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# TWO BRANCHES OF DAY-TIME WINTER IONOSPHERIC TROUGH ACCORDING TO COSMOS-900 DATA AT F2-LAYER HEIGHTS

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## ABSTRACT

With the large data set of the Cosmos-900 satellite it is shown that in the low-altitude day-time winter ionosphere, besides the high-latitude trough two other troughs are often observed: the "daytime main trough" and the "Muldrew trough". The first trough is observed in the shadow region as a continuation of the nighttime main trough close but equatorwards of the auroral oval. The second trough is observed at sunlit longitudes. Developing in the stagnation region (at 17-18 MLT) it is then transported by the westward drift into the day-time sector of the auroral oval, but equatorwards of the day-side cusp. The variations of their characteristic features are different in the Northern and Southern hemispheres creating an asymmetry of the high-latitude ionospheres. 

## INTRODUCTION

The deep trough in the density of the subauroral ionosphere was revealed by Muldrew (1965) from the Alouette-1 satellite data rather as a night-side phenomenon. Later on, a pronounced trough was found also by day (e.g. Tulunay and Grebowsky, 1978). There were only a few attempts to localize the trough position for all hours of local time (Ahmed *et al.*, 1979, Oksman, 1982, Evans *et al.*, 1983). It seemed to be associated with what follows: 1) it may be difficult to observe the high latitude daytime trough (Oksman, 1982, Evans *et al.*, 1983); 2) the daytime trough is seen less often than the one at night (Ahmed *et al.*, 1979, Oksman, 1982); 3) the location of the day-side auroral structures is strong IMF dependent (Gussenhoven *et al.*, 1981); 4) data reports show large scatter, that is possibly connected to the occurrence of not one, but two troughs (Ahmed *et al.*, 1979). The large data scatter is observed for the night hours also, but we succeeded in its essential reducing. A dependence on the longitude was found by Afonin *et al.*, (1992); the effective $K_p(\tau)$-index for the trough position determination was suggested by Annakuliev *et al.*, (1997); the more adequate, than $K_p$, index for the trough position determination during disturbances, DR-index, was introduced by Deminov *et al.*, (1996); the so-called "ring ionospheric trough", RIT, was separated from the main ionospheric trough, MIT, by the same authors. All this has allowed to construct a more adequate model of the nighttime trough (Karpachev *et al.*, 1996, Annakuliev *et al.*, 1997). The present work is an attempt of similar analysis for the daytime winter conditions.

## EXPERIMENTAL DATA

The work is based on the in-situ measurements of $N_e$ and $T_e$, obtained onboard of the Cosmos-900 satellite for middle and high solar activity (1977-1979 years) while the orbit decreases from ~ 550 km to ~ 350 km. The data set includes more than 3000 satellite passes through the winter high-latitude ionosphere covering all longitudes and hours of local magnetic time, MLT, in both hemispheres, with $K_p$-index ranging from 0 to 8.

Typical latitudinal variations of $N_e$ and $T_e$ for the daytime winter conditions are shown in Figure 1. Figure 1a presents the simultaneous observations of two troughs in the shadow region. The main ionospheric trough, MIT position is located at invariant latitude, $\Lambda$~72°. $T_e$ peak coincides usually with the trough minimum. The bottom of the poleward wall of the MIT lies near the equatorward edge of the auroral oval. The second trough at ~81° in Figure 1a is the high-latitude trough, HLT. It was most extensively studied with OGO-6 data (e.g. Grebowsky *et al.*, 1983). HLT was usually observed close to the poleward border of the auroral oval, by day and night. HLT shows complex structures not only at its poleward wall but also at the equatorward one. The HLT positions obtained with Cosmos-900 data for $K_p$ = 2-4 are presented by the squares in Figure 2a. For the comparison the HLT position averaged for the similar conditions with large OGO-6 data set is shown by the solid line. As it is evident from Figure 2a, OGO-6 HLT position is indeed located close to the poleward border of the auroral oval for the all hours of local time excluding the evening sector. The same feature appears in Cosmos-900 data too. All this needs further study.

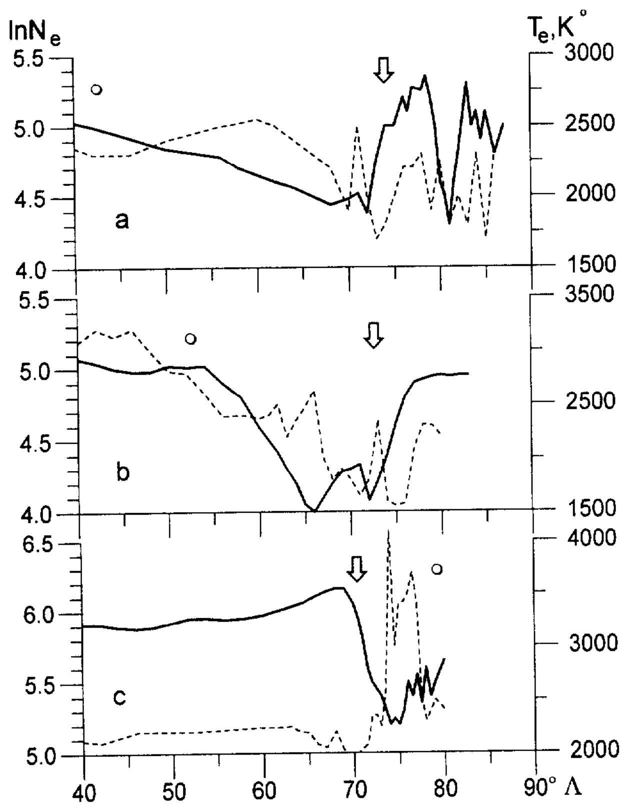


Figure.1. Ne (solid lines) and Te (dashed lines) versus invariant latitude from the Cosmos-900 data:
(a) 12/12/78, ~03:45UT, 16MLT, 180°λ, Kp=0, (NH)
(b) 06/28/78, ~16:20UT, 12MLT, 220°λ, Kp=1-, (SH)
(c) 01/18/79, ~17:10UT, 12.5MLT, 300°λ, Kp=3, (NH)
The terminator position is shown by a circle, that of the equatorial edge of the auroral oval (Holzworth and Meng, 1975) by an arrow.

Figure 2b shows the locations of the residual troughs after the HLT and RIT separation. It is seen on Figure 1b that by night the data scatter is not more than 6-7°, it is almost doubled by day. Since the daytime trough location is connected with auroral structures depending on $B_z$ IMF or the solar wind velocity $V_s$ we also tried to select after the product $B_zV_s$ without obtaining an improvement. The further analysis showed that the daytime troughs reveal very different features. Thus, it is reasonable to assume that in the daytime two troughs do exist (besides the HLT).

The second type of the trough is also observed by day and night, but in contrast to HLT, it is located near, but always equatorwards of auroral oval. By day it has the same shape as the nighttime MIT and is characterized by a steep poleward wall, a deep minimum and a well shaped equatorward wall. We shall therefore keep the traditional designation "daytime MIT". It is observed, mainly, at non-sunlit longitudes in both hemispheres where it may persist even in the noon-time (Figure 1b). Its occurrence probability ***P*** (averaged over all longitudes) is shown in Figure 3 versus local time. The daytime MIT is less often revealed in afternoon and in the Northern hemisphere (Figure 3b) than in the Southern one (Figure 3d). One more daytime trough by the position and especially by the shape differs from the considered above HLT and MIT. It is characterized by a very steep equatorward wall, a deep minimum and, as a rule, a poorly formed poleward wall. This shape is particularly well seen near noon, Figure 1c. In contrast to the daytime MIT the third trough is observed mainly at sunlit longitudes, its occurrence probability reaches maximum in the afternoon and is higher in the Northern hemisphere (Figure 3a), than in the Southern one (Figure 3c). In the evening this trough has the greatest depth and is located very close to the auroral oval, i.e. at higher latitudes than the MIT. The lower is the trough minimum latitude, the more resembles this trough the MIT and around 17-18 MLT it practically merges with MIT. Near noon this trough is usually situated inside the auroral oval, Fig1.c. At this time it sharply differs from the daytime MIT by position and from HLT by shape. It is less pronounced in the morning and disappears around 7 to 8 MLT.

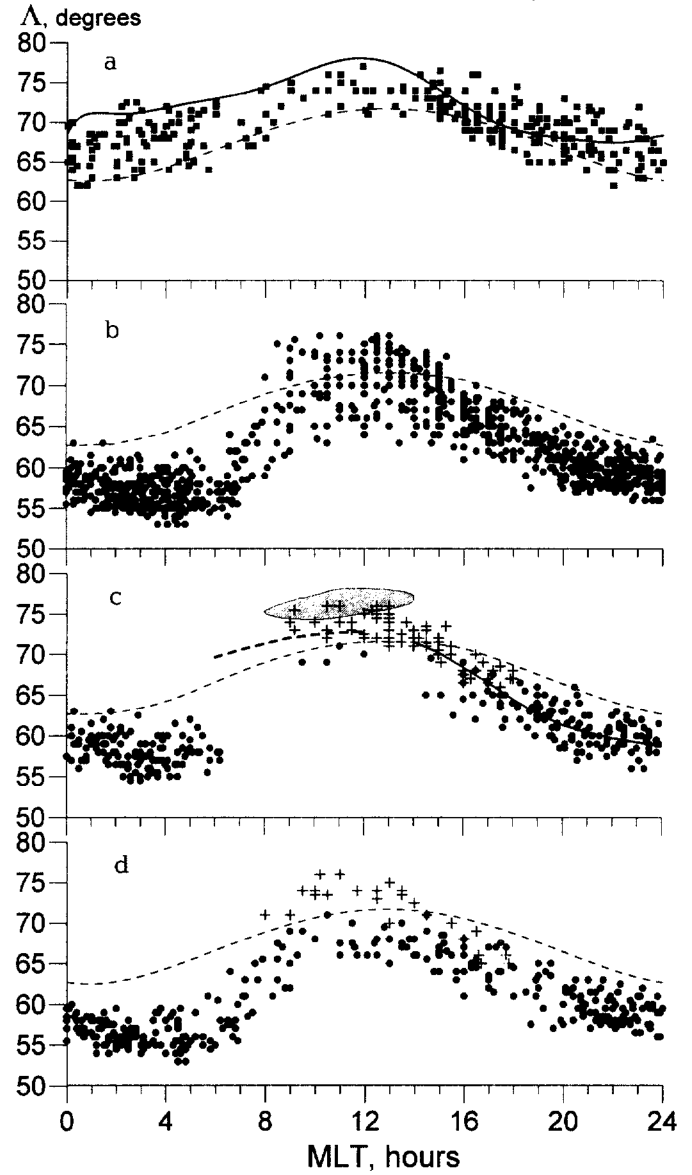


Figure.2. Locations of the minimum of the trough versus MLT: (a) the high-latitude trough, HLT; (b) all troughs without HLT and RIT for all longitudes of both hemispheres, (c) the main ionospheric trough, MIT (dots) and Muldrew trough (crosses) at the most sunlit longitudes (210-330° in the Northern hemisphere and 60-180° in the Southern one), (d) the same at the longitudes of "full shadow" (60-180° in the Northern hemisphere and 240-360° in the Southern one). The equatorward boundary of the auroral oval (Holzworth and Meng, 1975) is dashed line. In Figure 2a the HLT location averaged with OGO-6 data (Grebowsky *et al.*, 1983) is shown as a solid line. In Figure 2c the location of the trough obtained by Muldrew (1965) in the evening sector is shown as a solid line, the position of the field-aligned current maximum in the pre-noon sector (Iijima and Potemra, 1976) as a bold dashed line. The region of the soft precipitation from the cusp (Hardy et al., 1985) is hatched. All data refer for Kp = 3.

## DISCUSSION OF RESULTS

Since by day one trough is located in the shadow region, and the other one at the sunlit longitudes, it may be helpful to separate Figure 2b after clear sunlit (Figure 2c) or shadow conditions (Figure 2d). It is evident from Figure 2d that the daytime and the nighttime MIT form one, continuous feature at all times of the day, limited at the latitudes of the auroral oval. The other trough in the shadow region is masked usually by the well developed day-time MIT and can be observed rather as a second, more poleward and less deep $N_e$ minimum (Figure 1b). At sunlit longitudes (Figure2c) this trough forms a separate branch, which extends from ~ 09 MLT to the evening sector. Considering only noon hours the fixed in Figure 2 longitudinal sectors are equivalent with UT intervals of 14-22 and 00-08 UT for Figure2c and 00-08 and 12-20 UT for Figure2d in the Northern and Southern hemispheres correspondingly. Thus, a strong UT-control takes place in the daytime high-latitude ionospheres.

Let us compare the trough position obtained from the Cosmos-900 data with other observations. The ionospheric trough was revealed by Muldrew, (1965) from Alouette-1 data at longitudes of Northern America, i.e. at the sunlit longitudes in the afternoon and consequently should well coincide with Cosmos-900 data in Figure 2c. As seen from Figure 2c, the solid curve representing the Alouette-1 data at the night-time hours does coincide with the position of the nighttime MIT while in the afternoon it is located near the average position of the third type of the day-side trough. So, for brevity we call it "Muldrew trough".

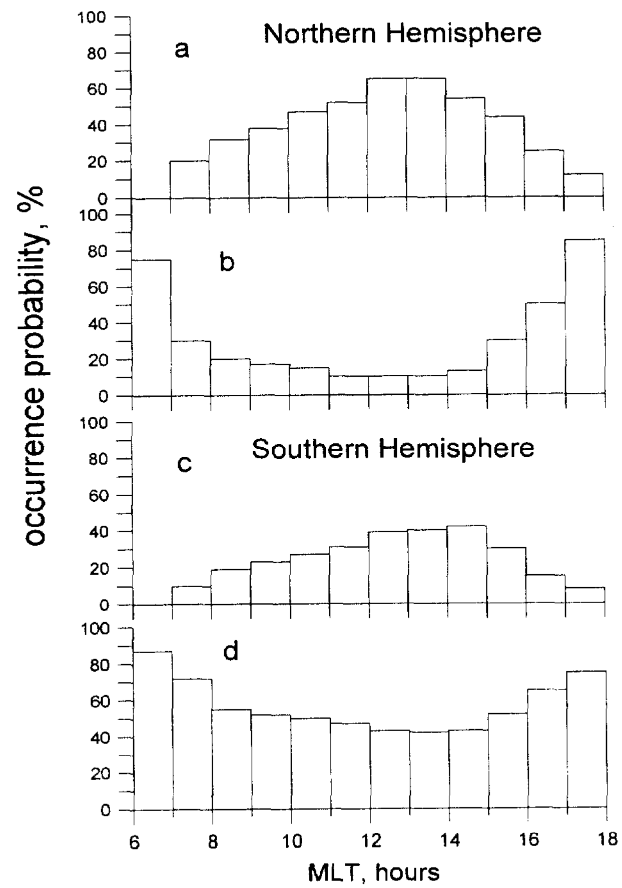


Figure 3. Variations of the occurrence probability of the Muldrew trough (a,c) and the day-time main ionospheric trough (b,d) for all longitudes in Northern hemisphere (a,b) and Southern one (c,d) for quiet winter conditions versus MLT.

The trough positions for all local times were derived from TEC measurements using the Transit satellites (Oksman, 1982, Evans *et al.*, 1983) and from the in-situ $N_e$ measurements onboard the ISIS-1 and Injun-5 satellites (Ahmed *et al.*, 1979). However the measurements of TEC (~ $N_mF2$) were limited in latitude by the locations of the observatories on the ground (≤68°) and as result the trough minimum position obtained by Oksman, (1982) for $K_p$=3 at noon is equal to ~ 69°, closer to the daytime MIT, than to the Muldrew trough. Due the high inclinations of ISIS-1 and Injun-5 orbits both troughs could be observed at the heights above 1500 km. No separation was however possible at lower altitudes so that an average position was determined at noon for $K_p$=3 near by 72°, i.e. between the daytime MIT and the Muldrew trough. Thus, the Cosmos-900 data are in good agreement with the data of other measurements and, moreover, allow to explain some discrepancies between them.

By night, soft ($E_e$ < 1 keV) particle precipitation forms the poleward wall of the MIT. At the day-side of the auroral oval the precipitation pattern is much more complicated, such that a clear equatorward boundary is not always existing. Besides, at the poleward boundary of the oval a zone of the intense soft electron precipitation connected with the day-side cusp is observed. These precipitations coincide with the polar peak of $N_e$ (Sato and Colin, 1969). At the ionospheric level the day-side cusp is usually represented as a zonally stretched spot with sizes of 500x200 km, corresponding to 10-14 MLT. However the precipitation region and the associated $N_e$ maximum are much wider than this spot. For example, in Figure 2c an isoline identifying a precipitation intensity of $3 \cdot 10^8$ el/sm$^2$ ·s·ster is shown, taken from the model of Hardy *et al.*, (1985). It is seen from Figure 2c that the precipitation zone (and $N_e$ peak) coincides with the poleward wall of the Muldrew trough. Thus, near noon the trough is connected with the day-side cusp. It is wknown that it frequently appears equatorwards of the cusp, in particular according to the Cosmos-900 data too (Besprozvannaya *et al.*, 1986).

So, the daytime troughs features are identified. The occurrence probability, the shape, and the position of the troughs depend on latitude, longitude, MLT, UT and $K_p$. (The analysis shows that the occurrence probability of the daytime MIT decreases with increasing $K_p$ while for the Muldrew trough the inverse tendency is observed.) With the above revealed characteristics the different types of daytime troughs can be identified.

Let us discuss how two troughs might be formed. The MIT is associated with the convection stagnation at 17-19 MLT (Spiro *et al.*, 1978). The developed trough is transported by the Earth's rotation into the morning sector at latitudes 63-65°. The situation further depends on the longitude. At sunlit longitudes the trough is quickly filled by the solar ionization immediately after sunrise. At non-sunlit longitudes the trough is observed during all times of the day at latitudes reaching from 72 to 74° at noon. The dependence of the trough formation on the solar illumination was investigated theoretically by Kolesnik and Golikov, (1983), Sojka *et al.*, (1985), Sojka *et al.*, (1990). It was shown that the region of "full shadow", where there are no ionization sources during the entire day is enclosed between the terminator and the equatorward border of the diffuse auroral precipitation (Kolesnik and Golikov, 1983). The size of the full shadow region varies with UT. Under winter conditions, at noon, at latitude of the daytime MIT (~ 73° for Kp=0) the full shadow is observed at longitudes from 40°W to 230°E in the Northern hemisphere and from 180°W to 70°E in the Southern one. It is connected with the displacement between the geographic and geomagnetic poles and the different geometry of the geomagnetic field in the Northern and Southern hemispheres. The difference between the poles is maximum at the longitudes near 290° in the Southern hemisphere, therefore there the shadow is deepest and consequently the daytime MIT occurs there in 80% of all cases. With increasing $K_p$ the precipitation boundary is shifted to the equator, the shadow region decreases and the trough disappears gradually. Therefore the occurrence probability of the daytime MIT decreases with increasing magnetic activity distinct from the behaviour of the nighttime MIT.

The Muldrew trough, apparently, is formed by more than one mechanism. Its occurrence in the evening sector is also connected with the stagnation effect. It is known that the trough minimum is formed not along the line of stagnation, but more polewards, inside the westward drift belt (Spiro *et al.*, 1978, Collis and Haggstrom, 1988). The depleted ionization is transported by this drift to the day sector. Solar illumination tends to decrease the depth but even at noon the trough is not completely filled-up. It is connected, apparently, to the action of the electric fields, which are frequently observed close to the equatorward boundary of the dayside cusp (Munch *et al.*, 1977). In the pre-noon sector it is necessary also to take into account the effect of the field-aligned currents. It was shown, that the current flowing into the ionosphere is capable to cause very deep decrease of the ionization (Deminov et al., 1979). The position of the field-aligned current maximum for 06-12 LT taken by Iijima and Potemra (1976) is shown in Figure 2c by the dashed line. As it is obtained for the lower magnetic activity (AE < 100 nT), the shift by ~5° to the equator is added for the agreement with Cosmos-900 condition (Kp=3). By such shift the current maximum position coincides practically with the trough minimum. The poleward wall of the Muldrew trough is connected to the intense soft electron precipitation in the cusp region.

## CONCLUSION

Apart from the HLT trough our analysis has shown two more trough types to be present in the winter daytime ionosphere: the daytime MIT and the more high-latitude Muldrew trough. Detail features like position, shape, occurrence probability and formation mechanism depend on longitude, local time, UT, and magnetic activity. Hemispheric differences cause strong asymmetry of the phenomena. The obtained results allow to build up a model of the winter trough for all hours of local time.

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