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Unusual longitude modification of the night-time midlatitude F2 region ionosphere in July 1980 over the array of tectonic faults in the Andes area: observations and interpretation

S.A. Pulinets, V.P. Kim, V.V. Hegai, V.Kh. Depuev
IZMIRAN, Troitsk, Moscow Region, Russia

S.M.Radicella
Abdus Salam International Centre for Theoretical Physics, Trieste, Italy

Abstract. Ionosphere topside sounding data from the INTERCOSMOS-19 satellite have been utilized to study longitude distribution of the night-time midlatitude F2 region peak electron density NmF2 in the Southern hemisphere over the array of tectonic faults in the Andes area for low geomagnetic activity periods in July 1979 and in July 1980 when solar activity was high and nearly the same, however, in July 1980 there was intensified tectonic activity in the Andes area, and in July 1979 the tectonic activity was lower. The results show that in July 1980 the observed value of NmF2 as a function of longitude decreased by a factor of ~ 3 with the change of longitude from 280° to 295°E over the latitude range 30° - 45°S, whereas the appropriate longitude profiles of NmF2 observed in July 1979 and reproduced by the ionospheric model IRI-90 do not reveal any appreciable longitude variations above the Andes area. Using model simulation we interpret the observed longitude anomaly of NmF2 in July 1980 as a result of the F2 region modification caused by a hypothetical large-scale long-living perturbation of the vertical electrostatic field on the Earth's surface associated with intensified tectonic activity.

Introduction

There are a number of observations of unusual perturbations of the vertical atmospheric electrostatic field E_z on the Earth's surface within the tectonic fault zone in fair weather conditions [e.g., *Kondo*, 1968; *Bonchkovsky*, 1954; *Chernyavsky*, 1955; *Hao*, 1988]. These perturbations of E_z were observed before earthquakes and the perturbation's amplitude ranged from tens to 100 – 150 V/m before moderate earthquakes [*Kondo*, 1968] and from hundreds up to 1000 V/m before strong disastrous earthquakes [*Bonchkovsky*, 1954; *Chernyavsky*, 1955; *Hao*, 1988]. However, *Morgunov et al.* [1990] observed the perturbation of E_z with the amplitude of 350 V/m in the fault zone which was not immediately accompanied by the consequent earthquake. In any case, the observed E_z perturbations are assumed to be associated with intensification of tectonic activity. It should be noted in this regard that as a direct indication of large-scale tectonic intensification major earthquakes with a magnitude $M \geq 6$ can serve. At the present time the physical mechanism of such perturbations of the vertical electric field E_z in the fault zone is far from being investigated. Some hypothetical mechanisms of this phenomenon are reviewed by *Johnston* [1997], but in this paper we shall not consider this subject.

Kim et al. [1994] showed that localized perturbations of the vertical electrostatic field E_z on the Earth's surface with the amplitude of several hundred V/m can be noticeably manifested up to ionospheric altitudes ($z \geq 90$ km) provided that the horizontal size of the electric field localization region exceeds 100 km. The electric field penetration into the ionosphere is more effective at night than in the daytime.

The electric field penetrated into the ionosphere can cause disturbance of, spatial distribution of ionospheric plasma density. In principle, the inverse problem can be solved, too, i.e., by using ionospheric disturbance features to evaluate parameters of perturbation of the vertical electric field E_z on the Earth's surface that has caused the ionospheric disturbance.

In the present paper, we utilize the ionospheric topside sounding data obtained by the INTERCOSMOS-19 to study the longitudinal peculiarities of electron density distribution at altitudes of the night-time midlatitude F2 region ionosphere over the global system of tectonic faults extended along the Andes in the Southern hemisphere. The appropriate interpretation of the observed ionospheric peculiarities is proposed by assuming the existence of a large-scale disturbance of the vertical electrostatic field on the Earth's surface in the area of the tectonic faults' system.

Observations

The measurements of electron density in the F2 region ionosphere were performed on board of the INTERCOSMOS-19 satellite by means of the topside ionospheric sounder IS-338 [*Pulinets*, 1989]. The INTERCOSMOS-19 satellite had the elliptical orbit (480 – 950 km) with the high inclination (~ 74°) and the orbit period duration of ~ 90 min. In the middle latitudes the satellite with a high inclination orbit is in the fixed sector of local time (within the range of 1 h), that allows us to evaluate ionospheric parameters for a certain moment of local time. We selected the ionospheric sounding data (ionograms) obtained above the Andes area at 05 – 06 LT for quiet geomagnetic periods ($K_p \leq 2$, $D_{st} < 10\ \gamma$) in July 1979 and in July 1980 (i.e., in local winter) when solar activity was high and nearly the same ($F_{10.7} = 230$ in July 1979 and $F_{10.7} = 210$ in July 1980). There were no strong

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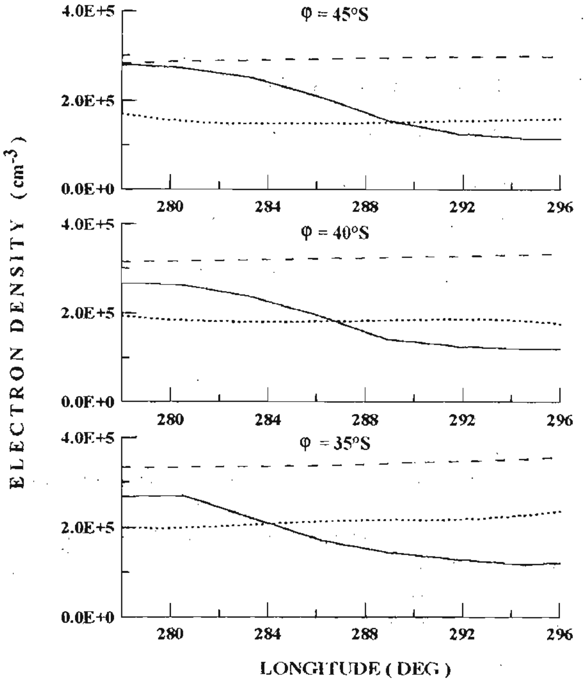

Figure 1. Longitudinal profiles of the F2 region peak electron density NmF2 observed by the INTERKOSMOS-19 satellite in July 1980 (solid lines) and in July 1979 (dotted lines) and reproduced by the IRI model (dashed lines) at 05 LT for three selected latitudes: 35°, 40° and 45°S.

earthquakes with $M \geq 6$ in the Andes area in July 1979, while in July 1980 one major earthquake with $M = 6.1$ took place in this area on July 19 at 08.47 LT. Thus, in July 1980 tectonic activity in the Andes area was high, whereas July 1979 corresponded to a period of lower tectonic activity. On the basis of the selected dataset, the mean longitude profiles of the F2 region peak electron density NmF2 were derived at three fixed latitudes φ = 35°, 40° and 45°S for 05 LT (see Fig.1). The appropriate longitude profiles of NmF2 given by the ionospheric model IRI-90 are also shown in Fig.1. It can be seen that in July 1980 the observed NmF2 as a function of longitude decreases by a factor of ~ 3 with the increase of longitude from 280° to 295°E at all the selected latitudes, whereas the longitudinal profiles of NmF2 observed in July 1979 and reproduced by the IRI model do not a reveal any appreciable longitude variations over this range of longitudes. The longitude anomaly of NmF2 observed in July 1980 can not be explain by helio-magnetospheric factors alone. Hence, it is reasonable to assume that the revealed longitudinal modification of the F2 region ionosphere is associated with some peculiarities of the considered geographical region (35° - 45° S, 278°- 296° E).

Interpretation

For explanation of the strong changes of NmF2 with longitude in July 1980, it is necessary to note that they were observed in the longitudinal sector, which incorporates the global system of tectonic faults extended meridionally along the Andes over thousands of kilometers. As was considered in the introduction, appreciable perturbations of the vertical electric field E_z on the Earth's surface can take place in the zone of active tectonic fault. The perturbations of E_z can manifest themselves up to ionospheric altitudes and cause changes of ionospheric electron density. In this connection, we have assumed that the observed longitudinal changes of electron density in the F2 region in July 1980 are caused by a large-scale perturbation of the vertical atmospheric electrostatic field E_z on the Earth's surface in the zone of the global system of tectonic faults in the Andes area associated with high tectonic activity and in the following subsections concrete calculations supporting the propounded hypothesis are presented. First of all, we shall calculate the distribution of the penetrated into the ionosphere electric field associated with the E_z perturbation localized in the region extending in the meridian direction on the Earth's surface.

Calculation of the Electric Field Penetrated Into the Ionosphere

In order to calculate the electric field penetrated into the ionosphere, we shall make use of the approach developed by *Kim et al.* [1994]. Let us take on the Earth's surface in the Southern hemisphere a Cartesian coordinate system (x, y, z) with z-axis directed upward and the x and y – axes directed southward and eastward, respectively (see Fig.2).

We assume that the perturbation of the vertical electric field E_z on the Earth's surface is localized in infinitely long stripe stretched out in the meridian direction, i.e., along the x-axis. The distribution of the electric field perturbation ΔE_z across the stripe is symmetric about the x-axis and given by

$$\Delta E_z = E_0 \exp\{-[y/(b/2)]^2\}$$

where E_0 is an amplitude of ΔE_z which does not depend on time and b is a transverse size of the electric field perturbation ΔE_z localization zone.

The distribution of the electrostatic field potential φ at the ionospheric altitudes can in general be determined from the stationary continuity equation for electric current density $\mathbf{j}$

$$\mathrm{div}(\mathbf{j}) = 0, \qquad \mathbf{j} = -\sigma \cdot \nabla\varphi \tag{1}$$

Here σ is the electrical conductivity tensor given in Cartesian coordinates by

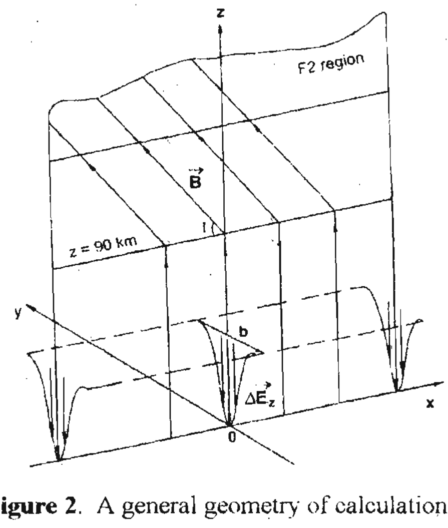

Figure 2. A general geometry of calculations.

$$\sigma = \begin{bmatrix} \sigma_1 & \sigma_2 \sin I & \sigma_2 \cos I \\ -\sigma_2 \sin I & \sigma_1 \sin^2 I + \sigma_0 \cos^2 I & (\sigma_1 - \sigma_0)\cos I \sin I \\ -\sigma_2 \cos I & (\sigma_1 - \sigma_0)\cos I \sin I & \sigma_1 \cos^2 I + \sigma_0 \sin^2 I \end{bmatrix}$$

where σ_1 and σ_2 are the Pedersen and Hall conductivities, respectively, σ_0 is specific conductivity, and I is the inclination angle of a geomagnetic field line with respect to horizontal plane.

In the approximation of the horizontally stratified medium and the vertical geomagnetic field lines ($I = 90°$) the following equation for electrostatic potential φ can be deduced from (1)

$$\frac{\partial^2}{\partial y^2}\varphi + (1/\sigma_1)\frac{\partial}{\partial z}(\sigma_2 \frac{\partial}{\partial z}\varphi) = 0 \qquad (2)$$

The height distribution of the conductivities for nighttime conditions we shall adopt the same as used by *Kim et al.* [1994]

$$\sigma_0 = \sigma_1 = s \cdot \exp(z/h) \qquad \text{at } 0 \le z \le z_1$$

$$\sigma_{0,1} = s_1 \cdot \exp\{(z - z_1)/h_{0,1}\} \qquad \text{at } z_1 \le z \le z_2$$

where $z_1 = 65$ km , $z_2 = 90$ km, $h = 6.5$ km, $h_0 = 3$ km, $h_1 = 4.5$ km, $s = 2\times10^{-13}$ mo/m, $s_1 = s \times \exp\{z_1/h\}$. Such distribution of σ_0 and σ_1 nearly fits the conductivity empirical model by *Cole and Pierce* [1965].

In this case the equation (2) has the general solution of the form

$$\varphi(0 \le z \le z_1) = \int_0^\infty \cos(ky)\{A_1(k)\exp(c_1 z) + B_1(k)\exp(c_2 z)\}dk$$

$$\varphi(z_1 \le z \le z_2) = \int_0^\infty \cos(ky)\{A_2(k) I_\nu(kf) + B_2(k) K_\nu(kf)\} f^\nu dk \qquad (3)$$

Here I_ν and K_ν are modified Bessel functions of the first and second kind with an order of ν, respectively, A_1, B_1, A_2, B_2 are coefficients, $c_1 = -1/(2h) - [1/(4h^2) + k^2]^{1/2}$, $\nu = h_1/(h_1 - h_0)$, $c_2 = -1/(2h) + [1/(4h^2) + k^2]^{1/2}$, $f = [2h_1 h_o/(h_1 - h_o)]\exp\{-[(h_1 - h_o)/(2h_1 h_o)]\cdot(z - z_1)\}$. Above the level $z = z_2 = 90$ km the geomagnetic lines of force can be assumed equipotential, hence the distribution of φ at $z \ge z_2$ is the same as at $z = z_2$. Therefore we obtain the following expressions for the electric field strength at the ionospheric heights $z \ge 90$ km:

$$E_x = -\frac{\partial \varphi}{\partial x}\bigg|_{z = z_2} = 0 \qquad (4)$$

$$E_y = -\frac{\partial \varphi}{\partial y}\bigg|_{z = z_2} = \int_0^\infty \sin(ky)\{A_2(k) I_\nu(kf|_{z = z_2}) + B_2(k) K_\nu(kf|_{z = z_2})\} f^\nu\big|_{z = z_2} kdk \qquad (5)$$

The coefficients $A_2(k)$, $B_2(k)$ are evaluated from the boundary conditions

a) $$-\frac{\partial \varphi}{\partial z}\bigg|_{z = 0} = E_0 \exp\{-[y/(b/2)]^2\}$$

b) φ is continuous at $z = z_1$

c) $$-\frac{\partial \varphi}{\partial z}\bigg|_{z = z_2} = 0$$

Results of calculations of the electric field in the ionosphere are presented in the next subsection.

Simulation of the Observed Longitudinal Changes of Electron Density

In order to reproduce the observed longitudinal changes of electron density (N_e) within the framework of our hypothesis that these changes of N_e are a manifestation of the perturbation of the vertical electrostatic field E_z on the Earth's surface, we shall make use of the continuity equation for the O^+ ion, which is dominant ion in the F2 region, i. e., $N(O^+) \approx N_e$. In the nighttime conditions this equation can be written as

$$\partial N(O^+)/\partial t + \text{div}\{N(O^+)[\mathbf{V} + \mathbf{W}]\} + \beta N(O^+) = 0 \qquad (6)$$

where $\mathbf{V}$ is the ion diffusion velocity, $\mathbf{W} = (\mathbf{E}\times\mathbf{B})/\mathbf{B}^2$ is the velocity of ion electrodynamic drift, $\mathbf{E}$ is determined by (4) and (5), $\mathbf{B}$ the geomagnetic field induction, β the ion loss rate coefficient. The time t is counted off from the termination moment of the photoionization at the F2 region ionosphere. In winter, in the middle latitudes this moment corresponds to ~ 20 LT. The expressions for $\mathbf{V}$ and β are adopted following *Schunk* [1988] for the case of $T_e = T(O^+) = T_n = 1000°K$ (T_n is the neutral atmosphere temperature). We assume, that the initial distribution of $N(O^+)$ is horizontally homogeneous and determined by the equation

$$\text{div}\{N(O^+)\mathbf{V}\} + \beta N(O^+) = 0 \qquad (7)$$

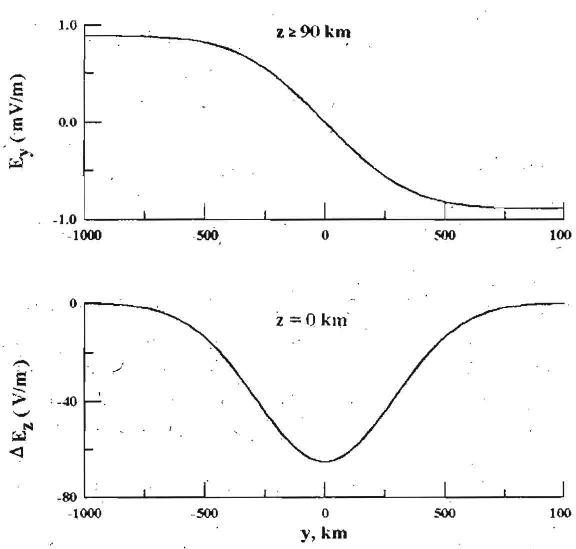

Figure 3. The adopted distribution of perturbation vertical electrostatic field ΔE_z on the Earth's surface and calculated electric field E_y at ionospheric heights $z \ge 90$ km as a function of y.

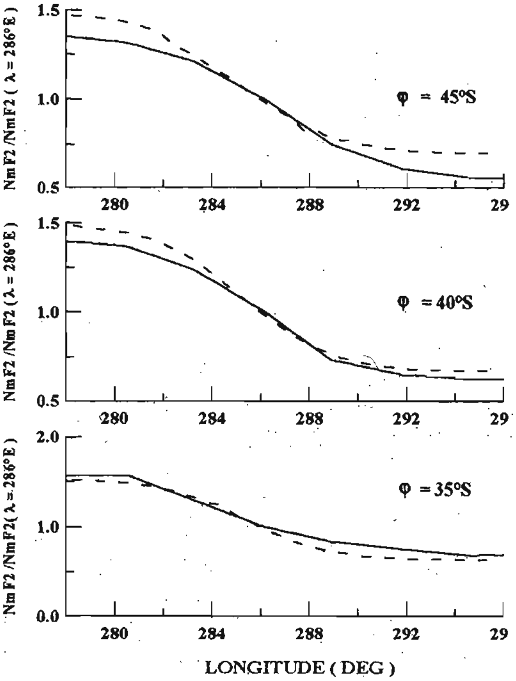

Figure 4. Comparison of the calculated (dashed lines) and observed in July 1980 (solid lines) longitudinal profiles of the normalized peak electron density NmF2 at 05 LT for the selected latitudes.

As the boundary conditions we adopt that at $z = 700$ km the downward O$^+$ flux is equal to 1.5×10^8 cm^{-2}·s^{-1} and at $z = 190$ km the O$^+$ density does not change in course of time and is equal to its initial value.

Note that the electrodynamic drift velocity **W** is directed vertical, since the meridian component of electric field $E_x = 0$.

We integrate the equation (6) in the assumption that the vector of vertical electric field perturbation on the Earth's surface ΔE_z is directed downward and $E_0 = -65$ V/m, $b = 800$ km, the x-axis coincides with the longitude of 286°E. For adopted parameters of ΔE_z the distribution of electric field E_y at the ionospheric altitudes $z \geq 90$ km is calculated from (5) and shown in Fig.3.It can be seen that east of the x-axis the electric field E_y is westward (**W** is downward) and west of the x-axis E_y is eastward (**W** is upward). The maximum value of $|E_y|$ is about 1 mV/m.

The results of calculation of the F2 region peak electron density NmF2 are illustrated in Fig.4 which displays the behavior of the normalized value of NmF2 as a function of longitude at 05 LT for 35°, 40° and 45°S latitudes as compared with the NmF2 longitudinal changes observed by the INTERCOSMOS-19 satellite in July 1980, which were discussed in the previous section. The comparison shows good agreement between the calculated and observed longitude variations of NmF2. Thus, the simulation results support the proposed mechanism of strong longitudinal changes of electron density in the F2 region over the Andes region.

Conclusion

Strong longitudinal changes of electron density in the night-time midlatitude F2 region ionosphere over the Andes area in the Southern hemisphere are revealed from the ionospheric topside sounding data obtained by the INTERCOSMOS-19 satellite in July 1980 when tectonic activity in the Andes area was high. There was a decrease of the F2 region peak electron density NmF2 by a factor of ~ 3 with the increase of longitude from 280° to 295°E over the latitude range 35° - 45°S. On the contrary, no appreciable longitude variations of NmF2 above this area were observed in July 1979 nearly for the same (as in July 1980) solar and geomagnetic conditions, but when tectonic activity in the Andes area was lower.

On the basis of model simulation, the revealed longitude anomaly of NmF2 is interpreted as a result of the F2 region modification caused by a hypothetical large-scale long-living perturbation of the vertical electrostatic field E_z on the Earth's surface, which can be associated with intensified tectonic activity. This perturbation of E_z is located in the stripe extended in the meridian direction along the global system of tectonic faults in the Andes region over thousands of kilometers. The stripe's width is about 800 km. The vector of E_z perturbation is downward likewise the normal vertical atmospheric electric field. The perturbation amplitude is – 65 V/m. It should be noted that such value of the perturbation electric field amplitude is in the range of common variations of the vertical electric field on the Earth's surface.

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S.A. Pulinets, V.P. Kim, V.V. Hegai, V.Kh. Depuev, IZMIRAN, Troitsk, Moscow Region, 142092 Russia.

S.M.Radicella, Abdus Salam International Centre for Theoretical Physics, Strada Costiera 11, 34014 Trieste, Italy.

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