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ELECTRIC FIELD ENHANCEMENT AND DISTURBANCES OF PLASMA DENSITY IN THE IONOSPHERE ABOVE THE ZONES OF PREPARATION AND DEVELOPMENT OF TYPHOONS.

N.V. Isaev[1] , V.M. Sorokin[1] , O.N. Serebryakova[1] , G.A. Stanev[2] , A.K.Yaschenko[1] and E.P.Trushkina[1]

[1)] Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, (IZMIRAN), Troitsk, Moscow Region, 142190 Russia, mail to: isaev@izmiran.rssi.ru

[2)] Space Research Institute of Bulgarian Academy of Sciences. 6 Moskovska str., Sofia, 1000, Bulgaria.

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Abstract

This paper presents the results of processing and analysis of experimental data on DC electric field and plasma disturbances in the upper ionosphere (h=950 km) observed from COSMOS-1809 satellite over the zones of strong tropical storms and typhoons. These data collected at the successive orbits during few days were related to catastrophic phenomena in the atmosphere. There were revealed the effects of DC electric field generation and excitation of small-scale and large-scale disturbances of plasma density in the ionosphere above the zones of preparation and development of tropical storms, cyclones and typhoons. The generation model of DC electric fields over the zones of preparation and development of tropical storms, cyclones and typhoons is developed. According to this model the electric field disturbance arises due to perturbation in the atmosphere – ionosphere electric circuit generated by the upward transport of charged water drops and aerosols in hurricane convection zone. Calculations of spatial distribution of DC electric field in the ionosphere were carried out with the account of oblique geomagnetic field and the conjugate ionosphere effects.

1. Introduction

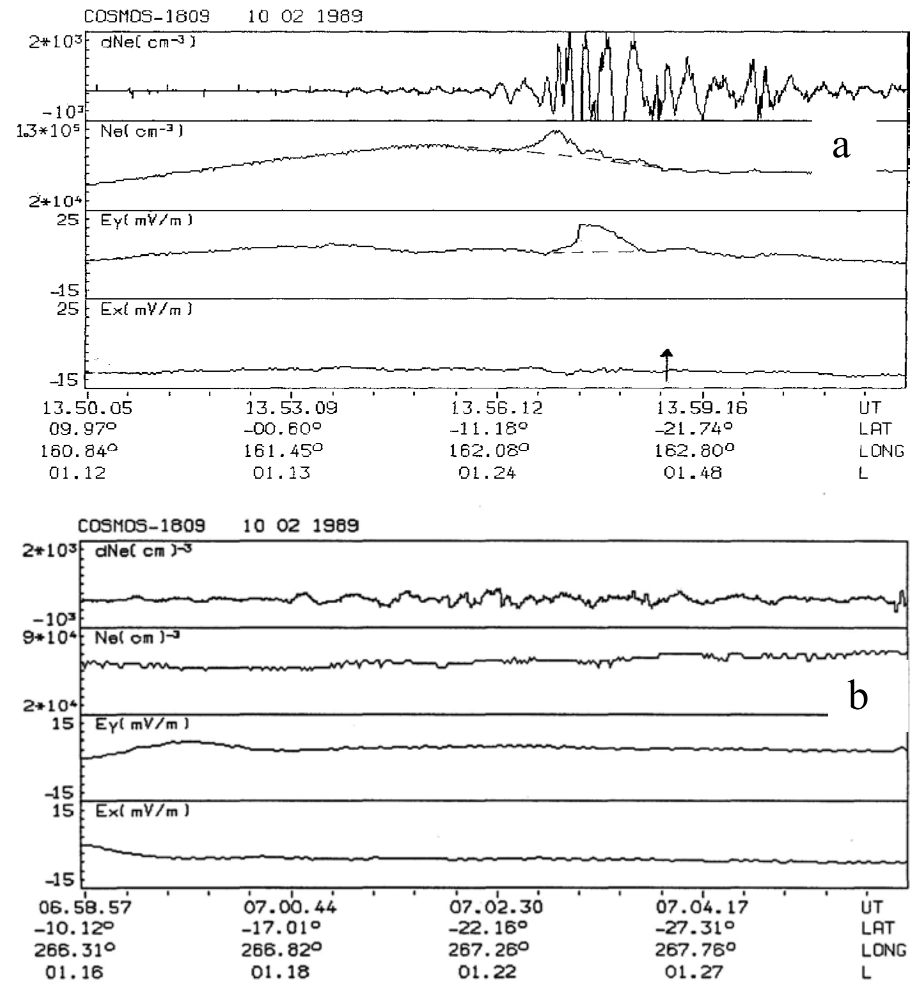
Response of the ionosphere and the upper atmosphere to intense meteorological processes was studied by Kelley et al. (1985) and Holzworth et al. (1985) who have made measurements of the electric field over active thunderstorm clouds. DC electric field exceeding 80 mV/m in magnitude were observed in the stratosphere at the distances ~ 100 km from thunderstorm cells. Besides AC electric fields with amplitude above 10 mV/m and significant magnetic field-aligned component were registered in the ionosphere. Electric conductivity at the altitudes 30-70 km appeared to be much lower then it was usually considered at the theoretical modeling. It was found that the vertical electric current density exceeded 120 pA/m^2 at the altitudes 50 – 60 km. Burke et al. (1992) reported the observations of AC electric fields ~ 40 mV/m over hurricane Debby. Mikhailova et al. (2000) discussed the satellite observations of ULF/VLF emissions possibly connected with hurricane development. Data on DC electric fields with magnitude up to 20 mV/m observed in the upper ionosphere over the tropical cyclone zone were presented by Isaev et al. (2002a, 2002b). One of the most developed interpretations of these phenomena is based on the atmosphere – ionosphere coupling provided by the effects of DC electric field generation (Sorokin et al., 1998; Sorokin and Cherny, 1999; Sorokin and Yaschenko, 2000; Sorokin et al., 2001). Calculation of the electric field in the ionosphere over thunderstorm clouds was carried out by (Park and Dejnakarintra, 1973). Mechanism of DC electric field formation in the ionosphere in a process of typhoon development was discussed by (Sorokin and Cherny, 1999; Isaev et al., 2002b). General idea of this mechanism is as follows. The electro physical parameters of the lower troposphere such as concentration, dimensions and mobility of charge marine aerosols and dielectric constant of air are correlated with the meteorological parameters – cloudiness, temperature, humidity, pressure and intensity of atmospheric convection. Perturbations in the meteorological parameters at definite phases of tropical cyclone development initiate the disturbances of electrical conductivity that leads to formation of external electric current in the lower atmosphere. This current arises as result of vertical atmospheric convection and related transport of charged water drops and aerosols. Insertion of external electric current modifies the distribution of conductivity current in global atmosphere – ionosphere electric circuit and leads to generation of DC electric field disturbances over a zone of strong atmospheric perturbation. The most important property of this mechanism is that numerous electromagnetic and plasma effects can be explained by the operation of only one source – an amplification of DC electric field in the ionosphere. This source is controlled by the dynamics of atmospheric processes through modification of electrical parameters of the lower atmosphere.

This paper also presents further development of the above mechanism taking into account the oblique geomagnetic field and the conjugate ionosphere effects. Results of theoretical modeling are compared with new experimental data obtained from electromagnetic and plasma measurements onboard the COSMOS-1809 satellite and meteorological observations of strong tropical storms and typhoons.

1. Experimental data

"Cosmos - 1809" satellite was operating in near - circular orbit with altitudes ~ 950 km. Accuracy and range of DC electric field measurements were ±0.5 mV/m and ±500 mV/m correspondingly. The spatial resolution was ~20 km for the electric field (E_x and E_y) and plasma density (N_e) measurements and ~4 km for plasma density variations dN_e. The data are presented in satellite co-ordinate system with x-axis directed along the satellite velocity, z-axis directed vertically upward and y- accomplishing the right-hand coordinates. Since the inclination of satellite orbit was 83^0 the orientation of E_x and E_y at the low latitudes and near the equator was approximately in the North-South and East-West directions correspondingly. For removing the induction and the co-rotation electric fields we used the methods of a digital filtration.

Fig.1a presents an example of records of two electric field components (E_x and E_y), plasma density (N_e) and plasma density variations dN_e made onboard the COSMOS-1809 at three passages over the zone of typhoon HARRY 10th and 13th February 1989. This typhoon was observed in South-West part of Pacific Ocean from 7 to 19 of February 1989. Co-ordinates of the typhoon center during the satellite passage 10th February were – $20{,}5^0$S and 161^0E. Vertical arrow in Fig.1a indicates a moment when satellite passed at minimal distance ~ 1.5^0 eastward of the typhoon center. These records were made in night sector of local time in the conditions of moderate geomagnetic activity ($K_p=3_+$). As it is seen from Fig.1a the electric field disturbance with magnitude up to 15 mV/m in y-component was observed in the longitude range from 162.3^0 to 162.7^0, that was ~1.5 degrees eastward from the center of atmospheric perturbation. Shift in latitudes between the electric field amplification zone ($-13^0 < \phi < -19.50$) and the typhoon area corresponds to conjugate matching along equipotential geomagnetic field lines from the dynamo-region of the ionosphere to the satellite heights. Fig.1b presents the results of similar measurements carried out at the large distance ~ 12000 km in longitude from the typhoon center (it was at -19^0S and 165^0E) during the same day about 7 hours before the event considered above. The observation conditions were practically the same with respect to satellite shadowiness and geomagnetic activity (K_p=3). It is seen from Fig.1b that neither electric field no plasma density disturbances were observed at this passage in vicinity of the typhoon latitudes. Variations of plasma density dN_e in this event are typical for low latitude ionosphere. The third event shown in Fig.1c is related to observation over the same typhoon approximately three days after the first one presented in Fig.1c. In this case the satellite passed about 10^0 eastward from the typhoon center, which was in the region with co-ordinates: λ = 159°S, ϕ = 19.3°E. Magnitude of the electric field disturbance in this event was 7 – 8 mV/m.



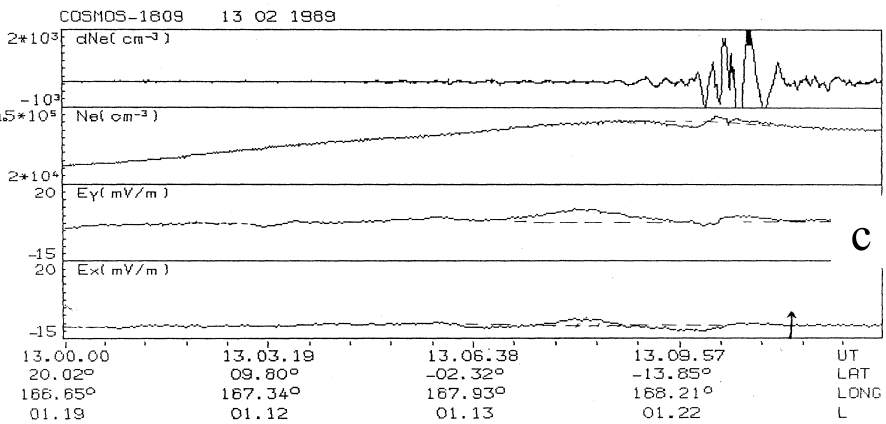


Fig. 1. Horizontal components of DC electric field *(E and Ey),* electron density N_e and its variations *dNc* as observed onboard the COSMOS-1809 satellite over typhoon HARRY (a and c) and in a distance of it (b). An arrow in panels (a) and (c) indicates the moment when the satellite was at the minimal distance from the typhoon center.

Analogous results of the satellite measurements were obtained for few other similar meteorological phenomena.

Fig.1a,c show that the electric field disturbances are accompanied by enhancement of plasma density up to 20 % with regard to background values and appearance of small-scale fluctuations of plasma density with relative magnitude dN_e/N_e ~ 8%. We assume that such fluctuations in satellite records arise when satellite crosses magnetic field-aligned plasma density irregularities.

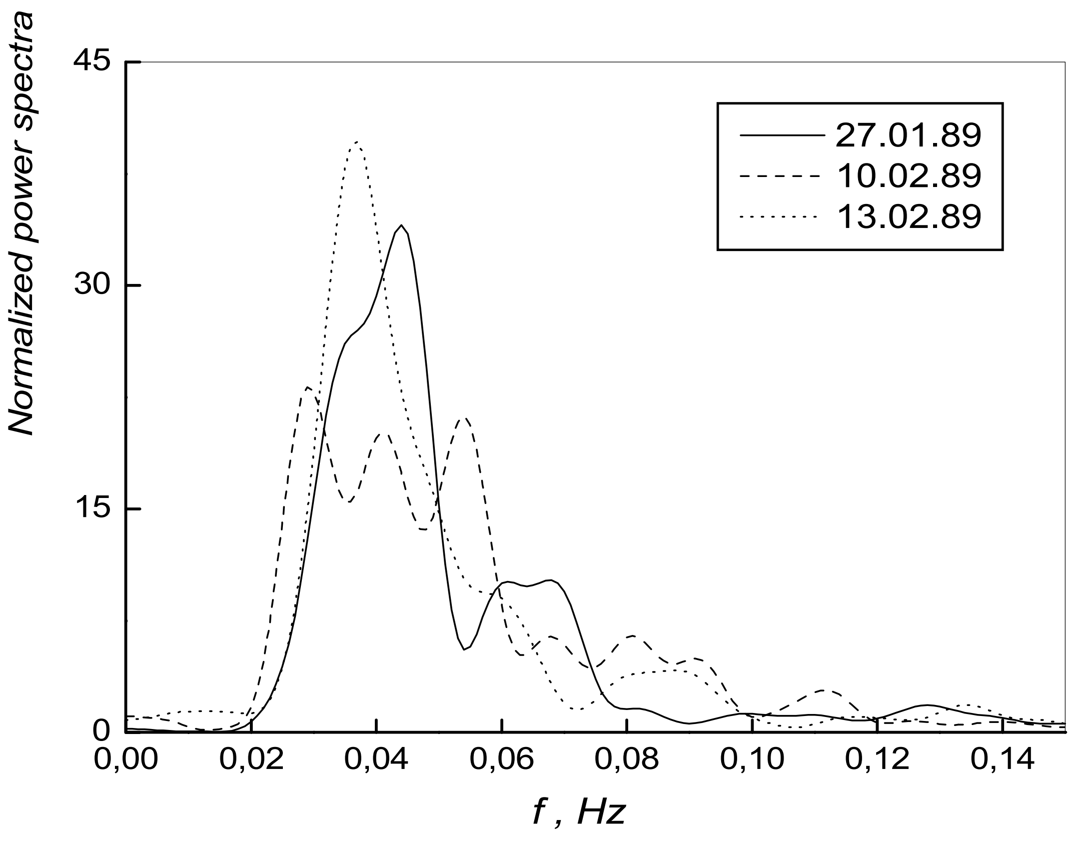


Fig.2 presents the power spectra calculated for the temporal dependences of plasma density fluctuations given in Fig.1 and for measurements over storm EDME (27.01.89).

The calculations show that in the event of 27th January 1989 there were two maximums in spectra at the frequencies 0.04 and 0.07 Hz (corresponding periods 25 and 14 seconds).

At the satellite velocity ~8 km/s it gives the spatial scale of irregularities along the orbit ~ 200 and 110 km. To estimate their transverse scale it is necessary to multiply these values by $\sin\alpha$ where α is an angle between the vectors of satellite velocity and geomagnetic field. At the low latitude α is about 5^0 - 10^0. Therefore the characteristic size of irregularities across geomagnetic field is 20-40 km and 10-20 km in the considered case. Similar results are obtained for the event of 13th February 1989. At the passage most close to typhoon center (10th February 1989, Fig.1a) there were three maximums near the frequency 0.04 Hz.

2. ESTIMATION OF THE MAGNITUDE OF THE IONOSPHERIC ELECTRIC FIELD RELATED TO THE TROPICAL STORMS

It consists in the formation of an external current due to vertical convective motions in the lower atmosphere and in the variation in their electrical conductivity. The electrodymanic effect on the ionosphere results from the change in the electric current in the global electric circuit, one section of which carries the current flowing from the ionosphere to the Earth. The current magnitude in the circuit changes at a generation of the external current and a change in the electrical resistance of the Earth-ionosphere layer. The main electrical load in the atmospheric current circuit is concentrated in the lower atmosphere. Its conductivity depends on ionization sources (chemical, electrical, radioactive) and ion mobility. The change in meteorological conditions in the zone of tropical storm formation may lead to changes in ion production rate and in the electrical conductivity of the lower atmosphere. The appearance of external vertical currents in the lower atmosphere changes the conductivity current and the ionospheric electric field. The disturbance of the ionospheric electric field is caused by the typhoon-related source, the horizontal dimensions of which at the Earth's surface are hundreds of kilometers. Therefore to estimate the electric field magnitude we will use the one-dimensional model, in which external current j_s depends on altitude z. In a DC approximation, when this current changes with a characteristic time of higher than $1/4\pi\sigma_0$, electric field strength E is defined by the equality

$$E(z,t) = -E_0(z,t) - \frac{1}{\sigma(z)}\{j_s(z,t) - \frac{\int_0^h j_s(z,t)\frac{dz}{\sigma(z)}}{\int_0^h \frac{dz}{\sigma(z)}}\}$$

$$E_0(z,t) = \frac{U}{\sigma(z)\int_0^h \frac{dz}{\sigma(z)}}$$

where h is the altitude of the lower ionosphere, σ is the atmospheric conductivity, $U = \varphi(h) - \varphi(0)$ is the potential drop between the Earth and the ionosphere, and E_0 and j_0 are the electric field and current in the absence of an external current. To estimate the magnitude of the ionospheric electric field at z = h, we will consider the case when the external current varies with altitude slower than the conductivity. In this case the altitude dependence of the external current may be taken out of the integral sign in the last summand and substituted by its value at the point when the integrand is maximal

$$\int_0^h j_s(z)\frac{dz}{\sigma(z)} \approx \overline{j}_s(0)\int_0^h \frac{dz}{\sigma(z)}$$

where *js* (0) is the average value of the external current near the Earth's surface. In this case we obtain

$$E(z) = -E_0(z) - \frac{j_s(z) - \overline{j}_s(0)}{\sigma(z)}$$

At the Earth's surface $j_s(0) \approx \overline{j}_s(0)$, therefore, $E(0) \approx -E_0(0)$. Let us estimate the magnitude of the ionospheric electric field. At *z* = *h,* we obtain

$$E(h) = -E_0(h) - \frac{j_s(h) - \overline{j}_s(0)}{\sigma(h)} \approx -E_0(h) + \frac{\overline{j}_s(0)}{\sigma(h)} = -E_0(h) + \frac{\overline{j}_s(0)}{j_0}E_0(h),$$

$$E_0(h) = E_0(0)\frac{\sigma(0)}{\sigma(h)}$$

To estimate the first summand in this equality, assuming that the magnitude of the undisturbed field on the Earth's surface is Eo(0) = 150 V/m and the conductivity values are σ(0) = 2 x 10-^{14} S/m and σ(*h* = 80 km) =10-^{6} S/m, we obtain that $E_0(.h)$ = 3 x 10-^{3} mV/m. The second summand differs from the first one by the ratio of the external current near the Earth's surface and the undisturbed atmospheric current j_0 = 3 x 10-^{12} A/m^2 = 8.7 x 10-^{7} CGSE. The external current may be related to the mean large-scale vertical motion of the atmosphere, which acts as an electrostatic generator. The ascending air carries small positively charged particles, and the atmospheric precipitation carries negative charge. The estimates for the convection in the cloudy atmosphere gives a charge separation rate *of dQ/dt* = 1 C/km^3 min ~ 10-^{11} C/m^3 s in a unit volume [Fleagle and Businger, 1963]. For cloudiness with *H* ~ (10^3 – 10^4)m, me obtain that the value of the external current j_s ~(*dQ/dt*)*H* ~(10^{-8} – 10^{-7})A/м^2 m . Therefore, the ionospheric field can reach values of $E(h) \approx \frac{\overline{j}_s(0)}{j_0}E_0(h) = (10-100)\frac{мB}{м}$, which corresponds to the above experimental data.

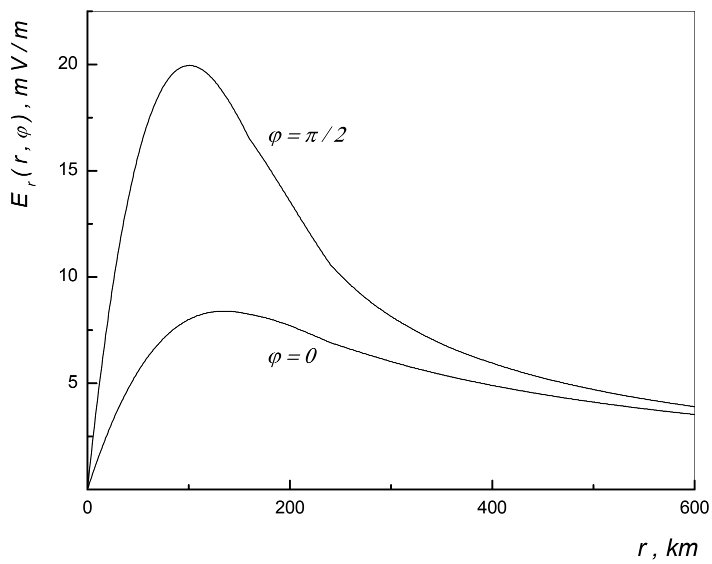
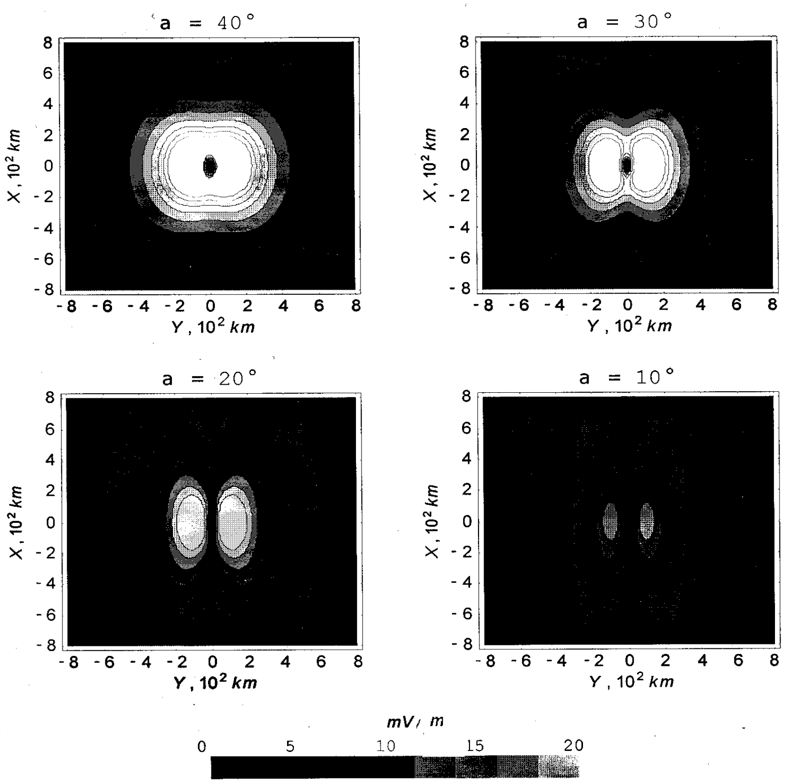


Fig3. Dependence of radial electric field component on distance along and across the plane of magnetic meridian.

Further development of the above mechanism taking into account the oblique geomagnetic field and the conjugate ionosphere effects ionosphere was carried out by Sorokin et al. (2005). Fig. 4 presents the horizontal distribution of radial component of the electric field *Er* calculated on the basis of this model for the same set of the parameters at different magnetic field inclinations (a). It is seen that the distribution strongly depends on (a). The field structure becomes two-cell (dipole-like) with very small component in the plane of meridian (in a center of hurricane) when inclination decreases below 20°.



$$\sqrt{E_x^2 + E_y^2}, mV/m$$

Fig.4. Spatial distribution of horizontal electric field component in the ionosphere over typhoon calculated for different magnetic field inclination.

Let us estimate now the degree of the field reduction due to its transfer to the satellite altitude along the magnetic field lines (mapping). According to Park and Dejnakarintra [1973], $E/E(h) = (\cos\varphi_h/\cos\varphi_s)^3$, where E_s is the electric field strength registered onboard the satellite, and φ_h, and φ_s, are the latitudes of the source and satellite, respectively. It follows from Fig. 3 that $\varphi_h = 17°$ and $\varphi_s = 5°$. These estimates show that $E_s/E_h = 0.88$, i.e., the difference between fields at the satellite altitude and in the lower atmosphere is small.

3. CONCLUSION

Data on the DC electric field measured onboard the Cosmos-1809 satellite over the regions of origination and development of the tropical typhoons are presented. As a result of the data processing, we selected more than ten typhoons, over the regions of which the ionospheric parameters were registered at the given instants. The effect of the electric field enhancement over the regions of development of the events studied was observed in all cases. The satellite data obtained evidence that tropical storms, at different stages of their evolution (from depression to typhoon), are accompanied by localized disturbances in the quasistationary electric field reaching tens of mV/m at an altitude of 950 km in the ionosphere. The detection of large-scale electric fields at such altitudes, observed in a sufficiently large number of events, allows us to conclude that a typhoon represents a global phenomenon. An effect of external electric currents on the global atmosphere-ionosphere electric circuit may be one of possible mechanisms of interaction between atmospheric and ionospheric components of this event. External currents with a horizontal scale of about one hundred of kilometers may be related to the vertical large-scale convection of the cloudy atmosphere in the zone of a typhoon and to the charge separation in this region. The order of magnitude of the electric field estimated in the ionosphere based on such a mechanism agrees with satellite data.

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