GEOMAGNETISM AND AERONOMY, English Translation, VOL. 35, NO. 6, JUNE 1996
Russian Edition: NOVEMBER–DECEMBER 1995

Electron concentration distribution in the high-latitude topside ionosphere of the southern hemisphere under nighttime summer conditions

A. T. Karpachev

Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Russian Academy of Sciences

Abstract. We studied the global distribution of the electron concentration in the topside ionosphere at middle and high southern hemisphere latitudes under quiet ($Kp = 2$) near-midnight (2300–0100 LT) summer conditions. The study revealed a steady longitudinal effect in the electron concentration, whose amplitude reaches a factor of 6 at a fixed invariant latitude of 55°. We demonstrated that the main ionospheric trough occurs during the winter solstice only under high solar activity. In January the trough is systematically registered in quiet conditions but only in the shadow and only at minimum background concentration (at longitudes of 30–60°). The ionization ridge, or "cliff," which presents a concentration peaking at longitudes of 240 – 300° and latitudes of 50 – 60° but sharply decreasing toward the auroral oval, is also observed only in January (November) but is absent during the December solstice. The formation mechanisms of the features examined in the distribution of ionization under summer conditions are discussed.

Introduction

The global distribution of electron concentration has not yet been thoroughly studied, especially above the oceans at high latitudes. Satellite observations can fill in this gap. For example, *Karpachev* [1992], using Intercosmos 19 data, has obtained a statistical picture of the f_0F2 latitudinal-longitudinal variations in the region of the winter nighttime trough. The latitudes of the main ionospheric trough (MIT) in the summer hemisphere are illuminated by the Sun, the illumination conditions depending on longitude. Solar ionization, in fact, fills the trough, and it is rarely observed in summer, under circumstances which are not yet clear. The polar wall of the trough related to energetic corpuscle precipitation is also weakly pronounced in summer. However, a structure absent in winter is the concentration maximum at latitudes of 50 – 60° and longitudes of 240 – 300° with a steep polar slope. This paper analyzes the peculiarities of the electron concentration distribution at middle and high southern hemisphere latitudes under summer nighttime conditions.

0016–7932/96/3506–0012$18.00/1

The Data

This paper uses N_mF2 data of the topside sounding, obtained at $F2$ layer altitudes onboard the Intercosmos 19 satellite, and the results of in situ measurements of the local concentration N_e at an altitude of about 470 km onboard the Cosmos 90 satellite. The latter data (100 orbits) were obtained during the period January 10–31, 1979, and the former were obtained during the period December 12–25, 1979. Both periods are characterized by quiet geomagnetic field ($Kp \leq 3$ and $\bar{K}p = 2$) and close solar activity ($F_{10.7} \sim 195$ in January and $F_{10.7} \sim 215$ in December). The Cosmos 90 data are for local time midnight hours (2300–0100 LT), and the Intercosmos 19 data are for the broader local time interval 2100–0300 LT. Under further treatment, Intercosmos 19 data were reduced to midnight, by taking account of diurnal variations in the IRI-86 model. Thus we can accept approximately that we are dealing with near-midnight periods of local time (2300 – –0100 LT).

Global Distribution of Ionization

On the basis of data from both satellites mentioned above, a distribution of $N_mF2(N_m)$ and $N_e(470)$ (below just N_e) is derived in the ranges 0 – 360° geographic longitude and 40 – 70° invariant latitude in the southern hemisphere. The data were processed by a special graphic program using the "reverse distance"

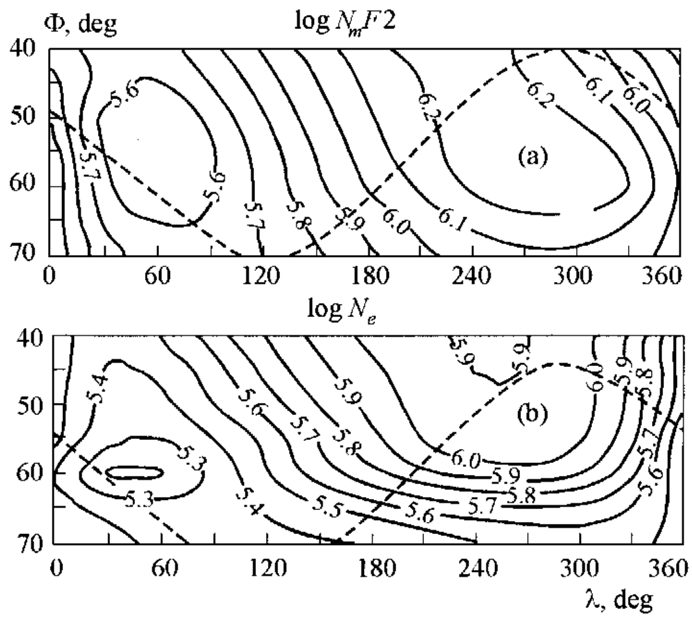

Figure 1. Electron concentration distribution at high latitudes of the southern hemisphere (a) at the $F2$ layer maximum altitude in December 1979 and (b) at an altitude of about 470 km in January 1979. The dashed line shows terminator position at an altitude of 200 km. LT = 2300 – –0100, $Kp = 2$ and $F_{10.7} \approx 200$.

method. The essence of this method is that every value of the concentration is taken into account in the data-averaging process with a weight, inversely proportional to the distance to the grid knot, created by the program. The grid knots were chosen to be 15° in longitude and 2.5° in latitude. The LT charts, obtained as described above, are shown in Figures 1a and 1b.

According to the Intercosmos 19 data, h_mF2 is equal to about 340–440 km for the conditions in question. Thus the Cosmos 900 data refer to the topside ionosphere just above the $F2$ layer maximum. The solar and geophysical conditions for both charts are close, so the electron concentration distributions are similar in the absolute value ($N_m \geq N_e$) and the shape of the relative variation. The most characteristic feature of both charts is the presence of strong latitudinal variations with a minimum of log $N^{\min} \simeq 5.2 - 5.5$ at $30 - 60°$ longitudes and a maximum of log $N^{\max} \simeq 6.1 - 6.2$ at about 270° longitudes.

There are, however, two very significant differences. In January under low background concentration a fairly well pronounced trough is formed with a minimum at $\simeq 60°$ latitude, which corresponds almost exactly to the position of the main ionospheric trough under the given conditions [e.g., *Ben'kova and Zikrach*, 1983]. In December a wide and small minimum of N_e is observed at these longitudes. A compression of the equal concentration lines at $240 - 300°$ latitudes, which is also absent in December, is the second feature of the electron concentration distribution in January. In other words, the high level of the midlatitude electron concentration declines very rapidly poleward, forming a sharp gradient of N_e at latitudes above 60°. This structure was observed earlier in the southern hemisphere, according to ISIS 1 data under nighttime (0002 LT) summer (November) conditions [*Eccles et al.*, 1973]. Let us analyze this feature in more detail.

Latitudinal Variations of the Concentration

Let us consider in detail the three most typical N_m and N_e latitudinal cutoffs at longitudes of 45°, 120°, and 270° (Figure 2). It can be seen in Figure 2 that at longitudes near 120° there is a monotonous decrease in N_m and N_e with latitude. This variation apparently can be considered a "normal" behavior of the electron concentration in the conditions considered. Because of the rather high background concentration ($\gg 10^5$ cm^{-3}), which is typical in summer, and the low level of magnetic activities during the observational period under consideration, energetic corpuscle precipitations introduce no pronounced enhancement of the electron concentration. Because of a longitudinal effect the background concentration at longitudes of about 45° is considerably depleted in comparison with the mean summer level. At these longitudes the concentration increases

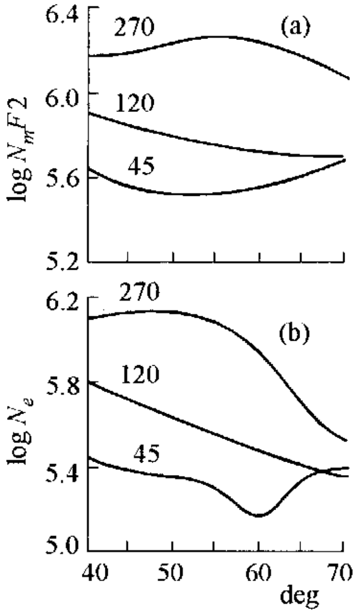

Figure 2. Values of (a) N_mF2 and (b) $N_e(470)$ versus latitude for the most characteristic longitudinal sectors of 45°, 120°, and 270° for the same conditions as in Figure 1.

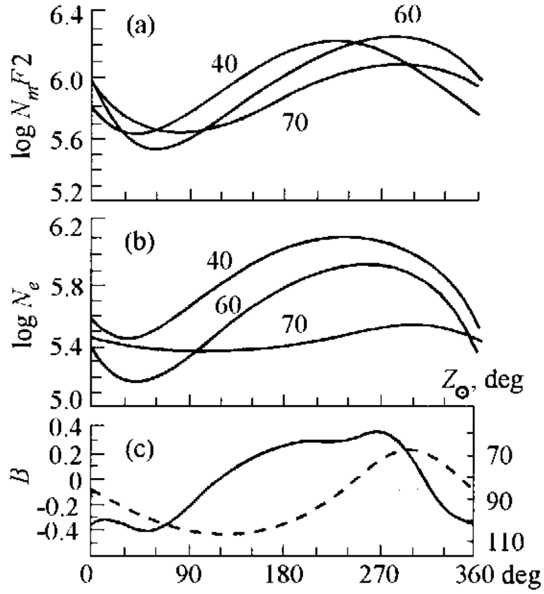

Figure 3. Values of (a) N_mF2 and (b) $N_e(470)$ versus longitude along fixed invariant latitudes of 40°, 60°, and 70° for the same conditions as in Figure 1. Variations of $B = \sin D \times \sin 2I$ (solid curve) and the solar zenith angle $Z_\odot$ for the December solstice (dashed curve) are shown.

as corpuscle precipitation in the auroral oval becomes pronounced; as a result a small and broad minimum of the electron concentration is formed. However, the well-pronounced trough with polar and equatorial walls is observed in the minimum background concentration only on N_e, i.e., only in January. The deepest trough is formed in the shadow region, at longitudes of $30 - 60°$. Additional analysis of the initial data demonstrates that with an increase in Kp the trough may be observed at any longitude, even at $240 - 300°$ (the maximum longitudinal effect). Under very high geomagnetic activity ($Kp \geq 5$) the trough, drifting equatorward in the more deeply shadowed region, apparently forms in the summer hemisphere at all longitudes [e.g., *Soboleva et al.*, 1993].

Thus the results obtained are easily incorporated into the common scheme of trough description: it is formed most likely in the shadow under low background concentration, and the probability of its occurrence increases with the higher magnetic activities. One can also estimate quantitatively contribution to trough formation by each of the factors above. The strongest influence is magnetic activities: it is well known that a deep trough is regularly observed even in the daytime during strong magnetic disturbances [*Deminov et al.*, 1985]. This event is undoubtedly a result of the electric field enhancement, which according to *Rodger et al.* [1992] forms the trough because of an increase in ion drift velocity in the trough minimum.

The stationary mechanism of trough formation is a classical one: the concentration diminishes rapidly under a low drift in the shadow region without ionization sources [*Spiro et al.*, 1978]. It is obvious that in that case, the trough would be seen most frequently in winter and at midnight and in the summer hemisphere at longitudes not illuminated by the Sun. The influence of seasonal and diurnal variations in illumination was studied by *Kolesnik and Golikov* [1983], using the "complete shadow" mechanism. They showed that during the winter solstice at any time (but only in the particular longitudinal region) a crescentlike region is observed with no ionization sources, neither solar radiation nor particle precipitation. The trough is observed at these longitudes ($0 - 20°$ in the northern hemisphere under $Kp = 3$) around the clock, even at midnight. Insofar as there is no such region in summer, the trough is not formed, but a monotonous decrease in poleward concentration is observed up to the auroral oval, where from 1800 to 0600 LT a quite pronounced enhancement of the concentration due to corpuscle precipitation is seen. It can be seen in Figures 1 and 2 that the longitudinal effect, in fact, modifies the numerical simulation results significantly. In particular, the trough is formed in the region of a "partial" shadow even in summer conditions. However, trough formation most probably occurs according to the rapid drift model, under low background concentration in the shadow region.

Thus the longitudinal effect in trough formation is manifested in two ways: via variations of the illumination conditions and via background concentration variations. It can be seen in Figure 1 that in January the trough occurs under low background concentration even under illuminated conditions and is not formed in shadow under high background concentration.

At longitudes of about 270° the situation also depends on the season. In December a very high level of N_m is supported at all latitudes up to the auroral oval. In January the increase of N_e with latitude is substituted by its sharp depletion at latitudes above 60°. Thus in January a maximum concentration relative to some background level forms at latitudes of 50 – 60° relatively to some background level. That is why *Eccles et al.* [1973], having distinctly observed this structure via ISIS 1 data, named it the ionization "cliff." Visually (as a sharp gradient of N_e, or a compression of the equal concentration lines, as in Figure 1b), the poleward slope of this ionization ridge would be manifested most distinctly. Let us try to understand the reasons for the formation of this structure and its seasonal variations. To do that, let us consider in more detail the longitudinal variations of the concentration.

Longitudinal Variations of the Concentration

Figure 3 shows an example of longitudinal variations in the electron concentration at latitudes of 40°, 60°, and 70°. We can see that if one moves from the middle latitudes to the subauroral latitudes and then to the auroral latitudes, the longitudinal effect changes in character by both its shape and its magnitude. Longitudinal variations in electron concentration have been studied by both theoretical and experimental methods [e.g., *Challinor and Eccles*, 1971; *Deminov and Karpachev*, 1988; *Eccles et al.*, 1971]. These studies found that the character of the longitudinal effect depends considerably on local time, season, latitude, and hemisphere. Using numerical simulation, *Deminov and Karpachev* [1988] demonstrated that the longitudinal variations at middle latitudes are due mainly to longitudinal variations in thermospheric composition and to neutral wind action, proportional to $\sin D \times \sin 2I$, where D and I are the declination and inclination of the magnetic field, respectively. The wind effect prevails at night, so the N_m and N_e variations at a latitude of 40° (Figures 3a and 3b) are similar at first approximation to the $\sin D \times \sin 2I$ variations shown by the solid line in Figure 3c.

At higher latitudes the situation depends on season. In winter the midnight ionosphere is not illuminated, and so the character of the longitudinal effects changes weakly with a latitude increase up to the auroral oval. The situation in the auroral oval is poorly studied; we know only that the amplitude of the longitudinal effect is much lower there than at middle latitudes and in the trough minimum. These findings, together with the longitudinal variations in position of the main ionospheric trough and the hemisphere asymmetry, determine the character of the longitudinal effect in the winter trough configuration, in which there is no structure similar to the summer ionization ridge [*Karpachev*, 1992].

In summer, high latitudes are illuminated by the Sun (see Figure 1), even at night, and the degree of illumination in the geomagnetic coordinate system depends not only on season but also on longitude. Figure 3c demonstrates as an example the solar zenith angle $Z_\odot$ variations for the Intercosmos 19 observational period, which corresponds practically to the December solstice. During that period the solar zenith angle changes with longitude from ~ 65° to ~ 105° at an invariant latitude of 70°. At longitudes of about 270° the illumination level is high enough to support the ionization in the auroral oval region practically at the middle latitude level (Figure 3a). The character of the longitudinal effect in the summer hemisphere changes under transition from middle latitudes to higher latitudes, because the electron concentration variations in the auroral oval are at first approximation similar to the variations of the solar zenith angle. However, the N_e maximum is not shifted very strongly, so that the ionization during the December (summer) solstice decreases only slightly with latitude in the longitude range considered. In January the degree of illumination of the southern hemisphere high latitudes diminishes, and there is no longer enough solar ionization to support high levels of N_e even in the most illuminated part of the oval (i.e., at longitudes of about 270°). The problem, however, is also that according to numerous evaluations, the neutral wind effect (under the same background concentration) should not decrease significantly with a latitude increase. In fact, variations of $\sin D \times \sin 2I$ at $\Phi = 70°$ are even higher in amplitude than at $\Phi = 40°$, and the wind amplitude also increases with latitude. Moreover, with the latitude increasing, the effect of the wind's meridional component (because of $\cos D$ variations) begins to show. Thus, there must be a source that sharply reduces the background concentration at high latitudes. We believe that such a source is the heating of the neutral atmosphere in the auroral oval region, which consequently depletes the O/N_2 ratio. [*Eccles et al.*, 1973]. Such a depletion was actually observed by the OGO 6 satellite [*Hedin and Reber*, 1972].

In the northern hemisphere, in analogy to the southern hemisphere, the "cliff" should be most illuminated in summer at nighttime longitudes of 120 – 150°. However, the difference between the geomagnetic and the geographic poles is considerably less in the northern hemisphere, so the influence of solar ionization is much weaker. The background concentration variations are also weaker, especially in the longitudinal sector given above. As a result, the structure so distinctly pronounced in the southern hemisphere is apparently not observed in the northern hemisphere [*Eccles et al.*, 1973].

To make the picture complete, let us note that the situation in the daytime in the high-latitude region is quite different from that at night: the background concentration level is higher, the neutral wind effect is much weaker and has an opposite sign, and the illumination decreases poleward and changes with longitude in antiphase in relation to midnight. Thus the ionization "cliff" is apparently formed only in the nighttime ionosphere of the southern hemisphere in summer conditions, excluding the period of December solstice maximum. Formation of the "cliff" is due to a concurrent action of several processes, the principal ones being the influence of the neutral wind, effects of solar ionization, and upper atmosphere heating in the auroral oval. However, to determine each factor's contribution, corresponding calculations need to be done.

Conclusions

Using statistical processing of the Cosmos 900 and Intercosmos 19 data, we obtained a model (empirical) description of the electron concentration in the high-latitude topside ionosphere of the southern hemisphere for summer near-midnight conditions. We analyzed peculiarities of the electron concentration distribution due to the variations in concentration with longitude, latitude, and season. The longitudinal effects have a stable character at middle and subauroral latitudes. The amplitude of the longitudinal variations in electron concentration reaches a factor of 5.5 – 6.0 at an invariant latitude of 55° and about 4.5 at middle latitudes, and it falls to ≈ 1.5 in the auroral oval (during the December solstice maximum).

The main ionospheric trough is not fixed in the LT chart, obtained by data averaging for quiet period in the December solstice maximum. The trough is observed in January only under very low (because of the longitudinal effect) electron concentration at longitudes of 0 – 120°. The most pronounced trough is formed in the shadow region, at longitudes of 30–60°. A stable trough is never formed in the shadow region under high background concentration; however, under low background concentration it can even occur at longitudes slightly illuminated by the Sun. With increased magnetic activities the trough occurs more and more frequently. With $Kp \geq 5$, it seems to exist in summer at all longitudes, including the sunlit ones.

In January (and likewise in November) a structure known as the ionization "cliff" is observed at longitudes of 240–300°. This feature is characterized by an ionization level that is high at latitudes of 50 – 60° but which sharply decreases poleward. In the December (summer) solstice maximum the ionization "cliff" is not observed, evidently because of variations in the illumination conditions in the auroral oval region.

A qualitative analysis shows that the peculiar structures of the summer nighttime ionization distribution observed in the topside ionosphere of the southern hemisphere are mainly associated with the action of the neutral wind, solar ionization, and variations in the composition of the neutral atmosphere. The wind effect is due to longitudinal variations of the terrestrial magnetic field (the inclination and declination). Variations in illumination conditions as well as the heating effects in the auroral oval are due to the difference between the geomagnetic and the geographic poles and thus, ultimately, depend on longitude. Thus the longitudinal variations of the electron concentration and the related variations in the main ionospheric trough configuration are a structure featured not only in the winter ionosphere but also in the summer hemisphere.

Acknowledgments. The work was supported by the Russian Fund for Basic Research (project 94-05-17352). The author thanks V. V. Afonin, who provided the Cosmos 900 data.

References

Ben'kova, N. P., and E. K. Zikrach, Main ionospheric trough according to ground-based observations in the Yakutsk region, in *Physical Processes in the Region of the Main Trough*, p. 7, Prague, 1983.

Challinor, R. A., and D. Eccles, Longitudinal variations of the midlatitude ionosphere produced by neutral-air wind, I, Neutral-air winds and ionospheric drifts in the northern and southern hemispheres, *J. Atmos. Terr. Phys.*, *33*, 3, 363, 1971.

Deminov, M. G., and A. T. Karpachev, Longitudinal effect in the nighttime midlatitude ionosphere according to the Intercosmos 19 data, *Geomagn. Aeron.*, *28*, 1, 76–80, 1988.

Deminov, M. G., A. T. Karpachev, Y. V. Kushnerevskiy, and Y. Shmilauer, Subauroral ionosphere structure during a magnetospheric storm according to the Intercosmos 19 data, *Geomagn. Aeron.*, *25*, 3, 406, 1985.

Eccles, D., J. W. King, and P. Rothwell, Longitudinal variations of the midlatitude ionosphere produced by neutral-air wind, II, Comparison of the calculated variations of electron concentration with data obtained from the Ariel I and Ariel III satellites, *J. Atmos. Terr. Phys.*, *33*, 3, 371, 1971.

Eccles, D., J. W. King, and A. J. Slater, ISIS 1 satellite observations of the ionosphere at high southern latitudes, *J. Atmos. Terr. Phys.*, *35*, 625, 1973.

Hedin, A. E., and C. A. Reber, Longitudinal variations of the thermospheric composition indicating magnetic control of polar heat input, *J. Geophys. Res.*, *77*, 2871, 1972.

Karpachev, A. T., Global variations of f_0F2 in the nighttime region, *Geomagn. Aeron.*, *32*, 5, 94, 1992.

Kolesnik, A. G., and I. A. Golikov, Formation mechanisms of the main ionospheric trough in the F region, *Geomagn. Aeron.*, *23*, 6, 909, 1983.

Rodger, A. S., R. J. Moffett, and S. Quegan, The role of ion drift in the formation of ionization troughs in the mid- and high-latitude ionosphere: A review, *J. Atmos. Terr. Phys.*, *54*, 1 30, 1992.

Soboleva, T. N., G. L. Gdalevich, L. N. Novikova, and B. D. Ozerov, Longitudinal variations of the relation between the subauroral and equatorial regions of the nighttime ionosphere and their response to interplanetary magnetic field changes, *Geomagn. Aeron.*, *33*, 3, 84, 1993.

Spiro, R. W., R. A. Heelis, and W. B. Hanson, Ion convection and the formation of the midlatitude F region ionization trough, *J. Geophys. Res.*, *83*, 9, 4255 4264, 1978.

(Received October 4, 1994.)