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On Some Problems in Geophysics Solved with the Help of Satellites on Polar Orbits

V. M. Balebanov, M. M. Gogoshev, E. M. Dubinin, I. S. Kutiev, I. M. Podgorniy, K. B. Serafimov

I. Convection

The initial *in situ* measurements on board Injun-5 and OGO-6 have shown the existence of two vortex convection [1, 2]. One of the major factors defining this picture is the direction of the interplanetary magnetic field (IMF). The convective fluxes in the polar cap become asymmetric in dependence on the sign of the magnetic field component B_y, in their shift to morning or evening side. Measurements on board AE-C provided for certain precision on this model [3]. The change of convection direction was found to occur in sufficiently narrow longitudinal band located near noon. Experiments with laboratory magnetospheric model [4, 5] have shown that in dependence on the sign of the vertical component of the interplanetary magnetic field B_z, the direction of convection changes to reverse in the polar cap. It was shown that magnetospheric field lines materialize into interplanetary field lines in the region of the polar casp. This gives evidence to the existence of magnetic field lines common for the earth dipole and the solar wind. If we use the concepts of the classical magnetic hydrodynamics, we may say that in the region of the polar casp reconnection of earth magnetic lines with solar wind takes place.

In dependence on the vertical component of the interplanetary field B_z, the reconnection appears either near the equatorial or the polar boundary of the casp. The convection in the polar cap in terms of the south component of the interplanetary magnetic field ($B_z<0$) always appears in direction away from the Sun. This fact has been confirmed by numerous measurements. Under $B_z>0$ the convection from the Sun is observed only at small B_z values. When increasing the positive value of B_z, the convection direction becomes reversive in the polar cap region. A typical dependence of the morning-evening (E_y) electric field component on B_z in the polar cap under undisturbed supersonic flux interacting with the magnetic field dipole is given in Fig. 1.

Besides the effects of reconnection, an important factor determinant of the convection picture are the viscous processes at the magnetospheric boundary. It is well seen in Fig. 1 that the sign of the electric field in the polar cap and therefore the convection direction changes become reverse only at sufficiently large positive values of B_z.

Important consequence from the viscous interaction effects is the fact that part of the convective currents generated by the solar wind plasma flux in the

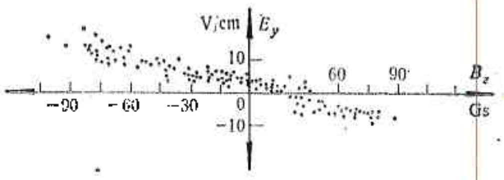

Fig. 1. Electric field dependence on the value and the sign of the vertical component (B_z) of the magnetic field in free flux (model experiment) for the polar cap.

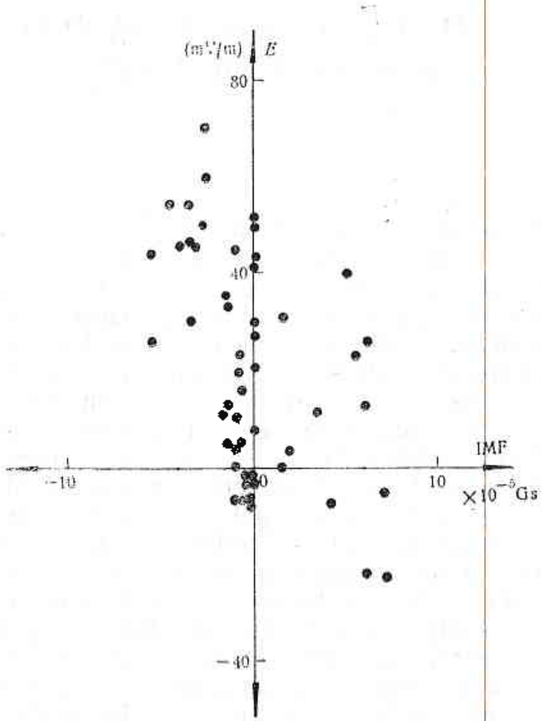

Fig. 2. Electric field dependence on the vertical component (balloon measurements) for the polar cap.

boundary magnetospheric layer is located at closed field lines [4]. Considering the south component of the interplanetary magnetic field, the convection remains in general the same but new convection fluxes appear on the open field lines in the polar cap. Although the conclusions based on laboratory experiments are confirmed by some ground-based observations, they still require further illumination.

Information obtained from measurements over the earth polar cap is often contradictory, i. e. the correct electric field measurements are not yet a reliable method. Balloon measurements [6], carried out by Mozer as early as 1974 (Fig. 2), agree rather well with the laboratory data but the large scatter of

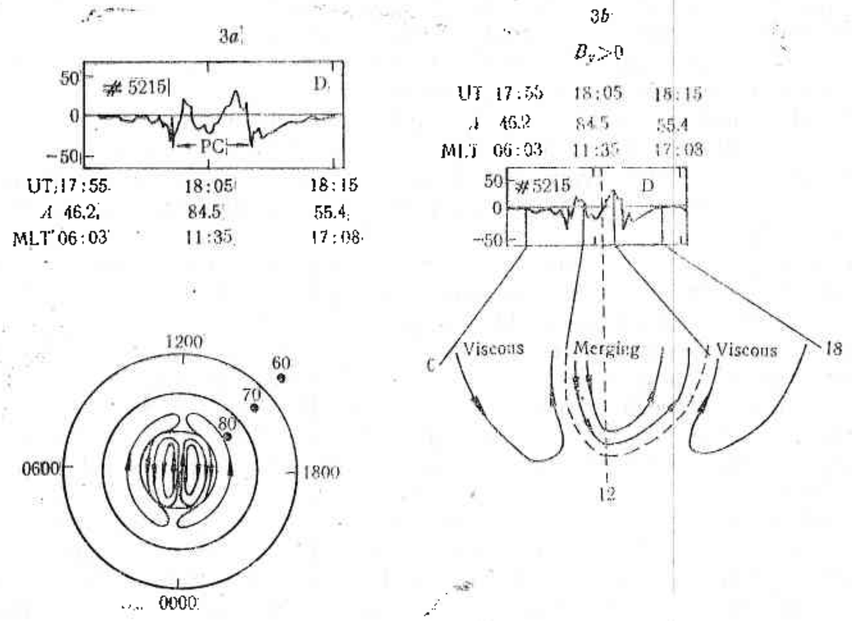

Fig. 3. Electric field distribution in the polar cap under the northern component of four-vortex convection model (a), three-vortex model (b)

the points in Fig. 2 makes questionable the statement that at large positive B_z values the plasma drift in the polar cap is really reversive to the solar wind. Many geophysicists even do not consider the possibility of existence of such drift phenomenon. Additional evidence on the correctness of the results obtained for the existence of the polar cap convection and sun convection at $B_z>0$ was obtained recently.

Data from [7] which give results from measurements of the electric field on board the polar satellite S3-2 show that at the northern component of the interplanetary field, a clearly expressed convection in the polar cap is to be seen oriented sunward. Nevertheless, it is difficult to state that the situation is completely comprehensive. Thus, for instance, some authors based on measurements from S3-2 conclude on the generation of two additional vortex systems in the polar cap under the northern component of IMF (two convective vortex systems result from effects of the viscous interaction and other two — from effects of the reconnection) (Fig. 3a). There is another interpretation of the same data given in [8]. Crooker considers the northern component of IMF to add only one convective nucleus to the polar cap (Fig. 3b). Thus, the results shown here demonstrate the necessity of systematic electric field measurements in auroral regions and in the polar cap.

2. Field-Aligned Currents

The field-aligned currents play a key role in the energy transfer from solar wind to polar ionosphere. Magnetic field disturbances due to the field-aligned currents have been studied for years. The basic portion of the data on the field-aligned current distribution was obtained on TRIAD satellite. The results from these measurements are already well known and it is aimless to consider them in detail. Brief summary on the results might be represented as follows 1) two current systems (1) and (2) are available (Fig. 4). The current system (1) coincides approximately with the polar portion of the auroral oval and system (2) — with its equatorial portion; 2) the current in system (1) flows to the ionosphere — in the evening side; the direction of currents in system (2) is reverse; 3) current in system (1) exceeds, on the average, the current flow in system (2).

We should note that only the magnetic measurements performed on board Triad satellite composed the experiment. Charged particles and electric fields experiments were not envolved in this program.

Many results support the fact of increased informativity in simultaneons measurements of charged particles and field-aligned currents. This is clearly expressed in the experiments on ISIS-2 [9, 10]. The data comparison between magnetic measurements and simultaneons electron fluxes measurements within the energy range of 0.15-10 keV enabled the discovery of new interesting features. The poleward boundary of the current system (1) coincides with the high-latitudinal boundary of plasma layer. In the case of B_z (IMF)$<1\gamma$, morning and evening sectors, change of convection direction often takes place at lower latitudes, compared to the latitude at which the outer boundary in plasma layer is projected. This provides for the very important conclusion that the outer region of the plasma layer at low altitudes, where the convection is oriented from the Sun, is projected in the viscous boundary layer adjacent to the magnetosphere boundary. This result supports conclusions reached on the basis of laboratory modelling. It is interesting to note that although electric field measurements were not performed on board ISIS-2, the picture of convection was reconstructed by magnetic measurements only. The magnetic lines which can be considered as elastic strings, convect in a conductive ionosphere and

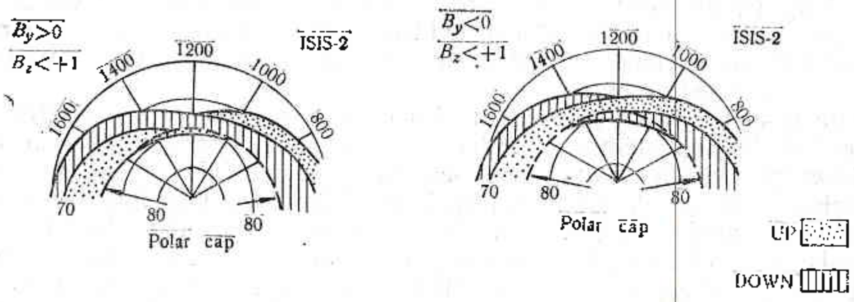

Fig. 4. Field-aligned current picture for $By>0$ and $By<0$ on TRIAD data and on ISIS-2 data. Convection directions are given with arrows

therefore experience a force $\mathbf{J}\times\mathbf{B}$. This force, acting in direction opposite to the convection, would result in a slight change of the magnetic field vector. Thus, we may judge by the sign of the disturbance about the convective flow direction. The orientation accuracy of ISIS-2 satellite was $\sim 0.1°$ which materializes records of field vector deviation $\sim 3'$. The data thus obtained give evidence for the reversive convection change in the polar cap under the northern component of IMF. Figure 5 shows the dependence of disturbance ΔB_x on the vertical component B_z IMF built up on data from ISIS-2 for the polar cap.

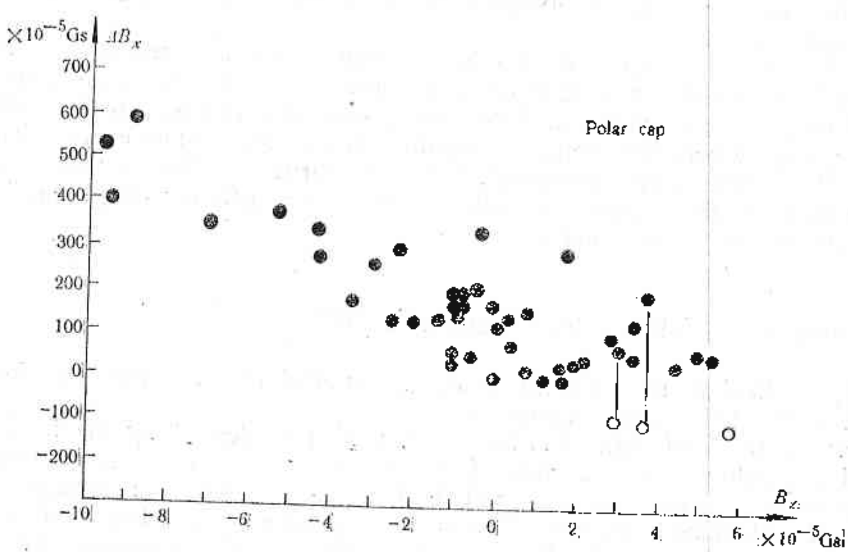

Fig. 5. Magnetic field disturbances dependence (ΔB_x) on (B_z) value and sign

The nature of this dependence is similar to laboratory experiments (Fig. 1) but naturally the statistics of the negative ΔB_x corresponding to tail convection is significantly lower here. Anyway, it should be considered that such picture, constructed on magnetic data only, is somewhat idealized and the directional change of the field line depends on the ionospheric conductivity which may vary incontrollably. Therefore, data obtained from ISIS-2 require additional support based on simultaneous electric and magnetic measurements.

An important feature of the results obtained on board TRIAD and ISIS-2 satellites from measurements of the magnetic field disturbances is the dependence of their sign on the sign of B_y in the noon sector (10:00-15:00 MLT). The sign of the magnetic disturbance due to field-aligned currents is such that plasma convection in the polar casp region appears mainly westward when $B_y > 0$ and eastward when $B_y > 0$ (Fig. 3). Currents available here are predominantly oriented upward from the northern polar cap for $B_y > 0$ and downward for $B_y < 0$. We should note that currents in the region of the noon meridian built up upon data from TRIAD satellite are different from the picture obtained by ISIS-2. It is seen in Fig. 4 that unlike the scheme built up with the TRIAD measurements, the scheme obtained by ISIS-2 depicts all currents in the casp region to flow either upward ($B_y > 0$) or downward ($B_y < 0$) — north polar cap. There are other differences, e. g. a Canadian team analysing data from ISIS-2 have found clear correlation between B_y value and the values of the field-aligned currents in the region of the polar casp while this fact has not been observed by others. Thus field-aligned current distribution, especially in the region 12:00 and 24:00 MLT, is not well studied yet. Poorly studied is the fine structure of the currents themselves. Measurements from satellite with circular polar orbit are needed for various longitudes in the polar ionosphere, the orbital height should be$\geq 10^3$ m, so that the satellite should be located considerably higher than the system of ionospheric currents.

Simultaneous measurement of electric and magnetic fields in the polar ionosphere should be carried out together with measurements of the interplanetary magnetic field. The operation of one or better of several satellites on ecliptic orbit is required for such measurements with apogee of more than 20 R_s (e. g. Prognoz-type satellites).

Interpretation accuracy of electric and magnetic field measurements should be controlled by direct determination of drift velocity of cold plasma. A retarding potential analyser on board the satellite can measure the vector sum of drift velocities and the spacecraft. Simultaneous measurements of angular and energy characteristics of magnetospheric precipitated charged particles allows for the correct determination of the topological link between the different magnetospheric regions and the polar ionosphere.

3. Anomalous Resistance and Double Layers

Problems on field-aligned electric fields and anomalous resistance are directly attached to the field-aligned currents.

Considerations of high mobility of charged particles along the field and the equipotentiality of the magnetic field lines are not always correct. Usually two reasons for violation of the equipotentiality are underlined: (1) anomalous increase of resistance when the electron current velocity reaches certain critical value; (2) formation of self-sustained electric charge distribution of double electric layer type. Both mechanisms of significant potential drop were observed in laboratory conditions and were considered in theoretical works. They result in significant potential drop within limited sectors and when precipitated particles appear.

Kindel and Kennel [11] have initially discussed in detail the problem of stability of field-aligned currents with regard to excitement of plasma waves in the auroral zone. Basic factors responsible for the generation of anomalous resistance at altitudes of$\geq$1000 km are the ion-acoustic instability and the ion-cyclotron wave instbility. In terms of ion-acoustic instability it is well known that in plasma with $T_e \gg T_i$ the critical drift velocity appears when the instability is $v_{kp} \sim 4\sqrt{2T_i/m}$. In isothermal plasma the threshold increases up to $v_{kp} \sim \sqrt{2T_e/m}$ as Landau damping for ions becomes very strong. Characteristic frequencies of these waves $\omega \simeq \Omega_{pi}$ correspond to wavelenght of the order of Debay radius. But as already shown by Kindel and Kennel, within a large range of electron and ion temperature ratios (e. g., in hydrogen plasma for $0.1 \leq T_e/T_i \leq 0.8$) the threshold of excitation for the electrostatic ion-cyclotron waves is lower than the corresponding threshold of the ion sound. For example, at $T_e \sim T_i$ $v_{kp} \sim 13\sqrt{2T_i/m}$. When the ion-cyclotronic threshold of the instability is attained, waves of frequencies slightly exceeding the cyclotronic frequency are generated ($\omega \sim 1.2\Omega H_i$ for $T_e \sim T_i$ and $\omega \sim 1.5\Omega H_i$ for $T_e \gg T_i$). Transverse wavelength of such occillations is of the order of the Larmour ion radius and the field-aligned ~ 10 Larmour radii. With the increase of current velocity the next harmonics are excited. It is interesting to note that the insertion of heavy ions into the light hydrogen plasma shock waves. Other bursts of the ion-cyclotron noise clearly correlate with electron fluxes (0.074-5.04 KeV) and turbulence field-aligned electric fields. It is interesting to note that one of the antennas on the S3-3 satellite could operate in Langmuir probe regime and this enables to receive the density fluctuations spectrum. Four maxima are clearly seen approximately at the ion-cyclotron frequency fH^+ and its harmonics. As far as f_{max}, T_e/T_i can be evaluated directly from the dispersion

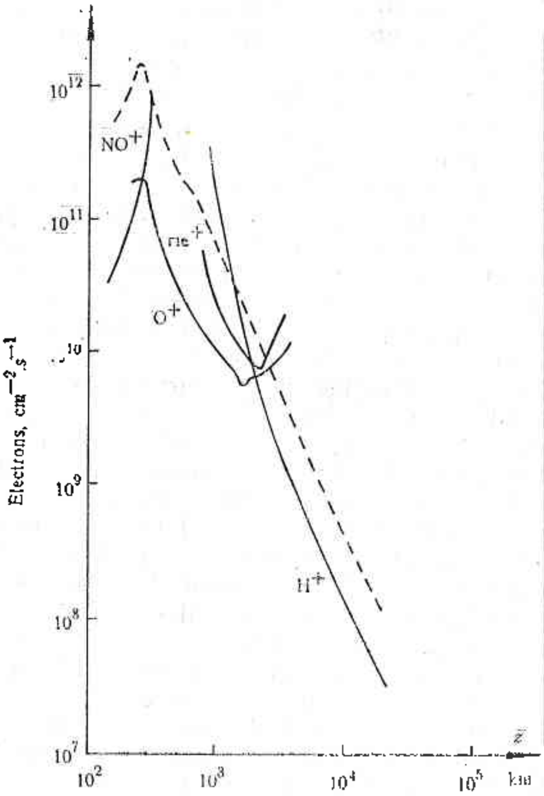

Fig. 6 Critical current dependence of height
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ratio of ion-cyclotron waves. This is $\gtrsim 1$. Noise level $\varepsilon = \frac{E^2}{8\pi n T_e} \sim 7\ 10^{-4}$. Anomalous resistance calculated on the measured ion-cyclotron fluctuation level $\eta \sim 10^{2\Omega}/m$ (for comparison we shall note that the value of the classic Coulombs resistance is $10^{-3\Omega}/m$, i. e. by 5 orders of magnitude lower). Thus the field-aligned electric field can be evaluated by $E = \eta j$ ($i \sim 10^{-5} a/m^2$). It is ~ 1mV/m i. e. if an anomalous resistance exists in several thousands of kilometres, it is easy to obtain potential drop along magnetic field line of several kilovolts, which is sufficient to explain accelerations of auroral particles observed.

We have to consider that ion-cyclotron turbulence was observed only at height of $\gtrsim 2{,}000$ km. This could be related with the fact that at lower heights the critical current velocity was not attained, to excite ion-cyclotron turbulence at the harmonics of ion hydrogen cyclotron frequency. At heights of 1,000 km, as seen in Fig. 6, the ion-cyclotron turbulence should be excited first at frequencies corresponding to heavier ions, i. e., oxygen ions, i. e. lower frequencies of 2-10 Hz. The instruments on board S3-3 could record electric fluctuations only with frequencies of $\geq$30-50 Hz. That is why measurements of AC electric fields at lower frequencies are necessary in order to understand whether waves of frequencies of $n\frac{eH}{M_0+c}$ are excited at heights $\sim$1,000 km, decreases the thershold of ion-cyclotron instability and increases the range of electron and ion temperature ratio, at which ion-cyclotronic turbulence is still dominant. Roughly speaking, the critical drift velocity in multicomponent plasma with respect to the ion sound is basically defined by light ions, while for the ion-cyclotron waves this is performed by the heavy ions. The initial excitation of ion-cyclotron waves starts at frequencies corresponding to the cyclotron frequencies of heavier ions O^+, followed by He^+ and H^+. This is well seen in Fig. 6, where critical current values are shown, exciting various types of waves depending on altitude. At low current density, the ion-cyclotron waves with frequencies corresponding to cyclotron frequencies of hydrogen ions are excited at heights higher than 1,000 km. When the current density increases, the region of instability descends until excitation of waves corresponding to heavier component — oxygen ions — begins. Which are the real current density values? For instance, in situation of a "calm" magnetosphere, the maximum currents were observed in the current system of type (1) within the region 7-8 hrs. MLT (10^9 electrons. cm^{-2} s^{-1}), i. e. practically such currents may easily excite an ion-cyclorton turbulence. Recent measurements of electric fields and the density fluctuation on board S5-3 satellite had confirmed these conclusions [12-13]. On board S3-3 the fields were measured in the range 0.5-16 KHz with wide band receiver (ion-cyclotron frequency corresponding to the hydrogen ions is of the order of 100 GHz). The ion-cyclotron turbulence was observed in large interval in the local time but as a rule on L-shelves [6] only. The typical duration of such phenomena is $\sim$5 s ($\sim$35 km) which corresponds to scale of $\sim$10 km in the lower ionosphere. Maximum noises were attached to large ($\geq$120 nV/m) field-aligned electric fields in the so-called electrostatic where $n=1,2,...$, or the turbulence source is located in fact at higher altitudes. Ion-cyclotron turbulence could be excited not only by field-aligned current electrons, but also by ion fluxes. It is quite possible for both mechanisms to operate. Therefore, simultaneous measurements of field-aligned currents, ion fluxes and electric noises would help to understand better the reasons of ion-cyclotron waves generation. In such a complex of measurements quite important are measurements in directions transverse to the magnetic field as far as the ion-cyclotron waves in a resonant way accelerate ions perpendicular to the field. According to the theory given in [14], the energy acquired by them could exceed 0.5 keV. Ion acceleration transversely to the field was actually observed on S3-3 satellite [15]. We shall also consider that modes correspondent to oxygen ions are difficult to identify as the phase velocity of these waves is about an order of madnitude lower and that is why the Doppler shift due to satellite motion would result in spectral enlargement.

Peculiarities in electron precipitation distribution from inverted V-type observed as early as Injun-5 experiment, and also O^+ and H^+ fluxes of ionspheric origin accelerated to energies of several keV moving upward along the field lines, seemed to be interpreted in terms of simple existence of field-aligned electric fields and anomalous resistance. At the same time, the value of field-aligned electric fields required to supply the observed potential drop have to be of the order of several mV/m.

Data from measurements performed on board S3-3 satellite obviously give considerably larger values — about several hundreds of mV/m (Fig.7). This value should be considered carefully as far as the error in the angular resolution of the antenna at strong field-aligned electric fields could significantly augment this value. If such electric fields really exist, it is already impossible to interpret them with the anomalous resistance effects (AC electric fields in

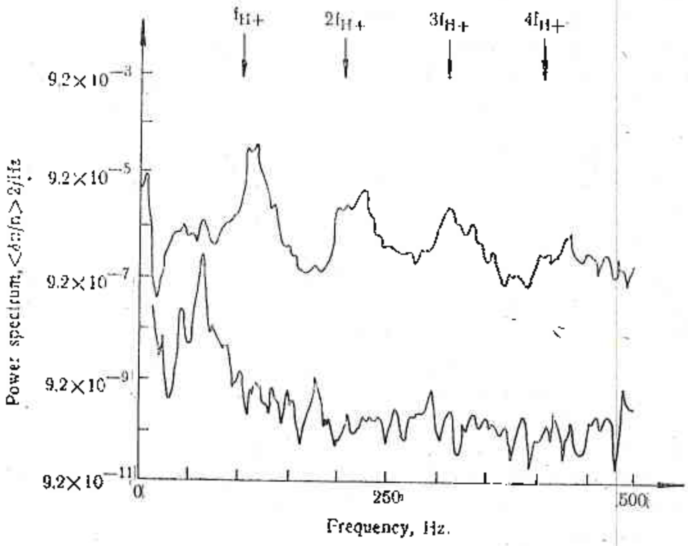

Fig. 7. Energy spectrum of ion-cyclotron turbulence as measured on board S3-3 satellite

such case have to attain values of about tens of V/m, which exceeds significantly the level of recorded noises). Obviously they are related to the formation of so-called double layers in the plasma. Double layers were discovered by Langmuir some 50 years ago in studies of gas discharges. Similar to the phenomenon of anomalous resistance, the double layer generates only when the current density starts to exceed some threshold values. In double layers observed in the magnetosphere, the low-potential boundary of the layer is further from the Earth than the high-potential one. Passing through the potential jump in the double layer, the electrons are enhanced in one direction and the ions in another. In order to generate a double layer, rather specific charged particles distribution is required. Their trajectories should be such as to enable abundance of one charge compared to the other at the double layer boundaries.

In the theoretical models of double layers the problem of distribution of charged particle populations is very important (as a rule in theoretical works only steady-state solutions are considered, i. e. the self-consistent problem is rather complicated).

Obviously the model of thermal electron and ion distribution, where ionospheric ions move upward and hot electrons move earthward, is most reasonable for the magnetosphere. But the problem of how the particle distribution functions are built to generate a double layer is still unclear. At present not only the evolution of distribution functions is not studied, but the same refers even to the steady-state charged particle distribution. The problem of what reflects upward acceleration of ions and provides for positive charge excess at low double layer boundary is still open. Whether they are back-scattered at ion-cyclotron fluctuations or at higher altitudes, double layers of reverse charge distribution are formed at its boundaries. It is not clear why often in measurements of field-aligned electric fields double structures are observed. Is this a simple result from equipotential short-circuit generated along the double layer field lines or a result from two double "steep" layers formation (ion-cyclotron shock waves)? It is hard even to predict whether anomalous resistance or double layers would result from field-aligned current instabilily. Therefore, further study on double layers is required, based on three-component electric field sensors and charged particle detectors, on board satellites on polar orbit.

Besides ion-cyclotron and ion-acoustic fluctuations responsible for the generation of anomalous resistance and electrostatic shock waves (double layers), rather interesting are emissions in the region of the low hybrid resonance and also Whistler mode controlling electron distribution in the earth radiation belts and various types of hydromagnetic fluctuations excited in auroral regions by the ring current precipitated particle fluxes.

We should pay attention to measurements of the so-called high latitude turbulence (HLT) characterized with wide band low-frequency spectrum (<500 Hz) and observed in auroral regions at all MLT. This turbulence is obviously attached to Kelvin-Helmholtz instability generated at plasma flows of heterogeneous velocity profile [16]. Although HLT-turbulence is pretty thoroughly studied on board OVI-17, S3-3 and Hawkeye satellities, simultaneous measurements of plasma drift variations and electrostatic noises would enable the better understanding of suggested cascade mechanisms of this turbulence [17].

4. Stable Auroral Red Arcs

The importance of ring currents in dynamic ionospheric-magnetospheric interactions comes from the amount of energy stored in this region ($\sim 10^{23}$ ergs). Even if a small portion of this is given to the ionosphere, it could result in a spectacular change in the ionospheric situation. Simultaneous measurements of emission spectra of the upper ionosphere, charged particles fluxes and electromagnetic waves would permit to clarify series of important regularities in such effects. In particular, these measurements would help to understand the nature of red arcs generated at latitudes corresponding to $L=2\text{-}4$ [18]. Subauroral red arcs appear in the recovery phase of the geomagnetic storm. According to the generally accepted viewpoint, these emissions (mainly oxygen line — 6,300 Å) are generated by heated electrons. The mechanism of electron heating is generally attached to ring current dissipation. During the recovery phase the ring current is located deeper in the plasmasphere [19]. When the plasmasphere is filled with sufficient amount of ring current ions, this generates the electromagnetic ion-cyclotron turbulence. Scattered at ion-cyclotron waves, ions fall into the loss cone and precipitate downward. In its turn, the ion-cyclotron turbulence could heat thermal electrons from the plasmasphere at the expense of Landau dumping. Experimental data [20] are available, which show that simultaneously with the increase of ring current the ion-cyclotron waves are to be observed. Together with this, dramatic change in the pitch angle distribution of ring current particles takes plase (it becomes anisotropic). But regardless of the fact that this theory correctly predicts red arcs location, it does not explain how the energy transferred to electrons is transported from the equatorial regions, where the heating takes place, downward to the ionosphere. For example, electrons heated at the plasmasphere boundary up to $\sim$10 eV could become trapped by the magnetic field (collision frequency $\sim 10^{-5} s^{-1}$), therefore a process resulting in their precipitation is required. We should also note that on board S3-3 satellite only 18 events were recorded, which may be identified as ion-cyclotron turbulence as some of them were not accompanied by any change in pitch angular distribution of ions [21]. On board Hawkeye-1 only 5 such events were observed in 18 months period, although in 14 cases when considerable weakening in D_{st} (-25γ) was observed, no ion-cyclotron turbulence was recorded [22].

In [23] another mechanism of electron heating is suggested. This is attached to the kinetic Alfven waves dissipation. Such waves (of transverse to the magnetic field wavelength of the order of the ion Larmour radius) could be excited at the expense of conversion from MHD-surface waves. Field-aligned electric fields existing in these waves could heat cold electrons by resonance mode ($V_A - 1.7 V_{Te}$). Heating is of local nature along L-shelves since its velocity rapidly decreases moving away from the resonance. Such a mechanism provides for direct precipitation of heated electrons, since the wavelength along the field line is comparable to the field tube length itself. Indirect support to this mechanism was obtained with ground-based magnetic measurements [24]. Large fluxes of precipitated electrons ($\sim$20 eV) were also reported in [25]. Thus various hypotheses interpreting red arcs are available. For the proper understanding of their generation mechanism, it is necessary to perform complex simultaneous measurements on polar orbit satellite on precipitated particles fluxes, wave measurements, space scanning of red line emissions. In order to obtain information on the ring current situation, the operation of another satellite is required as its orbit should cross the region of the ring current — plasmasphere at low latitudes. Very important are the ground observation of magnetic field pulsation.

5. Active Experiment

Recently, the mechanisms of particle filling and decay of the ring current are intensively studied. Important information on decay mechanism should be given by the experiment of forced particle precipitation, the point being that the ring current is in thermodynamic unsteady state and plasma injection could become a triggering mechanism resulting in particle evacuation to the atmosphere and therefore to excitation of aurora.

When compact plasma beam is injected into the magnetosphere, particles precipitation could be activated due to two reasons: (a) magnetic field distortion; (b) wave excitation and particle velocity vector shifted to the loss cone at the expense of resonance wave-particle interaction. In the second case, precipitation would appear after plasma filling in the respective field tube. Complex of wave measurements would enable the separation of these processes. The records of artificially excited aurora should be effected on board the satellite together with ground photographic and radiolocation means.

Compact plasma beam may be obtained by pulse electrodynamic accelerator. Such accelerators have been designed in the USSR as early as 1958 for the purposes of thermonuclear studies and are largely used recently in various technical fields, including spacecrafts. If barium is selected as operation material, we may observe the whole injection process after the beam injection near the terminator including the delicate effects of the beam and the magnetic field interactions. These observations could happen to be of unique nature since such experiments are difficult to be performed in laboratories due to the chamber wall effects. Ground observations of injections are possible at total quantity of injected particles $10^{19} \div 10^{20}$ cm^{-3}.

In order to avoid the negative effects of accelerator pulses on the proper functioning of the other instruments, it is useful to perform injection after the accomplishment of the geophysical experimental program.

6. The Midlatitudinal Trough

Specific for the upper ionosphere is the existence of sufficiently narrow regions of low ion density. Recently the morphology of such troughs (mid-and high-latitude) and their interaction with the plasmapause and the polar casp are thoroughly studied. The interpretation of these specifics, in agreement with observation data available, is not yet obtained. In accordance with some hypotheses, a very important role in trough formation is played by the electric fields generating plasma convection. Ion drift with respect to neutrals spectacularly increases the velocity of some plasmachemical reactions, e. g. the density of molecular ions [26] increases due to $O^+ + N_2 \rightarrow NO + N^+$. Molecular ions in their turn quickly recombine and the total ion density lowers. There is another hypothesis for the trough formation given in [27]. Insofar as plasma convection at ionospheric heights is defined both by electric fields, generated by solar wind interactions with the magnetosphere (effects of recombination and viscousity), and by electric fields related to planetary rotation, the resultant convection pattern (Fig. 8) could establish particular regions of very slow plasma motion on the night side. Since plasma in these regions is maintained for a long time, recombination processes decrease significantly the ion density. Simultaneous measurements of plasma convection with electric field and ion drift sensors, together with mass-energy analyser of thermal plasma in the trough regions, would enable the understanding of the nature of these interesting features.

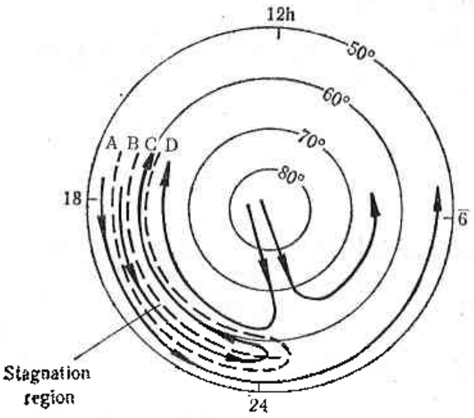

Fig. 8. Scheme of generation mechanism of the midlatitudinal trough. In the *D*-region the flux is defined by the electric field, while in the *A*-region it is determined by the field related to the earth rotation. In the intermediary regions *B* and *C* the flux direction changes from east to west. The "stagnation" region — E-W velocity component becomes zero.

7. Electric Fields in the Equatorial Ionosphere

We should pay attention to electric field measurements in the equatorial ionosphere, since recent experimental data provide evidence on the interactions between the electric field at ionospheric heights and the orientation of the interplanetary magnetic field [28, 29]. The electric field in the magnetospheric tail is usually oriented from morning to evening side (this field is either projected in tail by the solar wind or is induced by viscous plasma — field interaction at the magnetospheric boundary). In a stationary situtation the electric field cannot penetrate into the plasmasphere due to the screening effect of polarizing charges formed near its boundary. However, the variations of this field with the characteristic time of ≤1 hour could be observed deep into the plasmasphere. For example, the fast sign change in IMF from the stable south direction to the north generates anomalous turn in the zonal equatorial electric field. The interpretation of this very interesting effect could be related with the fact that such change of IMF vector direction leads to the decrease of the electric field in the polar cap and possibly changes its sign, therefore that happens inside the magnetosphere too. Screening charges in the plasma layer boundary cannot redistribute so fast, which results in electric field orientation from evening to morning side inside the plasmasphere. There are data showing dependence of the electric field on the B_y component of IMF, for the equatorial ionosphere. Such relationship between IMF and convection in the magnetosphere, on the one hand, and the processes taking place deeply into the plasmasphere, on the other, are quite intriguing and require thorough study. Drift measurements of charged particles and electric fields at low latitudes and the comparison with IMF data will give a key to the solution of this problem.

8. Altitudinal Thermal Plasma Distribution

Problems referring to thermal plasma distribution along field tubes are of particular interest, together with relations between ionosphere and plasmasphere. In daytime thermal proton fluxes from the ionosphere fill up the plasmasphere field tubes. During the night the recombination processes become predominant and the energy stored in the plasmasphere feeds back into the ionosphere, i. e. fluxes from the plasmasphere maintain the existence of the F-layer. The link between these two regions has a dynamic character. For instance, during magnetospheric disturbances, plasmaspheric field tubes may convect to the far magnetosphere where they lose their plasma content. Pressure gradients generated at this process in the "empty" tubes must create large plasma flow from the ionosphere similar to the polar wind, which refills the plasmasphere. The plasma flow induced in this way may be superimposed by a flow induced by the interaction of the F-region ionosphere with neutral winds. The neutral wind forces the ions to move along magnetic field lines. Depending on the magnetic inclination, the velocity component of the neutral wind along the field line should be different. This could result in lifting or descending ionization in the F-layer. Thus, for instance, an equatorward meridional wind in the northern hemisphere will result in altitudinal increase in the F-layer until the drag force between ions and neutrals is not balanced by the earth gravity, density gradient and polarization fields. Usually the time required for establishing the diffusive equilibrium in a given field tube is much smaller than the characteristic time of wind system variations in the F-region, therefore we may suggest that the shift of the F-layer will result in a corresponding increase and decrease of the ion density at heights of 1,000 km [30]. This means that the global measurement of the ion density at heights well above the F-layer maximum are important for the studies of large-scale air mass transfer in the night midlatitudinal F-region. In order to avoid effects of altitudinal change in the ion density, it is necessary to have a circular orbit satellite.

Basic difficulty in the interpretation on the experimental data is the necessity to select effects related to the different behaviour of O^+ and H^+ density. As shown in [30], the sharp decrease of the boundary above which the H^+

ion density slightly changes with the altitude, is observed during the night at magnetic latitudes of $\pm 30°$. The boundary at these latitudes is located at height of ~600 km. It appears that the ion density is approximately the same at both ends of the field tube at 1000 km where the invariant latitude is $\Lambda = 30$-$50°$, independent of how low the O^+ ion density is. This brings to the idea that H^+ ion in distribution along magnetic field lines is controlled by equalizing the pressure along the entire field tube and does not depend severely on O^+ and H^+ interactions in the ionosphere. Such conclusion means that measurements at heights of about 1,000 km of H^+ density reflect the dynamics of plasmasphere rather than that of the ionosphere.

9. Equatorial Anomaly

Figure 9 illustrates light ion distribution at 1,000 km at night [32]. It is well seen that the distribution of hydrogen ions is bi-maximal. Minimum H^+ density is to be found in the equatorial region. Hydrogen ion density falls sharply after ~40° latitude, forming the equatorial boundary of the midlatitudinal trough of light ions. The anomaly appears also in the ion composition and temperature. Such minimum and two maxima in the equatorial *F*-region are formed in afternoon hours as a result of two effects — $\mathbf{E}\times\mathbf{B}$ drift due to E-W electric field and plasma diffusion in meridional direction along the magnetic field tubes. This is familiar as "fountain" effect. But the theory of nighttime equatorial anomaly formation and its dynamic should not be considered accomplished yet. In particular, the equatorial anomaly property largely depends on longitude. Longitudinal variations of equatorial ionosphere result from upward and downward plasma motion effects. In their turn, the latter to a

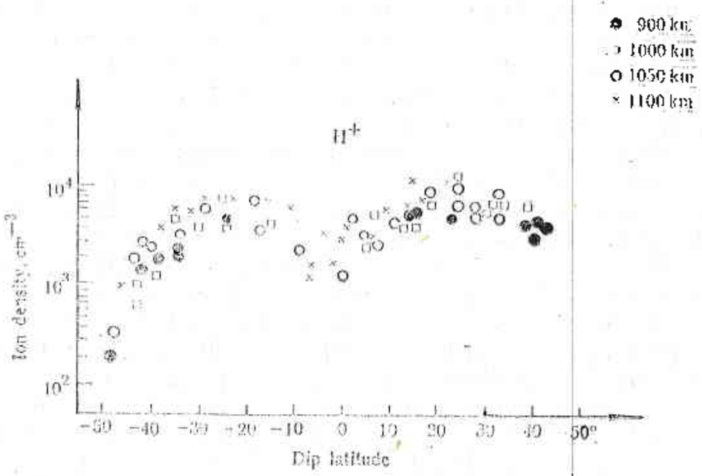

Fig. 9. Light ions distribution at height of ~1,000 km from latitude

large degree are determined by the neutral winds. Simultaneous measurements of electric fields, electron and ion density distribution and velocity of charged particles drift on board polar orbit setellites would enable the better understanding of the entire complex of sophisticated interacting factors.

10. Circulation in the Thermosphere

Certain ionospheric phenomena are directly linked to winds in the upper atmosphere. Interaction between solar wind and atmosphere is effected by two basic mechanisms: (1) auroral particle precipitation; dissipation of ionospheric current systems. These processes take place in general at high-latitude atmosphere, while ultraviolet heating has maximum at the subsolar point. The relatively constant heating by the solar uv generates thermospheric circulation which is the reason of the global wind system generation at heights of 100 km, described in [33, 34]. The Joule heating and heating from precipitated particles due to the above-mentioned process results in generation of a secondary wind system of variable equatorial boundary in dependence on the magnetic activity. Typical circulation pattern in the meridian plane is shown in Fig. 10 [33, 34, 35, 36]. The formation of a secondary wind system oriented from high to low geographic latitudes may be due to the fact that the heating in high-latitude regions becomes comparable to the solar ultraviolet heating [37].

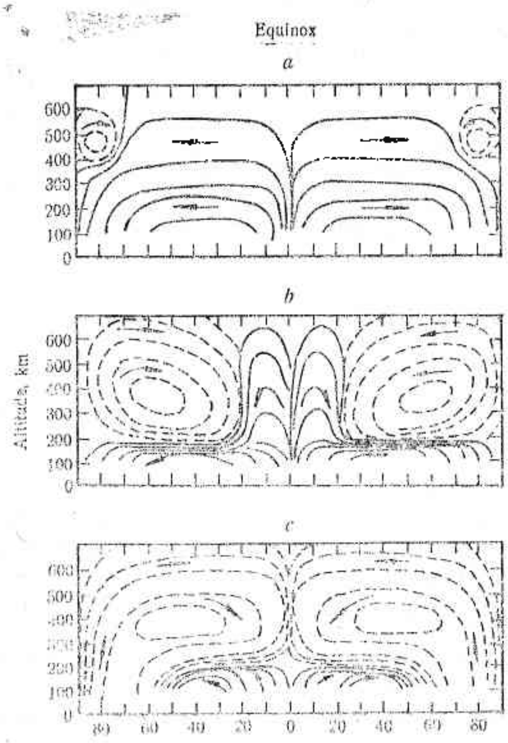

Fig. 10. Diagram of the zonal mid-meridional circulation in earth thermosphere for the equinox period with reference to various levels of auroral activity (*a*) extremely calm geomagnetic activity, (*b*) average activity (10^{18} erg. S^{-1}) and (*c*) geomagnetic storm (10^{19} erg. S^{-1}). The contours illustrate schematically the mass flux and the arrows show the motion direction

In equinox periods the circulation due to solar ultraviolet is manifested by upward motion over the geographic equator with a subsequent poleward streaming. The secondary circulation due to auroral heating has a reverse direction - - from the pole to the equator and its equatorial boundary depends on the energy supplied into the atmosphere. During magnetic substorms the normal circulation is constrained only to heights lower than 150 km and to low and mid-geographic latitudes.

During the solar solstice the circulation due to the solar ultraviolet has direction from summer to winter hemisphere. Auroral atmospheric heating gives rise to circulation from pole to equator in the winter hemisphere. Its equatorial boundary shifts depending on the degree of the magnetic disturbance. In the summer hemisphere the circulation is maintained at its normal state. The changes described above are the major motions of thermospheric circulation in which the Eerth upper atmosphere is involved during magnetic distrubances. Many small-scale motions are also observed.

Investigations of the three-dimentional circulation of thermosphere under various levels of solar and magnetic activity are still in their initial phase. The complete understanding of these processes would permit the evaluation of the ionospheric effect on circulation. Simultaneous measurements of the differential charge particle spectrum and the dissipation of current systems would enable the definition of total energy flux at subauroral and auroral latitudes. A possibility to establish a model of earth atmospheric circulation emerges from combined data on air-glow emissions [38].

11. Plasma Irregularities in the Ionosphere

Measurements performed on board satellites [32, 39] enabled the discovery of irregularities in the ionospheric plasma at relatively high latitudes. The spatial sizes of these irregularities range between 30 and 50 km. These irregularities play an important role for the problem of spaceborne radiocommunications. Particularly interesting is the shortwave irregularities phenomenon (10-100 km). In order to measure irregularities in ionospheric plasma density, the application of Langmuir probes may be useful. It is substantial to understand the main mechanisms of irregularity generation. Particularly large irregularities are observed in the region of the midlatitudinal trough which could result, for instance, from large gradients and strong electric fields triggering the generation of various types of plasma irregularities. Still open is the problem of interactions between midlatitudinal trough dynamics and the equatorial boundary of the high-latitude irregularities. Simultaneous measurements on thermal plasma and electric fields on board polar satellite of circular orbit may help to obtain the answer to these questions. Very important is the study of irregularities in the equatorial ionosphere. The nonreliability of satellite communication systems contributes to the increased interest toward this phenomenon. VHF-signals emitted by satellites and received on earth are largely deformed in the equatorial region.

Conclusion

The data presented in this work clearly show that the launch of satellites with circular polar orbits at heights of about 1,000 km would permit to solve a series of important problems related to phenomena in interplanetary medium, magnetosphere, ionosphere and earth atmosphere.

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О некоторых проблемах геофизики, решаемых с помощью спутников на полярных орбитах

В. М. Балебанов, М. М. Гогошев, Е. М. Дубинин, И. С. Кутиев, И. М. Подгорни, К. Б. Серафимов

(Резюме)

Рассматривается возможность установления зависимости между конвекцией магнитосферной плазмы и магнитным полем посредством измерения электрического и магнитного полей и регистрации плазменного дрейфа.

Такие эксперименты могут быть выполнены на спутниках на полярных орбитах как с целью выявления конвекции в области магнитной шапки, так и для изучения явления в экваториальных районах и термосферной циркуляции.