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The ionospheric trough dynamics in the northern and southern hemispheres: the longitudinal and IMF effect

V. V. Afonin,* N. P. Benkova,† A. S. Besprozvannaya,‡ T. I. Shchuka,‡
E. K. Zikrach,§ and L. V. Shestakova§

*The Institute of Space Research, Moscow, Russia
†The Institute of Geomagnetism, Ionosphere and Radiowave Propagation, Troitsk, Moscow region, Russia
‡The Arctic and Antarctic Research Institute, St. Petersburg, Russia
§The Institute of Cosmophysics and Aeronomy of the Siberian Division of the Russian Academy of Sciences, Yakutsk, Russia

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Abstract—A study was made of the dynamics of the main ionospheric trough in the northern and southern hemispheres using data of ion density winter measurements on the Kosmos-900 satellite from 1977 to 1979. Significant longitudinal variations of the trough position have been found which prove to be different in the different hemispheres: in the northern hemisphere they have the shape of a double wave (period 180° longitude) with an amplitude of 4–6° of latitude by both day and night whereas, in the southern hemisphere, they exhibit a simple wave (period 360° longitude) with amplitude of about 6° in the night hours and 10–12° of latitude in the day hours.

The analysis of the IMF influence on the trough position by day and night has shown both B_Z and B_Y to affect the shift of the ionospheric trough. It has been found that in the northern hemisphere the vertical and azimuthal IMF components act in opposite phase while in the southern hemisphere the effects of the two components are added. Analytic relationships between the trough shift magnitude and the values of B_Z and B_Y are discussed.

1. INTRODUCTION

The ionization troughs in the subauroral ionosphere were first found by the analysis of satellite data of topside sounding of ionosphere (Muldrew, 1965). The extensive studies of the features of the main ionospheric trough and of the conditions of its formation made it possible to determine the dependence of its position on time of day, season and the level of geomagnetic activity (Moffet and Quegan, 1983; Best and Wagner, 1983). In some cases, however, the comparison of data on specific trough positions with statistical dependences indicates the presence of significant deviations of experimental values of the trough latitude from the model values. This has been found to be possibly due to longitudinal and IMF effects on the trough position (Deminov and Karpachev, 1986a,b; Afonin *et al.*, 1989; Benkova *et al.*, 1989) which were not accounted for in the widely used analytic dependences such as those of Kohnlein and Raitt (1977), Spiro (1978) and others.

To investigate the nature of the influence of these effects on the trough position in more detail, the present study uses a great number of latitudinal profiles of electron concentration obtained with the Kosmos-900 satellite in the northern and southern hemispheres. The results of the investigation have revealed significant differences in the longitudinal variations of the trough position in the northern and southern hemispheres, both in phase and amplitude. The character of the IMF influence on the trough latitude in both hemispheres depends essentially on the relationship between the signs of the vertical and azimuthal IMF components.

2. EXPERIMENTAL DATA CHARACTERISTICS

Table 1 gives the list of observation periods on the Kosmos-900 satellite used in the study. The satellite Kosmos-900 was launched in March 1977 with an inclination of 83° into a near-circular orbit at an altitude of some 500 km. The orbital period is about 95 min. The positive ion concentration was measured by a three-electrode spherical trap with 'floating' potential. The use of the universal data processing system suggested in the work of Afonin and Kornacheva (1989) permitted us to select latitudinal profiles with ionization troughs at invariant latitudes below 72°.

Winter conditions only have been considered—the December and June solstices for the northern and southern hemispheres, respectively. The absence of cyclic variations in the trough position (Miller, 1970) allowed us to use all the available satellite obser-

Table 1. Experimental data

Satellite	Measured parameter	Observational period	The number of turns: Northern hemisphere 18–06 LT	Northern hemisphere 12–17 LT	Southern hemisphere 12–17 LT
Allouet.-1	*foF*2	XI.67–II.68	58	—	—
Kosmos-900	Nc (H_{max} 500 km)	X.77–II.78 X.78–II.79 VI.79	146	96	44
IX 19	*foF*2	X.80–III.81 II–III.82	57	—	—

vations without accounting for the level of solar activity.

The data analysis employed the technique described by Afonin *et al.* (1989). Instead of an absolute latitude scale, the authors used the latitudinal difference between the satellite observed position of minimum electron density with latitude and the model position. Since the trough configuration is different at different hours of the day, two models were used for day and nighttime conditions. In the nighttime sector, this was the Kohnlein and Raitt (1977) model determining invariant (magnetic) latitude of the trough minimum in degrees:

$$\Phi_L = 65.2 - 2.1K_p - 0.5t \quad (1)$$

where t is the time in hours from midnight. In the daytime a model of Besprozvannaya and Shchuka (1985) was used which determines the invariant latitude of the trough equatorial boundary coinciding with that of magnetospheric convection:

$$\Phi_L = 75.5 - 1.9K_p - (1.8 + 0.25K_p)(T - 14) \quad (2)$$

where T is local geomagnetic time.

Using the $\Delta\Phi_L$ difference has allowed us to eliminate the dependence of the trough minimum position of magnetic activity and time of day, since, as is seen from equations (1) and (2), both these parameters have been taken into account in the models used. The difference between the satellite and the model values in this case is determined by a number of other factors. It is shown below that of great significance are the longitudinal variations of the trough position and variations of the IMF parameters.

3. ANALYSIS AND DISCUSSION

The longitudinal effect

Figure 1 gives the $\Delta\Phi_L$ values for the nighttime sector of geomagnetic time in the northern and southern hemispheres against longitude. The upper and lower envelopes limit the range of observed $\Delta\Phi_L$ values. Along with a general rather large scatter of points at each longitude, certain longitudinal variations of $\Delta\Phi_L$ can be traced by the upper and lower envelopes. In the northern hemisphere the longitudinal dependence has the shape of a double wave, with the main maximum at 240–320°E and minimum at 140–200°E and a less pronounced maximum and minimum at 40–120°E and 340–20°E, respectively. The amplitude of the longitudinal variation is greater for the upper envelope than for the lower one. This is

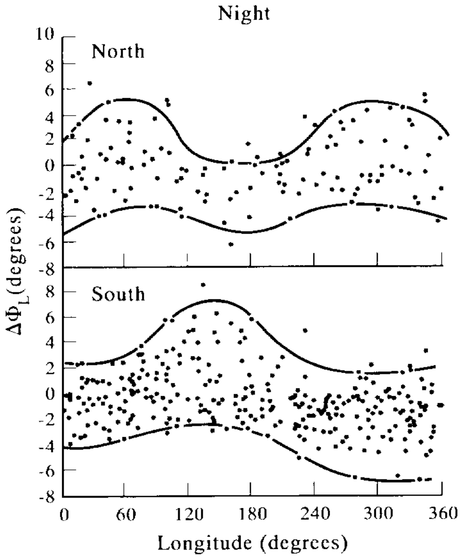

Fig. 1. The trough latitude departures ($\Delta\Phi'$) from model values vs geographical longitude using data from the satellite Kosmos-900 in the northern and southern hemispheres, local winter, nighttime sector MLT (2000–0400). The solid lines are the upper and lower bounding curves.

an indication of the weakening of the longitudinal dependence with the shift of the trough to lower latitudes.

The longitudinal variations of the trough position in the nighttime sector observed in Fig. 1 are in good agreement with the results of the works obtained by the data of several orbits of the IK-19 satellite (Deminov and Karpachev, 1986) and the rich statistical material of the IK-19 and Kosmos-900 satellites (Afonin *et al.*, 1992).

Figure 2 shows the dependence of $\Delta\Phi_L$ on longitude for the daytime sector in both hemispheres. The number of daytime troughs is known to be far less than that of the nighttime troughs (Ahmed *et al.*, 1979). Therefore, the total number of points in Fig. 2 is less than in Fig. 1. Besides, the features of the Kosmos-900 orbit turned out to be such that at a number of longitudes in both hemispheres there are no data with daytime troughs. In the southern hemisphere these longitudes are 300–100°E and in the northern hemisphere about 315–360°E. Nevertheless, the upper and the lower envelope curves show a distinct longitudinal effect in the trough position.

As the comparison of Figs 1 and 2 shows, the character of the longitudinal variations in the northern hemisphere remains practically unchanged during the transition from night to day. In the southern hemisphere, with the phase of the longitudinal variations intact, there is a sharp increase in amplitude when it can amount to 10–12° of latitude; this is comparable to the variations of the trough position during the day.

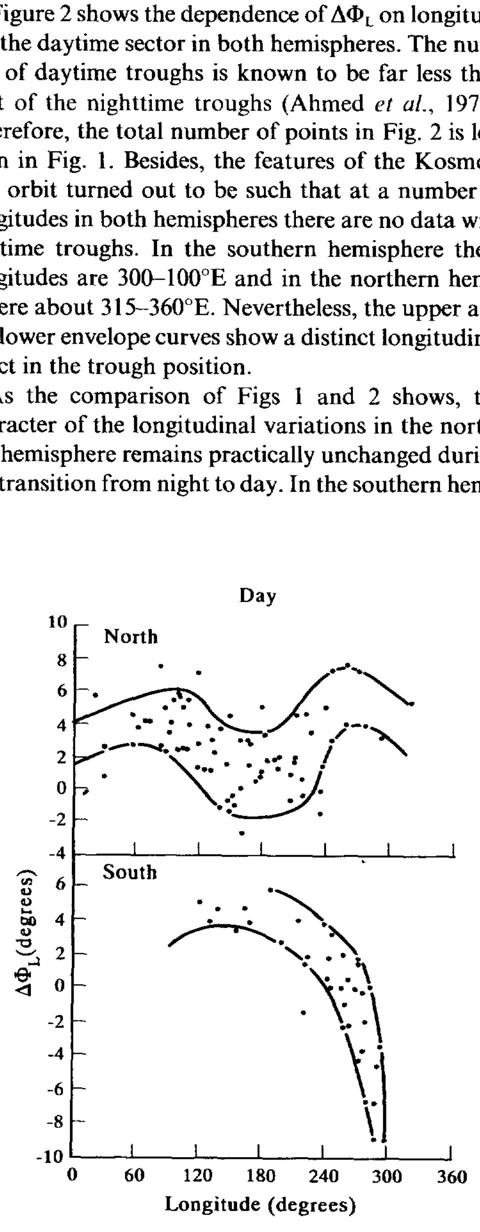

Fig. 2. As Fig. 1, but for the daytime sector MLT (1200–1700).

Deminov and Karpachev (1986a,b) have shown that the longitudinal effect in the main ionospheric trough position is not explicable just by the known UT control in the ionospheric plasma distribution. To begin with, the principal mode of UT control is the same in both northern and southern hemispheres, with the diurnal period over universal time (Sojka *et al.*, 1979; Sojka and Schunk, 1989). Besides, during nighttime the effect bears a rather weak influence on the latitudinal variations of ion concentration (Krinberg and Tashchilin, 1984). The longitudinal effect as is seen from Figs 1 and 2, has a different character in the different hemispheres: in the northern hemisphere a half-day wave is observed, while in the southern hemisphere there is a whole-day wave which is observed during both day and night hours.

This allowed Deminov and Karpachev to conclude that there is an essential influence on the formation of the longitudinal variations of the trough position on those parts of the magnetic field parameters (inclination, declination) which change with longitude and so determine the nature of the interaction between the neutral wind and the ionospheric plasma.

Indeed, as in variations of the magnetic declination, during both day and night we observe the half-day mode of the trough position in the northern hemisphere and the whole-day mode in the southern hemisphere. However, with the unchanged shape of the longitudinal variation of the trough position, one's attention is drawn to the significant difference of amplitudes for the daytime sector in the different hemispheres: in the northern hemisphere it is about 4–6° while in the southern hemisphere it is not less than 10–12° of latitude. This is possibly connected with the fact that in the southern hemisphere during daytime hours the longitudinal effect can be considerably stronger due to the UT control because of the substantially greater difference in the positions of the geomagnetic and geographic poles as compared to the northern hemisphere.

4. IMF INFLUENCE

Investigating the IMF components' influence on the trough position the authors used a whole array of data; only satellite orbits at the longitudes 271–300° in the southern hemisphere during day hours, when one observes a sharp shift of the trough towards the equator under the impact of the longitudinal effect, were excluded [Fig. 2(b)]. The effect in the area is of such magnitude, that using $\Delta\Phi_L$ values at these longitudes in the general data array would lead to significant distortion of the IMF effect on the trough position in the southern hemisphere.

Use has been made of the hourly mean values (in nT) of B_Z and B_Y from the King catalogue (King, 1983) following the accepted practice. If the time of the flight happened to be in the first half of an hour, the data were used with a one-hour lag and, if in the second half, the data for the given hour were taken.

The results of the work (Benkova *et al.*, 1989) have shown the dependence of the trough position on the IMF to be of a rather complicated character. It has been found that in the northern hemisphere for both night and day the trough position dependence on the value of the vertical component (B_Z) is distinctly revealed with $B_Y < 0$, and is non-existent with $B_Y > 0$. Our analysis has shown that in the southern hemisphere a reverse regularity is observed.

Figure 3 presents the $\Delta\Phi_L$ variations against the Z (vertical) IMF component for the day and night sectors of local geomagnetic time. To construct the dependences, values with negative azimuthal component were used for the northern hemisphere and with positive component for the southern hemisphere.

As seen from the figure, the trough position variations against vertical IMF component are the same in the northern and southern hemispheres and can be described by a common regression equation. For the nighttime, this has the form

$$\Delta\Phi_L = 0.83B_Z+0.60 \quad r = 0.78\pm0.04 \qquad (3)$$

and for the daytime

$$\Delta\Phi_L = 0.84B_Z+1.87 \quad r = 0.73\pm0.06. \qquad (4)$$

Comparison of the two regression equations for day and night shows that, starting with noon to the early morning, the trough clearly changes its position under the influence of B_Z. The difference in the value of $\Delta\Phi_L$ at $B_Z = 0$ is due to the fact that at night the position of the trough minimum was taken [equation (1)] while by day that of its equatorial boundary [equation (2)] was taken, i.e. this gives the average difference, in degrees, between the positions of the two trough characteristics. Figures 4 and 5 present graphs of $\Delta\Phi_L$ against azimuthal IMF component for the night and day hours of each hemisphere separately. Since the influence of B_Y is most noticeable with the northern direction of the IMF (Troshichev, 1982), the relationships given were constructed for the conditions $B_Z > 0$ only. The parameters of the corresponding regression equations are given in Table 2.

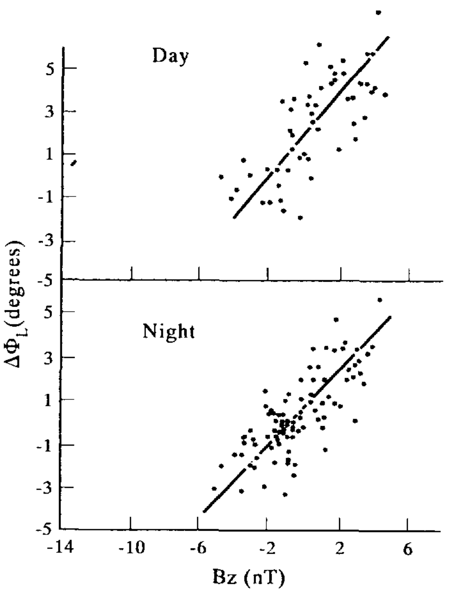

Fig. 3. Dependence of $\Delta\Phi'$ for the northern ($B_Y < 0$) and southern ($B_Y > 0$) hemispheres for the daytime and night sectors.

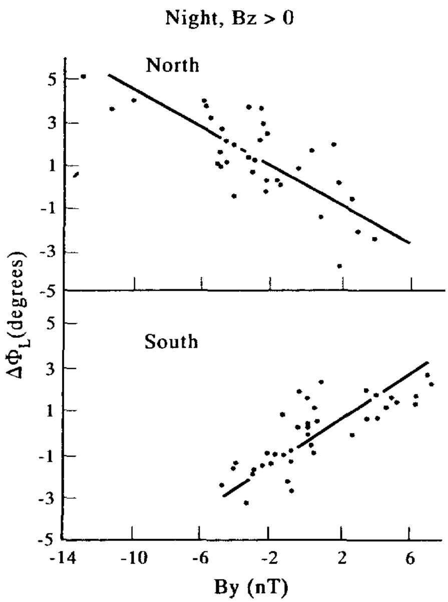

Fig. 4. IMF B_Y control of $\Delta\Phi'$ at $B_Z > 0$ for the daytime sector of the northern and southern hemispheres.

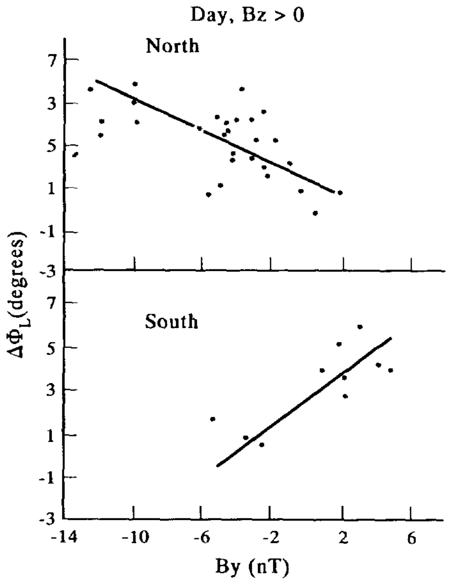

Fig. 5. IMF B_Y control of $\Delta\Phi'$ at $B_Z > 0$ for the nighttime sector of the northern and southern hemispheres.

In the northern hemisphere, during both day and night hours, a negative azimuthal component brings about a shift of the trough towards the pole and a positive component towards the equator. This implies that in that hemisphere the azimuthal and vertical IMF components act out of phase. In the southern hemisphere the situation is reversed: a positive azimuthal component brings about a shift of the trough towards the pole and a negative one towards the equator, which coincides with the effect of the vertical IMF component.

These results allow us to explain the use, while constructing the graphs of $\Delta\Phi_L$ against B_Z (Fig. 3), of the data sets for just one sign of the azimuthal component: $B_Y < 0$ in the northern hemisphere and $B_Y > 0$ in the southern hemisphere. This way we eliminate the distorting influence of the azimuthal components acting opposite in phase with the north–south component.

Table 2. The parameters of regression equations as follows: $\Delta\Phi' = aB_Y + b$

Sector MLT	Hemisphere	a	b	ε	σ
18–06 h	Northern	−0.33	−0.05	−0.74	0.05
12–17 h	Northern	−0.29	−1.86	−0.68	0.09
12–17 h	Southern	+0.49	+2.96	0.81	0.12

The results obtained on the influence of the IMF on the main ionospheric trough are in a good agreement with Nakai's studies of the B_Z parameter effect on the auroral oval size in the nighttime sector (Nakai, 1987). However, our results are not in agreement with the conclusion of Nakai (1987) concerning the effects of the azimuthal component. According to Nakai, the oval in both hemispheres extends in local winter for $B_Y > 0$ in contrast to our data (Figs 4 and 5) which show an equatorward displacement in the northern hemisphere and a poleward displacement in the southern hemisphere.

5. CONCLUSIONS

Summing up the results of our study the dependence of the variations of the main ionospheric trough position on longitude and the IMF parameters in the northern and southern hemispheres, we can conclude the following.

(1) The longitudinal variations of the trough position in the different hemispheres prove to be different. In the northern hemisphere, they have the shape of a double wave (180° longitude, day) with an half amplitude of 4–6° of latitude in both day and night sectors; in the southern hemisphere, a single wave (360° longitude, one day) with an amplitude of about 6° at night and 10–12° by day.

(2) The trough position depends on the direction and magnitude of B_Z. The dependence is the same for both hemispheres, and is more pronounced for $B_Y < 0$ in the northern hemisphere and for $B_Y > 0$ in the southern hemisphere. In the night sector, as well as in the day time, the trough shifts towards the pole by 0.8–1° for B_Z growing by 1 nT.

(3) The IMF azimuthal component influence on the trough position is most pronounced when there is a northern IMF component ($B_Z > 0$). The effect is different in the different hemispheres during the local winter. The trough shifts towards the pole (equator) with $B_Y < 0$ ($B_Y > 0$) in the northern hemisphere, and $B_Y > 0$ ($B_Y < 0$) in the southern hemisphere. That is, both IMF components (vertical, as well as azimuthal) affect the trough shift in the same direction in the southern hemisphere (the June solstice) but in the opposite direction in the northern hemisphere (the December solstice).

(4) The results obtained here indicate the need to correct existing models of trough dynamics. The established variations of the trough position with longitude and the IMF parameters are comparable with the diurnal variations and with the influence of geomagnetic activity.

REFERENCES

Afonin V. V., Besprozvannaya A. S., Benkova N P., Zikrach E. K., Mamrukov A. P., Strod N. S., Shestakova L. V. and Shchuka T. I. 1989 *Geomagn. Aeron.* **29**, 865.

Afonin V. V., Deminov M. G., Karpachev A. T., Benkova N. P., Besprozvannaya A. S., Shestakova L. V., Smilauer J. and Shckuka T. I. 1992 *Geomagn. Aeron.* **32**, 75.

Afonin V. V. and Kornacheva V. F. 1989 Universal data processing system of TM-information from the "Auso-type" satellites with the processing results visualization in the form suitable for interpretation. Preprint of the Space Reşearch Institute of the Russian Academy of Sciences, Pr. 1412.

Ahmed M., Sagalin R. C., Waldman P. J. and Burke W. J. 1979 *J. geophys. Res.* **84**, 489.

Benkova N. P., Besprozvannaya A. S., Kozlov E. F., Kochenova N. A., Samorokin N. I. and Shchuka T. I. 1989 *Geomagn. Aeron.* **29**, 863.

Besprozvannaya A. S. and Shchuka T. I. 1985 IAGA IAMAP 5th General Assembly, Abstracts, Prague, p. 282.

Best A. and Wagner C.-U. 1983 Physical Processes in the Main Ionospheric Trough Region. Proceedings of the Symposium KAPG, projects 5 and 6, Praha, 28–31 March 1983, p. 19.

Deminov M. G. and Karpachev A. T. 1986a *Geomagn. Aeron.* **26**, 63.

Deminov M. G. and Karpachev A. T. 1986b *Geomagn. Aeron.* **26**, 682.

King J. H. 1983 NSSDC WDC-A-R&S 83-01, Interplanetary Medium Data Book—Suppl. 2, 1978–1982.

Kohnlein W. and Raitt W. J. 1977 *Planet. Space Sci.* **25**, 600.

Krinberg I. A. and Tashchilin A. V. 1984 *Ionosphere and Plasmasphere*, p. 188. Nauka, Moscow.

Miller N. J. 1970 *J. geophys. Res.* **75**, 7175.

Moffet R. J. and Quegan S. 1983 *J. atmos. terr. Phys.* **45**, 315.

Muldrew D. B. 1965 *J. geophys. Res.* **70**, 2635.

Nakai H. 1987 *Geophys. Res. Lett.* **14**, 1162.

Sojka J. J., Raitt W. and Schunk R. W. 1979 *J. geophys. Res.* **84**, 5943.

Sojka J. J. and Schunk R. W. 1989 *J. geophys. Res.* **94**, 6739.

Spiro R. W. 1978 Ph.D. thesis, University of Texas, Dallas.

Troshichev O. A. 1982 *Space Sci. Rev.* **32**, 275.