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PHYSICS

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NONPOTENTIAL GEOMAGNETIC FIELD, SCHMIDT-BAUER CURRENTS AND ATMOSPHERIC ELECTRIC CURRENT

V.V. Kuznetsov

Institute of Cosmophysical Researches and Radio Wave Propagation Far-Eastern Branch, Russian Academy of Sciences, 684034, Kamchatskiy Kray, Paratunka, Mirnaya st., 7, Russia

E-mail: vvkuz38@mail.ru

According to the developing model, the nonpotential part of the geomagnetic field is due to the vertical current associated with positive charge transfer by water vapour during plant and water surface evaporation in the same direction and with negative rain current in the opposite direction. These two processes are quite irregular both in space and in time, but the total charge transfered upwards to the clouds is almost equal to the charge transfered downwards to the Earth surface. Nevertheless, these processes result in the accumulation of positive charge in the lower ionosphere at the height of about 90 km.

Key words: nonpotential part of geomagnetic field, Schmidt-Bauer currents, rain currents and evaporation currents

Introduction

Possible relation between geomagnetic field nonpotentiality, Schmidt-Bauer currents (A. Schmidt and L.A. Bauer currents) (Sch-B) and atmospheric electric current (J) has been discussed by scientists for more than 100 years. However, the problem has not been solved. The reason is that geomagnetic field is considered with high accuracy to be potential, and the Sch-B currents are considered to be nonreal. Moreover, according to the estimates of field nonpotentiality value, Sch-B current intensity exceeds atmospheric current by four orders, which also seems to be unnatural.

In 1895, A. Schmidt was the first one who showed that the Earth magnetic field includes a nonpotential part (references in [Schweidler, 1936]). It is known that in the potential field, line integral along a closed curve should be equal to zero. In reality, it is not quite so in the geomagnetic field. It turns out during such an operation that zero is not always obtained. This fact indicates the existence of vertical currents reaching the

Kuznetsov Vladimir Valeryevich – Dr. Sci. (Tech.), Leading Researcher comprehensive geophysical observatory «Paratunka», Institute of Cosmophysical Researches and Radio Wave Propagation FEB RAS.

Earth surface. Schmidt was doubtful of the reality of the estimate results, and attributed them to the inaccuracy of observations of magnetic elements [1].

Later Bauer [1] confirmed Schmidt's results during recalculation of larger and better observational material. The most surprising was that the currents associated with the Earth magnetism are partially directed upwards and partially downwards to the Earth surface. The density of these currents, called Schmidt-Bauer currents, is about 10,000 times higher than that of normal atmospheric electric current. Sch-B currents evidently have another source than atmospheric current. It is quite possible that they are associated with each other. For example, one may suppose that the difference between the oppositely directed Sch-B currents provides the light ion atmospheric current and so on.

In the result of calculations carried out by Schmidt and Bauer, it was discovered that in polar regions the «current» is directed upwards (Fig. 1), whereas in the equatorial belt the «current» is oppositely directed, on the whole. Densities of the both currents are almost equal. The Earth surface, where the currents flow upwards, is almost equal to the Earth surface with the currents flowing downwards. It follows from Fig. 1, that there is no difference in current directions flowing over oceans and continents.

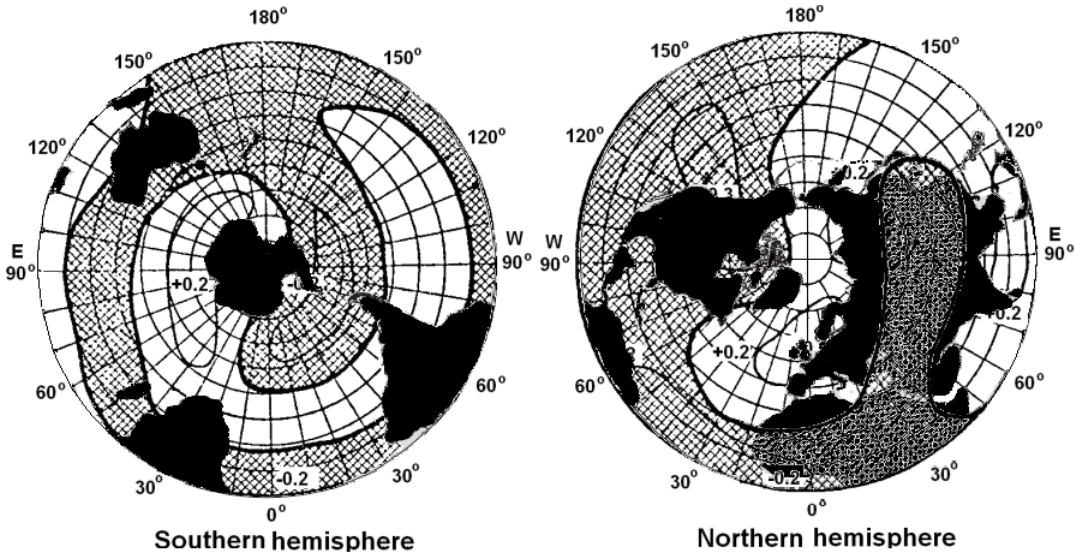

Fig. 1. Schmidt-Bauer currents [1] in Northern and Southern hemispheres. In the pole regions the currents are positive (directed upwards), in the equatorial zone the currents are negative (dark regions, currents are directed downwards)

Nonpotential field

The nonpotential part of the geomagnetic field is not only in the constant field but also in the variable field, i.e. in diurnal S_q – variations [2]. In particular, Ben'kova showed that the nonpotential part of S_q -variations reaches 1/5 of the whole variation field, and the density of variable «currents», which generate it, is two or three orders higher than the conduction current density of the atmosphere.

Serious discussion of the question about the nondipole part of the geomagnetic field B has lasted for more than several decades [3]. The nonpotential magnetic field is usually ignored in the well-known textbooks, such as, «Geomagnetism» (Chapman and Bartle), «Physics of geomagnetic phenomena» (Matsushita and Campbell), «Introduction to geomagnetism» by Parkinson [4]. There is a paragraph on geomagnetic field nonpotentiality in Parkinson's textbook.

Discussion of a possible source for the nonpotential part of the geomagnetic field, calculated from the data, obtained at many world magnetic observatories, is given in [3]. At every geomagnetic station, magnetization effect of natural environment and electric currents in the intermediate vicinity from the observation point is possible. To calculate rot $\boldsymbol{B}$, the difference between the observed B values at neighboring stations is used. For example, if we have observation results of $\boldsymbol{B}(\boldsymbol{B}x,\boldsymbol{B}y,\boldsymbol{B}z)$ at four stations: $(x1+dx,y1+dy),(x1-dx,y1+dy),(x1-dx,y1-dy)$ and $(x1+dx,y1-dy)$, rot $\boldsymbol{B}z$ value at the site $(x1,y1)$, will be:

$$\{\boldsymbol{B}\text{y}\ (\boldsymbol{x}_1+\text{d}\boldsymbol{x},\ \boldsymbol{y}_1+\text{d}\boldsymbol{y}) - \boldsymbol{B}\text{y}\ (\boldsymbol{x}_1-\text{d}\boldsymbol{x},\ \boldsymbol{y}_1+\text{d}\boldsymbol{y}) + \boldsymbol{B}\text{y}\ (\boldsymbol{x}_1-\text{d}\boldsymbol{x},\ \boldsymbol{y}_1-\text{d}\boldsymbol{y}) - \boldsymbol{B}\text{y}\ (\boldsymbol{x}_1+\text{d}\boldsymbol{x},\ \boldsymbol{y}_1-\text{d}\boldsymbol{y})\}/4\text{d}\boldsymbol{x} - \{\boldsymbol{B}\text{x}\ (\boldsymbol{x}_1+\text{d}\boldsymbol{x},\ \boldsymbol{y}_1+\text{d}\boldsymbol{y}) - \boldsymbol{B}\text{x}\ (\boldsymbol{x}_1-\text{d}\boldsymbol{x},\ \boldsymbol{y}_1+\text{d}\boldsymbol{y}) + \boldsymbol{B}\text{x}\ (\boldsymbol{x}_1-\text{d}\boldsymbol{x},\ \boldsymbol{y}_1-\text{d}\boldsymbol{y}) - \boldsymbol{B}\text{x}\ (\boldsymbol{x}_1+\text{d}\boldsymbol{x},\ \boldsymbol{y}_1-\text{d}\boldsymbol{y})\}/4\text{d}\boldsymbol{y}.$$

The calculated value of rot $\boldsymbol{B}$ will not vanish, if dx and dy are finite values, but it will decrease when d$\boldsymbol{x}$ and d$\boldsymbol{y}$ become small quantities and, finally, vanish, in extreme case, when d$\boldsymbol{x}=0$ and d$\boldsymbol{y}=0$. There is a possibility to check this supposition, distributing a large number of observation sites along a spatial loop in order to calculate rot $\boldsymbol{B}$.

Thus, the geomagnetic field nonpotentiality turns out to be quite possible. The principle causes for it are vertical currents flowing from the Earth surface to the atmosphere and backwards. It is known that there is atmospheric electric field (AEF) in the atmosphere, its value is 120-150 V/m over the oceans and 75-125 V/m over the continents.

Since the Earth has the AEF, it is natural to expect the electric current through the atmosphere. It does exist, and it is a flow of positive and negative ions directed vertically downwards, besides it has stable density slightly depending on height. The currents flowing in the opposite direction are considered to be caused by «thunderstorms and lightning».

Currents in the Earth atmosphere

Currents flowing in the Earth atmosphere are known:

- Ion atmospheric current density in the regions with fair weather conditions is $2-3\cdot 10^{-12}A/m^2$.

- Density of the current determined by charge transfer on rain, hail, show drops during calm showers is $10^{-7}-10^{-6}A/m^2$.

- Density of the current determined by charge transfer on rain, hail, show drops during thunderstorm showers and hail is up to $10^{-6}-10^{-4}A/m^2$.

- Lightning current intensity is up to 500 kA, (with the utmost probability in the range of 20-40 kA).

Lightning voltage is up to 10^9V, lightning length reaches 10 km, lightning channel diameter reaches 20 sm.

We should note that Sch-B current density ($10^{-9}-10^{-8}A/m^2$) is almost equal to the rain current density ($10^{-8}A/m^2$). As follows from Fig. 2, rain current may change its direction remaining mainly negative.

It is obvious, that there should be a current opposite to the rain current in the atmosphere. Apparently, it is the current generated in the result of charge transfer in

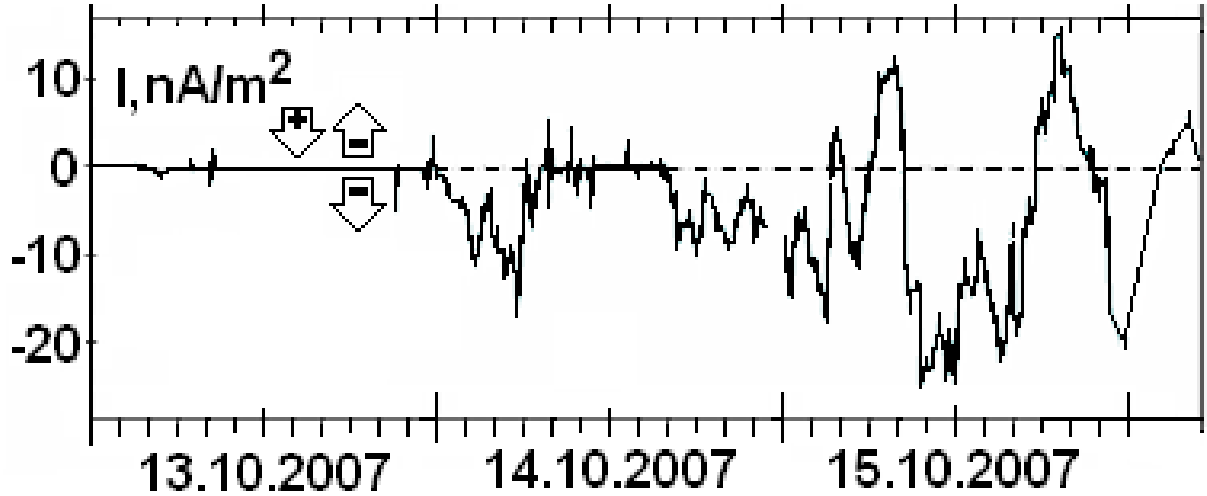

Fig. 2. Rain current [5]

the ascending warm and humid airflow. Such flows appear, as a rule, in warm forested and humid regions of continents. According to the paper [6], ascending flows, as well as rain currents have both positive and negative charges.

Some amateur radio operators proved that. They measured atmospheric currents received by their TV antennas. During clear and dry weather, the current was always positive (from antenna to ground). When there were no clouds, it was 0.1...0.3 nA. As cloudiness grew, fluctuations increased and sometimes reached 7 nA. During bad weather conditions, the current was always negative. During fog and drizzling rain, it was $-0.2\cdots-1$ nA and more during rain. The maximum registered value was -14 nA. Electrified fog and drizzle drops precipitated on an antenna and gave it their negative charge. If we admit, that the effective area of a TV antenna surface reached 1 m^2, the results of measurements of rain current are close in value.

Charges in the atmosphere

Compare the values of electric charges in the Earth atmosphere:

- Average charge of a thunderstorm cloud is 50 coulombs.

- Cyclone charge according to our estimates reaches $Q = 5\cdot10^3$ C. Its area is 100×100 km^2 [7].

- The Earth charge as a ball with radius R having the field $E = 100V/m$ is $Q_1 = \varepsilon_o R^2{}_E E = 5.7\cdot10^5$ coulombs, R_E is the Earth radius, ε_o is the electric constant.

- The charge of 1 km positive ion layer at the height of 85 km is $Q_2 = NShe = 10^4 \mathrm{cm}^{-3} \times 5\cdot10^{18}\ \mathrm{cm}^{2}\times10^5 \times1.6\cdot10^{-19}$ C $= 10^9$C, where N is charge concentration, S is the Earth surface area, h is the layer thickness, e is the electron charge [8].

- The charge transferred to the Earth by rain current during a day on the are of about 1% from the Earth total surface is $Q_3 = j\ S\ kt = 10^{-10}$ A/cm^2 $\times5\cdot10^{18}$ cm^2 $\times10^{-3}\times$ 1 day $(\approx 10^5 s) = 5\cdot10^{10}$C. Here, j is the rain current density, k is the Earth surface fraction covered by rain, t is the time for the Earth charging by rain.

- The charge of «Earth-ionosphere» capacitor $Q_4 = CU$, where C is the Earth-ionosphere (electrosphere) capacitor value $C = 4\pi\varepsilon_o\Delta R_E/R_E{}^2 = 5\cdot10^{-2}$ F. ΔR_E is the ionosphere height. U is the ionosphere potential $U = 300000$ $Q_4 = CU = 5\cdot 10^{-2}$ F $\times 3\cdot 10^5$ V $= 1.5\cdot 10^4$ C.

Comparison of charge Q_1 and Q_4 values, directly relating to AEF, with the charge values of positive ion layer (hydronium ions, H_3O^+) Q_2 and the rain cloud charges Q_3 show that electric charges of the atmosphere are significantly (by more than four orders) higher than those attributed to the AEF. The nature of AEF currents is known, it is light ion drift, but we cannot say the same about the nature of Sch-B currents. We have mentioned above that Sch-B currents are close to rain currents by value. Assume that the rain current is the Sch-B current. Then, the current with an opposite direction is the current of charges rising into the atmosphere by ascending air. Rain drops are negatively charged, as a rule. They fall downwards that means that the current is directed upwards. The rise of negative drops by ascending flows determines the downward current. The change of the drop charge sign result in the change of Sch-B current direction.

It is known that during evaporation of water, electric charge separation takes place in the gravitational field. This process is responsible for electric flashes and lightning in the atmosphere. Coulomb dynamic attractors focusing the electric field and the charge are formed during the dynamics of such processes. Formation of a double layer on a phase boundary is the common property (not only water and vapor). Intensive evaporation, ionization and charge separation occurs on the surface of warm, humid and forested continents. In tundra and deserts, an opposite process, precipitation, takes place. The hydrologic cycle determines electric charge cycle, and charge transfers are the Sch-B currents.

At the same time, water dissociation into hydrogen and hydroxyl ions occurs. A free ion H^+ is not ectogenous and is hydrated by a water molecular to form hydroxonium ion, $H^+ + H_2O$ (H_3O^+). An overall reaction is the transfer of a proton from one molecular to another one and production of hydroxonium and hydroxyle ions, $H_2O + H_2O$ $(H_3^+ + OH^-)$. Hydroxonium is a volatile gas which ascends quickly in the atmosphere to the height of 85 km and gathers there for unclear reason [8]. Hydroxyl coagulates water vapor, turns to water aerosol which is raised by ascending warmed airflow. Precisely this process is the Sch-B current directed downwards. It is known that clouds are mainly formed on the equator. They are transferred by winds to colder regions of the Earth and rain down.

Observations of the change of AEF polarity carried out in Kamchatka, in the region of thermal fields of Mutnovskii volcano, confirm the idea. We showed that when steam with large content of condensed water is ejected from a thermal well, the AEF value decreases and may change its polarity. If dry water steam is ejected form a well, the AEF value significantly increases [9].

Electric energy of the atmosphere

Compare the electric energy accumulated in the «Earth-ionosphere» capacitor with the atmosphere energy. The electric energy is $WC \approx Q$.

- The energy of atmospheric electric field is $W_1 = 3\cdot 10^4$J, the energy of ion layer is $W_2 = 5\cdot 10^7$ J, the energy of rain charge is textit$\mathrm{W}_3 = 2\cdot 10^9$ J. The capacitor energy is $W_4 = 5\cdot 10^2$ J.

Compare the obtained values with the atmosphere energy. According to [10], the inner energy of the whole atmosphere is estimated to be 8.6 $\cdot 10^{23}$ J, the potential one is $3.6 \cdot 10^{23}$ J, and the kinetic one is two orders less, 10^{21} J, which means that it is less than 1% from the potential energy. It is clear that the electric energy of the atmosphere is negligible in comparison to the kinetic energy.

The estimates given above show that the change of Sch-B currents should be observed on the Earth depending on climate variations under the general condition of equality of upward and downward currents. Currents should change during winter-summer seasonal periodicity, and during temperature change. Evidently, investigating the data changes of observatories for the last half a century, the tendency of Sch-B current change caused by global warming trend may be discovered (Fig. 3).

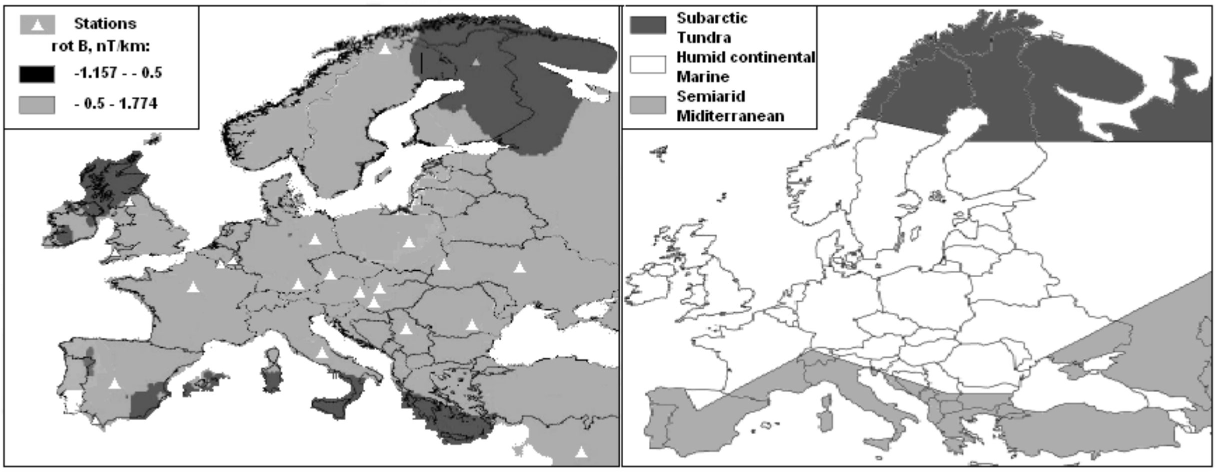

Fig. 3. Schmidt-Bauer currents (on the left). Climate of Europe (on the right)

Climate and Sch-B currents

This idea was checked by the authors [11]. They discovered the phenomenon of geomagnetic field nonpotentiality in Europe. The authors showed that induction rotor may be distinguished in the variable geomagnetic field. The negative sign of the induction rotor corresponds to negative current, and this current is directed from the atmosphere to the Earth surface. The positive sign of the induction rotor corresponds to positive current. Current density may reach $\pm 1\mu$ A/m^2. The preliminary results obtained by the authors [11] show that in northern and southern regions of Europe, negative currents (directed to the Earth surface) flow. Positive currents (directed to the atmosphere) flow in the central part of Europe (Fig. 3, on the left).

If we refer to the schematic view of European climate (Fig. 3, on the right).

We may see (Fig. 4) that there are no necessary conditions (forestlands) for the formation of ascending humid flows transferring negatively charged water aerosols into the atmosphere in the northern (Tundra) and southern (Semiarid) regions. Most likely, precipitation and transfer of rain negative electricity to the Earth takes place in these regions. The largest upward flows are formed in the forest regions where evaporation is the most intensive. During evaporation, ionization and formation of negatively charged aerosols occur, since it is the water property to keep negative charge.

Positive ions of mainly hydroxonium are raised by ascending flows, and, finally, gather at the height of about 80 km. They do not participate in Sch-B currents.

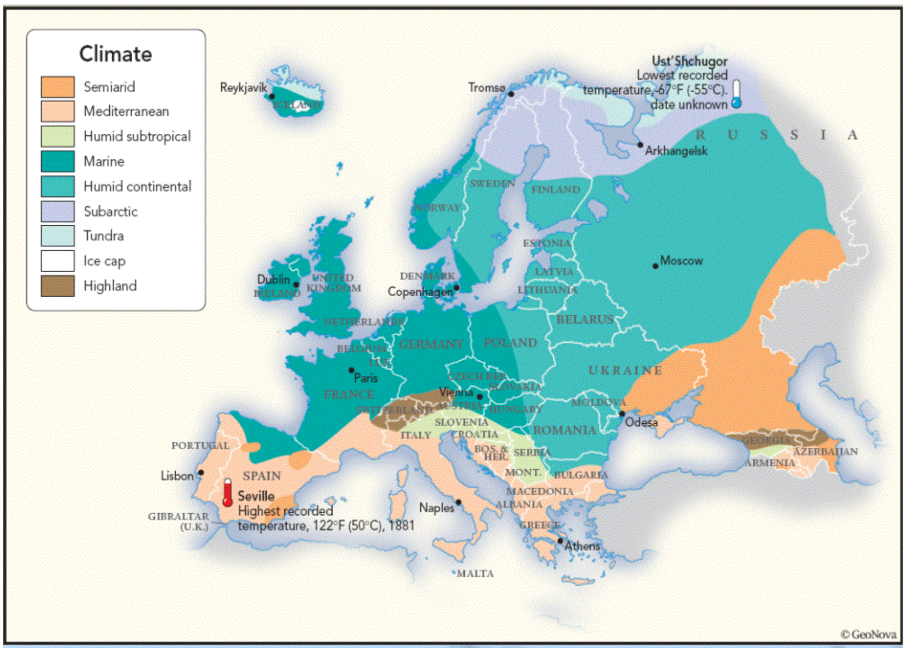

Fig. 4. Climate of Europe

The result obtained by the authors [11] does not contradict our model of Sch-B currents. However, it is difficult to compare it with the known pattern of Sch-B currents illustrated in Fig. 1. This pattern was obtained about 100 years ago and has not been updated.

Ideas, described in this paper, require proving the reality of existence of geomagnetic field nonpotentiality and Sch-B currents. There are all the grounds to realize such investigations (data bank of geomagnetic observatories).

It also makes sense to repeat the study of diurnal S_q - variations made by N.P. Ben'kova [2]. Such investigation was performed by V.V. Plotkin [12]. The author carried out spatial interpolation of time harmonic complex amplitudes of field component observation series obtained at sites and represented according to the universal time. Complex annual average amplitudes of diurnal S_q - variation time harmonics obtained according to the data of 132 stations of the global network for 1958 were used.

The author succeeded to show that there is a field nonpotential part in Sq-variations besides the potential one. It is comparable with the potential part and is about 10 nTl. If we take the atmospheric current into the account, the vortex part of its magnetic field should be 0.01 nTl. The author ascribes the nonpotential part to local noise of accidental origin at the sites. If we assume that the nonpotential part of the geomagnetic field discovered by Plotkin [12] is due to some other vertical current, its density may be of the order 10^{-9} A/m^2. It is quite possible that this current is the Sch-B current or the rain current according to our model.

Conclusion

According to the suggested model, Sch-B current have climatic roots. This approach did not quite agree with the results illustrated in Fig. 1, as we wished it to be. Confirmation of the results obtained by Schmidt and Bauer on the basis of modern data should show the validity or falsity of our model. Obviously, in the second case, we will have to find another ways to solve the problem of nondipole geomagnetic field.

To realize large-scale observations of Sch-B currents, simple devices for registration of rain currents and ascending flow currents should, possibly, be constructed and installed at different stations and observatories.

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