COLLECTIVE PROCESSES IN SPACE PLASMA

ELECTROMAGNETIC PHENOMENA IN ATMOSPHERIC PLASMA-LIKE SUBSYSTEMS

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Observational data testify to a crucial role of electromagnetic phenomena in some atmospheric processes. The multilayered charged system of clouds represents a dynamically equilibrium structure. Evaluations of acting forces are presented and it is demonstrated the necessity of taking into account plasma-like subsystems' effect on some atmospheric phenomena, including the formation and the maintaining of the structures and characteristics of their movement.

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INTRODUCTION

The electrical activity has manifested in thunderstorms during passage of tornados and in central part of tropical cyclones (TC) – in the eye's wall and rain bands [4, 5, 11, 14, 28-31]. TC's and tornado's nature has been systematically studied for a long time [8, 10, 22]. But despite the progress reached in this field of research, the situation still remains far from developing the exhaustive algorithmic theory [1, 6]. The hydrodynamic theories taking into account the convection and Coriolis force are still not capable answering some key issues concerning the physical mechanisms of origin and intensification of TCs, maintaining their stationary phase, manifestation of geographical, temporal, frequency and other asymmetries. In the customary hydrodynamic description, the system development trend is always specified "implicitly" (either via artificial specifying a great initial vorticity, or by specifying a desirable form of the required solution). However, if this key issue has already been specified "manually", one could ask, what we are searching for as a matter of fact (from physical viewpoint, but not meteorological one)? It would be desirable to find just the physical mechanism which is responsible for transition to TC stage and maintaining such vortical structure.

The main objective of this paper is to systematize the experimental data and carry out estimations of all influencing factors.

1. OBSERVATIONAL DATA

Let us present the "crucial" data set which forces one to think about possible role of electromagnetic factors in the atmospheric phenomena under study [1]. First of all, one should mention here the geographical asymmetry of a typhoon genesis [6, 10]. So, the number of TCs originated and developed in the northern hemisphere is greater from 1.5 times to 4 times than it takes place in the southern hemisphere. So a separation into the western hemisphere and eastern one is purely conventional approach from the hydrodynamic view-point; but nevertheless the distinct typhoon genesis asymmetry is observed: the number of TCs originated in the eastern hemisphere is twice greater than a similar number in the western one.

The attribution to temperature conditions (26.1°C and above) of the ocean surface cannot fully determine the physics of these phenomena. So in the north the TCs are observed above the northern latitude of 35° and this is not the case in the south [6]. Since the mean time of TC existence is about one-two weeks and the necessary temperature conditions exist in many parts of oceans during even much larger period of time it is strange that TCs do not arise there at all.

The average sizes of TCs in the Atlantic and Pacific oceans are different [3, 15]: Pacific-ocean TCs are larger and Atlantic ones are slightly smaller in size. But they have a greater rate of rotation (anticorrelates with the geomagnetic field value in the TC origination area).

It seems an absolutely unclear event that TCs are fully absent in the necessary zone of the ocean close both to the South America and Africa from the Atlantics side. Comparing Fig. 1 and Fig. 2, we see the following:

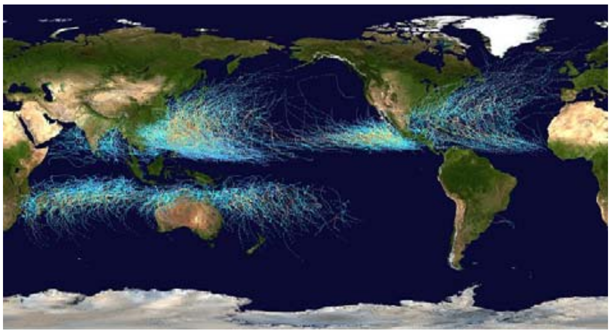

Fig. 1. Global tropical cyclone tracks

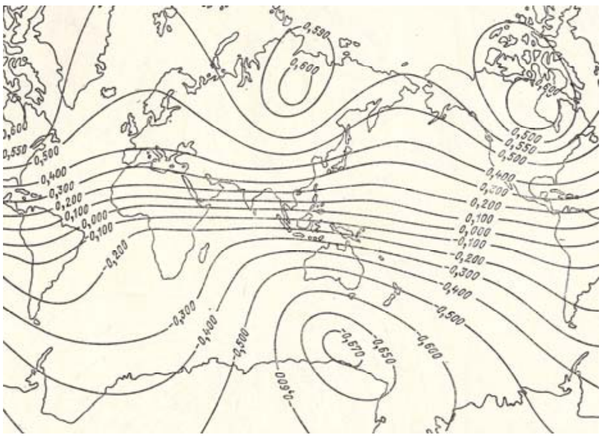

Fig. 2. Vertical component of the earth's magnetic field

The TC generation area is located not simply in the "hydrodynamic" zone (between the latitudes of 30°N and 30°S, except the near-equatorial region $\pm 5^\circ$), but at the last zone intersection with the region located around the geomagnetic equator. Threshold on geomagnetic field's vertical component is $|B_z| \geq 2\cdot10^{-5}$ T. What is it: the random coincidence or an additional condition?

Many TCs arise at the same midpoint of the trade-wind zone with an absolutely homogenous air mass. It means that the phrase about a great initial pulse and temperature contrasts in the convergence zone is often unfounded. The statement about the unique mechanism of converting the motions into the vortex one via the contact with ocean is wrong: the TCs, even if they enter the land, do often exist for a long time. It is necessary to note that a considerable part of TCs vanishes over the ocean. Besides, the rotation of opposite direction is observed over the TC (the anticyclone over the typhoon); this rotation obviously arises without contact with the ocean surface. For example, tornado's yoke drops from above; so the contact of aerodynamic flow with the surface is absolutely unnecessary for originating and developing the vortex motion. TC does not also originate from the surface but it drops from some altitude.

If there was only purely hydrodynamic mechanism causing the increase of TC's moment of rotation, then the existing, rather large initial twists in both directions would be "picked up", and the TC rotating both clockwise and counter-clockwise should be observed often enough in both hemispheres (Coriolis force is not enough here to counter the beginning of this process). But this is not the case: the direction of TC rotation is fixed for each hemisphere. This means that the additional mechanism must exist, which helps maintaining a strictly fixed structure of this phenomenon. Moreover in the northern hemisphere the anti-cyclonic rotation of tornado is less common and such tornadoes are more short-lived. But on these scales effect of Coriolis force is practically negligible therefore the internal structure of a tornado (we assume – electromagnetic one) can also play an important role here.

The highest tangential velocity in TC is observed at certain altitude and beginning at the other altitude another mechanism turns on that causes anti-cyclonic rotation. Here, the negatively charged region can have influence on the cyclonic rotation, and the anti-cyclonic motion is supported by positively charged region also. The jets of outflows from the top of TC are not axially symmetric, and their direction is not a random function. Possibly these jets are highly influenced by charged particles which tend to have drifts to the poles.

The axis of a mid-latitudinal cyclone or anticyclone is not vertical as a rule but it is highly inclined to the Earth surface. We remind that the Earth's magnetic field is also highly inclined to the surface and the charged region tends to have the axis of rotation along the magnetic field. In reality, the inclination of the axis, precession and motion of a system as a whole are determined by several factors: the hydrodynamic rotating subsystem, linked from below with Earth's surface and from above with a corresponding flow, and the rotating charged subsystem, which tends to move according to EMHD-laws in self-consistent heterogeneous electric and magnetic fields. Two charged regions are present at once in TC, and the axis occurs to be almost vertical that can be associated with electrical forces which pose oppositely charged rotating regions one under another and symmetrize the system.

If the hypothesis of electromagnetic nature of tornado and TC is correct, then some correlations should exist between the appearance of additional charged particles in Earth's atmosphere and origin of tropical depressions. There exists some connection of troposphere and upper atmospheric layers [24]. The TC interaction with a larger open system – stratosphere, ionosphere, space – can be conventionally sub-divided into two aspects: 1) the indirect effect of the ozonosphere, ionosphere and cosmic factors on the processes occurring in TC [19, 21, 26, 27], and 2) the TC effect on the ozonosphere etc. [9, 16, 17, 20, 23, 25].

2. ESTIMATION OF FORCES AND MOTIONS

Let's consider electrical characteristics of intensive atmospheric vortices ([2]; see also references therein). For TC, on the average, the following structure of charged plasma-like regions between the negatively charged Earth surface and the positive layer of tropopause is formed: near the Earth surface, at the TC center, there exists a small positive charge region; then, at the altitude of 4…8 kilometers, the most essential negative charge region is located; and, at last, at the altitude of 10…16 kilometers the positive charge region exists. The described three-polar TC structure is observed for very intensive TCs. In reality, the number of charged regions in altitude often occurs to be greater than three. Here it was found that if the number of charged regions is greater then the vertical wind velocity is lower, for example. Apparently, one can suppose that, as the TC evolves the corresponding charged regions are combined, and their number decreases. The multilayer electrical structures of a cloud cover are observed in thunderstorms [5, 14]. The typical values of the electric field in the central part of the TC are tens of kV/m [4]. Depending on the altitude they have either the same order of magnitude for tens of kilometers in radius or vary significantly (near the hurricane's eye and rain bands – Fig. 3).

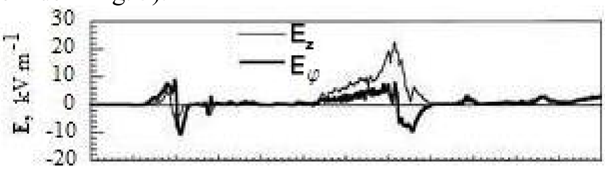

Fig. 3. Typical electrical fields in tropical cyclones

For TCs the rate of lightning strokes is quite variable (1…700) / hour and more. This value seems to be large, but with accounting for TC volume it can be small as it was noted by many researchers. Possibly the electrical structure of TC is more regular than in the case of mid-latitudinal thunderstorms since it participates in maintaining the stationary phase of TC (the electrification of TCs is connected not only with lightnings!). However the lightning flash rates can be considered as an indicator of the hurricane genesis [7, 13, 18].

At first, we estimate the density of electric forces associated with an surplus of charge of the same sign: $\mathbf{f}_q \sim n_q\mathbf{E}$. This value for eye's wall and charged TC regions (at the altitude near 6 km) lies within the range from 10^{-4} up to $10\,\mathrm{kg\cdot m^{-2}\cdot s^{-2}}$ with the mean value of $(10^{-3}...10^{-2})\,\mathrm{kg\cdot m^{-2}\cdot s^{-2}}$. This is rather a great value. Let us compare it with the density of the force which retains the charged clouds: $\mathbf{f}_c = (\varepsilon - 1)\varepsilon_0 \mathrm{grad}\,\mathbf{E}^2/2$. This value for TC lies within the limits from 10^{-7} to $6\times10^{-4}\,\mathrm{kg\cdot m^{-2}\cdot s^{-2}}$ with the mean value of the order of $10^{-4}\,\mathrm{kg\cdot m^{-2}\cdot s^{-2}}$. That is somewhat less than the density of forces which push away the charged particles in clouds. In order to explain the existence of charged cloud systems for such relation of forces, one must suppose some orderliness of charged particles in clouds. It is obvious that the total number of charged particles of both signs some orders of magnitude exceeds that number of charged particles which is provided by the observed surplus of charge of some sign. As a result, the charged particles of various signs on the average alternate with each other, forming some semblance of an ordered structure kept as a whole by ponderomotive forces (ion and polarization ones). Certainly, such an air-droplet (air-droplet-ice) "crystal" is dynamic one which is present in the statistical (dynamic) equilibrium only. If we take into account the total sum of all forces (of attraction $+\sum_i q_0 q_1 / r_i^2$ and repulsion $-\sum_i q_0^2 / r_i^2$) between the chosen charged particle q_0 and all remaining particles then we may be convinced that owing to such an orderliness the system can be retained as a whole unit even at some surplus of charges. If we take into account that one should substitute the local quantities rather than the mean value of field's square gradient then the existence of a charged cloud occurs to be a norm rather than an exception. At the excess of attractive forces the condensation increases, the droplets grow in size and fall down in the form of precipitation. So the equilibrium is restored (in the region of the greatest change of electric field – in rain bands – the dropping of precipitation occurs).

Now we will estimate what would be the velocity of a steady radial flow in TC in case of balance between the friction force and the radial electric force with density *f*. We will take for simplification the linear flow in a planar layer. With layer's height *h* we will have for the maximum velocity of flow in a planar layer [12]:

$$v_{\max} = -\frac{h^2 f}{12\eta},$$

where the dynamic viscosity of air is $\eta = 1.8\times10^{-5}\ \mathrm{Pa\cdot s}$. Substituting the mean values typical for TCs we will get for a one-kilometer layer the huge value of speeds. We will then consider the motion of a separate charged particle (if it would be alone) in air. In this case the steady uniform motion would have the following velocity: $v = N_e E/(6\pi a\eta)$, where N_e is the charge of the particle, *a* is its radius. For example, if we take the mean values for the central part of TC then for the field strength of $3\times10^5\ \mathrm{V\cdot m^{-1}}$ the charged particles with $N_e = 20\,\mathrm{nC}$ and radius from 1.5 to 0.01 mm would acquire velocities from $20\ \mathrm{m\cdot s^{-1}}$ up to $20\ \mathrm{km\cdot s^{-1}}$! If however we take the micron-size crystal, charged by 1000 charges of electron then the acquired velocity would be only $15\,\mathrm{cm\cdot s^{-1}}$ relative to the medium (with its own flow rate). But anyway to find the flow rate of the medium itself, we should sum up the influence of all layer's charged particles on a medium. Schematically this can be done in the following manner. We write from [12] the approximate formulas (in the spherical coordinate system) which express the components of flow velocities around a ball of radius *R* in the far region ($r \gg R$):

$$v_r = u\cos\theta + \frac{3uR^2}{2\mathrm{Re}\,r^2}\left\{1 - \left[1 + \frac{\mathrm{Re}\,r}{2R}(1+\cos\theta)\right]\exp\left[\mathrm{Re}\,r(1-\cos\theta)/(2R)\right]\right\}$$

$$v_\theta = -u\sin\theta + \frac{3uR}{4r}\sin\theta\exp\left[\mathrm{Re}\,r(1-\cos\theta)/(2R)\right],$$

where *u* is the flow velocity (directed along the *Z* axis), Re is Reynolds number. We pass into the Cartesian coordinate system (we are interested in the motion along the *Z* axis only) for the chosen particle sum up in coordinates of all remaining (N-1) particles and get the correction – the coefficient to velocity (it only slightly differs from unity). Further, one should take into account the fact that all influences are not independent, and each particle influences the «background basic velocity» for all remaining particles. In fact this implies that for obtaining a resulting correction the earlier obtained coefficient should be raised into power (N-1). As a result we will get again large velocities. The only possibility to obtain reasonable (observable) quantities is as follows. The steady velocity of particles motion cannot be reached in principle. In reality, for example, not only a huge quantity of negatively charged particles exists at the 6-km altitude but a lot of neutral and positively charged particles as well. The neutral particles move at the mean velocity approximately equal to the flow rate. The positive particles whose number is great one and close to the number of negative particles begin to move under electric field effect slightly faster than the flux and the negative particles begin to move in the opposite direction and have slightly lag to the mean flux motion. Each of these particles cannot gain essential velocity relative to the flux because of hindering (in addition to medium's resistance) from collisions with neutral particles and opposite-sign particles as a result of which the particles are pushed away to starting positions. One can schematically picture the elementary model of motion of such a "crystal element" (moving "ambipolarily on the average" toward the TC center) – the model of three particles in a medium – as follows (Fig. 4).

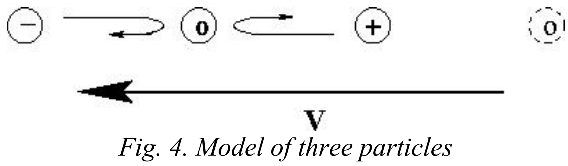

Fig. 4. Model of three particles

The particles spend longest time at the positions shown here because their relative velocity is zero at such positions (however at collision instants the relative velocities of particles are maximum, and particles "jump" rapidly through such positions). In essence this is the mechanism that converts the redundant work of electrical forces into the thermal energy and leads to rather low (really observed) velocities of radial motion. Since in numerical calculations the micro-motions cannot be taken into account, in principle, then on mesoscales one should take near the altitudes of 6 km and 12 km the quantities of the order of 2×10^{-9} kg·m^{-2}·s^{-2} or less (with corresponding signs) as an efficient value of electrical force density.

In addition to the radial motion, one should also consider the vertical motion. The motion of separate particles is influenced by the gravitational force, electrical force and aerodynamic drag force. Consider firstly the balance of gravitational force and electrical one for separate charged particles of radius *r*, possessing charge *q*. Let us suppose $r = 0.1$ mm, $q = 10^{-11}$ C in the field with strength $E = 5\times10^{4}$ V·m^{-1} (values close to mean ones in the charged TC regions), we will have for a liquid drop: $k \equiv mg/(qE) \approx 8.2\times10^{-2}$ i.e. the effect of electrical forces exceeds the gravity force effect for these particles. As the liquid drop size decreases down to r = 10 microns for the charge $q = 10^{-13}$ C in the field $E = 5\times10^{2}$ V·m^{-1} we obtain $k \approx 4.3\times10^{-4}$. Consider now the balance of gravity force and aerodynamic drag one. In ascending air flows the uncharged drops of water can be retained at upper levels due to the aerodynamic drag force $F_R = \pi r^2 C_R \rho_a v_z^2/2$, where C_R is the aerodynamic coefficient, ρ_a is the air density. The vertical velocity of an ascending flow required for this purpose is $v_z = (8r\rho_w g/(3\rho_a C_R))^{1/2}$. From here, for drops with radius $r = 0.5$ mm at the altitude z = 5 km for $T = -17$°C and $\rho_a = 0.74$ kg·m^{-3} we obtain $C_R = 0.8$ и $v_z = 4.7$ m·s^{-1}; for the drop radius r = 0.25 mm we have $C_R = 1.4$ and velocities $v_z = 2.5$ m·s^{-1} – such velocities are quite typical for TCs. For parameters the altitude z = 10 km, temperature $T = -50$°C and density $\rho_a = 0.414$ kg·m^{-3} we get $C_R = 1.75$, $v_z = 3$ m·s^{-1}. That it is quite real too. Concerning the balance of all three forces one should say the following. The electric field strength reaches extreme values only near the wall of TC eye, in the rain bands and close to the negatively charged TC region. It is these places, where the electrical force has significant part (whereas in the remaining TC parts the dominant role in the balance of forces belongs to the gravity and aerodynamic drag forces). For example, the formation of a small low-lying positively charged region near the TC center is promoted by the electrical force acting (together with the gravity force) against the aerodynamic drag force. The electrical force essentially favors formation of a vast, negatively charged TC region at the altitude of about 6 km, because it helps particles to levitate (together with the aerodynamic drag force it reacts against the gravity force).

Consider now the rotation (the azimuthal motion is the key one). The plasma-in-the-magnetic-field model can serve as a useful model for describing this motion. Let us recall the so-called L-H transition – spontaneous origination of rapid plasma rotation due to the $\mathbf{E}\times\mathbf{B}$-drift of charged particles (in the TC case we have the radial electric field and the vertical component of the magnetic field). It is essential that it is absolutely unnecessary to have fully ionized plasma since the given mechanism will also work in the presence of some fraction of free charges in gas. The presence of neutral particles leads to the situation where at collision instants the momentum will transfer from charged particles into the rotational motion of gas as whole. As a result, the large-scale motion (rotation) will arise energetically due to reconstruction of inner energy of the whole system: not only the plasma subsystem but also the whole adjacent region (the hydrodynamic system) starts rotating. All directions of rotation (both for the TC itself in both hemispheres and for the anticyclone over the TC) agree with observations. One can easily explain also the torus-like structure of TC with a calm region in typhoon's eye [1]. In the quiet atmosphere the number of ions is insufficient (the total number of ions does not exceed 10^{9} m^{-3}); just by this reason TCs arise rather rarely as compared to the other atmospheric phenomena (after all even the uncompensated surplus of charge in some regions of TC corresponds to the ion concentration of the order of $10^{11}...10^{13}$ m^{-3} and the real number of ions is some orders of magnitude greater). If we estimate the magnetic force

$$\mathbf{f}_m = n\cdot[\mathbf{v}\times\mathbf{B}]$$

from the mean concentration of a negative charge surplus in TC, then we would obtain an extremely small value of $\sim 2\times10^{-16}$ kg·m^{-2}·s^{-2}. But if the charge surplus in plasma-like subsystems constitutes a ten-millionth part of the total number of charged particles (what is quite possible) then such a force would already be capable of causing the observed macroscopic motion (for the central region of TC).

For a separate particle inside the charged region the equations of forceless motion in the cylindrical coordinate system, with allowance for collisions with neutrals, are:

$$eE_r(r,z) - m\nu_{in}(V_r - \overline{V_r(r,z)}) + eV_\phi B + mV_\phi^2/r = 0\,,$$

$$-m\nu_{in}(V_\phi - \overline{\Omega(r)}r) - eV_r B - \frac{mV_r V_\phi}{r} = 0\,.$$

Here the mean velocities and the rate of neutral gas rotation are distinguished by a bar on the top, r is the distance to the TC axis, ν_{in} is the rate of collisions with neutrals. As a result for the azimuthal velocity we have the cubic equation:

$$V_\phi\left(m\nu + \frac{eE_r}{\nu r} + \frac{m\overline{V_r}}{r} + \frac{eB\omega_H}{\nu}\right) + V_\phi^2\frac{2m\omega_H}{\nu r} + V_\phi^3\frac{m}{\nu r^2} = $$

$$= m\nu\Omega r - eE_r\frac{\omega_H}{\nu} - m\omega_H\overline{V_r}\,.$$

The azimuthal force produced by the charged particle (the negative ion with number i) on gas (due to collisions with neutrals) will be determined by the expression:

$$F_{\phi i} = m_i\nu_{in}(V_\phi - \overline{\Omega(r)}r)\,.$$

Multiplying by the ion concentration and summing up over all sorts of ions we will get the force acting on a unit volume of neutral gas from the side of a charged plasma-like subsystem:

$$\overline{F_\phi} = (V_\phi - \overline{\Omega(r)}r)\sum_i \nu_{in}m_i n_i(r,z)\,.$$

To obtain the moment of forces acting on a system one should multiply this expression by the corresponding radius and integrate over the whole volume of a charged subsystem:

$$M = \int_V r(V_\phi - \overline{\Omega(r)}r)\sum_i \nu_{in} m_i n_i (r,z) dV .$$

Due to the complicated process of microphysics and nonlinear relationships (the mean value of a function is not equal to the function of the mean value) accurate estimates are very difficult. For example, we choose the cloud layer of two-km thickness with radius of 100 km, the light ions with mass of the order of oxygen and make the estimations. $\omega_H \sim -10^2\,\mathrm{s}^{-1}$, $\nu_{in} \sim 4\times10^9\,\mathrm{s}^{-1}$, $m \sim 6\times10^{-26}$ kg, $\Omega r \sim 50\ \mathrm{m\cdot s^{-1}}$, $V_r \sim -10\ \mathrm{m\cdot s^{-1}}$, $E_r \sim -(10^4 ... 10^5)\ \mathrm{V\cdot m^{-1}}$. If the ion concentration will be supposed to be of the order of $5\times10^{12}\ \mathrm{m^{-3}}$ (the mean value for charged regions of TC), then as a result we will get for the moment of forces with magnetic spinning-up: $M \sim 4\times10^8\ \mathrm{kg\cdot m^2\cdot s^{-2}}$. The formula for the moment of gas' force of friction on the (disk) surface can be taken from (Landau and Lifshitz, 1987):

$$M \sim 0{,}97 R^4 \rho \sqrt{\nu \Omega^3} .$$

By making the substitution $\Omega^3 R^3 \to V_\phi^3$ as a result one can obtain the following estimate for the value of a moment of the force of friction (that determines the angular momentum outflow from a system):

$$M \sim 10^{11}\ \mathrm{kg\cdot m^2\cdot s^{-2}} .$$

If the total number of charges is at least two orders of magnitude greater than the number of uncompensated charges then the moment will exceed the frictional torque: $M \sim 5\times10^{11}\ \mathrm{kg\cdot m^2\cdot s^{-2}}$. That is in reality the contribution of the electromagnetic forces in maintaining the rotation amounts from a few to several tens of percent for charged regions.

Of course the electromagnetic processes do not provide the main contribution to the energy of tropical cyclones but only help to maintain their structure. Apparently the additional necessary condition for TC originating is accumulation of sufficient quantity of free charges in some atmospheric region. The ions appear also as condensation centers where the latent heat of evaporation is released. This is a triggering mechanism for converting huge stocks of thermal energy into the energy of motion. First of all medium's inflow upwards arises and air masses from an ambient spatial flow upwards to the TC axis on the place of ascending inflows. Some resemblance of a «cone in a trough» arises which spins-up additionally as air masses approach the axis due to angular momentum conservation.

The complexity of forecasting the TC motion consists additionally in the fact that except the mass of neutral gas submitting to conventional equations of hydrodynamics the charged rotating subsystem presents in a typhoon. The value of resulting force and its direction can vary in an arbitrary manner depending on the value of charges of regions, currents and other TC characteristics including TC coordinates. In all these motions the basic currents in TC will be convective ones from the motion of charged regions rather than conductivity currents. As a result in the Earth magnetic field varying along the TC trajectory and in existing varying electric fields the given subsystems tend to move according to somewhat different laws and for the TC we have as a rule the trajectory with hysteresis. Probably that is why the loops and other unpredictable types of TC motion often arise and the classic parabolic type of trajectory is observed in 47 percent of TCs only. If our suppositions are valid the perspective is opened not only to better forecast the origin, strengthening and motion of natural elements under studying but possibly even to control various phases of their evolution and trajectories of motion.

CONCLUSIONS

Thus in this paper the key observational evidences are presented showing that electromagnetic phenomena play a significant role in many atmospheric processes. The multilayer charged cloudy system in TC is an analogue of a dynamic equilibrium ordered structures. In the paper estimates of forces and of mechanisms are made, and it is proved that the motion of plasma-like subsystems must be taken into consideration for more complete description of processes in thunderstorms, tornados and TCs. Electromagnetic forces are involved in generation and maintenance of the charged structures (including a clear separation of movements inside TC) and can influence on the motion of TC as a whole.

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ЭЛЕКТРОМАГНИТНЫЕ ЯВЛЕНИЯ В АТМОСФЕРНЫХ ПЛАЗМОПОДОБНЫХ ПОДСИСТЕМАХ

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Данные наблюдений свидетельствуют о важной роли электромагнитных явлений в некоторых атмосферных процессах. Многослойная заряженная облачная система представляет собой динамически равновесную структуру. Представлены оценки действующих сил и показана необходимость учёта влияния плазмоподобных подсистем на некоторые атмосферные явления, в том числе на их формирование, сохранение структуры и характеристики движения.

ЕЛЕКТРОМАГНІТНІ ЯВИЩА В АТМОСФЕРНИХ ПЛАЗМОПОДІБНИХ ПІДСИСТЕМАХ

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Дані спостережень свідчать про важливу роль електромагнітних явищ в деяких атмосферних процесах. Багатошарова заряджена хмарна система являє собою динамічно рівноважну структуру. Представлені оцінки діючих сил і показана необхідність врахування впливу плазмоподібних підсистем на деякі атмосферні явища, в тому числі на їх формування, збереження структури і характеристики руху.