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# Contents

## Section C. Conductivity of the Earth

### Geoelectrical and geothermal models of the Pripyat Trough

*Astapenko, V.N. (State Enterprise "RPCG", Minsk, Belarus), Levashkevich, V.G.(National Academy of Sciences of Belarus) and Logvinov, I.M.( Institute of Geophysics NAS of Ukraine, Kiev, Ukraine)*

Pripyat Trough is a part of regional Palaeozoic – Phanerozoics Pripyat – Dnieper – Donets Palaeorift. The EUROBRIDGE'96 and EUROBRIDGE'97 profiles crosses the Pripyat Trough. Along this profiles seismic, geoelectrical and heat models of crust and upper mantle are compared. Complex interpretation allows to narrow a collection of alternative models and explains a nature of geophysical anomalies. Anomalous areas of conduction in the upper crust are in accordance with isotherms of 180–200°C. Anomalies in the lower crust are correlated with temperatures exceeding 450°C and connected with fluids which are separated from number of minerals. The Pripyat Trough is characterized by contrast heat field which values range from 40 mW/m$^2$ in the south part to 70 mW/m$^2$ in the north part of trough. The results of two-dimensional inversion of generalized curves of magnetotelluric soundings, which are situated on profile EUROBRIDGE'97 are shown. Existence of a conductive layer at depths exceeding 20 km is confirmed in large parts of profile. In the north part of the Pripyat Trough the resistance of upper mantle at depths of 60–100 km is lesser than 20 Ohm·m. Possible reason of anomaly is a presence of amphibolite in the mantle, as far as this region is expected to be a zone of the collision of palaeoproterozoic segments of the crust: Fennoscandia and Sarmatia.

### Physical scale modeling of TEM soundings using commercial Tcikl equipment

*Bobrov, N.Yu., Krylov, S.S., Mironov, A.A., Titov, A.V. (St.Petersburg State University, St.Petersburg, Russia)*

Physical modeling was carried out to evaluate the potential of transient electromagnetic soundings to unseal the peculiarities of saline-

dome tectonics. Two types of electromagnetic arrays were investigated: inductive excitement Qq array with rectangular loop as a transmitter and conductive excitement AMNB array. The simulated geoelectric structure was as follows: well conductive sedimentary cover overlaying resistive basement with salt formations of different size and shape penetrating sediments at bottom boundary.

Measurements with inductive array were made at aluminium full scale metal models with scaling factor 1:100000. Modeling of TEM soundings with AMNB array was carried out with scaling factor 1:10000 in electrolithic tank of size 4:4.5 m. Sedimentary cover was simulated by saturated NaCl solution, models of invaded salt formations were fabricated of concrete.

Commercially available Tcikl system was used for all experiments. At metal models the equipment was used as is without any modification. For measurements in the tank a separate generator with short pulse edge was applied and some improvements were made in the receiving channel to ensure possibility of measuring E-component of transient signal at short (mks) delays.

Valuable results have been obtained demonstrating effectiveness of AMNB array for detecting shape and size of salt domes.

### The distribution of electrical conductivity in the depths of the North Dobrudga and PeriDobrudga depression

*Burakhovych, T.K., Kushnir, A.N. (Geophysical Institute of NAS of Ukraine, Kiev, Ukraine)*

Our work is dedicated to the search for the interrelation between conductivity anomalies in the Earth's crust and upper mantle and foci of seismic events that have occurred on the territory of PeriDobrudga and North Dobrudga.

Based on the results of experimental MT and MVP investigation, regions of anomalously low magnitudes of electric resistivity ($\rho$) were found and 3D geoelectric models of the Earth crust and upper mantle. The velocity structure features of the mantle beneath Peridobrudga depression and its surroundings make a strong possibility to identify the preconditions of the mantle seismicity associated with the signs of mantle plumes (super-deep fluids) in the lower and middle mantle.

Three-dimensional deep geoelectric model built on results of modern MTS and MVP methods reflects inhomogeneous distribution of electric conductivity in the depth on the territory of PeriDobrudga depression and North Dobrudga. Anomalies of high electric conductivity from the surface of the Earth crust to the upper mantle are identified. Stretched for hundreds of kilometers conductors are associated with deep conductive fractures of different ranks and with their intersections: Frunze, Saratsky, Bolgrad, Cahul-Izmail, Chadyrlungsk fractures and others. A highly conductive layer is identified on the southern side of PeriDobrudga depression which lies at the depth corresponding to the lower crust and the top part of upper mantle. North side of PeriDobrudga depression is characterized by the distribution of electrical conductivity in the upper mantle which is the same as that of EEP, while presence of conductive structure at the depths of 110 to 160 km differs the southern slope from the northern one.

Without a doubt, there is a relationship between seismicity and geoelectric parameters that reflects the current state of the Earth's interior. The origin of high electric conductivity anomalies may be the result of geodynamic processes on the boundaries of regions characterized by various manifestations of these processes.

Earthquake sources as well as anomalies of high electric conductivity are mainly correlated with active deep tectonic fractures and juncture zones of geological structures such as different age zones of Precambrian EEP and Cimmerian Scythian plate on the territory of PeriDobrudga depression and North Dobrudga.

## Elaboration of a complex algorithm of neural network solution of the inverse problem of electrical prospecting based on data classification

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Solution of the inverse problem (IP) of electrical prospecting is the process of construction of an operator mapping the vector of components of electromagnetic fields measured on the Earth's surface to

the distribution of electrical conductivity in the studied underground area. As actual distributions are usually quite complex, their adequate description requires a large number of parameters, reaching several hundred even for the 2D-case. So this IP is a complicated high-dimensional ill-posed problem with a well-known instability.

To describe the sought distribution of the electrical conductivity, different parameterization schemes are used. The most general scheme G0 uses the values of conductivity in the nodes of a pre-defined grid, with further interpolation between nodes. More specific schemes may assume presence of one or several conducting or insulating layers with variable thickness and conductivity, on the top of the area of general parameterization.

Transfer from the solution of the IP within scheme G0 to its much more stable solution within one of specific schemes in a narrower class of geoelectric sections causes the necessity of prior classification of the studied data pattern, resulting in the selection of the most appropriate parameterization scheme.

In their previous studies, the authors considered the solution of the IP of magnetotelluric sounding (MTS) using artificial neural networks (ANN) (perceptrons). Also, it was demonstrated that the described classification problem can be successfully solved by ANN with average rate of correct determination of the parameterization scheme exceeding 97%.

Since then, the authors have elaborated a novel method of ANN-based solution of the MTS IP within scheme G0, based on simultaneous determination of a group of several parameters at once. Optimal conditions of such grouping were determined.

In this study, the developed method has been extended to other parameterization schemes. It is demonstrated that group determination of parameters is an effective method for ANN solution of the MTS IP for any parameterization scheme.

In future studies, it is planned to test the complex algorithm combining classification and IP solution within partial classes of geoelectrical sections against the general approach within the most general parameterization scheme G0.

**New stage of Lake Ladoga conductivity anomaly Mt/Mv studies**

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Observations of Lake Ladoga anomaly (LA) started in 1980-s when it was traced on the magnetovariational (MV) data as the most intensive segment of the Ladoga-Bothian Bay conductive zone associated with the Archaean-Proterozoic border. Further magnetotelluric (MT) studies, carried out mainly by St. Petersburg University, have permitted to construct in quasi-1D approach the first deep conductivity cross-section of the LA area.

New stage of LA studies started in 2013 due to collaborative efforts of MSU, SPbGU, IPE RAS and North-West ltd. The main purpose of these investigations is to extend limits of previous interpretation and proceed to 2D and 3D approaches on the base of modern synchronous MT/MV soundings in combination of broad-band and long-period ranges.

New 5 component observations have been carried out in 2013 by Nord-West ltd and in 2014 by Moscow State University. Viborg-Suoyarvi-2 profile across the Karelian Isthmus includes now 21 sites: 13 for MT/MV observations with Phoenix MTU-5 and LEMI-417M and 8 for deep (3-day) MT/MV observations with LEMI-417M.

We present estimates of impedance tensor, the tipper matrix and the horizontal magnetic tensor that have been received during RR processing of the 13 MT/MV sites of 2013 campaign, obtained by different processing codes, as well as the. These sites are located on the NW flank of LA and influence of the deep conductive zone can be easily traced on the results of transfer functions invariant analyses, namely tipper matrix and phase tensor ellipses behavior. On the

preliminary deep conductivity cross-section we can pick a few local conductivity zones, which we interpret as faults.

In addition, we present first SS data processing results from deep MT/MV observations of 2014.

### Different kind of induced polarization effects in rocks

*Hallbauer-Zadorozhnaya, V., Mare, L.P. (Council for Geoscience, Pretoria, 280 Pretoria rd, South Africa)*

It is known that there are at least four types of polarization effects occurring in the frequency range used in the electrical and electromagnetic exploration methods. These are electroosmosis, membrane, electrolyte (electrode) and Maxwell-Wagner polarizations. Each of these types has its own polarization mechanism and occurs in different types of rocks. Electroosmosis polarization is described by the Helmholtz- Smoluchowski equation and is related to the presence of electrical double layers. The membrane polarization mechanism is based on a little known IP model referred to as "induced polarization caused by constrictivity of pores". This polarization occurs in all types of rocks if surface areas and transfer numbers are different for connected pores. The Maxwell-Wagner effect is observed in rocks with isolated cells when an electric field is applied. Electrolytic (electrode) polarization occurs in pores containing metallic inclusions. Theoretical calculations for the different polarization mechanisms have been developed and laboratory measurements of resistivity, chargeability and pore size distribution in samples from different geological formations were carried out by the authors.

### TEM in South Africa: Recent Case Studies

*Hallbauer-Zadorozhnaya, V., Cheringe, E., Nyabeze, P.K. (Council for Geoscience, Pretoria, South Africa)*

Council for Geoscience carries out field works using time domain electromagnetic method (TEM) not only South Africa, but also in many countries in Africa (Mozambique, Rwanda, Zimbabwe, Congo (DRC). Three instruments have been used by CGS namely TEMFAST 48, Tsick 5 and Geonics. TEM in Africa has a number of features: most

of sections are high resistive and most of the TEM signals are affected by induced polarization effect. In addition, soil is presented by laterites through which superparamagnetic effect occurs. Various techniques not only eliminate these effect but use additional physics parameters for detalization of investigating objects. Here we would like to present some case studies, some results obtained in Southern Africa by TEM method using different instruments namely delineating diamondiferous gravel deposits, kimberlite fissure, map the border of mined-out and non mined area's, investigation of coal location, detection of aquifers above and below dolerite sill, study of water ingress, study of geological structures, delineation of hydrocarbon contamination of ground water and determination the internal structure of building material and it quality for planning and exploitation of carriers.

**Improving the accuracy of neural network solution of the inverse problem of electrical prospecting by group determination of parameters: verification on model data**

*Isaev, I.V., Dolenko, S.A. (D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia)*

The inverse problem (IP) of electrical prospecting is a problem of construction of the distribution of electrical conductivity in an underground area by the components of electromagnetic fields measured on its surface. The sought distribution in its most general form is described by parameters — the values of electrical conductivity at the nodes of a pre-defined spatial grid, with subsequent interpolation of values between nodes. To describe the distribution adequately, the number of such parameters must be sufficiently large, reaching several hundred even in the two-dimensional case.

In their previous studies, the authors considered the solution of the IP of magnetotelluric sounding (MTS) using artificial neural networks (perceptrons). First, the solution of the multi-parameter MTS IP with N determined parameters was performed by its division into N single-parameter problems. Later it was shown that joining of the sought parameters into small groups with simultaneous determination of the parameters within each group during neural network solution of the MTS IP allowed increasing accuracy and computational efficiency

of the solution in the case of similar relationships of the grouped parameters with input data.

In this study, the observed effect was verified in computational experiment on model data specified explicitly as complex polynomial dependences of the "observed values" (dependent variables) on the "parameters" (independent variables). The effect persists: in the cases of similar dependences of input data on the grouped parameters, simultaneous determination of the latter allows increasing the accuracy and computational efficiency of the IP solution. This leads to the conclusion that the observed effect of group determination of parameters is a fundamental property of perceptrons as a method of IP solution.

In their further studies, the authors plan to use this method to solve MTS IP using other parameterization schemes, including as determined parameters not only the values of electrical conductivity at certain points, but also the geometrical sizes of certain geological structures.

## Sounding of the Earth's crust using ULF phase-gradient method

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New method of the phase-gradient sounding (PGS) is proposed for investigation of geoelectric characteristics of the Earth's crust. In this method, magnetic gradientometers are used for construction of gradient and phase velocity vectors along the Earth's surface. The magnetic gradientometer consists of three three-component synchronized magnetic stations located in tops of a triangle at small distances (3–5 km) each from the other. The gradient vectors are directed to a local source of the ULF EM waves, and the phase velocity vectors — from the source. The vector directions give an opportunity to determine a location of geoelectric anomalies. Values of the phase velocities allow to calculate apparent resistivity of the Earth's crust for different frequencies in ULF range (F=0.001–10 Hz). The gradient and phase velocity vectors allow detecting epicenters of forthcoming strong earthquakes. Comparisons of the PGS method with the

widespread magneto-telluric sounding (MTS) method display a good coincidence.

### Results of electrical exploration data processing by statistical methods

*Karapetyan, K.A., Chilingaryan, A.Z. (Institute of Geophysics & Engineering Seismology NAS RA after A.Nazarov, Gyumri, Armenia)*

The problem of detection of weak anomalies is actual in solving problems of traditional exploration of ore deposits. In practice of geophysical works often such conditions arise when it becomes principally possible to use the methods of mathematical statistics to identify and interpret weak anomalies. Regarding the methods of ore geophysics, in practice the so-called inverse probability method is used successfully.

The presented statistical analysis method was used in combined electrical profiling data processing obtained at the site "Tigranasar" of Sotq gold deposit in Armenia. Electroprospecting studies have shown that low values of specific electrical resistivity of ore-bearing basic and ultrabasic rocks produce indistinct electric fields and anomalies that make their use difficult for the delineation of gabbro and peridotite massifs, as well as determination of prospects for detection of hidden gold mineralization. Specific electrical resistance of mineralized rocks varies within wide limits — from several hundred to several thousand Om.m. This also explains the need of statistical processing of combined electrical profiling data.

Thus, the anomaly detection algorithm obtained on the basis of applying statistical decision theory, on the one hand the optimal filtering of input data, i.e. anomalies selection process is ensured and on the other hand the possibility of calculating the a posteriori probability of the presence of anomalies.

At the result :

1. In Combined Electro Profiling data processing using the method of inverse probability anomalies in those areas can be identified where they have not been observed visually.

2. By higher values of P more than 0,5, the presence of anomalies can be noted with a certain probability, which coincides in form with the anomaly of the desired object.

3. The presented investigations lead to conclusion that it is feasible to use the inverse probability method in the stage of detailed work in order to trace mineralized quartz-carbonate zones.

**Non-invasive geophysical investigation of a palsa in Lapland, northwest Finland**

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Non-invasive geophysical prospecting was used to examine the structure, depth and lateral extent of the frozen core of a palsa near Lake Peerajärvi, in northwest Finland. A simple thermodynamic model verified that the current climatic conditions in the study area allow sustainable palsa development. A ground penetrating radar (GPR) survey of the palsa under both winter and summer conditions revealed its internal structure and the size of its frozen core. GPR imaging in summer detected the upper peat/core boundary, and imaging in winter detected a deep reflector that probably represents the lower core boundary. This indicates that only a combined summer and winter GPR survey completely reveals the lateral and vertical extent of the frozen core of the palsa. The core underlies the active layer at a depth of ∼0.6 m and extends to about 4 m depth. Its lateral extent is ∼15 m x ∼30 m. The presence of the frozen core could also be traced as minima in surface temperature and ground conductivity measurements. These field methods can be utilized in studies of climate impact on Arctic wetlands.

**Two-dimensional investigation of the Earth crust subsurface layer by method of internal sliding contact**

*Kolesnikov, V.E. (Geological Institute KSC RAS, Apatity, Russia)*

Method of internal sliding contact (MISC) is a DC investigation method of Earth crust subsurface, which combines elements of profiling and sounding. Variation of distance between current electrode A and receiver electrode M allows the carrying on the investigations of this kind. The depth investigation of the media (sounding) is conducted when the signal on receiver electrodes is registered and AM distance is varied. The electrode array movement along a profile permits to carry on investigations along earth-air surface (profiling).

The variation of AM distance is realized using the multi-electrode array. The array is a combination of AB current dipole and potential (receiver) array that includes M electrode connected with some N electrodes such as some MN distances are obtained. Low-frequency pulse current is injected to the ground through current dipole AB, and multi-channel digital receiver system records the signal from the ground. This system includes switch, AD-converter and mobile PC that registers the digital signal and saves the data obtained to HDD.

The data obtained processing was done by using ZondRes2D software that was designed by A.E. Kamisnskiy. The software permits to carry on 2D-interpretation (2D-inversion) of the DC resistivity and IP data taking into consideration topography and prior information.

The interpretation model divides the media half-space to rectangular blocks. The interpretation process involves several stages: (1) calculation of apparent resistivity values on the every point of observation over the model; (2) calculation the difference between model and observed apparent resistivity values on the every point; (3) model correction according to the values of the difference (misfit); (4) the new calculation of model apparent resistivity values. The iterative process continues until the misfit value required to all the profile is reached.

**Two-dimensional numerical modeling of MV and MT parameters on the Vyborg-Suoyarvi profile**

*Kovtun, A.A., Uspenskiy, N.I., Vardaniants, I.L. (St. Petersburg State University, St. Petersburg, Russia)*

Data of numerous soundings on the Vyborg-Suoyarvi profile made it possible to obtain the magnetovariational (MV) and magnetotelluric (MT) parameters distribution and approximately estimate resistivity distribution on this profile till the depth 200–300 km (Kovtun A.A., Usprnskiy N.I., Vardaniants I.L. Voprosy Geofiziki, 44, pp.124-132, 2011). Using 2D numerical modeling there has been built the MT and MV parameters distribution on the profile within the period range 1–104 s. There were revealed regions not corresponding with the experimental data at the South-East piece of profile which points to the more complicated structure of this piece of profile and indicates the necessity of supplemental soundings at this part. The work was performed according to the RFFI grant No 013-05-00-786.

**The peculiarity of the Ladoga-Bothnia zone at the North-Western piece of the Vyborg-Suoyarvi profile**

*Kovtun, A.A., Vardaniants, I.L. (St. Petersburg State University, St. Petersburg, Russia) and LADOGA-WG*

For the purpose of the more precise definition of the Ladoga-Bothnia zone (LBZ) structure at the piece from the Yanisyarvinsky fracture till the Pitkeranta fracture there has been performed according to RFFI grant N 13-05-00786 the MT-MV soundings within the period range 0.01–4000 s with the step 2–2.5 km. At present there is performed the express-analysis of the obtained data which allowed to find out a number of peculiarities in the structure of the abnormal zone. By the MV data there were built the frequency characteristics which made it possible to reveal, besides the large anomaly with the maximum at all sites on the period 2000–3000 s, a number of small anomalies on periods 0.15–0.30 and 2–100 s. The presence of the small anomalies is confirmed by the 1D interpretation of the longitudinal MT curves. By the longitudinal curves there was estimated the location of the upper edge of the conductive bodies. Using the known relation between the conductance G and $T_{max}$ ($G=3T_{max}10^5$ Sm.m) there were approximately estimated parameters of the conductive

bodies. It must be noted that G value, corresponding to the maximal period of the MV anomaly, practically coincides with its value obtained earlier on the Southern part of LBZ (A.A. Kovtun, 1989, 284 s). The crust and upper mantle structure at the North-East of the East-European platform), which points to the presence of the electrical contact between the conductive objects of the abnormal zone. Further on we suppose to perform the 2D inversion of MV-MT data.

## Geoelectric research the northern part of the Dnieper-Donetsk trough

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The main purpose of the work is to study a geoelectric structure of the lithosphere of the northern part of the Dnieper-Donetsk trough using modern methods (techniques) of synchronous electromagnetic sounding based on natural fields. Reliable tipper estimates for periods of geomagnetic variations 30–9000 s, horizontal MV responses 30 10000s and impedance parameters from 10–15 to 10000 s were obtained. Qualitative interpretation of MTS curves showed that the maximum depth to the upper edge of the conductor are in the northern end of the southern slope of DDT and Bragin-Loyev uplift, which vary from 40–30 to 18 km and correspond to the north-eastern end of the Prypyat conductivity anomaly. In the central part of the DDT the upper edge of the conductor occurs at depths of 3–5 km and is explained by the transition zone of sedimentary rocks and the decompacted rocks of foundation. On the slopes of DDT the depth of the upper edge of the conductor is 8 km.

The northwestern part of the DDT is one of the most promising areas for hydrocarbons. Oil and gas deposits are associated with Paleozoic sedimentary cover, as well as the Precambrian formations of the foundation. DDT foundation is characterized by considerable degree of fragmentation, which is confirmed by the result of a qualitative interpretation of the MTS curves. Laboratory studies of core samples from eight wells drilled in the northwestern part of DDT, showed decompacted area of argillites 5 km deeper up to the crystalline basement with a slightly increased magnetic susceptibility on

a background. This creates preconditions for hydrocarbon accumulation at these depths and at the top of the crystalline basement.

Collected material requires modern interpretation techniques, such as constructing of 3D models. Further investigations will allow more detailed determining of the conductor structure and identifying new geoelectric structures in the crust and upper mantle, which will take a fresh look at the nature and geological structure of DDT.

### Application of the radioholographic method for searching of ore bodies

*Lubchich, V.A. (Polar Geophysical Institute, Apatity, Russia)*

The radioholographic method is destined for quick visualization of geoelectric heterogeneities in the Earth's crust. The areal measurement of amplitudes and phases of electromagnetic field components is used for the holographic reconstruction of medium, anomaly areas with high electrical conductivity are localized in the Earth's crust by using the holographic reconstruction. The report deal with the application of the radioholographic method for searching of ore bodies on the mount Loipishnjun in the Monchegorsk ore region. Results of holographic visualization of geoelectric heterogeneities are in good agreement with the geological structure of this site, where rich sulfide ore zones have been discovered by drilling wells.

### Studying of seismoelectromagnetic effect at Baikal Lake using a seismic vibrator

*Moroz, Yu.F. (The Institute of Volcanology and Seismology FEB RAS, Petropavlovsk-Kamchatsky, Geological Institute SB RAS, Ulan-Ude)*

We conducted an experiment aimed at studying seismoelectromagnetic effect caused by the impact of the seismic field generated by a seismic vibrator to geological environment. Its mass is about 100 t, which allows developing the force of 100 ts. The frequency range of the vibrator is 5–10 Hz. It generates seismic waves to the distance of 400 km. Recording of the seismic field was made by means

of Japanese five-component magnetotelluric station ATD. It was installed at the distance of first hundred meters from the vibrator. Recording of electrical vibrations were performed by using 100 m grounded electrical circuits. As for grounding, we used low-polarizing electrodes dipped in the ground for 2–3 km. Variations in the geomagnetic field was recorded by induction sensors. Variations in the electric field were recorded as $E_y$-components (N-S) and as variations of $H_x$, $H_y$ and $H_z$ geomagnetic field components. Elastic vibrations were generated by the vibrator at 7 Hz. Recording of variations in electromagnetic field was performed at 64 Hz. The spectral analyses of variations in electrical and magnetic fields while the vibrator is not running revealed that the electric field has a complex spectral structure and is likely associated with signals generated by industrial sources. The reason for this is likely that the electric field has increased sensitivity to this kind of disturbances. In the component spectrum of the geomagnetic field in a range of 1–12 Hz, the industrial disturbances are not implicit. While the generator is running, the spectrum of vertical and horizontal components in the geoelectric field revealed a signal close to a frequency of 7 Hz. The occurrence of this signal might be related to physical and chemical processes generating the electromagnetic field in the geological environment.

## Anomalous variations of the MT response function caused by strong Kamchatka earthquakes

*Moroz, Yu.F., Moroz, T.A. (The Institute of Volcanology and Seismology FEB RAS, Petropavlovsk-Kamchatsky, Russia)*

The paper describes data from the long-term monitoring of low-frequency MT impedance at three monitoring areas at a distance of up to 150 km on the Avacha Bay shore, the Pacific. Priority was given to the impedance phase behaviour, which is less dependent from the local geoelectric heterogeneity and which characterizes the variations in deep conductivity. Monitoring data were processed using MT sounding. For all areas that have been monitored over the period of 12 years, only once in 2009 the standard deviation of the major impedance phase increased on the periods of 500 and 1000 s by several times. Increase in variations period makes the impedance phase dispersion closer to the background.

Variations with T=500 s are confined to the rising arm of amplitude

curves of MT sounding related to the lithospheric layer with the increased electric resistivity. On phase curves, variations of this period relate to the start point of the descending arm caused by asthenospheric layer with increased conductivity. Variations with period of 3000 s and longer are confined to the phase curve minimum, which characterizes the deep conductive layer. This analysis allows concluding that the increased impedance phase dispersion is typical for the lithosphere zones with high-resistivity. In the zone of conductive asthenosphere, the dispersion is close to the normal background level for the long-term period.

The processes related to the increased seismic activity in Kamchatka could explain the revealed regional effect in anomalous increase of the impedance phase dispersion. Strong and deep events in the Sea of Okhotsk have been the characteristic feature of seismic activity over the last decades. Their epicentres are confined to a zone, which adjusts to the transverse deep fault stretching in NW direction and crossing Southern Kamchatka. The MT data shows that the fault goes deeper than 100 km. The authors suggest that it may stretches farther to the Sea of Okhotsk and the Pacific Ocean.

It is suggested that the earthquakes caused processes in the deep fault. These active processes may result in increased geoelectric heterogeneity in the lithosphere. The geoelectric structure is unstable during seismic activation. Besides, the relation between the variations of the Earth's electric and geomagnetic fields becomes unstable as well, resulting in increased major impedance phase dispersion.

### The investigation of the three dimensional effect in magnetotelluric field of Kamchatka east coast

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The profile MTS-MVS is situated in the coastal part of the Litke channel, Karaginsky sound and Korf channel in the East of Kamchatka coast. The coast line has difficult form because of small peninsulas and sounds. The distances between points observation and coastline vary from first kilometers to several tens kilometers. MTS curves can be subjected to noticeable influence of three-dimensional

shore effect because of contrast between conductivity of land and the one of sea water. The investigation of the shore effect has been carried with three-dimensional model including difficult configuration of coastline. The thickness and electrical resistivity of sedimentary case have taken as constant values in order to estimate the influence of the shore effect independently influence of geoelectric heterogeneities.

It has been determined that orientation of model inductive arrows in the range of high frequencies has been connected with form of coastline. This connection weakens in the range of low frequencies and the direction of the arrows is caused by inductive influence of the current in the deep-water sea part. The shore effect has been used for estimation of deep conductivity in the east coast area. According to the MTS data noticeable influence of the shore effect is marked on the period 100 s. Picked out peculiarities of three-dimensional shore effect have been used for determination of interpretation MTS data methods. The geoelectric model of the coast has been got in the result. The turning reflects distribution of conductivity in upper and lower parts of the crust.

## Synchronous magnetotelluric sounding with non-uniform source field excitation

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At interpretation of magnetotelluric sounding (MTS) data, it is considered usually that the medium is excited by a vertically incident plane wave. However near auroral zones and sources of primary field, is quite real that this electromagnetic field is non-uniform along a terrestrial surface. Using synchronous registration of field components in three or more points, it is possible to apply algorithms of a spatial filtration for data processing. In simple situations, there is an opportunity not to register electric field components. Generally the bimodal electromagnetic field decomposition can be used for interpretation of these data. Data processing is carried out in the assumption that medium is excited by non-uniform primary field with a prevailing spatial harmonic. For verification of this assumption and determination of parameters of the spatial harmonic, it is used the angular spatial filtration of the wave field and the directional diagram calculation. The maximum of the directional diagram corresponds to

an azimuth of the wave vector of the field prevailing spatial harmonic. Optimization methods are applied to the subsequent definition of the wave vector components using bimodal decomposition of the electromagnetic field. Amplitudes of modes and various responses of the media depending on the temporary period can be defined using data of the synchronous registration of electromagnetic field components in three or more points. Testing of offered algorithm is executed using data of the BEAR project which confirms reliability of this approach.

### Studying the deep structure of the Earth under the seas based on the results of MT soundings on islands

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Magnetotelluric method is widely used for studying the Earth deep structure. Geoelectric cross-sections allow to observe fault zones and zones with a horizontal fissuring. It plays an important role in the analysis of different geodynamic hypotheses.The problem of carrying out magnetotelluric studies in regions with limited opportunities for sounding is especially actual. Such areas are, for example, the Arctic and the islands of the White Sea. Because of natural and geographical conditions very often source data are not enough either for two-dimensional inversion or specifically for three-dimensional. Furthermore the near-surface inhomogeneities and regional effects introduce distortions in electromagnetic response detected on the surface. For method adaptivity in such situations it is advisable to use the model calculations. Using results of the 1D inversion of data obtained from the soundings and data available for this area a preliminary three-dimensional model of the studied region was built. The effects of 3D foundation inhomogeneities, the geometrical dimensions of islands and the depth of the sea near the islands on the behavior of the amplitude and phase characteristics of the impedance were considered. The possibilities of using the results of magnetotelluric sounding on islands for studying the deep structure of the Earth under the seas were estimated.

**The influence of the perturbed state of the ionosphere onto results of the measurements electromagnetic field from ELF antenna "Zeus" in Western Siberia**

*Shevtsov, A.N. (Geological Institute of the Kola Sci. Center RAS, Apatity, Russia)*

Work is devoted to interpreting the results of measurements of electromagnetic field ELF antenna "Zeus" in the territory of the West Siberian oil and gas province in 2011–2012 within the framework of the project under the support from the RFBR. Measurements were carried out in the vicinity of two super-deep holes SH-6 (7502 m) and SH-7 (8250 m). Despite the considerable distance between the wells (160 km) there is an almost complete similarity of geological sections and electrical parameters of the cuts of the SH-6 and SH-7 according to the data received with the installations of the "potential probe" and the "lateral logging". This suggested that the geoelectric section of the sedimentary cover in the study area is close to the 1-D model. However, calculation of the electromagnetic field components for the forward problem in the vicinity of the SH-7 showed a significant excess of the measured values of the electric field components upon the values obtained theoretically.

Preliminary data analysis revealed a significant increase in the amplitudes of pulsations of the conjugate horizontal magnetic and electrical components with a high degree of correlation. A hypothesis was proposed of the perturbation in the Earth-ionosphere waveguide under the influence of solar radiation. The hypothesis was confirmed by using satellite data of X-rays – two flares – the X1.9 two hours before the measurement and M7.5 directly during the measurement of signals ELF antenna "Zeus" near to SH-7 24/09/2011 – were recorded by the satellite GOES-15. The calculation of the electromagnetic field for the perturbed and unperturbed conductivity distributions of the troposphere, stratosphere and ionosphere was performed. These models were based on the study of the Schumann resonances. The conductivities distribution of the upper half-space was obtained by trial. The work completed under the support from the RFBR (13-05-12044-ofi-m) and from the RAS (Earth Science Division, No 6).

**Deep structure of Golovanivsk suture zone of the Ukrainian shield from the magnetotelluric investigations**

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According to the current researches of many scientists to study ore genesis problems the fundamental cause of these processes is the Earth's degasation. In this concept postulated that the fluid regime is the major factor for the ore components formation and localization. Different fluid compounds in the process of their upwelling to the subsurface can interact with its material and such alterations become the cause of the ore formation.

Degasation is closely linked to the vertical and subvertical fracture zones in rock masses. Such zones often have a contrast in geophysical properties including geoelectrical ones. They are characterized by higher conductivity because have suffered the intensive metasomatic alteration. Thus the minerals such as graphite and sulfides have formed. At a greater depth electrical conductivity can be associated with the presence of the heated fluids. So such zones can be detected by MT methods.

Golovanivsk suture zone (GSZ) is situated between the Rosinskiy and Ingulskiy megablocks of the Ukrainian shield (US). This zone shares the shield into two significantly different parts: Eastern and Western. GSZ is the longest one of all suture zones of the US. This structure is S-shaped and can be divided into two closely structurally different parts: Southern and Northern.

On the territory of GSZ a considerable amount of MT investigations was carried out. According to their results it has been found a few anomalies of higher conductivity: Gayvoron-Dobrovelichkovskaya, Ryasnopolskaya and Ingulo-Inguletskaya. These zones are spatially correlated with the stretch of the regional deep faults.

Thus this region is perspective for the presence of mineral resources that are linked to the conductivity anomalies. For the more precisely studying this problem it is necessary to carry out the current field MT surveys and to build the 3D geoelectrical modeling of GSZ.

**MT/MV studies of Garhwal Himalaya verified by regional seismic data**

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Geoelectrical model of the Garhwal Himalaya along Roorkee-Gangotri (RG) profile has been constructed by Israil et al., 2008. The profile was further extended and all "Mertronix" and "Phoenix" observations were reprocessed under Indo-Russian project in 2010–2012. We present the updated resistivity cross-section, obtained by profile inversion of the extended data set, discuss 2D approach resolution problems on the base of synthetic 2D inversions and 3D modelling and focus on the interpretation of delineated conductivity features in the context of regional tele- and local earthquake tomography results, regional seismicity and geothermal models from adjacent segments of the Himalaya.

In the constructed resistivity distribution the following relevant features are recognized: sediments of IGP and Siwalik; descending top of the resistive Indian plate, Main Himalayan Thrust, and bright conductive anomaly within MHT rump at mid-crustal depths under Main Central Thrust zone. The areas responsible for generation of significant seismicity of Garhwal tectonic corridor have been attributed: a resistive block in the upper crust above the mid-crustal conductor and one more cluster of hypocentres (deep and strong earthquakes) underlying this conductive anomaly.

Being in a good agreement geoelectric and seismotomography images of MCT zone indicate the common nature of both kind crustal anomalies at this segment of subduction (due to flooded by dehydrated fluids/partially melted (?) mechanically week area) and contribute to the explanation of the observed bi-modal earthquake distribution at a depth. The reliable resolution of the main geoelectric structures approved by this comparison provides objective constraints on the regional seismogeneration pattern for Garhwal Himalaya as well as geodynamic models of the India-Eurasia collision.

RG MT/MV data have also revealed a strong elongated conductive feature at East flank of the profile, which most likely corresponds to the Trans-Himalayan conductor of (Arora and Mahashabde, 1987). We present first results of 3D EM modelling for the region to check

the THC hypothesis. This feature is probably caused by minor, rotational, component of Indian plate movement activating ancient trans-Himalayan structures and preparing arc segmentation. THC definitely needs a proper resolution, which could be achieved with a help of additional soundings planed in the frames of current bi-lateral project.

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**Applications of magnetic measurements at ExoMars Surface Platform for investigation of internal structure and electromagnetic environment of Mars**

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ExoMars mission scheduled for 2018 by ESA and Roscosmos plans to deliver the rover and long-living landing platform. The magnetometer included in the set of scientific devices at this stationary platform will provide the magnetic measurements on Martian surface for the first time in the space exploration history. The fluctuations of magnetic field are expected to be intensive due to time varying interaction of solar wind with ionosphere and crustal magnetic anomalies as well as atmospheric electromagnetic phenomena, e.g. ones connected with dust devils. We discuss possible implications of these observations to monitor the general state of Martian electromagnetic environment and to study the conductivity structure of the planet. Global magnetovariational sounding (MVS) method, which has already brought significant results in the exploration of Moon and Jupiter satellites, could be also used in ExoMars experiment basing on the analyses of three component magnetic daily variations of ionospheric origin recorded at mid-latitudes landing site. Additional options would be possible with joint consideration of the platform data together with synchronous distant magnetic observations at Martian orbiter. Long term monitoring of MVS transfer functions in a wide frequency range will supply valuable information on the temporal variability of the external excitation field. Analyses of magnetic field fluctuations will provide new information about dust devils' contribution to the near

surface electromagnetic medium. The relevant examples of such studies in the Earth conditions are presented, including robust estimation of MVS transfer functions in the presence of inhomogeneous source effects, their temporal monitoring and clustering with a help of original neural network methods as well as first attempts of MVS data inversion with assumption of arbitrary external electromagnetic field.

**A study of the possibility of using GPR to locate underground ice**

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In recent years GPR has become one of the main methods of engineering geophysics. GPR is often used for the study of the upper part of the geological section in the permafrost zone. Important geocryological problem is to locate ground ice. In practice there are often thin layers of ice (about 1 m) and ice wedges. Definition of parameters of such icy objects using GPR was the aim of our work. For a detailed study of propagation of GPR signal mathematical and physical modelling were used. Mathematical modelling was carried out using the free software MatGPR and GPRMax. The results of mathematical modelling cannot always be used in the interpretation of field GPR data. To test the new techniques of measurement physical modelling can be used. Physical modelling was conducted in a special GPR stand. The Russian GPR "OKO-2" was used. GPR stand is a tank filled with water with the coordinate system, which allows us to precisely move the antenna unit on the water surface. Models of polystyrene and organic glass were placed in the water. GPR survey was carried out and obtained data were processed using GeoScan and MATLAB. Mathematical modelling has allowed us to determine the thickness of the thin layers of ice and ice wedges. Physical modelling showed the possibility of determining the thickness of thin (less than the wavelength in the layer) layers of ice. It was found that the reflectance coefficient of the thin layer increases with increasing layer thickness according to analytical formula. Thus knowing the thickness of the thin layer at one point we can determine the thickness of the thin layer in another one. However, physical modelling did not allow us to determine the thickness of the ice wedge. It was possible to locate the ice wedge by the presence of surface waves on radar-

gram. Thus we can distinguish ice wedge from the ice lens, which is very important for solving engineering problems. The experimental results demonstrate the efficiency of physical modelling. The results of physical modelling can provide new information for field radargram interpretation.

### The acousto-electromagnetic activity of the cortex in borehole studies

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The conducted research of the acousto-electromagnetic emission crust using cased borehole in a seismically active region of Kamchatka. Found 4 basic types of abnormal signals. Analyzed the properties of these anomalies. The conclusion is made about the different types of relaxation processes of tectonic stresses crust.

### Analysis of two algorithms of the magnetotelluric data processing

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Now we can found two main algorithms of programs of magnetotelluric data processing. The most programs used the first algorithm — define impedance and magnetovariational parameters by criteria of stochastic processes (Bezruk I.A., 1964, Semenov V.Y., 1985, Vagin S.A., 2011). Second algorithm is based on the use and detection of quasi-periodic processes in the magnetotelluric field to determine MT and MV parameters. One of example of second algorithm is program of Astapenko V.N., 1976. The report presents realization of both algorithms on the example of the data depth soundings near Ladoga Bothnia zone processing. Sounding conducted by RFBR grant 13-05-00786. Conclusions about the appropriateness of these programs to assess MT-MV parameters in different period intervals.

**What is the nature of the Conrad boundary from Seismics, Geoelectrics and super deep drilling?**

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The Conrad discontinuity (K1) was believed to be where the chemical (substantial) composition of the Earth's crust changes: the upper granitic gneiss layer of aluminumsilicate (SIAL) rocks is replaced with a lower lying magnesium, basaltic (SIMA) layer. The position of this boundary is usually attributed to a sharp growth of seismic wave velocity from 6.1 to 6.5 km/s. According to the DSS data, the K1 depth in the area of Pechenga structure has been estimated of about 7 km [Litvinenko, 1968]. The deep soundings using the controllable sources indicate that there is a zone of sharp increase in resistivity in the Earth's crust in the depth range of 10–15 km and this zone marks the boundary between the upper brittle and lower quasiductile crust. However, it is this depth interval (about 12 km) where all breakdowns occurred in four shafts of the Kola super deep borehole SG-3. One of the main causes of these breakdowns should be attributed to the worsening of the drilling conditions due to a sharp increase in rock strength. So we can make the conclusion that the "impermeability boundary" established by the data of drilling at the SG-3 superdeep well at a depth of about 12 km can be considered as the Conrad discontinuity. In this case, the nature of the hypothetical Conrad discontinuity should not be related to the change in the rock chemical composition from aluminosilicate to substantially magnesian, but to the change in the physical state of the rock from brittle (fragile) to ductile (viscous). The cause of the increase in viscosity (strength) of rocks at the Conrad discontinuity can be related to the bigger role played by the lithostatic (vertical) pressure in the lower crust due to elimination of tangential (horizontal) stresses existing in the upper crust and leading to dilatancy in the depth range from 2–3 to 10 km.

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**The search of homologues of the Archaean part of the Kola SG-3 by means of DC profiling and CS AMT sounding**

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The Kola Superdeep Borehole SG-3 crossed the total thickness of the Pechenga volcanic-sedimentary strata of the Proterozoic age (6.8 km) and penetrated into the Archean granite-gneiss basement to the depth of 12 km 262 m. The chemical composition of the Archean rocks has not changed significantly till that depth, indicating absence of the supposed Conrad boundary and the expected transition from silicate (granitic) rocks to significantly magnesium (basaltic) rocks.

Among the many problems, associated with the interpretation of the results of drilling Kola SG-3, an important place is the question about the nature of a sharp decrease in apparent resistivity observed in the depth range of 6.8–10 km on the background of the high resistance of Archean rocks. The most profound decrease of apparent resistivity (more than 100 times) marked at depths of 7.3 and 7.9 km according to the lateral electric log. The geological nature of the anomalous decrease in conductivity could not be solved by a simple mineralogical survey because of the bad quality of the core and its poor output. Resistance anomalies can be caused or by presence of fluids (by the deep geodynamic factors), either by the presence of electronically conductive rocks (sulfides, graphite or iron oxides — magnetite, titanomagnetite).

Authors performed electric survey on the profile crossing the northern flank of the Pechenga structure in order to search on the surface the assumed geoelectric homologues of Archaean rocks crossed by SG-3. In the first stage (in 2013), the problem was solved by DC mapping the electrical properties of rocks by MISC profiling in combination with magnetic prospecting and with measurements of induced polarization (IP). The aim was to find contrasting conductive layers, according to the detected electric logging in the Kola SG-3. The results of measurements in 2013 showed the presence of two low apparent resistivity anomalies (about 10 times) in the frame of Archean

volcanic-sedimentary Pechenga Proterozoic complex comparable with reduced resistance in the SG-3 at depths of 7.3 and 7.9 km. Magnetic anomalies and anomalies of the IP in the area of apparent resistivity anomalies had not been detected.

Given the fundamental importance of the geological and geophysical interpretation of the result, the work was continued in 2014. At this time the work was carried out by methods of median gradient and three-electrode DC sounding in conjunction with the CSAMT sounding. Generator "Energy-4" has been used as the source of AC current in frequency range of 59 Hz–10 kHz. Preliminary analysis of 2014 results showed that conductivity anomalies, assumed as homologues of the Kola SG-3 at depths of 7.3 and 7.7 km, have a surface origin. Frequency sounding with generator "Energy-4" and AMT sounding showed that conductivity anomalies did not continue into the depths. Their nature is entirely explained due to local surface deflections of Archean crystalline base and increased thickness of flooded sediments (moraines).

This result suggests that the electric properties of Archaean section of the Kola SG-3 radically differ from those of the Archean section on the surface, in the alignment of the Kola SG-3. This gives grounds to interpret the results of drilling of Archean section in the SG-3 exclusively by the temperature and fluid regimes of the Earth's crust at a depth. That is of particular interest for the deep geology and geophysics.

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**Experiment FENICS-2014 (preliminary information)**

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The main feature of the experiment FENICS-2014 is a technique to study the interaction of the electromagnetic field with the ionosphere and the Earth's crust by using two mutually orthogonal grounded power supply lines - industrial transmission line of 109 km length (LEP sub-latitudinal L1) and 120 km length (LEP sub-meridional L2). Energy Generator-2 of 200 kW power will create in industrial power lines alternating current with amplitude from tens to 200 A in the frequency range from 194 Hz to 0.094 Hz. Measuring stations are distributed at distances from hundred till several thousand kilometers on the territories of different countries — Russia, Ukraine, Norway, Poland, Finland.

1. The main objectives of the experiment FENICS-2014.

1.1. To perform the electromagnetic sounding in different blocks of the crust of the Fennoscandian Shield for subsequent construction of quasi-3D model of the structure of the lithosphere and the assessment of a possible connection the deep electrical conductivity with metallogenic characteristics.

1.2. Study the properties of the high resistive transition zone between the upper and lower strata of the earth's crust at a depth range 10–30 km by a comprehensive solution of the inverse problem based on the frequency (induction) and distance (galvanic) principles.

1.3. Investigate the anisotropic properties of the lithosphere of the Fennoscandian Shield by making measurements at two orthogonal polarizations of the primary field.

1.4. Perform the deep sounding around the anomalous immersion of seismic boundary Moho to the depth of 50–60 km in order to study the possible connection between the electromagnetic and seismic properties of the lithosphere Fennoscandian Shield.

1.5. Explore the features of propagation of ELF-VLF electromagnetic field in the waveguide "Earth-ionosphere" under different conditions

of excitation of the primary field and at different angles of arrival of the wave.

1.6. To make the electromagnetic sounding of the waveguide walls "Earth-ionosphere" and evaluate the anisotropic properties of near-Earth space by applying an iterative procedure for solution of the inverse problem for the input impedance and for individual components with taking into account the different directions of polarization of the primary field.

2. Mode of power supply transmitting lines.

Experiment FENICS-2014 is performed in two stages. At the first stage (from 23 to 30 August), the measurements were made from current generated in latitudinal line L1. At the second stage (from 1 to 7 September), the measurements were made from current generated in latitudinal line L1. At both stages the current generation was made at night time, from 1-00 to 5-00 hours Moscow time on a common schedule of frequencies.

The results of observations are gathered now in the form of two types of database available to all researchers who has taken part in the measurements.

## Section P. Paleomagnetism and Rock Magnetism

### Blocking temperature of the heterophase titanomagnetite nanoparticles

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In this paper we have investigated the blocking temperature dependence on the size of areas of the products of titanomagnetite's heterophase decay and interfacial exchange interaction between phases within the model of two-phase particles. According to Neel, when assessing blocking temperature ($T_B$) of the single-phase (having one magnetic phase) single domain particles the expression for the relaxation time $\tau$ is used, which is expressed in terms of the transition frequencies $W_{ik}$ from one equilibrium state of the particle to another: $\tau\,(T_B)$=$W_{12}\,(T_B)+W_{21}(T_B)$, where $W_{ik}(T_B)$=$f_0 exp\,(E_{ik}(T_B)/k_B T_B)$ — potential barrier of transition from state 1 (or 2) to the state 2 (or 1), $f_0 \approx 10^9 - 10^{10} s^{-1}$ — the frequency factor. Biphasic nanoparticles, unlike single-phase ones can be in one of four magnetic states. Therefore, the spectrum of the relaxation times determined by the matrix of transition frequencies from i state to the k state: $W_{ik} = f_0 exp\,(E_{ik}/k_B T_B)$, where $E_{ik} = E_{max}\,(i \to k) - E_{imin}$ — a potential barrier separating $i$ and $k$ states, $E_{imin}$ — the total energy of nanoparticles in the $i$ equilibrium state, $E_{max}\,(i \to k)$ — the maximum value of the energy separating $i$ and $k$ states. Assuming that the total energy of nanoparticles composed of the anisotropy energy $E_A$, magnetostatic interaction energy $E_m$, the energy of the interfacial exchange interaction $E_{ex}$ and grain magnetic moment in an external magnetic field $E_H$: $E = E_A + E_m + E_{ex} + E_H$, spectrum of the relaxation times can be determined and thereon dependence of the blocking temperature on the geometric and magnetic properties of the nanoparticles. Our calculations of dependence of the blocking temperature $T_B$ on the size $b$ of biphasic nanoparticle $Fe_3O_4$-$Fe_{2,0.44}Ti_{0.56}O_4$ and interfacial exchange interaction showed that the growth of nanoparticle's volume V leads to the increase of TB up to the Curie temperature of the titanomagnetite. Increase of the interfacial exchange interaction constant $A_{in}$ regardless of its sign leads to a substantial increase in blocking temperature. With the growth of $A_{in}$ critical volume $V_c$ below which nanoparticle will always be a

superparamagnetic state decreases, which is consistent with the results obtained earlier. This feature of dependence $T_B = T_B(b)$ due to the fact, that the potential barrier height of nanoparticles in which phases are interact between each other $E_{ik}(A_{ik})$ is higher than in the case of noninteracting phases $E_{ik}(A_{ik} = 0)$.

**Dependence of hysteretic characteristics on the size of heterophase titanomagnetite nanoparticles**

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It is known that regions enriched and depleted titanium are released during the titanomagnetite decay. In the extreme case - releasing of areas of magnetite with sizes 10–200 nm surrounded by ulvospinel. We attempted to study the size effect on the hysteresis characteristics of the decay products of the heterophase titanomagnetite. The calculation was performed within the following model of two-phase nanoparticles:

1. Uniformly magnetized nanoparticle (phase (1)) which has the shape of an ellipsoid of rotation comprises uniformly magnetized ellipsoidal inclusion (phase (2)), the long axis of which coincides with the long axis of the particle and parallel to the axis Oz.

2. It is believed that the axis of anisotropy of both uniaxial ferromagnets are parallel to the long axis of the nanoparticle. The analysis of the total energy shown that two-phase nanoparticle can be in one of four states: 1 – the magnetic moments of both phases are parallel and directed along an axis Oz; 2 – the magnetic moments of phases are antiparallel, and magnetic moment of the first phase is directed along axis Oz; 3 – the magnetic moments of both phases are antiparallel with respect to the axis Oz; 4 – magnetic moment of the second phase is directed along the axis Oz, and the first – against the axis Oz. Magnetization of such nanoparticles is defined by the vector occupation probabilities of these states $n(t) = \{n_1(t), n_2(t), n_3(t), n_4(t)\}$, which is described by the equation $dn(t)/dt = \widehat{W} * n(t)$ with the initial conditions $n(0) = n_0$. Here $\widehat{W}$ — matrix of transition probabilities from one state to another, the matrix elements are given as the barriers separating the corresponding states. It is shown that the incidence of coercive force, saturation magnetization and residual saturation

magnetization with decreasing size of heterophase regions associated with an increased role of the superparamagnetism.

### Investigation and correlation of two Permian cross-sections using magnetic data

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This paper presents a study of two sites of international importance: cross-section of Permian system's Urzhumian Stage in the ravine "Cheremushka" and stratotype boundary of Tatar series near Monastyrskiy village. Cross-section of Urzhumian Stage in the ravine Cheremushka has local, regional and planetary correlation features that have different geographical scale events. Monastyrskiy ravine includes Urzhumian and Severodvinian stages rocks. Here is a "point of global stratotype boundary". The main aim of the research is the correlation between the two sections in order to make a reference stratigraphic section for the Permian time using paleomagnetic and magnetic methods of correlation. Basis for the correlation between a sediment magnetic susceptibility was measured for 600 samples from the ravine "Cheremushka" and 450 samples from the ravine "Monastic". On the basis of data on the magnetic susceptibility were identified for the study area on the coercive spectrometer and differential thermomagnetic analysis. Availability of cosmic and volcanic dust also can be used to match the cuts together. We also focused on identifying and tracing the event of changing Kiaman and Illawarra Superchrons and paleomagnetic zones of lower rank. The reported study was partially supported by RFBR, research projects No 14-05-31376, 14-05-00785, also by Russian Government Program of Competitive Growth of Kazan Federal University.

**Influence of diffusion on the Curie point and the magnetic properties of minerals such as solid solutions**

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Magnetic properties of the rocks caused by the minerals such as the solid solution of the magnetite-ulvospinel in many cases. In this paper, the influence of the diffusion of the atoms in the solid solution on its magnetic properties investigated in the framework of the random interaction field method. In the random interaction field method at frozen impurities Curie point is determined from the expression $\frac{pH_0}{B}\tanh\frac{m_0B}{kT_c}=1$, where magnitude $H_0=Jz$ is mean field, $z$ is number of nearest neighbors, $p$ is concentration of ferromagnetic atoms, $m$ is magnetic moment, $B^2=2\sigma^2=2p[1-M^2p]zJ^2$, $\sigma^2$ is variance, $M$ is relative average magnetic moment per atom. The obvious condition for the occurrence of spontaneous magnetization is $\frac{pH_0}{B}1$, therefore critical concentration is $p_c=\frac{2}{z}$. If the atoms are able to diffuse near phase transition point then $\langle pM\rangle^2=\frac{6\left(\frac{H_0\sinh\left(\frac{B}{T}\right)}{B\left(\beta+\cosh\left(\frac{B}{T}\right)\right)}-1\right)}{\frac{H_0^3\left(2-\beta^2+\beta\cosh\left(\frac{B}{T}\right)\right)\sinh\left(\frac{B}{T}\right)}{BT^2\left(\beta+\cosh\left(\frac{B}{T}\right)\right)^3}}$, $\beta=\frac{1}{2\lambda}$, $\lambda=\exp(\mu/T)$, $\mu$ is the chemical potential. Possibility of diffusion significantly reduces the critical concentration $p_c$, which means the local increase of the number density of ferromagnetic atoms in specific areas of the ferromagnet. Then a gradual transition will occur from rich region the ferromagnetic atoms to the area deprived of them. It is possible, the formation of residual magnetization, connected with the displacement of the Curie point $T_c$ and transitions from $T_cT$ to $T_cT$, where $T$ is transition temperature.

**Correlation properties of the secular variation forecast**

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In this work, statistical and correlation properties of SV, SV forecast (SVf) and SV forecast error (ErrSVf) were compared. Spatial structure of SV components was calculated from the IGRF11 coefficients. The SV forecast was reconstructed from the IGRF3-10 coefficients. Statistical and correlation characteristics were calculated both for globe and for six separate areas. Four of these areas were selected at the high latitudes and one of the high latitude areas includes Russia and adjacent waters. Two others include near-equatorial region and one of them includes so-called Brazilian Geomagnetic Anomaly.

The maximum of the ErrSVf was obtained for Russia and adjoining near-equatorial region. It should be noted, that although standard deviation the ErrSVf much less than SV standard deviation for Brazilian Geomagnetic Anomaly, it doesn't differ by an order of magnitude from the values obtained for other areas.

The three correlation coefficients for the spatial distribution of SV and the SVf were calculated. The first one is the correlation coefficient of SVi and SVi-1 for two consequent periods; the second one - the correlation coefficient of SVi and the SVfi for the same period; and finally - the correlation coefficient of the SVfi and SVi-1. As a result the maximum correlation coefficient obtained for the last variant. The SVf and SV for the same period correlate well only when high correlation between SVi and SVi-1 is observed. It means, that the SVf replicates in fact the spatial structure of the SV of previous epoch independently of the forecast method used. The existence of large and long-term anomaly provides high correlation of sequential periods, and correlation coefficient between the SV forecast and SV for the same period is greater than 0.9. Minimal correlation was obtained for Russia and adjoining near-equatorial region. It is caused by the presence of small-scale short-lived SV anomalies.

The spatial distribution of the ErrSVf is characterized by the existence of independent processes that run in liquid core, and of single anomalies of small scales. However if we can identify the individual flow, research of its parameter changes doesn't let us to improve forecast accuracy, since the causes of these flows today are not defined. We suppose that the topographic heterogeneity of the core-mantle

boundary, which actually remains a subject of discussions, could play an important part in these processes.

### The effect of heterogeneities in the structure of the lower mantle on the formation of the some secular variation focuses

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In this paper we consider a region which is at different times characterized by the well-known secular variation focuses of the main magnetic field of the Earth (GMPE): the Caspian and European. Previously, on the basis of the constructed macro model of the GMPE sources a study was conducted of the impact of the parameters changes of the different scale sources on the spatial structure of secular variation. The result is that the formation and decay of the considered focuses was determined by the parameters change of the two sources of the third order of smallness, coincided with the boundary of the core-mantle. This effect was also observed in the records of all nearby magnetic observatories. It remained a question about the reasons underlying this change of the sources parameters.

In this work we have considered trajectory visible movement sources in comparison with different models of the structure of the lower mantle, built on the base of seismic tomography data. As a result, we obtained that the heterogeneity of the density and temperature of the lower mantle have a decisive influence on the change of the sources parameters. This result coincides with that obtained earlier for the Caribbean region.

**Paleomagnetism of the Ulkan massif (SE Siberian platform) and the apparent polar wander path for Siberia in the Paleoproterozoic**

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Many researchers believe that the Siberian Craton is a series of terranes: Tunguska, Olenek, Anabar, Aldan, and Stanovoy. By the end of the Paleoproterozoic (2.2–1.9 Ga) these terranes had formed two separate provinces: Aldan-Stanovoy encompassing the Aldan and Stanovoy terranes, and Angara-Anabar formed as a result of collision of Anabar, Tunguska, and Olenek terranes. Later, these provinces joined to form a single Siberian Craton. The issue remains open as to the time and the kinematic model of its formation, in part because of the lack of reliable Paleoproterozoic paleomagnetic data for the Aldan-Stanovoy Province. The conducted paleomagnetic studies on rocks of the Ulkan Complex in the southeast of the Aldan-Stanovoy shield made it possible to calculate the coordinates of the paleomagnetic poles corresponding to two time intervals in the Paleoproterozoic: (1) 1732 Ma; and (2) 1720 Ma. The data obtained suggest that as volcanogenic-sedimentary rocks of Elgete Formation were forming the Ulkan massif was located at 18–26°S. Between 1732 to 1720 Ma the massif rotated about the vertical axis by 70° clockwise and its longitudinal displacement was 7°. The paleomagnetic analysis of the presently available data on the Siberian Craton allowed 12 key poles to be determined based on which the Paleoproterozoic APWP for Siberia was generated.

**Paleomagnetic studies of marine sediments for evaluation of sedimentation rates on the Mendeleev Ridge**

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Nowadays the Arctic Ocean is an area of higher scientific interest. Investigation of composition, genesis, sources and source areas of marine sediments is necessary for a gain of geological knowledge and geo-engineering development of the region. One should note that the dating issue in the Arctic Ocean is a challenge by itself. However,

magnetostratigraphy can offer a powerful stratigraphic tool applying to marine sediments here. The 6-meters length core was retrieved from the Mendeleev Ridge in 2012 and subjected to paleomagnetic studies. The examined core was revealed to dominate by normal polarity up to 123 cm below seafloor (cmbsf) and assigned there to the Brunhes polarity chron of the geomagnetic field (0.78 Ma). Then prevalence of reverse polarity persists up to 394–397 cmbsf, assigned to Matuyama age, and short positive intervals are believed to be subchrons of normal polarity. Change from reverse to normal polarity at 394–397 cmbsf is considered as the Matuyama – Gauss (2.58 Ma) boundary and is traced up to 530–531 cmbsf including one short reversal. After this depth a drop back to reverse polarity is ascribed to the beginning of the Gilbert polarity chron (3.58 Ma). The stepwise alternating field demagnetization and demagnetization by heating were performed to remove viscous overprints and then to define component magnetization directions. Spikes of natural remanent magnetization intensity and magnetic susceptibility are discovered near almost all assigned chron boundaries, and it may act as an independent factor for determination of polarity boundaries. Anisotropy of magnetic susceptibility is also considered in order to find out additional peculiarities of the sedimentation. The relative abundance of shallow inclinations at least implies the existence of secondary processes, which may have altered the paleomagnetic record. The mean sedimentation rates on the Mendeleev Ridge do not exceed 1.58 mm kyr-1 for 3.58 Ma and therefore represent the sedimentation rates as low for the whole Quaternary period and also for the part of the Pliocene epoch.

### Magnetic properties of Late Permian volcanic rocks from South Transbaikalia: preliminary results

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Rock magnetic study of Late Paleozoic–Mesosoic igneous -sedimentary rocks from Tamir volcano-tectoinic structure (VTS) were studied in two paleomagnetic laboratories of IGF PAS, Warsaw and IPE RAS,

Moscow in the frame of cooperation between both Institute. The investigation was based on preliminary paleomagnetic study of 200 oriented samples from 31 sites collected from the Tamir, Shazaga, Kiret, Ungurkuy and Ara-Kiret river valleys within South Transbaikalia (Fedyukin, I., Shatsillo, A., 2013). Coercive magnetic properties were carried out on about 40 samples from different suites. The purpose of this study was to identify of magnetic minerals, responsible for paleomagnetic record, and find the peculiarities of their magnetic properties. The complex of methods applied was the following: (1) measurements of hysteresis loops (HL) of natural state and after consecutive heating in two different modes (cooling without (ZFC) and with (FC) external magnetic field) in two temperature intervals 20-7500C and 270-90K using VSM of different constructions; (2) obtainment of thermomagnetic curves of M(T) and Mr(T) using VSM (LTD "Orion", Borok) and (apparatus TUS, Poland); (3) measurements of magnetic susceptibility during continuous heating to 7000C in air or in neutral atmosphere, and during heating from -1960C to room temperature (KLY3). The results obtained allowed to classify the samples under study on different behavior of Mr (T) dependences (Mr peaks in range of 150–2500C) and hysteresis loops shape (normal or constricted). Exchange bias of HL was observed for group of samples cooled in external magnetic field. All the results show nonuniform nano-layer magnetic structure of these Paleozoic samples.

## Paleomagnetism and magnetostratigraphy of the Cretaceous deposits of the south Kulunda basin (the south of Western Siberia)

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The complex (paleomagnetic, paleontological and geological-stratigraphic) the study of the Upper Cretaceous and border Cretaceous-Paleogene sediments, opened three wells (23, 19 and 11), drilled on the south Kulunda basin (south of the West Siberian Plate) has been performed. Paleomagnetic characteristics and paleomagnetic sections of the wells were made uncovered six regional horizons same name and suites: the Upper Cretaceous – Kuzntsovo, Slavgorod and Gan'kino and Paleogene: Talitza and Lulinvor. Paleomagnetic sections of wells

are correlated among themselves and with the paleontological data. In result Cretaceous and border Cretaceous-Paleogene magnetostratigraphic section of the south of Kulunda basin, covering stratigraphic units from the Cenomanian to Tanetian is constructed. This section consists from four magnetozones. So, normal magnetization Kuznetsovo suite, with three horizons reversal polarity, forms magnetozone normal polarity N(sn-tr). Reversal polarity Gan'kino suite, forms magnetosone – Rmt. Lower Paleogene Talitza and Lulinvor suites, also found reversal polarity with one low-power horizon normal magnetization in the Talitza suite, form two magnetozones of reversal polarity – R1zl and R2t separated by long interruption.

Cretaceous and border Cretaceous-Paleogene magnetostratigraphic section of the south Kulunda is correlated with magnetostratigraphic [Dopolnehiya..., 2000] and World magnetochronological [Gradstein et al., 2008] scales.

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### Karatau Uplift in the South Urals: New paleomagnetic data

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The western South Urals is the deformed margin of the East European Platform (Baltica). Major deformations are of Permian age here, and rotations occurring at that time between the fold belt and the platform as well as possible rotations of separate blocks relative each other can be evaluated by a widespread late Paleozoic overprint. The Karatau Uplift differs sharply in its sublatitudinal strike from other structures on the western slope of the South Urals. We took over 200 samples of Paleozoic and Late Proterozoic rocks from eleven localities of the Karatau Complex and performed their stepwise thermal demagnetization (up to 20 steps). A well defined and tightly grouped reversed component (often exceeding 90 percent of the remanence) with SW declination and upward inclination was isolated, between 200° and 500°, from about half of Paleozoic samples. A similarly directed component was isolated from Neoproterozoic carbonates and terrigenous rocks too. Most probably, this component also corresponds to Late Paleozoic overprint. Therefore, Paleozoic and Late Proterozoic data can be combined into one set. The results

on the Karatau Complex were compared with our previous results on the localities from the westernmost South Urals with submeridional strike. The analysis of the resulting data suggests that by and large there was no reversal of the Karatau Uplift both relative to any other structures of the Urals with submeridional strike and the whole East European Platform. The new data and their implications briefly discussed will be given in our presentation.

### Paleomagnetism of the Paleozoic volcanic rocks from the Magnitogorsk zone of the South Urals. Preliminary results

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The Devonian and Early Carboniferous are characterized by a large number of tectonic events responsible for the development and present-day structure of the South Urals. However, the existing concepts about paleogeography of this region during the Devonian and Early Carboniferous are very controversial. Specifically, it concerns the displacements of the Magnitogorsk island arc relative to the East European Platform. Such a situation is explained primarily by the fact that this time interval lacks sufficient paleomagnetic data, whereas the existing ones are highly discrepant. Paleogeographic and paleotectonic reconstructions of the South Urals during the Devonian and Lower Carboniferous require new, much more reliable paleomagnetic determinations for several Devonian and Carboniferous stratigraphic levels. We carried out preliminary sampling investigations on six igneous rock localities within the Magnitogorsk zone. In all, we took about 300 samples from four Lower Devonian and two Lower Carboniferous localities and performed their stepwise thermal demagnetization (up to 20 steps). Most of the studied samples shows intermediate temperature component corresponding to a widespread late Paleozoic overprint in the Urals. One Early Devonian lava flow from the Khvorostyanka locality displays a distinct high-temperature component (HTC) with SE declination and small positive inclination not coinciding with the reference direction for the East European Platform. Its nature still remains unclear and invites further investigation. A rather tightly grouped dual polarity high-temperature component with its direction almost identical to the reference one

for the East European Platform during the Early Carboniferous was found in the Early Carboniferous samples from three out of six lava flows. If we manage to find such HTC in a sufficient number of lava flows, this can suggest that the paleo-ocean was already closed at that time and parts of the island arc in question formed a single unit with the continent. In our presentation we shall compare these new results with the data obtained by other authors and discuss briefly their implications.

### Magnetomineralogical studies of the formation of TCRM on titanomagnetites from Kamchatka

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A laboratory modeling of the process of the formation of TCRM on natural titanomagnetites was carried out. The experiments were done on contemporary Kamchatka titanomagnetites with the Curie temperature $T_c$ 350°C. The samples were annealed in air in field 50 $\mu T$ at temperatures 400, 450, 500°C for times starting from 5 minutes up to 200 hrs with the purpose to impart the TCRM. Products of the oxidation were monitored by thermomagnetic and hysteresis properties measurements completed with the analysis of X-ray spectra obtained on different stages of the reaction and electron microscope observations. According to the electron microscope observations, the hemoilmenite component is not appeared at annealing at 400 and 450°C. However, a exsolution structure it is distinctively seen after 100 hours annealing at 500°C, especially at the surface part of the samples. At the same time, the results of the X-ray analysis clearly shows the persistent existence of the spinel phase which is strongly subject to the single-phase oxidation. During this, $T_c$ increases up to 540°C. The Day and Bol'shakov-Shcherbakova tests show the presence of the PSD grains as the main fraction of the ferromagnetic fraction. On our opinion, namely these grains are the TCRM carriers. Interestingly, we observe the direct correlation between the saturation magnetization and TCRM intensities.

**Some data on characteristics of the geomagnetic field direction during late Gauss and Gauss-Matuyama reversal (Western Turkmenistan)**

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Unfortunately, the structure of the Gauss chron magnetic field studied extremely fragmentary. Very few detailed data are available on the field changes during Gauss-Matuyama polarity transition [Channell et al., 2006; Laj & Cannell, 2007; Ohno et al., 2008, 2012]. We re-investigated Akchagylian sediments (the analogue of the upper Piacenzian and lower Gelasian) in Pirnuar locality (Western Turkmenistan), which have been studied by us in the first half of the 70-s [Gurary, 1976, 1977]. Undoubtedly, now the data must be verified and re-interpreted. For this reason, 170 samples were collected from the 135 m of the section, in which recorded the final and initial stages of Gauss and Matuyama chrons. Directly in the boundary part of the section (about 30 m) samples were taken from 970 stratigraphic levels. According to old and new data, we can make the following conclusions:

1. Nonuniformity of magnetic fraction in studied sediments has allowed us to study only the characteristics of the field direction. For analysis, were used the results obtained from specimens, magnetization of which is most likely to have the orientation nature.

2. Absence in studied section the data that can be compared with the Kaena gives evidence that the average sedimentation rate was more than 0.5 m/kyr.

3. In middle part of the section there are two anomalies in magnetization of the sediments which most likely reflect excursions of the geomagnetic field. If we compare the latest of them, which we have studied in detail in 1972 and 1976, with an excursion L6 [Ohno et al., 2012], then it must be assumed that the average sedimentation rates were nearly 1 m/kyr.

4. Duration of the interval, which can be associated with the Matuyama-Gauss reversal, is 11–22 kyr, full polarity change has occurred in the 5–10 kyr.

5. VGP in this period with rare exception were located in a band of longitudes 90–160°; it confirms the results obtained during previous studying field characteristics during the reversal in several locations of the region.

6. Through 14–28 kyr (14 m) after transition begins an excursion, the duration of which is not less than 2–4 kyr and which very tentatively can be compared with excursion L4 [Ohno et al., 2012].

## Paleomagnetism of the Early Devonian sedimentary formations of the Spitsbergen land

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A new paleomagnetic results on the collections of the Early Devonian rocks from north part of the Spitsbergen land are presented here. Detailed demagnetization of the Early Devonian rocks reveals the presence of two components of the natural remanent magnetization (NRM). Component A is most likely to be related to both the viscous magnetization of the rocks by the Cenozoic geomagnetic field and the chemical alterations caused by weathering. The second high-temperature component in most of the sections is bipolar. The polarity reversal test for component B is positive and corresponds to class C. The zones of normal and reverse polarity identified in our study for the Andreebreen and Fraenkelryggen Formations, Red Bay series and Keltiefjellet Formations, Wood Bay series. The reasonable correspondence between the locations of the zones of normal and reverse polarity revealed in our study and the general magnetostratigraphic scale also support the old age of the isolated characteristic components of NRM On the basis of these results and the available data of the World paleomagnetic database, the palaeogeographic layout of Spitsbergen and the Russian Platform in Early Devonian are reconstructed.

## Interpretation of marine magnetic anomalies. A survey of existing approaches and the least squares method

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In this work, we consider the problem of marine magnetic anomalies interpretation. The magnetic inversion is considered in the framework

of the Vine–Matthews spreading model. Analysis and a comparison of the methods proposed earlier for solving this problem are carried out. For a simple example it is shown that the analytic signal method has significant restrictions associated with the size and the depth of the bodies.

Based on the least squares method, a new algorithm for determining the position of direct and reverse polarity blocks is proposed. The global minimum of the residual is found by a combination of the multistart and Monte Carlo methods. Using an example of a field of three blocks perturbed by a normal noise, it is shown that the method yields an error close to the minimum possible. Using a model applying magnetic polarity time scale, it is revealed that the proposed algorithm allows one to find positions of block boundaries of the field without noise with a higher accuracy determined in fact by the computation time. Also calculations indicating the stability of the inverse problem of magnetometry under consideration.

## Paleomagnetic and rock magnetic study of Silurian-Devonian sediments from Podolia, SW Ukraine: remagnetization problems

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Paleomagnetic study of Silurian-Devonian sedimentary sequence in Podolia (Ukraine) may provide pole position for this time from another region than Scotland and Scandinavia. The deposits are exposed in the basin of the Dniester River. For paleomagnetic study ten outcrops of Upper Silurian and seven outcrops of Lower Devonian sequences which are represented by grey and red sediments (mostly limestones, dolomites and sandstones) were sampled during several expeditions. The remanent magnetization of specimens were measured in two laboratories — in the Institute of Geophysics Polish, Academy of Science, Warsaw and in the Institute of Geophysics of the National Academy of Sciences of Ukraine, Kiev. Two components of NRM were revealed in Devonian grey and red sediments. First component recognized in almost all samples has SSW declination and negative inclination. Pole positions calculated from these

directions lie in the Permian segment of APWP published by Torsvik et al. (2012) for Baltica/Stable Europe. Second component (ChRM) was isolated at the end of thermal demagnetization path for red sandstones and in some samples during alternating field demagnetization of grey limestones. This component has dual polarities with SW (NE) declination and positive (negative) inclination. Paleomagnetic poles positions lie close to Lower Devonian segments of APWP. There are several facts supporting the hypothesis that ChRM-components of grey and red sediments are primary magnetization which recorded Devonian paleofield. They are recognized in different sediments — limestones and sandstones. They were carried by different magnetic minerals — magnetite in the case of grey limestones and hematite in the case of red beds. AMS fabric of red sandstones and these samples of grey limestones which preserved Devonian magnetization are typical for sedimentary structure with minimum axes of AMS perpendicular do the bedding plate. In spite of similar remagnetized directions obtained for both rock units the mechanisms involved for acquisition of secondary components were different. In grey limestones usually only one component was isolated in single sample. Permian remagnetization was recognized in samples in which Devonian direction was not preserved. Magnetic carriers represent magnetite which occupies SD+MD field in the Day/Dunlop plot characteristic for unaltered rocks. On this basis we suppose thermoviscous mechanism of remagnetization without significant alteration of rock. In red beds Devonian directions were isolated as a second component at the end of thermal demagnetization path. Among five forms of hematite revealed in the red beds by petrographic analysis, the only hematite of unquestionable detrital origin is the hematite with the ilmenite-hematite intergrowths ('tiger striped' grains) which is a product of high temperature exsolution processes. It pointed to different carriers of Permian and Devonian components. The unblocking temperature spectra for secondary component are characteristic for fine grained pigmentary hematite. The best candidate for magnetic carrier of Permian remagnetization is secondary authigenic, pure hematite crystals resigns in ferruginous cement of sandstones or in chlorite grains. Because of that we suppose that in red beds the Permian component of NRM is of chemical origin. New paleomagnetic results are consistent with Silurian-Devonian data for Baltica, but allow us to make detailed reconstruction the Middle Paleozoic kinematics of East-European Platform. After drifting in a northerly direction in the Lower Silurian, the position of EEP in Wenlock -

Ludlow time was stabilized in equatorial latitudes. Drift direction in Pridoly time was changed towards equatorial latitudes of the Southern Hemisphere. Later the EEP always located near the equator and slightly to the north until the end of the Carboniferous.

## To the basic distribution of magnetization within the magneto active Earth's layer

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With increasing temperature the natural remanent magnetization decreases, vanishing at Curie isotherms depths and deeper, but in contrast the deepening and growth of interiors' temperature, according to the well-known in physics of rock magnetism Hopkinson effect, make magnetic susceptibility of rocks rising to a certain maximum and then dropping to zero by Curie isotherms. Physical principles that can lead to the Hopkinson effect may be interpreted as the following. Under the weak external magnetic field the positions of electron spins in magnetic minerals are mainly fixed along with the "easy" anisotropy axes and controlled by the magneto crystallographic anisotropy. Magnetic susceptibility in this state is performed by the motion of domain walls for multidomain, relatively large mineral magnetic particles, or by prevailing rotation of magnetic moments in pseudo-single domain or quasi single domain, relatively small particles. With increasing temperature at the interiors environments, the saturation magnetization and the magneto crystallographic anisotropy coefficients of magnetic minerals are reducing. According to the general regularities an efficient constant of magneto crystallographic anisotropy is straightly correlating with the magnetizations powered by entire degree, equal to three for magnetite like crystallography lattice symmetry. So at sufficient temperatures the rate of magneto anisotropy energy decrease turns up greater than the rate of the magneto static energy decrease, thus from this state magnetic moments became freer and magnetic susceptibility turns up rising with the temperature. Further heating leads to the progressing weakening of exchange interactions of electronic spins and thus to the vanishing of ferromagnetic ordering and transition to paramagnetic state with very low susceptibility. This implies the following conditions for the manifestations of Hopkinson effect in rocks: relatively weak external magnetic fields

and sufficient decrease of magneto crystallographic anisotropy energy contribution compared with the own magneto static interactions at rising temperatures.

Another cause of magnetization rising with depth is temperature rising of critical single domain sizes of the main magnetic mineral particles, like magnetite, titanomagneties and others. As the particle magnetic moment is proportional to the saturation of magnetization and cubic degree of the radius, for the equidimensional particles, then it turns that the magnetic moment is rising initially with the interiors depth. But there is the restriction of sizes up to maximal for the critical radius growth with the temperature elevation. From this point the volume is fixed and the magnetic moments are reducing according to the lowering of saturation magnetization with temperature up to the vanishing at Curie points.

## Comparison of Rock Magnetic Properties of Loess-Paleosol Sections in Baikal Region

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We present a detailed rock magnetic study of 3 Upper Pleistocene sections in Baikal Region. Novorazvodnaya (NR) section is located on the right bank of Angara river near Irkutsk city, Ust-Oda section (UO) on the left side of Angara river valley 48 km downstream from NR section in the foothills of East Sayan Mountain ridge and Malta (ML) section on the left bank of Angara river 54 km downstream of UO section. All sections belong to the same climatic zone and contain 2 buried pedocomplexes (PC) separated by loess. The age of the upper PC due to C14 data from ML and UO sections corresponds to MIS3. Thermomagnetic analysis suggests a uniform magnetic content – predominant magnetite with low content of hematite (in PC). Mean magnetic susceptibility (K) value in UO section for loess units is $250 \cdot 10^{-8}$ m$^3$/kg, in ML section – $130 \cdot 10^{-8}$ m$^3$/kg, in NR section – $80 \cdot 10^{-8}$ m$^3$/kg. K values in PC are generally 1,4–1,6 times lower. Moreover, PC show enhanced coercivity and smaller magnetic grain size. Such susceptibility pattern is generally considered as "Alaskan mechanism" (Chlachula et al., 1998). But a full complaisance with such mechanism is observed only in UO section, where FD% =0 all

over the section. Conversely, FD% in PC from NR and ML sections show enhanced (up to 5% –7%) values (up to 5% –7% ). So, the rock-magnetic records in ML and NR sections are better corresponding to "Siberian mechanism" — a combination of wind-vigor and pedogenic origin of magnetic minerals (Matasova et al., 2003). The difference in magnetic mechanism in closely spaced sections can be understood through the difference in magnetic grain size. In UO section magnetic minerals are represented by large magnetite grains which determine the high values of K, while FD signal in the PC can be carried by hematite grains, due to high coercivity in PC. High concentration of coarse magnetite and hence high bulk K values can obscure a weak signal from SP hematite and it becomes indistinguishable. Reducing of the concentration of coarse grains reduces the bulk K values and FD signal becomes distinguishable. FD% values are higher in the sections with lower concentration of large magnetic grains. Thus, proximity to the source of the coarse magnetic grains determines the "Alaskan mechanism" of magnetic properties, with the distance from the source, "Alaskan mechanism" is changed to "Siberian" one.

## Major stages of the tectonic evolution of western Urals reflected in the multi-component remanence of the Ediacaran Asha Group

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The understanding of the tectonothermal and structural evolution of Western Urals provides crucial clues for the mineral exploration in this region. Western Urals is the edge of the Eastern European Platform (EEP), which has been deformed in late Vendian (Ediacaran) to early Mesozoic during several collisional events (Puchkov, 2010). Such events are usually associated with paleomagnetic reprints, particularly in the Precambrian sedimentary rocks resulting in their multi-component remanence (e.g. Iosifidi et al., 2005). Consequently

a careful analysis of such cases provides an opportunity to reconstruct the deformation history of the studied area.

The sedimentary Asha Group of southern Urals and its correlatives in central and northern Urals might preserve such paleomagnetic record of the tectonothermal history of this region. This sedimentary succession is exposed in the western slope of the Urals Mountains along the Main Uralian fault. As this area has been a subject of multiple tectonic events in Late Ediacaran, Late Ordovician – Early Silurian, Devonian and mid-Permian (e.g., Puchkov, 2000; Puchkov, 2010; Willner et al., 2001; Glasmacher et al., 2003; Svyazhina et al., 2003), the spectrum of remanence components in the rocks of the Asha Group might potentially represent a record of these events.

First paleomagnetic study of the Asha Group has been carried out by Komissarova and Danukalov in 1960s. Most of these samples were never thermally demagnetised. Recently we did this for 219 samples (92 sites) from Basu and Kuk-Karauk formations in four locations: Kuk-Karauk Creek(28 samples from 4 sites in the 40 m-thick section); Old Beloretsk road (44 samples from 18 sites, the total thickness of the section – 800 m); Zilim River (68 samples from 38 sites, thickness – 15 m) and Basu River (45 samples from 16 sites, the total thickness – 230 m).

Multicomponent structures of the studied rocks magnetization have been identified. Component ages have been estimated by comparison with the data for the East-European plate. The results allow us to trace and to date the main stages of the tectonic history of the belt placed along the west side of the Main Uralian thrust.

**Low-temperature magnetic properties of iron-bearing minerals and their contribution to magnetism of cometary bodies**

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In this study, we present a review of low-temperature magnetic properties of alabandite (Fe,Mn)S, daubreelite $FeCr_2S_4$, pyrrhotite $Fe_{1-x}S$, troilite FeS, and chromite $FeCr_2O_4$ including new experimental data. The results indicate that, besides FeNi alloys, mainly daubreelite, with its Curie temperature of $T_C = 150$ K and strong induced and remanent magnetizations, may be a significant magnetic mineral in cold environments and may complement FeNi or even dominate the magnetic properties of sulfide-rich bodies at temperatures below $T_C$. Comets are known to contain iron-bearing sulfides within their dusty fraction. Their surfaces are subject to temperature variations in the range of 100–200 K down to the depth of several meters, whereas the cometary interior is thermally stable at several tens of Kelvin which is within the temperature range where chromite, daubreelite, or troilite are "magnetic". Thus, not only FeNi alloys, but also chromite and sulfides have to be considered in the interpretation of magnetic data from cometary objects such as the data that will be delivered by the Rosetta mission. Modeling indicates that magnetic interactions between cometary nuclei containing iron-bearing sulfides or chromite and the interplanetary magnetic field would be difficult, but not impossible, to detect from orbit. Rosetta's Philae lander present on the surface would provide a more reliable signal.

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### Magnetic susceptibility

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Modern lake sediments are a unique source of information for climate changes, regionally and globally, because all environmental variations are recorded by these sediments with high resolution. Magnetic minerals are hereby of particular interest, because they occur almost in any environment, because they are susceptible tracing environmental changes, which are closely related to their formation conditions, and because magnetic mineral concentrations in the ppm range can be detected. We investigated the magnetic properties of Chernyshov Bay (Aral Sea) sediments (N45°57'04.2"; E59°17'14.3") from core number 4 taken at f a water depth of 9.5 m. The length of the core is 4.16 m. Beside magnetic susceptibility, also remanent magnetization curves were measured for the separate determination of the different contributions to the bulk magnetic susceptibility. Our goal is to decipher the magnetic susceptibility signal in lake sediments by decomposing the bulk susceptibility signal of a lake sediment sequence into ferromagnetic ($\chi$f), dia-/paramagnetic ($\chi$p) and superparamagnetic ($\chi$sp) components. Each of these has a different origin: paramagnetic minerals are usually attributed to terrigenous sediment input, ferromagnetics are of biogenic origin, and superparamagnetic minerals may be of either biogenic or terrigenous origin. The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University also by RFBR research projects No. 14-05-31376, 14-05-00785.

### Rationale for location of coring using acoustic method

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Lacustrine sediments contain a long, high-resolution record of sedimentation processes associated with changes in the environment. Paleomagnetic study of the properties of these sediments allow a detailed trace the changes in the paleoenvironment. However, there are factors such as landslides, earthquakes, the presence of gas in the sediments affecting the disturbing sediment stratification. Seismic profiling allows to investigate in detail the bottom relief and get information about the thickness and structure of the deposits, which makes this method ideally suited for determining the configuration of the lake basin and the overlying lake sediment stratigraphy. This information is crucial when choosing the optimal place. Thus, continuous seismic profiling should be regularly used before coring lake sediments for the reconstruction of paleoclimate. We have carried out seismic profiling on lakes Yarovoye, Balkhash, White, Aslykul and CHebarkul. The results of the field work will be presented in the report.

### New determinations of the Campanian–Maastrichtian paleointensity

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The reconstruction of the paleointensity behavior in the Campanian - Early Maastrichtian using deposits selected in the Saratov Oblast (Volsk Town, Pudovkino Village, Banovka Village) was conducted. The intervals of the quiet geomagnetic field (during which paleointensity variations occur with small amplitude) and bursts of the paleointensity (large amplitude variations) were revealed. At the beginning and at the end of the Early Maastrichtian high values of the paleointensity took place. In addition, high values of the paleointensity revealed in the beginning of Middle and at the end of the Late Campanian. The distributions of obtained values of the paleointensity were analyzed. It was revealed that the cumulative distribution function (CDF) of the paleointensity values in these intervals is best approximated by a power function. The value of index of the power function

in the Campanian was higher than in the Early Maastrichtian. Based on these data it can be assumed that the turbulence of processes in the Earth's liquid core was higher in the Campanian than in the Early Maastrichtian.

### Dynamics of ancient geomagnetic field characteristics

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The distributions of polar intervals durations and values of the ancient geomagnetic field intensity in the 0–200 Ma interval were analyzed. The distributions of polar intervals and the paleointensity values one of the "canonical" distributions — exponential or power function are approximated. The distribution of the polar intervals durations is best approximated by an exponential function. We calculated indices of exponential functions for time intervals lasting 10 Ma. It is revealed that changes of the exponent indices correlated with changes of the polar interval durations. Paleointensity values (Jurassic - Early Paleogene) is best approximated by a power function. Paleointensity of the Middle - Late Paleogene is better approximated by an exponential function. The indices of power and exponential distributions varied depending on the geological time intervals which analyzed paleomagnetic data belonged. Our results of analysis led to the following conclusions: 1) the indices of exponent which approximated polar intervals durations reflect qualitative changes in the geomagnetic field polarity regime and can be used for to structuring of the polarity scale; 2) on the basis of changes of the indices of power functions which approximated the distributions of paleointensity assumed the important role of turbulence of a magnetoactive medium in Earth's geomagnetic field generation and intensification of turbulence in the Cretaceous compared with Jurassic and Paleogene; 3) the most significant qualitative changes in the paleointensity behavior occurred in the Paleogene near the Paleocene - Eocene.

**Relation between behavior of geomagnetic field characteristics and activation of basaltic magmatism**

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Relation between behavior of the geomagnetic field characteristics and the magmatism activity repeatedly has been refined as paleomagnetic data are accumulated. In this study, we compared beginnings of the basalt (plume) magmatism activations, behavior of reversal frequency and the geomagnetic field paleointensity for the past 260 Ma using the epoch superposition method. Since the intervals between activations of basaltic magmatism averaged about 15 million years, we have analyzed the behavior of the geomagnetic field characteristics for 7 Ma before and for 6 Ma after these events. A total we examined 15 cases of basaltic magmatism activations and related with its fragments of geomagnetic field behavior. It was revealed that for 3–6 Ma before magmatism activations the increase (statistically significant) in the frequency of inversions was occurred. Low supply of data does not allow for a correct comparison of the plume magmatism and paleointensity along the whole interval (260 Ma). Nevertheless, we were compared activations of magmatism with the paleointensity behavior in the last 80 Ma using the data obtained by termomagnetized rocks (PINT12). In this interval the mean values and amplitude of the paleointensity variations increased after the beginning of magmatism activations. Analysis of data obtained from sedimentary rocks of the Cretaceous also showed that after magmatism activations mean values and amplitude of the paleointensity variations increased.

**Magnetic properties of marker tephra layers in Late Quaternary sediments of the Okhotsk Sea**

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Volcanic ash layers (tephra) are reliable indicators of the large explosive volcanic eruptions within transitional zone from continent to ocean. They occur in terrestrial outcrops as well as in sedimentary cover of the adjacent marine basins. The Okhotsk Sea Quaternary deposits remained insufficiently studied until recently. Over the last 8-10 years, in several joint complex expeditions: R/V "Mirai" (2006), R/V "Yokosuka" (2007), R/V "Academik M.A. Lavrentiev"( 2011) Russian, Chinese and Japanese scientists studied the Okhotsk Sea interlayers tephra of different areas and age by petromagnetic methods. Ash layers age was identified on the basis of chronostratigraphic research of cores: paleomagnetic and biostratigraphic methods, AMS-carbon dating, etc. Identify of the ash layer was based on comprehensive research of ashes, particle morphology, chemical composition of volcanic glasses and minerals, rare earth elements were studied. Refractive index of volcanic glass and mineralogy were determined. Identification of the magnetic component of tephra made on the basis of thermomagnetic analysis and study of magnetic hysteresis parameters. In the Sea of Okhotsk ash falls of several large explosive eruptions of volcanoes of Kamchatka and the Kuril Islands were recognized. Tephra of those volcanoes was identified with caldera eruptions of the Kurile Lake (Kamchatka) (tephra KO, age ∼8.4 ka); Volcanic Group volcano about Nemo (Onekotan Island) (K2, 32 ka), (K3, ∼40 ka), (MR1, ∼66 ka) and (MR2, ∼201 ka,); Sredinny Ridge (Kamchatka) volcanoes (MR3, ∼310 ka, MR4, ∼312 ka), etc.

## Rock-magnetic study of archaeological sites of Bronze age in Western Siberia

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Archaeological and geophysical studies of ancient monuments in Western Siberia have shown that sometimes the magnetic survey becomes uninformative due to vague or false anomalies. In some cases, anomalies from archaeological objects are missing, which creates considerable inconvenience for the identification of archaeological sites. For

an explanation we studied the magnetic properties of all components of the natural environment over the area of high concentration of archaeological sites of Bronze Age in the Baraba forest-steppe in the Western Siberia (55,64 N; 76,74 E). To reveal the complete picture of distribution of the magnetic properties we studied locations in various geological and geomorphologic environments. Magnetic properties of top soils, underlying bedrock (loam, sand) and filling of archaeological recesses of different purpose (burial, domestic and ritual pits, etc.) are mostly determined by the amount of magnetite. With the decrease of the magnetic susceptibility (MS) the magnetic composition gradually changes from prevailing magnetite (humus horizons of soils) to the goethite-hematite (in the sands and floodplain soils). Frequency-dependent magnetic susceptibility (FD) indicates a substantial content of superparamagnetic (SPM) magnetite grains in the humus horizons of chernozems (FD 9–11%) that provides high values of the MS. In the meadow soils FD is lower (6%) in the floodplain – SPM grains are absent. In bedrock FD does not exceed 1.5%. The amount of SPM grains in the sediments within the studied area is the basic reason of differences in their magnetic properties and gives the main direction of evaluating the effectiveness of magnetic survey applications. The magnetic contrast between humus horizons and bedrock, defined as the relation K = MS(soil)/Ms(bedrock), makes effective use of magnetic survey in the areas between the rivers and the adjacent parts of the floodplain terraces (K = 3÷5). In the terraces gently sloping to the floodplain, this ratio decreases to 1.5÷2, thus reduces the prospects of magnetic survey due to decrease in the amplitude of the magnetic anomalies. On the floodplains the difference of the magnetic properties of the underlying rocks and filling material of archaeological recesses becomes indistinguishable, and the use of magnetic survey is impractical.

## High resolution estimates of Eurasia-North America plate motion on the basis of magnetic lineations, 20 Ma to present

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We estimate Eurasia-North America plate motion rotations at 1-Myr intervals for the past 20Myr from more than 10,000 crossings of 21 magnetic reversals out to C6no (19.72 Ma) and flow lines digitized from the Charlie Gibbs, Bight, and Molloy fracture zones and transform faults. Magnetic lineations older than C3An.1 (6.0 Ma) that are located within 200 km of the Azores triple junction and lineations older than anomaly 4A (9.1 Ma) along the Gakkel Ridge in the Arctic Basin are misfit systematically when they are inverted with data from other parts of the plate boundary, suggesting either localized, slow (1 mm/yr) microplate deformation in one or both regions or misidentifications of some magnetic anomalies in those areas. Excluding these possibly biased data, a simultaneous inversion of the remaining kinematic data gives a sequence of 21 best-fitting rotations with weighted RMS misfits of 1-2 km for the numerous reversal crossings and 0.2-7 km for the transform fault and fracture zone crossings. The rotations clearly define a 1000 km southward shift of the rotation pole and 20% slowdown in seafloor spreading rates between 7 Ma and 6 Ma, preceded by apparently steady plate motion between 19.7 Ma and 7. Data for times since 7 Ma are well fit by a constant-motion model, consisting of a stationary pole of rotation and constant rate of angular opening. The southward movement of the rotation pole at 7-6 Ma implies a transition in northeastern Asia from slowly convergent Eurasia-North America plate motion prior to 7 Ma to slow divergence afterwards. The new, well-constrained rotations document Eurasia-North America plate motion throughout most of the Neogene and should be useful for detailed, Neogene-era reconstructions of the motions of Eurasia and North America relative to the thirteen other tectonic plates with which they share boundaries.

## Some problems of stratigraphy and genesis of tuffs of Armenia

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The tuffs of Armenia in their texture and coloring are divided into three main types: (1) artik type with pink and ash-violet coloring; (2) Erevan–Leninakan type with black, dark gray and dark brown coloring; (3) burakan type with red, black and yellow coloring. Many problems of stratigraphy, genesis and temperature of initial masses of

formation of the tuffs of Armenia debatable. Some believe that the tuffs were formed from heated volcanic materials rich with gases relief depression as a liquid substance and cooled like lava. Others suggest that the Erevan–Leninakan type if tuffs was formed by compacting ash material dropped from the are, and artik tuff formation occurred in the water basin. It is believed that the tuffs were formed exclusively during the middle and late Pleistocene.

The composition of ferromagnetic fraction, type of magnetization In, the direction of its primary component and temperature at which this magnetization occurred (Curie point) are indicatives of rocks formation conditions. A collection of tuffs was studied from various fields (about 300) samples. The composition of ferromagnetic fraction of tuffs is determined by thermo-magnetic analysis the curves Irs(t), Ir(H) and H'cs value. Were studied coercive spectra Ir(h), Iri(h) and the demagnetization curves of a variable magnetic field Ir(h) and temperature In(t). The nature of magnetization in rocks defined by the method successive heating Thellier. These parameters are defined for some effusive Pliocene-Pleistocene age as well taken from the same endemic areas of tuffs.

According to the results of thermo magnetic analysis Curie point of studied rocks (for tuffs and dolerite- basalt and andesite-dacite), generally been in the temperature range 550–575°C. In tuffs Burakan type (red tuffs), except for samples containing only magnetite samples revealed, as part of the ferromagnetic fraction was found to maghemmite. Coercive spectra Ir(H) also confirmed the magnetite composition of ferromagnetic fraction. Petrography studies shoved that the ferromagnetic fraction for tuffs and effusive rocks is presented mainly by magnetite with sire ranging from 10 to 30–40 microns. Coercive spectra Ir(h) and Iri(h) differ in one maximum in the interval field 100–300 oersted. The direction In, when demagnetized by variable magnetic field and temperature remained constant up to field 700–800 oersted and temperature 500–600°C. This may serve as confirmation of single-component and the primacy In the studied rocks. The curve of successive heating Thellier for all the studied breeds, regardless of the types of rocks polarity of magnetization proved the thermoremanent nature of the studied rocks.

In the section view of pink artik tuff types 1,5meters inversely magnetized area was found that probably takes a certain stratigraphic position. Inversely magnetized samples were also marked in black tuffs of Erevan–Leninakan type. Yellow and red tuffs of burakan

type differ from each there by their magnetic characteristics. Red tuffs have higher values of In, than the yellow tuffs.

According to the results of analysis and study of magnetic and paleomagnetic characteristics of some tuffs and effusive rocks we can make the following conclusions: (1) the nature of In in all tuffs is thermoremanent; (2) the presence of inversely magnetized samples of artik and Erevan–Leninakan tuffs type suggest that some horizons of tuffs may have formed during stable reveres polarity of the Geomagnetic field (in the upper Pliocene and lower Pleistocene).

## Rock magnetic and geochemistry evidence of Younger Dryas in lacustrine sediment, NE Russia

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Younger Dryas is one of the last large cold of climate event according to radio-carbon date was between 11 and 10 thousand years ago (12800–11700 cal. yr). This climatic event is found in the sections located on continents, in a sea and lake sediment, in ice cores. The reference section is the ice core NGRIP in Greenland (Walker et al., 2006). Pleistocene and Holocene boundary (11700 cal. yr) are located on the top of this event, in this regard it is important for a stratigraphy. Though Younger Dryas is studied long ago, there are not solved problems about global and synchron character of this event. In the Northeast of Russia more than ten lakes are investigated, however only in a lake Smorodinovoye section (64°46' N, 141°06' E) in Yakutia according to a palynology data the Younger Dryas is established (Anderson et al. 2002). It is difficult to assume that in other lakes were gaps in sedimentation during this event. It is probable that this event (if it here was) was not reflected in the pollen data which are widely used for the paleoclimatic reconstruction. About ten lake sediment sections which could be formed in Younger Dryas are in details analyzed. From the obtained data follows that near peak of contents of Alnus pollen which is used as a correlation marker, there is an interval of sediment with the increased values of a magnetic susceptibility. This interval is characterized by rather high concentration of TiO2 and low values of Loss on ignition. It is supposed that this interval corresponds to the Younger Dryas level. High val-

ues of a magnetic susceptibility, the low content of organic material and the raised content of the titan can indicate reduction of intensity of organic accumulation and to bigger receipt of a detrital material from slopes. Probably, in some lakes abiotic parameters, including rock magnetic and geochemistry proxies are more sensitive to climate changes, than biotic indicators.

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**Geomagnetic field intensity in the region of Taman Peninsula in VII – XVII C.C.A.D.**

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Archaeomagnetic investigations of samples collection from the archaeological memorial – site of the ancient town Hermonassa (t. Taman) related to VII – XVII C.C.A.D were fulfilled. The aim of this research is to obtain data about geomagnetic field intensity. The material was selected from the northern section of the memorial excavation. Determinations of geomagnetic field intensity from 50 to 90 $\mu$T were obtained. Geomagnetic field intensity reached maximum in the interval X – XI C.C.A.D. The obtained picture of geomagnetic field intensity is well coordinated with the picture of intensity field variations obtained from the results of investigations of ceramic material from archaeological memorials of Georgia and Central Asia, related to the considered interval [Nachasova, 1998]. According to the data obtained from the material research results of archaeological memorials of Bulgaria [Nachasova, 1998] and Spain [Nachasova et al., in press] maximum of smooth alteration of geomagnetic field intensity in these regions falls on some earlier time interval. Thus, the recent data of geomagnetic field intensity variations during the time interval of the second half I th. A.D. – II th. A.D. in regions of Iberian and Taman peninsulas confirm that the maximum of intensity field of this time interval in regions of western sector of Europe (Spain and Bulgaria) falls on the earlier time interval than in the regions of the eastern sector (Taman and Georgia). The shift can be estimated approximately in 100 years. This work was supported by RFBR (project 13-05-00431).

**Rock-magnetic properties of bottom sediments from Tchany Lake (West Siberia)**

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The main objective of this project — to study petromagnetic properties of bottom sediments from different connected sections of Lake Tchany (Yudinskiy and Yarcovskiy reaches). Tchany lake located on the border of the steppe and forest-steppe zones and is an indicator of climate change in the south of Western Siberia. Climatic changes are recorded in the sediments of the lake. In this project we measure a petromagnetic characteristic of core of bottom sediments from two stretches of the lake. The collection presents 326 rock samples from two reaches was measured on the $J_{meter}$ instrument (Jasonov construction) in the laboratory of Trofimuk Institute of Petroleum Geology and Geophysics SB RAS. The results of petromagnetic measurements were compared with lithology. Next step was correlation cores from both reaches (Yudinskiy and Yarcovskiy) between themselves and definition the main stages deposition of lake sediments. Petromagnetic characteristics give us information about the sedimentation process and depositional environment. If conditions of sedimentation are changing, the concentration, composition, amount and size of magnetic minerals are changing too. Any changes are clearly visible on various petromagnetic parameters. We identified two stages of bottom sediments accumulation. At first stage of geological life, stretches Tchany Lake existed as a single reservoir. For this phase characterized bio-chemical type of the formation of magnetic minerals. Second phase characterized stretches of Tchany Lake like separate reservoirs with different deposition environments. In the second phases formation of sediment in the Yudinskiy reach dominated eolian material, and in the Yarkovsky reach dominated material from river.

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**Petromagnetism of igneous rocks of the submarine volcanoes from Kurile Island Arc**

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Research Vessel (R/V) "Vulkanolog" was realized considerable volume of the complex geological and geophysical survey of the submarine volcanoes from the Okhotsk Sea slope of the Kurile Island Arc (KIA) during 1981–1991 period. Now the study of the collection of igneous rocks from R/V "Vulkanolog" available in the Institute of Volcanology and Seismology FEB RAS are continued. Samples were picked out from the submarine volcanoes KIA. Measurements of standard rockmagnetic, thermomagnetic analysis, petrological studies and electron probe microanalysis were fulfilled. Rockmagnetic investigations of the samples and thermomagnetic analysis were fulfilled in Schmidt Institute of Physics of the Earth RAS. Volcanoes very different by NRM and K values. The highest values of NRM=31.56 A/m have basaltic andesites of Edelstein submarine volcano and of K=49.41 SI have aphyric basalts of Grigorea's submarine volcano, the lowest values of NRM=0.15 A/m and of K=10.5 SI have porphyric basalts of Belyankin's submarine volcano. All studded samples are magnetically isotropic and content relatively low coercive magnetically minerals of the various domain structure. The main carriers of the natural remanent magnetization in the studied rocks are often grains of unaltered and/or oxidized titanomagnetite. Highest values of NRM have a mainly SD and PSD titanomagnetite grains, and highest values of K due to a high concentration of ferrimagnetic grains. The oxidation of the initial titanomagnetite in samples passed already in natural conditions. In order to corroborate the composition of NRM carriers in the samples the petrological studies and electron microprobe analysis were carried out in using scanning electron microscopes in Geological Institute and at the Department of Geology of Moscow State University. For ferromagnetic grains in different locations and zones done some tests which showed a sufficiently homogeneous distribution of Ti and Fe suggesting a single-phase composition of grains. The homogeneous structure of titanomagnetite grains without a trace decay or secondary transformations were well seen. Receiving data about magnetic characteristics of the dredged rocks can be used for interpretations of the geophysical

investigations and for study peculiarities of the magnetization during evolution of the active submarine volcano.

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**Paleomagnetic characteristics of the Vendian-Cambrian boundary from section on the river Chaya (Northern Baikal)**

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Two sections (Nemakit-Daldynsk stage of upper Vendian and Lower Usatov series of Tommot stage of Lower Cambrian) from deposits at the south-western Patom highlands, r. Chaya are investigated. The boundary between the Vendian and Cambrian set on changing lithofacies composition of the rocks. The studied section of the Vendian is represented by limestones and dolomites gray, and the overlying deposits of Tommot stage of the Lower Cambrian - terrigenous redbeds. Boundary of their dissent. Paleomagnetic studies were carried out by the standard technique. Two bipolar components in two sections were obtained by the component analysis: NR1 and NR2, which differ by the direction of 39 degrees. Sections are presented frequent alternation of paleomagnetic zones of these components. A unblocking temperature zones N polarity higher than R polarity. Besides for N1 are higher than for N2. The both (N and R) polarity are observed in the different specimens from the same sample. This is evidence of remagnetization the rocks.

**The NRM components analyses of Lower Cambrian deposits of the Siberian platform (Anabar anticline, in the upper r.Olenek)**

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The paleomagnetic studies of two parallel sections of Emyaksinskoy suit (Lower Cambrian) that located on the south-eastern of Anabar massif (in the upper r. Olenek) were carried out. The deposits are frequent alternation of the different consist red limestone. The thickness of each section is 32 m. Four different high temperature component using component analyses were obtained. The hematite C3G component is similar to direction of magnetite C3M component. Another hematite C3G1component is very different versus C3G. The C2 component (unblocking temperature 300–570 degrees) does not correspond to high temperature components. Paleomagnetic poles calculated from C3G and C3M component (Emyaksinskoy suit). Con-

cluded the results are identical paleopoles of stratotype section of the Lower Cambrian Tommot stage that located on south-eastern Siberian platform. The paleopoles C3G1 and C2 components on the APWP meets of Llanvirn stage of Middle Ordovician and Upper Cambrian relatively. In the results our studied we obtained correlation between Emyaksinskoy suit (Lower Cambrian, in the upper r. Olenek) and stratotype Tommot stage (Lower Cambrian, r. Lena) sections. In addition, we established the time of occurrence of the selected components.

**Paleomagnetism of paleozoic deposits from the Paga river (subpolar Ural)**

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The collections of the Ordovician, Silurian and Devonian rocks from the Paga River section in the Subpolar Urals are studied. Detailed demagnetization of the rocks reveals the presence of two components of the natural remanent magnetization (NRM). Component A is most likely to be related to both the viscous magnetization of the rocks by the Cenozoic geomagnetic field and the chemical alterations caused by weathering. The fold test for the second component B is negative. It is established that the pre-Permian Paleozoic deposits from the Paga River were remagnetized during the Kiama hyperchron (C2–P2) probably due to magnetoviscous processes that were blocked as these sediments were leaving the zone of increased temperature during the collision between the East European Platform and the Urals. The thrusts that took place at the last stage of this collision rendered the paleomagnetic directions of the studied structures different from those extrapolated from the East European Platform. The estimates of local rotations and displacements are obtained. The amplitudes of the thrusts for r. Paga structures average 85 km.

**Timing of NRM components acquisition in sedimentary rocks from Asha series, South Urals**

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This study aims to trace the origin of directional components of NRM of sedimentary rocks from Basinsk and Kuk-Karauk suites, Asha series, South Urals to the composition and microstructure of their ferrimagnetic (sensu lato) fraction, and to constrain the timing of NRM acquisition. Samples were classified according to the presence of similar combinations of NRM components. NRM mineral carriers were identified by thermomagnetic analysis of magnetic susceptibility, optical and scanning electron microscopy, and electron microanalysis.

We observe two different types of transformation structures: replacement of magnetite by hematite and titanomagnetite-ilmenite exsolution, as well as several generations of neoformed hematite sized from $< 1$ $\mu$m (often developed over cement) to $\sim 100$ $\mu$m. Also, a significant amount of Ti-bearing minerals (titanite, rutile) is present. Samples from the Kuk-Karauk suite also contain iron hydrooxides (limonite).

Evolution of magnetic minerals in the studied rocks can be viewed as following: magnetite (titanomagnetite) present in the depositing material $\rightarrow$ transformation of magnetite (titanomagnetite) $\rightarrow$ neoformation of recrystallized hematite.

We propose that the conditions for neoforming small hematite grains both over cement and over major phases of the non-magnetic matrix (most often quartz) start to develop at a rather early stage and persist during a considerable period of rock evolution. For example, the case when large hematite grains are surrounded by small ones clearly reflects forming of the former from the latter.

**TCRM and paleointensity determinations**

*Shcherbakov, V.P., Gribov, S.K., Dolotov, A.V., Tselmovich, V.A. (Geophysical Observatory "Borok", Russian Academy of Sciences, Russia)*

Basaltic samples containing TM with Tc around 300°C were heated in air in fields (50–100) $\mu$T at temperatures $T_h$ between 400 and 500°C for times as long as 200 hrs with the purpose to impart the TCRM. Products of the oxidation were monitored by thermomagnetic and hysteresis properties measurements completed with the analysis of X-ray spectra obtained on different stages of the reaction. For short runs gradual oxidation of TM to titanomaghemite results in increase of Tc to (450–550)°C and widening spinel X-ray spectral lines. For runs about a few hrs duration near-magnetite SPM grains appear leading to increase of $M_s$. For longer runs hexagonal phase in X-ray spectra emerges. Pure TCRM and TCRM+pTRM($T_h$, $T_{room}$) acquired under various conditions were subjected to Thellier-type experiments with help of a fully automated vibrating and/or rotating sample thermomagnetometers. The resulting Arai CRM–TRM and TCRM–TRM plots crucially depend on the stage to which the oxidation proceeded. For short runs the Arai plots are mostly nonlinear and show obvious marks of ongoing chemical alterations (single- and/or heterophase oxidations). If the hexagonal component is present (exsolution develops), the plots become quite linear over the majority of the TRM blocking temperature range. However, pTRM checks in this case are not perfect when the high Tb are considered and this observation can be used for the detection of possible TCRM presence in practice. An apparent strength of the acquisition field of TCRM inferred from these diagrams is usually underestimated.

**Distribution function of the intensity of geomagnetic field during Brunhes as obtained from the GGP model and empric data**

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An explicit expression in quadratures for the distribution function (d.f.) $f(B)$ of the intensity of the geomagnetic field $B$ and for the corresponding d.f. $f(VADM)$ is obtained following the Giant Gaussian Process (GGP) scheme. The results are compared with the empiric data set for the Brunhes epoch presented in the World Paleointensity Database PINT. At any fixed co-latitude the d.f. $f(B)$ and $f(VADM)$ are closed to the Gaussian. At the same time, the global $fg(B)$ is significantly asymmetric with the coefficient of asymmetry $a = 0.35$ due to the fact that the means of $f(B)$ strongly depends on co-latitude. On the contrary, the global $fg(VADM)$ has considerably less asymmetry $a = 0.16$ as the means of $f(VADM)$ only slightly depends on co-latitude. The empiric data display bigger dispersions than those of predicted from the numerical modeling. We believe that this difference is due to errors in the paleointensity data.

**Estimating the Mezozoic dipole low hypothesis by paleointensity study of the Siberian trap rocks from Maimecha-Kotui and Norilsk Regions**

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New results on determination of paleointensity and paleodirections combined with investigations of petrography and magnetic properties of Siberian trap rocks are presented. According to esti-mates of absolute age (Kamo et al., 2003), the formation of the traps occurred about 250 Ma, took about 1 Ma and was associated with rapid eruptions of huge amounts of volcanic material (2.5 million $km^3$). Collections of rocks from two regions: Norilsk (section Ergalah, Permian-Triassic boundary) and Maimecha-Kotui (Tyvankitskaya and Delkanskaya suites, early Triassic) were sampled. Extensive study of magnetic properties of rocks and their thermostability, estimating the domain structure of grains were carried out. The Thellier-Coe procedure with the pTRM-check heating to lower temperatures after every two temperature cycles was the basic method for determining the paleointensity. The Wilson express-method of paleointensity estimations was applied also. Satisfactory (in terms of quality and statistics) determinations are obtained for 29 (from 70) hand samples of Ergalah section, 28 (from 41) and 5 (from 22) ones from Tyvankits-kaya and Delkanskaya suites. The VDMs were calculated using paleoinclination determined for the correspondent lava flow or for the pulse. The VDM values vary in the range of $(1-5)\cdot 10^{22}$ $Am^2$ and make less than a half of the present day value $VDM = 8\cdot 10^{22}$ $Am^2$. This result agrees well with the previous published data supporting the Mesozoic dipole low hypothesis.

**The magnetostratigraphic subdivision of the Neogene sediments in the valley of the Holu river (Ubsu-Nuur basin, southern slope of the East Tannu-Ola, Tuva)**

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The results of paleomagnetic and magnetostratigraphic research of Neogene sediments, opened on the southern slope of the East Tannu-Ola ridge (the right bank of the Holu river), framing the North of Ubsu-Nur basin in the Tuva Republic are presented. Ubsunurskaya, despenskaya and kozovrashskaya suites were studied. Horizons with direct and reverse polarity in the Holu cross section were located and mapped with the paleontological data. Correlation with the basic Hirgis-Nur cross section, which is in the same Great lakes basin (Mongolia), was conducted. Known paleontological data on these cross sections allow to refer investigated Neogene deposits to the end of the Miocene — early Pliocene, covering an era warming, which dates from the 6.0–3.2 million years. In this regard new paleomagnetic data allowed to identify Holu cross section with the lower part of negative Gilbert chron, including positive Thvera subchron (5.23–4.98 million years).

**Geodynamo-like scaling laws in the planets, geomagnetic and paleomagnetic periodicities**

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Scaling laws for hydromagnetic dynamo in planets initially express the characteristic strength of the magnetic field through the primary values, such as the size of the conductive core of the planet, the angular rotation rate, electrical conductivity and energy flows. Most of the earlier proposed scaling laws based only on observations and assumptions about force balances. Recent and my new approaches to fully take into account the energy and induction balance has additionally expressed here in terms of primary values such important characteristics as forces, magnitudes, energies, scales and orientations of hydromagnetic fields. The direct numerical simulation of the hydromagnetic dynamo and modeling ability in a fairly wide range of

parameters for the first time allowed direct test such laws. The obtained numerical geodynamo-like results for the Earth, Jupiter and partially Saturn postulated previously not identified analytically simplest law that predicts the field strength is only depended on the specific energy density of convection and the size of the dynamo area. This simplest and already widely used law was original way analytically grounded here along with other previously known and new laws. This analytic identifies the physics determining geomagnetic periodicities for jerk, secular variations and inversions. Mean period between the inversions is found to be roughly proportional to the intensity of the geomagnetic field that is confirmed by some paleomagnetic researches. Possible dynamos in Mercury, Ganymede, Uranus and Neptune are also discussed.

**Abnormal behavior of geomagnetic field in Eltigen section (stratotype of Karangat of Black Sea)**

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Eltigen section – stratotype of Karangat of Black Sea has been studied (∼130–70 ka BP). The section is located on the coast of the Kerch Strait between the village Geroevka (Eltigen) in the north and the mouth of Tobichik estuary in the south. The section is a series of marine terraces. Here at the covering deposits of Uzunlar terraces the thickness of marine sediments unconformably overlain – actually Karangat. Marine sediments are rich in marine molluscan fauna. The covering deposits of Uzunlar and marine deposits of Karangat are poorly deployed. The Sourozh terrace is unconformably overlain. The Sourozh terrace is represented by the beach deposits in the basal part and by the covering deposits above.

Age of Karangatian deposits is well known and corresponds to the fifth oxygen isotope stage. All five substages of fifth oxygen isotope stage is reliably identify here thanks by a high depth of Karangatian deposits (∼15 m). Absolute data (U/Th) on mollusk shells were obtained here by the Geochronological Laboratory of St. Petersburg University. So, the 5th substage is dated as $127 \pm 8.9$ ka BP, the 3d substage – $107 \pm 7.7$ ka BP, and the youngest, the 1-st substage ∼80 ka BP. The top of covering deposits of Uzunlar terraces in this

section can be dated as ∼150 ka BP. The Surozh terrace corresponds to the 3-d oxygen isotope stage and has an age ∼50–20 ka BP. It was shown in the Eltigen section that covering loam deposits of Uzunlar age, marine sediments of the 5th – 3d substages of the 5th oxygen isotope stage and covering deposits of Surozh terraces have layers of abnormal behavior of a natural remanent magnetization (NRM) vector. Therefore it was undertaken a detailed study of these intervals.

Studies have shown that as Uzunlar loam deposits so the lower part of Karangat marine deposits are characterized by abnormal behavior of the geomagnetic field during their accumulation. In Karangate deposits in the range of ∼120–100 ka BP have seen at least five portions of abnormal behavior of NRM (up to full reverse polarity) separated portions of normal behavior of NRM. This studied interval corresponds to the Blake Event in a scale of excursions. So here Blake Event is a stack of layers with positive, negative and abnormal polarities. Each of them can be considered as self-guided excursion. In their morphology (the low intensity of the geomagnetic field, the duration ∼20 ka, the behavior of the virtual geomagnetic pole) studied interval is most like a frustrated inversion.

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## Magnetic minerals encountered in Chelyabinsk meteorite ablation

*Tselmovich, V.A. (Geophysical Observatory "Borok" IPE RAS, Borok, Russia)*

99.95% of the Chelyabinsk meteorite material fell for the Earth in the form of microparticles, which arise in the processing of high-temperature fusion crust. The bulk Chelyabinsk meteorite formed silicates. Particles were detected Fe-Ni alloy (native metal) with a high content of Ni (taenite) and low- Ni (kamacite) and troilite, pyrrhotite and pentlandite, chromite, heazlewoodite $Ni_3S_2$, ilmenite, apatite. In the study of the fusion crust in the cortex and in the pores were found characteristic Mt balls that might have formed during the flight of the meteorite fragments that flew in front of the studied fragment. They got into the pores and become available for observation due to quenching in the snow. It was shown that these beads were formed from troilite during melting and oxidation to Mt. This is evidenced by the nano- and micro-sized beads troilite in silicates in

the melt zone at the surface of the meteorite. Troilite not mixed with glass. Unlike troilite, taenite and kamacite easily dissolved in the glass, which enriches its composition Ni and Fe. In the surface layer of the fusion crust discovered dendritic structure kamacite. Kamacite particle began to dissolve in the glass, and at this moment a fragment of a meteorite fell in the snow and was subjected to quenching, resulting in thin and having kamacite dendrites. The mechanism of the transformation of matter into silicate microspheres chondrite composition doped with Ni, and Mt microspheres resulting from the conversion of troilite. This mechanism differs from the conversion of iron meteorites substance during ablation, in which the formed Fe-Ni beads (Badyukov et al, 2012). Detecting paleomagnetic studies of sediment columns, large peaks in the magnetic characteristics may indicate the impact event.

## Russian aeromagnetic exploration and complex airborne geophysics at the start of a new phase — use of unmanned aviation vehicles

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1. History. 1995, the first ever published suggestion of using unmanned aviation vehicles (UAV) in aerogeophysics by VIRG — Rudgeophysica, Saint-Petersburg. Heavily limited capabilities of UAV at the time.

2. Main tasks. Application of aerophysics to exploration of the near-surface stratum; larger scale surveys to enhance the role of geophysics at the final stage of geological exploration. Additional possibilities for ecological or engineering research.

3. Topicality. Sharp rise in the rent of usual piloted aircraft resulting in an important rise of airborne surveys price; demand for a better suitability of air vehicles; problem of personnel safety; necessity for research in difficult territories.

4. General list on the basis of UAV: detailed prospecting of ore-bearing fields; delineation of ore controls and structures; analysis for local deposits of economic hard numerals; exploration for fresh water; exploration of oil and gas structures and salt domes etc.

5. Analysis of domestic UAVs available in Russia — choice of those

most suitable for bearing both complex or monomethod aeromagnetic equipment. Statement of demands for the possible use of UAVs. Hence — necessity for the combined efforts of both UAV and geophysical equipment designers.

6. Information on airborne geophysical surveys with the use of UAVs abroad. Absence of international rules concerning UAVs flights. Available types of foreign made Uavs. 2012–2013 aeromagnetic and airborne electromagnetic surveys for mapping geothermal sources.

7. Summary. Importance of starting scientific research and experimental constructor activities for creating a new type of aerogeophysical surveys allowing for solving a large spectrum of geological, ecological and engineering problems.

## Holocene paleomagnetic characteristics of Lake Sevan basin precipitation (Armenia)

*Vardanyan, A. (IPE RAS, Moscow, Russia), Minasyan J. (IGES NAS RA, Giumri, Armenia)*

In studies of the Earth's core evolution a special place occupy the study of the basic spectrum of secular variations of the geomagnetic field, which is a characteristic figure of this field's generation process. Changing spectrum of major variations (with characteristic time is 102–104 years) in the geologic past, may be indicative of the changing process of generation of the geomagnetic field, consequently, changes in the characteristics of the core itself. For these studies reference section of modern lacustrine sediments was selected, located on the western shore of Lake Sevan, near the village of Norashen. Incision has good timing - two radiocarbon dates (6270±110yr, 2090±70 yr) and two cultural layers, corresponding to the two stages of settlement in the region. Collection of samples was selected uniformly from 40 horizontal layers.

When studying secular variations of geomagnetic field by paleomagnetic methods the most significant thing is definition of In of studied rocks.

For primer diagnosis of magnetic minerals differential thermomagnetic analysis was applied, whereby it was found out that the main minerals are magnetite and titanomagnetite. This was confirmed by microscopic examination on the transparent sections. Two types

of precipitation were extracted. The first type is more recent sediments, which represented a fraction of ferromagnetic magnetite with a Curie temperature ∼6000C, H'cs = 800Oe for these rocks, which is characteristic of magnetite, but does not exclude the presence and titanomagnetite. For the second type the Curie point does not exceed 6000C and H'cs is located within 500–900Oe, maxima coercive spectra lie within 200–300Oe. To make sure that magnetite is primer and is associated with In of studied rocks, 14 samples were considered at liquid nitrogen temperature. It turned out that In decreases by an average of 40%. This suggests that magnetite is a significant contribution to the formation of In, which is synchronous with the time of formation of studied rocks. It can be concluded that the studied sediments are suitable for the study of secular variation of the geomagnetic field.

## Paleomagnetism of the Early Proterozoic formations of the south of the Siberian craton (Udokan ridge)

*Vodovozov, V.Yu. (Moscow State University; Geological Institute RAS, Moscow, Russia); Baklan, M.A., Shcherbakova, E.L. (Moscow State University, Moscow, Russia)*

Presents the first paleomagnetic poles for Early Proterozoic formations Olekminsky block of the Aldan province of the Siberian craton: granites of the Kodar complex with ages 1873±3 and 18774 Ma (Larin et al., 2000), and gabbroids of the China complex with age 1867±3 Ma (Popov et al., 2009).

By three granite massifs of the kodar complex obtained average high temperature components NRM. The primacy the directions confirmed positive reversal tests and concurrence of the components in remote massifs. Was calculate the mean paleomagnetic pole ($P_{lat} = -27.2°$, $P_{long} = 99.6°$, $A_{95} = 5.9$) and was made the correction because of the opening Vilyui rift, according to (Pavlov et al., 2008).

Gabbroids of the China complex was sampled in the central part of the Cnina massif (gabbro-norite). Was obtained mean NRM directions, was calculated average paleomagnetic pole ($P_{lat} = -19.5°$, $P_{long} = 87.3°$, dp/dm = 5.2/10.0) and was made the correction because of the opening Vilyui rift, according to (Pavlov et al., 2008).This pole coincides with the pole obtained K.M. Konstantinov for Large Udokan dike (Konstantinov et al., 2013).

Almost simultaneous poles of china gabbroids and kodar granitoids slightly different, which may indicate a small local reversals of individual massifs. Both definitions are shifted by Paleoproterozoic APWP (Vodovozov et al., 2013) towards a young part, which may indicate a slight turn Olekma block (or all of the Aldan province) with respect to the Angara-Anabar province in the early Proterozoic, ie later time of formation of the basement of the Siberian craton. The paper (Didenko et al., 2013) it was shown in the example of the Early Proterozoic formations of the Ulkan uplift. Without the correction by opening Vilyui rift, both poles lie at the very beginning of the Paleoproterozoic APWP.

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## Paleointensity determinations by Thellier's method on modern volcanic rocks of Kamchatka

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In order to investigate the reliability of the Thellier's method of paleointensity determinations 7 samples of modern lavas of Kamchatka was explored by Thellier's and Wilson' methods, and by thermocurves of saturation magnetization $M_s(T)$. As a result of Thellier's method three samples gave low values $H_{ant} = (26 - 36)\mu T$ ("bad samples"), the four other samples gave almost correct values $H_{ant} = (48 - 51)\mu T$ ("good samples"). Higher values of $pTRM$ (partial thermomagnetizations) check-points deviations on Arai plots have became distinctive property of bad samples from the good ones. However, it is one of the default criterions. Good samples gave values $H_{ant} = (40 - 60)\mu T$ by Wilson's method, i.e. deviations (errors) of Wilson's method higher than in Thellier's method. Bad samples gave values $H_{ant} = (15-55)\mu T$ by Wilson's method. Thus good samples differ from the bad ones by the best similarity of thermocurves $TRM(T)$ and $NRM(T)$. Stability of $M_s(T)$ thermocurves for good and bad samples is similar. But more difference observed for Curie points — (500–550)°C for bad samples and (250–350)°C for good samples. Hence it is possible to draw a conclusion that more reliable determinations are obtained on samples which major magnetization carrier is the titanomagnetite with high titanium content (low

$T_C$), and less reliable are produced by samples which major magnetization carrier is oxidized titanomagnetite with possible presence of magnetite. Further it is planned to continue investigations of reliability of Thellier's method on modern rocks with involvement of other methods (particularly microscopy) and other samples.

**Testing of the titanomagnetite method to detect magmatic chamber depth at Avachinsky Stratovolcano and Tolbachik fissure eruption**

*Zubov, A.G., Ananyev, V.V. (Institute of Volcanology and Seismology, Petropavlovsk-Kamchatsky, Russia)*

Two volcanoes were tested using the titanomagnetite method in order to detect the magma chamber depth. Curie temperature of andesite tephra shows that the magmatic chamber was situated on the depth of 18±7 km under Avachinsky Volcano ∼5 Ka ago, but one of the basalt-andesite tephra from Avachinsky results the chamber depth of 32±6 km ∼3 Ka ago. This method applied to the lava from Tolbachik Fissure Eruption (TFE) shows a chamber depth of 47±5 km. This result is inconsistent slightly with the depth of 35±6 km obtained by our microzond analysing of element composition of titanomagnetite grains into lava sample from earlier phase of the same eruption. This two different results between TFE lava samples may occur from magma differentiation or this is a methodical or occasional error. To know true it needs a sample statistics. At present, more microzond data from Tolbachik Fissure Eruption are being analyzed.

**New paleomagnetic poles of the Early Proterozoic akitkan formation south of the Siberian Craton**

*Zverev, A.R. (Moscow State University, Moscow, Russia); Vodovozov, V.Yu. (Moscow State University, Moscow, Russia; Geological Institute RAS, Moscow, Russia)*

There are the results of the study paleomagnetism of the chaya suite akitkan formation of the Early Proterozoic Minya river within the North Baikal volcanoplutonic belt. The rocks are low metamorphosed red siltstones, quartz latites and rhyodacites. Volcanics of the Chaya

suite are according to (Buldygerov, Sobachenko, 2005) Minya paleovolcano formation and combined in lambor volcanic complex. Obtained isotopic age dating of the U/Pb zircon – 1823±7 Ma (Neymark et al., 1991) makes this complex of the youngest in the Akitkan formation.

For all samples chaya suite carried out a complete thermal treatment. In the high temperature range NRM observed two components formed two narrow clusters. The component ht1 is a characteristic, fold test positive for it. Its average direction correlates well with the directions in the chaya suite of the Chaya river remote from the Minya river for about 160 km. Calculated pole ($P_{lat} = -24.1$, $P_{long} = 100.4°$, dp/dm=3.2/6.2) almost the same as the pole chaya suite (Didenko et al., 2009). By rocks containing component ht1, was obtained isotopic age dating of U/Pb zircon – 1874±22 Ma (A. Kotov, personal communication). The component ht2 has a bipolar distribution, reversion test is a positive, fold test indeterminate. Calculated pole from the component ht2 ($P_{lat} = -20.7°$, $P_{long} = 142.4°$, dp/dm=12.0/23.4) lies on the Early Proterozoic APWP of the Siberian craton (Vodovozov, 2010) to the east of the oldest poles akitkan formation. A similar view can be interpreted by the two phases of generation of the chaya suite Minya river. The first phase conform to the time of the chaya suite Chaya river (about 1860–1870 Ma), the second phase is associated with the introduction of the youngest volcanic rocks of the Minya paleovolcano 1823 Ma ago. These data can be used to develop the Early Proterozoic APWP of the Siberian craton.

The study was supported by the RFBR, grant No. 13-05-01138.

## Unconventional method of creating the model of the main magnetic field of the Earth

*Zvereva, T.I. (IZMIRAN, Troitsk, Moscow, Russia)*

A simple method for obtaining a space–time model of the main magnetic field from the high-precision satellite survey data is described. At the first stage, the satellite data for one-day interval are expanded into the spherical harmonics with constant coefficients. This yields a set of daily mean spherical harmonic models (DMM) over the survey interval of a few years. At the second stage, the coefficients of this set are used as source data for expansion into the natural orthogonal

components (NOC). It is shown that the terms of the NOC series decrease rapidly, and the accuracy of the space–time model of the main geomagnetic field over the time interval under discussion is not worse than the accuracy of the models obtained by traditional methods.

# Section S. Seismology

## Seismotectonic zoning of the the Finnish-Bothnian region by computer analysis method

*Assinovskaya, B.A., Ovsov, M.K. (Geophysical Survey Russian Academy of Science, St. Petersburg, Russia)*

This study describes the experience of joint usage of computer technology "Structural analysis of geophysical data" [Ovsov, 2000, 2000a, 2001] and geodynamic studies to regionalize seismically the area with low seismic activity and not enough studied geologically. The construction of multilevel hierarchical structure tree and a special maps of seismic regionalization showing the position and boundaries of buried structures of complex geological objects were carried out. Later the values of variation numbers in the form of normalized standard deviations were estimated additionally. This procedure allowed us to discover the most deformed and hence the mobile structures. As a result, a rather complicated configuration of potentially active areal structures which can be further formalized to facilitate calculations was obtained. Several potentially seismogenic zones were identified in the Finnish-Bothnian area including waters. Almost all active zones have the north-western extend and cross the Finnish graben. The data obtained can be used for the evaluation of seismic hazard in further work. A unified catalog of regional earthquakes is required for a valuable map of possible earthquake sources that is the basis for seismic hazard assessment. It would help to address parameters of the seismic regime like maximum possible earthquake magnitude and its repeatability for every domain described.

## Local seismic tomography model of the northeast Black Sea and Kerch Peninsula

*Gobarenko V., Yegorova T. (Institute of Geophysics, National Academy of Sciences of Ukraine, Kiev, Ukraine)*

The Greater Caucasus and southern Crimea form a part of a fold-and-thrust belt located on the southern margin of the East European Platform. The Main Caucasus Thrust (MCT), which marks the southern

boundary of the Greater Caucasus intraplate orogen in Russia and Georgia, extends to the west along the whole of the northern margin of the Black Sea and relates to a zone of seismicity where accumulated stress is relaxed by earthquakes with foci in the crust and uppermost mantle. Thick continental crust north of the MCT lies adjacent to thin sub-oceanic or transitional crust of the Black Sea basin. A local seismic tomography study of this area, in the vicinity of the Kerch and Taman peninsulas, which lie between the Azov and Black seas, has been carried out based on 195 weak (Mb$<$ 3) earthquakes occurring in the years 1975–2010 and recorded at four permanent and three temporary stations on the Kerch and Taman peninsulas. The tomographic inversion was based on the Backus-Gilbert approach. As a result of the applied seismic tomography procedure we obtained a stable solution for velocity structure for the depth range 15–40 km, which shows significant crustal heterogeneity. Velocities inferred in the northern part of the model suggest that the continental crust underlying the Crimea-Azov region north of the MCT is of different tectonic affinity (cratonic) than that underlying the northeastern part of the Black Sea, south of the MCT (Neoproterozoic-Palaeozoic accretionary). In the southern part of the model, at depths of 25–40 km, the uppermost mantle below the thin sub-oceanic crust of the Black Sea has anomalous characteristics, with low P-wave velocities but nevertheless a high P- to S-wave velocity ratio. This is tentatively interpreted as representing serpentinized upper mantle of continental lithosphere exhumed during Cretaceous rifting and lithospheric hyperextension of the eastern Black Sea. The transition between the continental domains and anomalous upper mantle one is closely related to the zone of seismicity, where earthquake foci deepen northwards suggesting that the latter is being thrust under the former in this intraplate setting.

## Study of pole tide triggering of seismicity

*Gorshkov, V.L. (Pulkovo Observatory of RAS, St. Petersburg, Russia)*

The pole tide (PT) is generated by the centrifugal effect of polar motion on the chandler and annual frequencies (0.84 – 1.0 cpy). These frequencies, their beat frequency (0.16 cpy) and doubled frequency of chandler wobble (1.66 cpy) were revealed in seismic intensity spec-

trum. The failure time for the weak earthquakes with magnitudes 3 MW 5 averages 1–10 years for various regions that is in a good agreement with the periodicity of stress oscillations excited by PT.

The CMT global seismic databases (1976–2014) were used for search of the pole tide influence on the intensity of seismic process. For 32.2 thousand seismic events from CMT were calculated normal and shear stresses excited by PT using strike, dip and rake angles of the earthquake fault plane from this catalogue. The phases of the PT stresses for each earthquake were assessed and then they were used for statistical estimation of pole tide influence on seismicity. The PT stress oscillations excite the week (MW$<$ 5.5) earthquakes of reverse fault type on 5% significance level by $\chi^2$ and Schuster's statistical tests. The shear and normal PT stresses for these types of earthquakes have the same phase. It is probably this fact that explains triggering of seismicity by weak enough PT stress variations (less 1 KPa).

## The seismic data preparation program for training of an artificial neural network for ultrashort earthquake warning system

*Gravirov, V.V., Kislov, K.V. (Institute of Earthquake Prediction Theory and Mathematical Geophysics RAS, Moscow, Russia)*

In our complex of programs for an ultrashort earthquake warning system we use an algorithm based on the recognition of the first arrival of seismic waves with the help of an artificial neural network. For its correct work it is required to have a large enough data set for qualitative training. To create such a set it is required to put various seismic records into a unified form, to transform them in a certain way and to select the most characteristic ones. For these purposes we created a complex of programs for preparation of seismic data for training artificial neural networks used in early earthquakes warning systems. It includes two independent program modules. SeismicDataReading is a program intended for reading initial seismic files in different formats and compiling intermediate text ASCI files. It understands the data received from different sources and in different formats, such as GSE (ORB), SAC UNIX/LINUX and E-24 ADC the IFZ format. The initial data, if necessary, are automatically recalculated by an interpolation method to the new clock frequency

and filtered by the frequency. Also there is a possibility of a manual choice of the needed fragment of the record. DataCollector is a program intended for compiling output data files for training neural networks. The data obtained with the help of the first program and divided into the classes of useful earthquake signals and noises, can be normalized by the amplitude and after that it is possible to create output ASCI files which are easy to apply in independent programs.

### Wavelet transform as a tool for processing and analysis of seismograms

*Gravirov, V.V., Kislov, K.V., Vinberg, F.E. (Institute of Earthquake Prediction Theory and Mathematical Geophysics RAS, Moscow, Russia)*

One of the current tasks of seismology is the improvement of the automated processing of seismic records on a time scale as close to reality. Along with the traditional methods of filtration and processing, using wavelet transform allows to simultaneously conduct any necessary filtering, and easily select a different phase of the input signal. The entire process of filtering and analysis can be represented as three-dimensional graphic images, which greatly simplifies the process of interpretation of seismograms. Since this method does not require large computational cost exist possibility of its realization in the form of real-time algorithms.

### Seismology and seismic survey: joint seismic micro-zoning problem solving

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The classical soil mechanics determinate the loss of constructions reliability as the loss of bearing capacity. The change in the bearing capacity of soils is associated with change in the density, jointing, stress, water content which arise under the influence of external loads. Physical properties of the soil are reflected in the waveforms of seismic

signals. Observations of waveforms changes allow to monitor changes of geological environment, predict the occurrence of natural hazards and to develop measures to reduce their risk. The seismic methods based on the registration of elastic waves are the most universal for measurement of internal conditions in the geological environment. Seismic micro-zoning is the process of seismic hazard refinement for the maps of general seismic zoning (GSZ-97 A, B, C). The report presents some results of seismic micro-zoning, based on the complex seismology and seismic survey.

### Numerical simulation of the restoration of the local inhonogeneities by the approaches based on the diffraction tomography method

*Kiselev, Yu.V., Troyan, V.N. (St.Petersburg State University)*

Geophysical diffraction tomography is an imaging technique that makes use of a large volume of the input data (recorded traces) to produce the image of underground medium parameters with a high spatial resolution.

Diffraction tomography with a sounding by elastic waves and with the help of the first-order Born approximation leads to the satisfactory images for not too weak inhomogeneities with the sizes comparable with the wavelength. In this case the relative error of restoration can be approximately equal to a ratio of the desired parameter perturbation relatively to a value of such parameter for the reference medium (a contrast of inhomogeneity).

We consider the results of numerical simulation on restoration of local inhomogeneities with the sizes exceeding the wavelength of the sounding signal and with the contrast of shear modulus smaller than 1.0. We study the restoration of inhomogeneities using iterative approach together with the diffraction tomography method and the first-order Born approximation. At the each step of the iterative procedure the direct problem (2-D SH problem) is solved by the finite difference method to calculate the difference field between the "experimental" data and the model data. The difference field is used to restore the shear modulus of the desired inhomogeneity by the algebraic procedure with an appropriate regularization. The results of such restoration we compare with restoration using back projection approximation.

## Magnitude threshold reducing for a network of close located mobile stations

*Kislov, K.V., and Gravirov, V.V. (Institute of Earthquake Prediction Theory and Mathematical Geophysics (IEPT RAS), Moscow, Russia)*

It is known that earthquakes of smaller magnitude occur more often. If the magnitude is decreased by 1 unit, the number of earthquakes grows about eight times. Reducing an amplitude threshold of the of registered kinematic components of Earth movements, first, is equivalent to decrease in the density of a network of observation and, secondly, allows to study of oscillations of small amplitudes, to determine their nature and common relations with other seismic and geophysical phenomena, interrelations.

Each seismic sensor is characterized by the radius of events detection of a certain magnitude. Stations of the mobile group have to be in close proximity so that the radii of event detection minimum magnitude intersect. If records of adjacent stations contain appropriate signal (amplitude, spectrum and arrival time), the seismic event is detected. However, the signal can be invisible at a high noise level. In addition, bursts of the noise may take place on neighboring stations simultaneously. We are feeling around for an answer to our difficulty by using an artificial neural network as a signal detector. What is more the artificial neural network will allow classifying seismic events by source type (earthquakes, landslides, nuclear or chemical explosions, collapsing caverns, etc.).

## On the metrological support of the long-period seismology

*Kislov, K.V., Gravirov, V.V. (Institute of Earthquake Prediction Theory and Mathematical Geophysics (IEPT RAS), Moscow, Russia)*

Modern seismological analyzes require well-calibrated instruments. How do you determine that a seismic station is good (its entries are usable) or in bad order? What is the data precision? Procedures for obtaining the answers to these questions are half-finished. Seismic stations and their long-period sensors are not measuring instruments. Standard procedures of in-use testing are not applicable to them. Nor their accuracy cannot be determined.

Some Russian stations are part of the Global Seismographic Network (GSN) and International Monitoring System (IMS). These stations should use appropriate methods of verification. These methods presuppose three basic approaches.

– There are two sets of long-period sensors installed at the station and the data are compared.

– They produce original calibration. They bring the reference instrument, which is considered as good, to the station and set it next to compare data.

– They compare how earthquakes records of other stations correspond to records of this station.

These techniques have already been partially applied.

The first two approaches appear to be too expensive and time consuming for the Russian stations, which are not in the GSN and the IMS.

In our opinion, in-depth development of the third approach, bringing it to a routine maintenance process stations, ie the creation of user-friendly programs and algorithms, is the most promising way out of this situation.

## Seismic monitoring and protection of extended objects

*Kislov, K.V., and Gravirov, V.V. (Institute of Earthquake Prediction Theory and Mathematical Geophysics (IEPT RAS), Moscow, Russia)*

The extended objects are construction objects and technological devices that make with them a single unit or a complete functional unit, which designed for transporting liquids, gases and other objects, or for transmitting power and signals. Thus, roads, power lines, communication lines, oil and gas pipelines and other pipelines, railway lines, network hardware and other similar structures here were meant. Seismic protection of such objects is the Early Warning System that allows to get current information on natural hazards (primarily talking about earthquakes). If such information is received before the event, it is possible to considerably reduce material and human losses by automatic shutdowns (to stop of trains, set up the red signals of traffic lights, kill power, reduce the pressure in the oil and gas pipelines,

etc.). After the event such information will allow to estimate the volume of destructions, to define necessary measures of a rescue and reconditioner of extended object. We, sometimes, pay a very high price for absence something similar, including in human lives.

Ensuring of the object seismic monitoring can demand additional seismic stations. Sites for placement of additional stations have to be chosen after mapping of the medium-term earthquake prediction. Well known that for approximate determination of the earthquake characteristics can be used for cheap short-period sensors, it does not cause great difficulties. More serious technical problem is a creation of warning data-transmission system.

We elaborate on these and some other tasks arising at development of the protection system of extended objects.

### Seismic early warning for Russia

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Earthquakes are a serious threat for many regions of Russia. Early warning systems, based on real time, automated analysis of ground motion measurements, can play an important role in reducing material and human losses. Russia is covered by numerous seismic networks. However seismic stations are located at considerable distances from each other and unevenly spaced. The early warning system should be geared at fully exploiting the possibilities offered by a real time analysis of the signals coming from seismic networks for a wide range of actions. These actions range from the shut down of critical systems of lifelines, industries, highways, railways, etc. and the activation of control systems for the protection of crucial structures, to decision support for rapid response of the emergency management (ground shaking maps, continuously expected damage scenarios, aftershocks hazard etc.).

Working is structured into the following blocks:

1. Mapping of the medium-term earthquake prediction
2. Choosing sites for additional stations.

3. Installing at stations of hardware-software complexes of automatic picking p and s waves of large earthquakes.

4. Making data communication systems and data processing centers.

5. Development of disturbing scenarios.

**The application of the ambient noise surface wave tomography to the study of the detail velocity structure of the upper crust by example of the Gulf of Finland and surrounding areas**

*Koroleva, T.Yu., Assinovskaya, B.A. (Geophysical Survey RAS (Pulkovo), St.Petersburg, Russia)*

We present the results of the velocity structure study of the upper crust in the region of Gulf of Finland and surrounding areas by the ambient seismic noise tomography.

The purpose of this study was to investigate possible relationships between crustal velocity structure as determined by the ambient seismic noise tomography and tectonics, seismicity and material composition. We used the records of seismic noise from 14 stations located in the vicinity of the Gulf of Finland. Records were received from the website of the program GEOFON http://geofon.gfz-potsdam.de.

Cross-correlation functions of the seismic noise were computed in the period range from 1.6 to 20 s, which would allow to build the group velocity dispersion curves of Rayleigh waves along the paths between stations in this period range. However, for the large number of paths the reliable dispersion curves were obtained in a range of periods from 1.6 to 6 s, which is apparently due to the uneven distribution of the noise sources. It allows to determine the velocity structure at depths up to 6 km.

Thus, a first for the Gulf of Finland region were obtained sufficiently detailed information on the 3D distribution of S-wave velocities in the upper crust. The resulting velocity structure is correlated in a certain way with tectonics, material composition of the upper crust and partly with seismicity.

**Seismicity level variations of Bezymianny volcano in 2000–2013**

*Kugaenko, Y.A., Voropaev, P.V., Konovalova, A.A. (Kamchatkan branch geophysical survey RAS, Petropavlovsk-Kamchatsky, Russia)*

The paper describes applying the method of statistical estimation of seismic level SESL'09 for Bezymianny volcano in 2000–2013. Estimates are calculated on the basis of the distribution functions of the seismic energy released in different time windows. Comparison variations of seismicity level seismoactive volume under Bezymianny volcano with database KB GS RAS "Active volcanoes of Kamchatka" and episodes of eruptive activity of the volcano is produced.

**A study of the fracture development process under the prolonged loading of rocks samples**

*Lementueva, R.A., Treussov, A.V., Bubnova, N.Ja. (Schmidt Institute of the Physics of the Earth RAS, Moscow, Russia)*

Experimental results of the rock samples deformation under sustained loading (over 24 hours) are considered. The combined analysis of the results were employed to determine the first entry of acoustic signals (AS) from micro– and macro– defects as well as the moment of occurrence of the main crack. The migration of the AS sources in the course of the sample loading was noticed. At the start of the loading the substantial spread of AS centers over the sample volume was discovered. After that the increase of AS centers concentration within the well–defined zone (about one–tenth of the sample volume) occurred. The prefracture zone tends to become next the zone of the main crack formation. AS signals could be divide into large, medium and noise types. The control over the deformation in the local points of the samples was carried out. The signals of the large and noise types arise at the all stages of loading. The formation of clusters of AS centers attests to the redistribution of the stresses within the volume of the sample and as a consequence the changes of the arising local deformation. This phenomenon is accompanied by the reorganization of the structure of the sample and leads to the emergence of novel defects and new AS. At the pre–destruction step AS signals are low by an amplitude but could be well–registered by all installed acoustic

sensors. Results of the calculations have shown that the coordinates of emission sources are close to X coordinate. The displacement of emission centers in the area of destruction zone amounts to 4–10 mm for marble samples and 5–8 mm for the dolomites. The formation of clusters of AS centers and their location in the area of main crack formation provide some evidence about the mechanism of destruction.

**Spatio-temporal distribution of seismicity of the lesser Caucasus South-Eastern part**

*Mkrtchyan, G. (Institute of Geophysics and Engineering Seismology NAS of RA, Gyumri, Armenia)*

The territory under consideration is bounded within the geographical coordinates 39,00N–40,83N and 45,50E–47,83E. It is located in the south-eastern part of Lesser Caucasus which is one of the most seismically active regions on the Globe and belongs to the Mediterranean latitudinal zone. The available seismostatistical data show that within the bounds of this zone severe and devastating earthquakes have taken place many times. The data analysis available on earthquakes in the region under consideration enables to determine the regularities of spatio-temporal and energetic distribution of seismicity, the average frequency of different energy earthquakes, to assess the average seismic shakeability. In this work the task is set to study the regularities of spatial distribution of seismic events, on the basis of historical and instrumental data observations, as well as the peculiarities of spatio-temporal occurrence of seismic processes' distributions. As the basis for these studies the unified electronic catalog is taken made by us and including data on more than 2500 earthquakes which have taken place in this region from prehistoric times to 2005. In the result of analysis of unified catalog data, the history of earthquakes in this regions were divided into two main temporal periods: historical, instrumental-divided into two sub-periods: early-instrumental and modern-instrumental. - The spatial distribution of earthquake epicenters shows that the northern part of the territory under study, as well as eastern and south-eastern regions bordering to it are zones with higher seismic hazard. - For a preliminary assessment of frequency periods of strong earthquakes temporal distributions of epicenters of the strong earthquakes with magnitude greater than or equal to 4.9 were built, also including the data

palaeoearthquakes. - For modern-instrumental period observation quantitative distribution of earthquakes and seismic energy released by years respectively were built.

## Mechanism of the source of strong earthquakes of the Armenian plateau and their geological interpretation

*Mkrtchyan, M.B. (Institute of Geophysics and Engineering Seismology NAS RA, Gyumri, Armenia)*

Revealing of regularities of earthquake generation in different geological structures is one of the most important tasks of modern seismology.The study of focal mechanisms of strong earthquakes is one of the stages of this task, that allows us to specify zone-specific type movements in active geological faults, their orientation in space, and also to find out the patterns of earthquake generation in different geological structures. To identify regularities of earthquake generation in different geological structures, mechanisms of 250 earthquakes with M5.0 in Armenian plateau and adjacent areas for the period 1975 to 2005 was studied and estimated. After classification solution of focal mechanisms for reliability group a joint analysis of survey results was held with the data of distribution of aftershock region and faulting direction of investigated earthquakes. The result shows the relation between focal mechanisms of strong earthquakes and tectonic movement type. During transition from one structure to another, focal mechanisms also vary along with geological condition. Regularities of focal mechanisms of earthquakes in different parts of studied area are reflected in the patterns of orientation of the axes of compression and tension.

## Physical simulation of earthquake triggering by fluid migration into the fault area

*Novikov, V.A. (Joint Institute for High Temperatures, RAS, Moscow, Russia)*

A large amount of laboratory and field studies carried out over the past fifteen years clearly showed a possibility of weak regional seismicity triggering by high-power pulses of electric current of 0.6 to

2.5 kA injected into 4 km-length emitting dipole. These phenomena have been verified under laboratory conditions with application of various press equipment and spring-block models. Nevertheless, the physical mechanism of electromagnetic earthquake triggering is not clear yet. 3-D numerical analysis of the current density distribution in the Earth crust has shown that for conditions of the field experiments the current value on 5–10 km depth of the earthquake epicenters typical for the region under study (Northern Tien Shan) is $10^{-7}$ to $10^{-8}$ A/m$^2$, which is not sufficient to trigger earthquakes due to generation of additional stresses in the rocks.

It is well known that fluids play an important role in the preparation and initiation of earthquakes, and therefore, it is reasonable to consider a secondary triggering mechanism involving fluid interaction with an electric current in the geomagnetic field resulted in stimulation of fluid migration. It should be noted that even a small amount of fluid migrated into a seismogenic fault under critical stress-strain state can provide a reduction of its strength due to friction reduction and Rebinder effect resulted in earthquake triggering. For verification of this hypothesis laboratory experiments were carried out on the spring-block model with water injection into the contact area between movable and fixed blocks. The experimental results confirm a possibility of application of fluid mechanism to explain the phenomenon of weak electrical impacts on the regional seismicity. It was shown that at the stress level in the fault area of 0.99 critical value, when the lab earthquake (slip of movable block) occurs, the threshold value of fluid action is about of 1% of contact area/volume. For triggering the slip of the spring-block model it is sufficient to inject 0.2–0.3 g of water into contact area that is 0.5% of weight of granulated material (fault gauge) filled the contact area. Application of obtained experimental results for field conditions is discussed.

### Earthquake triggering by variation of the fault normal stress: Insight from lab experiments

*Novikov, V.A., Okunev, V.I., Klyuchkin, V.N. (Joint Institute for High Temperatures, RAS, Moscow, Russia)*

There are many field observations of earthquake triggering by static and dynamic stress variations caused by impact of distant strong earthquakes, underground chemical and nuclear explosions, solar-

lunar earth tides, strong variations of atmospheric pressure etc., as well as by electric current injection into the Earth crust. It is supposed that the external impacts on the earthquake source result in exceeding the threshold stress and earthquake triggering. Nevertheless, the mechanisms of the earthquake triggering phenomena is not clear, and the problem of determination of stress variation threshold resulted in initiation of seismic events is very important. At present, based on analysis of field observations of dynamic triggering of earthquakes (by wave train from distant strong earthquakes) performed for various regions, including the USA, Japan, China, Greece, etc. it is considered that the triggering threshold of stress variations is about of 500 kPa.

An experimental study at the spring-slider system was carried out for detailed study of behavior of fault area under near-to-failure state and experimental triggering impacts, as well as for determination of the threshold variation of normal stress in the fault gauge resulted in earthquake (slip) triggering. The spring-slider system provides a spring loading rate of 0.001 to 0.02 mm/s. The travelling block of dimensions 250x120x65 mm is connected with electromechanical drive via the spring with 9.5 N/mm spring constant. The normal stress of the travelling block is up to 30 kPa. For determination of the triggering threshold of normal stress variations the electromagnetic system was activated by control system at the level of 0.98–0.99 critical (fault failure) shear stress, which provided reducing the normal stress (by 0.001% to 0.1%) in the form of rectangular pulses of 0.5 to 5.0 s duration generated in time interval of 20 to 40 s. The level of stress variation impact resulted in the slip of travelling block (with stable time delay after the pulse initiation) is considered as the threshold for the present experimental "stick-slip" system. The measured triggering threshold of normal stress variations in the fault simulator is 0.05% to 0.10%. An implication of obtained threshold values for various earthquake mechanisms is discussed.

## Dynamics and spectrum of seismogravitational oscillations in the 1–6 h spectrum range before deep earthquakes

*Petrova, L.N. (St.Petersburg State University, St.Petersburg, Russia)*

The dynamics of the seismogravitational oscillations in the 1–6 h

period range is being analyzed by using the time-frequency analysis. The time-and-frequency maps are obtained from the observations with duration of no less than 150 hours. The data of 4 seismogravimeters at SPbGU (Russia), SSB (France), HYB (India) and INU (Japan) with similar characteristic are used in this study.

To construct the time-and-frequency map the window size of 20 hours is used with the shift of 30 min. Thus, each time-and-frequency map is based on data from about 200 spectra. The choice of isolines of spectral power are performed on the basis of the maximum spectral amplitude in the set of reference spectra. As a minimum value the level has been selected, which was 0.1 of the level of maximum power.

It was found that even at such value of spectral power in the background seismogravitational process the common features in the distribution of oscillation power are formed in the analyzed frequency range. With time and with increasing of seismogravitational oscillations power the smooth and long-term changes in their frequency are recorded, that can be explained with the physical positions. This phenomenon is revealed from the data at all stations before 8 large and deep earthquakes. In relation to the deep earthquakes the whole frequency area on time-and-frequency maps can be divided into three parts depending on the power level of the excited oscillations: 50–100 micro hertz (3–6 h), 110–190 micro hertz (2.5–1 h) and 190–270 micro hertz (∼1–1.5 h). The observed difference in power levels, and sometimes in the nature of the dynamics of seismogravitational oscillations, in these frequency ranges is most noticeable at stations located on the periphery of the Eurasian Plate and less noticeable in its central part (station HYB), where the excited oscillations may have larger amplitude but are observed most often in the frequency band 50–100 micro hertz.

For the first time before the earthquakes with the focal depth of 200 km and greater the low-frequency oscillations are revealed in the spectral area 18–30 micro hertz (9.25–15.43 h). They are characterized in that there are not associated with tidal oscillations. These oscillations are excited long before a rupture process in the earthquake focus and can proceed 100 hours and even more, but most often they attenuate in 1–2 days prior to an earthquake. Long-term oscillations with stable frequency, damped long before the moment of rupture in the earthquake source, indicate not only that they are independent from the earthquake preparation process, but allow to consider them as a factor that facilitated the rupture moment.

Spectral-time analysis also confirmed the previously observed phenomenon associated with a changing of the oscillations frequency in time, which indicates the relationship of the oscillatory process with the change of the stress-strain state of the medium. This increasing of the frequency can be interpreted as a consequence of the increase of the tensile force acting in the direction of the radius of the Earth. Accordingly, the decrease in the frequency is a consequence of reducing the magnitude of the tensile force. Here it is necessary to emphasize that the observations of vertical seismometers (seismogravimeters) are analysed. Rate of oscillation frequency changes varies slightly at different stations in the above-mentioned frequency bands.

At the same time, in spite of the slight difference, the rates of change of the oscillation frequency are comparable with each other, their values vary from 0.5–0.6 to 1.2–1.3 micro hertz per hour. It should be noted that this is not relating to the lowest frequency range. From observations revealed no changes in time frequency oscillations with frequencies 18–30 micro hertz. It was also noted that the frequency is decreasing much faster than it is growing.

To summarize, the obtained data allow to begin studying of cause and effect relationships between analyzed oscillations and other known global processes on a planet.

## Reconstruction of the stress state before and after 2011 great Tohoku earthquake

*Polets, A.Yu. (Institute of Marine Geology and Geophysics FEB RAS, Yuzhno-Sakhalinsk, Russia)*

Indonesia was struck in 11 April 2012 by a massive double earthquakes with magnitude Mw=8.6 and Mw=8.2. Epicenters were in the Indic Ocean, at some 500 kilometers West from North Sumatra Island, 30 kilometers deep. These earthquakes continued the chain of the most powerful earthquakes in the modern era of digital instrumental observations: the 2004 Sumatra-Andaman earthquake (Mw = 9.3), the 2010 Chile or Maule earthquake (Mw = 8.8) and the 2011 Tohoku earthquake (Mw = 9.0). The goal of the present study is to investigate the stress distributions in the earth's crust before and after these earthquakes. During the work we applied the method of cataclastic analysis of earthquake focal mechanism. It allows us to determine both the orientation and the magnitude of the principal

stresses. The reconstruction of the stress state was implemented on the basis of the data of the – decisions for earthquakes taken from the HARVARD catalogue. Researches allowed getting new data about features of tectonic stress field for different deep shears before and after these earthquakes. This work was supported by the grant of the President of the Russian Federation No MK-1904.2013.5.

### 1995 Neftegorsk earthquake

*Polets, A.Yu. (Institute of Marine Geology and Geophysics FEB RAS, Yuzhno-Sakhalinsk, Russia)*

On May 28, 1995 at 01:04 a.m. local time in the northern part of Sakhalin Island in eastern Russia has occurred the strong earthquake with moment magnitude Mw=7.0 and focal depth of 11 km. The earthquake struck near the Neftegorsk town. Neftegorsk earthquake was the most destructive one in the history of the Russian territory. As a result Neftegorsk industrial urban settlement was completely destroyed. Nearly 2000 people died. The northern part of Sakhalin Island had always been much less prone to earthquakes than its southern part or the Kuril Islands. Earthquakes of such magnitude have never occurred in this region and was not expected. The general map of seismic hazard published in 1978 gives maximum magnitude M=6.0 for this region of the Sakhalin Island. The earthquake zone corresponds to poorly studied boundary of tectonic plates, moreover, near the rotation pole of one of them. In this study, we used teleseismic data from the Incorporated Research Institution for Seismology (IRIS) to study the source process of Neftegorsk earthquake. We inverted teleseismic data from the IRIS network to determine the fault-slip distribution. To find the source parameters of the Neftegorsk earthquake (the focal mechanism and the slip distribution) was used the waveform modeling computer codes of Kikuchi and Kanamori. This work was supported by the grant FEB RAS 14-III-B-08-057.

**Correlation between seismicity and S-wave velocity structure of the crust and the upper mantle in Central Asia**

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Probable correlation between seismicity, seismotectonic deformation (STD) field and deep velocity structure of the crust and the upper mantle of Central Asia has been investigated. A three dimensional (3D) model of shear wave (S-wave) velocity distribution up to the depth of 700 km has been calculated from the data on group velocities of Rayleigh waves in the 10–250 s period range along about 3200 paths. The STD state of the crust has been determined from focal mechanisms of strong earthquakes. The STD pattern obtained is in a good agreement with GPS and geostructural data. Complex analysis of the results has shown that the majority of strong shallow-focused earthquakes occurred in the regions with low S-wave velocities in the upper mantle (the Tien Shan, western Mongolia and areas of recent mountain formation in southern Siberia) and in the zones with high (about 2%) lateral gradient of S-wave velocity variations (northeastern flank of the Baikal rift). In the first case the dominated STD regime is compression manifested in a mixture of thrust and strike-slip deformations. In the second case we observe a general predominance of extension. Obtained features manifest at the depths of 20–250 km.

**Investigation of Bezymianny volcano by traveltime seismic tomography**

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Last ten years due to densifying of seismic station network near volcanoes of Kluchevskoy group (Kamchatka) new data were collected, allowed us to make the investigation of construction of magmatic systems more detailed and reliable by means of traveltime seismic tomography. This is urgent task of up-to-date Kamchatka seismology, which can help to interpret and predict activity of volcanoes of Kluchevskoy group. This work is dedicated to investigation of the construction of Bezymianny volcano by seismic tomography. It aims

to building the model of interior of the volcano and explaining observed eruptive processes.

We solve this task on the base of data, obtained during the observations within "PIRE" project of investigation of volcanoes in Alaska and Kamchatka. This project made special dense network of seismic stations around Bezimianny volcano, which hadn't been there anytime before. The data is processed only partially nowadays. In this work we present the results of processing data for several months of volcanic activity, including the comparison of manual and automatic picking of wave-breaking. The work is based on materials of "PIRE" project and of Kamchatka Branch of Geophysical Survey. The algorithm of seismic tomography with adaptive parameterization is elaborated in Institute of Physics Earth (IPE RAS).

## Changes of seismic activity of the Northern Ten Shan during experimental electromagnetic soundings of the Earth's crust

*Sychev, V.N. (Research Station RAS, Bishkek, Russia); Bogomolov, L.M. (Institute of Marine Geology and Geophysics FEB RAS, Yuzhno-Sakhalinsk, Russia)*

The paper is focused on the issues of interrelation between electromagnetic soundings with the application of high current electropulse systems carried out at Bishkek geodynamic proving ground, and variations of local seismicity. Previously the effect was revealed and discussed that short-term increment of weak seismicity was stimulated by electromagnetic soundings which were applied at Bishkek geodynamic test site (North Tien Shan, Kyrgyzstan) in 2000–2005. Experimental soundings can be distinguished among usual ones (which are applied for apparent resistivity monitoring) due to enhanced value of pulses duration and their energy. The data on Tien Shan seismicity in 2000–2005 which were obtained with the aid of KNET telemetric network are the most proper object for investigations of effect of powerful electromagnetic pulses over seismic regime. The most results describing responses of daily amount of seismic events number on powerful electric pulses were obtained by the simplest methods of data processing and visualization. Recent studies show that earthquakes display the signs of dynamically complex systems. It has been shown that during experimental actions of current pulses there appears a deterministic component in the seismic mode of North-

ern Tien Shan. That in case of research of earthquakes, we deal with dynamically difficult systems in which there is the strong interaction between all parts of system also is basic. It is reflected in violation of thermodynamic additivity: entropy of summary volume of several subsystems isn't equal to the amount of entropies of each subsystem. Application of statistics of Tsallis for the description of seismic process confirms the assumption that the observed geosystem is nonadditive, nonequilibrium with existence of distant correlations. The research has partially been supported by: grants of RFBR, the project 12-05-00234-a and Basic Research Program of the Presidium of the RAS No14.

## Dynamic parameters of seismic focuses of the northern Tien Shan

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By determining stress drops in seismic focuses we can describe the modern stress state of the Earth's crust of seismically active regions as well as the features of medium destruction process. This data can also be used in the methodology of reconstruction of crustal stresses developed by Yu.L. Rebetsky (Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences) for implementation of these assessments. Determination of stress drops $\Delta\sigma$ is related to calculation of dynamic parameters of earthquakes which also include the scalar seismic moment $M_0$, "cutoff" radius of spectral density, $r$ (Brune radius). The theoretical basis of calculation method was laid in the works of (Kostrov, 1996, 1975; Riznichenko, 1976; Brune, 1970, 1971). In this paper the dynamic parameters of seismic focuses are calculated using the data of KNET digital telemetric network. KNET includes 10 broadband seismic stations installed at the territory of the northern part of Central Tien Shan (Kyrgyz Range and adjacent territories). For our investigation we chose 85 earthquakes M=3–5 which occurred at the territory of the Northern Tien Shan in 1998–2012. We also determined focal mechanisms for these events. Stationary adjustments and transformation of spectra during propagation of seismic waves in medium were also taken into account in calculation of focal spectra. We plotted the received dynamic parameters (stress drop $\Delta\sigma$, $M_0$, $r$) as functions of magnitude and other

parameters. The level of stress drop for the considered class of events changes from 1 to 75 bars. We singled out the events with stress drop $\Delta\sigma > 10$ and plotted maps which estimate the relation of these events with fault zones and modes of stressed state. The research was partially supported by the awards of the Russian Foundation for Basic Research (RFBR) No 12-05-00234 and the Basic Research Program of Presidium RAS No 14.

### Method of detection of low-frequency acoustic oscillations crust

*Uvarov, V.N., and Malkin, E.I. (Institute of Cosmophysical research and Wave propagation FEB RAS (IKIR), Russia)*

The developed method of detection of low-frequency acoustic oscillations crust using cased wells, compensating antenna and optimal filtering. Observations using this method was carried out in a seismically active region of Kamchatka. They helped identify four main types of anomalous signals corresponding manifestations of relaxation processes of tectonic stresses crust.

### The upper mantle structure of the Carpathian region from the ambient noise surface wave tomography

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We present the results of the ambient noise surface wave tomography for the West Europe. The goal of the study is extraction of information on upper mantle structure in the region. The data used are the records of seismic noise at the stations in the East and West Europe available from IRIS and GEOFON. For upper mantle studies it is necessary to use spectra of the cross-correlation functions at large periods (10–100 s). It was shown earlier that the noise at large periods contains a contribution of signals from earthquakes, whose sources are distributed non-uniformly over the surface. To reduce this effect we calculated the cross-correlation functions for the time periods when no clusters of earthquakes were presented. The coverage of the territory by the paths is mostly dense in the central part of

the West Europe, especially in the Carpathian Region. Therefore we concentrated our study on this region. The locally averaged Rayleigh wave group velocity dispersion curves obtained from the 2D tomography are inverted to S-wave vertical velocity sections in the grid points. Finally, lateral S-wave velocity variations are obtained at different depths in the upper mantle in the depth interval of 75–275 km. The results indicate a complex configuration of the lithosphere plates in the Carpathian region and their movement in different directions.

# Section SEMP. Seismo-ElectroMagnetic Phenomena

## MAGDAS-9 magnetometer observations of strong earthquakes

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Earthquakes are usually registered by seismometers that measure an amplitude of seismic waves. In present study, we present a comparison of earthquake registration moments on seismometer data and ground-based measurements by MAGDAS-9 magnetometers in Yakutia. It is shown that strong earthquake emergences are marked on tiltmeter (horizontal level meter) data, i.e. a device is sensitive to large amplitude seismic waves. Calculations of seismic wave speeds from earthquake epicenter to a magnetometer location are in a good agreement with current understanding.

This work was partially supported by program "JSPS Core-to-Core Program, B. Asia-Africa Science Platforms".

## Fractal dimension variability in ULF magnetic field with reference to local earthquakes at MPGO, Ghuttu

*Chauhan, V., Rawat, G., Dhamodharan, S. (Wadia Institute of Himalayan Geology, Dehradun, India)*

Ultra low frequency (ULF) geomagnetic data recorded during 01 January, 2010 to 31 December, 2010 at multi-parametric geophysical observatory (30.53°N, 78.74°E) in Garhwal Himalaya region of Uttarakhand, India, are analyzed. From the temporal variation of polarization ratio, presence of seismo-magnetic disturbances superposed upon background geomagnetic variations are inferred. Considering earthquake process as a SOC system based on flicker noise characteristic, fractal dimension for each day is estimated using two methods namely power spectral (FFT) method and Higuchi method. Estimates from

Higuchi method are found consistent in comparison to estimates obtained using FFT method. Variability in fractal dimension is studied in the background of local earthquakes (M≥3.5) within a zone of radius 150 km from observing station MPGO, Ghuttu. From the temporal evolution of fractal dimension it was found that average fractal dimension for first half of the year is increased compare to average of second half of the year. It is interesting to note that during first half of the year, there is seismic activity within zone of 150 km radius centered at around MPGO-Ghuttu. However, there are no earthquakes during the second half of the year.

**Electric current penetration from a thunderstorm cloud into the middle-latitude ionosphere**

*Denisenko, V.V. (Institute of Computational Modelling, Krasnoyarsk, Russia)*

A quasi-stationary two-dimensional model of electric fields and currents in the conductor that includes a thunderstorm cloud as well as the Earth's ground, atmosphere and ionosphere is created. A cloud is simulated as a long cylinder with elliptical cross-section in a meridian plane with vertical and horizontal axes 10 km and 40 km respectively. Hall conductivity of the ionosphere is not included into the model that is possible only for a cloud which parameters are independent of longitude. Vertical external current about $10^{-10} A/m^2$ is used in the model as a generator that creates voltage 10 MV between low and upper boundaries of the cloud. The height distribution of the components of the conductivity tensor above the altitude of 90 km is calculated by the empirical models IRI, MSISE, IGRF. We use an empirical model by Rycroft and Odzimek below 50 km where the electric conductivity is isotropic and smooth interface between these regions. In accordance with the used empirical model conductivity inside a cloud is ten times decreased. The steady state electroconductivity problem is solved numerically. Electric fields and currents below 50 km do not depend on the geomagnetic field inclination. At the heights 80–100 km current goes almost along magnetic field lines because of that the field-aligned conductivity is much larger than Pedersen one. Conductivity current closes about a half and a quarter of the total external current inside and outside the cloud respectively in the atmosphere below 50 km. The rest current goes to the iono-

sphere where it is distributed all over the globe, goes down to the ground through the whole atmosphere and returns under the cloud by ground. The last current loop is the income of the cloud into the global electric net.

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## Electric current penetration from a thunderstorm cloud into the ionosphere at the geomagnetic equator

*Denisenko, V.V. (Institute of Computational Modelling, Krasnoyarsk, Russia)*

A quasi-stationary two-dimensional model of electric fields and currents in the conductor that includes a thunderstorm cloud as well as the Earth's ground, atmosphere and ionosphere with specific features of equatorial ionosphere is created. Pedersen, Hall and field-aligned conductivities are taken into account. A cloud is simulated as a long cylinder with elliptical cross-section with vertical and horizontal axes 10 km and 40 km respectively. The two-dimensional model is applied for two cases when such a long cloud is parallel or normal to the geomagnetic equator. Vertical external current about $10^{-10} A/m^2$ is used in the model as a generator that creates voltage 10 MV between low and upper boundaries of the cloud. The height distribution of the components of the conductivity tensor above the altitude of 90 km is calculated by the empirical models IRI, MSISE, IGRF. We use an empirical model by Rycroft and Odzimek below 50 km where the electric conductivity is isotropic and smooth interface between these regions. Conductivity inside a cloud is ten times decreased in accordance with the used empirical model. The steady state electroconductivity problem is solved numerically. The problem with Hall conductivity is harder from mathematical point of view. We use new statement of the problem that has a symmetrical positive definite operator in contrast with traditional problems for electric potential or current function. Electric fields and currents below 50 km do not depend on the geomagnetic field inclination. The main difference from high-latitude models appears when the cloud is parallel to the geomagnetic field lines. Then the field and current distributions are not symmetrical because of Hall conductivity. The incomes of these type clouds into the global electric net are analyzed.

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### Electromagnetic precursors of earthquakes and their repeatability

*Dovbnya, B.V. (Borok Geophysical Observatory, Borok, Russia)*

Analysis of the electromagnetic activity of aftershocks, which epicenters are located close to each other, was carried out using the data recorded by Borok and College Geophysical Observatories. It is found that in the case when the first earthquake is accompanied by its electromagnetic precursor, every next aftershock from this series is also preceded by its precursor. The concrete examples are presented and the results are discussed.

### Cumulative effect of converging seismic waves in California

*Guglielmi, A.V. (Institute of Physics of the Earth, RAS, Moscow, Russia), Zotov, O.D. (Geophysical Observatory Borok, IPE, RAS, Borok, Russia)*

In this work we study the earthquakes in California. The aim is to search for the impact of converging seismic waves on the earthquake source. Earlier, this effect was observed in the activity of aftershocks by statistical analysis of the global seismicity (arXiv:1207.0365v1). In this work we have attempted to observe the effect by using the data on regional seismicity. As a result, we succeeded in finding some non-trivial properties of the source of strong earthquake that manifest both before and after the formation of the main discontinuity of rocks at the mainshock. In the course of analysis of the foreshocks and aftershocks we found confirmation of the ideas of round-the-world seismic echo and cumulative effect of converging surface waves. Further research in this direction seems interesting and promising.

The work was supported by the Program N 4 of the Presidium RAS.

**About wave field modeling in hierarchic medium with fractal inclusions**

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The processes of oil gaseous deposits outworking are linked with moving of polyphase multicomponent media, which are characterized by no equilibrium and nonlinear rheological features. The real behavior of layered systems is defined as complicated rheology moving liquids and structural morphology of porous media. It is urgently needed to account those factors for substantial description of the filtration processes. Additionally we must account also the synergetic effects. That allows suggesting new methods of control and managing of complicated natural systems, which can research these effects. Thus our research is directed to the layered system, from which we have to outwork oil and which is a complicated hierarchic dynamical system with fractal inclusions. In that paper we suggest the algorithm of modeling of 2-d seismic field distribution in the heterogeneous medium with hierarchic inclusions. Also we can compare the integral 2-D for seismic field in a frame of local hierarchic heterogeneity with a porous inclusion and pure elastic inclusion for the case when the parameter Lame is equal to zero for the inclusions and the layered structure. For that case we can regard the problem for the latitude and longitudinal waves independently. Here we shall analyze the first case. The received results can be used for choosing criterions of joined seismic methods for high complicated media research. If the boundaries of the inclusion of the k rank are fractals the surface and contour integrals in the integral equations must be changed to repeated fractional integrals of Riman-Liuvill. Using the developed earlier 3-d method of induction electromagnetic frequency geometric monitoring we showed the opportunity of defining of physical and structural features of hierarchic oil layer structure and estimating of water saturating by crack inclusions. For visualization we had elaborated some algorithms and programs for constructing cross sections for two hierarchic structural levels. That allows managing the process of drainage and steeping by water displacement the oil out of the layer.

**Investigation of ULF magnetic field variations induced by tsunami in a coastal zone**

*Kopytenko, Yu.A., Ismaguilov, V.S (SPbF IZMIRAN, St. Petersburg Department of IZMIRAN, St.Petersburg, Russia), Hayakawa, M. (University of Electro-Communications, Chofu, Tokyo, 182-8585, Japan)*

Strongest in the known Japan history earthquake with magnitude M=9 had happened 11.03.2011 at 05:46:24 UT near the eastern coast of Japan. EQ epicenter was located 373 km to the northeast from Tokyo. This EQ stimulated huge tsunami that destroyed APS Fukushima. We investigated magnetic field variations induced by tsunami movement. Data of six three-component magnetic stations and one seismic station situated in the coastal zone of Japan were used. Values of magnetic field variations induced by the tsunami amounted to 5–8 nT in the every magnetic field component at a distance ∼30 km from the coast. Extreme values of the magnetic field variations induced by the tsunami at the closest to the EQ epicenter magnetic station Esashi (∼130 km from the epicenter) are observed in Z component in ∼9 minutes after the EQ moment, in H and D components in ∼10 and 12 minutes. Study of the magnetic field variations induced by tsunami in different frequency ranges shows a quite complicated spectrum. Comparing magnetic and seismic variations, we found that the seismic signal arrived in ∼1 minute earlier at the observation point Esashi than at the seismic st. Iwato situated very close to the Esashi. We observe magnetic field variations with period T=30–40 s in contrast to seismic field variations. It is possible that these magnetic field variations are closely related with process of the tsunami origination. Decreasing of Z component value (∼3 nT) just after the main seismic shock can arise from a vertical displacement of a part of the ocean crust as a result of the EQ. These peculiarities of the magnetic field variations arising ∼6 minutes before of the tsunami wave arrival to a coastline could be used for tsunami warning.

**Atmospheric electric field behavior during acoustic-deformative disturbances in Kamchatka**

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During the investigation of lithosphere effect on the atmosphere by a complex of joint measurements of vertical electric field in the near ground air and rock geoacoustic emission in Kamchatka, their simultaneous disturbances were discovered for the first time. Correlation analysis nonparametric methods were applied for their analysis. Complex atmospheric-electric, geoacoustic and deformation measurements showed that different in sign anomalous disturbances of emission and electric field appear when the deformation rate of near surface sedimentary rocks increases during their tension.

**Correlation spectra of magnetic field for the monitoring of seismically active zones**

*Moskovskaya, L.F. (SPbF IZMIRAN, St. Petersburg, Russia)*

To study the frequency patterns of the time series of geophysical fields, we have developed the method of correlation and spectrum analysis in separated fields. The source field under study (time series) is split into a set of time series with different degrees of functional smoothness. Primary field (time series) is split into a set of time series with different degrees of functional smoothness. The separation of the field is carried out by applying the operation of smoothing of a signal in a sliding window of a certain width. The original algorithm of robust filtering was applied for this.

Mathematical analysis is carried out consistently for all separated component. Correlation spectrum was defined as a statistical assessment of the degree of similarity of the analyzed signal to a pair harmonic functions with period defined window width analysis. For the unimodal frequency signal this estimation does not contain a signal amplitude, but reveals only its frequency response. In the analysis of the synthesized signal from a number of the component method reduces the degree of influence on the result of the signal amplitude.

Interval features in images correlation spectra are modified in the analysis of long time series. In this case it is possible to identify several prevailing measures of the correlation estimates. For their study, we used cluster analysis. We have defined a set of functions correlation spectra for a given number of clusters. Each cluster is characterized by its carrier and its total capacity. For individual cluster correlation functions of the spectrum can be defined sequence of frequency peaks, their coordinates, and measure the severity of extrema on the chart as the senior coefficient approximation by a parabola or curvature function.

The report compares correlation spectra with the usual Fourier spectra. We have fulfilled the spectral correlation analysis of measurements of the magnetic Observatory of Japan from 2009 to 2013 in the frequency separated fields. Statistical estimates of the amplitude and frequency characteristics of monitoring data were obtained. Their connection with seismic activity of the region was analyzed.

We analyzed time series of the magnetic field of three observatories Japan: Kanoya, Kakioka, Memambetsu (http://wdc.kugi.kyoto-u.ac.jp/) and seismic data catalog (http://www.ncedc.org/anss/catalog-search.html).

## Effects in the variations of the amplitude of low-frequency radio signals and atmospherics passing over the epicenter of a deep earthquakes

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The search for possible earthquake precursors of is one of the urgent problems of geophysics. One of the possible tools for detecting of the seismic activity is the observations of disturbances in the lower ionosphere caused by the effect of lithospheric processes, by low-frequency radio signal observations. In a sufficiently large number of studies, it is shown that phase variation of signals of low-frequency radio stations, observed a few days before the earthquake, can be considered as precursors. The monitoring measurements of characteristics of the electromagnetic radiation of lightning – atmospherics, are also proposed as a variant of this method. It is shown that the earthquake with the magnitude greater than 5, and the depth does not exceed

50 km, are manifested in the form of increasing of hourly average amplitude of atmospherics on the day of the event or within three days thereafter. Effects of amplitude increasing in the previous earthquake during the days preceding an earthquake are considered as precursors. At the same time, it has been found that the deep-focus earthquakes apparently also cause disturbances in the ionosphere. In this work examples of manifestations of deep-focus earthquakes in the amplitude variations of low-frequency radio signal and atmospherics are considered.

**Seismo-ionosphere coupling: current status of the problem**

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The problem of the seismo-ionosphere coupling can be divided into a few parts: (1) observations of ionosphere disturbances related with earthquakes; (2) their physical interpretation on the base of qualitative considerations; (3) their quantitative description using self-consistent physical models.

Satellite and ground-based data analysis revealed some ionosphere effects that happened before, during and after strong seismic events. It also led to special observational missions like French micro-satellite DEMETER which was specially designed to register electromagnetic emissions' disturbances from earthquakes and volcanoes. Its data revealed a quasi-static electric fields disturbances both over the earthquakes' preparation regions and magnetically conjugated ones. Some observed by GPS Total Electron Content (TEC) pre-earthquakes' features — magnetic conjugation of the TEC disturbances, modification of the Appleton anomaly and solar luminance effects — are also in favour of electromagnetic physical mechanism of ionosphere plasma pre-earthquakes disturbances' generation. This mechanism, namely $[\vec{E} \times \vec{B}]$ ionosphere $F2$-layer plasma drift mechanism was principally checked by a few researchers using several models: GSM TIP, UAM, SAMI 3, etc. Despite a few papers on the seismogenic impact penetration through the neutral atmosphere exist this is the most poorly investigated area. Here we highlight the challenges one has to solve to complete physical interpretation and quantitative description of the observed pre-earthquake ionosphere phenomena. The role of the ionization sources, recombination, attachment of electrons to heavy

particles, water vapor condensation and coagulation, electric charges separation and transportation to the ionosphere via vertical electric currents of seismic origin flowing between the Earth and ionosphere is discussed.

### Possible mechanisms of interrelation of magnetic storms and deformation processes in lithosphere

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An overview of research of possible relations between variations of geomagnetic field and seismicity is presented, including Sq-variations and geomagnetic storms. There are many papers demonstrating positive correlations between geomagnetic field variations and subsequent earthquake occurrence that allows to authors to talk about earthquake triggering impact provided by ionospheric processes on lithosphere. Nevertheless, there is another opinion on negligible impact of geomagnetic disturbances on the earthquake source supported by statistical analysis of correlation between variations of geomagnetic field and global and regional seismicity. Mainly, the both points of view on this problem are based on statistical research without detailed consideration of possible physical mechanisms which may be involved into the supposed earthquake triggering, or very rough estimations of possible increase of stresses in the faults under critical (near to failure) state were made.

Recently it was shown that the fluids may play very important role in the electromagnetic earthquake triggering, and the secondary triggering mechanism should be considered when the fluid migrating into the fault under electromagnetic action may provide fault weakening up to earthquake triggering threshold. At the same time, depending on fault orientation, local hydrological structure of the crust around the fault, location of fluid reservoirs, etc. it may be possible that fluid migration from the fault may provide the fault strengthening, and in this case the impact of variation of geomagnetic field may provide an opposite effect. In so doing, it is useless to apply only statistical approach for the problem of ionosphere-lithosphere coupling, and in each case the possible behavior of fluids should be considered

under electromagnetic impact on lithosphere. Experimental results supporting this idea and obtained at the spring-block model simulating the seismic cycle (slow accumulation and sharp drop of stresses in the fault gauge), as well as field observations of water level variations in the well during ionospheric disturbances are presented and discussed.

### The neural network forecast of seismic events based on the VLF/LF signal monitoring of the Kuril-Kamchatka region

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The analysis of VLF/LF subionospheric signal variations caused by seismic activity is considered using neural network (NN) approach. We compare the results of an estimating the sensitivity of the VLF/LF signal to the seismic activity using data processed for each of the two wave paths and for data of these two wave paths processed simultaneously. The paths are determined by the same position of the receiver in Petropavlovsk-Kamchatsky (PTK) and different positions of Japanese transmitters JJY (40 kHz) and JJI (20 kHz) correspondingly. We propose the backpropagation technique, based on a three-level neural network. In order to train a neural network the representative teaching data base was created as a result of VLF/LF subionospheric radio wave monitoring. It includes both the LF data received during three-year monitoring (2005–2007) at the station in Petropavlovsk-Kamchatsky and the seismicity parameters of the Kuril-Kamchatka and Japanese regions. At the stage of teaching the relationship between the mean and dispersion of amplitude in nighttime for a few days before the seismic event and corresponding level of correlation with the seismic event is established. The result of recognition is formed as a level of correlation with the seismic event at the output of NN. To estimate the sensitivity of the VLF/LF signal to the seismic activity we have chose time intervals in 2004, 2005, 2006, 2007. The time intervals were lasting from 6 to 8 days including the day of seismic events of magnitude M$\geq$ 5.5. The results of the recognition using data processed for each of the two wave paths (JJI-

PTK and JJY-PTK) and for data of these two wave paths processed simultaneously are discussed. The research was supported by RFBR grant No. 11-05-00155-a.

### Current challenges in the research of the fracture-induced pre-seismic electromagnetic emissions in the MHz and kHz bands

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A remote observation stations' network has been developed in Greece for the recording of the pre-seismic electromagnetic (EM) variations at the MHz and kHz bands. The hypothesis that the fracture-induced electromagnetic emissions (EME), which emerge from a few days up to a few hours before the main seismic shock occurrence, permit a real time monitoring of the damage process during the last stages of earthquake (EQ) preparation, as it happens at the laboratory scale, has been formulated based on the analysis of EME recordings in terms of a wide variety of time-series methods. This hypothesis is critically examined through a shift in thinking towards the basic science findings of fracture and faulting processes. The resolution of different puzzling features observed in the recorded pre-seismic EME and the negative views that have been expressed concerning their credibility is attempted. A three-stage model for EQ generation by means of pre-seismic fracture-induced EME is finally proposed.

### Induction vector variations related with geodynamics

*Rokityansky, I.I., Babak, V.I., Tereshyn, A.V. (Institute of geophysics NAS Ukraine, Kiev)*

Earthquakes (EQs) and volcanic eruption precursors have an aperiodic temporal regime and appear once or several times prior to their occurrence. Induction vector C is considered as convenient parameter which should reduce influence of external field structure and noise presented in the observed geomagnetic field time series. But regular

periodic variations of C are also observed with periods 1 year, 1 day, probably 1 month and we report on 11 years (solar cycle) variation. They are a new interesting geophysical phenomenon but it should be considered as a background while looking for precursory signals associated with EQs and volcanic activity. Global network Intermagnet presents 1-minute 3-component geomagnetic data during last 25 years. We processes data of 10 (BRW, BOU, CMO, FRN, MEA, NEW, SIT, SHU, VIC, YKC) North America geomagnetic observatories and found correlation of induction vector C with solar activity (Wolf numbers) during two last solar cycles. The observatories used are located in or near to auroral zone where the variability of external source structure is stronger than in middle latitudes. To study the C 11-years variation, we need long time series covering several solar cycles. Such data are not widely available. The longest (since 1897) sequence of C determination is known for Japanese Kakioka (KAK) observatory. Small 11 years variation of C appears only on few components but very strong and long (40 years) aperiodic variation related with Kanto EQ M7.8 at July 1923 was reported by Japanese scientists. In North America, C variations of geodynamic origin we observed at SIT observatory before 3 EQs.

### Seismo-ionospheric precursors of strong earthquakes: analysis of Total Electron Content observations

*Romanovskaya, Yu.V., Namgaladze, A.A. (Murmansk State Technical University, Murmansk, Russia)*

We continue investigating Global Positioning System (GPS) observations of Total Electron Content (TEC) of ionosphere in order to reveal TEC anomalies which can be consider as earthquakes precursors. We have analyzed regional maps of TEC relative disturbances calculated for eight days before each strong seismic event of the years 2005–2006 with a magnitude not less than 6 and a hypocenter depth up to 80 km. On the hypothesis of the electromagnetic mechanism of the pre-earthquakes TEC anomalies formation, TEC positive (or negative) disturbance regions have to satisfy the following main criteria to be accepted as precursors. They are: (1) relative TEC disturbance regions appear near the epicenter and/or in the magnetically conjugated point; (2) such regions exist mainly during the night-time hours; (3) lifetime of such anomalies is 6 hours at least.

We have selected 43 seismic events (27 for year 2005 and 16 for year 2006) with required values of a magnitude and a hypocenter depth. Analysis of TEC disturbance maps shows anomalies which can be characterized as precursors revealing before 32 events out of 43 selected earthquakes.

**Inversion of relative changes in the magnetic ratio into relative changes in the resistivities of the elements of a geoelectrical structure (numerical modeling)**

*Sholpo, M.E. (SPbF IZMIRAN RAS, St.Petersburg, Russia)*

Sensitivity of the magnetic ratio $h$ (ratio of the vertical component of the geomagnetic field to its horizontal component) to changes in resistivity of $i$th element of the 2D geoelectric structure $\varepsilon_{hi} = d\log h/d\log\rho_i$ is studied. Time and spatial dependences of this value have been investigated for separate elements of structure and for whole structure. Necessity of similar researches for definition of an effective regime of monitoring of $h$ as prognostic parameter is shown.

The formula connecting relative changes of $h$ with relative changes in the resistivities of elements of geoelectric structure $\rho_i$ (similar to the offered earlier for MT apparent resistivity) is built:

$$h_{j2}/h_{j1} \approx \prod_i (\rho_{i1}/\rho_{i2})^{\varepsilon_{ijav}}$$

Here, indices 1 and 2 mark the boundaries of the intervals of variations in $\rho_i$ and the changes induced in $h$ by these variations; $\varepsilon_{ijav}$ is the average in this interval sensitivity of $h$ to the variations in $\rho_i$ at the $j$th period. On the basis of this formula the method of inversion of relative changes in the magnetic ratio into relative changes in resistivities of structure elements can be developed.

**A study of ultra low frequency (ULF) magnetic field pre-earthquake signature observed at low latitude station Agra**

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The study of ultra low frequency (ULF) magnetic field emissions associated with earthquake has been progress at Agra (Geograph. lat. 27° N, long.78° E), India, since 30 May, 2002. For this work, a set of three component search coil magnetometer and accessories have been imported from Lviv Centre of Institute of Space Research Ukraine. Using this experiment, several ULF anomalies associated with earthquake have been reported. In this paper, we analyzed the ULF magnetometer data since August, 2009, – 31 December, 2012. The ULF data examined in the light of lightning, magnetic pulsation, local electric and electromagnetic disturbances, and earthquake. We found 09 cases as precursory signature in the magnetometer data which are affected by earthquakes. Various statistical technique like unipolar analysis and others has been applied to confirm this type of pre-earthquake signature.

**Self-Organized Critical (SOC) dynamics of the fault systems: SOC-based modeling of seismic-electromagnetic processes**

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It is now recognized that seismic activity exhibit properties of a spatiotemporal fractal, which is executed in the power-law distribution of the earthquake characteristics. Among such patterns we can indicate the following findings: the power-law distribution of earthquake magnitudes (Gutenberg-Richter statistics), fractal clustering of seismic hypocenters in space, temporal clustering of the earthquake onset times, power-law decay of aftershock activity (the Omori law), fractal matrix of faults etc. Since one of the most reasonable

mechanisms underlying fractal properties of geophysical parameters in spatiotemporal domains is self-organized critical (SOC) dynamics of the source system, it is essential to develop the SOC modeling of the earthquake processes. In this presentation, we introduce the novel SOC model, which is executed with particular application to seismic-electromagnetic processes. We show how a non-Abelian SOC approach can be used to explain the critical spatiotemporal dynamics of fractal tectonic systems exhibiting power-law earthquake statistics. Using a definite rule of the conductivity distribution upon a two-dimensional matrix, we calculate both the bulk and the percolation conductivities and demonstrate accordance between the fluctuations of conductivity obtained in our model and the real-observed pre-seismic ULF emissions. That proves the adequacy of the developing SOC model.

**Correlation of VLF/LF variations with cyclones and typhoons**

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Our main aim is selection of the very low and low frequency (VLF/LF) signal perturbations related to earthquakes, tsunami and volcano eruptions from other external forcing both from above and from below. In this work we use signals recorded in Petropavlovsk-Kamchatsky, Yuzhno-Sakhalinsk and Yuzhno-Kurilsk stations to study meteorological effects in the lower ionosphere. The region under consideration is characterized by active winter cyclonic activity in midlatitudes and strong summer and autumn typhoon activity in low latitudes. Correlation analysis demonstrates sensitivity of the VLF/LF signals to variations of atmosphere pressure, wind velocity, humidity and temperature. The disturbances in the signals during 9 tropical cyclones (TC) of different intensity in 2010–2013 are analysed. The TCs were selected for intervals with quiet geomagnetic conditions. Negative night time amplitude anomalies of the signals that are most probable caused by TC activity are revealed for 7 events. Anomalies are observed when TCs pass the sensitivity zones of the

subionospheric paths. No correlation between TC intensity and magnitude of the signal anomalies is found. The cause of variations of the VLF signal observed during 2 TCs is not clear. It can be due to the TCs influence or to seismic activity. Spectral analysis made for the typhoon-induced disturbed VLF/LF signals reveals the maximum of spectra energy in the interval of periods of about 7–16 min and 15–55 min. This result corroborates the theory of penetration into the lower ionosphere the typhoon-generated internal gravity waves.

**Acoustic-electromagnetic emission of the Earth crust**

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Registration of acoustic and electromagnetic radiation using a borehole was carried out to investigate the relations of acoustic and electromagnetic components of the Earth crust deformation effects. In order to exclude strong noise from the global lightning activity and anthropogenic sources, a compensating network with independent registration of noise and a mixture of a useful signal with noise was developed. The useful signal was detected by minimization of a mean square deviation of the mixture from noise. In the result of acoustic an electromagnetic signal analysis the following was discovered:

1) High degree correlation of acoustic and electromagnetic signals;

2) 2–4 minute powerful bursts of acoustic and electromagnetic signals;

3) Different types of bursts characterized by different composition may be referred to 4 types;

4) A suggestion was made that the basis of the mechanism for this phenomenon is the tectonic-deformation processes in the core in dry friction conditions.

**On quasi-static ionosphere electric fields observations over earthquake preparation regions**

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The paper analyzes scientific publications that report quasi-static electric field disturbances before, during and after strong earthquakes over their preparation regions. It has been shown the main observations are from INTERCOSMOS-BULGARIA-1300 and DEMETER satellites' data. The reported quasi-static electric field measurements are for 0.1–8 Hz frequency band, i.e. these are not electrostatic fields. Therefore, despite this is some estimation, a comparison with model-estimated ionosphere electric fields (required to produce the observed seismogenic Total Electron Contend — TEC — disturbances) should be done with care.

The only on-the-ground estimation we find is for Wenchuan earthquake derived from ground-based ionosondes (Lhasa ($29.63°N$, $91.17°E$), Chongqing ($29.50°N$, $106.40°E$), Kunming ($25.00°N$, $102.70°E$), Guangzhou ($23.15°N$, $113.35°E$) and Haikou ($23.15°N$, $110.35°E$)) data. This is the electrostatic field estimation but it suffers from both measurements' precision and assumptions made to derive ionosphere electric fields from these data.

Therefore, publications report some data for preliminary estimations of ionosphere electric fields' disturbances over earthquake regions that happen before, during and after strong seismic events, but this is still a topic for on-going research.

**The possible technosphere impact on the earthquake focal mechanisms in Japan**

*Zotov, O.D., Lavrov, I. P. (Geophysical Observatory Borok, IPE, RAS, Borok, Russia)*

This report is devoted to the problem of technosphere-lithosphere interaction. The so-called weekend effect in the global seismic activity has been discovered earlier [Zotov, Phys. Solid Earth, 2007, V. 43, N 12, P.1005–1011]. The essence of the effect is that the seismicity is experiencing a strict seven-day modulation, with the maximum of activity in weekends. This definitely indicates the trigger effects

of industrial activity on the lithospheric processes. The question arises whether it is possible to detect the weekend effect in variations of the earthquake mechanisms? To answer the question we examined the earthquake catalogue of Kanto-Tokai observation network (http://www.bosai.go.jp/kotai/kanto/kanto-tokai/index_e.html) of National Research Institute for Earth Science and Disaster Prevention (NIED, Japan). Catalogue contains 55000 earthquakes with fault plane solution data from 1980 to 2002. The synchronous detection method of analysis has been used. The weekend effect in variation of the earthquake focal mechanisms has been detected for the relatively shallow (less than 10 km) earthquakes. We have shown a statistically significant difference in the types of mechanisms in weekends and in weekdays. The effect was not found for the more deep earthquakes. The problems of interpretation of the lithosphere-technosphere relations are discussed. The work was supported by the Program N 4 of the Presidium RAS and RFBR (grant no. 13-05-00066).

# Section STP. Solar-Terrestrial Physics

## Global deformations of the magnetospheric equatorial currents as inferred from space magnetometer data

*Andreeva, V.A., and Tsyganenko, N.A., (St.Petersburg State University, St.Petersburg, Russia)*

Based on a data pool of 79 yearly files of space magnetometer data by Polar, Cluster, Geotail, and Themis satellites obtained between 1995 and 2013, we developed a new quantitative model of the global shape of the magnetospheric equatorial current sheet as a function of the Earth's dipole tilt angle, solar wind ram pressure, and interplanetary magnetic field. This work upgrades and generalizes an earlier model of Tsyganenko and Fairfield (2004) by extending the modelling region to all local times, including the dayside sector. In particular, an essential feature of the new model is the "bowl-shaped" tilt-related deformation of the equatorial surface of minimum magnetic field, similar to that observed at Saturn, whose existence in the Earth's magnetosphere has been demonstrated in our recent work (Tsyganenko and Andreeva, 2014).

## High latitude continuation of the ordinary ring current and auroral structures

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We summarize the results of observations and theoretical analysis demonstrating the difference of the processes at geocentric distances from 6–7 Re till magnetopause near noon and till ∼10–12 Re near midnight versus the plasma sheet proper with magnetic field lines stretched in the antiearthward direction. The first selected region has the form of plasma ring with the characteristics near to the plasma sheet proper. Plasma pressure in the ring is larger than in the plasma

sheet proper and the magnetic field lines have dipole like characteristics. Transverse currents in the surrounding the Earth plasma ring are closed inside the magnetosphere. Nightside part of the ring was previously selected as near the Earth plasma sheet. Magnetic field lines of the plasma sheet proper are stretched and its transverse currents are closed by magnetopause currents. It is a rather turbulent region with large fluctuations of plasma velocity and magnetic field filled by bursty bulk flows (BBF), thin current sheets, beams etc.

Plasma pressure at geocentric distances 6–7 Re is near to isotropic. Such feature gives the possibility to use plasma pressure as the natural marker of the magnetic field line as in the condition of the magnetostatic equilibrium plasma pressure has the constant value along the field line. We compare values of plasma pressure measured at low latitudes by DMSP satellites and plasma pressure measured at the equatorial plane. We show that the main part of the discrete auroral oval is mapped to the surrounding the Earth plasma ring. Such feature explains the existence of quite comparatively stable auroral arcs inside the oval. Mechanisms of arc formation are discussed and compared with the results of experimental observations.

The obtained picture of auroral domain mapping became rather useful for the explanation of different events during magnetic storms when auroral oval move to low latitudes and greatly expands. We demonstrate the localization of the region of the acceleration of electrons of the outer electron radiation belt inside the auroral oval and discuss the mechanisms of the acceleration of relativistic electrons frequently named electrons-"killers".

### 2D configuration of the magnetotail current sheet: THEMIS observations

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We consider two years of THEMIS observations to investigate the distribution of the magnetic field in the Earth magnetotail. Spacecraft configuration allows us to collect statistics of 40 events when three (or four) spacecraft crossed the magnetotail current sheet within the thirty minutes at different locations along the magnetotail. For these events we study distributions of the $B_z$ magnetic field component

along the tail and the $B_x$ component cross the current sheet. We use measurements of plasma bulk velocities along the current sheet normal direction to estimate a current sheet thickness and amplitudes of the current density at different locations along the tail. Finally, we obtain the 2D distribution (in the $x, z$ plane) of currents and fields within the tail and compare this distribution with several theoretical models.

## On the mid-long term weather and climate forecast based on the solar-geomagnetic signal

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Two possibilities are discussed concerning the use of the data on solar-geomagnetic activity for meteorological forecast (cloudiness, temperature and precipitation). The first possibility is consideration of quasicyclic recurrence of large solar flares and magnetic storms with periods of 2–6 years. For the periods shorter than one year the second possibility is taking into account: the positive correlation of the global cloudiness with the total solar irradiance (TSI) - the contribution of short wave radiation of faculae fields.

It was found that the temperature did not display any variability with the 11-year period. Stable quasi-periodic variations within 2–5.5 years, and also for the precipitation periods in the interval 2 to 6 years were observed. Each 11-year cycle displays two-three maximum points for the probability of EUV/X flares on the Sun and for geomagnetic storms (2 to 4 years for the large flares and 2 to 6 years for significant magnetic storms).

The discovered coincidence between TSI bursts and maxima of total cloudiness may be applied to forecasting of regional anomalies in the air temperature. To this end, we suggest that statistical data on the evolution of facular activity in the atmosphere of the Sun and on correlation dependences in average years-long variations of cloudiness and temperature anomalies (known for 5-day intervals throughout each year) be used in a certain region.

The physics of these manifestations of the effect of the "solar signal"

on the troposphere also is related with our radio-optical three-stage trigger mechanism. The microwave radiation generated by ionosphere under the influence of the increased flux of the ionizing solar radiation during solar flares and electrons precipitated from radiation belts during magnetic storms affects the cluster condensation process of origination and further evolution of cloudiness, including the formation of precipitation in the course of "sowing" by crystals from upper-layer clouds.

## The response of atmospheric pressure and air temperature to solar events in October, 2003

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Evidences for the solar impact on weather are vital in the problem of solar-weather relations. Here, we set the problem of search for effects of solar flares and magnetic storms in variations of basic weather parameters: air temperature $T$ and pressure $P$. We compare the data obtained at the mountain solar observatory near Kislovodsk (2100 m above sea level) and by the solar patrol of powerful solar-geomagnetic perturbations (bursts in the X-ray flux of solar radiation and indices of solar magnetic activity $K_P$), within one of the spells of most active space-physical perturbations, in October, 2003.

The data on the pressure are totally consistent with those obtained at high-mountain Jungfraujoch observatory (3475 m), where the solar flare resulted in a decrease in $P$: we also basically observed the decrease (9 cases, or 82 %), though in two cases the pressure increased. We took into account only medium- and high-intensity X-ray flares of the type $M > 4$ (in October, 2003, such flares were observed, 4 out of them of X). Dramatic dips in $P$ at the end of 28 and 29 October were apparently related to two powerful events of coming of solar cosmic rays to the Earth surface: on October, 28 at 12:20 UT and, 29 at 00:03 UT. Like short-wave (X-ray) solar flares, such events are known to increase cloudiness, which, as a rule, results in a decline in $P$.

Let us consider worldwide magnetic storms with the planetary index of geomagnetic activity $K_p \geq 5$. In the troposphere, a magnetic storm acts in the same way as a flare (due to an increase in perturbation of the ionosphere under the influence of electrons precipitating from radiation belts). Respectively, it is accompanied with an increase in cloudiness, which initially is basically cirrus-heating. This effect was manifested in the increase in $T$ in 16 out of 19 observed events (84%).

Thereby, we have proven direct manifestation of flares and magnetic storms in variations of meteorological parameters ($T$ and $P$) at the height of 2100 meters.

## Correlation of global cloudiness with the bursts in total solar irradiance

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Studies of response of parameters of global cloudiness to solar forcing is essential for meteorological forecasting. From ISCCP data for 1984 to 2009, we have found positive reaction of two types of cloudiness (upper and total) to bursts in total solar irradiance (TSI) on the month scale. It is known that the TSI bursts provide evidence for increase in UV radiation from facular regions.

Note that the best correlation with TSI is displayed by upper cloudiness (in 83% cases, with 77 % for total cloudiness). This result is consistent with our idea that in the times of solar forcing the upper cloudiness is generated basically as a result of acceleration of water vapour clusterization due to the increase in microwave fluxes from ionosphere (this mechanism was suggested by us previously).

Another manifestation of the response of parameters of global cloudiness to solar forcing was revealed in trends in the total and upper cloudiness. Within 1984–2004, that is in 75% of the total time of the measurements, these trends displayed the same direction, and were consistent with the hypothesis of the prevalence of secular variations in solar-geomagnetic activity at the present stage of global warming.

The corresponding parameters of solar-geomagnetic activity are the numbers of large solar flares and of geomagnetic storms accompanied with the increase in fluxes of ionizing radiation and corpuscles resulting in supplementary microwave radiation from ionosphere.

We also compared time variations in total column atmospheric water vapour (TCAWV) and in abundance of cloudiness in different layers. In particular, variations in TCAWV display virtually total anti-correlation with those of middle cloudiness, which indicates that the latter is generated through clusterization of water vapour. For upper cloudiness, the correlation was detected in 62% cases, which also provides evidence for the water vapour clusterization.

## ULF excitation and absorption revealed by the Doppler radar data

*Badin, V.I., Deminov, M.G. (IZMIRAN, Moscow, Troitsk, Russia)*

The Doppler radar data on the electron drift velocities (transverse electric fields) detected in the E layer of the high-latitude ionosphere at moderate disturbances are analyzed for studying the ultra low frequency (ULF) oscillations. Narrowband filtering of the Doppler data about the specific frequencies found earlier by the spectral studies of magnetic and radar observations reveals the spatial distributions of the intensity of ULF signals. These spatial distributions show the geometry and scales of the ULF excitations that enables us to make some conclusions on the origin of the signals revealed. In particular, some signals of the Pc 5 range observed in different events can be attributed to quite different sources.

High-pass filtering of the Doppler data reveals ULF penumbrae in the equatorial portions of the radar field of vision. Such a penumbra can be considered as an indication of the absorption zone that depends on the solar wind conditions. Low-pass filtering of the Doppler data shows that the ULF half-shadows extend equatorwards as far as the low-pass filter broadens, i.e. as far as the filtered frequencies increase. For each event analyzed, the discrete Fourier transforms of the Doppler data reveal stepwise decreases in the spectral power density above a certain frequency, which can be regarded as the lowermost frequency of the magnetospheric continuum of the field line resonance (FLR). We expect the frequency-dependent behavior to be an indication of the resonant ULF absorption. Using the revealed

features together, we can easily distinguish non-resonant ULF signals from the FLR excitations.

This work was supported by the Russian Foundation for Basic Research (project code 14-05-00179) and by the Russian Academy of Sciences Presidium Program no. 22.

### On the relation between solar wind and eveningside undulations during low planetary magnetic activity (Kp3)

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A statistical study of eveningside undulations during low planetary magnetic activity (Kp3) is performed using optical observations at Tixie (71.6 N, 128.9 E) in the interval of 1994–2008. 1-min data from OMNI database (http://omniweb.gsfc.nasa.gov/) are examined in order to determine the influence of solar wind parameters and geomagnetic indices on the occurrence of eveningside undulations. It is found that undulations occurred when the interplanetary magnetic field was southward and the solar wind energy flux was high for a long (up to 4 hours) time before undulation registration. A significant smooth growth in values of AE index and H component of the magnetic field at Tixie due to increased solar wind energy transfer into the Earth's magnetosphere is recorded. However, a generation of eveningside undulations under Kp3 is associated to a physical processes in the inner magnetosphere, which captures midlatitude variations of plasma drift on the duskside and is enhanced during subauroral polarization stream events as revealed by Cousins et al. (JGR, 2013).

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**Poloidal monochromatic pulsations in Pc4-5 range observed in the Earth magnetosphere**

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Monochromatic geomagnetic pulsations in the Pc4-5 frequency range in the morning sector for some events in 2007–2014 years were studied using geostationary GOES, THEMIS, RBSP spacecrafts. The satellite observations showed that these pulsations are a poloidal-type fundamental mode of Alfvén field line oscillations with the dominant radial and field-aligned magnetic components. The observed waves are small-scale in azimuthal direction; they are excited during low geomagnetic activity and are similar to Pg type pulsations. Contrary to typical Pg, these pulsations practically cannot be seen on the ground CARISMA magnetometers. The observed magnetic pulsations were accompanied by the simultaneous pulsations in the fluxes of energetic electrons and protons, as seen by LANL, GOES satellites. The modulation depth in the fluxes of energetic particles is larger than the modulation depth in geomagnetic field. A strong increase of the electron density in the magnetosphere was found before the onset of poloidal Pc4-5 waves. As seen by THEMIS satellites these pulsations propagate in sunward direction, i.e. in the direction of electron drift in the morning sector. We suppose that the injection of energetic electrons may be responsible for the excitation of the poloidal Pc4-5 pulsations at the morning flank of the magnetosphere, though specific excitation mechanism is still unknown.

**The causes of the geomagnetic induced currents increase during strong geomagnetic storms as observed over Russian subarctic region**

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In this work we study the relationship of geomagnetic induced currents (GIC) with the different geomagnetic disturbances. GIC recordings in the main power line at the North-West of Russia were carried out during EURISGIC project. Geomagnetic field variations from the IMAGE network, all-sky cameras and CNA data were used to estimate of the geomagnetic events development. The study of some magnetic storms during the period 2011–2013 showed the relation of GIC appearance with SSC events, auroral substorms and geomagnetic Pc5 pulsations.

The research leading to these results has received funding from the European Community's Seventh Framework Program (FP7/2007–2013) under grant agreement N 260330.

**Global thermospheric and ionospheric response to SSW events as obtained using different models of lower and upper atmosphere**

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This report presents our study of thermospheric and ionospheric response to the minor (2008) and major (2009) SSW events. Our studies were performed using the Global Self-consistent Model of Thermosphere, Ionosphere, and Protonosphere (GSM TIP) developed in West Deparment of IZMIRAN. The SSW events were modeled by

specifying the temperature and density perturbations at the lower boundary of the GSM TIP (80 km altitude) by different way: (1) analytical specification of the lower boundary parameters, (2) using output of middle atmosphere models (SOCOL and KASIMA), (3) using TIME GCM model results at the altitudes of mesosphere. The model results were compared with the global maps of GPS TEC disturbances and ionosonde data from some ionospheric stations. GSM TIP simulation allowed reproducing the negative response of F2 region electron density and the positive response of electron temperature at 300 km during SSW event. The main formation mechanism of the global ionospheric response is due to the decrease in the $n(O)/n(N_2)$ ratio. The change in zonal electric field is another important mechanism of the ionospheric response at low latitudes. In addition, we consider in detail the variability of the sporadic E layer from experimental time series at Kaliningrad station and the F3 layer characteristics before and during SSW events.

These investigations were carried out with financial support of Russian Foundation for Basic Research, grants 12-05-00392 and 14-05-00578.

### Do the cosmic rays regulate global temperature?

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Evolution of Dst index, cosmic rays and global temperature variations during solar cycles 20–23 are discussed. We have studied conditions in interplanetary space, which can have an influence on galactic cosmic ray (CR) and climate change. In this connection the solar wind and interplanetary magnetic field parameters and cosmic ray variations have been compared with geomagnetic activity represented by the equatorial Dst index from the beginning 1965 to the end 2012. The important drivers in interplanetary medium which have effect on cosmic rays as CMEs (coronal mass ejections) and CIRs (corotating interaction regions) undergo very strong changes during their propagation to the Earth. Because of the sunspot numbers (SSN) and long-term variations of cosmic rays do not adequately reflect peculiarities concerned with the solar wind arrival to 1 AU. Therefore, the geomagnetic indices have some inestimable advantage as contin-

uous series other the solar wind measurements. We have compared the yearly average variations of Dst index and the solar wind parameters with cosmic ray data from Moscow, Climax, Haleakala and Oulu neutron monitors during the solar cycles 20–23. During the descending phases of these solar cycles (CSs) the long-lasting solar wind high speed streams occurred frequently and were the primary contributors to the recurrent Dst variations. They also had effects on cosmic rays variations. We show that long-term Dst variations in these solar cycles were correlated with the cosmic ray count rate and can be used for prediction of CR variations. Climate change in connection with evolution of Dst index and CR variations is analyzed. We show that CRs play essential role in climate change and main part of climate variations can be explained by Pudovkin and Raspopov's (1992) mechanism of action CRs modulated by the solar activity on the state of lower atmosphere and meteorological parameters.

**Impact of geomagnetic disturbances and riometer absorption at Sodankyla on the OIS parameters**

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Two days were analyzed – March, 17 and April, 14 of 2012. The first one is characterized by the high level of riometer absorption at Sodankyla during morning and day-time hours when geomagnetic disturbances are absent. The second day is characterized by the high level of absorption too but due to a night magnetic storm. Our interest is to compare structures of signals and their intensities on three radio paths of OIS near Sodankyla for considered days. Main received results are the following.

On the distance of ∼300 km from riometer location, ionospheric processes associated with absorption may essentially differ from processes in the area of riometer location due to spatial difference of parameters of precipitating particles during essential riometer absorption.

During weak magnetic disturbances, the mode structures of OIS signals under weak and strong absorptions are different. For example, 14.04 signals are observed on all three paths, but 17.03 they all are absent because there is full absorption of signals.

During the magnetic disturbance at night of 14.04 the diffusion of signals reflected from F2 layer is observed although under quiet magnetic conditions in the morning and in the day-time of 17.03 any diffusion is absent. The considered diffusion is caused by strong magnetic activity.

A half hour before the essential peak of absorption one can see a sharp growth of MOFEs values on 30–80%. The considered effect probably is caused by beginning of precipitated particles. This precipitation is becoming more hard with time and causes a great absorption.

### Auroral activity during a recovery phase of magnetic storm

*Boroyev, R.N. ( Yu.G.Shafer Institute of Cosmophysical Research and Aeronomy, Yakutsk, Russia)*

The comparative analysis of auroral activity during a recovery phase for magnetic storms with an equal maximum value of Dst index has been carried out. It is shown that those magnetic storms whose solar wind speed is greater have a strong auroral activity. It is also found that at equal values of the electric field of solar wind during the recovery phase of magnetic storm, the auroral activity is higher in magnetic storms which have a high solar wind speed. It is supposed that a geometry of magnetospheric tail which is, apparently, determined by the solar wind speed has an effect on auroral activity of the recovery phase of magnetic storm. At great values of solar wind speed the magnetosphere tail is squeezed, thereby causes the current layer to be decreased. Hence, at small values of the solar wind electric field during a recovery phase of magnetic storm the plasma instabilities will strongly develop, thereby initiating a stronger auroral activity.

### A comparison of the electron density height profiles calculated by the theoretical UAM and empirical IRI models

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We have compared the electron density height profiles calculated by the global, three-dimensional, time-dependent numerical model UAM

(Upper Atmosphere Model) with the empirical IRI-2007 and IRI-2012 model values.

Model UAM simulations have been carried out with using two different UAM versions: (1) with neutral densities and temperature calculated by the empirical NRLMSISE-00 model (marked as UAM-TM) and (2) the fully self-consistent version with jointly calculated thermospheric parameters (marked as UAM-TT).

Electron density distributions have been calculated for two solar activity levels and different seasons: for the low solar activity (F10,7∼90) the modeled dates were the December solstice of 2004 and the April equinox of 2005, for the high solar activity (F10,7∼180) the modeled dates were the December solstice of 2000 and the April equinox of 2002.

The results of UAM simulations have been compared with the electron density profiles calculated by the IRI-2007 and IRI-2012 models.

For the altitudes below 600 km the UAM results demonstrate a good agreement with the IRI-2007 and IRI-2012 values which are close to each other. For the altitudes above 600 km the electron density values calculated by the UAM versions are between the IRI-2007 and IRI-2012 values being closer to the IRI-2007.

## Structure of weather system over the north-western part of the Pacific ocean in connection with lightning activity of the Far-Eastern region

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Applying the data of VLF direction finder receiving station of IKIR FEB RAS, included into the World Wide Lightning Location Network (WWLLN), the paper investigates the relations of field characteristics of recorded lightning discharges in the north-western part of the Pacific ocean with field characteristics of weather formation meteorological elements, evaluated according to the data of Earth remote sounding from satellites. On the example of separate tropical cyclones (TC) for 2012–2013, the relation of lightning discharge fre-

quency and density with spatial distribution of driving wind whirl is shown. TC structure evolution is traced in cloudiness fields, driving wind whirl, and lightning discharge distribution. This publication is based on work supported by a grant from the U.S. Civilian Research and Development Foundation (RUG1-7084-PA-13) with funding from the United States Department of State. The opinions, findings and conclusions stated herein are those of the authors and do not necessarily reflect those of CRDF Global or the United States Department of State.

### Features of the propagation of the AGWS generated by HF high-power transmissions at frequencies around the natural frequencies of the atmosphere

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Temporal variations of Doppler shifts in the HF Doppler radar signals transmitted near the City of Kharkiv at vertical incidence during the Sura heater impact on the ionosphere, with periods of 10 min and 15 min, were bandpass filtered in the period ranges of 4–6 min, 8–12 min, and 13–17 min, close to the Brunt–Vaisala frequency. The oscillations with the 4–6 min periods and the 50–100 mHz amplitude were observed intermittently. The oscillations with the 8–12 min and 13–17 min periods and the 60–100 mHz amplitude were detected almost in all observations. The former lagged behind the Sura heater turn-on by approximately 100 min and the latter by about 40–50 min. These lags corresponded to propagation group speeds of approximately 160 m/s and 320–400 m/s. The oscillations in the Doppler shift were due to acoustic gravity waves that may give rise to periodic variations in the electron density with relative amplitudes of 0.1–1%.

**Infrasound ionospheric oscillations during the Sura heater HF transmissions impact on the ionosphere**

*Chernogor, L.F. (Kharkiv V.N. Karazin National University, Ukraine), Frolov, V.L. (Radiophysical Research Institute, N. Novgorod, Russia)*

Temporal variations of Doppler shifts in the HF Doppler radar signals transmitted near the City of Kharkiv at vertical incidence during the Sura heater transmissions impact on the ionosphere, with a period of 6 min, were filtered in the 5.6–6.7-min period range. The turn-on and turn-off of the pulses of 3 min in duration with a 3 min pause in between have been detected to give rise to the generation of waves with a period of 6 min, a time lag of approximately 30–50 min, and an apparent speed of about 530–320 m/s, respectively. The amplitude of the quasi-periodic variations in the Doppler shift of frequency amounts to 10–40 mHz. The corresponding amplitudes of disturbances in the electron density are equal to 0.1–0.3%. The detected oscillations suggest that density waves of infrasound frequencies could be generated in the upper atmosphere.

**Traveling ionospheric disturbances generated by the periodic heating of the near-Earth plasma by the Sura heater HF transmissions**

*Chernogor, L.F. (Kharkiv V.N. Karazin National University, Ukraine), Frolov, V.L. (Radiophysical Research Institute, N. Novgorod, Russia)*

Observations of variations in the Doppler spectra and the Doppler shift of frequency in the HF radar signals reflected from the ionosphere at vertical incidence during the Sura heater tramsmissions impact on the ionospheric plasma are presented. The distance from the Doppler radar to the heater is equal to approximately 960 km. The high-power transmissions are confirmed to lead to generating (or enhancing) wave disturbances in the internal gravity wave range (periods of 10–30 min, speeds of 360–460 m/s). The amplitudes of the electron density disturbances on the relative scale are equal to 1–3%.

**Large-scale aperiodic disturbances in the D-and E- regions of ionosphere due to the impact of HF high-power radio transmission: data from a network of ionosondes**

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Disturbances in ionogram parameters are collected during an impact of the high-power Sura heater on the ionospheric plasma. The network of ionosondes included the ionosondes near Nizhniy Novgorod City (Russia), Kazan City (Russia), Moscow City (Russia), Kharkiv City (Ukraine), and Prohonice Village (Czech Republic). The diagnostic instruments were located at a range of 560 km – 2200 km from the Sura heater. The ionograms acquired near Nizhniy Novgorod City and Moscow City occasionally exhibited the presence of additional ionization layers with critical frequencies of 2.6 – 3.4 MHz, virtual heights of 120–160 km, and true heights of 110–130 km. The appearance of additional ionization layers below 100-km altitude was sensed with an increase in the $f_{min}$ frequency. The Moscow ionosonde detected an increase of 1 MHz in this frequency during the day and practically no changes at night. The Kazan, Kharkiv and Prohonice ionograms always exhibited less significant (0.3–0.5 MHz) $f_{min}$ variations.

**Wave disturbances in the ionosphere during its heating by high-power radio transmission: results of observations with incoherent scatter radar**

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The observations of the wave disturbances of the electron density in the ionosphere, which accompanied the impact on the near-Earth plasma by high-power radio transmission of the "Sura" heating facility, are made with the Kharkiv incoherent scatter radar. The possibility to generate the wave disturbances in the ionosphere in the

range of internal gravity waves is confirmed. The velocity of electron density disturbance propagation is close to the value of 320–400 m/s, and their relative amplitudes are of 1–10%. The wave disturbances appeared in the altitude range of 145–235 km.

### Variations in the spectra and the level of geomagnetic pulsations associated with an impact of high-power radio transmissions on the ionosphere

*Chernogor, L.F. (Kharkiv V.N. Karazin National University, Ukraine), Frolov, V.L. (Radiophysical Research Institute, Russia), Garmash, K.P., Leus, S.G., Davidenko, A.V. (Kharkiv V.N. Karazin National University, Ukraine)*

Aperiodic and quasi-periodic variations in the level of 40–1000-s period range geomagnetic pulsations observed with a fluxgate magnetometer near Kharkiv City (Ukraine) and associated with a quasi-continuous Sura heater impact on the ionospheric plasma near Nizhniy Novgorod City (Russia). The basic parameters of aperiodic and quasi-periodic disturbances in the geomagnetic field are determined. Mechanisms for the generation and propagation of the revealed disturbances are discussed.

### Experimental verification of isotropic boundaries formation conditions in the Earth magnetotail current sheet

*Chernyaev, I.A., Sergeev, V.A., Chernyaeva, S.A. (St. Petersburg State University, St. Petersburg, Russia)*

Isotropic boundaries of energetic particles fluxes in the ionosphere is well-known and well-observed by low-altitude satellites phenomenon which is formed by particles scattering in the Earth magnetotail current sheet. Quantitative threshold condition of the pitch-angle scattering is known only approximately from the trajectory calculations with model fields, so the experimental determination of the threshold values of the parameter K that controls the amplitude of the pitch-angle scattering is still urgent task. In our work we solve this task by researched method based on projecting of observed by low-altitude satellites isotropic boundaries to the magnetosphere using original

adaptive magnetospheric model AM03, that allow us to estimate the value of K for the charged particles of different energies.

### Energy dispersion at the proton isotropy boundary: a statistical study

*Chernyaeva, S.A., Sergeev, V.A., Chernyaev, I.A. (St. Petersburg State University, St. Petersburg, Russia), Angelopoulos, V. (University of California Los Angeles, Los Angeles, USA)*

The regular appearance of equatorward boundary of the isotropic proton precipitation (isotropy boundary, IB) is interpreted as a manifestation of the boundary between adiabatic and non-adiabatic particle motion regimes. Accordingly, the energy dependence of IB latitude (energy dispersion, with lower latitude IB observed for higher energy protons in case of normal dispersion) carries the information about the real magnetic field gradients (or, sporadic appearance of other scattering mechanism, in case of anomalous dispersion).

In this study we investigate statistically the IB energy dispersion of the energetic protons $\succ$ 30 and $\succ$ 80 keV. We have processed 373 satellite passes of low-altitude polar satellites NOAA-19 and -18 in September 2009, when two spacecraft follow each other along the same orbit.

We found that the events with normal dispersion at proton energies of 30 to 80 keV constitute less than 20% of the total number of events (regardless of geomagnetic activity). In other cases (80%) we see either the coincidence of the proton IB at different energies (within 0.2°), or the precipitation pattern is complicated by the presence of isolated precipitation structures equatorward of the IB. In small amount of cases the anomalous (inverse) energy dispersion was also observed, suggesting the presence of different precipitation mechanisms. To help discriminate between current sheet scattering and other mechanisms we also obtained the average relationship between empirical ratios of trapped and precipitated proton fluxes at different energies near the IB for cases of normal dispersion.

The near coincidence of the proton IBs can be observed in the case of sharp magnetic field $B_z$ gradients ($B_z$ jumps), whose amplitude should be about 28% of the Bz background value. Their existence is tested by considering magnetic field observations at radial passes

of THEMIS spacecraft near the IB observation meridian in the near magnetosphere, supported by adaptive modeling and other relevant information. Also, we determined the size of the transition region from the extended field lines to a dipole, which is 1.3 degrees. For comparison, the value obtained by this model T96 is 1.7 degrees.

The updated view of the energy dispersion at the proton isotropy boundary is discussed.

### Cyclotron acceleration of electrons by whistler-mode wave packets with varying frequency and amplitude

*Demekhov, A.G., Viktorov, M.E. (Institute of Applied Physics, Nizhny Novgorod, Russia)*

We consider the efficiency of gyroresonant acceleration of radiation-belt electrons by quasimonochromatic whistler-mode waves with varying frequency, such as chorus wave packets. It is known that trapping of electrons in the wave field can greatly increase the energy exchange between particles and waves, and in this case the frequency variation significantly influences the result of interaction. We compare the effect of an idealized wave packet with smooth amplitude and frequency profile with that of a realistic wave packet obtained from satellite wave measurements. Amplitude modulation typical of chorus wave packets significantly reduces the efficiency of energy exchange between the waves and particles; we study this effect depending on the parameters of the system. We also compare the integral contribution of trapped and untrapped particles to the energy balance during the wave-particle interactions.

### Geomagnetic activity corresponding to the median of the F2 layer critical frequency

*Deminov, M.G., Deminova, G.F., Badin, V.I. (IZMIRAN, Moscow, Troitsk, Russia)*

It is well known that the monthly median of the F2 layer critical frequency foF2 is an optimum value for long-range ionospheric forecasts. For example, the basic version of the international reference ionosphere (IRI) supplies us with the foF2 median. To estimate the

geomagnetic activity that corresponds to the foF2 median, one usually employs the monthly average of this activity. The idea to use the mean index of the geomagnetic activity for the foF2 median is explained by the fact that the date which determines the foF2 median for the station and UT given remains unknown. This is a reason for the comparatively low accuracy of routine foF2 median models built on the solar and geomagnetic indices of activity.

We propose another technique for solving the problem. The technique successively determines first the date (or two dates) when the foF2 value equals the median and then the geomagnetic index for this date thus specifying the given foF2 median to the particular solar and geomagnetic activity.

Using the data analysis applied to a number of ionospheric stations, we find that on the average, the geomagnetic activity corresponding to the given foF2 median is below the monthly mean activity and the difference increases with latitude. Also on the average, the variance in the geomagnetic index corresponding to the given foF2 median decreases with latitude. This is explained by the fact that the foF2 data are frequently absent for high-latitude stations at a high geomagnetic activity (for example, due to a sporadic E layer obscuring the F2 layer); therefore, the foF2 median found for the rest of the days corresponds to a lower geomagnetic activity.

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## The tendency of climate change over the past several millions of years and the current interglacial

*Dergachev, V.A. (Ioffe Physical-Technical Institute, St.Petersburg, Russia)*

The Earth's climate varies on all time scales, from regional to global. Large-scale climate variations in the past can be related to changes in geological (plate tectonic) and orbital cycles upon the Earth's climate. Astronomical theories of paleoclimate attributes climate cycles to changes in the Earth's orbital parameters: eccentricity (∼100 kyr), obliquity (∼41 kyr), precession (∼22 kyr).

It has been established from the paleoclimate and paleo-oceanographic

data that during the last more than 50 millions of years planetary temperatures were several degrees warmer than today, but there has been a progressive decrease in the average surface temperature on this time interval. Substantial glacial and interglacial temperature fluctuations are imposed on this decrease since about 2.8 million years ago. The last interglacial (peak at 125 kyr ago) was a period with significantly higher temperatures in many parts of the Northern Hemisphere compared to the current interglacial (start data is ∼11,000 years ago). Detailed analysis of recent oscillations in temperature show a clear 100,000 year correlation with interglacials coincident with maxima of the elipticity of the Earth's orbit.

To understand better our current interglacial (the Holocene, MIS-1 [Marine Isotope Stage]) and its future, it is necessary to investigate the response of the climate system to the peaks of interglacials in the past. Start of the last interglacial period occurred at 130 kyr ago (MIS-5). A similar to the Holocene latitudinal and seasonal distribution of the incoming solar radiation show two interglacials: MIS 11 (start — 427 kyr ago) and MIS 19 (start — 788 kyr ago). However, it is difficult to find a complete analogue to current interglacial climate in the available climate data. The available data on climatic changes and the cyclic influence of solar radiation on the climate change are analyzed and the problem of current interglacial duration is discussed.

## Migration of the north magnetic pole of the Earth, increase in the concentration of $CO_2$ and climate change in the twentieth century

*Dergachev, V.A., and Vasiliev, S.S. (Ioffe Physical-Technical Institute, St. Petersburg, Russia)*

The relationship between increasing concentration of atmospheric $CO_2$ and change of the terrestrial climate is widely discussed in recent years. Is this relationship the only reason for global warming? The authors investigate a possible connection between the position of the Northern magnetic pole of the Earth (NMP) and the changes of the mean temperature in Greenland. Kovaltsov and Usoskin (2007) investigated the ionization of the atmosphere induced by cosmic rays for different positions of the North geomagnetic pole. They showed that changes in the level of ionization of the atmosphere due to the effect of migration poles are comparable with variations because of so-

lar activity. Kerton (2009) has demonstrated that there is correlation between the position of NMP, on the one hand, and global temperature anomalies and temperature of the Northern Hemisphere, on the other hand. Thus, there is an evidence pointing to the influence of the position of the magnetic pole on the climate. Is there a connection between the position of the pole and the local climatic indices? We examined the average monthly temperature data for 1898–2007 years of four meteorological stations on the Greenland coast, the latitudes of which are significantly different. In the 20th century the NMP migrated to the direction of North-West, moving away from Greenland. We have compared the change of average monthly temperatures with a distance to the NMP. For the data analysis, we considered a linear regression model. Such parameters as the averaged over a 5-year interval latitude of NMP and the averaged values of mean monthly temperatures were used in the regression model. There is a statistical relationship between the latitude of the NMP and the temperature in Greenland in the 20th century. It was established that the larger the distance between the meteorological station and the magnetic pole the weaker is this relationship.

### Study of solar cyclicity stability on time scale of hundreds of millions of years

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Palaeoclimatic data with a high temporal resolution, i.e., the fossil tree ring widths and varve deposits, have been analyzed for time scales of several hundreds of millions of years with the aim of revealing periodicities in climatic processes. The climatic periodicities thus found are compared with the solar and climatic periodicities observed at present. The periodicities revealed in the climatic parameters prove to be similar in many cases to the observed solar activity cyclicities. This can indicate that these periodicities effectively affect climate change regardless of differences in the climatic conditions in the interval considered.

## "Polar" and "high-latitude" substorms and solar wind conditions

*Despirak, I.V., Lubchich, A.A. (Polar Geophysical Institute, Apatity, Russia); Kleimenova, N.G. (Institute of Physics of the Earth, Moscow, Russia)*

All substorms observed at high latitudes can be divided into 2 types — "polar" (observed only at $> 70°$ latitudes in the absence of substorms at $< 70°$ latitudes during the day) and "high-latitude" substorms (propagating from auroral ($< 70°$) to polar ($> 70°$) geomagnetic latitudes). The aim of this study was to compare solar wind conditions during these two types of substorms. For this purpose, we used the data of IMAGE magnetometers and OMNI solar wind data for 1995, 2000, 2006–2011 periods. There were selected 105 "polar" and 55 "high-latitude" substorms. It is shown that "polar" substorms observed during the late recovery phase of a geomagnetic storm, after passing of the high speed stream of the solar wind (when the velocity is reduced from high to low values). "High-latitude" substorms, on the contrary, are observed during passing of the recurrent high-speed stream of the solar wind, increased values of the southward $B_z$ component of the IMF and $E_y$ component of the electric field, increased temperature and pressure of the solar wind. Also, it is noted that variability of these solar wind parameters for the "high-latitude" substorms is stronger than for "polar" substorms.

## Magnetotail substorms observations during solar wind magnetic clouds and HSS streams

*Despirak, I.V., Lubchich, A.A. (Polar Geophysical Institute, Apatity, Russia); Koleva, R. (Space Research and Technologies Institute, BAS, Sofia, Bulgaria)*

In the literature there is enough evidence that in the course of substorm fast plasma flows in the magnetotail are observed and satellites in the near or middle tail can register a reversal of a tailward plasma flow to an earthward plasma flow. The observation of oppositely directed flows is interpreted as tailward movement of the reconnection site. In this work we will investigate the reconnection site location in the magnetotail during substorms observed under different solar wind structures - recurrent streams (RS), magnetic clouds (MC), and

the region of compressed plasma in front of these streams (Sheaths and CIRs). We use data from Geotail spacecraft in the magnetotail and solar wind parameters from Wind spacecraft observations; the auroral bulge parameters were obtained by the Ultra Violet Imager onboard Polar. We considered data from the Geotail spacecraft in the magnetotail measured in the course of auroral bulge formation, during passage of solar wind magnetic clouds, recurrent streams and Sheaths and CIRs regions. 17 events are selected. It is shown that magnetic reconnection in the magnetotail takes place closer to Earth when substorm is observed during MC, and further in radial distance for substorms during solar wind recurrent streams.

### X-ray effect in VLF radiation diurnal variations

*Druzhin, G.I., Cherneva, N.V., Mel'nikov, A.N. (Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS, Kamchatka region, Paratunka, Russia)*

According to the results of observations in Kamchatka, spectral analyses of VLF radiation noise component at the frequencies of 0,7, 1,2, 5,3 kHz for 1997–2006 and of pulse component in the frequency range of 3–60 kHz for 2002–2006 has been carried out. The analysis has shown that there are diurnal maxima in the spectra of VLF noise envelope and in the pulse component, which coincide with the Earth rotation relative to the Sun (1440 min) and relative to stars (1436 min). The highest intensity in spectral components coincide with the period of the Earth rotation relative to the Sun, and it is observed in radiation arriving from the south-western direction of Kamchatka. The cause of appearance of the maxima in spectral components with the periods of 1440 min and 1436 min may be the Sun X-rays and the galactic X-rays

### Current systems responsible for asymmetric variation of the mid-latitude geomagnetic field

*Dubyagin, S., Ganushkina, N. (Finnish Meteorological Institute, Helsinki, Finland)*

The SYM-H index has been actively used as a measure of the symmetric ring current strength. In contrast, the ASY-H and -D indices

(first order longitudinal harmonic of the magnetic disturbance) are rarely used since, for these indices, there is no such clear physical interpretation as that provided by Dessler-Parker-Scopke theorem. There are a few current systems which can contribute to the ASY indices: purely ionospheric currents, field-aligned currents, and equatorial magnetospheric currents. We use the Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE) system to estimate what fraction of the ground mid-latitude field variation is caused by field-aligned currents. In addition, we discuss the possible sources of the north-south asymmetry of the mid-latitude field variations.

## New 3D PIC simulation model to study lunar dust and plasma environment

*Dyadechkin, S., (Aalto University, Espoo, Finland) and Kallio, E. (Aalto University, Espoo, Finland; Finnish meteorological Institute, Helsinki, Finland)*

The Moon does not have a global intrinsic magnetic field and it does not have an atmosphere. Therefore charged particles originating from the Sun and outside of the Solar System can freely hit the lunar surface. The Sun is also the source of the interplanetary magnetic field (IMF) and, thus, the solar wind plasma is magnetized. The Sun also emits extreme ultraviolet (EUV) radiation that ionizes both the lunar surface and neutral atoms above the surface.

The aforementioned factors affect the properties of the charged particles, ions and electrons, near the Moon, and, consequently, the electric and magnetic fields near the Moon. The properties of the plasma near the Moon have various spatial and temporal variations. Modeling of the properties of the lunar plasma environment is, therefore, a challenging task because a self-consistent model should include all major plasma populations and electric and magnetic fields. Modeling is also complicated by the fact that the conductivity of the lunar surface is not well established. Moreover, local effects caused by geography (craters, slopes, hills etc.) and the magnetic anomalies are neither well known.

We have developed a new electrostatic full Particle-in-Cell (PIC) simulation model (HYBpic) which treats both ions and electrons as particles. The HYBpic simulation allows to simulate plasma and dust

lunar environment in 1D, 2D and 3D cases. It also allows to include into the simulated space an arbitrary landscape relief of lunar surface as well as human made objects on the surface. In the presentation we demonstrate the studies of properties of plasma and dust near the Moon surface for the different cases of surface reliefs.

The HYBpic simulation will be used to interpret in situ observations at Moon by forthcoming Russian Luna-Resource mission and Luna-Glob Lander. The simulation can also be used to simulate plasma environment of other airless objects, like asteroids, and dusty plasma objects like comet 67P/Churyumov-Gerasimenko, the target of ESA's Rosetta mission.

### Study of the polarization characteristics of magnetic ULF noise by the space separated receiving method

*Ermakova, E.N., Kotik, D.S., Polyakov, S.V. (Radiophysical Research Institute, Nizhny Novgorod, Russia)*

Work is devoted to experimental studies of the polarization of the background noise parameter characterizing the degree of ellipticity of low frequency magnetic fields and the azimuthal angle of horizontal magnetic components by gradient method. It was used the measurements in two low-frequency receiving points in the Nizhny Novgorod region, spaced at a distance of 100 km in EW direction. It was found that the spectra of polarization parameter at these stations are usually matched at night, even under a strong regional thunderstorm activity. At the same time, the spectra of the azimuthal angle at these stations were heavily dependent on the position of regional thunderstorm cells and, therefore, determined not only by the local properties of the ionosphere above the point of reception. It was found at the same time that spectra of this parameter at both stations distinctive have specific variations related to the influence of the sub-IAR structure. The spectra of the azimuthal angle at two stations coincided under developed global lightning activity.

It was also investigated the possibility of influence of powerful RF waves on spectra of background noise during periods of ionospheric plasma heating experiments with SURA facility (located 29 km away from one and 130 km from another receiving points) using analysis of the spectra of the magnetic field polarization parameter in separated stations in the night. In one of the sessions it was registered to 60%

difference in the polarization parameter at different points, which can be related to the horizontal inhomogeneity of the ionosphere due to its modification by heating, or to the generation of gravity waves by RF heating.

### The daily dynamics of the fine structure in the background magnetic noise spectrum at mid-latitudes

*Ermakova, E.N., Kotik, D.S., Ryabov, A.V. (Radiophysical Research Institute, Nizhny Novgorod, Russia)*

Work is devoted to experimental studies of the fine structure (FS) in the background magnetic noise spectra in frequency range 0.1–10 Hz. Experimental data obtained by measuring the magnetic noise components in RRI receiving point (Nizhny Novgorod region, 55.97 N, 45.74 E) were analyzed.

It was analyzed the time appearing of the FS and the position of the solar terminator relative to the receiving point and relative to global thunderstorm cells, the most active at the time of the appearance of FS. It was found that the fine structure may occur as soon after the passing of the solar terminator through the receiving point, so with a considerable delay in 2–4 hours after sunrise. It was also found that the time appearing of the FS can be correlated with the passing of the terminator across the meridian of the most active global thunderstorm cells. It was used for the analysis the data from networks WWLLN (World Wide Lightning Location Network), which allows us to track activity of global sources of thunderstorms in real time. It was also investigated features of the FS frequency spectrum dependence on the season. It was found that the maximum frequency range in which the FS is registered is 0.2–(4–5) Hz, and it observed in autumn and winter. During spring and summer the FS was observed at frequencies up to 1–1.5 Hz. The regular resonance structure observed simultaneously with the FS has a frequency scale more than 1–1.2 Hz.

**Evolution of the spectral structure of the Pc1 pulsations**

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The analysis of the Pc1 geomagnetic pulsations, recorded at the latitude network of several Finnish ground stations, demonstrates that sometimes there was observed a change of the wave polarization with the latitude. Some selected Pc1 events with latitude depending wave polarization are presented. The observations of the left-hand polarized Pc1 pulsations suggest that the given ground-based station is located near the projection of the field line of the Alfvén wave (Pc1) generation region. The observations of the right-hand polarized Pc1 pulsations at the higher and lower latitudes could be a result of the horizontal propagation of magnetosonic waves in the ionosphere waveguide. These waves can carry energy across the magnetic field lines. We also found that typically the Pc1 spectral width increase with geomagnetic activity increasing. The performed theoretical calculations showed that the evolution of the frequency width of the dynamic spectrum of the Pc 1 wave packets depends on the magnetosphere plasma parameters. It was found that the Pc1 spectral width increases with decreasing of the proton thermal anisotropy. A minimum of the frequency width of the Pc1 wave packet spectrum is consistent with a certain density of the background plasma.

**Ionospheric disturbances as a manifestation of cloudy IMF structure**

*Filippov, L.D., Stepanov, A.E., Plotnikov, I.Ya. (Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy, Yakutsk, Russia)*

In this paper, we compared changes in the critical frequency (foF2) of the ionospheric layer with events of coronal mass ejections in the near-Earth space. Analyzed the DPS-4 digisonde measurements in the daytime (06–18 LT) on ionospheric station Yakutsk. Discusses the statistical relationship between the characteristics of the regular semidiurnal foF2 course with parameters magnetic cloud associated with a coronal mass ejection. Considered short-period components

of the semi-diurnal foF2 course and possible their dependence on geometrical parameters of the magnetosphere dynamics when it influenced by a magnetic cloud.

### Study of the pulse magnetic reconnection with finite X-line

*Gabbasov, E.I. (St.Petersburg State University, St.Petersburg, Russia)*

Most of the current models of the reconnection are two dimensional models. At the same time the real reconnection is complex 3D process, which should be described with 3D model. In this study we made the generalization of the two dimensional Petschek solution for the 3D case in the outflow region. Next we compare the results of the simulations to check if the Petschek solution could be used for analysys of the real reconnection or we should use the 3D one.

Phases of reconnection were analyzed both for the 2D and 3D models. Since the differences between 2D and 3D simulations are quite small, we can conclude that 2D Petschek solution can be used for the study of 3D configurations with incompressible plasma.

### The role of IMF $B_x$ in the global magnetotail dynamics

*Gordeev, E.I., Sergeev, V.A. (St. Petersburg State University, St. Petersburg, Russia)*

Using the first principle (global MHD) simulation we try to take first steps in study of the large-scale magnetotail dynamics associated with IMF $B_x$ component. Displacement of the dayside reconnection line away from the equatorial plane due to presence of the $B_x$ IMF component leads to significant modification of the magnetopause draping and results in the global asymmetrization of entire magnetospheric system. Complicated changes in the magnetosheath and magnetotail lobes cause the geometrical reformation of all magnetospheric boundaries and initiate the neutral sheet vertical displacement that can be addressed to the three complementary processes. The first can be referred to the hypothesis that was proposed by Cowley [1981] and explains by asymmetrical loading of the magnetotail lobes with the

reconnected magnetic flux on the dayside magnetopause. The second is the non-symmetrical magnetic field draping that leads to the pressure difference in the opposite magnetosheath sides and displacement of the entire magnetotail together with embedded neutral sheet. And the third process is closely links to the substorm expansion: the asymmetrical loading of the opposite lobes causes an asymmetry in the magnetic and plasma parameters about the tail neutral sheet surface and the additional effective displacement of the neutral sheet can be qualitatively explained in terms of asymmetrical reconnection theory [Semenov et al., 1983].

## Do the solar wind magnetic clouds and magnetic holes have much in common from the MHD point of view?

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Among different heterogeneities existing in the solar wind flow strictly organized structures of magnetohydrodynamic (MHD) type are often observed. These are magnetic holes (MH), magnetic clouds (MC), tangential and rotational discontinuities (TD and RD). The first ones belong to so called pressure balanced structures (PBS). The effect of MH on the bow shock-magnetopause system at first is connected with the increase of plasma density across the frontal edge of MH and it gives the appearance of MHD fast shock wave inside the magnetosheath. The same but stonger effect we have for the perturbation of the system by the MC bow shock wave, going before the MC. By the way the second (trail) edge of the MH will give us the fast rarefaction wave inside the sheath. Just now it is supposed that there are different MHD discontinuities inside the boundaries of the MC, especially the RD, changing the direction of the northen-southern component of the interplanetary magnetic field. The collision of RD with the terrestrial bow shock may create 2 MHD slow shock waves going in opposite directions and the stationary contact discontinuity, which being unstable may disappear. Just this MHD result is confirmed by the observation of plasma density plateau on board of some spacecraft.

**Relationship of ground geomagnetic activity with the interplanetary magnetic field and solar wind parameters**

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The correlations between a geomagnetic activity and parameters of the interplanetary medium are investigated. To determine a quantitative assessment of the local and planetary geomagnetic activity we use the method, proposed earlier as a method of IZMIRAN. Quantitative assessment determined on the basis of the data of 26 stations. The northern hemisphere is divided by seven 15°-20° latitude belts closed to some geomagnetic activity indexes domains. All selected observatories are located in each belt within the each 90° longitude sector except for the near polar belt where there are only two ones. The quantitative assessment is the average value of H-component deviations from the level 2009 over belt stations. 2009 was recognized as the most magnetic quiet for long period of measurements. To find a complete assessment of the northern hemisphere activity, belt values are normalized to the areas of the corresponding belts. Correlation analysis is performed for the data of 1995–2009 because there is the most comprehensive set of data on the parameters of the interplanetary medium after 1995. The analysis shows that there is a consistent correlation between hourly mean values of geomagnetic activity and the vertical component of the interplanetary magnetic field $B_z$, as well as the function $\varepsilon$ Akasofu, especially for belts located southward 69°. The obtained correlation coefficients for the northern hemisphere reach 0,66–0,69.

**Spatial distribution of quantitative assessment of geomagnetic activity during storms of different intensity**

*Gromov, S.V., Levitin, A.E., Gromova, L.I., Dremukhina, L.A. (Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, RAS, Moscow, Russia)*

To estimate local geomagnetic activity during storms of different intensity we used our method of quantitative assessment of geomagnetic activity. It is based on measurements of H-component of the geomagnetic field of observatories located in the Northern hemisphere.

Hourly data of 1958–2009 from more than 100 magnetic observatories were processing. Extremely quiet 2009 state of the geomagnetic field was assumed as a reference level of the geomagnetic activity magnetic observations. Local geomagnetic activity is estimated in the latitudinal belts close to the geomagnetic activity indices domains. Our estimation of local geomagnetic activity differs from that presented by Kp and AE indices. We demonstrate our results for moderate, intensive, large and major storms selected during 1958–2009 in different seasons of a year and propose a method to estimate intensity of magnetic storms based on our quantitative assessment of geomagnetic activity.

**Observations of substorms during different storms and quiet conditions**

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All-sky cameras data at Kola Peninsula from the 2012/2013 and 2013/2014 winter seasons have been used to study the variation of substorm development in different conditions of interplanetary medium. Solar wind and interplanetary magnetic field parameters were taken from OMNI data base. Using solar wind data for the examined periods, the different solar wind streams were revealed: recurrent high-speed streams (RS) and magnetic clouds (MC). It is know that these solar wind structures are the sources of geomagnetic storms. In our study were compared substorm development during different storms and during quiet geomagnetic conditions. Substorm onset time and further development were verified by data of IMAGE magnetometers network and by data of all-sky cameras at Apatity and Lovozero. The particularities in behaviours of substorms observed by different storms and during quiet conditions are discussed.

**Event of the SAR arc occurrence as the mapping of substorm injection due to the interplanetary shock on December 14, 2006**

*Ievenko, I.B. (Yu. G. Shafer Institute of Cosmophysical Research and Aeronomy, Yakutsk, Russia)*

The stable auroral red (SAR) arcs are the consequence of interaction of the outer plasmasphere with energetic ions of the ring current. The diffuse aurora (DA) is caused by the low-energy electron precipitation from the plasma sheet. Our studies at the Yakutsk meridian (200°E geomagnetic longitude) indicate that the SAR arc appears and/or brightens during the substorm expansion phase. The SAR arc formation begins in the equatorward boundary region of DA (Ievenko et al, 2008). In this work the results of observations by all-sky scanning photometer of SAR arc formation during a substorm whose expansion phase has begun in 15 minutes after the onset of sudden commencement (SC) due to the impact of the strong interplanetary shock detected by the ACE spacecraft on December 14, 2006 are presented.

The intense substorm with amplitudes of AL $\sim$ -1300 and ASY-H $\sim$ 200 nT indices has started at 1430 UT. In 10 minutes ($\sim$2310 MLT) the photometer has registered the 630 nm emission intensification in the form of patch at $\sim$ 61°N geomagnetic latitude. The red patch with a diameter of $\sim$300 km appears in a vicinity of DA boundary and moves equatorward close to the Yakutsk meridian with the increase of velocity from 100 to 300 m/s. At 1510 UT the 630 nm emission intensification has been already observed in the form of SAR arc at 57°N geomagnetic latitude.

Geosynchronous observations of the fluxes change of energetic protons and electrons aboard the LANL spacecrafts in the evening and midnight MLT sectors points to the location of substorm injection centre close to the Yakutsk meridian. This suggests that the dynamics of SAR arc formation in this event maps a prompt radial diffusion (electric drift) of energetic particles from the central region of substorm injection into the inner magnetosphere.

**Imaging the energetic particle penetration from the substorm injection region up to a plasmapause**

*Ievenko, I.B., Parnikov, S.G (Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy, Yakutsk, Russia)*

The stable auroral red (SAR) arcs are the consequence of interaction of the outer plasmasphere with energetic ions of the ring current. The diffuse aurora (DA) is caused by the low-energy electron precipitation from the plasma sheet. Our studies indicate that the SAR arc appears and/or brightens during the substorm expansion phase. The SAR arc formation begins in the equatorward boundary region of DA (Ievenko, 1999; Ievenko et al., 2008). In this work we analyze the observations the dynamics of DA and SAR arc in the 557.7 and 630.0 nm emissions with an all-sky imager (ASI) at the Yakutsk meridian (CGM: 58°N, 200°E) during the isolated substorm on February 13, 2013.

The substorm expansion phase has started in 1849 UT in ∼25 min after fast southward turn of IMF $B_z$ and the convection intensification. Mid-latitude magnetograms indicate to the location of center of the substorm expansion onset at the magnetic meridian ∼0140 MLT. Near the center of the substorm active region the Van Allen Probe A satellite has detected the beginning of dispersionless substorm injection in orbit apogee at $L = 6.4$. The ECT HOPE Instrument has registered a sharp change in the energy spectra of particles with the increasing flux in the range of 5–20, 20–40, 1–10 keV for electrons, protons and ions $O^+$, respectively.

The ground-based ASI has observed the manifestation of substorm injection in the 0200–0425 MLT sector until 2015 UT. First the equatorward and eastward extension of DA has taken place. Further the formation of broad SAR arc at the geomagnetic latitude ∼60°N and its movement up to zenith of station has begun. On the basis of optical observation the radial and azimuth speeds of energetic particles at the magnetic equator have been appreciated. It is assumed that the dynamics of DA and SAR arc maps the penetration of hot plasma into the outer plasmasphere as the result of electric drift from the substorm injection region.

**Plasmasphere dusk-bulge mapping by the SAR arc according to simultaneous the ground and satellite observations**

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It is known that stable auroral red (SAR) arcs are the consequence of interaction of the outer plasmasphere (plasmapause) with energetic ions of the ring current. An arisen downward flux of superthermal electrons along the magnetic field lines increases the ambient electron temperature at the altitudes of ionosphere F2 region in the form of $T_e$-peak. As a result, an enhancement of the atomic oxygen red line intensity in the SAR arc mapping the plasmapause (cold plasma density radial gradient) takes place. A boundary location of plasmasphere in the dusk-bulge region strongly depends on LT and shifts towards the lower latitudes during evening hours. The ground observer can register a relative motion of this boundary projection at the height of the ionosphere F2 region if it is mapped by the red arc at this time.

In this work the results of observations of the SAR arc equatorward movement by the meridian scanning photometer at 19–20 LT at the Yakutsk meridian (200°E geomagnetic longitude) during a recovery phase of the weak magnetic storm on February 7, 2000 are presented. The data of simultaneous registration of $T_e$-peaks aboard DMSP F14 and F15 satellites at the meridian of optical observations and eastward of it shows that the SAR arc in this event maps the cold plasma density radial gradient in the dusk-bulge region. A wide band of the westward ionospheric drift (SAPS) observed by F14 and F15 is probably a specific signature of this plasmasphere region.

**Plasmoid formation in the inflated magnetosphere**

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Measurements carried out by Themis satellites near the magnetospheric tail neutral sheet show temporal magnetic signatures with a negative GSM $B_z$ component. Such behavior at ∼30 Earth Radii

distance is typically explained by plasmoid formation. Here we show that two effects: tail current enhancement and its inner edge shifting to the nightside, can also produce such magnetic structures in the tail. Such an event was observed during a small magnetic disturbance on 14.02.2009, during an extremely quiet epoch. The radial profile of the geotail magnetic field and A2000 magnetospheric model parameters were obtained on the base of simultaneous measurements from the THEMIS satellites during February 14, 2009. Solar wind conditions were consistent with those during moderate magnetic storms with minimum Dst of about $-100$ nT. However, strong currents, measured in the geomagnetic tail were located at larger geocentric distances than typical and produced only small disturbances on the Earth's surface. The observed magnetic field structure with negative GSM $B_z$ near the tail current inner edge was reproduced by A2000 magnetic field model for given solar wind conditions.

## Interrelation between recurrent indicators of human electroencephalograms and geomagnetic activity

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The purpose of the study was to establish influence of a geomagnetic field on recurrent indicators of the human electroencephalogram (EEG). It is known that the recurrence quantification analysis (RQA) is a new nonlinear method of the EEG analysis, allowing to reveal subtle EEG dynamics (Marwan et al. 2007, Schinkel et al. 2009, Saroka et. al. 2013, etc.).

The data obtained as a result of carrying out longitude experiments with 8 subjects at which multichannel EEG in 16 sites at background was registered were exposed to the analysis. For each site 9 recurrent indicators of EEG (RR, DET, L, DIV, ENTR, RATIO, LAM, TT, CLEAN) which were compared with data of geomagnetic activity in day of experience were calculated. In the previous work a number of significant correlations was received, but to judge what areas of a brain react to changes of a geomagnetic field it was impossible since recurrent indicators were characterized by high variability and at different subjects significant correlations were observed with various indicators.

In the present study the procedure according to which recurrent indicators of EEG of each site were compared for two groups of data Ap-index of geomagnetic activity was carried out: for low values Ap-index (from 0 to 9 units) and for its high values (from 15 to 146 units). And this comparison was carried out for set of all 8 subjects. Actually it is a question of comparison of disturbance of a geomagnetic field with some background level of a field.

It appeared that significant distinctions for an indicator of RR were found for temporal areas of the right hemisphere (T6) where values of an indicator of RR were significantly higher at the increased geomagnetic activity in comparison with background level (P=0.0082) and for the right occipital site (O2) (P=0.0079). When comparing an indicator of ENTR (entropy) of EEG in the right temporal site (T6) its reliable differences in comparison with background level of a geomagnetic field (P=0.02) also were found.

Results of comparisons of other seven recurrent indicators of EEG allows to create the map of those cortical areas of a human brain which are most sensitive in relation to influence from a geomagnetic field.

The study was supported by the St.Petersburg University project 1.01.132.2010.

## Geomagnetic field and climate variability: possible mechanism of connection

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Analysis of main geomagnetic field (from IGRF model) and climatic parameters (near surface air temperature and surface pressure in the winter-time) allows us to determine their variability and spatial-temporal relations between them during the 20th century. Integral characteristics and dynamics of the above parameters have been investigated, applying one and the same approach. This gives us the possibility to reveal their global and regional characteristics – the differences and similarities between them. There is a good correspondence between geomagnetic field, near surface air temperature

and pressure spatial distributions during the 20th century. The main problem in this case is that the mechanisms of magnetic filed influence on climatic parameters are less investigated and poorly understood. We offer a new mechanism of such an influence consisting of modulation the intensity, and depth of penetration into the Earth's atmosphere, of highly energetic particles of galactic and solar origin. Releasing their energy at different altitudes, these particles activate ion-molecular reactions of different types, which impact the balance of the lower stratospheric ozone. The latter controls the temperature and humidity near the tropopause — through an influence on the atmospheric static stability. The upper tropospheric water vapour, which has the highest impact in the Earth's radiation budget, mediates the ozone influence down to the surface, through strengthening or weakening of the greenhouse effect. Thus, ozone abundance near the tropopause reduces humidity and cools the Earth's surface air temperature, while ozone depletion warms it.

## Long-period irregular pulsations in the conditions of the quiet magnetosphere

*Klain, B.I., Lavrov, I.P., Kurazhkovskaya, N.A. (Geophysical Observatory Borok, Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences, Borok, Russia)*

The results of studying simultaneous observations of high-latitude long-period irregular pulsations in the 2.0–6.0 mHz frequency range (ipcl — irregular pulsations continuous long period) and magnetic field disturbances in the solar wind plasma at low geomagnetic activity (Kp ∼0) are presented. The 1-second data on the magnetic field at the Greenland magnetometer chain as well as the 1-minute data on the plasma parameters of the solar wind and interplanetary magnetic field (IMF) for 2011–2013 have been used in an analysis. We analyzed the behavior of the average frequency and amplitude of the ipcl pulsations and solar wind parameters by the epoch superposition method. It was found that at the reorientation of the IMF $B_z$-component from the northern direction to the southern the spectral content of ipcl pulsations changes and their intensity increases. It is shown that the average frequency of the ipcl pulsations linearly related to the velocity of IMF $B_z$-component change. The proportionality coefficient of obtained regression equations depends on the

geomagnetic latitude. This experimental fact indicates on a change in the magnetic field topology of the magnetosphere at the subsolar area of the magnetosphere during $B_z$-component reorientation. From the obtained results, we conclude that an unsteady-state of solar wind plasma (turbulence) leads to intensification "the wind instability" (the Miles–Phillips instability) at the magnetopause when Kp $\sim$0 and $B_z < 0$ and which can be responsible for the formation of the ipcl spectrum.

## Polar geomagnetic effects of magnetic storm of 24 Nov 2001 under strong positive $B_z$ IMF

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The huge positive $B_z$ IMF values (up to $\sim$ +60 nT) were observed during the main phase of the strong magnetic storm on 24 Nov 2011 (Dst$\sim -220$ nT) under the very high solar wind speed ($\sim$ 900 km/s) and several sharp bursts of the solar wind dynamic pressure (at $\sim$ 7.30, 09.30, 12.00 and 14.00 UT). About 30 min after SC, the $B_z$ IMF value reached $\sim -30$ nT and the strong substorm with the highest amplitudes at the morning sector occurred. Later on, at $\sim$ 07 UT, the $B_z$ IMF turned to the high positive values reaching more than +60 nT. The most unusual phenomenon during this storm was the bay-like magnetic disturbance at 08–11 UT with the amplitude $\sim$ 1000 nT which was observed near local magnetic noon only at the polar latitudes ($> 70^\circ$) at the Scandinavian IMAGE magnetometer profile. At that time AE-index was 500 nT. This event occurred after very strong burst of the solar wind dynamic pressure (up to $\sim$ 70 nPa). We suppose that the polar magnetic bay was caused by the enhanced high-latitude NBZ system of the field aligned currents (FAC). The IZMEM model distribution of the high-latitude FAC confirmed this suggestion and demonstrated strong FAC at the polar magnetic bay location.

Some bursts of 2–7 mHz geomagnetic pulsations (ULF waves) represented the fine wave structure of this magnetic bay. However, the ULF bursts were not coincided with the similar frequency range

bursts of the fluctuations in the solar wind density. The latitude distribution of these 08–11 UT polar bursts of ULF geomagnetic pulsations differed from the ULF geomagnetic pulsations accompanied the morning 06.30–07.30 UT substorm. We suppose the polar ULF pulsations represented the fluctuations of the intensity of the corresponding field aligned currents.

## Northern auroral structures before breakup as signatures of the external force, driving magnetic reconnection

*Kornilov, I.A., Kornilova, T.A. (Polar Geophysical Institute, Apatity, Russia)*

Rather bright auroral arcs usually appear in the northern horizon of TV imager field of view 30–40 minutes (substorm preliminary phase) before breakup onset at the southern arc, and are projected to 20–30 Re in the tail (breakup arc projection is at 5–7 Re), where plasma fluxes are generated, manifesting as auroral structures moving earthward (BBFs and auroral streamers, respectively), and finally lead to a breakup development. The northern arc projection (20–30 Re) is appropriate for magnetic reconnection site, but northern arc development and luminosity variations are definitely not a breakup type explosive process. It should be also noted that if breakup is a result of explosive magnetic reconnection, there is a problem, how to stop this self-sustaining and self-supporting process (Akasofu, 2013). We have measured integral luminosity variations of the northern arc (about 50 cases in total) and compared them with solar wind parameters (mostly with magnetic field vector) registered by ACE and WIND satellites with an appropriate time shift (50–60 minutes). In many cases rather good correlation between northern arc luminosity variations and solar wind parameters was found. We can suppose that if northern auroral structures have magnetic reconnection nature, this reconnection is completely initiated and controlled by the solar wind and actually operates as some kind of converter, or transformer between external force (solar wind) energy, and plasma energy in the inner magnetosphere.

**Breakup and pseudobreakup plasma injections and magnetic field variations at -60 Re (lunar orbit – ARTEMIS data)**

*Kornilova, T.A., Kornilov, I.A. (Polar Geophysical Institute, Apatity, Russia)*

Six months of complicated ballistic maneuvers (with the maximum using of Earth, Sun and Moon gravitational forces, and minimum spacecraft fuel consumption) successfully finished by two Themis satellites placing at the Moon orbit in summer 2011. Now they have new names – Themis B is Artemis P1, and Themis C – Artemis P2 (ARTEMIS - Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun), and move together with the Moon around the Earth. Spacecraft give a possibility to study solar wind plasma interaction with a Moon surface, plasma dynamics in the distant tail, effects of Moon shadowing, etc. About once per month the satellites cross the magnetospheric tail in the E-W direction at the distance about 60 Re. In this study we present some results on the distant tail plasma and field dynamics for 27 January 2013. Artemis P1 and P2 space separation was 0.05 Re in X, 4.0 Re in Y, and 1.3 Re in Z coordinate, correspondingly. Satellite observations were coordinated with auroral (Canadian stations SNKQ and NRSQ) and ground-based magnetic data. For the first auroral activation of pseudobreakup type, P1 and P2 detected a rather weak increase in the electron and ion fluxes, the plasma bulk velocity was about 100 km/sec in the earthward direction. 40 minutes later, a full-scale breakup occurred, which was accompanied by strong tailward plasma flows with a speed about 300 km/sec.

**The wave-like nature of the East-West aurora activities prior to the substorm onset**

*Kornilov, I.A., Kornilova, T.A., Golovchanskaya, I.V. (Polar Geophysical Institute, Apatity, Russia)*

This is a study of the East-West (E-W) aurora activities, preceding the major onsets, made to verify the wave-like nature of this phenomenon. The precise auroral observations at PGI observatories LOP, LOV and Tumanny, as well as at Canadian THEMIS all-sky imager array, are used, which enable to derive the propagation velocities of the auroral perturbations in the ionosphere. In all cases of

conjugacy with THEMIS probes during the E-W activities prior to the auroral onset, the presence of large-amplitude ballooning perturbations in the probe measurements was identified. In some cases it was possible to claim that these are ballooning waves, propagating in accordance with their dispersion relation.

### The dispersion curve of a double-gradient (kink) magnetic instability in tail-like magnetic configurations with guide field

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The kink double-gradient mode developing in the magnetotail-like magnetic configuration with tailward growing normal magnetic component and finite guide field is studied by means of analytical approach in a frame of ideal incompressible MHD, linearized 2-dimensional and non-linear 3-dimensional MHD modeling. We consider a particular case of a weak tailward growing normal magnetic component providing for large magnetic field line curvature, which makes the configuration unstable to a special branch of ballooning instability known as "double-gradient" mode, introduced recently to describe the magnetotail flapping oscillations. The approximate solution of Grad-Shafranov equation obtained in a frame of the so-called tail-approximation provides for initial equilibrium configuration. The results of the 2-dimensional linearized MHD code, particularly the growth rate peak values and corresponding wave numbers, are in agreement with the analytical predictions. Both 2-dimensional and 3-dimensional calculations confirm that non-zero guide field reduces the growth rate significantly for large (compare to the current sheet width $L$) wave numbers $k$, hence the modes $kL \sim 1$ are the fastest growing. Thus, the non-zero guide field introduces a characteristic wavelength corresponding to the dispersion curve peak. For the guide field of $\sim$0.5 (in the lobe magnetic field units), the double-gradient mode decays totally.

**Changes in ionospheric parameters before crust earthquakes with energetic class (K) from 10 to 12**

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The 15-minute measurement data from the station of vertical ionospheric sounding in Irkutsk, obtained in the summers of 2008–2011 were analyzed. Deviations from the background of the critical frequency of the regular layer F2, the frequency of blanketing, the E-sporadic reflection limit frequency and the virtual height of the E-sporadic layer within a specified period of time were calculated. It was found that significant part of the deviations with the lead time T up to 2.5 days before earthquakes with energy class K in the range of 10 to 12 units exceeds the standard error for 1–2 hours. The pointed ionospheric deviations result in the dependence relating the lead time T of the earthquake with its power class and the distance from the epicenter to the observation point. This dependence is consistent with earlier observations on geophysical fields in the crust.

**On the unexplored psychological problem of manned flight to Mars**

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The presentation discusses so far unexplored biophysical problem of manned flight to the Mars, scheduled for the next decade. In long-term manned space flights on the orbital stations “Salyut-6” Soviet cosmonaut crews under the command of one of the co-authors (cosmonaut V.V. Kovalenok) had repeatedly observed the effect of certain geophysical conditions on the psychological state of each crew. It is important that, during all these periods, the geomagnetic pulsations were completely absent. Previously a new but very important for long interplanetary expeditions problem of psychophysical state

of the crew in the absence of alternating electromagnetic fields and emissions, including the ionosphere one, was first raised for evolutionarily adapted humanity. The aim is to confirm the need of considering possible pathological effects of the complete lack of rhythm forming, inherent for terrestrial environment geomagnetic pulsations on psychological and physical state of the cosmonaut crew. This is important for the preparation and conducting the manned flights beyond the Earth's magnetosphere, particularly to the Mars.

The influence of the presence of different types of geomagnetic pulsations recorded by the Geophysical Observatory "Borok" of the O. Yu. Schmidt Joint Institute of Physics of the Earth, Russian Academy of Sciences, on the statistics manifestations of various diseases for Murom City, located in the same region (Central Russia) at a distance of about 50 km has been investigated. It has been observed that the period of the absence of pulsations is typical for the maximum number of events in the manifestation of the diseases, especially nervous ones. High-frequency pulsations similar to frequency in the basic human biorhythms are absent in 60–100% for neurasthenia and 100% — for neurosis and psychosis.

All these electromagnetic waves are usually the background for the earthling to disappear with the release of the interplanetary spacecraft beyond the magnetosphere, and after a few days of flight the cosmonauts will be out of the usual electromagnetic "noise", as well as outside the geomagnetic field. It is unknown however if under the simultaneous absence either the geomagnetic field or electromagnetic waves in a wide range of frequencies — from low (including those of the field of brain rhythms, heart, etc.) to the highest ones the extremely high frequencies affect the human organism upon the resonance effects on the body cells. Therefore, in the coming years, during the preparatory stages of the first interplanetary flight, it is required to study synergistic effects of exposure to the fields on human — under expected absence of the usual "sets" oscillations of electromagnetic fields, especially geomagnetic pulsations, when real background of hypo-magnetic field exists.

## MAIN (Multiscale Aurora Imaging Network) auroral cameras: overview of events observed during last two winter seasons

*Kozelov, B.V. (Polar Geophysical Institute, Apatity, Murmansk region, Russia)*

The report presents an overview of aurora events observed by MAIN (Multiscale Aurora Imaging Network) camera system during last two winter seasons 2012–2013 and 2013–2014. The MAIN camera system consists of 5 auroral cameras installed at Kola Peninsula in Apatity for observations of auroral structures at different scales: from fine structures near magnetic zenith to all-sky luminosity. The MAIN cameras and all-sky camera in Lovozero observatory give possibilities to triangulate auroral structures. Two pairs of cameras can be employed: (i) narrow (18 degrees) field-of-view cameras with 4 km distance between them, and (ii) two all-sky cameras which were 86 km spaced.

Typically there are more than 200 hours of aurora observations by the MAIN cameras during each winter season. The most part of the observations contains of slow aurora which is located near the north horizon and which is always seen near the local midnight in cloudless sky even in quiet geomagnetic conditions. The disturbed magnetospheric conditions lead to active aurora near the zenith of the camera system. There are a few events (magnetic storms) then the bright aurora moves to south horizon of the field of view. The report presents a statistics of the observed auroral events and the most interesting examples. All the data are available through INTERNET and the description of the access to the data is given.

The work is supported by Presidium of Russian Academy of Sciences through Program 22.

## Dynamics of the plasma sheet in the dawn sector of the magnetosphere from THEMIS observations

*Kozelova, T.V., Kozelov, B.V. (Polar Geophysical Institute, Apatity, Murmansk region, Russia)*

It is well known that during the magnetospheric substorm the initial disturbance begins in a localized region which then expands in

all direction. The dipolarization of the magnetic field in the night magnetosphere along with the Pi2 pulsations, ground perturbations, and poleward expanded auroral bulge are prominent signatures of the substorm explosive phase. Westward of onset, a dynamic boundary dividing the areas with different particle pressure appears during simultaneous WTS observations in conjugate ionospheric region.

Eastward of onset, the evolution of the magnetospheric signatures of the substorm explosive phase has received much less attention than westward, perhaps because it is not associated with dynamic aurora as remarkable as the WTS. However, it is the region where downward FACs of the SCW and an enhanced eastward flow channel are usually observed.

In this study we examined a dynamics of the plasma sheet and the equivalent transverse currents of perturbations during stretching of magnetic field line and sequent dipolarization using the THEMIS observations at the dawn sector of the magnetosphere during the substorm on 6 January 2008. Possible association of particle injection with magnetotail dynamics is discussed.

The work is supported by Presidium of Russian Academy of Sciences through Program 22.

## The UT and semiannual variation of SSC occurrence frequency

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The old definition, that "an SSC is a sudden commencement of a magnetic storm", is now changed into "sudden commencements followed by a magnetic storm or by an increase in geomagnetic activity (GA)". In this definition more importance is given to the change of rhythm in the GA. Obviously, the SSC time marks the time favorable for effective solar wind–magnetosphere interaction. Though the UT and semiannual variation of GA is well established in geomagnetic data, its cause is a long-standing problem. We suggested earlier a new mechanism for the variations to explain based on change of mutual orientation of large-scale electric field in solar wind ($E$) and geomagnetic moment ($M$) during annual and daily rotations of the Earth (Adv. Space Res, v.47, 2011). In particular, the semiannual

variation of GA with classical peaks near equinoxes is determined by annual variation of the moment component $M_y$ (GSE) with extrema at equinoxes on the interaction plane $yz$. Amplitude of the variation is modulated by the solar wind electric field $E_z = [V, B_y]$. Focal point of our approach is effective component of the dawn-dusk electric field $E_{mv} = VB_yM_y$ that provides interaction efficiency for $B_{y0}$ during the 1-st half of year and for $B_{y0}$ during the 2-nd one. We use SSC data for period of about two solar magnetic cycle 1968–2011 (since 1968 about 40 observatories began to identify SSC), data of interplanetary magnetic field and solar wind velocity $V$ (omni base). UT distribution of the SSC numbers shows clear maximum near 13.5 h. This UT variation is similar to the UT variation of magnetic index Am with maximum in range 10.5–13.5 h for $B_{y0}$ (independent on $B_z$). As we showed earlier, the UT variation of $A_m$ is explained by the UT variation in parameter $E_{mv}$ calculated on basis of spaced data: the $E_{mv}$ parameter has the highest values at 10.5–13.5 h during August-November. So, these UT variations (of SSC, $A_m$-index, $E_{mv}$) demonstrate similar profile with the maxima in range of 10.5–13.5 h. The result allows to consider this time interval with the maximal SSC occurrence rate as favorable one for effective interaction to be realized during August-November (due to presence of maxima in $E_{mv}$ and $A_m$ for $B_{y0}$). Annual statistical variation of SSC occurrence frequency has unusual minima at equinoxes and classical minima at solstices. Besides, there are two groups of semiannual peaks on April, October and May, November and absolute maximum in August. To understand this variation we study annual variation of $K_p$ for different directions of the IMF spiral longitude angle $f$. The annual variations of $K_p$ for different ranges of $f$ show the largest $K_p$ in April, May for $f = 180 - 270°$ ($B_{y0}$, $B_{x0}$) and in July-August for $f = 0 - 90°$ ($B_{y0}$, $B_{x0}$). The $f$ of the largest $K_p$ identify violation of the classical sector structure and point to a major solar wind disturbance. However, all the peaks in the annual variation of the SSC occurrence rate can be explained by our rule above described: $B_{y0}$ is effective during the 1-st half of year and $B_{y0}$ is effective during the 2-nd one. Besides, we showed earlier that component of Poynting vector of electro-magnetic flux $P = [E \times B]$ along $M$ has two semiannual peaks: in November ($P$ is directed to the earth at South pole) and in May ($P$ is directed to the earth at North pole). This part of polar disturbances is considerable for high GA. Cause of the absolute peak in August is not quiet clear. In general storms are attributed to two main heliospheric features — recurrent stream interaction regions and transient coronal

mass ejections CMEs. The latter, when ejected fast enough to form a shock wave, produce the largest storms. Here we propose that strong dawn-dusk $E_{mv}$ field in the postshock flow results from an increase of the IMF component $B_y$ (connected with the $E_{mv}$-field) through compression and draping preceding the driver plasma CMEs.

## Trend changes of Sq-variations of geomagnetic field at the observatory "Akademic Vernadsky" (AIA)

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Solar-diurnal Sq-variations of the geomagnetic field have long-term trend of its amplitude, which depends on regional characteristics. They reflect the changing trend of ionosphere parameters related to solar activity, with the secular variations of the geomagnetic field (magnetic dipole moment, the orientation of Earth's magnetic field, the magnetic activity) and with changes in the concentration of greenhouse gases, etc. The secular variations of the observed geomagnetic field and model calculations of standard components integrated ionosphere conductivity for magnetic quiet days were used in the range from 1958 to 2010. Cross-correlation analysis between the some characteristics of Sq - variations and influencing factors: the total magnetic field; $CO_2$ concentration and the rate of change in the atmosphere's temperature, the increase in ionosphere conductivities were carried out for the same interval. The values of the Sq-variation amplitude trends were calculated for magnetic field components at the observatory AIA, which had the largest secular decrease in the intensity of the field in the last century. After the exclusion of the dominant influence factors such as the solar activity (F10.7) on SQH and integrated ionosphere Pedersen conductivity at SQZ geomagnetic field variations the trend values were respectively 9% and 11% in the summer. Seasonal differences of the amplitude Sq–variation trends with the actual value of 0.21 nT / year for SQZ in spring and 0.09 nT / year for SQZ in summer were shown. Uneven trend with increasing its value for the amplitudes Sq in the first half of the interval and changing the sign of the trend for individual seasons and magnetic field components were also revealed at the AIA. The seasonal features

of long-term dependence between the amplitude of SQZ- variations and F10.7 index of solar activity are discussed.

### Current sheets under the influence of magnetic shear: internal structure and evolution

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Self-consistent 1D and 2D equilibrium models of thin current sheets in space plasma are presented. In the presence of magnetic shear component current structure can be perturbed, particularly, due to the asymmetry of particle scattering after interaction with current sheet. Mechanisms of current sheet formation under magnetic shear mode are investigated. The comparison with in situ observations is discussed.

### Behavior of the plasmaspheric electron density during Space Weather events

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Knowledge of Space Weather effects is important both for geophysical investigations, and for applications. As it is noted in the report of authors on the previous symposium, Space Weather effects are studied in behavior of such ionospheric parameters, as the critical frequency foF2, the maximum height hmF2, the total electron content TEC, but not in behavior of N(h)-profiles. In it the behavior of topside parts of a N(h)-profile is explored during disturbances. The IRI-Plas model and the following data were used: (1) foF2 of a chain of ionosondes (Loparsk, Leningrad, Moscow, Rostov), (2) TEC of the JPL global map, (3) plasma frequencies fne measured on satellites CHAMP and DMSP on an example of April 2001 including two

strong disturbances (1–2.04, minimum Dst =-228 nT, 11–12.04, minimum Dst =-271 nT) and two weak disturbances (18 and 22–23.04) with minimum Dst∼-100 nT. 9 cases of flights of satellites over all stations have been selected. It allows for estimation of latitudinal variations. These flights were near to midday and midnight and captured both the positive (1–6.04) and negative (all the other days) disturbances. Quantitative estimation of variations is given for an electron density Ne in the topside ionosphere for each station, and gradients in a chain. It is indicated on redistribution of ionization in the topside ionosphere and sign change of latitudinal gradients. The presented report is development of the previous paper with reference to density in the plasmasphere. The plasmasphere plays an important role in space weather. It is very important to have an empirical model of electron density Ne in the plasmasphere as it can be used for investigation of propagation of waves (whistler, chorus, hiss), dynamics of radiation belts, an estimation of velocity of filling of a plasmasphere after disturbances, for forecast of Space Weather. It is necessary to estimate whether the IRI-Plas model can serve as such a model. Development and addition is fulfilled in following directions: (1) maps IGS, CODE, UPC are used, (2) coefficient K(PL) for updating plasmaspheric parts of N(h)-profile is introduced and dependence of its behavior on UT and latitude is investigated, (3) behavior of Ne in the plasmasphere is explored during disturbances of April 2001, (4) distribution of Neq(L) is obtained in an equatorial plane with use of data of measurements from the radio plasma imager (RPI) on NASA's IMAGE satellite. It is shown that values IGS lie between JPL and CODE, being often close to UPC. Coefficient K(PL) depends on TEC, giving for the JPL map of value in a range 1.5–4.5. For the CODE map, K(PL) is frequently less zero. This testifies that the N(h)-profile transiting through observational values of foF2, fne (sat1), fne (sat2), TEC cannot be constructed. For IGS, K(PL) is less than value for JPL, but can be negative. The Ne(RPI) model is developed for L=1.6–4, therefore N(h)-profiles could be used only for the Athens station. The IRI-Plas model well corresponds to the Ne(RPI) model. It allows us to use its coefficients for the solution of an inverse problem, i.e. deriving Neq(L) with use of the IRI-Plas model and TEC. For all disturbances of April, values of Neq (L) were higher than for RPI.

**Simulation study of the evolution of small-scale irregularities in the near-earth rarefied plasma**

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Electron density irregularities are often observed in the near-earth plasma, in particular, in the ionosphere. The electron density depletions and increases inside irregularities can lie in the range from a few portions to some tens of percents. These irregularities have a wide range of spatial scales, ranging from a few Debye lengths to thousands of kilometers. Not large-scale irregularities are predominately magnetic field aligned. Small-scale irregularities either are naturally present in the ionosphere, for example radio aurora, or maybe artificially produced by high-power, high-frequency radio waves, pumped into the ionosphere by ground based ionospheric heaters.

The purpose of this work is to investigate numerically the time evolution of the magnetic field aligned small-scale irregularities in the electron concentration, existing in the near-earth rarefied plasma, with the help of the two-dimensional mathematical model, developed earlier in the Polar Geophysical Institute. The plasma is assumed to be a rarefied compound consisting of electrons and positive ions and being in a strong, external magnetic field. In the applied model, kinetic processes in the plasma are simulated by using the Vlasov-Poisson system of equations. The system of equations is numerically solved applying a macroparticle method. The time evolution of a plasma irregularity, having initial cross-section dimension commensurable with a Debye length, is simulated during the period sufficient for the irregularity to decay completely.

The evolution of small-scale irregularities is investigated for two distinct situations. The first situation corresponds to natural conditions in the F-region ionosphere without external forcing on it. The second situation corresponds to disturbed conditions in the plasma when the F-region ionosphere is illuminated by powerful high-frequency radio waves, usually utilized in experiments with artificial heating of the ionosphere.

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**Extreme Solar Particle Events: Look into the Past, Prognosis for the Future**

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Radiation conditions at the Earth's orbit, disturbances of the ionosphere, state of the ozone layer, ionization in the upper atmosphere and other geophysical phenomena, to a considerable extent, are determined by variations of the fluxes of solar energetic particles (SEPs) accelerated at/near the Sun, — so-called solar cosmic rays (SCRs). These particles are registered at the Earth's orbit in the form of Solar Proton Events (SPEs). Magnitudes and significance (or geoefficiency) of those processes (phenomena) vary in dependence on the level of solar activity (SA). It is suggested to consider the problem for different stages of 11-year cycle of SA, at different levels of SA and different occurrence rates of extreme solar flares, for different epochs of the solar evolution (in particular, for the epoch of "young" Sun).

Indirect data on SCRs in the past may be obtained from some natural archives (nitrates in the ancient Antarctic and Arctic ices, radiocarbon $^{14}$C in the tree rings, $^{10}$Be, $^{26}$Al and other cosmogenic isotopes in lake sediments etc.). At present, we have information about a few extreme SPEs for the period of last 1200 years (from 775AD). Amongst them, the most known is a flare of 1 September, 1859 ("Carrington Event"). By nitrate data starting from 1561, in the combination with the results of real measurements of SCR in modern epoch we constructed a distribution function of SPEs by their fluences for the Earth's orbit.

In the whole, available data of observations and methods of investigations do not allow, for the present, to resolve precisely the problem of spectrum break and estimate maximum potentialities of solar accelerator(s). This restricts considerably an extrapolation of obtained results for the past and future, for the epochs with the levels of SA different from the modern one. Nevertheless, data on SCRs and their geophysical effects allow us to understand better the mechanisms of solar-terrestrial relations. In its turn, this is important for modeling the evolution of terrestrial biosphere in the past and future (Obridko et al., 2013), as well as for the quest of possible seats of life at the Mars and other planets of the Solar System.

**Excitation of pulsations localized spatially during the sudden geomagnetic impulse: a case study**

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The development of Psi pulsations in the range of Pc5 (f $\sim$ 1.6–2 mHz) accompanying the geomagnetic sudden impulse (SI) in the event of April 24, 2009 is studied. Psi were registered asymmetrically relative to the noon meridian in the prenoon and premidnight sectors at L-shells from 4 to 10. Psi were localized in space both by data of satellite and ground-based observations. Aboard satellites whose positions differ by 1 Re, Psi were registered with the amplitude differing substantially. Observations in the magnetosphere showed that at different L-shells the different components of wave were dominated. At distances of 5–7 Re both in the prenoon and premidnight sectors the Psi pulsations had characteristics typical for toroidal mode oscillations. Closer to the subsolar magnetopause the compressional and poloidal oscillation modes were dominated. The changes of horizontal components of magnetic field of Psi pulsations correspond to vortices in the magnetosphere and ionosphere both by data of satellite and ground-based observations. The modulation of energetic particle fluxes by Psi pulsations was observed. It was found that the contribution into the flux modulation was made by both the azimuthal component of the magnetic field and longitudinal component of electric field. The analysis of conditions in the solar wind showed that aboard the WIND satellite ($X_{gsm}$ =230.14 Re; $Y_{gsm}$ =79.81 Re; $Z_{gsm}$ = 55.84 Re) located closer to the magnetosphere, the solar wind discontinuity was recorded $\sim$17 min before than aboard the ACE satellite ($X_{gsm}$ =238.94 Re; $Y_{gsm}$ = $-$23.10 Re; $Z_{gsm}$ = $-$34.59 Re). From this it follows that the front of discontinuity interacting with the magnetosphere was inclined to the Earth-Sun line. A position of vortices relative to the noon meridian is in agreement with an inclination of discontinuity front relative to the dawn-dusk meridian. The possible mechanisms of Psi pulsation excitation are discussed.

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**Dust acoustic solitons in a dusty exosphere of the Moon being under the action of solar radiation**

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It is known that dusty plasma system in the surface layer of the illuminated part of the Moon includes positively charged dust, photoelectrons, as well as electrons and ions of the solar wind. In Ref. [1] basic characteristics of the dusty lunar exosphere under the action of the solar radiation are determined. Here, we discuss a possibility of propagation of dust acoustic solitons over the Moon. The regions of soliton existence and the main soliton parameters are determined. The intensity of solitons as a dependence on height over the lunar surface and a possibility of observation of solitons are estimated.

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[1]. S. I. Popel, S. I. Kopnin, A. P. Golub', G. G. Dol'nikov, A. V. Zakharov, L. M. Zelenyi, and Yu. N. Izvekova, "Dusty Plasma at the Surface of the Moon", Solar System Research 47, No. 6 (2013), 419-429 (Astronomicheskii Vestnik 47, No. 6 (2013), 455-466.

**Formation of inhomogeneities of dusty ionospheric plasmas as a result of modulational instability development of electromagnetic waves of solar radiation**

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The paper is devoted to the description of inhomogeneities in dusty ionospheric plasmas. The modulational interaction is known to be the most important nonlinear process in a plasma which results in an appearance of inhomogeneities. At the daytime solar radiation influences significantly processes developing in the ionospphere. Methods

of the description of the modulational instability of a monochromatic pump wave are developed in a good manner. When describing the modulational instability of spectra of solar radiation the use of the standard methods is restricted to very specific ranges of parameters whose consideration does not give a possibility to cover all inhomogeneity scales. In this context, an adequate description of the modulational instability of wave spectra is required. The purpose of this paper is to develop methods of the description of the modulational instability of broad wave spectra in dusty ionospheric plasmas. The basic equations are derived and their analysis is carried out. The estimates of characteristic scales of plasma inhomogeneities in the ionosphere excited by the modulational interaction are made. The comparison with the observational data is performed.

This work was supported by the RF President Grant Council for support of young scientists and leading scientific schools (grant no. MK-3764.2013.2). T.I. Morozova acknowledges the financial support of the Dynasty Foundation.

### Study of the outer radiation belt of the Earth by segmentation of multi-dimensional time series

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The outer radiation belt of the Earth (ERB) is a part of inner Earth's magnetosphere. The intensity of the flux of relativistic electrons in the outer ERB is subject to strong and abrupt changes under the influence of factors that are difficult to take into account. This kind of electrons may cause dangerous malfunction of the electronics onboard spacecraft and therefore they are often called killer electrons.

Prediction of the relativistic electron flux in the outer ERB is a complicated problem. This is due to the fact that Earth's magnetosphere is a complex dynamical system. The state of this system can be described by a multi-dimensional time series, including various physical features — parameters of interplanetary magnetic field, solar wind, geomagnetic indexes, relativistic electron flux at geostationary orbit etc. Here we consider the approach to investigation of time series characterizing the dynamics of the outer ERB with the help of machine learning algorithms.

There is every reason to believe that there may exist several different basic states of the outer ERB – significantly diverse regions in the phase space of the states of this dynamical system, for which the most efficient prediction models may be different. To separate out such regions, in this study we used segmentation of multi-dimensional time series with the help of k-means clusterization algorithm and Kohonen neural networks.

The initial data which are a multi-dimensional time series with delay embedding were split into three, four, and five clusters (segments) with Kohonen self-organizing map and k-means algorithm. The same operations were repeated for different sets of input physical features. The obtained variants of segmentation of the time series were compared to each other and correlated with various possible states of the outer ERB.

## Objective discrimination of geomagnetic disturbances and prediction of Dst index by artificial neural networks for their different types and phases

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Strong disturbances of the Earth's magnetic field (geomagnetic storms) may have significant effect upon operation of engineering devices and well-being of people. Therefore, prediction of the state of magnetosphere is a very important problem. Geomagnetic disturbances (GD) are one of important factors of space weather. In this study, we suggest an algorithm for objective discrimination of boundaries and different phases of GD based on the time series of hourly values of Dst geomagnetic index. Two or three phases were marked for each GD: initial phase (optional), main phase, and recovery phase. With the help of the suggested algorithm, the boundaries of GDs and their phases for the period from November 1997 till March 2014 have been marked automatically in an objective way. Then all the discovered GDs from 2010 till March 2014 were manually divided into three groups depending on the mechanism of their origin. In this study, the following physical phenomena were considered as the main GD sources: (1) coronal mass ejections (CME), connected as a rule with solar flares, and causing sporadic GD upon reaching the Earth's orbit;

(2) quasi-stationary high-speed streams of solar wind (SW) from coronal holes, responsible for recurrent GDs; (3) turn of the $z$-component of interplanetary magnetic field (IMF) towards south, resulting in the SW energy being freely injected into the Earth's magnetosphere. Note that existence of negative (southward) $B_z$ for a sufficiently long time is a necessary condition for a GD. Then, neural network prediction of the value of Dst index by the parameters of SW and IMF in L1 point and by preceding values of Dst index itself, has been performed. Prediction results and efficiency were compared for different GD phases and different types of GD origin. In this study, we perform detailed analysis of the obtained results, and suggest ways of improving existing approaches to neural network prediction of GDs with account for possible types of GD origin.

## Consistency variations of the components of ionizing radiation, atmospheric electrical and meteorological variables

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Cosmic rays and the decay of radioactive substances crust and atmosphere control the electrical characteristics of the surface layer of the atmosphere, as they are the main "suppliers" of light ions.

Discussed concerted variation of ionizing radiation (neutron component of cosmic rays, $\alpha$-, $\beta$- and $\gamma$-ionizing radiation of terrestrial origin) with atmospheric electrical and meteorological parameters of the terrestrial atmosphere in the region with a sharply continental (Western Siberia) type of climate. Integrated monitoring data, recorded in 2006–2014 years in IMCES SB RAS, NR TPU and observatory Kluchi (Novosibirsk), were used.

Variations in the levels of the neutron component of cosmic rays and $\gamma$-background closely related to changes in atmospheric pressure at time intervals from synoptic to annual. Maximum $\gamma$-background observed in November in the atmospheric surface layer and the minimum – in February-March. Level variations of the neutron component of cosmic rays, $\gamma$-terrestrial origin and background of atmospheric electrical parameters of the surface layer behave consistently. As a result, the restructuring of the atmospheric circulation over

vast areas related to global climate change, leading to changes in the agreed levels of the neutron component of cosmic rays and $\gamma$-background of natural origin and therefore to changes in the electrical characteristics of the atmospheric boundary layer of a similar time scale.

During the passage of the cyclone levels of variation of the neutron component, $\gamma$-background and atmospheric pressure correlated. Precipitation plays a major role in the variations of atmospheric $\gamma$-background and can lead to short-term increases in the level of background $\gamma$-radiation up to the order of magnitude or more. Variations of $\alpha$-, $\beta$- and $\gamma$-ionizing radiation in air and soil with the diurnal period were in opposition. Communication variations of meteorological variables and component subsurface background radioactivity in the summer and winter conditions has a different character.

## Geomagnetic and auroral Pc4-5 pulsations in the polar cap and an auroral substorm

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The growth of ULF activity during in the polar cap several hours before a substorm onset was reported in (Yagova et al., 2000). However, this effect has never been studied systematically. In the present study we study geomagnetic and auroral pulsations in Pc4–5 (1–15 mHz) frequency range before and during isolated and storm-time substorms, and for quiet geomagntetic conditions to discriminate local pre-substorm activation in the geomagnetic tail from the global geomagnetic storm effect. The data of the high latitude magnetometer network and Meridian Scanning photometer (Svalbard) during the years of the solar minimum in 2008–2012 and the subsequent growth phase is analyzed.

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**IRI-2012 model adaptability estimation for automated processing of vertical sounding ionograms**

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The possibility of IRI-2012 global empirical model applying to the vertical sounding of the ionosphere semiautomatic data processing is determined. Main ionosphere characteristics from vertical sounding data at IZMIRAN Voeikovo station in February 2013 were compared with IRI-2012 model calculation results. E and F2 layers critical frequency (foE, foF2) and the maximum altitudes (hmE, hmF2) were determined from the ionograms. 2688 model values and 1866 real values of foF2, foE, hmF2, hmE were processed. Vertical profiles of the electron concentration were restored with IRI-2012 model by measured frequency and height. The model calculation was also made without the inclusion of the real vertical sounding data. Monthly averages and standard deviations for the parameters foF2, foE, hmF2, hmE for each hour of the day were calculated according to the vertical sounding and model values. Model applicability conditions for automated processing of ionograms for subauroral ionosphere were determined. Initial IRI-2012 model can be applied to the sub-auroral ionograms processing at daytime with undisturbed geomagnetic conditions in absence of sporadic ionization. In this case model calculations can be adjusted by the near-time vertical sounding data. IRI-2012 model values for foE (in daytime) and hmF2 can be applied to reduce computational costs in the systems of automatic parameters search and preliminary determination of the searching area range for the main parameters. IRI-2012 model can be used for a more accurate approximation of the real data series in the absence of the real values.

## The coronal mass ejections, geomagnetic storms and Forbush decreases

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Geomagnetic storms and Forbush decreases of cosmic ray intensity were compared with the events of coronal mass ejection passes through the near-earth space. According to interplanetary shock data catalog various types of ground-based events were selected: (a) – magnetic storm with Forbush decrease; (b) – magnetic storm without Forbush decrease; (c) – Forbush decrease without magnetic storm; (d) – no magnetic storm and no Forbush decrease. The regression dependence of the four heliogeoeffects (a–d) on the compression measure $\sigma$ and interplanetary shock speed $V_{sh}$ were discussed. The characteristics of statistical communication of these parameters were determined. This dependence shows that the heliogeoeffective structures are located near the central or peripheral regions of a coronal mass ejection. The results of ground-based diagnostics of such locations qualitatively agree with the orientation of interplanetary shock normals **n**.

## IAR emission characteristics and parameters of the ionosphere

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We analyze continuous magnetic observations of ionospheric Alfvén resonator (IAR) emissions at mid-latitude observatory Mondy. The measurements were carried out by a LEMI-30 search-coil magnetometer covering the period from March 2010 to May 2011. The results are compared with data from simultaneous ionospheric sounding data and International Reference Ionosphere (IRI-2012) model parameters. The large amount of observational data allowed us to inspect the daily and seasonal variations in some morphological characteristics of the emissions as well as their relationship to ionospheric conditions. The main factor affecting the duration of the emission is how long the

lower ionosphere stays in Earth's shadow. We demonstrate a close inverse correlation between the diurnal and seasonal IAR frequency variations, on the one hand, and changes in the ionospheric critical frequency, f0F2, on the other. Additionally, the expected emission frequency scale calculated with the IRI-2012 model is in good agreement with the values measured from the emission spectrograms.

### Conjugated observations of energetic proton fluxes at low altitude and EMIC waves in the source region

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Using the NOAA POES observations we found that EMIC wave events registered by THEMIS, Cluster and Van Allen Probes near the equatorial plane of the magnetosphere are conjugated with precipitation of energetic protons equatorward from the proton isotropic boundary. This fact provides direct evidence that such proton precipitation appears as a result of the ion-cyclotron instability, and observations of the proton precipitation by low-orbiting satellites can be used to monitor the EMIC wave source region in the near-Earth magnetosphere.

### ULF waves in the corotating interacting regions of the solar cycle 23 minimum

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We analyze parameters and magnetospheric effects of CIR-type high-speed streams (HSS) observed during period of low solar activity between 2007 and 2010. The superposed epoch method was chosen as our main research technique. The goal was to study the impact of wave patterns associated with CIR structure on the variable geomagnetic field and the trapped radiation. The focus was on the connection between regime of ULF waves in high-speed streams and ULF oscillations in the magnetosphere. A time profile of normalized ULF amplitude in the solar wind during a stream pass was shown

to be close to time profile of magnetospheric pulsation intensity. Radiation belt electron flux responds to ULF enhancement associated with CIR streams. We also compared effects of the solar-wind plasma fluctuations and interplanetary magnetic field oscillations on the magnetospheric ULF activity.

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## Catalogue of aurora borealis events observed in 19th century in Russia

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Auroral observations has proven to be a valuable data source for the study of variability of solar and geomagnetic activity, especially for historical epochs. There are several catalogues of aurora borealis observations in 19th century. However, there was a lack of Russian records. We filled this gap, collecting auroras observations made by the Russian Meteorological network of stations. We collected and analyzed data from 53 stations localized in a very wide geographical zone in Europe, Asia and Alaska ($\varphi$ from 70°40' to 50°15'; $\lambda$ from 21°26' to 224°35'). Our catalogue comprises 1675 auroral events registered in 1841–1883. Aurora occurrence maxima correspond to the maxima of solar cycles; the secondary increase of auroral occurrence falls on the descending phase of solar cycles. Our data are in general agreement with data from known European auroras catalogues.

**Correlation analysis of simultaneous solar wind and magnetosheath measurements at different locations of near-Earth space**

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The report is devoted to study of modification of solar wind (SW) plasma and magnetic structures in magnetosheath (MSH) using correlation analysis of simultaneous measurements in SW and MSH. THEMIS mission data obtained during 2008–2009 years is used. We analyze more than 300 hours of data at different parts of near-Earth space. We find out that bow shock and MSH not only add high-frequency fluctuations to SW parameters but also modify SW structures. Structure modification leads to the absence of correlation on scales exceeding 50–100 seconds. We consider dependencies of correlation level on different factors such as: the angle between bow shock normal and interplanetary magnetic field vector, Alfvén's Mach number, relative standard deviation in SW and MSH and its ratios, solar wind density and velocity and interplanetary magnetic field magnitude, distance between spacecraft in MSH and magnetopause.

**Southern boundary of the ultra-relativistic electron precipitations (for several cases of 1982–1986 years)**

*Remenets, G.F., Astafiev, A.M. (St. Petersburg State University, St. Petersburg, Russia)*

The phenomenon of an ultra-relativistic electron precipitation into the polar atmosphere from the near-Earth space was analyzed earlier [1, 2]. The analysis was based on the very low frequency (VLF) data in the cases of abnormal disturbances for two radio paths (a shorter one and a long one) with common receiving point (Aldra (in Norway)-Apatity and Ragby (in England)-Apatity). It was stated that energy of the precipitating electrons was such (about 100 MeV) that they could generate bremsstrahlung X-rays, which were capable to create a sporadic $D_S$-layer of electric conductivity at the altitudes 10–40 km. The effective height $h$ of radio wave reflection is changing during a disturbance from the undisturbed value $h \approx 60$ km to $h \approx 30$ km

in the maximum of powerful disturbance. The same VLF data can be used for estimation of the latitude of southern boundary of an abnormal disturbance. This work is devoted to determination of parameters and southern boundaries of the disturbances for the dates: on September 15, 1982, on December 3, 1982, on April 16, 1984, and on April 23, 1986. The problem was solved in two stages. The first stage is finding of the solution of a VLF inverse problem of first kind according to the data for the auroral shorter radio path only (with 885 km length). In the frames of this problem we found the reflection coefficient of the first ray from the ionized atmosphere and the effective height of the radio-path. The ground - ionized atmosphere waveguide was considered homogeneous at every moment of the disturbance. The VLF inverse problem of second kind was formulated for an inhomogeneous radio path (with its length - 2497 km) consisting of 3 homogeneous parts: (i) a middle latitude part of the path, (ii) an auroral undisturbed part of the path, and (iii) a disturbed northern part of the radio path. The place of boundary between (i) and (ii) parts was taken from literature and corresponded to 62° N. The place of boundary between (ii) and (iii) parts was an object of our searching and was characterized by the length D along the path of the third disturbed part. Its value was gotten due to a process of minimization of a discrepancy function between the experimental data of the long radio path with 16 kHz signal and the calculated ones with the solution of the VLF inverse problem of first kind being the input data. For 4 events of 1982, 1984, and 1986 years we obtained according to the phase data (16 kHz) for long radio path an interval of values D = 320–470 km which corresponds to $66.1^\circ - 64.3^\circ$ N interval. That proves that the abnormal disturbances are the electron analogs of the solar proton precipitations.

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2. Remenets G.F. and Beloglazov M.I. Ultrarelativistic electrons in the near cosmos and X-ray aurora in the middle polar atmosphere. // JGR – Space Physics. V.118. N11. P.6829–6838. DOI: 10.1002/2013JA018822.

**Cases of doubled period of Pc4 auroral pulsations in comparison with simultaneous Pc4 geomagnetic ones**

*Roldugin, V.C., Roldugin, A.V. (Polar Geophysical Institute, Apatity, Russia); Kleimenova, N.G. (Institute of Physics of the Earth, Moscow, Russia)*

The regular geomagnetic pulsations Pc1-5 are accompanied always by similar pulsations of auroral luminosity. Usually both pulsations vary concurrently as spike-to-spike, with the same period. However, the events occur when period of the auroral pulsations is equal to doubled period of geomagnetic pulsations, and such cases can not be explained by different fields of view of magnetometer and photometer. This phenomenon is displayed by the examples of Pc4 pulsations in Lovozero. The period doubling in different magnetic components in GOES satellite observations and also during confrontation of pulsation in GOES and on the surface is mentioned in some work, and we connect it with our phenomenon. We interpret the period duplication as diamagnetic effect of plasma in the pulsating magnetosphere tube.

**Peculiarities of particle precipitation during SC on 24 January 2012 in the evening sector of the auroral zone**

*Roldugin, V.C., Roldugin, A.V., Pilgaev, S.V. (Polar Geophysical Institute, Apatity, Russia); Sigernes, F. (University in Svalbard, Norway)*

The sudden commencement on 24 January 2012 at 1503 UT was caused by the shock wave with changes on the front by pressure from 1 to 10 nPa, by velocity from 400 to 700 km/s and by $B_z$ from +1 to +15 nT. The sky transparency permitted to make optical observations during the event in Lovozero, Barentsburg and Longyearbyen.

In Lovozero three minutes after SC and two minutes after an electron aurora the hydrogen emission $H_\alpha$ appears. It is seen during 5 minutes and moves poleward. In Barentsburg the $H_\alpha$ appears eight minutes after SC at one time with 1PGN2 band which due to high energy electrons, and it has been observed during twenty minutes. The meridional scanning photometer in Longyearbyen disclosed beginning of 5577 emission at 1507 UT along the all meridian, its maximum oc-

curred at 1512-1515. The $H_\alpha$ appears also at 1507 and it is maximal at 1512 with brightness about of 300 R, is seen mainly in the South.

In Lovozero a particle precipitation starts at 15:03.30 UT, but the perceptible magnetic disturbance by negative polarity begins at 15:04:20, i.e. 50 sec later. The peak of luminosity lags one and half minute to the positive magnetic peak. In Lovozero this SC gives rise to beginning of Pc5 geomagnetic pulsations, but they are absent in Barentsburg.

## Solar X-ray flares influence on VLF/LF signals in different middle-latitudes paths

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Sudden Phase Anomalies (SPAs) of VLF/LF signals recorded in Graz (Austria), Sheffield (UK) and Moscow (Russia) stations during two solar flares of intensity class X1.0 and M3.8 in November 2013 are examined. Data from seven transmitters in frequency range from about 20 to 45 kHz are used for the analysis. SPAs were observed in middle-latitudes paths with length from 200 to 7000 km and different orientation. Solar X-ray burst data were taken from the satellite GOES observations in the band of 0.1 – 0.8 nm. SPA characteristics like types, onset times, growth times, duration of SPA events and their amplitudes are studied. Observed SPAs are positive in 24 cases and they are negative in 2 cases regardless of the length or orientation of paths or signal frequency. The amplitude of SPAs in different paths varies from 10 to 230 degrees and no clear correlation between amplitude of SPAs and intensity of the solar flares or length of the paths are found. The SPAs begin within 3 and 4 minutes after the start of the first and second flare events, respectively. The time of growth for the first event is from 4 to 23 minutes and for the second event it is only 2–5 minutes. The duration is longer for the first event (∼1h 20 min – 2 h) and it is shorter for the weaker flare (∼30 min – 1h 30 min).

**Propagation of inclined interplanetary shock through the magnetosphere: results of global MHD simulations**

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We present global MHD simulations in which the normal of solar wind discontinuity is not directed strictly along the Sun-Earth line, as usually assumed. We use appropriate relations between magnetic field components at the solar wind boundary to satisfy the divergence-free condition. We obtain some interesting results. In the artificial case with an interplanetary shock coming from the evening side, the magnetosphere is more compressed on the same (evening) side. Tracing the magnetopause position in time, we obtain a large overshoot of the magnetospheric compression on the opposite (morning) side. The simulations confirm the generation of flow vortices on the both magnetospheric flanks near the equatorial plane discussed in details by Samsonov and Sibeck (2013). We find a large difference in ground signatures of sudden impulse between the morning and evening sides. The horizontal magnetic field at middle latitude stations during sudden impulse increases in one step on the evening side and with overshoot on the morning side. If an interplanetary shock has both the west-east and north-south normal components, then the magnetotail current sheet is bent and shifted from the equatorial plane.

**The dependence of the maximum of current density for different values of pitch angle**

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Thin current sheet (TCS), with the width of order of ion Larmor radius, appear as a fundamental physical object which plays an important role in structuring of major magnetospheric current systems (magnetotail, magnetodisk, etc.). The TCSs are nowadays under extensive study by means of space missions and theoretical models. We

consider a simple model of the TCS separating two half-spaces occupied by a homogenous magnetic field of opposite sign tangential to the TCS; a small normal component of the magnetic field is prescribed. An analytical solution for the electric current and plasma density in the close vicinity of the TCS has been obtained and compared with numerical simulation. The number density and the electric current profiles have two maxima each. The characteristic spatial scale $z_S$ of the maxima location was investigated as a function of initial pitch-angle of an incoming charge particle.

**Bow shock. Power aspects of processes**

*Sedykh, P.A. (Institute of Solar-Terrestrial Physics SB RAS, Irkutsk, Russia)*

The process of energy transfer from the solar wind into the magnetosphere, or rather, to convecting magnetospheric plasma, appears to be rather complicated. Bow shock is a powerful transformer of the solar wind kinetic energy into the gas dynamic and electromagnetic energy. A jump of the magnetic field tangential component at front crossing means that the front carries an electric current. The solar wind kinetic energy partly transforms to gas kinetic and electromagnetic energy during its passage through the bow shock front. The transition layer (magnetosheath) can use part of this energy for accelerating of plasma, but can conversely spend part its kinetic energy on the electric power generation, which afterwards may be used by the magnetosphere. Thereby, transition layer can be both consumer (sink) and generator (source) of electric power depending upon special conditions. The direction of the current behind the bow shock front depends on the sign of the IMF $B_z$-component. It is this electric current which sets convection of plasma in motion. The process of current penetration into the magnetosphere is two-step. First, a polarization field is formed that penetrates layer-by-layer into the magnetosphere. More exactly, a pulse corresponding to this field penetrates into the plasma. Then, if the system is inhomogeneous, the flow may redistribute the pressure so that gradients appearing in the plasma induce an electric current. In power terms, this current is required to maintain convection in the inhomogeneous system. Any change in the external current through the magnetosphere causes a convection restructuring within a time on the order of travel time of the mag-

netosonic wave from the magnetopause to the center of the system, because the restructuring wave comes from both flanks. Using the expressions (obtained in this paper) for normal components of the electric current, the flow of matter brought into the magnetosphere, total change of matter in the Earth's magnetosphere can be estimated.

## Transformations of parameters of the solar wind at transition through the bow shock front and magnetosheath

*Sedykh, P.A. (Institute of Solar-Terrestrial Physics SB RAS, Irkutsk, Russia)*

When crossing the bow shock front at the nose point, the tangential magnetic field component increases nearly four times, and the magnetic field density – 15 times. The physics of the phenomenon implies that the Earth in the solar wind stream disturbs the stream supersonic for the Earth. This suggests that a bow shock front is formed, the upstream wind plasma is undisturbed, and new scales of fluctuations appear downstream, where the minimum scale is the front thickness. This paper relies on the results of earlier researches (Ponomarev et al. 2006), where we obtained the expression for electric current generated in the bow shock front. I shall assume the bow shock front to be a paraboloid of rotation with its axis coinciding with the $x$ axis in the solar-magnetospheric coordinate system. In the paper I shall be limited to a simple case — I shall consider the dependence only from coordinate $x$. Certainly, more full decision of the general problem (when dependence not only on one coordinate is examined) has to be considered. However, it is not possible to solve at once a complex problem analytically. Therefore in this study I shall be limited to such statement of a problem. Further, the obtained solution can be generalized on more difficult case. A parabolic system of coordinates (Madelung, 1957) is convenient for the description. In this paper, the magnetopause potential and the power consumed by the magnetosphere as a function of solar wind parameters have been determined.

**A study of the influence of magnetospheric disturbances on the lower atmosphere**

*Sedykh, P.A., Lobycheva, I.Yu. (Institute of Solar-Terrestrial Physics SB RAS, Irkutsk, Russia)*

We examine the effect of geomagnetic activity on meteorological processes in the atmosphere. The collected data on magnetic storms and tropical cyclones, which were observed in the North Atlantic, East Pacific, and West Pacific, are analyzed for understanding of the mechanism of magnetospheric disturbances effects on complicated nonlinear system of atmospheric processes. Also we study the problem of the effect of the solar wind electric field sharp increase via the global electric circuit during magnetospheric disturbances on the cloud layer formation.

The math statistical analysis has shown low correlation dependence between total power of Joule heating of the ionosphere (and power of particle precipitations) and change of meteorological parameters (temperature, geopotential heights and so on) in the allocated six zones (Pacific, Canadian, Atlantic, European, Siberian, Far East) for all selected periods of magnetospheric disturbances. The Joule heating during extra powerful magnetospheric disturbances is effective in the ionosphere but it does not play key roles in the lower atmosphere.

The geomagnetospheric disturbance effect on the troposphere is weak compared with a multitude of other factors affecting it. A further study of geomagnetospheric storm effects on tropical cyclogenesis is necessary, because character of some influence has regional peculiarities.

**The change of the magnetic pole position and the magnetic moment value during day and night**

*Semakov, N.N., Kovalev, A.A., Fedotova, O.I., Pavlov, A.F. (Novosibirsk State University and Geophisical Survey of SB RAS, Russia)*

The way and the velocity of the magnetic poles and the velocity of the change of the magnetic moment during day and night for the magnetic observatories of the different regions were calculated. Some interesting common features and regional distinctions were detected.

**A new (old) variable in the solar wind – magnetosphere – ionosphere coupling studies**

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The amplitude of auroral zone magnetic perturbations (e.g., AL index) is commonly used to characterize quantitatively the magnetospheric driver and magnetospheric activity. This approach ignores the long-established fact that ground magnetic perturbations are basically formed by the Hall currents (Fukushima theorem), which depend on the Hall conductivity and, therefore, are sensitive to the plasma sheet electron parameters ($T_e$ and $N_e$) which control the production of energetic electrons via their field-aligned acceleration. Using a long-term monitoring of plasma sheet electrons by THEMIS, we demonstrate that a low-density/hot plasma sheet generates stronger magnetic variations in the dark nightside auroral zone compared to cold/dense sheet (for similar driving level). The $T_e/N_e$-dependent difference may exceed a factor 4 in conditions of the substorm growth phase, whereas substorm-related acceleration smears the difference. The background state of plasma sheet is controlled by the solar wind velocity and density, but it can be altered by substorms which produce the hot/tenuous plasma favourable to create enhanced Hall conductivity. We suggest that plasma sheet $T_e/N_e$ variable is a factor contributing to many changes (solar cycle and different SW driver-related efficiency variations , the pseudobreakup phenomenon etc.) which are not related to variations of solar wind electric field and magnetospheric driver, so it constitutes an important (but currently ignored) variable in SW-M-I coupling.

**Interplanetary shock geoeffectivity during the growth phase of solar activity**

*Shadrina, L.P., Krimsky, G.F., Plotnikov, I.Ya., Starodubtsev, S.A. (Academy of Sciences of Sakha (Yakutia) Republic, Yakutsk, Russia)*

The analysis the cosmic ray intensity and the geomagnetic field ground responses on the interplanetary shock passages are fulfilled. There

were selected 96 interplanetary shocks during the growth phase of 23-th solar cycle. More than a half (49) of the events were accompanied by the cosmic ray intensity and geomagnetic field decreases. Other 40 shocks had the effects only in cosmic ray or in geomagnetic field, and 7 shocks had no any ground effects. More part of the strong and moderate geomagnetic storms with amplitude more then 60 nT (44 from 60) did not associated with the cosmic ray intensity decreases or these effects were very week. This results confirm our previously conclusions that the regions in the interplanetary disturbances which are response for the geomagnetic storm and Forbush-decrease generations spatially are located separately.

**Sporadic and recurrent geomagnetic storm responses in the human cardiogram**

*Shadrina, L.P., Samsonov, S.N., Manykina, V.I. (Academy of Sciences of Sakha (Yakutia) Republic, Yakutsk, Russia)*

The analysis of two types of geomagnetic storms (recurrent and sporadic) responses in human's electrocardiograms were fulfilled. The inhabitants of Yakutsk city and of the geophysical observatory in Tiksi Bay, which are located near the auroral zone, were included in the selection. It was shown that with the beginning of a storm the increase of the parameter characterizing a condition of a human cardiovascular system (a symmetry coefficient of a T-wave of the electrocardiogram) was observed. Maximum values were reached on the first day after the sporadic storms beginning and two days before Dst minimum for a recurrent storms.

**Variety of proton whistlers: satellite observations and theory**

*Shklyar, D.R., Vavilov, D.I. (Space Research Institute of RAS, Moscow, Russia); Titova, E.E. (Polar Geophysical Institute, Apatity, Russia)*

We present experimental observations and detailed investigation of the variety of proton whistlers that includes trans-equatorial and ionospherically reflected proton whistlers. The latter have previously

been indicated from numerical modeling of spectrograms. The study is based on 6-component ELF wave data from the DEMETER satellite which permits to obtain not only spectrograms displaying the power spectral density, but also such wave properties as the polarization, wave normal angle, wave refractive index, and normalized parallel component of the Poynting vector. The explanation of various types of proton whistlers is based on the properties of ion-cyclotron wave propagation in a multicomponent magnetoplasma, with special consideration of the effect of ion-hybrid resonance reflection. Analysis of experimental data is supplemented by numerical modeling of spectrograms that reproduces the main features of experimental ones. As a self-contained result, we provide conclusive experimental evidences that the region illuminated by a lightning stroke in the Earth-ionosphere waveguide may spread over a distance of 4000 km in both hemispheres.

**Substorm growth phase: magnetic flux accumulation or reconfiguration?**

*Shukhtina, M.A., Dmitrieva, N.P., and Sergeev, V.A. (St.Petersburg State University, St.Petersburg, Russia)*

According to classical point of view isolated substorms consist of three phases: growth, explosive and recovery one. It is assumed that the tail magnetic flux $F$ is accumulated during the growth phase and suddenly released during the explosive one. However such magnetic flux behavior occurs only in 33 out of 142 isolated substorms identified by Geotail in 1995–1998 with explosive phase defined as sudden flux unloading (type 1 substorms). In 32 cases Balanced Tail Flux (BTF) period ($F$ $\sim$const) with enhanced dissipation and pseudobreakup activity was registered during 0.5–2 hours before unloading (type 2, new substorms class). The rest 77 substorms lie between types 1 and 2. Using the superposed epoch analysis we found that during $\sim$40 min before unloading all groups demonstrate almost identical plasma sheet thinning and $B_z$ decrease in the midtail (as follows from Geotail data) as well as at 6.6 Re. We conclude that in spite of different system evolution magnetotail configuration, rather than the specific $F$ value, is crucial for substorm onset.

**Magnetotail magnetic flux calculation based on empirical and MHD models**

*Shukhtina, M.A., Morachevsky, N. A., Gordeev, E.I. (St. Petersburg State University, St. Petersburg, Russia)*

We propose two new modifications of the algorithm of magnetotail magnetic flux F calculation. All algorithm versions are checked on an artificial event, created by the new Tsyganenko model T13 with an IMF-dependent magnetopause with a given external IMF/solar wind variation as input. The algorithm develops the Petrinec and Russell [1996] (PR96) approach of the tail radius determination. Unlike in the PR96 model the tail radius value is calculated at each time step based on simultaneous magnetotail and solar wind observations. Our former algorithm required that the "tail approximation" were fulfilled, i.e. it could be applied tailward $X \sim -15R_E$. The new modifications (F1 and F2) take into account the approximate uniformity of the magnetic field of external sources in the near and middle tail and estimate the magnetic flux of the external magnetic field $B_{EXT}$. The variable F1 is an approach of the $B_{EXT}$ flux through the whole tail cross-section, whereas F2 is an approach of the $B_{EXT}$ flux through the cross-section confined by the "virtual" magnetopause lying inside the real one. The latter proxy takes into account the reduced magnetic flux through the plasma sheet and plasma mantle. The F1 and F2 quantities are compared with the F values, obtained by direct integration of the T13 magnetic field through the tail cross-section at X=-15 $R_E$, confined by T13 magnetopause. The tests show that the F1 and F2 proxies may be applied not only tailward X= -15 $R_E$ as before, but much Earthward, up to X= -3 $R_E$ for the F2 value. Regression analysis of the F1 and F2 values with the T13 flux was carried out for "measurements" in the tail lobes of cross-sections X= -15 $R_E$ and X=-7 $R_E$ both for untilted and tilted dipole. For the untilted dipole the analysis for both cross-sections gives high (0.9) correlation coefficients, regression coefficients about 1.3 – 1.5, and average flux values, close to the T13 ones. However at some times in some points of the cross-section X= -7 $R_E$ the F1 algorithm does not work; the F2 algorithm works everywhere, though it gives the flux value, smaller than the T13 ones by about 0.15 GWb. For the dipole tilt $-33^0$ the test for the cross-section -15 $R_E$ gives reasonable results, whereas at X=-7 $R_E$ the results are unacceptable. All tests were done for two formulas of the magnetopause radius at terminator: for that from PR96 and for the new one, which we obtained from multifactor

analysis. The tests showed larger CC values for the new formula of the terminator radius.

The same external parameters, used for the artificial event created by T13, were used as the inputs for the Global MHD simulation in the Community Coordinated Modeling Center CCMC (http://ccmc.gsfc.nasa.gov/). The F values, given by T13, on average exceed those, obtained from MHD, by about 0.3 GWb. The correlation coefficient between T13 and CCMC flux values is about 0.6 with the regression coefficient close to 1.

## Earth magnetic field disturbances and active experiments in the ionosphere

*Sivokon', V.P., Cherneva, N.V., Khomutov, S.Yu., Serovetnikov, A.S. (Institute of Cosmophysical Research and Radio Wave Propagation (IKIR) FEB RAS, Paratunka, Kamchatka, Russia)*

Variations of ionospheric-magnetospheric relation energy, as one of the possible outer climatology factors, may be traced on the basis of analysis of natural geophysical phenomena such as ionosphere artificial radio radiation and magnetic storms. Experiments on active impact on the ionosphere have been carried out for quite a long time in Russia as well. The most modern heating stand is located in Alaska; it has been used within the HAARP Program. The possibility of this stand to affect geophysical fields, in particular, the geomagnetic field is of interest.

## The conditions of magnetic barrier formation in the magnetosheath

*Slivka, K.Yu., Semenov, V.S., Dmitrieva, N.P. (St.Petersburg State University, St.Petersburg, Russia)*

Magnetic barrier is a region with depleted plasma and enhanced magnitude of the magnetic field. It is formed into the inner magnetosheath layer along the magnetopause. There is a general point of view that magnetic barrier can persist only for the northward interplanetary magnetic field (IMF) whereas it is completely absent for southward IMF.

We made a study to check presence of magnetic barrier for different orientations of IMF. We created and analyzed special data base consisting 74 events of low-latitude dayside magnetopause crossings by the THEMIS satellites. Moreover, we also used the superposed epoch analysis to study variations of magnetic field and key plasma parameters near the magnetopause in a systematic way. Although magnetic barrier is the most pronounced for northward IMF, we are still able to find signatures of magnetic barrier for southward IMF. According to theory magnetic barrier builds up more slowly than it collapses due to reconnection. We found out that magnetic barrier field was about 80% of the magnetospheric value for southward IMF cases with minimum magnetopause reconnection rate. In the other hand, previous statistical studies show that magnetic barrier field is no more than 50% of the magnetospheric value for southward IMF. Furthermore, we use the Walen test and the Cowley diagrams to verify the presence of the magnetopause reconnection. For events with destroyed magnetic barrier, we made a histogram of events distribution by the reconnection rate.

## General relations for particle diffusion in pitch angle and energy

*Smolin, S.V. (Department of Theoretical Physics, Siberian Federal University, Krasnoyarsk, Russia)*

General expressions for particle diffusion coefficients in both pitch angle and energy are obtained. Simple relations between the diffusion coefficients are found. The results illustrate how particle diffusion coefficients vary with pitch angle, energy and other parameters in the Earth's magnetosphere.

## Modeling of proton ring current dynamics with variable boundary conditions

*Smolin, S.V. (Department of Theoretical Physics, Siberian Federal University, Krasnoyarsk, Russia)*

The dynamics of the ring current protons with variable boundary conditions in the inner magnetosphere during the magnetic storm

is studied. The temporal and spatial evolution of the proton phase space densities in a dipole field are calculated using a two-dimensional ring current model, considering radial and pitch angle diffusions. The loss terms are described due to charge exchange and wave-particle interactions. The simulation starts with a quiet time distribution. The model is tested by comparing calculated proton fluxes with Polar/MICS measurement during the magnetic storm on 21–22 October 1999.

**Directly observed effect of extreme solar energetic particle events on polar chemical composition of the middle/lower stratosphere**

*Soboleva, M.A., and Mironova, I.A. (St. Petersburg State University, St.Petersburg, Russia)*

This work is an extension of a phenomenological study of the middle polar atmosphere response to severe solar energetic particle (SEP) events. The present work is focused on evaluation of the potential influence of atmospheric ionization caused by solar cosmic rays upon the chemical composition of polar stratosphere. We have performed thorough analysis of variations of the daily profiles of $NO_2$ and ozone by the SAGE III and SAGE II instruments for North Polar Regions. We found statistically significant changes in the chemical compositions associated with the SEP events.

**Geomagnetic observations at Pavlovsk Observatory in 1878–1914**

*Sokolov, S.N., Soldatov, V.A. (SPbF IZMIRAN, St. Petersburg, Russia)*

Meteorological and magnetic observations at Pavlovsk Magnetic Meteorological Observatory conducted from 1878 to 1941. Most of the results of observations made before 1914 was scanned at NOAA in 2000 and is now available to the public (http://docs.lib.noaa.gov /rescue/data_rescue_russia.html). These magnetic measurements over the years were published in 1879–1916 and are available in a few

research libraries and archives. Only data on average annual declination (D), horizontal (H) and vertical (Z) components of the geomagnetic field in Pavlovsk is available In the World Data Centers (Kyoto and Edinburgh). Hourly values of D, H and Z, as well as inclination, north and west field components in Pavlovsk are given in the original form of monthly tables. We transferred them to a digital format by hand, visually, as some pages of paper originals are worn-out and contain a significant amount of text fragments, poorly recognizable by OCR software. As an intermediate result, we produced tables of the geomagnetic field elements for the 1878–1911 and 1914 in form similar to the original (useful for comparison with paper version and error checking). The data was then converted into time series (in netCDF format) which is more suitable for further processing and analysis. They contain about 1.3 million hourly values. This database (http://db.izmiran.nw.ru/) may be useful to study different variations of the geomagnetic field, for example, magnetic storms, and reconstruct the solar wind at 12–14 cycles of solar activity.

### Quasi-periodic VLF emissions with short-period modulation and their relationship to whistlers: a case study

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We study properties of quasiperiodic (QP) VLF emissions recorded on December 24, 2011 during the VLF campaign in Northern Finland. The main attention is paid to interrelationships between different characteristic periods in the QP spectra. In particular, we analyze regular variations in the QP repetition intervals (1–10 min) during the event from 15 : 30 to 22 UT, their changes during substorms, and short periodic (several-second) modulation observed within separate QP elements. We explained the variations of periods of QP emissions in terms of the model of auto-oscillation regime of the cyclotron instability in the magnetosphere. During the considered event lasting about 7 hours we observed a regular increase in the time intervals between the QP elements. We relate this increase with weakening of the

magnetospheric source of energetic electrons. Significant variations in the QP period occurred during substorms. These variations can be due to a substorm-related increase in the energetic-electron flux and/or due to the precipitation of these electrons into the ionosphere which changes the reflection coefficient of VLF waves. We analyze the fine structure of QP element spectra and reveal the periods related to the time scales of guided propagation of whistler-mode waves along the magnetic field line, which suggests that ducted propagation regime took place for the QP emissions. The periods were about 6–9 s for frequencies 3.5–1.2 kHz respectively, which was similar to the period of almost simultaneously observed two-hop whistlers. In the low-frequency part of QP spectra periodic emissions with periods of about 3 s were observed. Analysis of fine structure of QP elements shows that their formation is affected by both linear effects (i.e., group-velocity dispersion) and nonlinear effects related.

### *PC* index as a proxy of the solar wind energy that entered into the magnetosphere: 1. Development of magnetic substorms

*Troshichev, O.A., Podorozhkina, N.A., Sormakov, D.A., Janzhura, A.S. (Arctic and Antarctic Research Institute, St.Petersburg, Russia)*

In 2013 the International Association of Geomagnetism and Aeronomy approved *PC* index as a new international index of magnetic activity. Application of the *PC* index as a proxy of a solar wind energy that entered into the magnetosphere determines a principal distinction of the *PC* index from *AL* and *Dst* indices, which are regarded as characteristics of the energy that realized in magnetosphere in form of substorm and magnetic storms. This conclusion is based on results of analysis of relationships between the polar cap magnetic activity (*PC*-index) and parameters of the solar wind, on the one hand, relationships between changes of *PC* and development of magnetospheric substorms (*AL*-index) and magnetic storms (*Dst*-index), on the other hand. This paper (the first of a series) describes in detail the following main results which demonstrate a strong connection between the behavior of *PC* and development of magnetic disturbances in the auroral zone: (1) magnetic substorms are preceded by the *PC* index growth (isolated and extended substorms) or long period

of stationary $PC$ (postponed substorms), (2) the substorm sudden onsets are definitely related to such $PC$ signatures as *leap* and *reverse*, which are indicative of sharp increase of the $PC$ growth rate, (3) substorms generally start to develop when the $PC$ index exceeds the threshold level $\sim 1.5 \pm 0.5$ mV/m, irrespective of the substorm growth phase duration and type of substorm, (4) linear dependency of $AL$ values on $PC$ is typical of all substorm events irrespective of type and intensity of substorm.

## $PC$ index as a proxy of the solar wind energy that entered into the magnetosphere: 2. Relation to the interplanetary electric field $E_{KL}$

*Troshichev, O.A., and Sormakov, D.A. (Arctic and Antarctic Research Institute, St.Petersburg, Russia)*

The analysis of relationship between the $PC$ index and the geoeffective $E_{KL}$ field presents the additional evidence that the $PC$ index should be regarded as a proxy of the solar wind energy that entered into the magnetosphere. Response of the $PC$ index to the $E_{KL}$ variations was studied for the time intervals preceding the sudden onset (SO) of those magnetic substorms (1998–2001), which have been analyzed in the paper [*Troshichev et al.*, 2014]. Examination of 162 isolated substorms, 968 expanded substorms and 254 events with coordinated changes in $E_{KL}$ and $PC$ values for period 1 showed that the $PC$ index is connected directly with the $E_{KL}$ field: correlation $R > 0.5$ between $PC$ and $E_{KL}$ is typical of $> 90\%$ of isolated substorms and $> 80\%$ of expanded substorms. Correlation $R > 0.75$ is observed in 82% of isolated substorms and in all coordinated events. The low ($R < 0.5$) or negative correlation is typical of $7 \div 9\%$ of events with isolated substorms, although all of them were chosen as related to the really observed SO preceding by the obvious precursors in $PC$. It means that the solar wind measured on board ACE spacecraft passed by the magnetosphere in these cases. Under conditions of perfect correlation ($R > 0.75$) the delay time $\Delta T$ of the $PC$ response to $E_{KL}$ variations (reduced to magnetopause) varies in range from 0 to 35 min with prominent maximum at $\Delta T = 15 - 20$ min and secondary maximum at $\Delta T = 0$. Delay times do not demonstrate any essential correlation with the solar wind parameters but are evidently related to the $E_{KL}$ growth rate ($R = -0.93$). The slope coefficient

$\boldsymbol{\alpha}$, characterizing the efficiency of the $E_{KL}$ influence on the $PC$ index ($PC = \boldsymbol{\alpha} E_{KL} + \boldsymbol{\beta}$), depends on level of magnetic activity ($PC_0$): it increases up to level $PC_0 \sim 2.5$ mV/m $\boldsymbol{\alpha}$ and then decreases.

## Thin current sheets with strong bell-shape guide field: observations and models

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We study the kinetic structure of intense ion-scale current sheets with strong electron currents and the guide field having a bell-shape profile. We consider four crossings of the Earth magnetotail current sheet by the Cluster mission in 2003. The thickness of these current sheets is about the ion inertial length and significantly smaller than the characteristic ion gyroradius. We analyze the asymmetry of the electron velocity distribution functions and show that the electron current is provided by the small electron subpopulation interpreted as an electron beam or two counter streaming electron beams. The beam (counter streaming beams) has the bulk velocity of the order of the electron thermal velocity and the density (difference of beam densities) of about 1–5% of the plasma density. To describe observed current sheets we develop the kinetic model with particle beams. The model predicts different thickness of the current sheet for different types of current carriers (one electron beam or two counter streaming electron beams). The observed ion-scale current sheets can be explained assuming that the current is carried by one electron beam and a co-streaming ion beam. Although the ion beam does not carry a significant current this beam is required to balance the electron current perpendicular to the current sheet neutral plane. The developed model explains the dominance of the electron current and ion scales of the current sheets.

**Standing shear Alfvén waves driven by the Jupiter dipole wobbling**

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We present Galileo observations of $\sim$ 10 h periodic variations of azimuthal and radial magnetic fields in the Jovian magnetotail (at $X-40\ R_J$, where the Jupiter Solar Equatorial (JSE) system is used). The radial magnetic field variations correspond to the magnetotail flapping motion generated by the diurnal Jupiter dipole wobbling. The azimuthal magnetic field variations are phase shifted with respect to the radial variations by a quarter of the period. The azimuthal magnetic field has maximum in the magnetotail neutral sheet and its amplitude is comparable with the amplitude of the radial magnetic field. We suggest that azimuthal variations represent the manifestation of shear waves standing along magnetotail flux tubes and driven by the dipole wobbling. The large amplitude of observed azimuthal variations could be attributed to the shear wave standing along the resonant flux tube. We have found that azimuthal magnetic field variations are associated with flat plasma density profiles across the magnetotail current sheet. We suggest that the flattening of the plasma density profile is due to the action of the ponderomotive force induced by standing shear waves.

**Possible reasons for the correlation reversal between low clouds and galactic cosmic rays**

*Veretenenko, S.V. (Ioffe Physical-Technical Institute; St.Petersburg University, St.Petersburg, Russia); Ogurtsov, M.G. (Ioffe Physical-Technical Institute, St.Petersburg, Russia)*

The nature of correlation links detected between low cloud anomalies and galactic cosmic ray (GCR) variations in the 11-year solar cycle was investigated, with possible reasons for the reversal of the correlation after 2000 being discussed. It was shown that cloud field formation at middle latitudes is closely related to cyclonic activity, so GCR effects on low cloud cover observed on the decadal time scale are not direct, but they are realized through circulation changes associated with GCR variations. As the character of GCR influence on

the lower atmosphere dynamics reveals a roughly 60-year periodicity related to the evolution of the stratospheric polar vortex, the reversal of correlations between cloud cover anomalies and GCR intensity detected after 2000 seems to be due to the change of the vortex state resulting in the sign reversal of GCR effects on the development of extratropical baric systems. The results obtained suggest an important part of the stratospheric polar vortex evolution in the character of solar-atmospheric links.

### Study of relationships between the polar vortex intensity and auroral activity

*Veretenenko, S.V. (Ioffe Physical-Technical Institute; St.Petersburg University, St.Petersburg, Russia); Ogurtsov, M.G. (Ioffe Physical-Technical Institute, St.Petersburg, Russia)*

Relationships between the intensity of the polar vortex which is a cyclonic circulation formed in the polar stratosphere and auroral activity have been studied, geomagnetic AE-indices and electron fluxes at high latitudes according to NOAA/POES measurements being used. It was found that that there is a tendency to a roughly 60-year variation in the intensity of auroral activity characterized by AE-indices. A similar 60-year periodicity was detected in the correlation coefficients between the polar vortex strength and AE-indices, the correlations being most pronounced for winter months. The sign reversals of the correlation coefficients were detected in the early 1970s and 2000s. The correlations between the polar vortex intensity in winter and electron fluxes in the energy ranges 30–100 keV and 100–300 keV reveal distinct 22-year and 6-year periodicities. The results obtained suggest a possible influence of auroral activity on the state of the polar vortex which in turn affects the large-scale circulation of the troposphere.

**Effect of lightning activity of the world lightning centers on whistler rate variations recorded in Kamchatka**

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Data on March 2013 were used to verify the theory of whistler propagation along a magnetic field tube, from which the recorded whistlers are expected to be associated with lightning discharges in Kamchatka and in magnetically conjugate point in Australia. When comparing the whistler rates recorded at AWDANet station in Kamchatka with lightning discharge rates according to the data of the World Wide Lightning Location Network, it was determined that the intensity highest values are associated with lightning in magnetically conjugate points. At the same time there were some small splashes in the intensity which clearly correlated with the activity of American and African sources. Some splashes may be associated with the activity in all thee sources in America, Africa and Indonesia. This publication is based on work supported by a grant from the U.S. Civilian Research and Development Foundation (RUG1-7084-PA-13) with funding from the United States Department of State. The opinions, findings and conclusions stated herein are those of the authors and do not necessarily reflect those of CRDF Global or the United States Department of State.

**The formation of the two-dimensional auroral structures of the ionospheric convection**

*Volkov, M.A. (Murmansk State Technical University, Murmansk, Russia)*

The formation of the two-dimensional auroral structures in the cold ionospheric-magnetospheric plasma under convection is considered. The convection inhomogeneity leads to the currents across and along the magnetic field lines. The field-aligned currents flowing from the

ionosphere into the magnetosphere are creating positive feedback between magnetospheric and ionospheric perturbations. The ionosphere is assumed by a thin conductive layer, but the processes of the ionization and recombination of charged particles are considered. The ionospheric processes were considered as non-linear. In the magnetosphere the linear approximation was used. The plasma in the magnetosphere was cold. The linear equation for the Alfvén waves propagating along the magnetic field from the ionosphere to the magnetosphere was solved with the realistic change of the velocity along the magnetic field lines. The growth rate of the disturbances with the scale 1 km is ∼60 c for the enhanced Hall ionosphere conductivity equal 8 S. The growth rate of the disturbances depends on the conductivity of the ionosphere. The perturbations grew faster for the lower conductivity. The disturbances at the smaller scale also developed faster. The consideration of the thermal motion of particles in the ionosphere leads to weakening and even suppress the development of ionospheric disturbances.

## Large amplitude undulations of evening side diffuse aurorae. Optical characteristics and conditions of generation

*Vorobjev, V.G., Roldugin, V.K., Yagodkina, O.I. (Polar Geophysical Institute, Apatity, Murmansk region, Russia)*

Optical characteristics of large amplitude undulations (LAU) observed by all-sky cameras at Kola Peninsula on December 28, 2010 were examined. Both interplanetary medium conditions and characteristics of magnetic activity before and during LAU were analyzed. It was shown that the development of undulations could be activated by sharp short-living of ∼20 minutes solar wind dynamic pressure impulse and existence of the undulations during about two hours was supported by electric field of stationary magnetospheric convection originated from large smoothly changed southward IMF $B_z$ component of about -12 nT. The altitude of undulation luminosity determined by triangulation method was $120 \pm 10$ km. The undulations amplitude changed from about 100 to 300 km and the average wavelength was ∼250 km. The undulations were observed moving westward with the average phase velocity of ∼0.7 km/s. The pass of DMSP F16 spacecraft just along "the tongue" of undulations showed that the wave of luminosity was located in the region

of the predominantly ion (proton) precipitation with the average energy of particles of ∼18 keV. Rayed auroral structures were observed continuously in the region of diffuse aurorae during interval of LAU existence. These structures were observed moving westward with the velocity of about 2 km/s that corresponds to the northward electric field of ∼100 mV/m.

## Global distribution of precipitating ions and height-integrated conductivities

*Yagodkina, O.I., Vorobjev, V.G., Katkalov, Yu.V. (Polar Geophysical Institute, Apatity, Murmansk region, Russia)*

We present the model of global distribution of precipitating ions and height integrated ionospheric conductivities. The model was developed on the base of DMSP F6 and 7 spacecraft observations. Observations of precipitating particles with energies from about 0.3 to 30 keV are used to examine precipitation ion characteristics in different MLT sectors under different magnetic activity levels. It is shown that in the dusk sector the positions of electron and ion precipitation boundaries are nearly coincident for all levels of magnetic activity. However, the latitudinal distribution of energy fluxes indicates that the positions of electron and ion precipitation maxima are spatially separated. Maximum energy fluxes of ions is observed at the equatorial precipitation boundary, while those of electrons at the poleward one. In the dawn sector, the electron precipitation region is 3–4° wider than that of ions. The isotropy boundary in the dusk sector is located in the region of diffuse precipitation (DAZ) near its poleward boundary for all levels of magnetic activity, while in the dawn sector it falls in the region of structured precipitations (AOP). Electron precipitations are dominating in all MLTs with the exception of the evening sector from 1500 to 2100 MLT. Here in the region of diffuse precipitation (DAZ) the ion energy fluxes are significant. The ratio of ion to electron energy fluxes increases from ∼0.7 to ∼3.0 with AL magnetic activity index changing from -100 nT to -1000 nT. The magnetic activity depending global ion precipitation model is developed on the base of statistical treatment of spacecraft observations. This model (APMI – auroral precipitation model, ions) at a specified level of magnetic activity (AL and Dst indices) has allowed one to receive a global distribution of both average ion energy and ion energy flux

in coordinates of corrected geomagnetic latitude – MLT. Comparison of APMI with the model of electron precipitation (APME) show that one hemisphere power of ion precipitation makes only about 14% as compared to the electron power during a low magnetic activity level and decreases up to ∼4% during |AL| > 1000 nT. Calculate of the Hall and Pedersen conductivities was made from electron and ion precipitation data and taking into account the background values of conductivities in different seasons for different UTs.

**High-latitude aurora during week magnetic storms and model description of auroral electron precipitation: case studies**

*Yagodkina, O.I., Vorobjev, V.G., Katkalov, Yu.V., Despirak I.V. (Polar Geophysical Institute, Apatity, Russia)*

Auroral luminosity and pattern of auroral precipitation during week magnetic storms on December 11–12, 2004 and on January 11–12, 2005 were examined. These two storms were caused by solar wind high-speed recurrent streams. Meridian scanning photometer data at Barentsburg and Lovozero stations and Interactive Auroral Precipitating Model (APM) were used to show the possibility of APM using for the description of the auroral luminosity boundaries. Spectral characteristics of aurorae observed from MSP in the pre-noon and after-noon sectors on Dec. 12, 2004 on the recovery phase of the storm showed that discrete forms were caused by relatively soft electron precipitation. In the after-noon auroral arcs were observed near the poleward edge of the red auroral band which was narrower than in the pre-noon and observed at latitudes from 73° to 77° CGL. On Jan. 12, 2005 discrete structures with intensity up to 40 kR in 557.7 nm emission were registered inside the red band at latitudes from 74° to 77° CGL during the main phase of storm. These structures were caused by precipitation of hard electrons and their intensifications coincided with solar wind velocity increased and growth or drop of the solar wind dynamic pressure.

**Some characteristics of the magnetospheric source of dayside proton aurora flashes during magnetospheric compressions**

*Yahnin, A.G., Popova, T.A., Yahnina, T.A. (Polar Geophysical Institute, Apatity, Murmansk region, Russia)*

During magnetosphere compressions proton aurora flashes are observed on the dayside in the sub-oval region. The proton aurora projection onto the equatorial plane locates the region of the proton precipitation source. The data from geosynchronous LANL spacecraft, which measure the cold plasma density, show that typically the proton aurora source region lies outside the plasmasphere. During enhanced geomagnetic activity the source region is found to be closer to the Earth. Energetic proton flux observations onboard low-orbiting NOAA satellites demonstrate the existence of a low intensity proton precipitation from the source region before the compression. This means that a mechanism responsible for the proton precipitation operates permanently on the dayside, and its affectivity increases during the compression. We discuss if the cyclotron interaction of ring current protons with EMIC waves can explain the source region characteristics described above.

**Precipitation of relativistic electrons as seen by NOAA POES**

*Yahnin, A.G., Yahnina, T.A., Semenova, N.V., Gvozdevsky, B.B. (Polar Geophysical Institute, Apatity, Russia)*

The MEPED instrument onboard NOAA POES is able to monitor proton and electron fluxes in a wide range of energies. We performed a survey of relativistic electron precipitation (REP) events seen with MEPED P6 telescope during a 36-day interval. This telescope was designed to monitor 6.9 MeV solar protons, which, in fact, are rarely observed. At the same time, this channel is contaminated by 800 keV electrons. This allows using the P6 telescope for REP observations. Combining P6 data with simultaneous energetic electron and proton observations we divided all REP events into three groups. One group consists from REP enhancements forming the isotropy zone at the poleward edge of relativistic electron fluxes. These REP events are observed on the night side, and are produced by isotropization process related to non-adiabatic motion of particles in a stretched night

side magnetic field. Second group is REP events related to simultaneous enhancements of energetic 30–300 keV electrons. These events have a wider MLT range of occurrence with the maximum in the premidnight sector. These REP events can be related to interaction of electrons with ELF/VLF waves in a wide range of frequencies. Third group of REP events correlate with burst-like precipitation of 30-keV protons. Such proton bursts indicate the location of the EMIC wave source. It is generally accepted that EMIC waves can effectively scatter relativistic electrons into the loss cone. However, such cases are also associated with the precipitation of energetic (30 keV) electrons. This fact poses a question: Whether REP is due to EMIC waves, or it is due to ELF/VLF waves generated in the same place.

## Pi2 geomagnetic pulsations behavior in "polar" and "high-latitude" substorms: Case study

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In our terminology, the "polar substorms" are isolated substorms, observed at geomagnetic latitudes higher 71° and not accompanied or preceded by substorms at auroral latitudes. The "high-latitude substorms" are the substorms which start at auroral and then drift to the polar latitudes. Here we apply the methods of the discrete mathematical analysis (DMA), namely the calculation of the general dispersion of the two-dimensional covariance matrix of the wave, to study the global latitudinal structure of the Pi2 ($f = 8 - 20$ mHz) geomagnetic pulsations, which were observed during several polar and high-latitude substorms. For this analysis, we used the observations of 10-s sampled IMAGE meridian magnetometer profile data and 1-s sampled data from some mid-latitude and equatorial INTERMAGNET stations. We found that generally the Pi2 pulsations bursts associated with both types of substorms occurred simultaneously from polar to equatorial latitudes. However, the wave polarization was different at different latitudes. The strongest Pi2 pulsations were recorded at the electrojet centre location. The examples of Pi2 behaviour during two considered types of substorms are shown.

**Long-term coherent changes in sunspots and polar fields**

*Zolotova N.V., Ponyavin D.I. (St. Petersburg State University, St. Petersburg, Russia)*

Coupling between low and high latitude solar phenomena is considered. We found that the global organization of large-scale photospheric magnetic fields originates from sunspot clusters. Using the polar faculae database over the last 100 years as proxies, we show that (i) sunspot clustering determines the polar magnetic flux; (ii) the Even-Odd effect observed in sunspots is also reflected in the polar fields. Finally, the origin of the Even-Odd effect is discussed.

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