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GEOPHYSICS

Influence of Cyclones on the Atmospheric Electric Field of Kamchatka

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The effects of the influence of cyclones in Kamchatka on the vertical component of the atmospheric electric field (AEF) E_Z were studied. The cyclones were recorded on the basis of electromagnetic radiation of thunderstorm discharges [1] using a VLF-direction finder [2] developed at the Institute of Cosmophysical Research and Radiowave Propagation. The maximal distance to thunderstorm sources recorded by the direction finder reaches $4 \cdot 10^3$ km. Azimuthal distributions of VLF-radiation sources and distributions of the epicenters of cyclones determined on the basis of synoptic charts of the Hydrometeorological Service of Kamchatka are presented. Azimuthal displacements of thunderstorm sources located in the regions adjacent to Kamchatka are shown. Monitoring of E_Z was carried out at the Paratunka observatory in Kamchatka using the Pole-2 instrument [3]. It is shown that the E_Z value decreases synchronously with the atmospheric pressure as the cyclone approaches the observatory. The estimates of the electric charge of the cyclone, maximal atmospheric pressure drop in the cyclone center, and so on are presented. It is shown, that the AEF parameter responds to the displacement of a cyclone at a distance greater than 1500 km.

The seasonal recurrence of cyclones and their distribution over the territory of Kamchatka are governed by the peculiarities of the atmospheric circulation over the Far East region [4]. Kamchatka is characterized by significant thermobaric contrasts, active cyclonic activity, and rearrangement and variability in the general direction of meridional components of the atmospheric circulation, which are responsible for the complex and variable weather. One of the peculiarities of the atmospheric circulation over the territory considered here is active cyclonic activity especially during the cold period at the Polar and Arctic fronts. It is known that cyclones dominate over the Far Eastern seas and Kamchatka in winter [5] and reach maximal activity in January. This fact was crucial for the choice of the season of observations.

Figure 1 presents data on the frequency of the appearance of cyclones in Kamchatka in January 2002. The zone of maximal cyclone recurrence is located in the southern half of the peninsula and adjacent waters of the Sea of Okhotsk and Pacific Ocean. The recurrence of deep cyclones is undoubtedly of interest since they propagate to the Bering and Okhotsk seas and influence the weather of all of Kamchatka. The cyclones observed in the Sea of Okhotsk and the Aleutian Islands during the cold period are formed mainly in the southern regions of the Far East. The southern cyclones account for 70% of all cyclones observed over the Bering Sea and 52% of the cyclones over the Sea of Okhotsk [4]. Figure 1b shows typical trajectories of cyclones that influence the weather of Kamchatka.

Figure 1c demonstrates the trajectories of two close cyclones observed during the observation period (January 2002) among a great number of the rapidly appearing and decaying cyclones shown in daily synoptic charts. It is seen that these cyclones were closest to Kamchatka on January 11–12, when the intensity of VLF-radiation was maximum (Fig. 2).

The continuous observation of cyclones and recording of thunderstorm discharges were carried out with a VLF-direction finder developed at the Institute of Cosmophysical Research and Radiowave Propagation. The equipment of the direction finder operates in frequency range from 3 to 60 kHz. The signals from the thunderstorm sources are received by the antenna system, which consists of two mutually perpendicular frames and a rod antenna. The information received by the antennas is recorded on a digital carrier and processed on a real time basis.

The azimuthal distribution of thunderstorm discharges and epicenters of cyclones from January 8 to January 16, 2002, is shown in the upper part of Fig. 2

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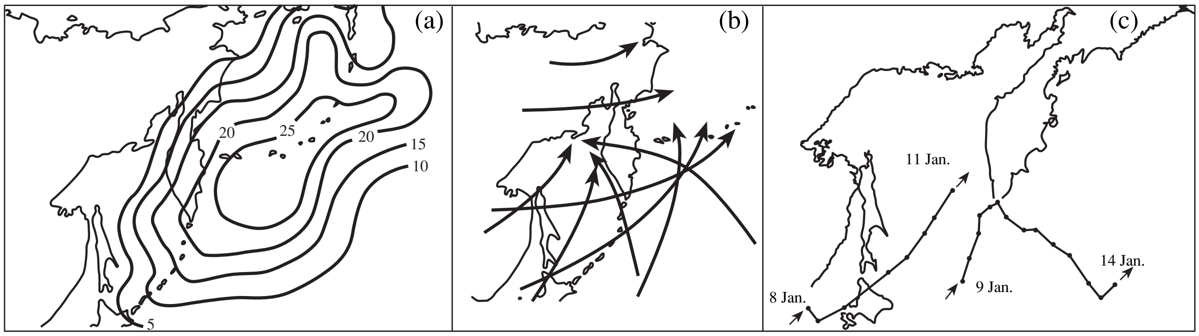

Fig. 1. (a) Annual mean number of deep cyclones in January; (b) trajectories of cyclones influencing the weather in Kamchatka; and (c) displacement of epicenters of two cyclones during the observation period from January 8 to January 16, 2002.

(dots). The rhombs show the location of cyclone epicenters based on synoptic charts compiled by the Hydrometeorological Service of Kamchatka. It is seen that the greatest density of thunderstorm discharges is observed near their epicenters. The number of discharges per unit time increases when a cyclone approaches the point of recording (Paratunka). This can be seen from a comparison of the upper and lower parts of the figure. The lower part of the figure shows that the cyclone came within 50–100 km of Kamchatka January 10–12.

Figure 3a shows time dependence of the distance between the recording point and cyclone centers. Figure 3e demonstrates the minimal distance L to the nearest cyclone epicenter. It is seen that the cyclones were at a minimal distance from the recording point January 10–12. This is consistent with Fig. 1. The direction finder recorded VLF-pulses usually considered as thunderstorm discharges (atmospheric noises). The number of atmospheric noises N (Fig. 3b) generally repeats the time evolution of minimal L values. However, anomalous behavior of N was found on January 12 when precipitation in the form of sleet was observed in the south of Kamchatka. The sleet was probably responsible for the anomalous atmospheric behavior. Like the hail, the sleet induces strong electrization of snow, which, in turn, generates electric discharges recorded by the direction finder as atmospheric noise. Figure 3c shows variation in the atmospheric pressure at the Paratunka observatory. One can see almost complete coincidence between the time evolution of the minimal L values and atmospheric pressure P. Hence, the pressure drop is caused by approaching cyclones. The time evolution of E_Z is shown in Fig. 3d, in which two anomalous cases of the behavior of N are seen on January 10 and 12. The January 12 event is related to strong electrization of snow during precipitation of sleet, while the January 10 event is related most likely to strong snowfall clearly manifested in the electric field. However, this event is not reflected in the data recorded by the VLF direction finder.

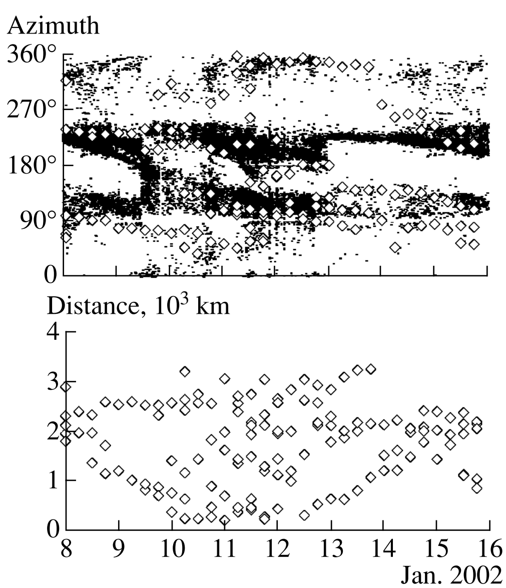

Fig. 2. Azimuthal distribution of thunderstorm discharges, distribution of epicenters of cyclones, and distance from the epicenters of cyclones to the Paratunka observatory.

Thus, a high correlation is observed between E_Z, L, N, and P excluding the cases when the cyclone is located at small distances from the observation point.

Figure 4 demonstrates the obtained results. Dots (curve *1*) show the E_Z values as function of the distance to cyclones L. It is seen that cyclones begin to appear in the E_Z field at a distance of $L \approx 1.5$ km from the observatory. At a distance of 200–300 km to the cyclone center, the E_Z field decreases to a very small value. Crosses in this figure show the dependence of pressure in Paratunka (curve *4*) on distance L. The dependence of E_Z on pressure is shown in the inset in this figure. One can see a linear dependence of these parameters. The E_Z field decreases almost to zero, while the pressure decreases only by 5%.

It is considered that pressure in a tropical cyclone starts to decrease at a distance of 200 miles (~400 km) from the measurement point, and the cyclones are not recorded at a distance of 250 miles. Usually, a notable

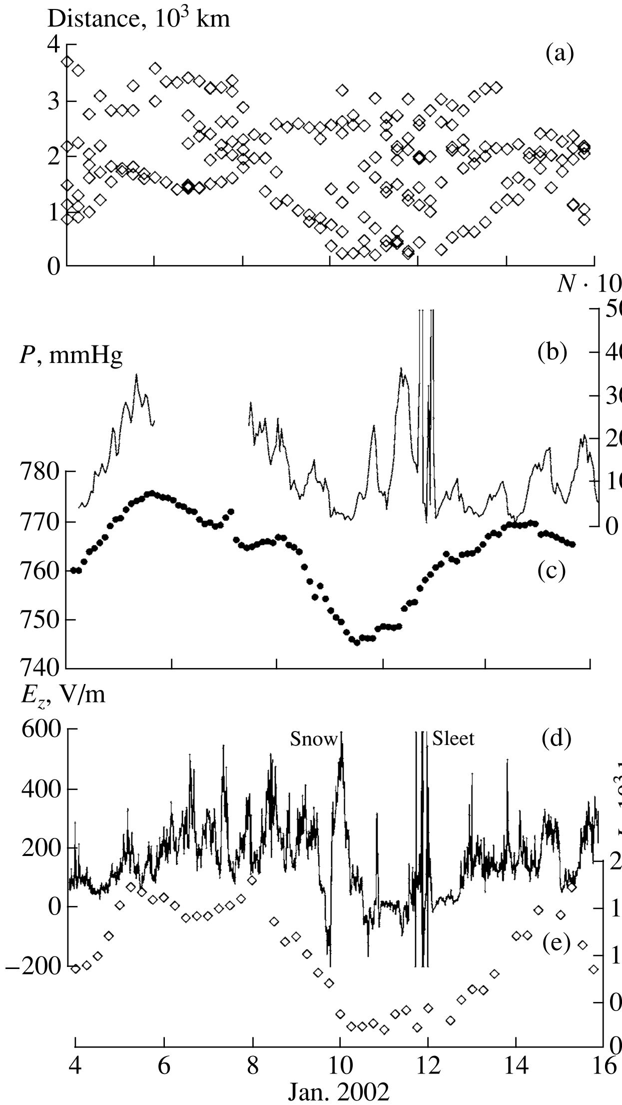

Fig. 3. (a) Distance from the epicenters of the closest cyclones to the Paratunka observatory; (b) number of thunderstorm discharges, which propagated in a unit time from azimuth 90°–180°; (c) evolution of the atmospheric pressure (P, mmHg); (d) atmospheric electric field E_Z (V/m) in Paratunka; (e) minimal distance L to cyclones.

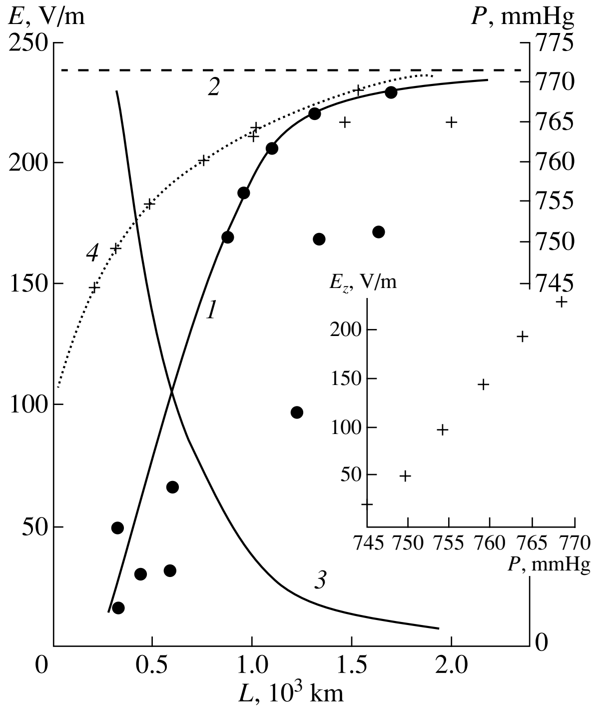

Fig. 4. Curve *1* and dots show AEF in Paratunka; (*2*) AEF (E_Z) value; (*3*) electric field of cyclones; (*4*) crosses indicate variations in the atmospheric pressure (P, mmHg) during the approaching of cyclones. Inset shows the E_Z vs. P relationship.

pressure drop is observed at a distance of 100–150 miles and the daily cycle is conserved. It is also accepted that the daily cycle of the atmospheric pressure is disturbed at a distance of less than 100 miles if the pressure drops at a rate of ~10 mmHg/h. In our case, the maximal observed rate of pressure drop did not exceed 1 mmHg/h. The minimal distance between the cyclone and recording point was approximately 200 km, and the pressure decreased from 767 to 745 mmHg. Thus, records of the variation of the dependence between atmospheric pressure versus distance to the cyclones at the Paratunka observatory show the following: the pressure decrease rate in Kamchatka versus the distance to cyclones has a stronger dependence than was considered earlier.

According to the commonly accepted concepts about atmospheric electricity as a product of thunderstorm activity, the E_Z value should increase when the thunderstorm discharge source approaches the observation point, but repeated observations indicate the reverse relationship. It is known that an increase in the atmospheric pressure at the observation point leads to an increase in E_Z and vice versa [6]. Although repeatedly confirmed by many observations, including our data, this fact does not have a credible explanation. Two versions of explanation are possible if we accept that the decrease in the atmospheric pressure is caused by the approach of the front of cyclones to Kamchatka. The simplest explanation, which does not have a clear physical basis, is as follows. Since the AEF value decreases with decreasing pressure, the cyclones approaching the observation point provoke a pressure decrease and the consequent decrease in the atmospheric electric field.

According to the alternative explanation, the decrease in the AEF is related to the fact that cyclones are carriers of a large negative charge, which induces an electric field of the opposite sign when the cyclone approaches the observation point (Fig. 4, curve *3*) and the consequent decrease in the AEF value. Curve *3* was obtained by subtraction of the E_Z field in the presence of cyclones (curve *1*) from the cyclone-free E_Z field (curve *2*). This model, at least, does not require any substantiation for the correlation between E_Z and atmospheric pressure. Naturally, decrease in the E_Z field with increase in thunderstorm discharges remains a debatable issue.

The problem is solved by applying the AEF model based on the idea of a nonthunderstorm source of E_Z [7]. The essence of the model is as follows. Electric charge is introduced into the Earth's atmosphere by galactic cosmic rays (GCR), and the charges are separated under conditions of fine weather and weak nonthunderstorm cloudiness. The essence of separation of charges was formulated by Wilson: water drops grow on negative charges falling to the Earth, while positive ions are transported to the upper atmospheric layers by ascending flows of warm air. The separation of charges is determined eventually by the ratio between the rates of condensation of water vapor and evaporation of small drops. The GCR intensity and the Earth's mean temperature are very stable in time. These parameters govern the stability and constancy of the Earth's electric charge $Q = 4\pi\varepsilon_0 R_E^2 E_Z$ and, correspondingly, the stability of E_Z. Here, R_E is the Earth's radius and ε_0 is dielectric permeability.

According to this model, cyclones have natural electric charge Q_C, which is not fully compensated. If the charge of the cyclone Q_C is located at distance L from the observation point (where $L = 0$) and the polarity of the cyclone charge is negative (same as the charge of the Earth), the charge forms the E_C field at the observation point: $-E_C = \dfrac{Q_C}{4\pi\varepsilon_0 L^2}$. The distance between the cyclone and the observation point has a positive correlation with the field of cyclone E_C (Fig. 4, curve *3*). As the cyclone approaches, pressure P at the observation point decreases (this relationship is also proportional to the L^2 value). The model suggests a correlation between the AEF and pressure without direct application of the cause responsible for the dependence of the E_Z field on the atmospheric pressure. In addition, this model cannot explain the mechanism of the local decrease in the AEF value to zero and even the change in the sign of E_Z at a pressure change by 30–40 mmHg, which does not exceed 5% of the nominal. We should also take into account that the observations described here were carried out in winter when there is no sense to discuss the local variation in AEF due to the processes of condensation and evaporation because the local temperature is significantly lower than the temperature of evaporation–condensation phase equilibrium.

The results obtained in this work allow us to make two interesting estimates. First, it is possible to estimate the electric charge of cyclone Q_C and analyze whether this value changes with distance L. If we assume that $Q_C = 4\pi\varepsilon_0 L^2 E_C$, it appears that the charge of the cyclone Q_C does not depend on distance L and it is equal to 5000 C. If we suppose that the volume density of the charge in a cyclonic cloud is the same as in a thunderstorm cloud $q = 10^{-10}$ C/m^3, then the equivalent size of the cyclone is ≤100 km. If we take into account that the cyclone loses approximately 25–50 C during the lightening strike, this means that the cyclone can produce 100 strikes without recharging. Second, knowing the character of the dependence of the pressure decrease with distance to the cyclone L, one can estimate the maximal pressure decrease in the cyclone center, which would be equal to ~730 mmHg. Since both estimates are quite reliable, the model is credible. However, a nontrivial fact follows from these estimates: the AEF begins to "feel" the cyclone at a distance greater than 1500 km. If this is true, this fact can be considered as proof of the long-range action of the AEF.

Let us make a final note. It is naturally not surprising that, like a thundercloud, a cyclone located close to the recording point influences the AEF. It is quite different if the cyclone can be detected at a distance of 1500–2000 km. This fact opens new possibilities in the study of the nature of the AEF and its implementation in atmospheric physics and solar–terrestrial physics.

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