the same set of formation mechanisms, a clear idea of the presence of two troughs appeared only after an attempt to combine all data in a single structure failed and the characteristics of both troughs were studied in detail. Note also that in controversial cases (mainly in the evening sector), the trough was classified as belonging to both types.

If the troughs are not distinguished but considered together, then, as we see from Fig. 3, the total probability of occurrence of the trough is at a minimum in the morning; in this case, it decreases to ~50% in the northern hemisphere. In the southern hemisphere, the variations in probability for both troughs are in antiphase, and the total probability of occurrence of the trough without separating it into different types is virtually constant with local time and is very large (~80%) for daytime. This fact is rather unexpected. Thus, the probability of occurrence of the trough at daytime depends markedly on observing conditions: what type of trough is recorded, in which hemisphere, at which longitudes, etc. Therefore, the results of a statistical analysis for daytime may differ markedly (see, e.g., [3, 16]).

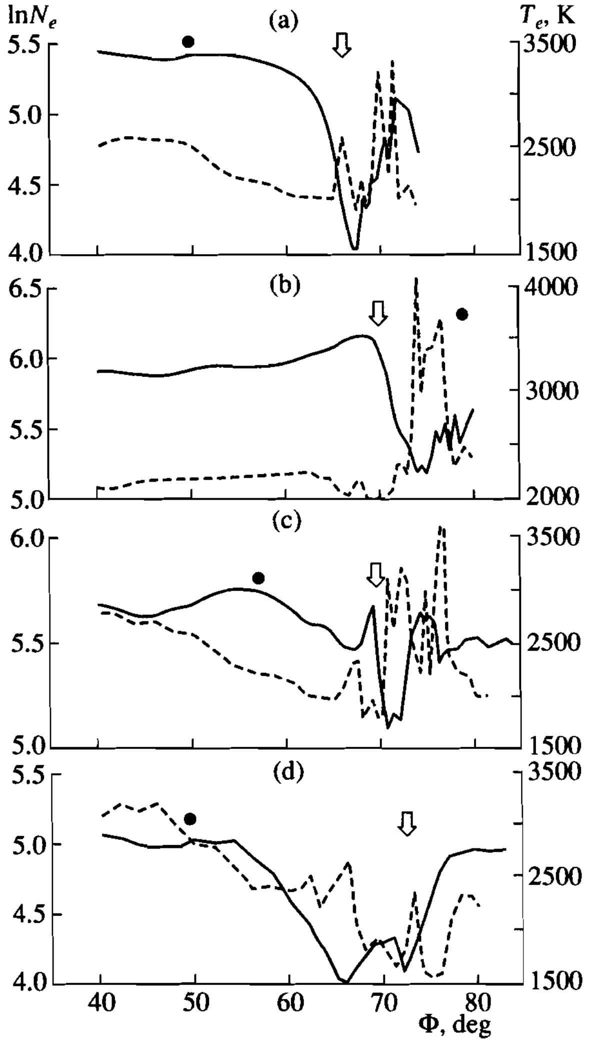

Fig. 2. Variations of N_e (solid curves) and T_e (dashed curves) with invariant latitude as obtained from *Kosmos-900* data under the conditions given in the table (for a latitude of 60°). The terminator location is indicated by circles, and the equatorial boundary of the auroral oval according to the model [20] is indicated by arrows.

DISCUSSION OF RESULTS

Since at daytime one type of trough is observed only in the shadow, while the other is commonly observed at sunlit longitudes, it will be more correct to present

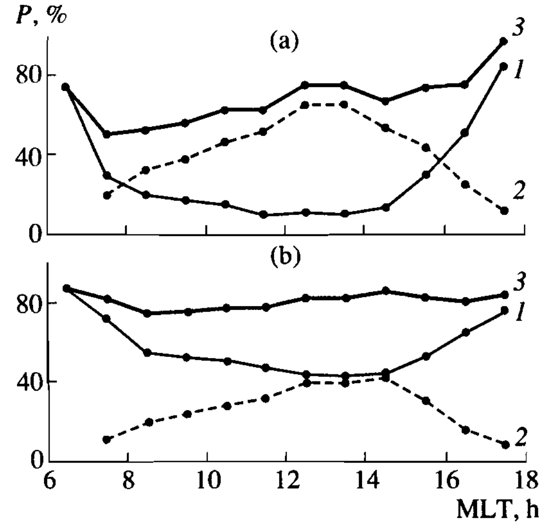

Fig. 3. Variations in the probability (P) of occurrence of ionospheric troughs with magnetic local time in the northern (a) and southern (b) hemispheres: (*1*) the daytime MIT, (*2*) Muldrew's trough, (*3*) the two troughs together.

Fig. 1 in two variants. Figure 1b shows the daytime troughs observed only at the most illuminated longitudes of 210°–330° in the northern hemispheres and 60°–180° in the southern hemisphere. By contrast, Fig. 1c shows the troughs that are observed in the region of the deepest shadow at longitudes of 60°–180° and 240°–360° in the northern and southern hemispheres, respectively. We see from Fig. 1c that at unilluminated longitudes, the daytime and nighttime MIT represent one, continuous (during the day) branch of the trough bounded in latitude by the auroral oval. Figure 1b presents the higher latitude branch of the trough, which begins in the evening sector, goes into the auroral oval at near-noon hours, and is rarely observed in the morning. If we restrict our analysis only to the noon hours, the above fixed longitude sectors also mean fixed intervals of universal time: 14–22 UT and 00–08 UT in the northern and southern hemispheres, respectively, for Fig. 1b and 00–08 UT and 12–20 UT for Fig. 1c, respectively. In other words, there is a UT control of the daytime trough, which was previously discussed theoretically in comparison with ground-based sounding data [17–19].

In Fig. 1, the dashed line indicates the location of the equatorial boundary of the auroral oval obtained for the magnetic activity in question from the model [20]. At nighttime, the precipitations of soft electrons ($E_e <$ 1 keV) near this boundary are known to form the polar wall of the trough. In the dayside oval, the precipitation structure is much more complex, so a well-defined equatorial boundary of the precipitations is observed here only in ~30% of the cases, and the scatter of data is much larger [21]. The precipitation structure at daytime is also more complex, because a band of intense precipitations of soft electrons associated with the dayside cusp is observed at the polar boundary of the oval. The polar peak of N_e [22], the peak of T_e [23], and the abrupt increase in the intensity of the 6300 Å line emission [24] are usually associated with these precipitations. At the ionospheric level, the cusp is normally projected as a latitudinally elongated spot. The size of this spot is ~200–500 km, which is approximately ±2 h of local time (10–14 LT). However, the region of particle precipitations and of the appearance of N_e and T_e peaks, as well as the region of daytime 6300 Å line emission in the F region, are much wider than the cusp projection. As an example, Figure 2b shows the contours of the band of soft-electron precipitations at a level of 30×10^7 electrons/(cm^2 s ster) obtained from satellite data in [21]. The polar peak of N_e associated with the dayside cusp [22] is located in time and latitude in just the same way, and the region of 6300 Å line emission [24] appears in just the same way. As we see from Fig. 1b, the precipitations of soft particles and the related ionization peak are observed on the polar wall of the daytime trough of the second type. Thus, at near-noon hours this trough is associated with the dayside cusp. The observations of a well developed trough equatorward of the dayside cusp, including *Kosmos-900* [25] and *Interkosmos-19* [26] data, have long been known.

Let us compare the trough positions determined from *Kosmos-900* data at upper-ionosphere heights of 350–550 km with the trough positions as deduced from other observations. The first observations of the trough were carried out by Muldrew using the *Alouette 1* satellite over North America [1], i.e., at sunlit longitudes and, consequently, must closely agree with the *Kosmos-900* data in Fig. 1b. Indeed, the solid line which represents *Alouette 1* data in Fig. 1b coincides with the

Data on the *Kosmos-900* turns presented in Fig. 2

Sequential number	Revolution number	Date	UT	MLT	Longitude	K_p index	Hemisphere
a	9663	Dec. 21, 1978	15:33	18.0	15	2–	Northern
b	10098	Jan. 18, 1978	17:11	12.0	290	3°	Northern
c	9781	Dec. 29, 1978	03:14	13.0	180	3–	Northern
d	12607	June 28, 1979	16:24	12.0	290	1–	Southern

position of the nighttime MIT at night hours and determines the mean position of the trough of the second type at afternoon hours for *Kosmos-900*. For brevity, this trough can therefore be called "Muldrew's trough".

The trough position for all days was determined from data of ground-based oblique sounding in Yakutia [4] by the Doppler method using the *Transit* satellites [5, 6] and direct *ISIS 1* and *Injun 5* satellite measurements [3]. However, oblique sounding reveals a sharp gradient in density (the polar wall of the MIT?) north of the Tixie Bay Station ($\Phi = 65°$), and its data are difficult to use for a direct comparison. Transit satellite measurements of the total electron content ($\sim f_0F2$) are restricted by data of the station located at $\Phi = 68°$ and, consequently, allow the position of only the lower latitude trough to be determined. Indeed, the position of the trough minimum determined by this method in [5] for $K_p = 3$ is at $\Phi \sim 69°$ at noon, which is much closer to the mean position of the daytime MIT than to the position of Muldrew's trough in Fig. 1. As for the *ISIS 1* and *Injun 5* satellites, they had orbital inclinations large enough to observe both troughs. And, indeed, two troughs were detected at heights $h > 1500$ km, but no such a separation could be made for smaller heights. Since the position of the top of the trough equatorial wall for $h < 1500$ km was determined from these data for $K_p \le 3$ in terms of LT and L shells, a direct comparison with the trough minimum in Fig. 1 is impossible. To do this, at least approximately, the positions of both structures were matched for midnight hours, because the trough at this time is identified by all methods most clearly. If the trough positions coincide at midnight, then, as one might expect, the trough position determined in [3] for heights below 1500 km at daytime is between the MIT and Muldrew's trough positions obtained from *Kosmos-900* data (at noon for $K_p = 3$ at $\Phi \sim 72°$). This appears to be the mean for the entire set of daytime data. The aforesaid also fully applies to the trough distinguished by the so-called "bite-out" in the diurnal variation of f_0F2 using data of vertical-sounding stations in the afternoon sector [27]. Theoretical studies of the longitude effect (UT control) based on data of ground-based sounding for the IGY period reveal the presence of both troughs in the shadow region and their complete absence at sunlit longitudes [19]. However, the experimental data from [19] are in agreement with the *Kosmos-900* data in Fig. 1. Finally, based on the total-shadow mechanism, Kolesnik *et al.* [17] calculated the position of the daytime MIT, and it coincides with the position of Muldrew's trough obtained for sunlit longitudes (see Fig. 5.18 on page 158). However, there is no contradiction here, because in their calculations the authors used the model of particle precipitations from [21], according to which the trough polar wall is formed by precipitations in the cusp region. As was noted above, the particle precipitations in the dayside oval are irregular in nature; therefore, the polar wall can apparently be formed in a fairly wide range of latitudes. Figure 1c also provides circumstantial evidence for this. This fact introduces additional uncertainties into the picture of the dayside high-latitude ionosphere, and, consequently, a comparison of calculations with experimental data should be made with maximum caution. It should also be remembered that the situation in the cusp region (the pattern of convection and particle precipitation, the distribution of field-aligned currents, and the position of the cusp itself [25, 28]) depends strongly not only on B_z but also on the IMF B_y. Thus, Fig. 1 shows an average situation in the dayside auroral ionosphere, which will apparently change significantly with conditions.

An additional analysis also shows that the positions of the equatorial boundary of auroral structures, such as the boundary of density irregularities and the associated scintillations and F scatterings, behave in a similar way; i.e., under different conditions they coincide alternatively with the low-latitude and high-latitude branches of the trough (see [29]). Thus, the *Kosmos-900* data are in good agreement with other measurements and, moreover, allow some discrepancies between them to be explained.

Let us discuss the possible formation mechanisms of both troughs. Most frequently, even during very quiet periods, the trough is observed in the evening sector (17–18 LT). This is undoubtedly associated with the classical, stagnation trough formation mechanism attributable to convection stagnation in the shadow region [30]. During disturbances (substorms), the effect of rapid drift [31] is added to it, because the probability of occurrence of the trough in the evening sector increases with growing magnetic disturbance. As the Earth rotates, the emerged trough is brought to latitudes $\Phi \sim 62°$–$64°$ in the morning. Next, the situation depends on longitude. At sunlit longitudes, the trough is rapidly filled with solar ionization immediately after sunrise. At unilluminated longitudes, the trough exists for the entire day but at much higher latitudes, which reach 73°–74° Φ at noon under quiet-time conditions. As one might expect, it is observed most rarely at near-noon hours and most frequently at the longitudes of the deepest shadow, which is reached, other things being equal, at longitudes of 240°–360° in the southern hemisphere. The effect of a "total" shadow was studied theoretically in [17–19] for various UT. It was shown that the total shadow, where there are no ionization sources in winter throughout the day, is observed in a crescent-shaped region between the terminator and the DPB; its sizes vary with UT [17]. During winter solstice at noon at the MIT latitude ($\Phi \sim 73°$ for $K_p = 0$), the total shadow is observed at longitudes 320°–0°–230° in the northern hemisphere and 175°–0°–70° in the southern hemisphere, i.e., approximately on 70–75% of the entire length of the 73° Φ parallel. This is because of the difference between the geographic and geomagnetic poles and the different magnetic-field geometry in the northern and southern hemispheres. At the ionospheric height, given the ionization at large (90°–95°) solar zenith angles, the shadow occupies a smaller area; however, there is still a wide range of longitudes in which the effect of solar ionization at daytime is weak, while at nighttime, as a consequence, the flux from the protonosphere that maintains the F region is low. As we see from Fig. 2, the general ionization level in the shadow region is much lower than that at sunlit longitudes. Since the difference between the poles is at a maximum at longitudes close to 290° in the southern hemisphere, the shadow is deepest here. For this reason, the daytime MIT is observed more frequently in the southern hemisphere than in the northern one, and the probability of its occurrence in the region of the deepest shadow of the southern hemisphere reaches ~80% even at noon. Furthermore, the position of the daytime trough, along with that of the nighttime MIT, also depend on longitude. However, a detailed analysis of longitude variations in the daytime-trough characteristics is beyond the scope of this paper and will be performed separately. In the northern hemisphere, the latitudes of the daytime trough are illuminated in a wider range of longitudes than those in the southern one, and probably for this reason the daytime MIT is observed less frequently in it and the trough of the second type is recorded more frequently (Fig. 3). The probability of its occurrence in the northern hemisphere at afternoon hours reaches 60%. As the K_p index increases, the DPB displaces equatorward, the shadow size decreases, and the trough is gradually filled. An analysis of the *Kosmos-900* data shows that, indeed, the probability of occurrence of the daytime MIT decreases with growing magnetic activity. Thus, the trough formed in the evening in the stagnation region exists for the entire night until the morning at latitudes 62°–64° Φ, while the trough formed in the total-shadow region is observed up to latitudes 73°–74° Φ. Thus, in general, these are different troughs, although their formation mechanism is basically the same—the decay of ionization in the absence of its sources.

Several factors are probably responsible for Muldrew's trough. Its occurrence in the evening sector is also associated with stagnation. In this case, the trough minimum is known to be formed not along the stagnation line but slightly poleward, in the band of the westward drift [30, 32]. Therefore, the depleted flux tubes are carried away by this drift at noon. Muldrew's trough appears to be virtually always in the region of auroral particle precipitations. Its polar wall is determined by the polar peak of N_e, which is usually associated with the band of intense precipitations of soft electrons (E_e = 0.2–0.5 keV) from the dayside cusp. The band of these precipitations, the polar peak of N_e, and the irregular structure of the F region are much broader than the ionospheric projection of the dayside cusp and extend to the morning, as shown in Fig. 1b. This may be attributable to particle precipitations not only from the transition layer but also from the dayside boundary layer [33], as well as to the plasma redistribution due to the heating by precipitating particles [34] and under the effect of large-scale convection [35].

The decrease in density at the minimum of Muldrew's trough at near-noon hours is apparently caused by strong electric fields, which are commonly observed in the band of auroral particle precipitations in general and near the equatorial boundary of the cusp in particular [35]. In the prenoon sector, it is also necessary to take into account the field-aligned current. It is shown in [36] that the current flowing into the ionosphere is capable of producing a strong electron-density depletion. The position of the inflowing current for 06–12 LT is indicated in Fig. 1b by the dashed line. Since it is given in [36] for a lower magnetic activity (AE < 100 nT), we introduced an equatorward shift by 5°. As we see from Fig. 1b, for such a shift, the position of the field-aligned current coincides fairly closely with the trough minimum. The presumed formation mechanism suggests that Muldrew's trough must be observed at all longitudes, and not only at sunlit ones. In the shadow at the latitudes of its steep equatorial wall, the ionization apparently decays to form the daytime MIT. Thus, the MIT masks Muldrew's trough, as can be seen in Fig. 2d.

Thus, we determined the sets of characteristics of both daytime troughs by which they can be distinguished from each other. The daytime MIT lies several degrees equatorward of the auroral oval, while the higher latitude Muldrew's trough at near-noon hours is located deep in the auroral oval but equatorward of the cusp. The daytime MIT is observed in the shadow; it is recorded most rarely at noon and more rarely in the northern hemisphere than in the southern one. By contrast, Muldrew's trough is mainly observed at sunlit longitudes, it is recorded most frequently at noon and more frequently in the northern hemisphere than in the southern one. Since the daytime and nighttime MITs are essentially similar in shape and position (with respect to the auroral oval), they form a single branch of the main ionospheric trough at the longitudes of the total shadow. Muldrew's trough is distinguished by its characteristic shape with a very steep equatorial wall and an indistinct polar wall. Since it is indistinct and rarely observed in the morning, the ionospheric troughs are not observed as a single branch throughout the day at sunlit longitudes. Our analysis also shows that the positions of both daytime troughs depend on longitude; for the daytime MIT, this dependence is stronger. The probability of occurrence of the daytime MIT decreases with growing magnetic activity, whereas for Muldrew's trough the tendency is opposite. The daytime MIT is formed in the total-shadow region between the terminator and the DPB, where there are no ionization sources throughout the day. Muldrew's trough is formed in the stagnation region in the evening sector and is brought by the westward drift to the dayside sector, where it is apparently maintained by strong electric fields and field-aligned currents.

CONCLUSION

Thus, the assumption that there are two types of daytime troughs—the dayside MIT and Muldrew's trough—can apparently be considered to be proven. The main parameters of both troughs by which they are distinguished fairly clearly have been identified. These distinctions concern the shape of the troughs, their positions with respect to other structures in the high-latitude ionosphere, the probability of occurrence, and their formation mechanisms. An overall picture of the trough has been constructed for all days. This picture is not only in good agreement with other observations but also allows us to explain some significant contradictions in the relative positions of auroral-ionosphere structures. Our results can serve as a basis for constructing a complete model of the winter ionospheric trough, i.e., the model for all hours of local time. Note, however, that, in contrast to nighttime, this model for daytime is probabilistic in nature.

Our results also suggest that the high-latitude ionosphere of the northern and southern hemispheres is highly asymmetric. The asymmetry manifests itself in a different dependence of the probability of occurrence, configuration, and localization of the troughs on longitude, local and universal time, and magnetic activity. As a result, the distribution of electron density in the winter dayside high-latitude ionosphere of different hemispheres differs markedly for different local and universal times. In other words, the longitude effect and the UT-control of the high-latitude ionosphere are different in different hemispheres.

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REFERENCES

1. Muldrew, D.B., *F* Layer Ionization Troughs Deduced from Alouette Data, *J. Geophys. Res.*, 1965, vol. 70, no. 11, p. 2635.
2. Tulunay, Y.K. and Grebowsky, J.M., Temporal Variations in the Dawn and Dusk Mid-Latitude Trough Positions—Measured (Ariel 3, Ariel 4) and Modelled, *Ann. Geophys.*, 1978, vol. 31, no. 1, p. 29.
3. Ahmed, M., Sagalyn, R.C., Wildman, P.J.L., and Burke, W.J., Topside Ionospheric Trough Morphology: Occurrence Frequency and Diurnal, Seasonal, and Altitude Variations, *J. Geophys. Res.*, 1979, vol. 84, no. 2, p. 489.
4. Filippov, L.D. and Mamrukov, A.P., Studies of the Polar Wall of the Main Ionospheric Trough, *Magnitosfernaya subburya i geofizicheskie yavleniya* (Magnetospheric Substorm and Geophysical Phenomena), Yakutsk, 1980, p. 32.
5. Oksman, J., Apparent Diurnal Movements of the Trough in Total Electron Content (TEC) of the Ionosphere, *Geophysica*, 1982, vol. 19, no. 1, p. 13.
6. Evans, J.V., Holt, J.M., and Wand, R.H., On the Formation of Daytime Troughs in the *F*-Region Within the Plasmasphere, *Geophys. Res. Lett.*, 1983, vol. 10, no. 5, p. 405.
7. Gussenhoven, M.S., Hardy, D.A., and Burke, W.F., DMSP/F2 Electron Observations of Equatorial Boundaries and Their Relationship to Magnetospheric Electric Fields, *J. Geophys. Res.*, 1981, vol. 86, no. 1, p. 768.
8. Rycroft, M.J. and Thomas, J.O., The Magnetospheric Plasmapause and the Electron Density Trough at the *Alouette 1* Orbit, *Planet. Space Sci.*, 1970, vol. 18, no. 1. P. 145.
9. Best, A. and Wagner, C.-U., Morphology and Characteristic Parameters of the Trough, in *The Physical Processes in the Main Ionospheric Trough Region, Proc. KAPG*, Prague, 1983, p. 19.
10. Afonin, V.V., Deminov, M.G., Karpachev, A.T., *et al.*, Longitude Variations in the Position of the Main Ionospheric Trough for Nighttime Winter Conditions as Deduced from *Kosmos-900* and *Interkosmos-19* Data, *Geomagn. Aeron.*, 1992, vol. 32, no. 2, p. 75.
11. Deminov, M.G., Karpachev, A.T., Afonin, V.V., *et al.*, Dynamics of the Mid-Latitude Ionospheric Trough during Storms. 1. A Qualitative Picture, *Geomagn. Aeron.*, 1995, vol. 35, no. 1, p. 73.
12. Annakuliev, S.K., Afonin, V.V., Deminov, M.G., and Karpachev, A.T., An Empirical Formula for the Position of the Main Ionospheric Trough during a Magnetic Storm, *Geomagn. Aeron.*, 1997, vol. 37, no. 3, p. 183.
13. Deminov, M.G., Karpachev, A.T., Annakuliev, S.K., *et al.*, Dynamics of the Ionization Troughs in the Night-Time Subauroral *F*-Region During Geomagnetic Storms, *Adv. Space Res.*, 1996, vol. 17, no. 10, p. 141.
14. Karpachev, A.T., Deminov, M.G., and Afonin, V.V., Model of the Mid-Latitude Ionospheric Trough on the Base of *Kosmos-900* and *Interkosmos-19* Satellites Data, *Adv. Space Res.*, 1996, vol. 18, no. 6, p. 221.
15. Grebowsky, J.M., Taylor, H.A., Lindsay, J.M., Location and Source of Ionospheric High Latitude Troughs, *Planet. Space Sci.*, 1983, vol. 31, no. 1, p. 99.
16. Tulunay, Y. and Sayers, J., Characteristics of the Mid-Latitude Trough as Determined by the Electron Density Experiment on *Ariel III*, *J. Atmos. Terr. Phys.*, 1971, vol. 33, no. 11, p. 1737.
17. Kolesnik, A.G., Golikov, I.A., and Chernyshev, V.I., *Matematicheskie modeli ionosfery* (Mathematical Models of the Ionosphere), Tomsk: MGP Rasko, 1993.
18. Sojka, J.J., Raitt, W.J., Schunk, R.W., *et al.*, Diurnal Variation of the Dayside, Ionospheric, Mid-Latitude Trough in the Southern Hemisphere at 800 km: Model and Measurement Comparison, *Planet. Space Sci.*, 1985, vol. 33, no. 12, p. 1375.
19. Sojka J.J., Schunk, R.W., and Whalen, J.A., The Longitude Dependence of the Dayside *F* Region Trough: A Detailed Model–Observation Comparison, *J. Geophys. Res.*, 1990, vol. 95, no. 9, p. 15275.
20. Holzworth, R.H. and Meng, C.-I., Mathematical Representation of the Auroral Oval, *Geophys. Res. Lett.*, 1975, vol. 2, no. 9, p. 377.
21. Hardy, D.A., Gussenhoven, M.S., and Holeman, E., A Statistical Model of Auroral Electron Precipitation, *J. Geophys. Res.*, 1985, vol. 90, no. 5, p. 4229.

22. Sato, T. and Colin, L., Morphology of Electron Concentration Enhancement at a Height of 1000 Kilometers at Polar Latitudes, *J. Geophys. Res.*, 1969, vol. 74, no. 9, p. 2193.

23. Titheridge, J.E., Ionospheric Heating Beneath the Magnetospheric Cleft, *J. Geophys. Res.*, 1976, vol. 81, no. 19, p. 3221.

24. Pike, C.P., Modelling of the Arctic *F*-Layer, in *Arctic Ionosphere Modelling, Five Related Papers*, Preprint Air Force Cambridge Res. Lab., 1972, p. 29.

25. Afonin, V.V., Besprozvannaya, A.S., Ben'kova, N.P., *et al.*, Influence of the IMF on the Location of the Dayside Cusp, *Issledovaniya subavroral'noi ionosfery* (Studies of the Subauroral Ionosphere), Moscow: IZMIRAN, 1989, p. 36.

26. Deminov, M.G., Karpachev, A.T., Kushnerevskii, Yu.V., and Shmilauer, Ya., Structure of the Subauroral Ionosphere during a Magnetospheric Storm as Inferred from *Interkosmos-19* Data, *Geomagn. Aeron.*, 1985 vol. 25, no. 3, p. 406.

27. Besprozvannaya, A.S., Pirog, O.M., and Shchuka, T.I., Latitude–Temporal Peculiarities of the Afternoon Ionization of the *F*2 Layer as Inferred from Data of a Meridional Chain of Ionospheric Stations, *Geomagn. Aeron.*, 1986, vol. 26, no. 2, p. 320.

28. Sandhold, P.E., IMF Control of Polar Cusp and Cleft Auroras, *Adv. Space Res.*, 1988, vol. 8, no. 9–10, p. 21.

29. Sagalyn, R.C., Smiddy, M., and Ahmed M., High-Latitude Irregularities in the Top Side Ionosphere Based on *ISIS 1* Thermal Ion Probe Data, *J. Geophys. Res.*, 1974, vol. 79, no. 28, p. 4252.

30. Spiro, R.F., Heelis, R.A., and Hanson, W.B., Ion Convection and the Formation of the Mid-Latitude *F*-region Ionization Trough, *J. Geophys. Res.*, 1978, vol. 83, no. 9, p. 4255.

31. Schunk, R.W., Banks, P.M., and Raitt, W., Effects of Electric Fields and Other Processes upon the Nighttime High-Latitude *F*-layer, *J. Geophys. Res.*, 1976, vol. 81, no. 19, p. 3271.

32. Collis, P.N. and Haggstrom, I., Plasma Convection and Auroral Precipitation Processes Associated with the Main Ionospheric Trough at High Latitudes, *J. Atmos. Terr. Phys.*, 1988, vol. 50, no. 3/4, p. 389.

33. Candidi, K., Kroehl, H.W., and Meng, C.-I., Intensity Distribution of Dayside Polar Soft Electron Precipitation and IMF, *Planet. Space Sci.*, 1983, vol. 31, no. 5, p. 489.

34. Whitteker, J.W., The Magnetospheric Cleft–Ionospheric Effects, *J. Geophys. Res.*, 1976, vol. 81, no. 7, p. 1279.

35. Munch, J.W., Brown, H.I., Brinton, H.C., *et al.*, Thermal Electron Densities and Temperatures in the Dayside Cusp Region, *J. Atmos. Terr. Phys.*, 1977, vol. 39, no. 3, p. 699.

36. Deminov, M.G., Kim, V.P., and Hegai, V.V., Effects of Field-Aligned Currents on the Ionospheric Structure, *Geomagn. Aeron.*, 1979, vol. 19, no. 4, p. 743.

37. Iijima, T. and Potemra, T.A., Field-Aligned Currents in the Dayside Cusp Observed by Triad, *J. Geophys. Res.*, 1976, vol. 81, no. 34, p. 5971.