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GC2024-U001

Macroseismiic studies: Historical earthquakes

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Solicited talk

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Macroseismology describes and studies the effects observed on the Earth's surface caused by an earthquake, as well as the relationship of these effects with the parameters of the earthquake source. To assess the intensity of shaking, macroseismic scales are being developed: they allow the comparison of reported effects with standard effects listed in the scale. The construction of scales does not require the assumption of any earthquake model. Vice versa, the solution to the other problem - determining the parameters of sources based on the macroseismic effect - requires the development of an equation for the macroseismic field, which necessarily contains a model. In addition, any macroseismic field equation by default assumes uniformity of the macroseismic scale (“distance” between each grade is equal), which has not been strictly proven. If the assumption is correct, then the path to quantitative macroseismology opens. Great achievements are associated with quantitative approach; all parametric catalogs of historical earthquakes owe their existence to it. At the same time, classical macroseismology is far from exhausted. It makes it possible to understand in which direction one should search for sources of information on earthquakes in historical documents, how to assess the reliability of information, and how to take into account the historical and cultural context of messages. In general, the purpose of the presentation is to demonstrate the capabilities of classical macroseismology. The presentation includes several blocks. The first block discusses the concepts of scale rank, hidden and explicit models (assumptions) in macroseismology. The second block examines historical earthquakes in Eastern Siberia. Various types of data source are recognized, and it is shown what advantages and disadvantages each of them has. The third block shows that classic macroseismology can significantly clarify knowledge on seismicity even for a period of time that cannot in any way be considered historical - the second half of the 20th century. The fourth block presents the problems faced by studies of remote earthquakes when data from the epicentral zone is not available.

GC2024-U002

Yesterday, today, and tomorrow of the Earth's climate system

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Solicited talk

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The problem of climate change, which is occurring at an unprecedentedly rapid pace, is one of the most pressing in the 21st century. Thanks to the improvement of ground-based observation systems and the establishment of regular satellite monitoring, as well as significant progress in the field of computer technology, in particular, the development of integrated climate models, in recent decades there has been a breakthrough in understanding the processes occurring in the Earth's climate system. However, the lack of long, statistically representative time series of weather data, the enormous inertia of the climate system (primarily the ocean) and its chaotic nature give rise to significant uncertainties in research estimates.

According to modern scientific ideas, climate change is mainly caused by human economic activity (primarily, the growing emissions of greenhouse gases), therefore, combating the negative consequences of such changes requires joint coordinated actions of the entire world community. For this purpose, scenarios for anthropogenic greenhouse gas emissions in the next decades (until the end of the 21st century) are being developed and constantly updated. These scenarios become the basis for model forecasts of how key characteristics of the climate system will change (temperature, precipitation, circulation of air and water masses, the number of abnormal weather events, etc.). Such forecasts form the basis of economic and political decisions. At the same time, due to the inertia of the climate system, these decisions cannot lead to an immediate improvement of the situation, therefore, along with them, it is necessary to take measures to adapt to current and expected climate changes in the near future.

Climate change is extremely important for Russia. The increase in temperature over its territory occurs 2.7 times (and in the Arctic zone - ~4 times) more intense than on a global scale. As a result, the permafrost, on which 2/3 of the country’s territory is located, is degrading, the ice of the Arctic seas is melting, the regimes of heavy precipitation or aridity in certain regions are worsening, etc. Thus, when developing economic policy in the future, considering regional climate change becomes a necessity.

Of particular interest are studies devoted to the peculiarities of the formation and evolution of the Earth's ozone layer, since ozone is not only a greenhouse gas, but also a filter of ultraviolet radiation.

Considering the above, I will discuss the following: (i) the current state of climate on a global scale, trends and causes of its changes, the role and contribution of the main greenhouse gases and the inherent variability of the Earth's climate system; (ii) principles for constructing scenarios for future greenhouse gas emissions; (iii) model predictions based on these scenarios; (iv) features of current and future climate changes on Russian territory and in the Arctic, the expected consequences of these changes; (v) the need for adaptation measures; (vi) the problem of ozone deficiency, ozone being both a greenhouse gas and a filter of ultraviolet radiation.

GC2024-U003

Beyond the Solar System: methods of detection, characterisation, and classification of exoplanets

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Solicited talk

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Since the first extrasolar planet detection in 1992, exoplanetary science has experienced exponential growth. To date, about 6000 planets have been detected beyond the Solar system, and these detections have greatly advanced our understanding of planetary systems' formation and evolution, as the population of exoplanets is rather different from what we know from the Solar System, both in terms of planetary types and planetary architectures. Thus, the first ever detected exoplanet represents a so-called Hot Jupiter -- the giant planet orbiting in close proximity to its host star, which planets turned out to be astonishingly common. Furthermore, the majority of exoplanets known to date represent the planets with masses between those of the Earth and Neptune, spreading the wide range of densities, the type of planets absent in the Solar System. In my talk, I will briefly overview the main exoplanet detection and characterisation methods used today and discuss the main trends in exoplanetary population statistics and their implications for planetary formation and evolution modeling. To conclude, I will present some highlights on the studies of exoplanetary (upper) atmospheres and the information one can gain thereof from recent and future observational missions.

GC2024-OLD001

Analysis of the quality of current forecasts of total ozone behavior in the 21st century

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The anthropogenic impact on the ozone layer is expressed in the anomalies in the total ozone content (TOC) state on a global scale with periodic enhancement at the high latitude areas. In addition, there are significant variations in TOC time trends at different latitudes and seasons. The reliability of the TOC future trends projections using climate chemistry models must be constantly monitored and improved exploiting comparisons against available measurements.

In this work, the Earth's system model SOCOLv4.0 is used to simulate TOC behavior from 1960 to 2100. The model is based on the combination of the MPI-ESM climate model with the MEZON module for the ozone-related chemical processes. To assess the quality of the forecast we analyzed the accuracy of the hindcast simulations for the period 1990-2023 using ground-based (Brewer and Dobson instruments) and satellite TOC measurements based on reflected and scattered solar radiation (OMI instrument), as well as thermal IR radiation (IKFS-2 instrument). The analysis was carried out for different earth regions (as well as for the entire Earth) and seasons.

The study presents the results of comparisons of TOC modeling data and measurements for the considered period. Initial results have demonstrated that the global correlation between TOC temporal variation by the SOCOL and satellites is above 0.8. Mean bias and its standard deviation are in ranges ~5-30 and 10-50 DU, respectively and highly depend on Earth region. The best agreement is found in the tropics and middle latitudes of the Southern Hemisphere. In the conclusion, we provide recommendations for possible further model improvement.

The work was carried out within the framework of the state assignment of St.Petersburg State University No116234986.

GC2024-OLD002

Climatology of mesoscale perturbations of OH and O_2 rotational temperature in Rikubetsu, Shigaraki and Sata

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The method of digital difference filters was applied to the analysis of OH and O_2 rotational temperature observations in years 2010-2018 at altitudes of 85-90 km by photometers installed in Rikubetsu (43.5N, 143.8E) Shigaraki (34.8N, 136.1E) and Sata (31.0N, 130.7E) in Japan. Seasonal variations in the monthly-average values of rotational temperature and variance of perturbations with periods of 0.7 – 11 hours, which may be associated with internal gravity waves in the mesopause region, have been studied. Seasonal variations in the relative standard deviation of rotational temperature near the mesopause have maxima in winter and summer, also minima in spring and autumn. The details of the changes in the rotational temperature of OH and O_2 may differ. This may be due to the different heights of the luminous layers.

Currently, much attention is being paid to the study of internal gravity waves (IGWs). Their sources are mainly located in the lower layers of the atmosphere and, propagating upwards, IGWs are able to transfer energy and momentum into the middle and upper atmosphere, thus influencing the thermodynamic regime and dynamics of the atmosphere. Measuring the intensity and rotational temperature of nightglows is one of the ways to monitor the thermodynamic regime and composition of the upper atmosphere.

In this work, the rotational temperature of hydroxyl and molecular oxygen at altitudes of 85-90 km is analyzed, which is obtained from measurements with photometers installed in Rikubetsu (43.5N, 143.8E) Shigaraki (34.8N, 136.1E) and Sata (31.0N, 130.7E) in Japan in 2010-2018. A detailed description of used instruments is given in [1].

A method for estimating the intensity of mesoscale disturbances near the mesopause was described in [2,3]. The initial data are taken from the registration of night glow characteristics at time t_i, which are averaged by the device over the accumulation time δt. Numerical filtering is used to estimate the monthly standard deviations δ_f of mesoscale variations by determining the differences between the recorded values spaced over time intervals Δt.

One of the reasons of mesoscale nightglow variations may be IGW propagating in the emission layers of the upper atmosphere. The polarization relations of the atmospheric IGW theory [4] allow us to obtain the following formulas for the relationship of the wave variations of the horizontal velocity amplitudes U and the potential wave energy E_p with mesoscale temperature standard deviation δT.

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GC2024-OLD003

Comparative analysis of photolysis rates calculated using Cloud-J and LibRadran tools

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Photolysis, the dissociation of molecules by solar irradiance, drives atmospheric chemistry and controls the chemical composition of the air. Photolysis rates are governed by the intensity and spectral distribution of solar irradiance, which is altered by scattering and absorption processes within the atmosphere. Clouds, aerosols, and gases control these processes, but ambiguity in the representation of clouds in atmospheric models is currently the largest source of uncertainty in photolysis rates. A new approach for modeling photolysis rates (J values) in atmospheres with fractional cloud cover has been developed and is implemented as Cloud-J – a multi-scattering eight-stream radiative transfer model for solar radiation. Using observations of the vertical correlation of cloud layers, Cloud-J provides a practical and accurate method for modeling photodissociation processes [1]. In this work, the latest photolysis rate calculation code (Cloud-J v8.0) is evaluated by comparison with the widely used high-resolution “uvspec” model from LibRadtran, which has demonstrated good accuracy in several validation campaigns [2]. Using these two tools we calculated photolysis rates of several important species using spectral solar irradiance (SSI) provided by the Naval Research Laboratory (NRL) [3]. The NRL data set is chosen because it is the most frequently used data set in chemistry-climate models. We performed calculations using a tropical standard atmosphere with 42 vertical levels from 0 to 80 km [4], for cloud and aerosol-free conditions, for three solar zenith angles (10°, 40°, and 70°), and surface albedo equal to 0.1. The results confirmed the high quality and applicability of the Cloud -J for the atmospheric chemistry studies.

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GC2024-OLD004

Parameters of sudden stratospheric warmings from the reanalysis database jra-55

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The purpose of the study and classify parameters of sudden stratospheric warmings (SSW) using an automated method for determining the characteristics of SSW for the period from 1958 to 2017 according to Japanese reanalysis of meteorological information JRA-55. The times of start and end of the SSW are determined using the moments of the maximum rate of temperature change and the average zonal speed at an altitude of 30 km and latitudes above 60º N. Algorithms and programs have been developed in [1,2] to search for zero values of the second derivative of temperature and zonal velocity with respect to time, which corresponds to extreme values of the rate of change of these parameters. In this study, this method is used to search and determine the characteristics of SSW at an altitude of 30 km for the period from 1958 to 2017 using the JRA-55 database of the Japanese meteorological reanalysis. Based on the data from an automated search for SSW dates, an attempt was made to modify the generally accepted classification of SSW events based on the presence or absence of a reversal of the mean zonal wind and the magnitude of the temperature increment relative to its median at an altitude of 30 km. A search for early-winter, mid-winter and final stratospheric warmings was performed. A total of 148 winter-average SSW were detected, with an average of 2.5 events per year. The moments of maximum rates of change in temperature and zonal wind differ by no more than two days. Criteria for determining strong and moderate SSW, which can be considered as analogues of major and minor warming in the international classification of SSW, are described. The proposed method is highly sensitive and has made it possible to identify an additional class of weak SSWs. Early winter stratospheric warming occurring in late autumn or early winter (November-December) is considered separately. The final warming is also analyzed, for which there is no return of the average zonal wind to the west within 30 days after its reversal to the east, which occurs during the spring restructuring of the circulation of the middle atmosphere. A total of 63 strong warmings were detected at an altitude of 30 km. On average, strong warming occurs once a year. Most of them occur in the month of January. On average, the number of moderate warming events is 0.6 – 0.7 events per year. In addition, 44 moderate warming events have been found. On average, this type of warming occurs 0.75 times a year. The greatest number of SSWs occurs in the month of February. Number of detected weak SSW events is 44. On average, there is also more warming in the month of January. Final warming and early winter warming were considered separately. Total 18 early winter warmings were detected. They were also subdivided into strong, moderate and weak SSWs. Their average duration is 7-9 days. A total of 18 final warmings were detected. All of them began in March. It has been confirmed that the development of SSW is always preceded by an increase in the meridional heat flux directed towards the North Pole. These flows can contribute to the heating of the polar stratosphere and the development of SSW.

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GC2024-OLD005

Measurements of the total ozone column by the IKFS-2 instrument for the period of operation from 2015 to 2022 on board the «Meteor-M» №2 satellite

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Ozone is one of the most important gases in the earth's atmosphere. It makes a major contribution to climate formation and protects the biosphere from hard UV radiation, so an important task is monitoring ozone content using various methods and instruments. The global ozone monitoring system includes remote, ground-based and local sensing methods. Satellite monitoring methods provide a wide range of data on global ozone distribution and anomalies. Among the various satellite methods for measuring ozone, only outgoing thermal radiation measurements provide data independent of solar illumination.

The study presents a method for obtaining information on total ozone content (TOC), based on measurements of the spectra of outgoing thermal radiation by the Russian IKFS-2 instrument on board the «Meteor-M» №2 satellite during the period of normal operation in orbit from 2015 to 2022.

In the period from 2015 to November 2020 (6 years), measurements were carried out with a scanning band of 1000 km, but starting from December 2020, the scanning band was increased to 1500 km. St. Petersburg State University has created a method for obtaining TOC from the spectra of outgoing thermal IR radiation measured by IKFS-2, based on the use of artificial neural networks (ANN) [1]. The inverse problem is solved using an ANN trained using TOC data obtained using measurements from the OMI instrument on the «Aura» satellite and the principal component method (PC). Previously, this technique was developed and applied to measurements with a range of 1000 km (a period of 6 years) [2].

This report investigates the application of the same methodology to measurements in 2021-2022, when the satellite swath width has increased to 1500 km. Based on comparisons of the results with independent measurement data, it’s shown that the transition to the period 2021-2022 slightly worsens the agreement of the IKFS-2 data with independent data. This’s caused by an increase in the scanning angle measurement range, and not by an increase in the TOC variability statistics. It is also shown that training an ANN on the entire data set over 8 years of measurements improved the agreement over the last 2 years, while practically not worsening it over the first 6 years of measurements. The mean differences between the data of independent measurements and the TOC data obtained by IKFS-2 are less than 2%, and the standard deviations of the differences are less than 3%. In polar regions, there is an increase in divergence during the winter and spring periods. Analysis of results in the polar regions is carried out using ozonesondes, which take measurements throughout the year, as well as during the polar night.

There is good qualitative agreement between IKFS-2 and ozonesonde data, including extreme drops in total ozone column at high latitudes of both hemispheres in the winter-spring period. The standard deviations of the differences between the IKFS-2 TOC data and the ozonesonde data ranged from 5.3 to 11% (17 – 33 DU), which corresponds to the uncertainty of the integral ozone concentration in the vertical column according to the ozonesonde data.

The authors acknowledge the support from Saint-Petersburg State University (project ID 116234986).

Key words: ozone, total ozone column (TOC), Fourier spectrometer IKFS-2, ozone measurements, outgoing thermal radiation, polar night, ozonesondes

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GC2024-OLD006

The variability of stratospheric gases in the vicinity of St. Petersburg

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Ozone anomalies that occur during winter-spring periods in the Northern Hemisphere have been increasingly observed in recent decades not only in polar, but also in mid-polar regions, including territories of megacities. A decrease in stratospheric ozone content can lead to an enhanced level of UV radiation that is dangerous for humans, therefore, the study of processes associated with the variability of stratospheric ozone is an important task especially for developing the methods for predicting the appearance of ozone mini-holes and the growth of UV surface illumination.

Regular monitoring of stratospheric gases involved in ozone-depleting processes is required for validation of various atmospheric models and understanding the climate changes. Long-term ground-based FTIR (Fourier Transform Infrared) measurements have been performed at the SPbU site in Peterhof since 2009. The observational site is equipped with the Bruker IFS 125HR instrument of high spectral resolution, which is used for measurements of total columns and vertical structure content of many atmospheric gases. The location of Saint Petersburg (60°N, 30°E) near the border of mid and high latitudes allows us to observe changes in stratospheric gases content under different atmospheric conditions, including polar vortex intrusion. In this work, we demonstrate the capabilities of ground-based FTIR-method to study and explain the temporal variability of stratospheric trace gases.

We analyzed time series of O_3, HNO_3, $ClONO_2$, HCl, and HF total or stratospheric columns derived by the ground-based FTIR-method in the vicinity of St. Petersburg in 2009-2023; compared them with independent satellite measurements (ACE-FTS) and the results of the SOCOLv3 with meteorological data assimilation. We compared the results of measurements at the Peterhof site with similar FTIR-measurements at the Kiruna site (68°N, 20°E) located 1000 km away.

The variability of stratospheric gases is affected by both chemical and dynamical processes in the atmosphere. Calculating the ratio of chemically active stratospheric gases (such as O_3, HCl, $ClONO_2$ and HNO_3) total columns to HF total columns allowed us to remove dynamical variability and separate time periods of their chemical activity only, that affect stratospheric ozone depletions.

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GC2024-OLD007

Information content of the outgoing thermal radiation spectra with respect to vertical ozone distribution

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The significance of ozone for atmospheric processes has stimulated the development of systems for its monitoring. Satellite methods of remote sensing that measure outgoing thermal radiation are the only sources that provide information on ozone independent of solar illumination. The outgoing thermal radiation spectra measured by the IKFS-2 spectrometer aboard the “Meteor-M” N2 satellite contain information on the ozone content in the atmosphere. To study the information content of the spectra with respect to ozone profiles, we constructed experimental covariance matrices of the vertical ozone distribution and cross-covariance matrices between ozone and temperature profiles using ozonesonde data over the years of the instrument's mission. We built and analysed the averaging kernels of the inverse problem and estimated the degrees of freedom for signal (DOFS). For calculating derivatives of the outgoing thermal radiation, we used the LBLRTM (Line-By-Line Radiative Transfer Model) code. The calculations were performed for different mean climatic temperature profiles. We considered both the retrieval using ozone mixing ratio profile covariance matrices only and the retrieval which took into account temperature-ozone cross-covariance matrices. The largest DOFS value, which is up to 4, is observed for the tropics and summer temperature models. The smallest DOFS (3.0–3.8) correspond to the winter middle and subarctic latitudes.

We estimated the relative errors of the ozone content retrieval. Simultaneous retrieval of ozone and temperature profiles considering their cross-covariances leads to a 0.5–2.5% reduction of the retrieval errors. One independent piece of information corresponds on average to the 1000–230 hPa layer, which is equivalent to the tropospheric layer. Thus, the ozone content in the troposphere may be derived from the IKFS-2 measurements with an error of 7.7–8.5% depending on the atmospheric temperature profile.

We demonstrate the possibility of deriving the ozone vertical distribution elements from the satellite measurements of the outgoing thermal radiation spectra.

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GC2024-OLD008

Numerical modeling of simultaneous changes of ozone content in the lower and middle atmosphere in the past, present and future

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Two chemistry-climate models of INM RAS RSHU and SOCOL are used to analyze the factors influencing the ozone content in the troposphere and stratosphere. Among the influencing factors, changes in ozone-depleting substances, greenhouse gases, solar activity, aerosol content, ocean surface temperature and ice coverage are considered. Particular attention is paid to changes in ground-level ozone due to changes in surface emissions of greenhouse gases and primarily methane, nitrogen oxides, and the influence of stratospheric ozone variability. Several scenarios of changes in the atmospheric content of greenhouse gases and nitrogen oxides are considered. It is shown that in the past and present, the variability of ground-level ozone is determined by the competing influence of the increase in the greenhouse gas content, contributing to the increase in the ground-level ozone content, and ozone-depleting substances, determining the decrease in the stratospheric ozone content at the end of the twentieth century, which led to a decrease in the inflow of ozone from the stratosphere to the troposphere. In the present, at the beginning of the twenty-first century, the stratospheric ozone content has stabilized, while the greenhouse gas content continues to increase. Numerical estimations have shown that in the future, depending on the scenarios of increase in the content of greenhouse gases and nitrogen oxides, the content of ground-level ozone, which is a toxic gas, can both increase and decrease starting from a certain point.

GC2024-OLD009

Analysis of the synergetic ground-based MW+IR method for determining vertical profiles of ozone content

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Ozone is one of the important trace gases of the Earth's atmosphere, as the main absorber of dangerous UV radiation from the Sun, which has stimulated the creation and regular use of various methods for monitoring its content. Papers [1, 2] show that the use of joint MW and IR measurements increases the information content of remote ground-based sensing of the ozonosphere.

The report discusses a new ground-based method for determining the vertical profile of ozone (VP O_3), based on simultaneous MW and IR measurements (MW+IR). In addition, a method that combines measurements of two MW devices (MW + MW) is also considered. The following equipment operates at St Petersburg University (59.88˚ N and 29.82˚ E):

1. MW ozonometer measuring the spectrum of downward radiothermal radiation of the atmosphere in terms of brightness temperature (BT) in the region of the ozone absorption line 110.836 GHz;
2. MW radiometer HATPRO (Humidity And Temperature PROfiler), which has 7 spectral channels in the region of the water vapor absorption line of 22.235 GHz and 7 channels in the region of the oxygen absorption band of 60 GHz;
3. Fourier spectrometer (FS) IFS-125HR, performing measurements in the direct sun in the IR region of the spectrum with high spectral resolution (up to ~0.005 cm-1).

The characteristics of this equipment were used to simulate the spectra for the linear regression method. As an ensemble of atmospheric states, we used the ensemble prepared at the CNRM (Centre national de Recherches Météorologiques, France, https://iasi.aeris-data.fr/IASI-NG_4A_data/, access date: 05/10/2022) for the latitude zone 50-70˚ N.

Estimates of the errors in determining the VP O_3 were calculated with measurement errors in the MW region of 0.1-0.2 K and 1% in the IR region. These estimates show near 10 km the MW+MW method reduces the a priori uncertainty (AN) of ozone content from 65 to 45%, the MW+IR method - by 2 times. In the troposphere, the errors of the MW+IR method do not exceed 27%, in the 10-20 km layer - 17%. In the 20-40 km layer, the error estimate of the method is ~5-10%, in the 40-50 layer - 5-8% with an AN of 14-25%, above 50 km, an increase in the error estimate is observed along with an increase in the AH of the ozone content.

An important characteristic of the remote sensing method is its vertical resolution, which is usually defined as the width of the averaging kernel at half its maximum. Calculations of the MW + IR method averaging kernels were performed using a diagonal a priori ozone matrix. The half-widths of the averaging kernels are 10-20 km, and the high-altitude ceiling of the method’s sounding is ∼50-55 km.

Conclusions

1. Simulation has shown that joint measurements of the MW ozonometer and the HATPRO radiometer (MW + MW method) can reduce the error of retrieving in the altitude range of 9-16 km
2. Errors two times less than AH can be achieved at certain altitudes (9 km, 45 km) using simultaneous MW and IR measurements
3. Combining the MW and IR methods leads to an increase in the range of heights for which a decrease in AN is observed when retrieving a VP O_3
4. MW+IR method shows the best vertical resolution in the troposphere and lower stratosphere. In the troposphere, the vertical resolution is ∼10 km, in the stratosphere from 10 to 20 km

The research was carried out in the “Ozone Layer and Upper Atmosphere Research Laboratory” of St. Petersburg State University and was financially supported by St. Petersburg State University as part of the project “Analysis and forecasting of the state of the climate, ozone layer and ionosphere using modeling and measurements of the gas composition of the atmosphere” 116234986

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GC2024-OLD010

The vertical profiles of O_3, CH_4, and N_2O into the polar stratosphere of the SH. Model investigation with CCM SOCOL

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We have used the chemistry-climate model (CCM) SOCOL-3 to calculate the annual cycle of the O_3, CH_4, and N_2O vertical profiles in the southern polar stratosphere. The sensitivity of the model results was estimated against the main factors influencing the composition of the polar stratosphere of the SH: (1) photo-dissociation rates of ozone for large zenith angels of the Sun; (2) intensity of the meridional species transport on the model sub-grid scales into the polar area . For this purpose, a series of 5-year model runs were performed for each of the factors with a range of their variability . Comparisons of the model results with the correspondent calculations of other CCM models (CMAM and GEOSCCM), reanalysis data (ERA5), and data of the satellite measurements (Aura MLS) allowed us to evaluate the main biases of the CCM SOCOL-3 species profiles in the polar stratosphere and to define the ways to improve the model representation of the polar ozone through (1) and (2) factor corrections.

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GC2024-OLD011

Sensitivity of the ozone content and temperature to different forcing

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Our study assessed the contribution of different forcing to the climate and atmospheric composition changes between 1980 and 2020. This period is characterized by significant changes in temperature and ozone content, making it an interesting and important period to study. A correct understanding of the ozone and temperature reactions to different forcing in the past will allow us to better understand future ozone trends and the driving physical processes. We analyzed the influence of different forcings using the chemistry–climate model SOCOL version 3 (CCM SOCOLv3) which has been developed as a combination of the general circulation model for the middle atmosphere (MA-ECHAM) and the chemical module MEZON (Model for Evaluation of oZONe trends). The MA-ECHAM provides the MEZON the 3-dimensional fields of the temperature, and MEZON gives back to MA-ECHAM the concentrations of water vapor, ozone, methane, nitrous oxide, and chlorofluorocarbons for the radiative forcing calculations.

In the study we considered ozone content and atmospheric temperature response to (1) ozone-depleting substances; (2) greenhouse gas concentrations, ocean surface temperature, and sea ice area; (3) solar radiation; and (4) stratospheric aerosol loading, (5) greenhouse gas concentrations and (6) ocean surface temperature and sea ice area only. To assess the relative influence of different factors we performed model runs considering the effects of each factor and a control experiment in which the influence of all factors was considered simultaneously. The results of the control run were verified by SBUV and MSU/AMSU satellite measurements and reanalyzes (ERA 5 and MERRA2).

The results show a significant decrease in ozone content at the end of the 20th century and pronounced stratospheric cooling, which is primarily driven by greenhouse gases and the effect of ODS on stratospheric ozone. Despite a slight decreasing ODS content decline during the 21st century, has not yet resulted in an increase of stratospheric temperatures. The minimum values of stratospheric ozone concentration in the mid-1990s can be related to the simultaneous impact of the increased ODS content, volcanic aerosol emissions into the stratosphere, and decreased solar activity. The main cause of the observed increase in tropospheric ozone content is related to climatic factors. Climatic factors make the most important contribution to the increase in tropospheric temperature, with the increase in ocean surface temperature being more important than the direct effect of the increase in atmospheric greenhouse gas content.

The study of the influence of various factors on climate change and the content of global atmospheric ozone was carried out within the framework of the state assignment of the Russian State Hydrometeorological University (draft state assignment of the Ministry of Education and Science FSZU-2023-0002). The analysis of variations in ozone and temperature of the lower troposphere of the Northern Hemisphere was carried out with the support of the Russian Science Foundation (project No23-77-30008). Numerical calculations and analysis of changes in ozone content in the stratosphere were carried out within the framework of the state assignment of St. Petersburg State University (project ID 116234986).

GC2024-OLD012

Formation of the extreme Arctic stratospheric polar vortex of winter 2019/2020 and related ozone loss

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The Northern Hemisphere polar winter stratosphere of 2019/2020 featured an exceptionally strong and cold stratospheric polar vortex. The initial conditions favorable for the occurrence of such an extreme vortex were formed in the upper stratospheric/ lower mesosphere (USLM). Thermal and dynamic perturbations in the polar USLM in the Arctic winter of 2019–2020 as measured by the Sodankyla meteor radar at 67°N, Aura Microwave Limb Sounder and MERRA reanalysis are presented [1]. The most severe disturbances occurred from late December to mid-January, while the rest of the winter is relatively stable. Mesospheric winds were dominated by several impulsive increases in the zonal component, an abrupt descent of the wind core and alternating north- and south-ward flow with a period of half a month. Reduced temperature at 90 km height accompanied by thermal inversions was observed in association with USLM warming in the eastern hemisphere. The warming trend was interrupted by a strong cooling in the entire USM column. As a result the upper middle atmosphere appeared considerably stratified. During the initial formation of a strong stratospheric polar vortex the USLM seem largely decoupled relative to the forcing from below. High "walls" surrounded the vortex that was favorable for its stability. In the stratosphere, the vortex turned out the coldest in the MERRA-2 record. A large number of polar stratospheric clouds formed and persisted for more than 4 months until the end of March. Total column ozone amounts in the NH polar cap decreased and were the lowest ever observed in the February–April period.

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GC2024-PERM001

Problems of paleomagnetism in the Altai-Sayan region and Mongolia

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Generalization of paleomagnetic data for Tuva, Khakassia and Mongolia showed that the curves of latitudinal displacement of Siberia, Tuva, and northern Mongolia differ insignificantly and, possibly, these geological blocks, starting from the Ordovician, moved as a single geological body. South of the Mongol-Okhotsk suture to the west of the 107^{o} meridian, the paleolatitudes of the formation of the Late Carboniferous-Permian strata are close to the "Siberian" ones, and to the east of the meridian - to the North Chinese ones. The wide variations in the declination of the magnetization of sequences located south of the Mongol-Okhotsk suture could possibly be associated with strike-slip displacements that were active in southern Mongolia during different periods of the Late Phanerozoic. The regions of Tuva, Khakassia and Mongolia differ sharply in the set of components of the natural remanent magnetization of Phanerozoic rocks. Postfolding Permian remagnetization of rocks by a magnetic field of reverse polarity is widespread in Mongolia. In Tuva and Khakassia, perhaps the secondary Permian magnetization is pre-folding.

GC2024-PERM002

Paleomagnetism of the Phanerozoic Sequences of the Central Part of the Central Asian Fold Belt

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A generalization of paleomagnetic data for Tuva, Mongolia and Eastern China was carried out, which showed that in the central part of the Central Asian Fold Belt (CAFB) there are areas with different paleomagnetic characteristics. These are areas located north of the Mongol-Okhotsk mobile belt, the Mongol-Okhotsk mobile belt belt, areas of the western part of Southern Mongolia and areas of the eastern part of Southern Mongolia and north-eastern China. The areas located north of the Mongol-Okhotsk mobile belt were part of the structure of the Siberian continent from the Ordovician and experienced movement similar to the Siberian continent. The regions of the western part of Southern Mongolia have been part of the structure of the Siberian continent since the late Carboniferous. The geological complexes of the eastern part of Southern Mongolia and the blocks of north-eastern China in the Middle Paleozoic and Early Mesozoic were located in a latitudinal interval close to the North China block and experienced similar latitudinal movements and similar rotations.

The large difference between the paleolatitudes of coeval strata in the west and east of Mongolia and Eastern China south of the Mongol-Okhotsk mobile belt suggests the existence of a tectonic boundary that divided blocks formed at paleolatitudes close to Siberia and Northern China along the 107° longitude meridian. To the west of the 107° meridian, the paleolatitudes of formation of the Late Carboniferous–Permian strata are close to the paleolatitudes of Siberia, and to the east of the meridian – to the paleolatitudes of Northern China. The width of the Mongol-OkhotskOcean in the late Paleozoic-early Mesozoic was 30-40° in latitude, which is ~ 3000-4000 km. The southern limit of the Mongol-OkhotskOcean was segmented and consisted of terranes of various genesis and structure. The closure of segments of the Mongol-OkhotskOcean occurred as a result of the collision of terranes with the Siberian continent during the period from the Late Carboniferous (in the west) to the Jurassic (in the east). The work was carried out within the framework of the IGEM RAS, topic No. 121041500224-8 and with the financial support of the Russian Science Foundation, project No. 22-17-00033.

GC2024-PERM003

Paleosecular variations indicate the specific mode of geodynamo operation during the Cretaceous Normal Polarity Superchron

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The volcanic rocks of the Okhotsk-Chukotka volcanic belt represent a promising object for studying the characteristics of the ancient geomagnetic field, in particular for estimating the amplitude of the paleosecular geomagnetic variations during the Cretaceous Normal Polarity Superchron. Obtaining such estimates is critically important for testing hypotheses on the origin of geomagnetic superchrons and for assessing their relationship to mantle dynamics. The performed work shows that the amplitude of the PSV at high latitudes during the Cretaceous Superchron was ~15% less than during the periods, when the geomagnetic reversal frequency was relatively high. This result confirms a possible connection between secular variations and the frequency of geomagnetic inversions and supports the hypothesis that the superchron is a special state of geodynamo, probably caused by an external forcing by mantle geodynamic processes. The work was supported by the Russian Science Foundation grant N◦23-17-00112.

GC2024-PERM005

Rockmagnetic and archaeomagnetic investigations of ceramics of the multilayer archaeological site Ivanovskoe III

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Rockmagnetic and archaeomagnetic investigations were carried out for four fragments of ceramics from two cultural layers of the multilayer archaeological site Ivanovskoe III. The site of ancient people was located in the Pereslavl district of the Yaroslavl region, approximately 4 km southeast of the village Ivanovskoe. Based on correlation with the author's VADM data obtained for the central part of the Russian Plain, the age of two ceramic fragments from the first cultural layer, determined by archaeological and radiocarbon methods, was confirmed as the Bronze Age. For two other fragments of ceramics from the second cultural layer of the archaeological site Ivanovskoye III, a Neolithic age has been proposed. These archaeomagnetic age determinations, when correlated with generalized VADM data, are in good agreement with the radiocarbon ages of undecomposed wood found in the peat layer located under the second cultural layer, as Neolithic, and are not consistent with the archaeological age determination - the Bronze Age. Presumably, the low VADM values for the ceramic fragment from the second cultural layer are due to the fact that the main carrier of thermoremanent magnetization is thermally unstable maghemite. A possible explanation for the presence of Neolithic ceramics in the second cultural layer, whose age is the Bronze Age, is the mixing of the contents of cultural layers as a result of the economic activities of people who repeatedly inhabited this territory. Archaeomagnetic and rockmagnetic studies were carried out at the Center of Shared Research Facilities “Petrophysics, Geomechanics and Paleomagnetism” of the Schmidt Institute of Physics of the Earth RAS with the financial support of the State. assignment No. FMWU-2022-0005 IPE RAS.

GC2024-PERM006

Deep structure model of the Taragai area of the Sutarsky ridge (Lesser Khingan) from geophysical field and magnetic petrology data interpretation

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The study area is located within the Lesser Khingan part of the Bureya-Jiamusi superterrane, where a unique stock of garnet peridotites was discovered near Mount Taragai [1]. Authors concluded that the temperature and pressure during the formation of this high-pressure mantle mineral association were 1400°C and 5 GPa, respectively. Later on, geochemical and microscopic investigations revealed that the garnet peridotite stock is a diatreme [2].

The prime objective of the study is to create a depth model for the Taragai area based on the interpretation of geophysical field and magnetic petrology data, which is of interest not only for paleogeodynamic reconstructions to constrain the formation of the junction zone between the Central Asian and Pacific fold belts, but also for the development of a model for mineralization in the area associated with explosive activities.

Calculation of various transformations of Bouguer gravity and magnetic anomalies showed that the Taragai diatreme is an almost vertical stock; at a depth of 10 km beneath it no bodies with anomalous magnetization were identified. An increase in the density at a depth of 2-5 km is probably due to the non-magnetic ultrabasic intrusion of the Birobidzhan igneous complex of Ordovician age [3]. At depths of 12-25 km, another area of increased density is revealed, in the marginal western part of which a body with high magnetization is located. This anomalous area possibly reflects a larger mafic intrusion, which, along a south-dipping slope, is associated with an area of mantle compaction; the latter can be identified with a mantle magma chamber. Analysis of the depth model suggests the presence of two magmatic paleo-foci: in the mantle and in the crust at depths of 40-70 km and 12-25 km. The calculated depths reflect the current density and magnetic inhomogeneities and not the paleodepths at the time intrusions formed.

Compositional analysis of titanomagnetites from gabbro-dolerites of the Birobidzhan igneous complex showed that the TiO_2 content in them ranges from 13.61 to 27.44% averaging 21.25±3.34%. To eliminate the silicate matrix effect, the composition of titanomagnetites was calculated using the TiO_2/FeO value, the distribution of which is clearly bimodal with mode values of 0.23±0.02 and 0.34±0.03, and the distributions of both sets are close to normal. This distribution of the TiO_2/FeO value indicates the co-occurrence of two groups of titanomagnetite compositions in the studied dolerites of the dike. Applying the 2σ rule to estimate the range of possible TiO_2/FeO values at 95% confidence level, we obtain two ranges of Curie temperatures for primary titanomagnetites - approximately 260-340 and 50-200°C. Further, according to the empirical “magma chamber depth – titanomagnetite Curie temperature” relationship [4], the depths of magmatic paleo-chambers that “remembered” the primary titanomagnetites were calculated. According to the calculations, the first was located at depths of 50-70 km in the upper mantle and the second at 25-38 km in the Earth’s crust.

A preliminary paleomagnetic study on gabbro-dolerites of the Birobidzhan igneous complex showed that they formed near the equator, which indirectly confirms the Early Paleozoic age of magmatites of the Birobidzhan igneous complex, since, according to reference paleomagnetic data (Siberia, Northern China), in the late Paleozoic and Mesozoic the Bureya-Jiamusi superterrane was located at higher latitudes of the northern hemisphere.

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GC2024-PERM007

Changes in rock magnetic data in Late Pleistocene-Holocene sediments of the glacial lake Sosednee (Upper Kolyma region)

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Lake sediments are an important archive of data on changes in the natural environment of the past. Changes in the rock magnetic parameters in lake sediments are due to the quality and quantity of magnetic minerals. These characteristics depend on the conditions of sedimentation, catchment, post-sedimentation processes, and bioproductivity.

The results of a study of lake sediments of the mountain glacial lake Sosednee (62°03'29.62" N, 149°31'21.18" E) of the Yagodnoye district of the Magadan region are presented. It is located on the southern shore of the lake. Jack London, height 823 m above sea level, length 1.4 km, width 0.6 km, depth up to 13.4 m.

Drilling of Lake sediments was carried out using a Livingston sampler [3]. The sediments of 4 cores was studied: SD-1 (424 cm), SD-2 (64 cm), SD-3 (361 cm), SD-4 (190 cm).

The sediment of the cores has been studied by various methods, including optical, rock magnetic, geochemical, mineralogical, and palynological analyses.

According to the results of radiocarbon dating and age model, as well as palynological analysis, the age of the lake is 22570 cal. years. The sediments of this lake carry information about changes in the natural environment during the Holocene and Late Pleistocene

3 layers are distinguished, differing in lithology and rock magnetic properties (description according to core SD-1).

Layer 1 (0-246 cm) is represented by non-laminated organic silts. The layer was formed during the Holocene in the age range of 0-11 640 cal. years ago in a warm climate. The magnetic parameters of sediments are low, due to the dilution of terrigenous material with biogenic. The average values are: MS = 0.06 10^{-6} m^3/kg; Jrs = 0.0003 Am^2/kg; Js = 0.0012 Am^2/kg, Bc = 18.22 mT, Bcr = 52.32 mT. At a depth of 201-202 cm, a white, acidic tephra layer (SiO_2 – 77.4%) was observed. It is associated with the eruption of the Kuril Lake volcano in Kamchatka, which occurred 7600 A.D. [2].

Layer 2 (246-290 cm) is composed of silts. It is formed in the age range of 11,640 - 14,950 cal. years ago. The layer is transitional between the Pleistocene and Holocene. According to palynological data, the climatic conditions at that time were still warm. The pollen content of herbaceous plants increases from top to bottom along the layer, the role of detrital sedimentation and autigenic mineral formation increases, the amount of organic matter and paramagnetic components decreases directionally, the average values of MS (0.09 10^{-6} m^3/kg), Jrs (0.0009 Am^2/kg), Js (0.0015 Am^2/kg) increase.

Layer 3 (360-424 cm) covers the age range 14 950–22 570 cal. Years ago. The sediments are composed of laminated silts. According to palynological data, cold climatic conditions are reconstructed during this interval. There was no biogenic sedimentation in the lake. The layer is characterized by active autistic mineral formation. The average magnetic parameters are high – MS = 0.19 10^{-6} m^3/kg; Jrs = 0.0043 Am^2/kg; Js = 0.0081 Am^2/kg, Bc = 43.63 mT, Bcr = 75.05 mT, the contribution of the paramagnetic component is low.

In Late Pleistocene sediments (15,996-19,370 cal. years ago) are strongly magnetic samples (MS = 0.47-2.88 10^{-6} m^3/kg) with autigenic magnetic sulfides of greigite-pyrrhotite composition at several levels. At the Dey-Dunlop diagram [1], they lie in the area of single-domain particles. The values of Js/Jrs range from 0.48 to 0.56, Bcr/Bc – from 1.46 to 1.53. Detrital magnetic minerals are represented by titanomagnetites and magnetites.

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GC2024-PERM008

Iron sulfides in the lacustrine sediments of North-East Russia

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Iron sulfides are widespread minerals in lake sediments. They are often indicators of anoxic environments. The formation of sulfides can occur directly in the water column, as well as during diagenesis, due to the redistribution of iron and sulfur in sediments. The most common mineral is pyrite (FeS_2). Pyrite is a paramagnetic mineral and does not significantly affect the magnetic properties of sediments. Among magnetic minerals, greigite (Fe_3S_4) is often found, pyrrhotite (Fe1-xS) is rarely noted [1, 2]. Sulfides are numerous in the sediments of glacial lakes of the North-East of Russia. They are a mineral component of the therapeutic mud of the Talaya group of lakes. Magnetic iron sulfides formed during diagenesis distort the “primary” magnetic signal of sediments, in particular, make it difficult to determine secular variations of the geomagnetic field. These minerals were studied in Gryazevoe (61°08'21" N, 152°19'57" E), Nalimnoe (61°07'41" N, 152°20'8" E), Sosednee (62°03'29" N, 149°31'22" E), Vodorazdel’noe (63°44'8" N, 148°13'4" E), Sapog (63°29'9" N, 147°50'41" E), Chernoe (59°31'56" N, 147°23'07" E) lakes. Most lakes were formed at the end of the Late Pleistocene or at the beginning of the Early Holocene. The sediments are composed mainly of detrital and/or organogenic detrital silts.

The sulfides were studied using optical, mineralogical, and thermomagnetic methods. Heavy and magnetic fractions, smear slides, and sediments were studied. Hysteresis characteristics were determined for individual samples. Studies of the elemental composition of sulfides were carried out on an EVO-50 scanning electron microscope with Bruker AXS XFlash energy dispersion spectrometers and the Quantax Esprite 1.9 X-ray microanalysis system, as well as on a Camebax microanalyzer with an X-Max energy dispersion detector.

Iron sulfides of the studied lake sediments s are mainly in the form of framboids. In transmitted light they look like opaque spheres of various sizes. Framboids are often destroyed to a dark dusty mass (individual crystals). Sometimes sulfide minerals fill the diatom valves.

The composition of sulfide formations is not homogeneous. According to energy dispersion X-ray spectroscopy (EDS), the spherules consist mainly of iron and sulfur. The framboids of pyrite composition are most numerous. The ratio of Fe (wt %)/S (wt %) is about 0.9. The size of the spheres varies from several to 48 mm. The sediments of Gryazevoe lake are dominated by framboids 20-30 mm (up to 48 mm), Nalimnoe – (10-20 mm), Sosednee (up to 20 mm), Vodorazdel’noe – 20-30 (up to 48 mm), Sapog – (20-30 mm), Chernoe – up to 35 mm.

Greigite is found in the sediments of Gryazevoe, Sapog, Vodorazdel’noe, Sosednee, Nalimnoe lakes. The magnetic particles are single domain, the ratio of Fe (wt. %)/S (wt.%) is about 1.1-1.3. On the thermomagnetic curves resulted from heating, there is a significant decrease in MS and Ji around 400°C. The characteristic growth of MS during heating, possibly associated with iron hydroxides or Hopkinson peak of greigite, begins at a temperature of about 200°C. Pyrrhotite were found in the sediments of the Sosednee, Gryazevoe, and Sapog lakes. They often have a needle-like structure. According to EDS data, the Fe/S ratio is about 1.5. Curie points according to TMA data are about 320°C.

Many grains of magnetic fractions from sediments contain high iron content, but low sulfur content. The Fe/S ratio is over 1.5, often above 2. It is difficult to diagnose iron sulfides by thermomagnetic methods, since the magnetic fractions are polymineral and even in one sample may contain the entire set of sulfides. The interlayers with magnetic sulfides show high values of MS, Jrs, Js, and a low content of the paramagnetic component.

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GC2024-PERM009

Thellier's experiments on artificial ceramics to determine the magnitude of the magnetic field

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When determining the value of the archaeointensity of the Earth's magnetic field using the Thellier method, which took place in ancient times during the firing of ceramics, it is assumed that it was equal to the modern value. The process of making and firing ceramics is relatively short-term and can fit within a short period of magnetic disturbances, when the value of the Earth's magnetic field differed from the modern value, for example, by a factor of two. Then the question arises: how will this affect the results of experiments to determine archaeointensity using the Thellier method. To bring the experiments as close as possible to natural conditions, fragments of two clay vessels made using technology common in the Neolithic Age in middle zone of Central Russia were chosen as the object of study. Petromagnetic and X-ray diffraction studies were carried out on these samples in order to study the ferrimagnetic composition of the ceramics. Next, duplicate samples were heated to 600°C, and thermoremanent magnetization was created on them in a constant magnetic field: 20, 50 and 100 μT. These samples were then subjected to Thellier-Coe analysis in order to study the dependence of the formation of thermoremanent magnetization during the cooling of ceramics in laboratory magnetic fields of various strengths. Thus, in this methodological work, the authors tried to recreate as much as possible the conditions for the emergence of the “archaeomagnetic” record with a known value of the laboratory magnetic field and artificial ceramics with a known ferrimagnetic composition like in the Neolithic one. Archaeomagnetic and rockmagnetic studies were carried out at the Center of Shared Research. Facilities “Petrophysics, Geomechanics and Paleomagnetism” of the Schmidt Institute of Physics of the Earth RAS with the financial support of the State assignment No. FMWU-2022-0005 IPE RAS and No.FMWU-2022-0026 IPE RAS.

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Paleomagnetic and rock magnetic studies on peats from the Nerpichiy bay coast, Southwestern Priokhotie

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The eastern Nerpichiy Bay coast (the northern part of Nikolai Bay of the Sea of Okhotsk) is almost completely covered with peat. Coastal outcrops consist of clay loams and sandy loams with gravels and pebbles, underlying a thick layer of peat. The total thickness of the studied peat section (Nerpichiy section) is 546 cm. Continuous sampling was performed to collect 273 oriented samples for rock magnetic and paleomagnetic studies.

Radiocarbon measurements on samples from two parallel section profiles performed at the Institute for Monitoring Climatic and Ecological Systems, Siberian Branch of the Russian Academy of Sciences and the North-East Interdisciplinary Scientific Research Institute, Far East Branch of the Russian Academy of Sciences yielded 15 dates which placed the onset of peat formation at 10,000 cal. BP, with rates of peat accumulation in different intervals of the section varying from 0.25 to 2.71 mm/year.

In the course of rock magnetic research, time dependences of initial magnetic susceptibility (k) and natural remanent magnetization (NRM) were plotted. The mean NRM value of peats in the examined section is 9.03×10^{-7} A/m., with the amount of scatter in values being three orders of magnitude, from 2.33×10^{-7} to 1.20×10^{-5} A/m. Negative values of k are recorded almost throughout the entire profile of the examined section interval, which is characteristic of diamagnetic materials. The measured magnetic susceptibility ranges from -5.46×10^{-3} to 1.14×10^{-3} SI units, with the mean value of k being -3.1×10^{-5} SI units.

Paleomagnetic studies allowed relative paleointensity values to be calculated using the pseudo-Tellier and Bagina-Petrova methods. The good agreement of results obtained by different methods showed 214 samples (78.4%), with the correlation coefficient of 0.89. Based on the calculation results, a relative paleointensity curve was plotted for the last 10,000 years.

Alternating field demagnetization revealed intervals with negative magnetization inclination in the studied section, which most likely correspond to geomagnetic excursions in the Holocene.

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GC2024-PERM011

Geomagnetic paleointensity at ~1.75 Ga of Paleoproterozoic volcanic rocks from the Ukrainian Shield

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New determinations of paleointensity have been obtained for igneous rocks of the Ukrainian Shield — from the Korsun-Novomirgorod pluton (1735–1760 Ma, Ingul Domain) and from the Korosten pluton (1750–1760 Ma, North-Western Domain). Sample selection, palaeomagnetic studies and rock age determination were carried out by Ukrainian geophysicists [1]. Determination of paleointensity and accompanying studies of rock properties were carried out in GO “Borok” IPE RAS. To obtain reliable determinations of paleointensity, the magnetic and thermomagnetic properties of the samples were studied and X-ray diffraction studies were carried out. This revealed that the carriers of the characteristic component of natural remanent magnetization are single-domain and small pseudo-domain magnetite grains. Two methods were used to determine paleointensity: the Tellier-Coe procedure with the pTRM-checks procedure and the Wilson method. Paleointensity determinations were obtained for five sites and met quality criteria. The obtained paleointensity and virtual dipole moment (VDM) values are extremely low, in the range of (3.6–9.76) μT and $(0.92–2.43)\times10^{22}$ Am^2, respectively. Analysis of the data available in the paleointensity database (WDB) suggests that geodynamo operation during the Proterozoic era may have been characterized by alternating periods of strong and weak magnetic dipole regimes. However, the validity of this conclusion depends entirely on the reliability of the data reported in literature and presented in WDB. This work was supported by the State program GO “Borok” IPE RAS number FMWU-2022-0026.

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GC2024-PERM012

Magnetic properties of the soil cover of active arable lands

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Soil formation can last for hundreds or thousands of years, and soil being a renewable resource today, may soon become non-renewable due to the growing population in the world and the gradual transformation of grasslands and forests into arable land and pastures which has been happening over the past few centuries.

The study of the magnetic properties of active arable soils by the method of cappametry, coercive spectrometry, thermomagnetic analysis, will allow to obtain analytical data and assess the degree of anthropogenic load in the studied soils.

The object of the study is arable soils in the Vysokogorsky district of the Republic of Tatarstan.

The aim of the work is to study the magnetic properties of arable soils and changes in magnetic susceptibility depending on the distance of the road.

The most widely studied magnetic property of soils is magnetic susceptibility. According to the results of measuring magnetic susceptibility, it is shown that the studied soil profiles are characterized by both accumulative and eluvial-illuvial type of distribution of mineral components depending on the conditions of soil formation, ongoing microerosion processes, and increased automotive activity in this area.

According to differential thermomagnetic analysis, it was revealed that the main carriers of magnetization of the presented soils are magnetite.

To determine the magnetic rigidity and the domain state of the grains of the magnetic fraction, the parameters of the magnetic hysteresis Bc, Bcr, Js, Jrs, which depend on the composition, concentration of the magnetic fraction, shape and size of the magnetic grains, are analyzed. Judging by the Day-Dunlop diagram (Day et al., 1977), magnetic minerals of the studied soils fall into the region of single and pseudo-single-domain particles.

Estimates of the relative contributions of the dia-/paramagnetic, superparamagnetic and ferromagnetic components obtained from coercive spectra show that the increase in magnetic susceptibility in the organogenic horizons of forest-steppe soils is due to the contribution of the ferromagnetic component.

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GC2024-PERM014

Current issues of paleomagnetism of the Katav Formation (Upper Riphean, Southern Urals)

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There are two views on the nature of the bipolar high-temperature component of magnetization (HTC) of the redstones of the Katav Formation. The question of the age of the magnetization of the Katav carbonates has not yet been finally resolved, despite the numerous arguments in favor of its primacy that have appeared in recent years. A very large number of changes in magnetic polarity were revealed in the upper part of the section. In case of a more reliable substantiation of the primary magnetization of the Katav sediments and depending on the actual frequency of these reversals, the rocks can record a hyperactive interval during the Neoproterozoic. In this case, the Katav rocks are a convenient object for studying the nature of geomagnetic reversals. In order to judge about the frequency and character of reversals, it is first necessary: 1) to be sure that the high-temperature characteristic component of the magnetization of the Katav carbonates is synchronous with the time of rock formation; 2) to be able to estimate the duration of transient processes. We present new results that provide additional important arguments in favor of the primacy of the characteristic component of the magnetization of the Katav Formation rocks. These are: 1) a positive fold test; 2) a positive reversal test; 3) independence of the characteristic component direction from magnetic mineralogy; 4) the presence of a trend of paleomagnetic directions from bottom to top in the section of the Katav Formation and further to the Inzer Formation; 5) different directions of the characteristic component of Katav and underlying and overlying rocks; 6) clear similarity of the magnetostratigraphic record in distant sections separated by several tens and hundreds of kilometers and located in areas with somewhat different geologic histories. The primacy of the high-temperature component of the magnetization is also supported by the recently published preliminary results of one of the two direct paleomagnetic tests, the conglomerate test, and its new results obtained this year.

The cyclostratigraphic study of variations in magnetic susceptibility of rocks of the upper part of the Katav Formation in the Yuryuzan section made it possible to estimate both the average sedimentation rate and its variations along the section. This makes it possible to estimate the frequency of reversals and the duration of transient processes when studying geomagnetic field reversals.

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A cyclostratigraphic study of the Katav Formation, (Upper Riphean, Southern Urals)

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Geochronological data are lacking for many Precambrian sedimentary sequences. In this case, cyclostratigraphy has proved invaluable in identifying periodicity in the stratigraphic record and therefore can constrain reversal frequency absent an absolute time scale. Cyclostratigraphy is based on the recognition of astronomically forced climatic changes in sedimentary strata. In paleomagnetism, the orbital cycles can be teased out of magnetic susceptibility (MS) variations in both terrestrial and marine sediments. Assuming that the magnetization of the limestones of the Katav Formation is synchronous with the time of its formation, an attempt was made to estimate the duration of accumulation of the studied strata. MS variations from an updated collection of samples in the upper part of the Yuryuzan section were used to detect orbital cyclicity. A cyclostratigraphic analysis was performed using Acycle software (https://github.com/mingsongli/acycle). The section was sampled for MS measurements in parallel with paleomagnetic sampling at 0.2 m intervals. This allowed us to identify only cycles that could presumably be interpreted as cycles of large and small eccentricities. For a more reliable interpretation in order to reveal the influence of cycles of small eccentricity, nutation, and precession, we additionally sampled a 14.25 m thick section in the upper part of the section every 0.05 m. Our combined approach to section sampling allowed us to identify the expected influence of all four Milankovitch cycles commonly used in interpretation. Spectral analysis of the MS series of the upper part (69.8 m) of the Yuryuzan section allowed us to identify the expected Milankovitch cycles and estimate the duration of sedimentation within the studied part of the section. According to our estimates, 69.8 m of the section accumulated over ~3.4 Ma, which gives an average sedimentation rate of ~20.5 m/Ma. This result does not contradict the current understanding of sedimentation rates in a shallow marine basin under a relatively stable tectonic regime. An assessment of variable sedimentation rates along the section was also made using a sliding stratigraphic window. Cycles with similar, but slightly different, periodicities are the result of different sedimentation rates (with values ranging between ~8 and ~ 31 m/Ma). The results obtained allow us to estimate the frequency of geomagnetic reversals and can be used to estimate the duration of transient processes.

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GC2024-PERM016

Paleomagnetism of rocks of the Okhotsk-Chukotka volcanic-plutonic belt of the Krest Bay (Chukotka): questions and tasks

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Paleomagnetic studies provide information about both the paleolatitude of the studied geological bodies and the polarity of the geomagnetic field during their formation. Therefore, conducting paleomagnetic studies in Northeast Eurasia, particularly the Chukotka Peninsula, is necessary to decipher the tectonic history of the region. This, in turn, helps solve various tasks related to the search for mineral deposits in the region and the adjacent Arctic shelf.

It is widely accepted that the volcanic rocks of the Okhotsk-Chukotka Volcano-Plutonic Belt (OCVB) formed after tectonic activity in the Verkhoyansk-Chukotka region [1]. However, there are rare records of deformations and strike-slip faults within the OCVB structure [2]. Some paleomagnetic studies show discrepancies in the obtained poles compared to the expected ones, considering the hypothesis of Eurasia's rigidity at the end of the Mesozoic-Cenozoic era [3]. To accurately assess possible rotations of blocks in the OCVB, paleomagnetic data from the OCVB eastern sector are necessary.

For this research, the Krest Bay area was chosen due to its abundant tuff-lava rocks of the Nyrvakinot suite (88.1±1.2 Ma) [4]. The accessibility of the sampling location, modern age assessment, and thickness of well exposed sections make it promising for paleomagnetic studies. The area consists of sedimentary, volcanic-sedimentary, and volcanic rocks mainly of andesitic composition in the Olkhovka formation, overlying the Nyrvakinot and Amga suites. The entire section is intruded by a large number of thin basic dikes and granite bodies of various sizes and undefined ages.

During two field seasons, two powerful sections of the Nyrvakinot suite were sampled in the area of Matachingai mountain and Egvekinot town. Samples were also taken from the largest Iskaten granite massif, located 10-20 km from the sampled Nyrvakinot sections, and from three basaltic dykes intersecting the sampled sections. Additionally, samples were taken for limited conglomerate testing from tuff-conglomerate layers.

Over 800 samples were studied from the Nyrvakinot suite, with demagnetization conducted using temperature and alternating field methods. Despite the Cretaceous normal polarity superchron, predominantly reverse polarity magnetization was recorded in the Egvekinot area, while normal polarity magnetization was found in the Matachingai section of rocks from the same age. The report will present detailed results of paleomagnetic studies in the Krest Bay area, discussing the complex paleomagnetic record, reliability tests, and assessments of primary magnetization.

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Cretaceous Magnetostratigraphy of the Severnaya Sosva River (Northern Urals)

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The results of comprehensive paleomagnetic and biostratigraphic study of Cretaceous sediments of the Sosva section (the basin of the Severnaya Sosva River, northwest of Western Siberia) are presented. The deposits of the Upper Albian and Lower–Middle Campanian have been studied. The material for the study was collection of oriented samples selected from a natural outcrop located in the basin of the Severnaya Sosva River 6 km downstream from the village Ust–Manya. The studied deposits are represented by black clays, siliceous siltstones, flakes, siliceous sandstones, massive, thick- and thin-layered, and combined into six rock packs. 57 oriented rock samples were selected from this outcrop with thickness of 27 m, from which 138 cube samples (57 stratigraphic levels) were made. The studied deposits differ significantly in magnetic properties. According to the magnitude of the magnetic susceptibility (K), a three-membered division of the outcrop is observed. The highest values of this parameter are characterized by black clays (pack 1). Here the magnetic susceptibility varies within 7.9–14.5*10^{-5} SI units. The lowest values of the K are characterized by siliceous siltstones and flanks (packs 2 and 3), the values of which are 1.0–4.2*10^{-5} SI units. Siliceous sandstones massive, thick- and thin-layered (packs 4, 5, 6) have magnetic susceptibility from 2.5 to 9.2*10^{-5} SI units. Natural remanent magnetization (NRM) vary from 0.05 to 8.40 mA/m. The highest NRM are observed in black clays (pack 1). Measured parameters included magnetic susceptibility its temperature dependence and anisotropy (AMS), as well as natural remanent magnetization. The Koenigsberger ratio was determined as, (Qn=Jn/(KH_T). To determine the magnetic minerals, an analysis of the dependence of magnetic susceptibility on temperature was used. This analysis showed that the rocks contain pyrite and siderite. These minerals not being carriers of magnetization, serve as supplier to sedimentary rocks of magnetic formations (goethite, hydrogoethite and other magnetic formations).The studied rocks have a low degree of anisotropy, these are practically isotropic – the magnetic texture of these sediments corresponds to the primary texture of sediments. The samples were subjected to stepwise thermal and alternated field (AF) demagnetizations. The AF demagnetization was the most efficient for samples of pack 1 (black clays) and revealed unstable (low coercivity) and stable (high coercivity) NRM components. The low-coercivity component be removed by a low field of 20–30 mT, while that of high coercivity, which we consider as the characteristic magnetization (ChRM), held till 60-100 mT. Thermal demagnetization was carried out up to 350-400-600°C for packs 2-6. During stepwise thermal demagnetization, two components of magnetization low-temperature and high-temperature are also identified. The primary origin of the revealed ChRM component is supported by two main lines of evidence: (i) the presence of samples of normal and reverse polarity in the section: (ii) the independence of polarity from the lithological composition of sediments. Based on ChRM component, paleomagnetic section of Cretaceous sediments was constructed. Two zones of normal *N*K_1al_2 and reverse *R*K_2cp_1, polarities were isolated in paleomagnetic section. The Early-Middle Campanian age of the rocks of packs 2–6 and the reverse polarity of these deposits, identified in the *R*K_2cp_1 zone. Underlying zone *R*K_2cp_1 are zone normal polarity of pack 1 identified in the zone *N* K_1al_2 . The zone of reverse polarity *R*K_2cp_1 is corresponding with Chron C33r of the global magnetic polarity scale, the zone of normal polarity *N*K_1al_2 is corresponding with Chron C34 of this scale. This magnetostratigraphic section will be one of the fragments of the regional of magnetic polarity scale of the Upper Cretaceous for Western Siberia.

GC2024-PERM018

Theory of anhysteretic remanent magnetization of randomly oriented single-domain grains

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A generalization of the theory of formation of anhysteretic remanent magnetization (ARM) for non-interacting randomly oriented uniaxial single-domain (SD) grains is developed. The results obtained justified the approximations for ARM intensity presented earlier by [1 - 3]. However, the calculations revealed a striking discrepancy between the theoretical conclusions and the experimental results reported in literature. As it follows from the theory, the intensity of ARM is several times higher than the intensity of TRM, while experiments indicate the opposite relationship between ARM and TRM. The general conclusion is that in order to resolve this discrepancy and to understand the mechanism of ARM formation in rocks, it is necessary to supplement the theory presented here with consideration of magnetostatic interactions. On the experimental side, it needs to conduct experiments to create ARM and TRM in ensembles of non-interacting grains, that is, at extremely low concentrations in the sample. The study was carried out using the Russian Science Foundation’s Grant No. 23-27-00290, http://rscf.ru/en/project/23-27-00290/.

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GC2024-PERM019

Late Cretaceous-Cenozoic tectonic history of Chukotka according to new paleomagnetic data

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The Verkhoyan-Chukotka (VCSO) and Koryak-Kamchatka fold regions are generally characterized by the tectonic structure of Northeastern Eurasia. Most geologists accept that the formation of the former region was completed by the start of the Late Cretaceous, as a result of successive accretions of the Kolyma-Omolon and Chukotka terranes to Eurasia [1]. These terranes then formed the VCSO region, which is overlain by the Okhotsk-Chukotka volcanic belt (OCVB).

Today, the Northeastern part of Eurasia forms the junction of at least three major lithospheric plates - North American, Eurasian, and Pacific - as well as smaller plates such as the Bering and Okhotsk. The location, magnitude of displacement, and active lifetime of boundaries between the aforementioned plates in the geological past have been described very vaguely. For example, [2], [3] provide limited information on the kinematic behavior of plates in the past. The paleomagnetic technique can provide constraints on the kinematics of plates during geological time. However, the few existing studies [4], indicate the presence of significant post-Late Cretaceous motions of the entire Verkhoyan-Chukotka fold region in a southern direction over considerable distances (up to 1,000 kilometers). Despite the existence of several plates that have articulated in this region, these large-scale movements clearly contradict existing geological models that describe the development of Northeast Asia. The resolution of this discrepancy forms the main goal of this study.

Such data were collected for two objects located in the northern parts of the Okhotsk-Chukotka Volcanic Belt. The age of the first object, the Kupol, was determined to be 88 to 84 million years old. The youngest object, Valunistoe located in the Eastern Chukotka sector of the OCVB, and has an age range of 76 to 68 million years. Kupol now refers to the North American Plate, while Valunistoe is approximately located at the border between the North American and Bering Plates. When comparing the new paleomagnetic poles according to Kupol to the reference ones, there are no statistically significant differences, indicating the absence of significant tectonic movements of Kupol compared to the main parts of North America and Eurasia. This is true at least since 86 million years ago. The paleomagnetic data from Valunistoe differ significantly from both North America and Eurasia, supporting the model of existing of the Bering Plate and its relative kinematics with respect to Eurasia that was previously proposed in [3].

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GC2024-PERM020

Ultralow geomagnetic paleointensity at ~2 Ga of Paleoproterozoic igneous rocks from the Ukrainian Shield

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New determinations of paleointensity of the Ukrainian Shield Paleoproterozoic rocks aged 1980–2040 Ma are presented. The Ukrainian Shield is the exposed crust of a large Palaeoproterozoic protocraton and consists of metamorphic and igneous rocks.

Sample selection, palaeomagnetic studies and rock age determination were carried out by Ukrainian geophysicists. The samples were collected in two different regions of the Ukrainian Shield at two sites — Novoukrainka (“NU”, 48.3733N, 31.4930E) and Novaya Rudnya (“DE”, 50.1783N, 28.3320E). NU is the Novoukrainka intrusive massif in the southern part of the Ingul Domain of the Ukrainian Shield, formed by gabbro-monzonite rocks, zircon U-Pb age is 2035 ± 10 Ma. DE is the Buky massif, Northwestern (Volyn) Domain of the Ukrainian Shield, monzonite rocks, zircon U-Pb age is 1987 ± 14 Ma.

The samples were demagnetized by temperature and an alternating field, characteristic components (ChRM) were isolated, and paleodirections were determined. For the NU site: D = 46.5°; I= 36.4°; k = 33; α95 = 7° (based on 14 samples); for DE site: D = 40.6°; I= 38.8°; k = 59; α95 = 5.7° (based on 12 samples) [1]. The paleomagnetic poles calculated from these sites [1] are in good agreement with previously obtained data for Ukrainian Shield rocks of this age [2].

Determination of paleointensity and accompanying studies of rock properties were carried out in GO “Borok” IPE RAS. Two methods were used to determine paleointensity — Thellier (with the pTRM-check-points procedure) and Wilson. The thermal stability of rocks, the domain structure of magnetic grains were studied, X-ray diffraction analysis and micrographs are made. The rocks are thermostable. Carriers of the characteristic remanent magnetization are single- and small pseudosingle-domain magnetite grains. The reliability criteria are met by 3 determinations of paleointensity on the NU rocks and 18 (21 with duplicates) on the DE rocks. The average values of paleointensity are extremely low: 3.3 ± 1.3 μT (NU) and 4.3 ± 0.8 μT (DE), the corresponding VDM values are 0.73×10^{22} Am^2 (NU) and 0.93×10^{22} Am^2 (DE). The results obtained are consistent with the few determinations of VDM of similar age presented in the world paleointensity database, and indicate an extremely low field strength in the Paleoproterozoic in the period 2040–1980 Ma, an order of magnitude lower than VDM in the Cenozoic (~8×10^{22} Am^2). This work was supported by the State program GO “Borok” IPE RAS number FMWU-2022-0026.

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Study of biomineralization of iron oxyhydroxides by magnetometric methods

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Rift valleys of mid-ocean ridges (MOR) are an expression of the spreading axis in the relief of the ocean floor: in the midparts of MOR, the oceanic crust is newly formed, they are characterized by high values of heat flow, increased seismicity, intense magmatism, and often by high hydrothermal activity. Unique conditions for the formation of various mineral associations. Biomineralization processes are active here, including the formation of magnetic iron-bearing minerals. Biogenic iron minerals with ferrimagnetic properties are found in many living organisms: magnetotactic bacteria, some species of protists (algae and protozoa), and eukaryotes (insects, mollusks, fish, birds, and mammals). These minerals are involved in the magnetotaxis processes, as a means of iron storage, and for tissue strengthening. Such processes are fairly well studied (primarily magnetite formation in magnetotactic bacteria). The mechanisms of iron mineral formation and its physiological functions in eukaryotic protists, particularly foraminifera, remain largely unknown. In this case, foraminifera shells are porous microparticles of calcium carbonate. Under the influence of hydrothermal fluids, protist communities accumulate chemical elements on the surface and inside the carbonate shells. According to literature data, iron oxyhydroxides, in particular goethite and ferromanganese formations, which are represented by small isometric clusters on the shell surface, are formed here. Such particles, which can be controlled by an external magnetic field, are of particular interest to researchers.

The structure, chemical and mineral composition, and magnetic properties of the shells of planktonic foraminifera (species Globigerinoides ruber, Globigerinoides conglobatus, Globigerinoides sacculifer, Globigerinoides tenellus, Orbulina universa, Globorotalia inflate, Globorotalia truncatulinoides, and Globorotalia menardii) and ferromanganese formations from carbonate sediments of the Mid-Atlantic Ridge (MAR) rift zone, one of the largest MORs.

For the ferromanganese formations, experiments were also performed to extract and identify organic matter from the sample to confirm their biogenic origin.

The magnetometry data, including those at cryogenic temperatures, were compared with the new author's data on magnetosomes isolated from lyophilized magnetotactic bacteria.

GC2024-PERM022

Heat capacity of spin glasses in the model of random interaction fields

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The nonuniform distribution of the iron ions in titanomagnetites can lead to the fact that in areas with a low concentration of such ions, ordering of the spin glass type and the dependence of the residual magnetization on the time of exposure to an external field are possible. Features of the behavior of spin glasses are reflected in the dependence of the heat capacity on the external field, and this dependence was studied in our work. It is shown that in the vicinity of the critical concentration of ions C less than Cp, when there is no flowing cluster, the dependence of the maximum heat capacity on the external field changes its direction when a certain critical value is reached.

GC2024-PERM023

Holocene paleoclimate history of the lakes Bolshoe and Maloe Miassovo (Southern Urals) based on magnetic and geochemical investigations

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The main aim of the work is to identify the sedimentation conditions features in the Southern Urals. In these purpose lacustrine sediments of lakes Bolshoe and Maloe Miassovo were studied.

Core column No. 3 of Lake Bolshoe Miassovo (BM) was selected for detailed comprehensive investigations (N 55°09’51.1”; E 60°17’21.9”) [1] and core column No. 2 of Lake Maloe Miassovo (MM) (N 55°10’13.6”; E 60°21’04.6”) [2].

Radiocarbon dating of BM and MM samples was carried out at the National Taiwan University (NTUAMS Lab). The OxCal v4.2.4 software product was used to calibrate the age of the samples [3] and IntCal 20 calibration curve [4]. According to radiocarbon dating, the age of the studied sediments of BM is ~ 13.4 thousand years [5]. The age of MM sediment is ~20.1 thousand years.

The J_meter coercivity spectrometer [6] was used to determine the hysteresis parameters. It allows the separate measurements of remanent and induced magnetization in magnetic fields of up to 1.5 T at room temperature. On a base of obtained curves the contribution of various components of lake sediments to the magnetic component of the sediment was determined [7]. X-ray fluorescence (XRF) analysis was used to determine the elemental composition of lake sediments. To determine the factors of chemical composition, factor analysis by the method of principal components using the "Varimax normalized" method in the STATISTICA program was used.

It was found that the factor F1 of both lakes reflects allotigenic input into the sedimentation basin. Decrease in the values of F1 reflects an increased input of terrigenous detrital matter into the sedimentation basin. To establish the allotigenic nature of the magnetic parameters, a correlation matrix was calculated. This revealed a close relationship between the paramagnetic component and the input of an allotigenic material into the sedimentation basin.

In general, F1 shows a decreasing trend of the terrigenous elements from the first (youngest) sample to subsequent stages. It can indicate an increasing role of peneplenization of the relief, demolition sources and catchment areas and a decrease in the hydrodynamic slopes of drains.

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GC2024-PERM024

Influence of orientation errors associated with the use of a magnetic compass on the accuracy of determining the position of the paleomagnetic pole and the amplitude of paleosecular variations

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Abstract. The use of a magnetic compass in paleomagnetic studies of highly magnetic rocks (for instance, basalts) can lead to large errors in the orientation of paleomagnetic samples. On the other hand, alternative methods of orientation are relatively time-consuming, and in the case of using a solar compass, they also require sunny weather – a condition that is rarely met, especially when sampling at high and subpolar latitudes. This often leads to the fact that researchers in their work rely on the results of magnetic compass measurements, while assuming that the resulting errors are of a random nature and, with sufficiently good statistics, are averaged. In this study, numerical modeling is performed, which allows us to verify this assumption and assess how much orientation errors associated with the use of a magnetic compass can affect the final results of paleomagnetic studies, such as determining the position of the paleomagnetic pole and the amplitude of ancient geomagnetic variations. As a result of the work performed , it is shown that: 1) the amplitudes of paleosecular variations and the positions of paleomagnetic poles are weakly sensitive to moderate and even relatively large errors in the orientation of paleomagnetic samples associated with the use of a magnetic compass; 2) very large errors in the orientation of samples lead to a significant increase within-site scatter of paleomagnetic directions, which makes it possible to detect and exclude the corresponding sites with a large (for instance >15°) value of the α95; 3) the influence of distortions associated with the use of a magnetic compass on the accuracy of determining the position of the paleomagnetic pole and the amplitude of ancient geomagnetic variations depends on latitude. At near-equatorial latitudes, this effect is maximal, at medium latitudes – minimal. 4) With a systematic error in the orientation of paleomagnetic samples within the site, the largest deviations of Sb values and paleomagnetic poles are observed in the range of latitudes up to 60°; at higher latitudes, these deviations become insignificant.

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GC2024-PERM025

Test of intraformational conglomerates for the Katav Formation of the Upper Riphean (Southern Urals). New data

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A repeated test of intraformational conglomerates was carried out to verify the ideas about the time of formation of the high-temperature component (HTC) of natural remanent magnetization ($\boldsymbol{J_n}$) of limestones from the Upper Riphean Katav Formation, Southern Urals. The result obtained from the previous experiment corresponded to the criteria necessary for this type of work, but at the borderline significance level and required confirmation. For the new study, we selected blocks of flat-bedded synsedimentary breccias from sections in the vicinity of the village of Tolparovo and the town of Katav-Ivanovsk. The obtained data correspond to the Graham criterion, as well as to the Rayleigh and Hodges-Aine uniformity criteria, which confirms the conclusions made in the conclusion of the first experiment about the primacy of HTC of magnetization in the limestones of the Katav Formation of the Upper Riphean. Such a strong argument in favor of primordiality of the characteristic component of $\boldsymbol{J_n}$ makes it possible to use VGP known for the Katav Formation in global paleogeographic reconstructions and the study of the morphology of geomagnetic field inversions imprinted in the Formation.

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GC2024-PERM026

Can the traces of the impact events in the sedimentary sequences be recorded by rockmagnetic properties?

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Today the majority of researchers recognize that astronomical events can play an important role in the evolution of life on the Earth. For example, the link between the Great Ordovician biodiversification and the Middle Ordovician impact event, the latter being associated with the breakup of the parent body in the asteroid belt between Mars and Jupiter ~470 Ma, is currently hotly discussed. Thus, reconstructing the chronicle of impact events throughout geological history would be of great importance.

Sedimentary sequences are the most promising archive of impact events in the history of Earth, but methods for determining impact events in sedimentary deposits remain quite complex, time-consuming, and expensive. That is why we decided to consider the prospects of a relatively cheap express petromagnetic method for identifying traces of impact events in sedimentary records. To do this, we selected one of the most studied Ordovician Linna reference sections, where the presence of traces of the Middle Ordovician impact event was reliably established [1].

In this report we present the preliminary results of our current study and discuss the prospects of use of the main petromagnetic parameters to detect the impact events in the sedimentary records.

Paleomagnetic and petromagnetic researches were performed at the Shared research facilities “Petrophysics, Geomechanics, and Paleomagnetism” of the Schmidt Institute of Physics of the Earth, Russian Academy of Sciences and was financially supported by the Russian Scientific Foundation (grant no. 24-27-00370).

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GC2024-PERM027

Study of the morphology of geomagnetic reversals in the Late Riphean Katav Formation. New results

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The study of the character of geomagnetic field reversals, as an extreme manifestation of its variability, is of undoubted interest. A large number of works are devoted to this issue, mainly on “young” reversals. Ancient reversals are much less studied. We are trying to fill this gap.

In continuation of the previous studies, we sampled 4 intervals of sediments of the Katav Formation from the Yuryuzan section, presumably containing zones of geomagnetic field polarity reversals. The total thickness of the tested section intervals is about 6.8 meters. Approximately 300 oriented samples were studied. The record of geomagnetic reversals was identified in 3 of the studied section intervals.

The new data obtained are compared with the results of previous studies of our group, as well as with the results of numerous studies of Cenozoic geomagnetic field reversals.

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GC2024-PERM028

Experiments on samples carrying a sum of laboratory induced TRM and TCRM imparted perpendicular each other

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The experiments reported here simulate a situation where the primary magnetization is represented by TRM acquired on the original titanomagnetite, which has undergone significant magneto-mineralogical changes during the cooling of the igneous rock. Subsequently, this rock experienced secondary heating and gained a secondary magnetization. To simulate these processes, we took a block of tholeiitic basalt raised from the Reykjanes Ridge; rock age does not exceed 1 Ma. The block was cut into cubic samples with 1 cm size. Then, four samples were taken and heated in air in a two-component rotating thermomagnetometer to a maximum temperature T_{max} = 600 °C in nonmagnetic space. Upon reaching 600 °C an external field B = 50 μT was turned on and the samples were annealed for 0, 4, 20 and 80 minutes, correspondingly. On further cooling in the field all samples acquired total TRM in Y-direction. Then a sample was rotated in the horizontal plane at an angle of 90° and, in the absence of an external field, was heated to 400 °C where the field was turned on in X-direction and the sample was kept at this temperature for 200 hours, during which it acquired TCRM.

Then four duplicate samples were cut into a number of small specimens which were subjected to similar experimental procedure which however was stopped at different stages of the thermal treatment. Then each of small specimens was studied using scanning electron microscopy, X-ray electron probe, X-ray diffractometry and thermomagnetic analysis and measurement of the magnetic hysteresis loop parameters.

As occurred, the intensity of the TCRM for the sample with no annealing at 600 °C is three times more than the TRM_{rem} intensity, but it sharply decreases with increasing exposure time so that for t = 80 minutes the ratio $TRM_{rem}/TCRM \sim 0.1$.

Analysis of the Arai-Nagata and Zijderveld diagrams showed that two straight segments can be distinguished there located in (400-530) °C and (530–580) °C temperature intervals. The segment (400 < T < 530–540 °C) is associated with the TCRM formed at 400 °C likely by the mechanism of growth of single-phase oxidized volumes. The values of calculated field B_{calc} are ≈50% less then the true value of the field. The orthogonal plots for these samples demonstrate a deflection by (10–20)° from the X-axis along which the external magnetizing field was directed during the TCRM formation. The high-temperature segment most likely corresponds to the combination of TRM_{rem}, the carriers of which are near-magnetite cells and that part of the TCRM that was formed due to subsequent oxydecomposition of newly formed metastable titanomaghemites. The values of calculated field B_{calc} here are strongly underestimated for the samples with short annealing time t = 0 and 4 min but they are close to the true intensity for the samples with long exposure t = 20 and 80 min. For the orthogonal plots, a deflection of the magnetization direction from the Y-axis (TRM formation field) reaches 53° and 26° for the samples with short annealing time t = 0 and 4 min but decreases to 8° and 3° for the samples with t = 20 and 80 min.

In the practice of paleomagnetic studies, it is usually accepted that straight sections on Zijderveld plots indicate the direction of primary and secondary components. However, the data reported clearly show that such a concept can produce significantly erroneous results that do not reflect the true direction of the field generated one or another component. For the most important case of high-temperature component, the errors are increasing as the contribution of the TCRM component to the resulting magnetization increases.

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GC2024-PERM029

Paleomagnetism of Mesoproterozoic intrusive complexes of the Bunger Hills (East Antarctica)

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The almost complete absence of reliable paleomagnetic poles for the Precambrian of East Antarctica determines the relevance of our research. In this paper we summarize the results of a paleomagnetic study of rocks from two Mesoproterozoic basitic complexes of the Bunger Hills. It is one of the largest exposed fragments of Precambrian basement in East Antarctica. The geological structure of the Bunger Hills includes 8 complexes of metamorphic rocks from the Neoarchean to Mesoproterozoic and at least 5 complexes of Mesoproterozoic intrusive rocks.

The priority object for obtaining paleomagnetic pole was a gabbro-dolerite dike swarm aged 1131-1134 Ma [1]. The dikes are post-kinematic, weakly metamorphosed, and contain a large number of bodies. This is one of the best Precambrian geological objects of East Antarctica for paleomagnetic analysis. A total of 503 samples from 38 dikes of this complex were studied. The paleomagnetic record of gabbro-dolerites reveals high-temperature components of NRM and remagnetization circles. The mean directions of the high-temperature components of dikes form the bipolar distribution on the stereogram, but the reversal test is negative (γ/γc = 23.5/17.9). The primary nature of the components is confirmed by a positive contact test. The paleomagnetic pole calculated using 38 VGP: Plat=-23.4° Plong=263.5° A95=5.8°. This pole coincides with one of two reliable paleomagnetic poles for the Precambrian of East Antarctica – obtained of the Coats Land intrusions of similar age [2]. A rigid connection can be assumed between Mawson and the Coats Land, starting at about 1110 Ma.

The second object of our study was the largest intrusive of Bunger – the Paz Cove massif. The rocks of the massif are represented by metamorphosed quartz gabbro, monzogabbro and monzodiorite. The crystallization age of the rocks is 1170+/-4 million years, in the interval of 1170-1150 Ma the rocks were metamorphosed [3]. A total of 214 samples from 18 sites were studied. On Zijderveld diagrams can be distinguished components of NRM and remagnetization circles. Mean high-temperature components of NRM form bipolar distribution, but the reversal test is negative (γ/γc =18.3/10.7). Mean direction of distribution: D=175.2° I=-18.8° k=28.8 a95=6.6°. A positive contact test with gabbro-dolerite dikes suggests the primary nature of the remanent magnetization. The paleomagnetic pole, calculated from 18 VGP (Plat=-13.7° Plong=276.3° A95=5.3°), is close to the pole of the Bunger gabbro-dolerite complex, but differs from both it and other Mesoproterozoic poles East Antarctica. The age of the obtained pole probably corresponds to the time of partial metamorphism of the rocks; that is corresponds to the interval of 1170-1150 Ma.

Our results represent an important limit for interpreting the accretion and breakup of Rodinia with the participation of East Antarctica and demonstrate to the need to correct the paleogeodynamic models for the amalgamation of Gondwana.

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GC2024-PERM030

Magnetostratigraphic method in geology: current state, problems and the ways to their solutions

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Solicited talk

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Magnetostratigraphy is a branch of modern stratigraphy involved in studying magnetic properties of supracrustal rocks with the aim at revealing the spatial-temporal relationships. One of its purposes consists in developing the General Magnetostratigraphic Scale.

The boundaries of the polarity magnetozones are determined from the events isochronous on a planetary scale – geomagnetic reversals, that is why magnetostratigraphic comparisons result in the most precise global correlations, as compared to other methods. The sequence of magnetic polar zones acts as an independent “ruler” for calibrating the detailed biostratigraphic scales from remote regions. In certain instances, the paleomagnetic characteristics are chosen as the primary markers of boundaries for the general stratigraphic units (e.g., for the base of the Thanetian).

To solve the problems of the local and the regional stratigraphy, alongside with the polarity magnetozones, magnetostratigraphy makes use of the units of petromagnetic substantiation, recognized from the magnetic properties associated with the rock material compositions and structural-textural features. Basically, the petromagnetic units represent a variety of lithostratigraphic ones.

Magnetostratigraphy in itself is not capable of precise dating of the rocks. But being integrated with other methods (primarily, with the biostratigraphic one), the paleomagnetic data play an important and occasionally a decisive role in further specification of the deposit ages and in procuring more detailed correlations.

A common methodological error in integrated stratigraphic research (exclusive of the Quaternary stratigraphy) consists in regarding the paleomagnetic data as the secondary one as compared to the paleontological materials. If the results from the magneto- and the biostratigraphic methods are contradictory, the paleomagnetic information is frequently ignored or (which is still worse), with the assumed priority of paleontological information, used as the basis for some false geological conclusions (e.g., on the occurrences of depositional breaks). As a rule, such situations arise from the ignorance regarding the true potentials of the biotic methods for solving the problems of modern stratigraphy. In particular, the results of the infrazonal correlations from various paleontological groups are practically always contradictory. But consistency of all the available materials was and still remains the major principle of stratigraphic interpretation, and the paleomagnetic data should not represent any exclusion in this respect. Especially since there are numerous cases of successful reconsideration of the previously established stratigraphic notions with regard to the paleomagnetic information.

An important blunder in compiling unified stratigraphic charts lies in combination of the regional and the local units with the paleomagnetic scales developed in other localities. This very methodological error is inherent in the Geological Time Scale (GTS) [1], with the sequence of geomagnetic reversals “mechanically” integrated with the zonal standards of various paleobiochores, inclusive of those from the areas not studied magnetostratigraphically. Similar manipulations are known to have shaped false ides of the magnetic polar structures of biostratigraphic zones in some regions. To avoid this, the taxonomic units of the stratigraphic charts and the GTS provincial zones should be labeled with epyinformation on the availability or the lack of real paleomagnetic characteristics. Whenever possible, boundary diachroneity of the local, regional and detailed biostratigraphic units should be shown relative to the geomagnetic reversals.

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GC2024-PERM031

Magnetostratigraphy of the Danian stage from the Saratov Volga region

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For the first time, magnetostratigraphic data has been obtained from the Klyuchevskaya member constituting the lowermost of the Danian from the Saratov Volga region. The Klyuchevskaya member has been recognized as a local stratigraphic unit in the lowermost of the Lower Syzran subformation; with a certain degree of conditionality, the member is regarded as the oldest Paleogene deposit in the Volga Right Bank region near Saratov [1]. The criterion for the member isolation lies in the carbonate contents of the constituent gaizes and gaize-like clays, as opposed to the carbonate-free gaizes from the Lower Syzran subformation. Scanty macro- and micropaleontological finds indicate that the Klyuchevskaya member corresponds to the lowermost of the Danian (not younger than the zone NP3 according to nannoplankton), but preclude any precise determinations of its stratigraphic age.

The paleomagnetic description of the deposits (from the uppermost Maastrichtian to the lowermost of the Lower Syzran subformation inclusively) in the stratotype region of the Klyuchevskaya member occurrence is based on the study of the oriented samples from 66 levels. Characteristic magnetization components, corresponding to the field normal or reverse polarity, were recognized in most samples. In some cases, projections of the magnetization vectors in the course of demagnetization by alternating field or by temperature were displaced along the great-circle arc, which was interpreted as the presence of a magnetization component corresponding to the reverse polarity within the sample.

The Klyuchi–Teplovka composite magnetostratigraphic section is composed of three alternating magnetozones, identified as the analogues of the chrons C29n, C28r and C28n. Thereby, it has been substantiated, that formation of the Klyuchevskaya member took place at the beginning of the Danian age (zones NP2-NP3 according to nanoplankton).

A depositional break represented by hardgrounds occurs between the Cretaceous and the Paleogene in the study area [2]; its extent can’t be determined from the available paleontological data. Comparison of the acquired magnetostratigraphic data with the Geological Time Scale shows the Klyuchi-Teplovka section to lack any analogues of the chron C29r. This enables us to estimate the break minimum duration as corresponding to the C29r duration – 0.722 million years [3].

Distribution of the axes of magnetic susceptibility ellipsoids in the studied sections corresponds to the magnetic texture of the deposits formed on a gentle slope: the minimum axes of the magnetic ellipsoids take up subvertical positions, while the maximum axes display weak ordering along the line perpendicular to the inclination of the sedimentation surface [4].

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GC2024-PERM032

The Matuyama-Brunhes reversal in the loess-paleosol series of the Otkaznoe section (Terek-Kuma Lowland)

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The loess-paleosol series (LPS) of the Eastern Ciscaucasian region are unique within the Eastern European plain. In terms of stratigraphic completeness and thickness, they are almost comparable to the loess-paleosol series of China and Central Asia. The loess-paleosol series of the Ciscaucasian region have been forming for over 700-800 ka, and their thickness ranging from 10-30 m in the west (Sea of Azov) to 100-140 m in the east (Terek–Kuma Lowland) [1]. To date, a detailed chronostratigraphic scheme for the Upper Quaternary loess of the Ciscaucasian region has been established [2]. However, the Middle and Lower Neopleistocene loess-paleosol series have not been as extensively studied, leading to challenges in connecting them to the chronostratigraphic scheme of the Eastern European plain and correlating with the marine oxygen-isotope stages (MIS) [3].

The Matuyama–Brunhes magnetic polarity transition is one of the most significant and widely used chronostratigraphic markers in the Quaternary period (approximately 780 ka). Identifying the Matuyama–Brunhes boundary in Quaternary sedimentary sections enables to determine geochronological constraints on the sequences and carry out stratigraphic correlations of them. In this regard, during the summer of 2023, we carried out fieldwork on loess-paleosol series of the Otkaznoe section (44.17° N, 43.51° E), which is located within the Terek-Kuma Lowland, eastern side of the Otkaznoe reservoir. For a detailed study of the Matuyama–Brunhes transition, 74 oriented samples were continuously selected from the lower part of the section and cut into standard paleomagnetic specimens (2x2x2 cm) in the laboratory. In total, 270 stratigraphic levels were studied, with 3 to 5 specimens from each level. All magnetic measurements were conducted at the Institute of Physics of the Earth RAS (Laboratory for Geomagnetic Field and Rock magnetism) according to standard protocols.

As a result of paleomagnetic studies, a detailed record of the parameters of the geomagnetic field has been obtained (declination and inclination of the characteristic component of remanent magnetization (ChRM), latitude of the virtual geomagnetic pole (VGP)) for the transition zone of the Matuyama–Brunhes reversal. The M/B boundary in the Otkaznoe section is established, which allows us to designate the stratigraphic position of the Eopleistocene and Neopleistocene boundary in this section.

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GC2024-PERM033

Statistics of dipole and non-dipole geomagnetic energy

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The total energy of the potential geomagnetic field is divided into dipole and non-dipole parts. The statistical properties of the both energy parts, their powers and characteristic frequencies are determined and compared basing on the COV_OBS (1840-2020) model [1].

Previously, from an evolutionary analysis presented in [2], we showed that the dipole energy decreases quite slowly and monotonically, while the non-dipole energy changes faster and quasi-periodically. The characteristic times of the dipole and the entire field are about a thousand years, which is consistent with the known times [3-4]. Non-dipole times of the order of hundreds of years have not been previously identified. The purpose of this work is to identify the statistical properties of the corresponding energies, powers and characteristic times.

The cumulative distribution functions were chosen as tools of our statistical analysis. They were derived for the total energy E, its dipole part E1, the non-dipole part E-E1, the sum of the quadrupole and octupole E2+E3, for all corresponding powers or the time derivative of the corresponding energies (P, P1, P2, P3) and for frequencies (S, S1, S2, S3), which were defined as the corresponding ratios of powers to energies.

The root mean square RMS is 7.0 EJ for E and is close to the arithmetic mean, median and most probable with a small standard deviation Q = 0.3 EJ. E1 is characterized by the same statistic parameters and a monotonic profile of the cumulative function, coinciding with evolution. P and P1 with their close profiles and RMS~200 MW are in even better agreement with each other. The RMS values derived for S and S1 is such that they correspond to a characteristic time of about a thousand years. Thus, from the behavior of the dipole component it is quite possible to consider almost the entire global potential field, which is very positive for paleomagnetic reconstructions.

The situation is much worse with all non-dipole E-E1. Its behavior cannot be confidently assessed using E2+E3, the most accessible to paleomagnetologists. In our study, E2+E3 is characterized by RMS=0.6 EJ, which is almost 3 times less than for E-E1. The profiles of the cumulative functions also differ significantly, and the RMS for total non-dipole power P2=d(E-E1)/dt is equal to 220 MW, which is more than twice the RMS for P3=d(E2+E3)/dt. It is interesting to note that the powers of the dipole and the entire field are quite close to the power of the non-dipole field. In this case, Q is very large (~200 MW) for the entire P and its small part P3, but several times less for P1 and P2.

Manifestations of the non-dipole component (both E-E1 and E2+E3) can be identified by their inherent frequencies S2 and S3, which are approximately four times higher than frequencies for the dipole components. Accordingly, we obtain a characteristic time of the order of 250 years for global non-dipole components.

The problem of extending the results obtained on a relatively short time interval to longer periods studied in paleomagnetism remains not fully resolved. This problem is supposed to be solved in the future by systematically comparing the properties of short-term and long-term models, as, for example, this was done in [5].

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Paleomagnetic studies of marine sediments collected from the northern Barents Sea during the 2023 expedition

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Geological and geophysical study of the Russian Arctic shelf and water areas is an urgent task, one of the most studied regions of the Arctic sedimentary Basin is the shelf of the Barents Sea. The use of paleomagnetic studies on sediment cores allows to dissect, correlate and obtain relative ages of sedimentary strata. In this paper, paleomagnetic studies were carried out on six sediment cores (IP23-29t, IP23-36t, IP23-26t, IP23-33t, IP23-62t, IP23-15t) obtained during the expedition of FSBI VNIIOkeangeologia in the northern part of the Barents Sea on RV Ivan Petrov in 2023. Expedition was performed within the framework of the "Program of State Geological Mapping of the Territory and Continental Shelf of the Russian Federation at a scale of 1:1 000 000" [1].

During the expedition, the magnetic susceptibility of the sediments was measured using a PIMV kappameter, manufactured by GEODEVICE. Samples for paleomagnetic studies were collected by the method of continuous sampling using glass cylinders with an internal volume of 8 cm^3 according to the method of V.V. Kochegura [3]. Subsequent paleomagnetic measurements were carried out at the Geomodel resource center of the Science Park of St. Petersburg State University. Magnetic susceptibility and its anisotropy (AMS) were measured with the MFK1-FA device. A SRM-755 SQUID magnetometer by 2G Enterprise was used to determine the intensity and direction of the natural remanent magnetization (NRM). The alternating field demagnetization was carried out with a step of 5 mT in the range from 5 to 60 mT and with a step of 10 mT from 60 to 100 mT.

The values of magnetic susceptibility are on average in the range (15-55) 10^{-5} SI, which indicates that the distribution of magnetic minerals in the sediments is not quite uniform. In addition, peaks of magnetic susceptibility are noted in the cores at different depths; their values reach 100-10^{-5} SI and higher. The AMS data illustrate a calm sedimentation environment for core IP23-15t; for other cores the values of the minimum axis are concentrated outside the central part of the stereographic projection, that is characteristic of currents influence during sedimentation. For the IP23-36t core the NRM changes insignificantly in contrast to the inclination values, which varies from -61º to 88º.

Newly obtained paleomagnetic data for the northern Barents Sea are used to characterize the peculiarities of Quaternary sediments of this region. The negative inclinations can be related both to the fixation of excursions mentioned in the literature [2,4]. The direction of flows is demonstrated in the AMS results. The magnetic susceptibility curves can indirectly trace the change in sedimentation rate from northwest (IP23-36t) to southeast and from deeper parts of the section (IP23-29t) to the Perseus Rise (IP23-26t) by wedging the interval with higher magnetic susceptibility values relative to lower ones. The results will be used to correlate and stratify sediments in the northern part of the Barents Sea water area with sediments in other parts of the region.

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GC2024-PERM035

Analysis of the Devonian paleomagnetic direction distribution in the Minusa basin

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There have been several lengthy periods in the Earth's history when the geometry of the geomagnetic field may have differed from the central axial dipole model. One such problematic interval is the Devonian period [1, 2], for which the array of available paleomagnetic data suggests a significantly more complex structure of the geomagnetic field. In this report we present initial results of a comprehensive analysis of the current database for Devonian rocks, including our own new paleomagnetic data.

Based on our own collection of 568 samples collected from 63 sites and already available data [1], we studied the distribution of paleomagnetic directions within Early–Middle Devonian dolerites and basalts of the Minusa Basin. The studied paleomagnetic record varies not only between different magmatic bodies but also within each outcrop, making it difficult to determine the predominant direction at a given sampling point. The distribution of paleomagnetic directions often appears chaotic, making it even more difficult to identify a clear pattern. Among the sampling points where we were able to analyze the data, we identified 9 clusters of paleomagnetic directions. We hypothesized that the different components that are fixed in the rocks of this period are due to a decreased contribution from the primary dipole component, which is related to the strength of the Earth's magnetic field [2]. This decrease in field strength may have led to an increase in magnetic anomalies, which contributed to the overall magnetic signal observed in the rocks.

According to the fold tests, all clusters predate folding. Two clusters (S and N) are antipodal, the reversal test is positive (γ/γc = 5.61/11.89; class C [3]. The calculated paleopole (Plat = -11.5; Plong = 107.3) is close to the expected Devonian directions for Siberia [4]. Thus, we believe that the S and N directions correspond to the central axial dipole and can be used for paleotectonic reconstructions. The paleopoles calculated for the other seven clusters differ significantly from the expected Devonian and younger directions for the study area [4]; they are currently not suitable for solving tectonic problems. Despite the difficulty in interpreting the nature of the clusters, combining the S-cluster with the north geographical pole (Euler pole: Lat = 0, Long = 197.3, angle = -101.5) positions the clusters close to world gravitational anomalies, which, in turn, correlate with world magnetic anomalies [5]. Thus, the observed correlation between paleomagnetic clusters and global anomalies is difficult to explain. However, it is possible that, during "low-field" times, when the contribution of the primary dipole component was reduced, other sources of magnetization, such as anomalous sources, could also have played an important role in the process of obtaining magnetization.

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GC2024-PERM036

Local, regional and global components of environmental variability of the Southern Urals in the Neopleistocene-Holocene on the basis of petromagnetic parameters of modern lakes sediments

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Paleogeographic reconstructions are particularly important for areas with extreme climatic conditions, such as high-altitude, polar, arid or borders between geographical zones. In these places the slightest climatic changes cause significant shifts in regional variations of various biological, geophysical, meteorological, litochemical and other parameters. One of these regions is the Southern Urals, which is a climatic zone between the Eastern European and Western Siberian plains.

The study of the magnetic minerals (and their properties) of lakes sediments considered more and more as one of the essential step in the reconstruction of lake sedimentation conditions. However, the magnetic properties of the Southern Urals lakes sediments are poorly studied and described only in several articles. Therefore, this paper shows the possibility of identifying regional and local components of environmental variability according to the variations of petromagnetic parameters and their components based on the data obtained by the team. Lake Turgoyak, Bolshoy Kisegach, Bolshoe and Maloe Miassovo, Bannoe and Sabacty, located on the eastern slope of the South Ural Mountains were selected for the study.

For each lake AMS-measurements of ^{14}C (7 - 10 dates) were carried out, which allowed to create fairly accurate age models. However, in some cases age models need to be refined with taking into account additional information based on lithological, mineralogical, geochemical, paleobiological and other data that may allow distinguish the boundaries of sharp paleoclimate changes. The sediments of these lakes are Neopleistocene and Holocene age.

Magnetic susceptibility (MS), natural remanent magnetization (NRM), dia/paramagnetic component of magnetic susceptibility (kp) have been selected as the main parameters for comparison. And also for the magnetic characterization of the Southern Urals lakes sediments the ratios of the main hysteresis parameters (Bcr/Bc and Mrs/Ms) are proposed. Magnetic properties have been measured in step of 2 cm along the entire length of the selected core column of each lake.

It should be noted that the Neopleistocene and Holocene differ significantly in the behaviour of the variations and values of magnetic parameters. Filtration of MS, NRM and kp curves were used to isolate regional components represented by long-period fluctuations in petromagnetic parameters. In the initial stage, a frequency analysis of the studied curves was performed. Wavelet transformation was used as a tool for analysis the frequency characteristics of data series. Morlet wavelet was chosen as the mother wavelet. The low-frequency component is represented by oscillations with periods of 6000-8000 and 3000-4500 years BP. This component is characteristic for all objects of research. Similar spectral characteristics may indicate regional climatic changes simultaneously affecting the selected group of lakes. For the long-period component (3000-8000 years) low-frequency filtration of the original curves was carried out.

Starting from the Old Drias, three periods of increasing in sediment input into the sedimentation basin and three periods of reduction in the demolition of terrigenous material were identified. Big incoming of allotigenic material occurred during the period of deglaciation, in the Atlantic stage and 4000-3000 years BP in the Subboreal stage. Reduced inputs of allotigenic material occur during the warming of the Boreal stage, the cold substage of Subboreal stage and the Subatlantic warming substage (~2000-1000 years BP).

Against the background of regional paleoclimatic trends, a number of lakes show local changes. A striking example of this is Lake Bolshoy Kisegach, where a sharp change in sedimentation conditions occurred 1800 cal BP.

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Relative paleointensity of geomagnetic field obtained from the sediments of Lake Shira (Khakassia)

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Investigation of the geomagnetic field behavior in the geological past requires a diverse approach that includes constant monitoring of the world database on paleointensity (H_{anc}) and its continuous filling with new reliable determinations.

The paper presents the results of petromagnetic studies and determination of relative paleointensity in sediments of Lake Shira (Khakassia). The importance of obtaining data lies, in particular, in the fact that in the large area around Lake Shira, located at a distance of at least 900 km from the mentioned sampling sites, the Geomagia 50 [1] geomagnetic database currently has no data at all by paleointensity, both relative and absolute.

To determine the carriers of magnetization, measurements of hysteresis parameters, thermomagnetic and X-ray phase analyzes were carried out. According to radiocarbon dating, the age of the studied sediments spans about 9,100 years. Relative paleointensity was determined by the pseudo-Thellier method [7]. The selection of qualitative definitions of H_{anc} was based on the following criteria: at least 5 number of points for slope calculation; quality criterion $q \geq 1$; fraction of NRM demagnetized in the paleointensity determination interval $f \geq 25\%$; relative paleointensity determination error - $\sigma \leq 20$. The obtained data were compared with paleointensity values calculated for Shira coordinates using different models (CALS10K.1b [4], PFM9k.1 [6], HFM.OL1.AL1, CALS10k. 2 ARCH10k.1 [3]). A comparison of new data was also made with a data from the neighboring region obtained from archaeomagnetic objects in Siberia and Mongolia in 1970 – 2015. [2; 5 and references within].

A comparison of the relative paleointensity data from the sediments of Lake Shira and various models of the behavior of the geomagnetic field intensity showed their agreement, if take into account the general trend of changes in intensity, and not the correspondence of individual definitions. This gives possibility for applying this technique to the determination of paleointensity using the pseudo-Thellier method as applied to sedimentary rocks. Specific features in the behavior of the measured relative paleointensity also appear, for example, the anomaly of the maximum intensity in the interval from 7100 to 7300 years ago may be a result of non-dipole variation, which is not taken into account in modern models, or a result of a sharp change in rock magnetic parameters in this interval.

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GC2024-PERM039

RMS velocities and magnetic fields in the Earth's liquid core

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A hypothesis has been put forward and partially (based on order of magnitude estimates) confirmed that the integral power of the Lorentz magnetic force is determined by the square of the vector product of the magnetic field vector and the velocity vector of the electrically conductive flow in the liquid core of the Earth. In this case, we neglect the integrand of the alternating sign component of this power, which, when integrated, can practically be zeroed out, which still needs to be justified practically based on self-consistent 3D numerical models or proven theoretically if this is possible.

Integrals based on the equations of momentum and induction of the geodynamo is physically correctly simplified to a dynamic system of two ordinary differential equations for the rms convection velocity and the rms magnetic field in the Earth's liquid core. Convection and through it magnetism are generated due to the sufficient power of Archimedes' buoyancy force, which is given in integral form as, generally speaking, a function of time $a(t)$ based on the known and estimated heat and mass transfer in the outer liquid core of the Earth. Other parameters of the system are the magnetic diffusion time and kinematic diffusion time estimated from observations and theory. The last (fourth) combined parameter L of the resulting system is determined by the ratio of the characteristic size to the typical sine of the angle between the velocity vector and the magnetic field vector. This parameter is an order of magnitude greater than the radius of the Earth’s core, which indicates the almost parallelism of convective currents and magnetic field lines. Accordingly, the geodynamo is a highly nonlinear system with the magnetic field energy significantly dominant over the kinetic energy.

The main stationary points of the system corresponding to a non-zero magnetic field are obtained. For them, with a typical stationary velocity of 1 mm/s and a magnetic diffusion time of about a thousand years, L = 30 Mm. This, in addition to point 1 above, indicates a corresponding and very significant excess of the critical geodynamo level. With a typical geodynamo power a = 0.3 pW/kg, I find that for the very existence of a significant stationary magnetic field, it is necessary that the kinematic diffusion time exceed a value of the order of one month. If, as is typical for a geodynamo, this condition is satisfied with a margin, then the rms magnetic field is quite large - about 10 mT (100 G), which corresponds to a geodynamo of a strong Braginsky field. At the same time, the relative geomagnetic energy is about 10^{-2} J/kg, which is significantly greater than the relative kinetic energy ~10^{-6} J/kg.

It is shown that the specific power of the Archimedes force a is usually large enough for the main stationary points to be stable and for small deviations from them the system returns to them, reducing the initial deviation by e times in about a quarter at the parameter values accepted above. This extremely short time period of several months may well correlate with such a phenomenon as the well-known geomagnetic jerks, the physical nature of which still remains unclear. In this case, periodic oscillations occur with a period of about a decade, which are in excellent agreement with directly observed and well-known geomagnetic variations.

It was found that secondary stationary points with a zero magnetic field are stable in velocity, but under realistic conditions for a modern geodynamo, they are unstable in the magnetic field, moving away from the zero fields. However, with a rather low convection speed possible in the past, a tendency towards a stationary zero of the magnetic field could appear. These original manifestations of the geodynamo, apparently, can be associated with inversions and excursions, and possibly with a catastrophic zeroing of the geomagnetic field.

GC2024-PERM040

Record of climatic and paleomagnetic events of the late Holocene in takyr deposits of western Turkmenistan

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A study of the Holocene deposits of Western Turkmenistan was carried out. The thickness of the takyr deposits of the Donatinsky corridor - a clay desert between the Maly Balkhan and Kyurendag ridges - was studied.

Two times a year (Spring-Autumn) the plain is flooded with water, turning into a shallow lake. In summer the lake dries up. Thus, a layer of sediments with seasonal layering is formed, which makes it possible to apply varvochronology methods to dating these sediments. A similar process is typical for periods of climate aridization. During periods of climate humidification, the lake does not dry out, and layers of carbonate aurolites are deposited in the central part of the basin, and layers of silty sand are deposited in the periphery. This nature of the deposits makes it possible not only to record the history of climatic events in the region, but also to date them varvochronologically. By the nature of sedimentation, these deposits are extremely homogeneous and have magnetization of detrital origin.

Here, about a dozen pits were dug to a depth of 7 m across the entire area of takyrs from the deluvial train of the Small Balkhan to the deluvial train of the Kurendag ridge. Some of them were described in detail with the calculation of seasonal layers and selected by continuous sampling (pillars) for paleomagnetic analysis.

The magnitude and direction of natural remanent magnetization, magnetic susceptibility and a number of laboratory magnetic parameters were studied. As a result, it turned out that the studied sections are characterized by correct secular variations (SV) - declinations and inclinations with well-defined periods of about 1800 and 1200 years and a less expressive period of about 300 years.

In addition to intervals of calm behavior of the geomagnetic field, two sections of disturbed behavior of the natural remanent magnetization vector are distinguished in two parallel sections. One varvochronologically can be dated in the range of approximately 600 – 800 BC. This interval is known in the literature and is called the Etrurian excursion. The second interval is located at approximately 2000 – 2200 BC and we named Danat’s excursion after the name of the nearest village.

The reliability of the obtained paleomagnetic results can be verified by direct comparison with the observatory data available for the upper parts of the sections, since they accumulated immediately before our sampling. Data for a fairly long period (about 500 years) are available only for declination (D). A comparison of declination curves over approximately 500 years demonstrates a striking similarity for geophysical data between the obtained D curves and the curves of direct observation of variations in declination D for a given period (British Admiralty Data Bank)

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Volcanogenic rocks of the Kresta Bay (Chukotka): petrographic studies in the context of substantiating the nature of the paleomagnetic signal

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The paleomagnetic method has long been established as a powerful tool for solving tectonic and geodynamic problems. However, the presence of a paleomagnetic signal in the studied rocks does not guarantee successful resolution of the tasks at hand - it is necessary to prove the primacy of the discovered paleomagnetic record in the rock. Among other things, petrographic studies of rocks are often used to substantiate the primacy of magnetization.

In studying the history of the development of the Okhotsk-Chukotka volcanic-plutonic belt (OCVPB), the paleomagnetic method is indispensable. At the moment, only a few major works dedicated to the study of paleomagnetism in the OCVPB have been carried out [1], [2]. Within the framework of our research, work was carried out in the northern part of Kresta Bay near the settlement of Egvekinot, where a collection of volcanic and volcano-sedimentary rocks of the Nyrvakinot formation and intruding dykes of dolerites and granite masses was collected by us.Lying on the terrigenous rocks of the Olkhov formation, the Nyrvakinot strata is divided into two parts, where the lower one is represented by tuffs and tuff conglomerates of rocks of medium composition, and the upper one is represented by flows of andesite lavas with lenses of tuff sandstones, tuffoaleurites. The age of the sampled stratified formations was previously estimated based on plant remains as Albian-Rannessian [3], however, later dating of the base of the Nyrvakinot formation indicated its significantly younger age: 88.1±1.2 million years [4].

During reconnaissance studies of the volcanics of the Nyrvakinot formation, a fairly complex paleomagnetic signal recorded in them was discovered by us, allowing for a highly contradictory interpretation [5]. The studied samples of the Nyrvakinot formation consist of andesite lavas and tuffs with pronounced secondary alterations, such as carbonatization, chloritization. The dykes intruding them are highly chloritized and carbonatized dolerites. The samples of the studied granite massive demonstrate relatively good preservation, but they also exhibit secondary alterations.

The report will present preliminary results of the study of secondary alterations in rocks, especially in the context of the formation of secondary magnetic minerals as a potential cause of possible remagnetization. The results of electron microscopic studies, supported by results of thermo-magnetic analysis, will also be demonstrated.

The research was conducted within the framework of the RSF project №23-17-00112.

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Paleomagnetic data of Jurassic igneous rocks of the Greater Caucasus: comparison with Lesser Caucasus

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Paleomagnetic studies of Jurassic igneous rocks selected from undeformed rocks of the northern slope of the Greater Caucasus show primary bipolar magnetization, which differs from modern trends. The calculated paleomagnetic pole indicates a high convergence with the APWP of boudary Lower and Middle Jurassic for the European Platform [1].

In the Jurassic period, the Scythian and European plates were in a single rigid block. Comparison with Jurassic volcanic rocks of the Lesser Caucasus, Transcaucasia and Pontides shows significant differences in paleomagnetic poles [2]. The data for the Lesser Caucasus and Transcaucasia differ by more than 20 degrees in paleolatitudes, which considered with north part of African craton [3]. The data on Pontides for the Jurassic period show similarities with the data obtained on the northern slope of the Greater Caucasus, but there is a significant difference in declination – more than 25 degrees [4].

With the help of Gplates software, the paleomagnetic poles of the Greater Caucasus, Lesser Caucasus and Transcaucasia were evaluated and a geodynamic picture of the closure of the Tethys Ocean was developed.

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Devonian deposits of the southern Timan: Paleomagnetic data

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Paleomagnetic data allow us to quantify a number of important parameters: paleolatitude, meridian azimuth, and polarity of the geomagnetic field in geologic time for the sampling point. This allows us to define a basis for geodynamic and other paleoreconstructions (climatic, geographic, tectonic, geodynamic), which is important for designs model of sedimentary basins and orogenic belts. In 2007, A. N. Khramov and N. S. Oknova reconstructed the geodynamic evolution of the Timan-Pechora basin using paleomagnetic data. The first paleomagnetic data for the Northern Timan were obtained by G. I. Goncharov in the 70s of the last century. In 2000-2020 numerous paleomagnetic data have been obtained for sites of the Upper Devonian sediments (Frasnian Stage) from Russian Platform and Timan. Comparison of the paleomagnetic poles of Timan with the Russian Platform shows a 15-25 degrees rotation of Timan structures with respect to the Russian Platform. Paleomagnetic studies of a reconnoitering sample collection (Frasnian age) taken from 11 sections along the Ukhta and Izhma rivers showed the presence of several different age components of natural remanent magnetization of the studied rocks. Two of them are pre-folding: component C of the Late Carboniferous age and component D3 of the Late Devonian age, which pass the geomagnetic field polarity reversal test. Comparison between paleomagnetic results for the Carboniferous deposits of the Main Devonian Field and the secondary component C shows agreement. All of them shifted in longitude to the east relative apparent polar wander paths. The position of the paleomagnetic pole according to the characteristic component D3 is also shifted in longitude with respect to the available data on the Main Devonian Field of the Russian Platform, but to the west. The bipolar component D3 allows to detect several zones of normal and reverse polarity of the geomagnetic field in the studied sections. The obtained data, despite their fragmentary character, are in agreement with the available world magnetostratigraphic scales. As a result of the collision with the active margin of the Pechora plate in the late Vendian-early Cambrian, the Riphean complex accumulated on the submarine margin of the East European continent was crushed and partially metamorphosed as a result of the volcanic arc thrusting over it. The presence of rotations of Timan structures, according to paleomagnetic data, during thrusting processes (Caledonian, Hercynian, and Alpine cycles) shows the possibility of conditions for fluids into the thrusted rock strata. This work was financially supported by RNF grant 23-27-00461, https://rscf.ru/project/23-27-00461/.

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Rock-magnetic indicators of climate in subaerial deposits, how do they work?

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Loess and loess like subaerial deposits are one of the most complete and least ambiguous palaeoclimatic archives on the continental Earth's surface. It is the most extensive type of Quaternary sediments deposits, covering nearly 10% of the land surface, including large territories of semi-arid and forest steppe environments from Europe Asia and America. Measurements of magnetic properties play a sufficient role in palaeoenvironment reconstructions of loess-palaeosol successions all over the world. In early studies the magnetic proxies, such as low field (Klf) and frequency-dependent (Kfd) magnetic susceptibility, were the most popular magnetic parameters me and which were interpreted in commonly accepted models: the pedogenic magnetic enhancement. This "pediogenic "or "Chinese" mechanism explains synchronous increase of Klf and Kfd in soil horizons by the neoformation and enhancement of ultrafine superparamagnetic grains in palaeosols in the course of pedogenesis. This mechanism was firstly developed for loess-palaeosol successions of the Chinese Loess Plateau and later successfully applied to European and Central Asian loess provinces [1]. Relation between Klf and Kfd in this model follows so called 'true loess line" [2]. Nevertheless, loess-palaeosol magnetic properties in some regions not al do not fit this line and located far from the predicted model. Thus for loess-palaeosol successions in Alaska, which demonstrate an opposite trend – increase of Klf in loess and decrease in paleosol with near zero Kfd values the "wind-vigour" or "Alaskan" model was proposed. The opposite character of rock magnetic characteristics was explained here by strong winds bringing more magnetic materials during glacials and low wind intensity and weak pedogenesis during interglacials [1]. These two models are finite members of the whole variety of climatic changes in different climatic and geomorphological environment and, consequently, the response of magnetic parameters to climatic changes in there will be different. This, in turn, prevents a wide application of the magnetic parameters of loess-paleosol successions.

This brief review highlights the current magnetic enhancement models with special emphasis on the identification of unusual trends in magnetic enhancement and understanding their drivers. Using specific examples from the world practice and our research, the main mechanisms of changes in magnetic properties under the influence of climate will be discussed. Among them are: superposition of the "Alaskan" and "Chinese" mechanisms, which we called the "Siberian" one [3]; dissolution of fine magnetic grains due to leaching in waterlogging conditions in periglacial zone; variations in the source of magnetic minerals of aeolian origin; surface oxidation of magnetic grains; chemical alteration of magnetic grains; physical fragmentation of magnetic grains resulted from weathering and some other. It will be demonstrate that all mechanisms can coexist in one section and mechanism change can occur in same section and/or within one region. Because the behavior of different magnetic parameters is not uniform in the models described above this differences should considered in interpretations of magnetic data in climatic sense.

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GC2024-PERM045

Dependence of the magnetic properties of the metal/metal oxide system on the degree of oxidation

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The problem of the influence of ferromagnetic metal oxidation on the magnetic properties of the metal/metal oxide system has been the subject of many experimental studies. For example, in [1] it is shown that the oxidation of a thin film of cobalt leads to a decrease in the coercivity and in the saturation magnetisation. A similar dependence of the hysteresis characteristics on the degree of oxidation has been obtained for Co/CoO nanoparticle systems [2]. In [3], a detailed study is presented on the dependence of hysteresis characteristics on the degree of oxidation. The study is devoted to porous films of cobalt nanoparticles that were oxidised in air for more than 1400 hours as a result of controlled annealing at 100°C. The authors have shown that the hysteresis characteristics increase with low oxidation and then decrease with increasing oxidation.

In this work, atomistic modelling of the effect of cobalt oxidation on the hysteresis characteristics of the Co/CoO system has been carried out using cobalt films as an example.

The Landau-Lifshitz-Gilbert equation was used for the atomistic modelling of the magnetisation processes:

$$(\partial \mathbf{S}_i/\partial t)=(\gamma/(1+\lambda^2))(\mathbf{S}_i\times\mathbf{B}^{(eff)}_i+\lambda\mathbf{S}_i\times\mathbf{S}_i\times\mathbf{B}^{(eff)}_i)$$

where $\mathbf{S}_i$ – spin momentum of the atom, γ – gyromagnetic ratio, λ – the damping parameter, which we have set: $\gamma=1.0$ and $\lambda=1.0$, $\mathbf{B}^{(eff)}_i$ – the effective field vector was determined using the Hamiltonian :

$$\mathbf{B}^{(eff)}_i=\{B_x=\partial H/\partial S_x , B_y=\partial H/\partial S_y , B_z=\partial H/\partial S_z\}$$

The Hamiltonian of a Heisenberg spin system is given by:

$$H=-(1/2)\sum_{i,j} J_{ij}S_iS_j - K\sum_i S^2_z - \mu_s\sum_i (\mathbf{H},\mathbf{S}_i)$$

the sum of the exchange interaction energies between spin moments with constants J_{ij}, the magnetic anisotropy energy with constant K and the energy of the magnetic moments of the atoms μ_s in an external magnetic field **H** .The study will investigate two models of thin film oxidation: i) layer-by-layer oxidation, where the first monolayer (free surface of cobalt) is oxidised, forming islands that increase in size until complete oxidation of the layer. This process is repeated for the second, third and subsequent layers; ii) combined oxidation, which is a combination of surface and bulk oxidation. The oxidation process begins with the first layer, followed by the formation of cone-shaped structures that sprout layer by layer into the film.

The results of the atomistic modelling of the influence of the oxidation process on the hysteresis properties of Co/CoO films are presented. The dependences of the residual magnetic moment (Mr) (equal to the saturation magnetic moment (M_s)) and coercive force on the relative volume of cobalt oxide $V=V_{CoO}/V_{Co}$ for different oxidation models were calculated. The linear drop in M_s (M_r) was found to be determined by the increase in the relative volume of the oxide in the paramagnetic state for both models. The dependence of the hysteresis characteristics on the degree of oxidation is practically independent of the model used, whether it is layer-by-layer or combined oxidation. It follows from the calculations that the dependence of the hysteresis characteristics on the degree of oxidation is practically independent of the model used.

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When magnetite is truly magnetite?

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Magnetite (Fe_3O_4) is the most ubiquitous magnetic mineral in terrestrial rocks and also is present in extraterrestrial environments. Magnetite-bearing rocks provide an essential part of paleomagnetic record. At the same time, Fe_3O_4 can be formed in nature by about a dosen of pathways and therefore may serve as a potential indicator of rock-forming environments. All this warrants the central role of magnetite in rock magnetism.

In this talk, I will review the methods, both magnetic and non-magnetic, that are in common use to detect magnetite presence in rocks paying a particular attention to their limitations and caveats. I present a few examples showing that the simplictic approach which assumes that a magnetically soft phase with a Curie and/or unblocking temperature around 580°C is magnetite may be in error. Measurements at cryogenic temperatures to detect the Verwey phase transition appear by far the most reliable magnetic method to prove the presence of (near-)stoichiometric magnetite, and are able to discriminate the latter from e.g. cation-deficient Ti- or Al-substituted varieties.

GC2024-PERM047

Rock magnetic characteristics of loess -soil series in Tajikistan (based on materials from the study of the reference section Khonako-II)

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Introduction: The loess-soil sections of Tajikistan constitute a unique paleogeographical archive, providing information about the glaciations and interglacial periods of Central Asia. The studied site is the loess-soil section of Khonako-II (38.359268°N, 70.046344°E), located near the village of Khovaling in the Khovaling district. This study presents the results of rock magnetic research on the upper part of the section (first 20 meters), corresponding from Holocene to Marine Isotope Stage 5 (MIS 5).

Methodology: Rock magnetic analysis involves measuring the frequency and temperature dependence of magnetic susceptibility, its anisotropy, natural remanent magnetization, as well as hysteresis experiments to study saturation remanent magnetization, coercivity remanence, and other parameters. The Kappabridge MFK1-FA was used for measuring the frequency dependence of magnetic susceptibility (Kfd) at low (976 Hz) and high (15616 Hz) frequencies. A total of 500 samples were measured (every 4 cm).

The Kappabridge MFK1-FA was also used to measure the temperature dependence of magnetic susceptibility (kT). A pilot collection was measured: 5 from the Holocene soil, 5 from the first loess horizon, 5 from the first pedocomplex. Additionally, the Kappabridge was used to measure the anisotropy of magnetic susceptibility (AMS).

Coercivity spectrometer (J-meter) (Jasonov et al., 1998) was used to measure characteristics of isothermal magnetization and coercivity. 192 samples were investigated under continuous growth of the external magnetic field (at the maximum field of 1,5 T).

Results: Correlation of the magnetic susceptibility pattern with the marine isotope stage (MIS) record, age constraints were established for the upper part of the reference section Khonako-II. Specifically, the first pedocomplex was correlated to MIS 5 with an age of 100-130 thousand years.

According to thermomagnetic analysis, magnetite is the main magnetic mineral The Curie temperature for all samples is about 580˚C; however, the samples are not completely demagnetized, confirming the presence of the hematite t.

The predominant wind directions were obtained by the base of AMS data. The main wind directions for both the first loess horizon and PC-1 are NNW-SSE and NNE-SSW wind directions.

By the results of rock magnetic research, 11 stages of sediment accumulation and environmental development were identified within the first 20 meters of the section. We identified a Holocene soil, a loess horizon containing 2 small periods of warming (corresponds to MIS 3) and the pedocomplex consisting of 2 paleosols and corresponding to the stages of MIS 5c and MIS 5e. The contribution of the paramagnetic component to the total magnetization (Kpar/Kint%) ranges from 4 to 23%. There are two intervals of increasing paramagnetic signal in the lower part of the soil (1720-2040) and in the middle part of the loess (520-820). In the last interval, the concentration of paramagnetic grains sharply increases - apparently these are paleopic MIS 3, which is not distinguished according to the results of lithological analysis. Based on the results of the analysis of rock magnetic characteristics, it was established that in the Middle Pleistocene there were significant climatic fluctuations even during the cooling stage. The ferromagnetic, paramagnetic, and superparamagnetic components of magnetic

susceptibility change synchronously along the section, increasing several times in magnitude in soil horizons.

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GC2024-PERM048

Rock magnetic characteristics of loess-soil series in the Azov region (Beglitsa and Chumbur-Kosa sections)

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Introduction. The Beglitsa and Chumbur-Kosa sections are located in the Eastern Azov region. Here, in the coastal cliffs of the Azov Sea, loess-soil series of the south of the Russian border, formed in the middle and late Pleistocene, are exposed. The Beglitsa loess-soil section is a stratotype of the Late Pleistocene LPS of the region (Konstantinov et al., 2018). Here, two developed paleosols MIS-5c and MIS-5e, dense liss soils MIS-4 and MIS-3, as well as the poorly developed paleosol MIS-3 are reached (Velichko et al., 2017). In the Chumbur-Kosa section, a thick thickness of the LPS of the Upper and Middle Pleistocene is revealed, where 4 PCs are distinguished, which correspond to the interglacial epochs MIS-5, MIS-7, MIS-9 and MIS-11 (Chen et al, 2022). The thickness of these sections is about 20 meters.

Methods. In the sections of Beglitsa and Chumbur-Kosa, 13 and 22 oriented blocks measuring 10x10x15 cm were visible, representing all the loess horizons and pedocomplexes exposed in the studied finds. Oriented cubic fragments measuring 2x2x2 cm were cut from the blocks, which corresponds to 160 and 128 pieces for the Beglitsa and Chumbur-Kosa sections. For rock magnetic studies, a pilot collection of 10 pieces (5 from each section) was studied, consisting of various soil and loess horizons of the Beglitsa and Chumbur-Kosa sections. To measure the temperature dependence of magnetic susceptibility (kT) and the anisotropy of magnetic susceptibility, visit the laboratory of the Institute of Physical Sciences of the Russian Academy of Sciences (MFK-1, AGICO). Coercivity spectrometer J-meter (KFU), used to measure normal magnetization and coercivity characteristics. The 32 measurement (10 samples for Beglitsa and 22 samples for Chumbur-Kosa) of determination around V = 1 cm3 was studied with a continuous increase in the external magnetic field (in a maximum field of 1.5 T).

Results. Based on the results of the temperature dependence of magnetic susceptibility, it can be concluded that magnetite is the main carrier of magnetic susceptibility (Curie temperature (Tc) = 580°C) with a smaller contribution from the hematite component. Most examples of bending use a heating curve around 520–550°C, which is presumably due to the Hopkinson effect. It is also worth noting that all samples have a very weak magnetic susceptibility, which can have a negative impact on the use of magnetic methods in these conditions. Based on the results of hysteresis parameters obtained as a result of measurements on the J-meter coercivity spectrometer at KFU, the following were obtained: 1. values of inductive magnetization Ji, residual saturation magnetization Jrs, saturation magnetization of ferromagnets Jfer, magnetization of paramagnets Jpar). 2. Coercivity characteristics (coercivity Vs and residual coercivity Bcr). 3. Various biparametric rock magnetic characteristics. The obtained data on the anisotropy of magnetic susceptibility indicate that the magnetic texture of the loess-soil deposits of the Beglitsa and Chumbur-Kosa reference sections is probably deformed and secondary, and the resulting formations are not suitable for paleowind reconstruction. Based on the results of the rock magnetic work, it can be noted that the main magnetic mineral in the Beglitsa and Chumbur-Kosa sections is magnetite with a minor contribution of the hemagite component. Using Day plot, it was determined that the images of the lower sections were viewed in the same zone (very close to each other), which indicates a slight difference in the sizes of the magnetic particles. The concentration of magnetic particles is very low (visible on the kT curve), the susceptibility is very weak, which allows us to assume that it is not possible to reconstruct the

directions of paleowinds from these sections.

GC2024-PERM049

Spectral analysis of geomagnetic field variations at the Eskdalemuir Observatory in the range of 2-41 years

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Today, the study of the internal structure of time series is carried out using various methods: constructing difference integral curves, correlation and spectral functions; using spectral-time analysis, each of which has its own advantages and disadvantages. One of the most preferred methods is spectral analysis, based on the expansion of functions, graphically represented as an oscillatory process, into a Fourier series. When carrying out our studies, the initial data for high-frequency oscillations of the geomagnetic field were data from instrumental observations from 1941 to 2023 of three components of the magnetic field at the Eskdalemur observatory. Eskdalemuir Observatory is located near the village of Eskdalemuir in the Dumfries and Galloway region of Scotland. The spectrum is interpreted in the range of 2-41 years.

The research was carried out within the framework of the state assignment of the IPE RAS and the state assignment of the IDG RAS No. 1220329000185-5 "Manifestation of processes of natural and man-made origin in geophysical fields".

GC2024-PERM050

Prospects of studying and possibilities of indication of catastrophic flood deposits by petromagnetic methods

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Traces of catastrophic floods have been recorded in different regions of Siberia. In Altai [1] and Tyva [2], these floods were associated with outbursts of glacier-dammed lakes, and in the Baikal region [3] with a catastrophic landslide in Lake Baikal and the subsequent tsunami. Research on catastrophic floods and associated sediments in Russia began in the 80s of the 20th century, but the most intensivity has been reached in the last two decades. In the USA they have been known since the first half of the last century [4]. In general, more significant experience has been accumulated abroad in the use of various methods to study the sediments in question. In particular, petromagnetic methods have been used quite widely in a variety of aspects. Below we will consider the main directions of studying catastrophic floods in which petromagnetic methods were used abroad. This experience may also prove valuable in studying the deposits of the corresponding formations in Siberia.

Studying the direction of magnetization in catastrophic flood deposits allows us to determine whether they were formed by one or many floods [5]. If the average direction changes greatly within the section of such deposits, this may indicate a multiplicity of flood events.

Sometimes a drastic change in a number of magnetic properties (natural remanent magnetization, magnetic susceptibility, magnetic saturation, etc.) along a section also makes it possible to determine the boundary more accurately in the case of relatively smooth transitions between deposits of outburst floods and glacial-dammed lakes [6].

Viscous remanent magnetization can be used to date catastrophic floods [7] due to the gradual and partial change in the direction of magnetization in boulders moved by the flow and the dependence of the degree of this change on time.

Analysis of magnetic susceptibility and isothermal remanence can show whether different units of catastrophic flood sediments have the same or different sources [8].

Thus, petromagnetic methods can be used to study a variety of aspects of the structure and formation of catastrophic flood deposits. Their application to the corresponding deposits in Siberia would significantly deepen the understanding of the general and individual features of their structure and conditions of formation.

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Paleomagnetism and Anisotropy of Magnetic Susceptibility in the Late Quaternary Lava Flows from the Tolmachev Dol area (the Southern Kamchatka)

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Paleomagnetic investigation of the Quaternary volcanic rocks of Kamchatka is important due to several reasons. First, the existing global models of the geomagnetic field are still insufficiently reliable because the data are non-uniformly distributed across the Earth's surface (e.g. [1,2]. For instance, only scarce reliable information about secular variations of geomagnetic field is available for northwestern Pacific, and data for some regions are absent altogether. Given that, the new detailed paleomagnetic information on basaltic lava flows from Kamchatka can be an important contribution to the global models, in particular, for determining the nondipole components of the geomagnetic field. Also, these data can be applied for the regional correlation of volcanic events.

Another vital problem is a reconstruction of the dynamics of the eruptive processes. In Kamchatka, recent volcanic activity is related to large stratovolcanoes, monogenetic cones and domes, and fields of areal volcanism. For the latter, the reconstruction of local volcanic centers and distribution directions of lava flows is important in the context of the volcanic dangers estimation.

Within this study, we analyzed 13 paleomagnetic sites from basaltic lava flows of the Tolmachev Dol area (the Southern Kamchatka). This district is a well-known field of the areal volcanic activity in the Southern Kamchatka with the age of 25-3 Ka [3]. At this moment, 11 site-mean paleomagnetic directions, satisfying the modern methodical and instrumental standards of paleomagnetic studies, were calculated. For 3 sites, we obtained anomalous directions with low inclinations, which can correspond to the geomagnetic excursion. Future perspectives are to obtain the reliable ages from the OSL-dating and to perform the paleointensity experiments.

Furthermore, we measured anisotropy of magnetic susceptibility in the studied lava flows. The majority of sites demonstrate the low degree of anisotropy, typical of the basaltic flows ($P<1.05$). Based on the magnetic lineation, the patterns of lava transport were reconstructed. Preliminary results point out the eruptions from the multiple volcanic centers.

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High-Latitude paleointensities after the end of the Cretaceous Normal Superchron from the Okhotsk–Chukotka Volcanic Belt

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This work presents the results of studies of paleointensity H_{anc} on the Cretaceous igneous rocks from the northern part of the Okhotsk-Chukotka volcanic belt. The goal of the study is to trace the behavior of the Earth's magnetic field during the Cretaceous superchron (the superchron time frame is 121–84 Ma - Geomagnetic Polarity Time Scale, [1]) and after its termination. According to isotope dating, the studied magmatic rocks were formed 72-71 Ma (or 71-67 Ma; [2]). Based on the results of AF and temperature demagnetization, the mean paleomagnetic direction of flows is D=10.2º, I=80.3º. For this time interval after the end of the Cretaceous superchron, there is no data available in the paleointensity database (PINT database, [3]) for high paleolatitudes, and the determinations obtained in this study were aimed to fill this gap.

Ninety-three flows were studied. Fifty lava flows stable to heating (up to 10%) and with an excellent paleomagnetic record were selected for pilot Thellier-Coe experiments (1–4 samples from each of flows) with pTRM checks. Eleven flows were selected for further detailed experiments.

As a result, after 180 Thellier-Coe experiments, only 3 flows were selected. Two flows from one volcanic sequence demonstrate H_{anc}=14.49 μT (mean for 9 samples) and H_{anc}=17.7 μT (mean for 7 samples). One flow from other volcanic sequence demonstrate H_{anc}= 31.19 μT(mean for 8 samples). All determinations meet to criteria PICRIT03 [4] and have at least 5 (out of 8) points according to qualitative reliability criteria [5]. At the Day plot [6] the majority of samples belong to the area usually referred to pseudo-single-domain (PSD) behavior. In accordance with $pTRM_a$ tails[7] for most studied flows MD grains are carriers of remanence to the 300-450ºC interval, and SD and PSD grains are carriers of remanence from 350 ºC to 600 ºC interval. Although Arai-Nagata Diagrams show one slope, for most samples, the high-temperature intervals were selected for interpretation. Selected intervals fully correspond to the primary magnetic component identified during component analysis.

Thus, the obtained determinations of H_{anc} satisfy the reliability criteria and can supplement the existing knowledge about the paleointensity of the geomagnetic field after the end of the Cretaceous superchron with previously unreported data for high latitudes.

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GC2024-PERM053

Devonian paleomagnetic data on the East European Platform in the context of the problem of complicated magnetic field record and the presence of atypical Devonian components

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The Devonian field problem is an actual question of Paleozoic paleomagnetism. The available data are controversial, and it is difficult to obtain reliable paleomagnetic data because of the widespread remagnetization of Devonian rocks and the low value of natural remanent magnetization.

The results of studies of magmatic rocks indicate a complicated configuration of the Devonian magnetic field. This, together with the low paleointensity, may indicate its multipolarity and, as a consequence, the presence of atypical (different from the expected) field components. This, in turn, calls into question paleotectonic reconstructions and magnetic polarity scales for the Devonian time, since they are based on the central axial dipole hypothesis.

Despite the complexity, the study of the geomagnetic field purely from magmatic rocks does not allow us to reconstruct a continuous paleomagnetic record and it is discrete in this case. Therefore, in order to confirm the hypothesis of multipolarity of the Devonian geomagnetic field, it is necessary to study objects not only from magmatic but also from sedimentary rocks. The sediments of the East European Platform and its surroundings are one of the available objects for solving this problem. In this paper, we summarize the data obtained in this region from the 1970s to the present time, including our preliminary results.

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GC2024-PERM054

Study of the structure and evolution of the axial zone of the Carlsberg Ridge

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We present the results of detailed studies of the axial zone of the Carlsberg Ridge (CR), which is located in the northwestern part of the Indian Ocean and is the divergent boundary of the Indian and Somali plates. More than 300 magnetometric and bathymetric profiles were analyzed, crossing the CR practically along its entire length and allowing to study variations of the seafloor depth along the ridge axis. As a result of the analysis of these data, as well as the analysis of free-air gravity anomalies and the vertical gravity gradient [Sandwell, D.T., et all., 2014], off-axis tectonic structures were mapped and a total of about thirty first- and second-order continuity discontinuities were identified.

Using linear regression of the dependence of the ocean floor opening distance for anomalies younger than C4n.1 (7.537 Ma) on the age of the isochrones for the Somali and Indian plates [Merkouriev, S., and C. DeMets (2006)], estimates of the linear spreading rate relative to its center were obtained for each segment. This allowed us to estimate the crustal accretion asymmetry ratio on the Indian and Somalia plates and its variation along the ridge. The obtained estimates of linear velocities are in good agreement with the estimates obtained from kinematic rotation models of the Indian and Somali plates [DeMets et all., 2010].

The analytical signal method was used to determine the width of the axial (Brunhes) magnetic anomaly over the Carlsberg Ridge from the magnetic profiles. Comparison of the obtained estimates of the axial anomaly widths with those calculated from the linear spreading velocity allowed us to estimate the amplitude of outward displacement of the of the polarity boundaries due to Gabbro's layer magnetized over a range of distances by cooling through a sloping blocking-temperature isotherm (at which magnetization becomes stable over geological time) and lava flows that acquired magnetization at various distances, accumulating away from the axis.

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GC2024-PERM055

Paleomagnetic studies of marine sediments of the Russian Arctic seas under the project of state geological mapping of the territory and continental shelf of the Russian Federation at a scale of 1:1,000,000

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Marine sediments of the Arctic seas of the Russian Federation have been studied with varying degree of detail.

Under the project of state geological mapping of the territory and continental shelf of the Russian Federation at a scale of 1:1,000,000, sediment cores were collected using a gravity corer from the Chukchi, East Siberian, Laptev, Kara and Barents seas by FSBI «VNIIOkeangeologia» in different years [1], [2], [3]. In 2020-2021, also within the framework of this program, two cruises were carried out by FSBI «A.P. Karpinsky Russian Geological Research Institute» to the East Siberian Sea, where sediment cores were also obtained [4],[5].

Here, we present results of paleomagnetic studies on numerous sediment cores, collected during the expeditions mentioned above. The studied cores, which age varies from the Middle Pleistocene, or even from the Pliocene-Early Pleistocene, up to the Late Holocene, have shown how diverse the processes and sedimentation conditions are across the Russian Arctic shelf (for example, see [6], [7]).

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GC2024-PERM056

Remagnetization during hydrothermal process: paleomagnetic data and geodynamic consequences

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It well known that the fixation of magnetic minerals by magnetic minerals of the direction of the ancient geomagnetic field occurs at the time of their introduction or outpouring, and subsequent changes in the composition of the magnetic fraction are the result of later tectonic-thermal events. At the same time, numerous publications have shown that in mid-oceanic ridges, when interacting with seawater, the transformation of magnetization carrier minerals begins almost immediately.

For island-arc systems, such a transformation mechanism has been poorly studied. We tried to consider and systematize such secondary transformations using the example of the Middle Jurassic volcanic complex of Cape Fiolent (Heraclea plateau, Crimea).

The Middle Jurassic volcanites in the area of Cape Fiolent are described as an ophiolite association, including serpentinized ultrabasites and serpentinites, stratified basite-ultrabasite complex, gabbro and gabbro-dolerites, fragments of a complex of parallel dikes, pillow lavas, siliceous black layered formations and jaspers. The chemical composition, including the distribution of rare earths and a wide range of other trace elements, cushion lavas and dolerites from the ophiolites of the Cape Fiolent area, indicates their suprasubduction nature and belonging to the back-arc basin, which has reached the spreading stage in its development (Promyslova et al., 2014). These rocks are penetrated by extrusive domes, rods and dikes of plagioriolites (Promyslova et al., 2016).

Plagioriolites are porphyritic rocks of light greenish-gray color. Porphyry secretions up to 1.5−2.0 mm in size are represented by tabular acid plagioclase and isometric quartz crystals immersed in a cryptocrystalline quartz-plagioclase bulk (Promyslova et al., 2014). According to petro-geochemical characteristics, plagioriolites belong to low- or moderate-potassium silicic acid rocks of the calcareous-alkaline series with a flat distribution spectrum of rare earth elements and a quite distinct negative Eu anomaly (Kuznetsov et al., 2022; Promyslov et al., 2014). According to the U-Pb zircon dating data (SHRIMP-II, VSEGEI, St. Petersburg), the age of plagioriolites is defined as 168.3□1.3 million years (Kuznetsov et al., 2022).

Numerous publications have shown that rocks of different composition containing different magnetization carrier minerals can be magnetized in different ways [1 and references in this work]. The opposite is also true – magnetic minerals in different composition (acidic ↔ basic) and genesis (igneous ↔ sedimentary) rocks under the same conditions are most often remagnetized in different ways.

According to [2], the mechanisms of chemical remagnetization can be divided into two groups: changes caused by the influence of fluids, and changes associated with the process of diagenesis. Fluid motion is often associated with orogeny, according to [3] this mechanism is typical for many examples of residual chemical magnetization (CRM).

The study of the samples revealed several factors contributing to chemical remagnetization due to the formation of secondary single-domain magnetite: (1) the mineral composition of the rock and (2) the concentration of sodium chloride in solution. In highly concentrated solutions, the formation of magnetite occurs faster. With increasing temperature and pressure, the rate of magnetite formation increases. The rate of magnetite formation in olivinite and pyroxenite samples is proportional to the square root of time, which corresponds to the model of diffusion control of metasomatic reactions.

GC2024-PERM057

Current update of the magnetostratigraphic scheme of the key Ordovician section of the Moyero River and the behavior of the geomagnetic field on the eve of the Moyero superchron

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There are different points of view on the origin of the geomagnetic superchrons. According to some of them the onset of the superchron is a consequence of the gradually changing conditions on the core-mantle boundary, others consider the superchrons as an accidental state of the geomagnetic field arising from the non-linear stochastic nature of the geodynamo process. This issue is of crucial importance for the development of the modern geodynamo models, for our understanding of the geomagnetic field evolution. If the first point of view is true, then we can expect the relatively gradual change of the geomagnetic reversal frequency when approaching the superchron. If the onset of superchron is an accidental event – we should observe no regular changes in the geomagnetic field behavior and, in particular, in geomagnetic reversal frequency. Thus the study of the geomagnetic reversal frequency on eve of superchrons can be very useful for testing various conceptions and different geodynamo models describing the geomagnetic field evolution.

Numerous studies of changes of geomagnetic reversal frequency just before the youngest Cretaceous superchron result in rather ambiguous conclusions and require additional data from other superchrons. Second by age – Kiaman superchron – is rather difficult to study mainly due to the limited number of suitable sections. On the contrary, the third Phanerosic superchron – superchron Moyero seems to be very interesting for such studies as in Siberia there are a number of sections which have been formed over the time preceding the Moyero superchron and in its beginning. One of them - the carbonate-terrigenous section of Moyero River is perhaps the most promising ones to obtain the detailed magnetostratigraphic record of the geomagnetic polarity changes on the eve of the third Phanerozoic superchron. This section is very well exposed, composed often by favorable for paleomagnetism lithologies and its Tremadocian part (recall that Tremadoc is the time immediately preceding the Moyero superchron) has thickness which is unusually high for platforms.

Over the past few years, we have conducted an extensive paleomagnetic study of the Moyero section, and in this report we demonstrate its preliminary new magnetostratigraphic scheme, which represents a significant update to our previous scheme published more than a quarter of a century ago (Pavlov and Gallet, 1996). The available Tremadocian magnetostratigraphic data from the Chinese Tangshan section (Yang et al., 2002) do not contradict our results.

Our data, in particular, indicate rather low geomagnetic reversal frequency during the Tremadoc, that can be considered as probable evidence for the gradual change of conditions on the core-mantle boundary on the eve of the Moyero superchron.

GC2024-PERM058

AMS study of the evolution of the Middle-Late Ordovician sea basin in the North of the Siberian platform

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Anisotropy of the magnetic susceptibility (AMS) in the sedimentary rocks may be largely determined by hydrodynamic forces et, hence, by the velocity and by the directions of currents of the medium in which the detrital grains are being transported and deposited (Tarling and Hrouda, 1993). Thus, AMS measurements can provide us with information about the hydrodynamics of sedimentary basins and its evolution over time. In this report, we demonstrate AMS data that were obtained from the upper part of the Ordovician strata which are exposed in the middle reaches of the Moyero River (Northern Siberia, south of the Anabar uplift) and include the rocks of the Volginsky, Kirensko-Kudrinsky, Chertovsky, Baksanian and Dolborian regiostages. The rocks under study were formed within a vast shallow marine basin that covered a significant part of the Siberian Platform in the Ordovician, so our AMS data may have application for understanding the paleogeography and hydrodynamics of this basin and its evolution. Analysis of the distribution of the axes of magnetic anisotropy indicates that a significant reorganization of the sedimentary basin took place in the middle part of the chertovskian (Sandbian) time.

GC2024-PERM059

Cyclostratigraphic study of the Upper Cambrian deposits of the Kulyumbe key section (NW of the Siberian platform) aimed to constrain the duration of magnetic zones and δ ^{13}C SPICE anomaly

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One of the most practically significant tasks in paleomagnetism is the development and constant refinement of the magnetostratigraphic scale. On the one hand, this makes it possible to correlate sedimentary sequences outside a single sedimentation basin, and on the other hand, determining the position of the boundaries and duration of magnetic polarity zones on the geochronological scale provides important information about the dynamics of processes occurring in the inner shells of the Earth.

The cyclostratigraphic method makes it possible to construct an age model of a sedimentary section with a resolution unattainable by geochronological methods. It is based on recording in sedimentary rocks a signal of climate variations forced by cyclic changes of the Earth's orbital parameters (ellipticity of the orbit, obliquity, precession angle). This is a kind of “pulse” that allows you to move from the thickness scale to the time scale when studying a sedimentary section.

However, such a time-calibrated signal still remains unattached to the geochronological scale. To do this, the signal needs to be anchored by a well-dated event, such as a stage boundary, a volcanic event, or a peak in a stable isotope ratio curve (so called “isotope anomaly”).

Summarizing the above, in theory, cyclostratigraphic studies make it possible to determine the exact age of the boundaries of magnetic zones, their duration, and also to assess the completeness of the stratigraphic record.

The δ^{13}C SPICE (Steptoean positive isotope carbon excursion) anomaly has been described in many Cambrian sections of the world, including on the Siberian Platform. Here it is recorded in the terrigenous carbonate section of the Yurakhian horizon of the Kulyumbe Formation, the lower boundary of which correlates with the lower boundary of the Paibian Stage of the Cambrian and has an age of 497 million years.

Our report will present the first results of a preliminary cyclostratigraphic study of the Yuryakhian horizon of the Kulyumbe Formation of the Kulyumbe river section and its application to constraint the duration of the SPICE anomaly as well as long interval of the magnetic polarity both recorded in these sediments [Kouchinsky et al. 2008]. Data on the magnetic susceptibility (MS) of rocks were used as a proxy. MS variations have a distinct cyclic nature, well coinciding with the cyclicity observed in the section, expressed in the color and composition of the rocks. This fact gives grounds to consider MS to be the primary characteristic of sediments. MS, in turn, mainly depends on the concentration and mineralogical composition of iron oxides, which are sensitive to climate change.

GC2024-SG001

Ionospheric perturbations caused by a complex of atmospheric acoustic waves radiated during and after earthquakes

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The report examines several modern theoretical models of the acoustic coupling channel of the lithosphere-atmosphere-ionosphere, which can describe the effects of strong earthquakes and volcanic eruptions on the atmosphere and ionosphere. A key component of such a coupling channel is the effect acoustic-gravity waves (AGW) generated in the atmosphere due to earthquake-induced vibrations of the earth or ocean surface. The amplitude of the gas velocity in AGW increases with altitude due to an exponential decrease in atmospheric density. Ionospheric plasma is carried away by the wave movements of a neutral gas, which leads to the generation of electric currents in the ionosphere and geomagnetic perturbations.

We deal first with perturbations caused by both a direct acoustic wave radiated from the earthquake epicenter and AGW generated by seismic waves and tsunamis [1]. The phase velocities of ionospheric perturbations associated with these waves can be different, since the seismic waves excite the acoustic branch of the AGW in the atmosphere, whereas tsunamis generate mainly internal gravitational waves. Underwater earthquakes can also cause surface Lamb waves propagating along the boundary of the atmosphere with the ocean. The amplitude of the gas velocity in these waves decreases with altitude. Therefore, Lamb waves, as well as meteotsunamis generated by these waves, appear to have little effect on the ionosphere.

Recently, experimental data have been obtained on simultaneous oscillations of the geomagnetic field and atmospheric pressure with frequencies of 3.5-4 MHz occurring after a seismic event. These oscillations lasted about one hour and were localized in the vicinity of the earthquake epicenter. It is assumed that this effect is due to the propagation of vertical atmospheric waves generated by vibrations of the earth's surface. Under certain meteorological conditions, the acoustic wave may partially reflect from the lower boundary of the thermosphere, which leads to vertical acoustic resonance at millihertz frequencies. Theoretical analysis shows that this effect can explain the magnitude and spectrum of the observed GMPs not only in the vicinity of the earthquake epicenter, but also in the magnetically conjugate region [2].

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GC2024-SG002

Theoretical models of atmospheric and ionospheric anomalies that can be interpreted as earthquake precursors

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The report provides a critical analysis of some modern theoretical models and hypotheses explaining the origin of atmospheric and ionospheric precursors of earthquakes. One of the most noticeable phenomena is the bay-like variations of the near-surface atmospheric electric field (AEF) with an amplitude of about 100 V/m. These phenomena were sometimes observed before strong earthquakes under fair weather condition. In early theoretical studies, it was assumed that such variations were caused by so-called mechanoelectric transducers located in the earth's crust. In more recent studies, abnormal changes in the electrical conductivity of the near-surface atmospheric layer and an increase in radon emissions from the soil were considered as possible causes of these phenomena. However, theoretical estimates have shown that all these models predict variations in near-surface AEF that are much smaller than the observed values. The analysis shows that another mechanism is more effective [1]. The observed AEF anomalies can be due to the vertical circulation of weak air flows, which carry away charged aerosols, light and heavy ions thereby producing space charge re-distribution in the atmosphere. Such a mechanism makes it possible to explain large variations in the vertical AEF up to changing the sign of the field to the opposite. However, the connection of this mechanism with earthquakes remains hypothetical.

The transport of aerosols and other charged particles, which are carried away by turbulent flows of air masses, can lead to the formation of vertical seismogenic currents in the atmosphere, which are carried by these charged particles. The electric fields excited by seismogenic currents in the ionosphere are studied in the report on the basis of a generalized model of such currents. The theory predicts that ionospheric perturbations generated by seismogenic currents are insignificant regardless of the nature of these currents and they are unlikely to explain the amplitude ionospheric earthquake precursors.

An increase in radon gas emissions from the soil was observed in seismically active areas prior to some earthquakes. Additional ionization of the air due to the radioactive decay of radon nuclei can lead both to an increase in the electrical conductivity of the near-surface atmospheric layer and to a change in the fair weather atmospheric electric current. There is a hypothesis that this effect can cause variations in the total electron content and currents in the ionosphere.

Another hypothesis suggests that an increase in radon emission is accompanied by heating of the lower layers of the atmosphere due to the release of latent heat during condensation of water vapor on light ions and ion clusters resulted from the radon nuclei decay. Theoretical analysis shows that both of these effects are insignificant and therefore cannot affect the ionosphere.

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On the possibilities and problems of using creepex as a characteristic of the seismogenic environment stress-strain state

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This paper highlights the development of the conceptual provisions and solutions set out in [1-4] on the creepex-analysis of seismicity in the tasks of geodynamic research of the major earthquakes preparation areas: 1) by the change in the creepex value around their foci [1] or in the accompanying seismic swarms [2], 2) by the correlation of the creepex with magnitude and depth during the major shock preparation [3]. The influence of the medium-depth seismicity of regional and global deep faults on the processes of focus preparation was also studied [4].

In this paper the dynamics of the correlation coefficient K_{KOR} (of the pair correlation of the magnitude M_S(t) and the creepex Cr(t)) is considered on a global scale according to the Harvard CMT catalog by deep (H≥50 km) seismicity extended along two strictly orthogonal to each other "main" seismic belts of the Earth [4], that are detecting by GIS-ENDDB seismolineamentic algorithm [5] and covering all earthquakes of the Globe with M_S≥7.5.

The K_{KOR} graphs demonstrate the four earthquakes having the most extensive K_{KOR} anomalies with approximately the same time intervals between them: 27.12.2003, 18.01.2011, 8.9.2017 and 9.01.2023.

This is two earthquakes: New Caledonian 27.12.2003 (M_S=7.0) and Mexican 8.9.2017 (M_S=8.3) corresponding to positive anomalies and the maximum of the trend growing before and decreasing after these events. Similar display can be associated with endogenous processes that increase the medium decompression, i.e. with episodes of global geotectonic stretching.

The Pakistani 18.01.2011 (M_S=7.0 and 7.0) and Indonesian 8-9.01.2023 (M_S =7.0 and 7.7) events have the largest negative anomalies, starting 49 and 15 days before them. It is logical to associate them with the consolidation of the environment along global seismic belts, presumably due to episodes of the most intense geotectonic compression of modern times. Such episodes may be connecting with the registered now fluctuation of the Earth's rotation [6].

Thus, the analysis results confirm the validity of the previously obtained conclusions [5] on the classical parameter creepex Cr_0~M_S-m_b according to the IDC catalog. The need to verify these results arose in connection with the observed cases of mass recalculation of the M_S values of this catalog. The lack of sufficient stability of the paired definitions of M_S and m_b forced us to involve other pairs of magnitudes in the creepex-analysis, in particular, the surface M_S and the moment one M_W (available in the CMT catalog). The resulting modified kind of the creepex Cr ~M_S-M_W has a clear physical meaning of estimating the degree of enriching the rupture in the focus by seismic energy E_S per unit of seismic moment [7] and therefore, just like the classical creepex, reflecting the relationship between creeping and explosive shift component [8].

The possibility of confirming the conclusions of the creepex-analysis with data from other catalogs (including with the involvement of other magnitude pairs), greater reliability of the definitions of M_S and m_b magnitudes and their completeness would increase the reliability of the results of retrospective geodynamic analysis.

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A possible thermal mechanism of electromagnetic earthquake triggering: Insight from laboratory press experiments and field estimations

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During the fields experiments on electromagnetic monitoring of the Earth crust at the Pamir and Northern Tien-Shan regions, when DC current of 0.6-3.5 kA has been injected into the crust through emitting grounded dipole of 4.2 km length, the spatio-temporal variation of regional seismicity has been found, which is explained by electromagnetic triggering of weak earthquakes around the dipole. The field data were confirmed by laboratory experiments at the press and shear machines, where it was demonstrated that DC current injection into the tested rock sample is resulted in sharp increase of acoustic emission (crack formation), sample failure, and triggering of laboratory "earthquakes" at the spring-block models of seismogenic fault. Nevertheless, the mechanism of electromagnetic earthquake triggering is still poorly understood. We discuss a possibility of earthquake triggering by Joule heating of porous fluid-saturated rocks during DC current flow through the rocks resulted in increase of fluid pore pressure and corresponding decrease of the effective rock strength followed by the fault rupture, when it is in subcritical strain-stress state. For verification of this hypothesis, we carried out the laboratory experiments at the specialized press, where the increase of the sample deformation rate is observed during electrical processing of the sample. The experimental results are compared with numerical data calculated by COMSOL Multiphysics© software, which indicate the clear pore pressure increase due to DC current impact. Nevertheless, the DC current density applied in the laboratory experiments is by 6-7 orders more than the numerical estimations of the current density in the earthquake preparation areas of the Northern Tien Shan where the field experiments on DC current injection were carried out. Thus, in our opinion, the Joule heating mechanism resulted in pore pressure increase and rock strength reduction cannot be employed for explanation of earthquake triggering observed during the field experiments.

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GC2024-SG005

Seismic moment tensor: a review

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A seismic moment tensor (SMT) is the most complete characteristic of an earthquake source in an instant point source approximation, i.e., when analyzed wavelengths significantly exceed source dimensions. In general, the SMT has six independent components and can be decomposed into isotropic and deviatoric parts. The isotropic part describes a volume change in an earthquake source. Usually, its estimates are characterized by significant errors. Therefore, in routine procedures used, for example, in the Global Centroid Moment Tensor Project, only the deviatoric SMT is determined. In turn, the deviatoric SMT can be represented as a sum of compensated linear vector dipole (CLVD) and double-couple components. The CLVD-component describes a complex geometry of a fault plane and, as a rule, is observed in sources of large tectonic earthquakes or volcanic seismic events. The double-couple component relates to a shear planar dislocation. The double-couple model well satisfies sources of a major part of small to even large earthquakes. In this approximation, the SMT can be constrained by a scalar seismic moment and earthquake focal mechanism. An earthquake focal mechanism can be determined by parameters of nodal planes (strike, dip, and slip angles) or by orientation of principal stress axes. One of the nodal planes is a fault plane and the second nodal plane is auxiliary.

In this review, some methods of SMT calculations, mainly used in international seismological agencies, are briefly discussed. Special attention is paid to determination of an earthquake focal mechanism from P-wave first-arrival polarities, as it is still the most common approach to constrain parameters of a seismic source in a double-couple approximation. The requirements to initial data and their quality are formulated. Finally, some applications of data on earthquake focal mechanisms for various geological and geophysical tasks (calculations of the crustal stress-strain field and a seismotectonic analysis) are illustrated.

GC2024-SG006

Focal mechanisms of earthquakes occurred in 1927–2022 in the East Arctic region

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The East Arctic region is characterized by a complex geological structure and relatively high level of seismic activity. Nevertheless, it is poorly-studied due to its remoteness. Determination of earthquake focal mechanisms is also restricted due to a small number of regional seismic stations and inappropriate geometry of seismic network. In such a case, available solutions of focal mechanisms are of high value for various fundamental and practical purposes.

In this study, we compile a database of earthquake focal mechanisms for the East Arctic region using information from international seismological agencies and literature sources. It consists of 595 focal mechanism solutions for 273 seismic events with M = 3.5–7.6 occurred in 1927–2022. Source depths, scalar seismic moments, and moment magnitudes are also presented there for many events. In addition to the source parameters, their quality assessments are available that facilitates a comparison of different solutions. For user convenience, the database has a graphical interface that allows searching by various attributes (coordinates, time, magnitude, and depth).

Our database significantly exceeds in terms of volume of the collected information all the analogues available at the current time. It can be used to perform a seismotectonic analysis, to estimate the stress-strain state of the lithosphere, and to assess seismic hazard for the entire East Arctic region or its separate areas. We illustrate implementation of the compiled database for comparison of different solutions of earthquake focal mechanisms and their seismotectonic analysis on an example of seismic events occurred in the Olenek Bay of the Laptev Sea and adjacent territories.

The database is available at https://www.itpz-ran.ru/ru/resultaty/maps-and-databases/east-arctic/ (registration No. 122041300106-8 from 19.02.2024). We suggest adding new information to the database every five years in the future.

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GC2024-SG007

Solving direct and inverse geophysics and geodynamics problems in site selection, construction and operation of nuclear power plants in accordance with federal norms and rules for the atomic energy use

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During surveys to select the area and site of nuclear power plants (NPP) that meet the requirements of the federal norms and rules in the field of the atomic energy use [1], [2], a set of geological, geophysical and geodynamic methods is used on the basis of known solutions of direct and inverse problems. For example, in order to identify a single tectonic block within which a nuclear power plant site can be placed, according to the requirements of paragraph 12 of NP-032-19, 3D seismic surveys are conducted. As a result of seismic exploration, the sections of true elastic wave velocities can be reformatted into rock density sections, and then the calculated values of Δg are compared with the observed values of Δg by solving a direct problem of gravity exploration [3]. In this way, the accuracy of the results of geological-geophysical and tectonic surveys in the area and at the nuclear plant site is assessed.

During the NPP design, the design values of settlement and tilts of the NPP buildings and structures (NPP B&S) are calculated using the data of geological sections of NPP B&S foundation soils and the values of physical and mechanical properties of the foundation soils.

At the NPP design stage, the program for monitoring of settlement and tilt of the NPP B&S using a high-precision geodetic method (inverse problem) is prepared, the requirements for which are defined in [4].

At the construction stage, periodic measurements of ground deformations of the NPP B&S foundations at the controlled points of the building structures are made. The initial cycle of geodetic monitoring of foundation ground deformations of the NPP B&S foundations shall be performed after completion of foundation creation before the start of erection of subsequent NPP building structures.

Before commissioning of the NPP, the act on completion of geodetic monitoring of ground deformations of the foundations of the NPP B&S and the existing observation network of geodetic monitoring shall be handed over to the operating organization for continuation of monitoring. The act on completion of geodetic monitoring of ground deformations of the foundations of the NPP B&S foundations contains the actual values of settlement and tilt of the foundations of the NPP buildings and structures at 10, 25, 50 and 100% load on the foundations [4].

At the NPP operation stage, the periodicity of geodetic observations of foundation ground deformations of the NPP B&S foundations is determined depending on the conditions of settlement stabilization.

During commissioning and operation of the reactor building, the non-exceedance of the design limits of settlement and tilt of the reactor building is justified by the sum of the results of two monitoring surveys: geodetic monitoring of foundations (base soils), which was discussed above, and geodynamic monitoring of modern vertical movements of the Earth's crust (surface), as detailed in [5].

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The Influence of Earthquakes on the Temperature Regime of Rocks

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During monitoring of the rock's temperature regime, a correlation was discovered between the signals of a laser strainmeter, a laser LIDAR (measuring the density of aerosol variations) and temperature values inside the rock base in the dead-end tunnel of the Baksan Neutrino Observatory (BNO), during the first and second strong earthquakes in Turkey (06 February 2023), having almost identical magnitudes 7.8 and 7.7.

We estimate of the stress zone radius from the epicenters as a value around 2000 km. It exceeds the distance from the earthquake epicenters to the BNO tunnels (~900 km), and thus allows the possibility of variations in the stress-strain state in the strainmeter, thermometer and LIDAR signals. And during the preliminary analysis of the captured data it was discovered.

In the underground laboratory, monitoring of variations in aerosols, temperature and deformation of the Earth's crust was performed using unique instruments developed at institutions of the Russian Academy of Sciences: Schmidt Institute of Physics of the Earth (precision multichannel thermometer), Prokhorov Institute of General Physics (LIDAR) and Sternberg State Astronomical Institute Moscow State University (laser strainmeter).

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Chandler wobble changes in 2020s

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We are contemporaries of a unique planetary event, observed once 90 years ago and not yet explained: the disappearance of the Earth's rotational axis wobble with a 433-day period and usual amplitude of ~3-6 m, named after S.C. Chandler, who discovered it in 1891.

The theory of Earth rotation given by the Euler-Liouville equations of rotation of the visco-elastic Earth derives the Chandler frequency as a resonant frequency of the wobble. We do not observe other processes at this frequency in the Earth's shells. It is generally accepted that small random variations in the atmosphere and ocean are responsible for the Chandler wobble (CW) excitation.

At the end of the 1920s and early 30s, CW decayed and changed its phase by 180°. Some specialists believe it was a random event. Recently it happened again. The removal of a trend and annual polar motion from the EOP C01/C04 time series clearly demonstrates that the amplitude of CW has been decreasing since the 1990s, and in 2019–2020, CW disappeared. We found out that in 2021 it appeared again, and by 2024 it made two oscillations with increasing amplitude. But the CW phase changed by 180° with respect to the observed before disappearance (turned upside down).

Researchers from China, Japan, and the USA already started to look for explanations for the amplitude decrease, analyzing atmospheric AAM and oceanic OAM angular momentum, putting forward the ideas that AAM disappeared or that AAM and OAM mutually destroyed each other. Some scientists put forward the hypothesis that processes in the core, or climate change and glacial melting, are responsible.

We discuss this phenomenon, suspecting the Moon and luni-solar tides responsible for the re-occurrence of the observed anomaly not only in CW but in LOD as well. Length of day (LOD) has reached its minima in 2023, making our epoch prominent. Earth rotates quicker than ever since the 1930s.

90-year periodicity is a half-period of mutual reoccurrence of phenomena related to the motion of the nodes and perigee of the lunar orbit. All luni-solar tides change with an 18.6-year cycle of nodal precession and an 8.86-year motion of the line of apses, defining the closest perigee position of the Moon. Ascending node (AN) and perigee meet every 6 years, but the difference between an 18.6-year cycle and a double 17.7-year cycle of rotation of perigee by ~0.9 years makes them meet at different points in the sky. Two loops close after ~10 cycles of nodal precession. If, for example, in 2024 AN and perigee meet at the point of vernal equinox (eclipse 8.IV occurs in perigee) at the equator, such an event occurred around 1838 and will happen around 2210 next time.

Two minima of CW amplitude and LOD separated by ~90 years could happen as a result of the transition of the perigee syzygies occurrence from higher declinations in the northern sky to higher negative declinations in the southern sky. Two events of quadrature: a) AN in the summer solstice, perigee in the vernal equinox in 1927, and b) AN in the summer solstice, perigee in the autumn equinox in 2020, separate these epochs. If it's true, the next CW zero-amplitude crossing will happen around the year 2113.

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GC2024-SG011

Seismic effects of industrial explosions in a granite quarry in Belarus

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The paper deals with an instrumental estimation of the seismic effect of massive industrial explosions in the Mikashevichy granite quarry. The observations have been carried out with digital stations being integral parts of a short-period three-component velocity-type seismometers LE-3DLite/1s [1] and seismic recorders GeoSig GMSplus [2], as well as LE-3DLite /1s as a unit with a recorder Delta-03M [3].

In order to obtain valid data about the nature of the seismic effects of explosions of varying power at different rock mining horizons in a quarry some parameters mentioned below have been studied:

1. A character of decay of the total vector velocity and its components in dependence on distance both for some separate explosions, and for all the explosions under consideration.

2. A dependence of the total vector velocity on the reduced distance.

The network of stations named “Granite” and intended for monitoring the industrial explosions and estimation of their impact on the dwelling zone was developed at the Mikashevichy building stone deposit in August, 2023.

A software package SeisComP of 5 version [4] was used for data processing.

During the primary processing of the seismic records the “useful” signal is selected from the microseismic noise with the subsequent interpretation of the amplitude variations as an arrangement the P-wave and S-wave phase arrivals.

A high level of vertically polarized seismic wave amplitudes is a characteristic feature of the majority of explosions recorded by the network stations, the horizontal components contribute insignificantly to the values of the total vector velocity of the ground motion.

Such initial data as the explosion power (average explosive charge of a single borehole, charge mass in a block), position of an explosion, distance to the seismic observation stations, instrumentally recorded ground motion velocity were used to determine the seismic impact rate.

The ML magnitude values obtained from the results of the cameral treatment of explosions were compared with charge masses actually applied in industrial explosions taken from the mining enterprise documents with the subsequent linear approximation within the specified confidence interval ± 0.2σ. The results obtained cause the author to state that the planned explosions with an average charge in one borehole from 150 to 750 kg (or a charge mass in block from 10,000 to 1000,000 kg) fall within the confidence interval considered with probability of 98%, which coincides with the magnitude measurement range from 2.25 to 3.05.

It is important to mention that when studying the seismic effect of industrial explosions it is necessary to have available microseismic background data in the region of works. Explosions which ground motion total vector velocity is not higher than 0.3 cm/c were selected for the similar spectral analysis. The frequencies below 15 Hz make the greatest contribution to the spectrum. In all the spectra a small peak can be noted about 100 Hz. Absolutely all the Nakamura spactra [5] show a maximum frequency around 2.5 Hz, which permit a conclusion that for the buildings and constructions located near some seismic stations of the network this frequency is as a resonance one and should be taken into consideration when estimating the seismic impacts.

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Precision Rock Temperature Monitoring System

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A multichannel precision system for monitoring the temperature of mountain rocks has been developed at the Schmidt Institute of Physics of the Earth Russian Academy of Sciences, which can record temperature changes with a relative accuracy of 0.005 degrees Celsius [1]. Currently, the system is constantly being modernized, both with the aim of improving resolution and reducing noise components of temperature signals, and increasing the number of observation channels [2].

The developed system is part of a comprehensive installation for monitoring geophysical parameters of the North Caucasus Geophysical Observatory of the IPE RAS, located in the adit of the Baksan Neutrino Observatory. Simultaneous recording of the air temperature in the adit and the temperature of the surrounding mountain rocks (at a depth of about 5 meters from the adit walls), as well as tilts, humidity, atmospheric pressure and monitoring of the density of aerosols inside the adit is performed [3, 4].

Knowledge of quantitative information about heat flow from the Earth's interior is of great importance for understanding the relationship between fluid-magmatic and geodynamic processes. Today, only the first kilometers of the Earth's crust are available for direct measurements of deep temperatures. However, precision temperature measurements are sometimes difficult because of the presence of interference associated with changes in the temperature of air masses at observation points, as well as because of wind impulses. Therefore, for precise temperature recording, it is necessary to ensure the most stable conditions at the measurement point.

One of the most suitable places for such observations is the adit of the Baksan Neutrino Observatory. Its location in proximity to the magma chamber of the Elbrus volcano makes it possible to obtain unique data on the structure and dynamics of the thermal field in its vicinity. The study of this volcano is an important task, both from the point of view of obtaining new fundamental knowledge about the structure of magmatic structures, and from the point of view of assessing the volcanic hazard caused by the presence of liquid magmatic melt in the depths of the volcano.

Further assessment of the contribution of conductive and convective components to the heat flow will allow us to draw conclusions about the dynamics of the fluid-magmatic system of the Elbrus volcanic center and study the mode of its functioning. The data obtained can also be used directly for monitoring volcanic hazards.

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Full-Scale Testing of the Use of Distributed Acoustic Sensing (DAS) Technology to Determine Ice Cover Parameters

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This paper presents preliminary results of an experiment conducted in the ice-covered waters of the Klyazma Reservoir in February 2024. The purpose of the experiment was to study the possibility of using a distributed acoustic sensor (DAS) to record seismoacoustic signals arising in a floating ice sheet.

It is known that the study of dispersive waves propagating in a layer of ice makes it possible to restore the characteristics of the ice cover [1]. Continuous recording of seismoacoustic waves in ice by two or more sensors makes it possible to implement a scheme for monitoring ice parameters (thickness, elastic properties) along fairly long routes.

This task is especially relevant in connection with the ongoing warming processes in the Arctic, which leads to the need to assess the degree of ice cover of the Northern Sea Route. In addition, the solution to this problem may be in demand, for example, for organizing winter ice crossings.

During the experiment, preliminary results were obtained that showed the possibility of using DAS to record seismoacoustic signals in an ice sheet. Further research in this area may lead to the development of new methods for monitoring ice parameters and optimizing the process of organizing ice crossings.

The use of DAS in ice conditions represents a scientific novelty [2]. The fact is that the sensor, formed from a straight fiber-optic cable laid along the ice surface, is sensitive only to deformations along the cable line. In this case, the most informative from the point of view of ice characteristics is precisely the vertical component of the vibrations of the ice plate, which is effectively measured, for example, by a geophone, but is not recorded by such a fiber-optic line.

To solve this problem, a unique scheme for laying a fiber-optic cable was used with the formation of mutually perpendicular rings, which make it possible to measure fiber deformations both along the linear group and across.

As a result of the study, a comparative analysis of DAS measurements on ice was performed with a reference instrument, which used a linear group of 24 vertical geophones, the distance between which was 5 meters.

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Digital Data Acquisition Systems for Data Capturing of Geophysical Information: Methods for Testing Performance in the Field

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Today, almost all geophysical research is carried out in digital format. For this, various digital data acquisition systems (DDAS) are used. The basis of any information DDAS is analog-to-digital converters (ADCs), which can be implemented both in the form of microcircuits and in the form of independent electronic units or boards.

Unfortunately, during fieldwork, personnel rarely pay attention to monitoring the correct operation of the ADCs used and promptly assessing the quality of their work. This issue becomes especially relevant when carrying out work far from civilization, where it is not possible to use expensive and complex service equipment.

Article [1] offers simple ways to test the performance of almost any ADC or DDAS. There is shown how, using the simplest equipment and instruments, you can make an initial assessment and check of almost any DDAS.

For example, for a three-component DDAS, by conducting just three independent tests (changing the input signals at each input in turn), it is possible to identify both the values of the critical parameters of the ADC and their possible main faults.

As a test signal generator, it is proposed to use a simple Wien generator circuit, which can generate a harmonic signal that is asymmetrical regarding zero (ground).

Thus, with just a simple set of tools, anyone can quickly evaluate and test almost any DDAS, determine the correctness of analog-to-digital conversion and display of input voltages, as well as the levels of inter-channel penetrations and even self-noise of the acquisition systems [1].

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GC2024-SG015

Advantages and Disadvantages of Distributed Acoustic Sensing Technology for Geophysics Tasks

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Distributed Acoustic Sensing (DAS) is experiencing exponential growth in its application and development today [1]. DAS technology is based on the use of Rayleigh scattering in fiber optic cables to obtain data on strain distributed along the length of the cable. In DAS, the cable is both a sensing element and a data transmission line. Today, DAS is used in volcanology, seismic microzonation, geophysics, etc. [2]. However, despite the significant advantages, this technology also has disadvantages that must be taken into account when using this technology. For example, one of the significant problems of this technology is that for each virtual sensor (channel) a large amount of work is required to determine its position, orientation, transfer function and intrinsic noise, etc.

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GC2024-SG016

Manifestation of the earthquake of January 23, 2024 (Northern China) in the components of the electromagnetic field (Northern Tien Shan)

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Modern geodynamic processes, as a rule, are reflected in variations of the Earth's electromagnetic (EM) field. The study of ones is of significant interest for understanding their internal mechanisms, since variations contain important information that is in demand when developing models of interactions and transformation of geophysical fields [1-4].

In order to determine the relationship between variations in the electrical conductivity of the Earth's crust and geodynamic processes, the Research Station of the Russian Academy of Sciences in Bishkek carried out EM soundings during the Kambarata explosion [5]. To process the sounding results, a technique for azimuthal magnetotelluric monitoring was proposed [5, 6], which makes it possible to identify not only anomalous changes in the modulus and phase of the apparent electrical resistivity (ρ_{app}), but also to determine the directions corresponding to their maximum increase and decrease (compression and tension axes). Based on the analysis of field data, experimental confirmation of the relationship between the stress-strain state of the medium and changes in ρ_{app}, due to the idea of redistribution of mineralized fluids between systems of cracks, was obtained [7-10].

As an example of the existing relationship between variations in geophysical fields and seismicity, in this work we considered 5 components of the Earth's EM field obtained at the Ak-Suu station, located in the Chu region during the earthquake 23.01.2024 (Tien Shan). This earthquake with a magnitude of M=7.0-7.27 occurred at 18:09:05 UT at a depth of ~13 km. The source of the earthquake was located in China, city of Aikol in the Xinjiang Uygur Autonomous Region (41.23° N, 78.59° E).

The data obtained indicate pronounced variations during the earthquake for 5 time series - two horizontal telluric components (E_x, E_y) and two horizontal (H_x, H_y) and vertical (H_z) components of the geomagnetic field. The maximum amplitude of variations is observed in mV for E_x = 0.45, E_y = 0.34, H_x = 450, H_y = 150, H_z = 530; the duration of the variations manifested themselves to a greater extent in the horizontal components of the magnetic field. As for the nature of the observed variations, they can be associated with mechanoelectric processes that arise at the extreme stage of preparation of the earthquake source and during the implementation of the seismic event.

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GC2024-SG017

Lithospheric magnetic sources in the East Arctic region

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We consider the thermal regime of the lithosphere under the East Arctic region (Northern Eurasia, marginal seas and the Arctic Ocean) based on geomagnetic data. Firstly, we calculate the depth to the bottom of the lithospheric magnetic sources using the EMAG2v3 model of the lithospheric geomagnetic field. A modified centroid method, developed for a fractal character of magnetization, is applied for the Eurasia Basin. For other areas, a centroid method, assuming a magnetization to be uncorrelated, is used. This bottom depth to some extent can be regarded as the Curie point depth (CPD). Secondly, taking into account that the temperature at the CPD is 578° C (CPD of magnetite), we suggest that our results provide some insights into the lithospheric thermal state under the considered territory and we estimate surface heat flow on their basis. We consider a case when the thermal field is steady-state and 1-D, the convection at all the depths is negligible, and only the radioactive sources of heat production exist in the crystalline crust. The CRUST 1.0 model is used to constrain the crustal structure.

The obtained distributions of the bottom depth of the lithospheric magnetic sources and surface heat flow show that the hottest lithosphere within the study area is attributed to the Eurasia Basin of the Arctic Ocean, where the modern spreading along the Gakkel Ridge is observed. Relatively high lithospheric temperatures are also seen under the East Siberian Sea and eastern part of the Laptev Sea, while the lithosphere is cold under the western part of the Laptev Sea including the Lena River delta and Buor-Khaya Bay. On the continent, the eastward lithospheric heating is traced from the Siberian Platform to the Koryak-Kamchatka fold belt. The most large-scale revealed tendencies are confirmed by independent geophysical data (available surface heat flow values and lithospheric temperature distributions based on seismic tomography data). The obtained results are of great value due to the lack of surface heat flow measurements within the study region.

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GC2024-SG018

Lithospheric magnetic anomalies over the Anatolian Plate (Turkey) as a reflection of the crust-mantle interaction processes

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Solicited talk

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In the last decades, ability of the lithospheric magnetic field data for studies the deep structure of the Earth is evident. Sources of this part of the geomagnetic field are located in the crust and uppermost mantle, i.e., up to depths where the temperature reaches the Curie point temperature of lithospheric magnetic minerals.

The Alpine-Himalayan orogenic belt, which includes Anatolia, has an extremely complex lithospheric structure. It is composed of groups of folded belts, terranes and crystalline massifs (microcontinents) with Precambrian basement. Tectonic activity is very high there, and its nature is interpreted as interplate interaction and (or) mantle processes. In many aspects, Anatolia can be considered as a "younger version" of the Tibetan Plateau, which lithospheric magnetic anomalies were analyzed by us previously. In the western part of the Anatolian province, the subduction of the African lithosphere under the Eurasian Plate is taking place in a northern direction. In the eastern part, the process of convergence between the Arabian Plate in the south and the Eurasian Plate in the north occurs. An overlap of these ongoing tectonic processes causes intense seismic activity, widespread volcanism and movements of the Anatolian Plate to the west.

Lithospheric magnetic anomaly (LMA) maps based on satellite data are used in the complex interpretation of large-scale geological and tectonic formations as they carry out information about the deep layers of the Earth's lithosphere magnetization and reflect the magnetic properties of regional tectonic structures associated with the topography of the Curie surface, geothermal regime and the history of tectonic development of the lithosphere at different levels. In order to study the LMA over the territory of the Anatolian Plate and its surroundings, detailed maps of anomalies of the lithospheric magnetic field were constructed based on the CHAMP satellite data. Measurements at the lowest possible orbit were used for the maps construction that allowed us to increase the resolution by getting closer to the sources of the field.

The obtained results show that regional lithospheric magnetic anomalies have a complex pattern with positive and negative areas of various shapes and amplitudes that is due to the tectonic structure of the territory. In our distribution of the lithospheric field, one can observe the consequences of tectonic processes which took place earlier and (or) are currently developing. In particular, the spatial distribution of lithospheric anomalies, constructed according to the CHAMP data, correctly reflects the superposition of collision processes. In addition, an observed change in the sign of anomalies as well as a sharp decrease in the LMA values, can be probably explained by the fact that a part of the Arabian lithosphere, sinking to the north, is being breaking away, that leads to the replacing this part of the plate with ascending hot asthenosphere substance, causing the recent volcanism. At the same time, mantle heating of the lower crust occurs, the Curie isotherm rises, and as a result the loss of the initial magnetization of the lower crust appears.

Maps of the lithospheric magnetic field and their analysis show that the images of lithospheric magnetic anomalies clearly correlate with modern ideas about the location of large-scale geological and tectonic structures of the Earth's crust in the region of the Anatolian Plate. In addition, their localization coincides with other geophysical data, such as seismic wave velocity. The results show that satellite magnetic observations add valuable information to regional tectonic studies.

GC2024-SG019

Some Features of Earthquakes Distribution in Turkmenistan

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Most regions of Turkmenistan are not characterized by high seismicity, but some of its areas are still characterized by high seismicity. The famous destructive Ashgabat earthquake, which occurred on October 5, 1948 in the Kara-Dag region, is well known.

In the paper compares the distributions of earthquake hypocenters in Turkmenistan obtained from the ISC catalog data for the period from 1964 to 2021 and the results of recalculation of hypocenters according to the ISC bulletin data for the same period. In total, the ISC catalog for the specified period contains about 1000 events with a magnitude greater than 2.5. The authors recalculated the hypocenters of slightly more than 350 earthquakes. It is shown that the depths of earthquake foci in the areas under consideration can be located at depths of up to 600 km, while according to the ISC catalog; the maximum focal depths do not exceed 100 km.

Based on geological and seism tectonic characteristics, the territory of Turkmenistan can be divided into three regions: Prikopetdag region (Ashgabat region); Krasnovodsk district (Western Turkmenistan); Eastern Turkmenistan [Seismicity, 1968]. According to the results of earthquake observations, the highest seismic activity is observed in the region of Western Turkmenistan and the Ashgabat region [Rustamovich, 1967].

From the analysis of the ISC catalog data, it follows that the bulk of the hypocenters are located in the depth range of 0-20 km. There are two horizons at depths of 0 and 33 km, where earthquake foci are concentrated. Both of these horizons are most likely determined by the method used to determine earthquake hypocenters. Moreover, the location of the hypocenters at zero depth, in our opinion, is due to the fact that it was not possible to determine the true depth of the foci. The depths of earthquake foci mainly in the Krasnovodsk region reach 100 km.

The recalculation of earthquake hypocenters in Turkmenistan was carried out according to the methodology outlined in [Burmin, 2019]. As can be seen from a comparison of the catalog data and the results of recalculation, the distributions of epicenters differ mainly only in the density with which they are located on the surface.

At the same time, the results of the recalculation showed that the bulk of the foci are located in the depth range of 0-300 km. At depths from 300 to 500 km there are also a sufficient number of sources. And several foci are located in the range of 500-600 km.

In conclusion, we can say that the existence of deep earthquakes is not unique. Thus, for the Crimean-Black Sea region, earthquake foci with depths of up to 300 km have been recorded [Burmin, Shumlyanskaya, 2017], and in the Caucasus to depths of 500 km [Burmin et al. 2019]. On the territory of Turkmenistan, the depths of the foci reach 600 km.

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GC2024-SG020

Graphic representation of the parameters of hydrogeochimical composition of mineral water in central Armenia

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Abstract

The possibilities of graphic representation of the geochemical parameters of the composition of mineral water is shown. In order to represent visually the results of the chemical composition of water, formulas were designed; hydrogeochemical profiles of the ionic and cationic composition of water were constructed in a certain direction and in time. Vertical sections of changes in concentration are made for a separate chemical component of the composition of water along the locations of mineral springs. The analysis and the results of hydrochemical observations are accurate if the obtained data is systematized and processed. The graphic method of systematization of hydrogeochemical materials is applied. These are hydrogeochemical maps. The maps of separate components such as magnesium, chlorine, sulfate-ion etc., profiles and sections are of the greatest interest. M.G. Kurlov's formula is applied for the results of single analyses of the chemical composition of underground water and graphic representation [1]. This formula allows to show graphically the composition of water as a pseudo fraction in which numerator indicates the content of anions, and denominator - the content of cations in a % equivalent form in decreasing order. In order to determine changes of the chemical composition of underground water in a certain direction (along borehole), the hydrochemical profile was constructed according to A.A. Brodsky [2]. . Analysis and systemization of hydrogeochemical information allows broadening the basis for quick decision making during the interpretation of results Seismological sections along the I and II profiles reflect the distribution of seismic centers of the occurred earthquakes deep in the earth crust in the territory of Central Armenia. The formed hydrochemical profiles allow to track the changes of ionic and cationic composition of mineral water for each mineral source as well as to give quantitative assessment of the ionic and cationic composition. Vertical sections are formed on a separate chemical element of water composition [3]. The analysis of changes of concentration (increase or decrease) of chemical element is assessed by increase of the activation of seismicity and stress-strain state of earth crust of Central Armenia.

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GC2024-SG021

Ice Geo-Hydroacoustic Buoy

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Recently, a new geo-hydroacoustic buoy was built at IPE RAS [1]. This buoy is designed to collect acoustic, underwater acoustic or seismic data under a variety of environmental conditions. It can be installed in onshore and offshore wells. The main purpose of this buoy development is to be used as an element of a distributed ice-class antennas in Arctic latitudes. These buoys are suitable to be used in the polar regions. The buoys are of modular construction and can be combined with sensors such as vector scalar underwater acoustic accelerometers, broadband molecular electronic velocimeters, and additional underwater listening devices. A major advantage of the buoy is its robust housing, which allows it to be used in ice fields and underwater at depths of up to 300 meters. This is especially important when transported by special means such as boats or helicopters. The advantage of buoys is their low power consumption, which guarantees stable autonomous operation for at least one week. Several field tests of the buoys have recently been conducted, and the results confirm that the buoys meet the high standards of modern seismic equipment.

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GC2024-SG022

Study of the Internal Structure of Geothermal Deposits in the Southern Part of the Kamchatka Peninsula

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In 2023, we studied the Pauzhetsky hydrothermal system and the Kambalny volcanic ridge. The study and exploration of Kamchatka geothermal deposits is a very perspective task. Currently, geothermal deposits are widely used as sources of electrical energy; several geothermal power plants have been built and put into operation in nearby areas. In the southern part of the Kamchatka Peninsula, a large number of wells have been drilled for the extraction of thermal waters for economic, resort and recreational purposes. There are many scientific works devoted to the study of geothermal deposits in the south of Kamchatka using various geological and geophysical methods. However, only some work has been done on seismic probing of hydrothermal systems at the moment.

GC2024-SG023

Integrated geophysical modeling of the lower crustal - upper mantle structure in the area of the Yenisei-Khatanga trough

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The Yenisei-Khatanga trough is intensively investigated by various geological and geophysical methods due to its oil and gas potential. In our study, we consider the crust and upper mantle structure under the trough based on geomagnetic, gravity, and seismological data and infer some geodynamical insights from all the obtained results.

Firstly, we performed a spectral analysis of the lithospheric geomagnetic field, presented with the EMAG2v3 model, using the centroid method for the Yenisei-Khatanga trough and adjacent areas of the Siberian platform and Taimyr Peninsula. Secondly, a 3D density distribution was calculated for the crust and uppermost mantle under the trough. Restrictions from independent geophysical and geological information, including deep seismic sounding (DSS), 2D seismic profiling, borehole, and magnetotelluric data, were applied during the inversion of the observed gravity field. Finally, 2D S-wave velocity patters along the existing DSS profiles, crossing the considered area, were estimated from local Rayleigh wave group velocities within the periods of 10–250 s, which had been determined by us previously for the whole Arctic.

It has been shown that the deepest bottom depth of the lithospheric magnetic sources (about 50 km) is observed along the whole Yenisei-Khatanga trough. Assuming that this depth to some extent can be regarded as the Curie point depth (CPD) and the main magnetic mineral in the lithosphere is magnetite with the CPD of 578°C, our results contradict available data on lithospheric temperatures inferred both from surface heat flow measurements and inversion of different seismic tomography models. At the same time, an area with high densities (3.1–3.2 g/cm ^{3}) is traced at the depth of 30–45 km under the trough axis according to our 3D density model. Along with the deep CPD, this fact allows us to propose an existence of a basification area in the lower crust and uppermost mantle there with partly serpentenized rocks, for which the CPD reaches 620–1100°C. Therefore, our results support a hypothesis of the riftogenic nature of the Yenisei-Khatanga trough. According to this hypothesis, rifting was developed there in the Permian-Triassic due to the mantle upwelling at its early stage. Remnants of the upwelling are, probably, seen as a low S-wave velocity area at the depths 120–180 km, revealed under the western part of the trough from surface wave data. Remarkably, that for the whole trough the deepest CPD is observed there. Under other parts of the trough, decreased S-wave velocities at the same depths are also traced, but velocity variations are smoothed.

GC2024-SG024

Relocation of Early Instrumental Earthquakes in the Arctic

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The source parameters of earthquakes in the Arctic during the entire instrumental period were calculated using a small number of stations, which in addition were remote from each other. Furthermore, during the 20th century, the source parameters of Arctic earthquakes were most often calculated from bulletin data from only part of the seismic stations operating at that time, using outdated velocity models and localization algorithms. The present article describes an approach that has already been successfully used by the authors to recalculate the source parameters of early instrumental earthquakes in the Arctic. The approach uses all currently available archives of bulletins and seismograms from the seismic stations that operated in the early 20th century; it also employs the modern ak135 velocity model, new method of the probabilistic location of early instrumental earthquakes based on macroseismic and instrumental data [1] and an improved localization algorithm implemented in the NAS program [2].

We have relocated the epicenters of earthquakes recorded within the Arctic in the early 20th century and compiled an updated catalog of relocated seismic events. The new coordinates of some earthquakes appeared to significantly differ from the previously determined ones. As a result, this may significantly affect the ultimate seismic hazard assessment of such areas as Severnaya Zemlya and Franz Josef Land, which are characterized by weak seismicity. Most of the relocated earthquake epicenters are confined to the main seismically active zones of the Arctic, namely, mid-ocean ridges, the Svalbard archipelago, and the Laptev Sea shelf.

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GC2024-SG025

Variations of the electron density in the topside ionosphere during the earthquake on January 22, 2024 in Central Asia

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According to the US Geological Survey (https://earthquake.usgs.gov/earthquakes/) strong M7.0 earthquake occurred on January 22, 2024 at 18:09:04 (UTC), 128 km WNW of Aykol, China with coordinates of the epicenter 41.263°N, 78.659°E at the depth 13.0 km. In this study, observations from the Swarm satellites that provide in situ measurements of the local ionospheric parameters during the M7.0 China earthquake on January 22, 2024 are analyzed. Analysis of observations of plasma density perturbations along the trajectories of Swarm satellites over the area of earthquake, revealed the features, which are likely associated with the penetration of the seismogenic electric field into the ionosphere [1]. The EQ occurred during a prolonged period of geomagnetic quietness. Several hours after the main shock, the tandem of Swarm_C and Swarm_A satellites crossed the EQ area in the dark ionosphere and observed a small-scale irregularity of the plasma density. The satellite flying first measured higher values of Ne, while the second satellite, flying 12 s later and ~150 km to the east, detected a drop of about $1.5*10^4$ cm^{-3}. The anomaly started developing just over the epicenter a day before the EQ and maximized on the day of the main shock and aftershocks. We suppose that the observed irregularity is a signature of a seismogenic electric field penetrating the ionosphere. The magnitude and shape of the observed ionospheric irregularity appears to be consistent with the predictions of models representing the concept of lithosphere-atmosphere-ionosphere coupling in terms of electrodynamic processes [2].

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GC2024-SG026

On the current state and prospective of waveform cross correlation in seismic studies: improvements in signal detection, parameter estimation, relative location, and identification of seismic sources

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In the matched filter approach, cross correlation of fixed waveform templates and unknown signals is used to maximize the signal-to-noise ratio, SNR, in the presence of additive stochastic noise. The ambient seismic noise in many cases is a good approximation of such noise, allowing for optimal detection of repeating signals. In the long run, natural seismicity is a highly repeatable process. Mining activity also creates clusters of repetitive seismic signals. Therefore, waveform cross correlation, WCC, significantly reduces detection thresholds for repeating events, improves arrival time estimation as well as the estimation of relative signals amplitudes. The usage of WCC allows for significant improvements in the quality, consistency, and completeness of the global and regional seismic catalogs. For example, the estimates in various oceanic and continental regions demonstrate that the catalog of the International Data Centre (IDC) also used by the ISC misses from 30% to 70% of valid (according to the IDC definition) events.

The gain in relative and absolute location accuracy is demonstrated by the series of six underground explosions conducted by the DPRK between 2006 and 2017 within the Punggye-ri test site. All explosions were well detected by the seismic network of the International Monitoring System (IMS) of the CTBTO at regional and teleseismic distances. The travel time differences from the six events at the same stations are determined with the accuracy of 0.005 s corresponding to the relative location accuracy of less than 100 m. The smaller events located with fewer stations borrow the absolute location accuracy of the best located events. As a result, all six events are located within a circle of 3 km in diameter instead of 15 km for standard location method.

The capability of signal detection by the WCC method is demonstrated by finding of the low-magnitude aftershocks of the DPRK underground explosions. After the fifths test with mb(IDC)~5.1, the first aftershock with the estimated relative mb of 2.5 was detected by IMS and non-IMS regional stations. After the sixths test with mb(IDC)~6.1, many aftershocks were detected at regional and teleseismic distances. The signals generated by the biggest aftershocks of the DPRK 6 and DPRK 5 were used to detect weaker aftershocks using the multi-master technique also based on WCC. The sequence of low-magnitude seismic events from the Punggye-ri test site has not stopped yet, with the most recent detected on March 15, 2024. The total number of found low-magnitude events (DPRK aftershocks and likely seismic events of different origin) exceeds 200. Based on relative cross correlation level, there were two clusters of aftershocks found as related to the DPRK 5 and DPRK 6 epicentral zones. Comprehensive retroactive processing with the multi-master method, which significantly reduces the detection threshold and has higher statistical reliability for event hypotheses, has found several aftershocks of the DPRK 3 and 4, which were all missed by standard detection methods.

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Lateral variations in travel times of reflected from the inner core waves and their connection with thermal and gravitational fields

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The inner core (IC) remains the most difficult object of our planet to study, the only one for which no unified and consistent picture of the description of its properties has been formed so far. The main process determining the dynamics of formation of structural features of the inner core is apparently its growth, which results in the development of various surface relief profiles, anisotropy of P wave velocity, gravitational anomalies and heat flow anomalies. The most suitable means with high spatial resolution to study these features are IC reflected PKiKP waves.

In this work, we have analyzed the differential travel times δτ = t(PKiKP)-t(PcP) of more than 1300 pairs of PcP and PKiKP waves reflected, respectively, from the outer and inner core at epicentral distances up to 40^o. The probed core regions are located under Eurasia, Southeast Asia, Central and South America. Three-dimensional models LLNL [1] and Detox-P3 [2], with low and high resolution in the lower mantle, were used to exclude the influence of mantle inhomogeneities. In the Northern Hemisphere at east longitude 40^o, a sharp change in δτ of ~1 s is observed, which may be related to a 0.6% P wave velocity jump at the top of the inner core [3] and a change in geoid height [4]. Under South America, according to [4], a structure with anisotropy strength up to 5% is present in the upper part of the inner core, which is absent under Central America. Different gravity anomalies [4] and values of δτ, differing by ~1 s, correspond to the regions probed under South and Central America. In the west of Eurasia, low heat flow [5] corresponds to regions with higher values of the analyzed differential travel times. The use of a high-resolution 3D model of the mantle does not reduce the discrepancy, which averages 0.5 s, but new trends are detected that can be interpreted as a weak change in the relief of the inner core surface.

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GC2024-SG028

Typification of the Earth's Crust

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The typification of the Earth's crust was proposed by G.I. Reisner using the example of the territory of Europe and Central Asia [1]. The Earth's crust is divided into cells of approximately equal area, each characterized by a set of geologic-geophysical parameters, such as the heat flow density, the thickness of the Earth's crust and sedimentary cover, the absolute elevation of the relief, and the magnitude of isostatic gravity anomalies. It is assumed that this set of characteristics will uniquely characterize each cell, enabling the division of cells into groups based on endogenous mode. Typification was carried out with the aim of determining the forecast parameters of seismic events - earthquake magnitudes. In other words, the maximum earthquake magnitudes recorded in cells of the same group were compared. If the magnitude in a certain cell was unknown, a forecast was made that the achievable magnitude in that cell was comparable to a known value. This methodology is not limited to forecast events. In the broadest sense, the Earth's crust is divided into oceanic and continental. Flat and mountainous regions represent the continental crust. Within the oceanic crust, the ocean basins, continental slopes, and mid-ocean ridges are distinguished. Types of Earth's crust have a hierarchical structure, so the problem of typification is expected to be addressed using hierarchical clustering methods, employing the method of hierarchical clustering in this case. Hierarchical clustering algorithms create not only a single arrangement of a sample into non-intersecting classes, but also a system of nested partitions. The result is presented in the form of a dendrogram. Each cell is characterized by an identical set of parameters, and thus occupies a defined point in space with a number of dimensions corresponding to the number of parameters. To perform the clustering procedure, rules must be established for determining distances between points in space (i.e., a metric), as well as the rule by which distances between clusters are calculated - aggregates of points. There are several ways to define the distance between clusters; the most appropriate approach will be selected in this work. The Euclidean metric is suggested for use as the metric. During G.I. Reisner's research in the 1980s, the knowledge level of Earth's crust parameters, as well as computing resources for data processing, were lower than in modern times, and there has been an increase in the volume and resolution of data on physical fields[2, 3], relief[4], sediment and the Earth's crust thickness [5]. The typification procedure can be updated for the entire surface of the Earth.

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GC2024-SG029

Source parameters of earthquakes in the Laptev Sea (1996, 1997 and 2023) from surface wave records

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In this study we consider three earthquakes that occurred in the Laptev Sea: June 22, 1996 (Mw=5.8), April 19, 1997 (Mw=5.5) and July 13, 2023 (Mw=5.3). Records of surface waves, registered at teleseismic distances, were used as initial data. For each of the seismic events under the study, records of Rayleigh and Love waves were filtered and their amplitude spectra were calculated using a frequency-time analysis procedure [1]. The source parameters were calculated by minimizing a misfit between observed and calculated surface wave amplitude spectra in an instant point source approximation [2]. As a result, we have obtained scalar seismic moments, corresponding moment magnitudes, source depths and a focal mechanisms (strike, dip, and slip angles of earthquake nodal planes). To constrain a unique solution of an earthquake focal mechanism, additional data were used, such as P-wave first-motion polarities or surface wave phase spectra. Integral characteristics of the earthquake sources, describing their development in space and time, were also estimated from surface wave amplitude spectra [3]. For this purpose, an earthquake source is modeled as a plane elliptical dislocation.

Our results were compared with the data by seismological agencies and available geological and geophysical information about the considered region.

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GC2024-SG030

Comprehensive study of stress effect on filtration-capacitance properties of underground gas storage reservoirs using geomechanical and CT-based approach

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The system of underground gas storage facilities (UGSF) is an integral part of the Russian gas supply infrastructure, providing stability in the presence of large climatic differences and significant length of the country's territory [1]. UGSF are created in depleted gas, gas condensate fields, aquifers or caverns eroded for them in salt formations. Reservoirs suitable for UGSF must be formed by rocks with high porosity and permeability, they have low strength characteristics often. One of the main problems in the operation of underground gas storage facilities, sand production, is related to this. The destruction of the reservoir rock and the production of sand into the well leads to wear of underground and surface equipment, clogging of filtration channels in the bottom-hole zone, and the formation of sand plugs [2]. In addition, the specific feature of UGSF operation is cyclic gas injection and extraction, which affects changes in reservoir pressure and stress-strain state in the vicinity of the wells. These factors can also negatively affect well quality creating a reduced permeability area in the bottom hole zone, which deteriorates the hydrodynamic connection between the well and the reservoir.

In order to justify the optimal regimes of well operation, as well as to find effective methods of construction and impact on the bottom hole zone of wells, it is necessary to conduct preliminary comprehensive studies of reservoir rocks.

This work presents the results of multidisciplinary experimental study of filtration-capacitance characteristics of highly porous reservoir rocks of an UGS aquifer. The geomechanical part of the research included the study of the dependence of rock permeability on the stress-strain state, which changes in the vicinity of the well during well operation, and physical modeling of the implementation of the directional unloading of the reservoir (DUR) method [3]. The tests were carried out on the unique Triaxial Independent Load Test System (TILTS) of the Ishlinsky Institute for Problems in Mechanics RAS [3]. The digital part of the research included non-destructive computed tomography-based analysis of the internal structure, pore space and filtration characteristics before and after tests. The study of changes in the internal structure of specimens was performed using a high-resolution X-ray micro-CT scanner ProCon X-Ray CT-MINI [4]. Numerical modeling of filtration flow on 3D models of rocks was carried out using GeoDict software modules.

The porosity, geodesic tortuosity and permeability values of rocks were obtained in the results of digital studies and numerical modeling. High homogeneity and cohesion of rock pore space was revealed on the basis of analysis of pressure field, pore size distribution and flow velocity field. The reasons of weak transversal anisotropy of permeability are revealed. The destruction character of specimens after tests on TILTS were analyzed. The results obtained by digital method are in good agreement with the results of laboratory measurements.

Physical modeling on specimens of the DUR method implementation confirmed the efficiency of the method for the conditions of the studied reservoir. Necessary parameters of its application were calculated: an optimal stage of operation, bottom hole design, and pressure drawdown.

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GC2024-SG031

Comparing estimates of crustal deformation in Altai-Sayan mountain region based on seismic and GNSS data

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We compare crustal deformation parameters obtained from seismic (seismotectonic deformation, STD) and space geodetic (based on Global Navigation Satellite System, GNSS) data. The analysis was done for the Altai-Sayan mountain region.

We computed distribution of crustal deformation rate tensor values based on a catalogue of velocities of space geodetic observation networks' points for the period of the last 25 years. Data from three space geodetic networks were used: Altai GNSS network (Altai Mountains), Baikal-Mongolian GNSS network (Gobi and Mongolian Altai, Sayans and Baikal Rift Zone) and Central Asian GNSS network (Kazakh platform). We calculated earth surface points' velocity gradient tensor by solving system of equations based on linear part of Taylor expansion of function of point's velocity versus its radius vector.

Then we studied territory of Altai-Sayan mountain region using the seismotectonic deformation (STD) method. The calculation of STD was done based on approaches proposed in publications by Yu.V. Riznichenko and S.L. Yunga. We analyzed directions of STD using focal mechanisms data for 591 earthquakes occurred between 1963 and 2021. For each value of STD directing tensor we calculated four angles that completely describe it. Of these angles two characterize mode of deformation and of the other two one shows azimuth of maximal horizontal shortening axis. We plot on maps distribution of horizontal part of STD directing tensor using classification of STD modes.

Between seismic and GNSS deformation's tensors we compare directions of horizontal shortening and extension and also a sum of tensor's horizontal components. This comparison was done for two areas where STD results are available in greater detail: Gorny Altai (the region of 2003 Chuya earthquake) and a region including Academician Obruchev ridge, southern part of Eastern Sayan Mountains and Southern Baikal region. The analysis showed that a good agreement between the computed values of deformation is observed in areas where there are both a good amount of seismic data and a sufficient number of GNSS observation points.

GC2024-SG032

Research of the features of seismicity and seismotectonic deformations of some areas of the Altai-Sayan mountain region

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The work presents the results of a STD study of two zones of the Altai-Sayan region: the Altai Mountains (the region of the Chuya earthquake) and the territory that includes the Academician Obruchev ridge, the southern part of the Eastern Sayan Mountains and the Southern Baikal region. The STD computation has been performed on the basis of the approaches proposed by well-known publications of Yu.V. Riznichenko and S.L. Yunga. The derivations on STD directions are based on focal mechanisms data (591 events) that occurred from 1963 to 2021). For the considered areas, a description of seismicity is given and STD maps are constructed. According to the STD maps, the directions of the axes of shortening and elongation are determined and the deformation modes is marked. The distributions of the Lode–Nadai coefficient, the angle of kind of the stressed state (the angle of the generalized plane deformation, the phase angle of STD tensor-deviator) and the vertical component (ZZ) have been constructed using the obtained averaged STD tensors for seismogenic layer of 0–35 km depths. The zone around Chuya earthquake source site is characterized by horizontal shear deformation, with a band of transpression (Chagan-Uzun block) passing though this zone. The territory, which includes Academician Obruchev ridge, the southern part of the Eastern Sayan Mountains and the Southern Baikal region is divided into two parts according to the deformation regime. The boundary runs along the Darkhat depression: the regimes of compression, transpression and horizontal shear occur in zones lying to the west of it; the regimes extensions, transtensions, and the transitional regime from vertical shear to extension occurs to the east. The Chagan-Uzun block and the Academician Obruchev ridge are uplifted, and the territory to the east of the Darkhat depression is lowered.

A comparison has been made with the results of a study of the current stress state of the earth's crust in the region under study, carried out using the STRESSseism software procedure, which is based on the algorithms of the Cataclastic Method of Yu.L. Rebetsky.

GC2024-SG033

Nonextensive analysis of earthquakes and man-made impacts

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The paper examines the application of Tsallis q-statistics, based on the principles of non-extensive statistical physics, to the analysis of seismic events and man-made impacts. Non-extensive statistical physics (NESP) is based on the concept of entropy, which was introduced in 1988 by Constantino Tsallis [1] as a generalization of the standard Boltzmann-Gibbs entropy.

To describe the energy distribution functions of events, a modified stick-slip earthquake source model was used – intermittent sliding of two plates relative to each other along a fault in the presence of friction and filling fragments between the fault surfaces and the principle of maximum entropy Tsallis [2]. In this model, fragments filling the space between fault planes can play the role of bearings and also impede the relative movement of the planes. In this model, stress accumulates until the filling fragments are displaced or destroyed, and energy is released. Based on this, the displacement of tectonic blocks and the energy released are proportional to the size of the fragments between the faults. In [3], an analytical expression was obtained that describes the energy distribution of earthquakes over the entire range of magnitudes, in contrast to the empirical Gutenberg–Richter formula, which is demanding in choosing the boundaries of the linear section of the recurrence graph. In addition, it is possible to approximate the frequency distributions of time and distances between successive events with a q-exponent and find the value of the Tsallis parameter q.

It is shown that the flow of earthquakes is a system with memory and long-range spatial correlations, and the obtained values of the Tsallis parameter $q \sim 1.5$ practically coincide with the values calculated for the magnitudes of the catalogs of various seismically active regions[4]. At the same time, series of industrial explosions occurring in the same regions are not processes with memory and long-range correlations, since they have reduced values of the Tsallis parameter q. Such areas where blasting operations are carried out are characterized by a low value of the Tsallis parameter q. This may mean that there is no mutual correlation between these events.

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GC2024-SG034

Anomalies of RTL function and Gutenberg-Richter parameter preceding earthquakes in California

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Seismicity anomalies are characteristic changes in the distribution of earthquakes in the spatiotemporal domain and their energy spectrum. To detect anomalies preceding strong earthquakes, parameters of the seismicity are analyzed, each corresponding to a precursor pattern – a specific behavior of values over time, accompanying the process of earthquake source preparation.

The present study investigates seismicity anomalies preceding the 15 largest earthquakes in California (with magnitudes M>6.5) from 1984 to 2023. Two parameters were selected for the analysis: the RTL function, sensitive to stages of seismic quiescence and foreshock activation, and exponent of the energy spectrum of seismicity (Gutenberg-Richter parameter, or b-value), reflecting the ratio of frequencies of earthquakes with different magnitudes. These statistical parameters have been previously used by the authors to search for and analyze seismicity anomalies in subduction zones (Kamchatka, Japan) and in the rift zone (Iceland) [1].

For all investigated earthquakes anomaly characteristics were determined: duration, spatial size, distance from the earthquake epicentre. The values of tuning parameters for the algorithms are presented. The durations of the identified anomalies correspond to typical values for mid-term precursor anomalies [2, 3]. The average (median) duration of RTL and b-value anomalies in California was found to be shorter than the durations of such anomalies in the subduction zone in Kamchatka [1]. Regarding the comparison of RTL anomaly durations in California, Kamchatka, and Japan, [4] notes the same relationships but with a smaller event statistic than ours.

It was found that for 12 out of 15 earthquakes, RTL parameter anomalies are registered earlier than anomalies of b-value. The obtained staging of anomaly occurrence differs from the staging found by the authors previously when analyzing strong earthquakes in subduction zones and the rift zone [1]. This may be related to differences in earthquake depths in California and in subduction zones, as well as differences in earthquake preparation processes in strike-slip zones, subduction zones in Kamchatka, and transitional zones from ocean to continent [4]. Most of the studied earthquakes occur with a delay after the end of RTL anomalies, reflecting the completion of the formation of a metastable area. The nature of this delay remains unclear, and the time of earthquake occurrence in such situations is associated, in particular, with triggering mechanisms [3, 5].

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GC2024-SG035

Precursors of strong earthquakes in Kamchatka (according to data from 2005-2022)

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The Kamchatka Peninsula is one of the most earthquake-prone regions of Russia. Here, earthquakes with magnitudes M_W up to 8–9 are possible, which accompanied by tsunamis and shaking up to 9–10 points on the MSK-64 scale in continental areas. Over the period of detailed seismological observations since 1962, the average frequency of earthquakes with $M_W \geq 6.8$ is 0.47 events per year (28 events in 60 years). The average frequency of earthquakes with MW ≥ 7.5 is 0.17 $year^{-1}$ (10 events in 60 years).

Seismological, geophysical, geochemical and hydrogeological observations in order to search for earthquake precursors have been carried out in the Kamchatka Peninsula area from the late 1970s to the present. Most of the stations for “non-seismological” observations of precursors are located in a small area of the Petropavlovsk-Kamchatsky geodynamic polygon (PKP).

The priority of the KB GS RAS activity is the development of observation networks for seismicity, geophysical and geochemical parameters in order to search for precursors and develop methods for predicting strong earthquakes. From 1998 to the present, the Kamchatka branch of the Russian Expert Council for Earthquake Forecasting (KB REC), whose competence includes the collection and analysis of all seismic forecast information, has been operates under the KB GS RAS. Seismic hazard assessment in the form of issuing long-term, medium-term and short-term earthquake forecasts is carried out through expert analysis of the results of comprehensive geophysical monitoring in the territory of the Kamchatka Peninsula [1].

This work is a continuation of the authors’ research on the manifestations of the precursors of strong earthquakes in the area of the Kamchatka Peninsula [2, 3]. The data on seismological, geophysical and geochemical precursors before seven earthquakes 2005–2022 with M_W = 6.6–7.7 at depths up to 180 km were examined taking into account their composition according to various types of observations and duration (time of manifestation before each earthquake). An increase in the number of precursors with increasing parameter M_W/lgd_h, where dh is the hypocentral distance of the earthquake to the center of the PKP (km) is detected, which is an indicator of the integrated manifestation of precursors before the strongest and closest earthquakes in the area under consideration.

It is discussed the need to study the phenomenon of integrated manifestation of precursors, diagnosed in real time, for use in predicting the time of a strong earthquake in the Petropavlovsk-Yelizovo agglomeration area, where most of the population of the Kamchatka Kari lives. It is

proposed to use materials from the archives of expert councils on earthquake forecasting operating in the Kamchatka Krai to create a database of regular forecast conclusions on individual observation methods, subsequent formalization and retrospective analysis of the properties of the complex manifestation of precursors in connection with earthquakes that have occurred. This direction of seismic prognostic research will contribute to obtaining more definite estimates regarding the parameters of earthquakes and the time of their occurrence when a complex of precursors is detected, diagnosed in real time.

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GC2024-SG036

Fiber optics in geophysics. Distributed acoustic sensing (DAS)

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Solicited talk

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Optical fibers have been developed to transmit information over long distances with extremely high transmission speeds and traffic-carrying capacity. Ideally, the use of total internal reflection allows light pulses to be transmitted without loss over any distance. As light travels through an optical fiber, however, it undergoes reflection, scattering, absorption, and radiation outward. Because of these effects, every 50 km, there is an optic repeater, powered by an electrical cable laid along with the optic fiber. Some of these effects (Raman scattering, Brillouin scattering and Rayleigh scattering) are used for distributed measurements.

Optical fibers are widely used in geophysics [1]. Let us introduce such a classification.

1. Fiber optic data lines.

2. Optical sensors of mechanical movements [2] with further data transmission via optical fiber; in some cases it allows to completely abandon electronic components inside the sensor.

3. Sensors without mechanical elements that use the optical fiber as a sensing element, for example fiber optic gyroscopes [3].

4. Seismic sensors sited along the fiber optic cable. A prominent example is Smart cable [4]. SMART cables are a marriage of standard fiber optic telecommunication cables with deep-sea scientific sensors ineide repeaters. SMART cable sensors “piggyback” along the power and communications infrastructure of a million kilometers of undersea fiber optic cable.

5. Interferometric and polarization-based systems [5], where the entire long-distance fiber optic cable acts as a sensor.

6. Quasi-distributed measurements are made using special engineered optical cables [6] designed to improve the signal-to-noise ratio (SNR) or to increase the distance over which fiber-optic sensors operate. Most often, fibers which are used for these purposes, are made with Bragg gratings written into them at certain intervals [7].

7. Distributed measurements, which are made using much cheaper standard fibers. In geophysical research, Distributed Temperature Sensors (DTS) and Distributed Acoustic Sensors (DAS) are used, which can be presented in a form of a virtual strain meters installed along the cable [8].

The DAS, which are in our point of view of special interest, can be organized along the cables that are already placed and therefore are cheap and easy to deploy. They provide unprecedented measurement density, and have a wide frequency range.

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GC2024-SG037

Disturbances of the lower ionosphere during strong seismic activity in 2023-2024 as observed on the Kamchatka peninsula

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Data from the very low/ low frequency (VLF/LF) receiver in Petropavlovsk-Kamchatsky have been used to study the response of the lower ionosphere to two strong (M≥6.5) earthquakes. The M_w=6.5 earthquake has occurred on April, 3rd, 2023 in offshore area of the Avachinsky gulf (Pacific coast of the Kamchatka peninsula); the M_w=7.5 earthquake has occurred on January, 1st, 2024 on the Noto peninsula, Japan. Disturbances of the electromagnetic signals were observed for some days before the earthquakes and in days of earthquakes in the radio wave paths from two transmitters which crossed epicenters' areas. During the intervals under consideration the influence of other factors (magnetic storms, cyclones) which could cause similar disturbances was absent. We suppose the anomalies in the radio signals behavior in the two wave paths have been caused by preparation and realization of these strong earthquakes. An additional argument in favor of such statement is absence of the anomalies in signal variations in other radio wave paths passing far away from the epicenters of the earthquakes. The wavelet-analysis of the filtered in a range of frequencies 0.3-15 mHz of the amplitude and phase of night signal variations, has shown that the maximum of radio signals disturbances corresponded to the atmospheric internal gravity waves (IGW) with periods of 10-50 minutes.

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GC2024-SG038

Earthquake Productivity

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Solicited talk

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The ability of earthquakes to trigger other seismic events (or aftershocks) is characterized by productivity. Productivity determines the number of events within the spatiotemporal interval resulting from a stress disturbance caused by another earlier earthquake. This concept was used by Utsu [1] to develop a model for the occurrence of aftershocks. Since the advent of epidemic seismicity models (e.g., ETAS [2]), the study of productivity properties has become a major task. Initially it was assumed [3-5] that the number of events triggered by an earthquake with magnitude □□ changes as a Poisson process with intensity $K\exp(\alpha m)$.

Recent studies [6, 7] showed that the number of events with $M \geq M_m - \Delta M$, triggered by an earthquake with magnitude M_m, is a random variable that obeys an exponential distribution (the law of earthquake productivity). In [6, 7] the regional differences and a decrease in productivity with depth were revealed. Using Japanese earthquake statistic, it was shown that the productivity law is satisfied over a wide magnitude range ($\Delta M = 6$) [8]. In [9] it was shown that the productivity law is satisfied for weak mining-induced seismicity ($0 \leq M \leq 3.3$) in Khibiny massif. The seismic productivity of mining blasts (the number of events triggered by blasting) also obeys the earthquake productivity law [10].

These results led to the conclusion that productivity does not depend on the type of source and is determined by the stress-strain state and physical properties of the medium. This conclusion is also confirmed by the increase in earthquake productivity with increasing watering of the environment [11].

Thus, the earthquake productivity law, like the other two laws of statistical seismology (Gutenberg-Richter and Omori-Utsu), is universal. The combination of these three laws allows to theoretically substantiate Batht's empirical law [12], as well as generalize it by the time factor [7, 13]. A combination of the productivity and Omori-Utsu laws results a model for the duration of the dangerous period of aftershock activity. By combining the law of productivity and the model of aftershock decay with distance from the main shock, one can derive the distribution of the region where strong aftershocks are expected [14]. The fit of these models to regional and global earthquake statistics is an additional test of the productivity law.

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GC2024-SG039

Insights into the crustal structure beneath Central Kamchatka revealed by ambient noise tomography

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The central region of the Kamchatka Peninsula (Russian Far East), bounded by latitudes 52.8 and 54.1 degrees, hosts several active volcanoes of the Eastern Volcanic Front and a number of dormant back-arc volcanoes, as well as parts of two mountain ridges, Sredinny and Ganalsky. The volcanoes of Central Kamchatka pose a tangible threat to the relatively densely populated Petropavlovsk-Kamchatsky urban district (approximately 162,000 inhabitants), and therefore are actively investigated. Another motivation for conducting research in this area is the search for geothermal resources, which should optimize the electricity and heat supply to the local population.

To perform ambient noise tomography, we used the vertical component of continuous seismic records from the permanent stations deployed by the Kamchatka Branch of the Federal Research Center of the Geophysical Survey (KB FRC GS) [1] and the temporary network installed in 2019-2020 within a joint project by Trofimuk Institute of Petroleum Geology and Geophysics SB RAS (Novosibirsk), Institute of Volcanology and Seismology FEB RAS, KB FRC GS (Petropavlovsk-Kamchatsky) and Academia Sinica (Taiwan). The data was processed following the standard workflow developed by [2], resulting in cross-correlation functions that contain information about Rayleigh surface waves [3]. Each of these correlograms was subjected to a frequency-time analysis [4], [5] and based on its outcomes we picked 489 dispersion curves of the fundamental mode of Rayleigh wave group velocities. The tomographic inversion of the dispersion curves was conducted using the SURF_TOMO algorithm [6] that initially generated the two-dimensional maps of group velocities for periods ranging from 1 s to 30 s, then found the optimal 1D model of shear wave velocities and derived the three-dimensional S-wave velocity distribution.

In the resulting model, a prominent low-velocity anomaly is observed beneath the active Avacha and Koryaksky volcanoes, reaching depths of ~40 km and potentially indicating a zone of heated rocks. This anomaly is hypothesized to represent a common magma pathway through the crust feeding both volcanoes. Beneath the active Zhupanovsky volcano, we observe three low-velocity layers at depths of 2 km, 8 km and 20 km, suggesting a multilevel magma feeding system. Our model reveals a high-velocity pattern at shallow depths under the Sredinny Ridge, likely associated with consolidated magmatic structures. We interpret the low-velocity in the lower crust as a high-temperature zone preserved here since the time when this area hosted an active volcanic arc. Below the Ganalsky Ridge, a prominent high-velocity anomaly extending to a depth of ~15 km is attributed to the Precambrian to Carboniferous metamorphic rocks, predominantly of mafic composition.

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GC2024-SG040

Aftershock domain estimation by first aftershocks on the example of the Khibiny deposits

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Seismic monitoring has been provided in rockburst hazardous apatite deposits of the Khibiny massif [1] since the mid-1990s. In result, a catalog of mining-induced earthquakes with the magnitude of completeness $M_c = 0$ has been compiled by the Kirovsk Branch of JSC Apatit. The completeness and accuracy of hypocenters estimates (25 m) in the catalog allow filling a gap between laboratory and in-situ studies.

Former studies of post-seismic activity features of the Khibiny deposits had proved the earthquake Δ-productivity law [2], [3] and the power law of mainshock-aftershock distances distribution [4]. The main shock-based aftershock forecast model has been designed based on these studies [5].

The current research refines forecast models for prospect aftershock domains based on first aftershocks data. The scaling technique on different parameters of the mainshock and first aftershocks training set has been applied to test various forecast domains. The best forecast domain has been selected using the loss function defined as a sum of type I (false alarms) and type II errors (target miss) with the Molchan error diagrams. In total, 11 aftershock activity domains with different shape, size and estimation methods applied have been tested for the epicentral forecast. Eight aftershock activity domains have been tested for the depth forecast.

In result, the optimal epicenter domain has proved to be a stadium with a size depending on a mainshock rupture, and the location and orientation on an aftershock training set. The depth optimal forecast occurs as a segment, which size depends on the mainshock rupture and its location depends on the magnitude weighted aftershock training set as well.

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GC2024-SG041

Upper mantle – classic ideas and new insights

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The first ideas about the Earth’s structure appeared at the beginning of the 20th century, and from that moment on they were actively supplemented and developed. To date, six main structures are to be highlighted. They differ significantly from each other both in physical parameters and composition.

The upper mantle is one of the main shells with which most of the Earth's tectonic processes are associated, as well as a significant part of convective currents. Classically, the upper mantle is divided into a number of structural elements - the lithosphere, the asthenosphere, the underlying part of the upper mantle and the mantle transition zone. However, due to the rapid growth in the volume and quality of seismological data and the increasing density of the seismic network, the understanding of the upper mantle structure has changed significantly over the past 20 years.

We provide an overview of the evolution of seismological concepts of the upper mantle structure, and also provides confirmation of new ideas of its structure based on experimental data collected in various regions of the East European Platform, as well as the Fennoscandian Shield and other regions of the World.

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Performance of Seismic Observations by DAS Technology in Different Environments

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The utilization of fiber-optic distributed acoustic sensors for seismic monitoring offers several advantages over traditional methods of seismic data acquisition [1]. By leveraging existing telecommunication infrastructure, the deployment of these sensors can be done at a much lower cost and with less environmental impact. The ability to continuously monitor seismic activity in real-time allows for early detection of potential hazards, providing crucial information for disaster prevention and mitigation efforts [2].

The capabilities of fiber-optic sensors for seismic monitoring can be enhanced by use of DAS technology. Its simplicity, consistent sensitivity, and robustness make it an ideal tool for detecting seismic activity with high accuracy and reliability [3] . Additionally, signal processing techniques can be applied to extract valuable information from ambient acoustic noise, further enhancing the usefulness of DAS technology for seismic monitoring.

Overall, the integration of fiber-optic sensors with DAS technology presents a novel and cost-effective solution for global seismic monitoring. By leveraging existing infrastructure and advanced signal processing techniques, this approach has the potential to revolutionize the field of seismic tomography and enhance our understanding of seismic activity on a global scale.

We would like to explore variations of DAS data obtained from the cables installed in different environments: vibration data collected from sensing cables, ambient noise data variations, subsurface strain and seismic data measured by acoustic sensors buried underground vs seafloor [4; 5].

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GC2024-SG043

Experimental study of mechanical and filtration processes in low-permeability reservoir rocks of Verkhnevilyuchanskoye oil and gas condensate field at implementation the method of directional unloading of the reservoir

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Hard-to-recover (HTR) reserves of oil and gas are being actively developed due to the continuous depletion of easy-to-recover reserves. Approximately 2/3 of the world's HTR reserves are located in low-permeability rocks, which are characterized not only by low permeability, but also by low porosity, which significantly hampers the flow of hydrocarbons to the bottomhole [1]. In this regard, it is necessary to adapt new efficient environmentally safe oil and gas production technologies to the conditions of fields with HTR reserves, primarily with low-permeability reservoirs. The most promising among such technologies are those based on the geomechanical approach, which is centered on increasing the permeability of productive formations by creating in them stress states of the required type and value. Separately, it should be noted that for building geomechanical models of oil and gas fields with low-permeability rocks, it is especially important to understand the dependence of rock permeability on the nonuniform external stress field. Such studies are only possible using true triaxial loading facilities.

In order to increase the permeability of the productive formation, an environmentally friendly, effective and economically favorable method of directional unloading of the reservoir (DUR) has been developed at the Ishlinsky Institute for Problems in Mechanics (IPMech) RAS [2]. The idea of this approach is to induce a system of micro- and macro-cracks in the vicinity of the borehole by creating the necessary stress state, which will thereby increase the permeability of reservoir rocks. This stress state can be realized by creating a pressure drawdown in the bottomhole zone and performing a number of technological operations, including creating a system of perforation holes on the wellbore.

In this work presents the results of a series of experiments on physical modeling of mechanical and filtration processes in productive formations of Verkhnevilyuchanskoye oil and gas field, when using the DUR method can lead to an increase of reservoir rock permeability. The tests were carried out on the unique Triaxial Independent Load Test System (TILTS) of the IPMech RAS [2]. The dependence of filtration properties of the studied rock specimens on the type of stress-strain state is presented in the work, and the values of pressure drawdown which can lead to an increase of rocks permeability under a certain bottomhole design are determined. In order to analyze the change in the internal structure of rock specimens after geomechanical testing, complementary studies were performed using a high-resolution X-ray micro-CT scanner ProCon X-Ray CT-MINI [3]. The obtained results indicate that the DUR method can be successfully applied to wells drilled in the Verkhnevilyuchanskoye oil and gas field.

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GC2024-SG044

Designing a side-by-side experiment to compare low-power impulsive artificial seismic sources

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Artificial seismic sources are required for seismic exploration as well as for many other areas of science, for example, for archaeological research [1]. There is an extensive cluster of tasks for which the use of low-power impulsive sources (LIS) is sufficient. These is surface and near-surface work carried out in hard-to-reach areas, with difficult terrain, in urban areas, and low-budget work. Here are the requirements for the LIS.

- repeatability;
- mobility due to light weight and size;
- easy to use and autonomous;
- there is no repeated impact after recoil;
- cost effective;
- environmentally friendly.

The simplest source is hammer blows on plate. Plates can be of various types [2, 3]. To achieve the repeatability of the impacts, a proctor hammer [4] or a tamper [5] are used. Lifting the weight by using a tripod allows you to increase the force of impact. The tripod can be made from locally available materials, and the weight can be almost anything. The main disadvantage is the presence of the repeated impact after the recoil. In addition, the tripod is not easy to carry. A more compact tool is the accelerated weight drop [6]. The lifting height of the weight is less, but the weight is accelerated by a spring or elastic band. Other more expensive tools include application of electromechanical, electromagnetic, pneumatic or other principle and they use anadditional power source [7]. Generation of waves using seismic guns requires the presence of wells up to 1 m deep [8]. Sparkers operate by discharging high capacity energy storage devices [9]. Such sources require the preparation of a well filled with salt water. There are a lot of works devoted to comparison of artificial sources of seismic waves [10].

There cannot be a universal source. We are developing a set of tests for the outlined group of LIS. The following tasks are expected to be solved.

1. Comparison of site preparation, weight and configuration of plate.

2. Comparison of different seismic gun loadings.

3. Comparison of impacts from different sources.

4. Comparing the repeatability of different sources.

5. Comparison of sources for generating shear waves.

We plan to deploy two geophone arrays that include vertical and horizontal sensors. One should surround the impact site, another one should be placed along a strait line going away from the impact site. Available or locally manufactured devices will be used as sources.

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GC2024-SG045

Integrated geophysical observations at the Petropavlovsk-Kamchatsky test site, Kamchatka Peninsula

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The article presents data on the types of observations and information resources of the Kamchatka branch of the Geophysical Service of the Russian Academy of Sciences (as of 2022), which can be used by scientific and educational organizations of the Russian Federation for studying precursors and developing methods for predicting earthquakes and volcanic eruptions, solving a wide range of research tasks in the field of geophysical monitoring of seismically active areas and others. Information resources and observation data are illustrated on the example of the Unified Information System of Seismological Data of the KB GS RAS and time series data of meteorological, hydrogeological observations and observations of volumetric radon activity in the soil gas at the Moroznaya station.

GC2024-SG046

Experiment on physical modeling of ash clouds with simultaneous recording of the atmospheric electric potential gradient

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In order to study the processes of formation of bulk charges in the eruptive cloud on the Ebeko volcano in the period from 07/29/2020 to 08/05/2020, observations of the atmospheric electric potential gradient (PG) in the near zone from the crater of the volcano were carried out. As a result of the observations, 24 responses of the PG associated with the propagation of an eruptive cloud were recorded. Three types of characteristic responses were identified: I) bay-shaped, negative polarity, 17 events were registered or 71%; II) a bay–shaped, negative polarity and in the minimum region there is a positive pulse-type disturbance exceeding the background value of PG - 5 events (21%); III) a bipolar response, the shape of which indicates the passage of a horizontal dipole – 2 events or 8%. Based on the analysis of the data obtained, the question was raised about the possibility of forming a positive volumetric charge in the lower region of the eruptive cloud during its lateral demolition, as a result of two main factors: the first is the induced positive charge on the surface of the volcano slope from the main charge of the eruptive cloud, the second is the occurrence of turbulent movement of ash particles at the boundary with the surface of the volcano slope, which occurs in its lower region when it propagates at a speed of more than 8-10 m/s. To confirm this pattern, an experiment was conducted on the physical modeling of an ash cloud and its propagation conditions with simultaneous registration of PG. Laboratory studies of the ashes for granulometric composition, chemical analysis and natural radioactivity were previously carried out. An experimental stand has been developed. Charging the ash cloud to the intensity values at which discharges are possible [1; 2] was not required, which greatly simplified the design of the stand. The release of ash from the chamber occurs due to the supply of compressed air from the compressor to the funnel. The ash under the influence of air pressure from the chamber rushes into the narrow neck of the upper funnel. This design significantly increases the triboelectric effect of ash charging. The atmospheric electric field sensor (type EF-4 [3]) was installed at distances of 0.5 m from the ash chamber, 1 m, and 5 m.

As a result of the experiments, a set of data was recorded and three types of responses corresponding to field observations were identified. Modeling the conditions of the ash cloud propagation during the experiment allowed us to show that when the lower region of the cloud interacts with the earth's surface, this region is recharged and a positive volumetric charge is formed. The work was supported by the RNF grant 22-17-00125.

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GC2024-SG047

Demonstration of the capabilities of Distributed Acoustic Sensing technology

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Distributed Acoustic Sensing (DAS) is an emerging technology in wide range of seismic applications. It has been already widely used in fundamental and applied seismology [1] providing beyond comparison spatial resolution of the seismic wavefield with high density. The demonstrated T8 DAS product detects seismic waves by measuring successive phase changing of Rayleigh backscattering light of the interrogating pulses, converting it to the strain rate recordings in the uppermost layer [2, 3]. Currently a lot of work is being carried out using DAS technology in different areas including comparison of DAS channel signals with conventional seismic sensors.

We demonstrate a simple showcase of how DAS works. We demonstrate DAS functionality jointly with traditional seismic sensor comparing tap tests records with corresponding 2D space-time amplitude “waterfall“ displays.

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GC2024-SG048

Automated system for seismological monitoring

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Conducting continuous seismological monitoring is accompanied by technical difficulties resulting in several significant problems: 1) the presence of vast amounts of continuous, high-discretized data in various formats; 2) heterogeneity of seismological catalogs and metadata of seismological stations; 3) labor-intensive routine processing of seismological data requiring a large amount of time.

The SeisComP software package helps address issues related to data systematization and storage [1]. This software uses commonly accepted formats for storing continuous seismic records "MSEED," information about seismological stations "StationXML," and seismological catalogs "QuakeML." These formats have a flexible set of fillable fields that can be customized for specific types of research. Access to data is provided through an interface implemented via the FDSNWS server.

SeisComP also has functionality for real-time automatic data processing. However, for detecting earthquake signals in continuous records, SeisComP uses STA/LTA algorithms, which produce many false triggers and are not suitable for detecting signals with a low signal-to-noise ratio. In addition, SeisComP allows get continuous seismic data by SeedLink protocol, but this way works when the equipment is installed in place with good internet connection. Therefore, there is a demand for creating a more reliable system that allows for getting seismic data from remote territories, automatic detection of local earthquake signals, distinguishing P- and S-wave arrivals, and visualizing processing results for analysis.

Currently, a prototype system for automatic data processing is being developed to fill the gaps in SeisComP. The system consists of a set of web applications, including data processing and visualization modules. Neural network algorithms are being developed [2] for detecting and determining wave arrival times, which will be integrated into the server application. A web service has been developed to evaluate the performance of the algorithms and adjust P- and S-wave times. After evaluating and correcting the arrival times, earthquake parameters are determined: hypocenter coordinates, origin time, and magnitude. Processing results are displayed in the data analysis web application. This application implements a set of basic tools for data analysis: 1) construction of a recurrence plot to assess a- and b-values; 2) construction of depth distribution profiles of earthquake hypocenters.

Besides, device for remote data transfer is under development. The operating logic is to isolate earthquake signals and transmit short data intervals through module «LoRaWAN».

At present, the developing service allows for manual data processing and result analysis. Additionally, ongoing improvements and testing of developed neural network algorithms are being conducted, with plans to add automatic detection and picking of P- and S-waves. In the future, this system will complement the SeisComP software package, enabling real-time seismological monitoring of local events.

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GC2024-SG049

Paleoseismological studies of the Jumgal depression

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Using paleoseismological methods, in particular trench work, morphometric analysis of the relief and remote sensing data, it was possible to detect and parameterize several objects marking strong earthquakes in the geographically densely populated Zhumgalsky district.

The Jumgal depression is located in the Naryn region, which is located in the central part of the Kyrgyz Republic, in the Inner Tien Shan, which consists of a system of ridges separated by inland valleys.

The geological structure of the territory of the Naryn region is due to the variety of rock structures and bedrock, which in turn consist of igneous, metamorphic and sedimentary complexes combined into rocky and semi–rock groups, in which dangerous exogenous processes are developed - landslides, rockfalls, scree, karsts. Intermountain depressions are filled with loose Mesozoic-Cenozoic rocks. Numerous dislocations in the form of landslides, gully erosion, mudflows, solifluction, planar flushing and other exogenous processes and phenomena are common in them [1].

In the newest stress field, there is a partial activation of ancient seams and movements along them. Large depressions (Naryn, Kurai, Chui) are associated with the zones of the Kurai-Chui, Sayano-Tuva, Chingiz-Naryn faults. The sides of the depressions are raised relative to the bottoms of the depressions by 1000 m or more. The depressions are drawn into the uplift of adjacent territories, their marginal parts are partially deformed, and the associated uplifts are pushed over the deposits of the depressions [2].

A characteristic manifestation of tectonic movements of the Quaternary period can be found in the central part of the Jumgal depression to the north of the administrative center of the Jumgal district, Naryn region, the city of Chaek. The depression is an asymmetric syncline approximately 70 km long and up to 35 km wide with a rather gentle southern edge and a complex fractured and folded northern boundary.

The system of plateaued hills with a width varying from 1 to 3.0 km stretches along the axis of the syncline for more than 25 km. The largest site is located in the central part of the depression to the north of the city of Chaek [3].

On average, the total displacements along the terraces range from 6 m to 40 m. Considering that in strong earthquakes, vertical movements range from 1 m to 2 m per event, it can be assumed that 15 to 25 paleoseismic events with a magnitude of M = 7-8 occurred during the formation of this landscape.

A fault located in the structure of one of the quarry hills made it possible to study in detail one of these fault zones, at the place of their practical access to the surface.

Using paleoseismological methods, in particular trench work, morphometric analysis of the relief and remote sensing data, it was possible to detect and parameterize several objects marking strong earthquakes in the geographically densely populated Jumgal depression. Vertical movements along the fault running along the Jumgal River were revealed and the ramp structure of the Jumgal depression was noted.

The data obtained indicate the need for a detailed study of the region and clarification of the seismic hazard of densely populated areas, often located along seismic generating structures.

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GC2024-SG050

Temporal variations of S wave attenuation field structure in the region of Zaili Alatay ridge: possible correlation with solar activity and large earthquakes

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We consider investigation results of spatio-temporal variations of S wave attenuation field in the lithosphere of the North Tien Shan.

It was shown that essential temporal variations of the attenuation field are observed in the middle and lower crust. We studied variations of Qs value for the period of 1985-2017 using data of stations TLG and MDO, situated near Almaty city. We have been analyzing recordings of explosions, conducted at the Kotur-Bulak quarry. It is essential, that lines cross large Zaili deep fault zone for the both stations.

We studied variations of Qs values in the middle and lower crust using coda wave envelopes at frequency of ~1 Hz. Note, that the lowest Qs values (~60-100) are observed in 1990-1995 for the both stations. It is important that the largest earthquakes in the North Tien Shan region for the last 40 years occurred in this time interval: Baisorun one (1990, Mw=6.4) and Suusamyr one (1992, Mw=7.3). It's possible to suggest that especially sensitive areas exist within zones of large regional faults. These areas can react on changes of the stress conditions within the crust sections, connected with large earthquake preparation, even located at considerable distances from such areas. (In the case of the Suusamyr earthquake such distances were about 250 km). The data on the attenuation field variations suggest that supersensitivity of such areas can be explained by active migration of deep-seated fluids in the middle and lower crust, which makes easier due to existence of large deep fault zones.

We found that a tendency of Qs growth in the years of the low solar activity exists in comparison with the years of high solar activity. This can testify to influence of solar activity variations on fluid migration in the earth's crust of the region under investigation.

A comparison of the attenuation data with the location of the seismic activity zones shows that, as a whole, high attenuation corresponds to Zaili and Kemin zones. We found the most dangerous strips of these zones, where the lowest values of effective Qs values are observed. First of all, such areas are located to the south-west and south-east of station MDO.

GC2024-SG051

The relationship between M_w and other magnitude scales for earthquakes of the North Caucasus

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The study of earthquake source spectra helps to better understand the physics of an earthquake source, and important for different engineering seismology problems. Particularly, using source spectrum one can determine seismic moment and moment magnitude which are crucial parameters for seismic hazard studies. The source spectra of 127 earthquakes in the North Caucasus for the period 2008–2021, with h=1-85 km, were calculated, using the Brune source model [1]. Data processing was realized in the SEISAN program [2] . The processing procedure involves calculating the S-wave displacements spectrum, correction for attenuation in the crust and upper mantle and geometric spreading. The seismic moment M_0 was determined from records of earthquakes from hypocentral distances of 50–250 km and with SNR more than 2. The data of individual estimates of different type of magnitude accumulated by present time allowed for a detailed study of intermagnitude relationships in the North Caucasus region. We compared the magnitude M, obtained by recalculation from Rautian energy class KP, with other magnitude scales M*: mbISC – teleseismic magnitudes based on body P-wave, calculated at the International Seismological Center [3], M_w^{SS} – spectral moment magnitude and local magnitude M_L. Assuming a linear relationship between magnitudes, regression analysis was performed, using linear and orthogonal regressions. For the relationship between M and M_w is obtained the minimum RMS for all analyzed events, and a linear dependence with a slope close to one (0.88 and 0.95 were obtained by linear and orthogonal regression, respectively). The relationship between M and the regional scale of local magnitudes M_L, as well as M_w, show smaller RMS values and also represents a linear trend with a slope close to 1. The difference in estimates of individual seismic station estimates of local and moment magnitudes shows that M_w estimates are more stable than M_L. On the other hand, M_L estimates is easier to obtain, especially for small earthquakes (M_L=1.5 and M_L =0.5–1.0 for some areas), while the M_w for the North Caucasus for a given seismic network configuration can now be determined as M=2.9. Also, for moderate and small earthquakes of the North Caucasus, relationships between M_w and M_L magnitudes have been established as M_w=M_L+0.02 in the magnitude range M_w=3.0-4.5 We also got a comparable general linear relationship between M_w and mbISC. However, the RMS for the resulting relationship is noticeably higher than for M_L and M_w, therefore, individual mbISC estimates should be used carefully. The scaling of focal spectra of 44 earthquakes in the North Caucasus has been studied, which is an important practical result, since it allows us to estimate the probabilistic range of strong ground motions for the study area, which is one of the basic characteristics are using to seismic hazard assessment. Based on the above, in the magnitude range of 1.5-4, we can recommend the local magnitude M_L as a “quasi M_w” magnitude for earthquakes in the North Caucasus, which correlate with M_w as M_L=M_w–0.02 in the magnitude range M_w=3.0-4.5

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GC2024-SG052

Earthquake on January 24, 2024 in the in the region of Krasnodar city (North-West Caucasus) with M_w=4.1, I_0=4-5

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The instrumental and macroseismic data of the earthquake on 24.01.2024 at 11:19 (UTC) with M_w=4.1, h=20 km were studied. The epicenter and parameters of the earthquake were determined using instrumental data from the network of regional seismic stations in the western zone of the North Caucasus of the GS RAS. Location of the epicenter according to instrumental data near the city of Krasnodar (29 km). The processing based on the arrival times of P- and S-waves according to records from 49 seismic stations of the North Caucasus network GS RAS (Δ=28-699 km) and additionally 8 seismic stations of the Crimean network. The territory of the Krasnodar region in geological and tectonic terms is located in the transition zone between the Alpine meganticlinorium of the Greater Caucasus and the Scythian plate (young platform) include Indolo-Kuban trough. This territory is characterized [1] by both moderate (1.8<M<4.2) and high, mainly historical, seismicity (M≥6.8). The epicentral zone of the earthquake 24.01.2024 is located within the high-magnitude Akhtyrka zone of potential earthquake source zones (ESZ) with M_{max}=6.5-6.8 and represents the boundary between the Northwestern part of the structures of the Greater Caucasus and the West Kuban trough. The zone is characterized by a low level of modern seismicity, but according to historical data, an event was registered on May 25, 1968 with M=4.4, which caused macroseismic with an intensity of up to IV MSK-64. The focal mechanism was calculated for the earthquake. The solution of the focal mechanism was obtained from the polarization in P-waves at 69 seismic stations [2]. The movement in the source occurred under the influence of compression forces. The type of movement is Reverse fault with Right-Lateral Strike Slip component. The authors used the social network «Vkontakte» to collect macroseismic information. According to the results of the study, 120 respondents were interviewed in 15 settlements. The maximum observed intensity was I=IV–V MSK-64 in some areas of Krasnodar city. Based on the results of the macroseismic survey, a map of the distribution of intensity points were created. Spectral parameters of the earthquake, seismic moment and moment magnitude Mw were determined using SEISAN software [3].

Acknowledgments

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GC2024-SG053

The influence of layer orientation on the mechanical properties of 3D printed models

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The objective of this study was to conduct mechanical tests on 3D core models [1] manufactured using 3D printing with the photopolymer method, specifically SLA (stereolithography apparatus). The tests were performed using the uniaxial compression method. The novelty of this research lies in the manufacturing technique of the samples, with printing conducted in different layer directions, vertical, horizontal, and at angles of 30 and 60 degrees. This variation in layer directions was employed to investigate the influence of layer orientation on the mechanical properties of the material. Based on the test results, the relationship between axial displacement and stress was established for each sample, enabling the determination of the elastic modulus for each variant. It was found that samples with vertically oriented layers exhibited greater elasticity, with an elastic modulus of 13.02 MPa. Conversely, samples with horizontally oriented layers showed the lowest elasticity. This phenomenon is attributed to the development of tensile stresses within the model's thickness for samples with inclined or horizontal layers, subsequently leading to layer slippage. The identified patterns and findings have been utilized to simulate the impact of deformation on the conductivity [2-3] of 3D printed core models. The results of this study contribute to understanding the mechanical behavior of 3D printed materials and inform the modeling of their conductive properties in deformation scenarios.

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GC2024-SG054

Comparative analysis of the reduction in permeability under loading in laboratory and field conditions

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The productivity of wells is influenced by the permeability of formations, which can decrease due to compaction caused by pressure drop. Accurately predicting permeability changes during hydrocarbon production is crucial for optimizing oil recovery and maintaining maximum productivity. However, despite the consensus among researchers that permeability changes follow a power law under loading, predicting permeability in field conditions is challenging. Coefficients of the power equation can differ significantly between comparative well tests and laboratory studies. Research indicates that rocks are more sensitive to a decrease in pore pressure under field conditions [1]. While the same trend may be observed in fractured rocks during laboratory studies, the cause of the large difference in permeability reduction in porous formations remains unclear. To investigate the mechanism of permeability decrease in porous rocks during field conditions, this study presents a comparative analysis of laboratory permeability tests on core samples and field tests on wells. The findings reveal that permeability decreases by over 95% under field conditions, whereas laboratory studies indicate a maximum decrease of only 20% under loading. The primary reason for this significant difference is the disparity in scale between the objects being examined. In core samples, even substantial loads result in purely elastic deformations with minor displacements [2]. However, at the reservoir scale, these same deformations can lead to displacements of several centimeters, causing the movement of rock blocks and the localization of deformation within bands [3]. Further studies have demonstrated that the degree of permeability reduction is linearly dependent on the thickness of the formation. A greater thickness of the formation results in the movement of more rock blocks, leading to the formation of a larger network of deformation bands that decrease well productivity. The research findings also indicate that this mechanism is characteristic of all kinds of porous formations, including terrigenous and carbonate formations.

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GC2024-SG055

Uqturpan earthquake with Mw=7.0 on January 22, 2024, in the south of the Tien Shan

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The first results of the analysis of instrumental and macroseismic data of the large earthquake on January 22, 2024, (Mw=7.0) in the south of the Tien Shan in the Gissar-Kokshaal fault zone are presented in the report. The area under study was characterized by seismic calm for many years. The most significant in terms of energy, the Suusamyr earthquake of 08/19/1992 with Mw=7.3 occurred at a distance of more than 200 km from the epicenter of the Uqturpan earthquake.

The earthquake was preceded by a ten-year period of increased seismicity in a wide region of Central and South Asia, which began with 2 large earthquakes (Mw = 7.7) in the Makran region in 2013, after which an increase in subhorizontal stresses was recorded in the region, which led to the more rapid preparation of a series of strong earthquakes.

The characteristics of seismicity in the Central Tien Shan region are considered, it is observed that before the earthquake of January 22, 2024, ring structures of seismicity were formed in two depth ranges: 0–33 and 34–70 km, which indicate the presence of earthquake precursors, by analogy with others seismically active areas.

The intensity of shaking at the epicenter of the main shock of the Uqturpan earthquake in Xinjiang province reached 8-9 points. On the southern coast of the Issyk-Kul lake it was 5-6 points, in Almaty and its suburbs - 5 points. The earthquake was felt in Kyrgyzstan, Kazakhstan, Tajikistan, Uzbekistan, Turkmenistan, Azerbaijan, Russia, and India. The dependence of the intensity in points on the distance for this earthquake was shown. An analysis of records from strong motion instruments based on data from corresponding stations in Central Asia showed that the highest amplitudes of PGA accelerations equal to 30–43 cm/s^2 correspond to an intensity of 6 points and were recorded from 88 to 182 km from the epicenter.

The main shock was followed by a large series of aftershocks: on January 22, 179 events were recorded, on January 23 – 459 ones, in total, as to the end of February, 2024, 2883 aftershocks were already recorded, the strongest of them was the event with mpva = 5.9. The process of stress relaxation continues to this day.

The obtained fault plane solutions of the main shock and the strongest aftershocks showed the domination ща reverse-thrust type mechanisms, the strike of nodal planes along the Gissar-Kokshaal fault was identified, which is consistent with the northeastern orientation of the cloud of aftershocks and, in general, with the geodynamic situation of the Tien Shan and Tarim Basin junction zone.

The dynamics of the rupture in the source was complex; several sub-foci of different energies were presumably identified. This was reflected in the discrepancy between the parameters of the hypocenters, especially depth, according to the data of different seismological centers.

GC2024-SG056

The source and consequences of the Kungey earthquake on March 4, 2024 (mpv=5.8) in the Northern Tien Shan region

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On March 4, 2024, a strong earthquake occurred near the largest metropolises of Kazakhstan and Kyrgyzstan, Almaty and Bishkek correspondingly, which was felt over the vast territory of Kazakhstan and Kyrgyzstan.

The uniqueness of this earthquake is that: firstly, its hypocenter is confined to the zone of the Kemin earthquake of 1911, secondly, only one aftershock of weak energy was recorded, thirdly, the Kungey earthquake was felt in Almaty, Bishkek and its suburbs with intensity 5 points on the MSK-64 scale and had the most significant impact on the metropolises after the 1990 Baysorun earthquake.

The historical seismicity of the area, the macroseismic impact of the 1911 Kemin earthquake, as well as the modern seismic regime are considered in the report.

An interesting feature of the earthquake was the fact that before this event the seismicity formed a ring structure generated by earthquakes with depths of up to 33 km. Such ring structures were formed before strong and powerful earthquakes with magnitudes greater than 7, in various regions of the world, and were a clear prediction’s feature. The formation of a ring structure of seismicity before earthquakes of lower energy is a unique fact.

On the northern shore of the Issyk-Kul lake, in Almaty, Bishkek and its suburbs the intensity was 5 points. The dependence of the intensity in points on the distance for this earthquake was shown. An analysis of records from strong motion instruments based on data from corresponding stations in Central Asia was carried out.

The fault plane solution of the Kungey earthquake on March 4, 2024 with mb=5.5 was determined by the signs of the first arrivals of P-waves at 52 stations that well surrounded the epicenter and remote at distances Δ=88–2900 km. Compression waves were recorded at 23 stations, and 29 sites registered tension waves. The earthquake occurred under the influence of submeridional near-horizontal compression, which is typical for sources in the Northern Tien Shan. As for deformation state, the area of research is well studied; here most of the events have a reverse type of motion with a strike-slip component. The type of motion in the source on March 4, 2024 along the steeply dipping plane NP1 with a southwestern strike is a reverse with a left-sided strike-slip component, along the plane of an eastern strike is a thrust with a right-sided strike-slip component.

GC2024-SG057

The influence of rock conductivity on the of detached particles size distribution during filtration and cyclic loading

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The objective of this study was to analyze the impact of cyclic and static loads on permeability and the characteristics of carried-out particles during nitrogen filtration through sandstone samples. The experimental setup involved placing the samples in a test setup with filters positioned one by one under the end surface to capture exhausted particles. A different testing algorithm was implemented for each sample, considering variations in loads, number of cycles, and filtration. Four terrigenous core samples with varying permeabilities were used in the study. Analysis of the filter results provided graphs illustrating the normal distribution of the diameters of the carried-out particles. The findings indicated that, in most cases, an increase in the number of filtration cycles correlated with an increase in the standard deviation of the particle distribution. This observation suggests a higher degree of data dispersion or uneven particle sizes, as evidenced by the heavy tails in the distribution curve. Moreover, an increase in the number of filtration cycles resulted in the mathematical expectation or average diameter value increasing and a rightward shift of the distribution density curve. Interestingly, the distribution curves of highly permeable samples exhibited a flatter character and larger standard deviation compared to samples with lower permeability. This observation could potentially be attributed to the loose structure of the sample, in addition to the influence of filtration. As expected, rocks with lower permeability demonstrated smaller particle removal and exhibited minimal impact on permeability. These findings shed light on the relation between cyclic and static loads, particle characteristics, and permeability changes during filtration processes, thereby contributing to a better understanding of the behavior of sandstone samples under nitrogen filtration [1,2,3,4].

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GC2024-SG058

Distance corrections to surface-wave magnitudes of Far East shallow earthquakes

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Surface wave magnitude *MS* has a number of advantages over other magnitude types - more than 100-year period of its determination, the ability to calculate *MS* for earthquakes around the world, established regional and global relationships with other magnitude types, participation of *MLH* (analogue of *MS*) in macroseismic field equations for the regions of the former USSR, which made it possible to use *MLH* and *MS* as a reference magnitude when compiling earthquake catalogs for seismic zoning of the USSR and Russia territories.

However, *MS* has two significant disadvantages - dependence on depth, which the authors of [1] proposed to compensate for using depth corrections, and on distance, as shown in this work.

In most seismological centers, *MS* is determined using the “Prague formula” [2]:

$$MS=\lg(A/T)_{max}+1.66\times\lg r^{o}+3.3, \qquad (1)$$

where A is the displacement in micrometers, T is the period in seconds corresponding to the maximum velocity, r is the epicentral distance ($2^{o}< r <160^{o}$).

After the IASPEI adopted “Prague formula” as a standard (in 1967), the adequacy of the calibration function (the last two terms in formula (1)) was repeatedly discussed in publications and at conferences, but, despite some changes to the standard procedures for determining *MS*, the formula remained the same.

We checked the compliance of the calibration curve used in the “Prague formula” with the attenuation of A/T values depending on distance for Far East earthquakes with $h\leq 50$ km for 2013–2018, the *MS* magnitudes of which are presented in the Seismological Bulletin of GS RAS (ftp ://ftp.gsras.ru/pub/Teleseismic_bulletin/). The distance dependence of the deviations *dMS* of station magnitudes *MSst* from the network average *MSav* was analyzed. For epicentral distances r=4–80°, a loglinear dependence is established:

$$dMS= MSst–MSav=0.661\times\lg(r^{o}) - 1.06,\ R=0.62,\ N=8738. \qquad (2)$$

At distances r=17–160^{o} absolute values of *dMS* do not exceed the generally accepted error in determining *MS* (±0.25), and only at $r<17^{o}$ *MSst* are significantly lower than average magnitudes *MSav*. When analyzing macroseismic data from 34 earthquakes in Northern Eurasia, we also discovered an underestimation of ISC and MOS magnitudes *MS* of weak earthquakes (*MS*<4.5) compared to the magnitude required in the regional macroseismic field equations. This is probably due to the big contribution to *MSav* of underestimated *MSst* due to small epicentral distances. Such an underestimation can be compensated for either by introducing corrections to *MS* for distance according to eq.(2) or by refining the calibration function.

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GC2024-SG059

The role of geodynamics and the deep fluid regime in seismicity, and oil and ore generation processes

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The geodynamic processes play a key role in seismicity, and in the genesis of oil and ore. The very important characteristic of the geodynamic processes and the mostly changeable one is the deep fluid regime. Fluid concentrations in the lithosphere can vary by a few orders of magnitude, the permeability values of rocks vary in the very wide range of 5-7, and rarely up to 10 orders of magnitude. Thus, it is clear that the deep fluid regime can play a key role in the mentioned processes.

The important role of the deep fluid in seismicity is generally recognized. At the high pressures and temperatures typical of the Earth's interior, the brittle failure cannot occur at depths greater than a few dozen kilometers [1-3]. Nevertheless, earthquakes do occur at depths up to 700 km depth. The paradox is explained by the presence of the deep fluid that decreases the effective friction in rocks; this model is believed to be applied for explanation of earthquakes occurring at depth shallower about 150-200 km [3, and others]. The main source of the fluid appears to origin in dehydration processes occurring in the subduction zones and other deep crust thrust faults. The deeper earthquakes down to depth 700 km appears to be connected with the phase transformations occurring in the downgoing slabs [1, 2, 4, and others].

Examination of the trace element (TE) content in oils and other caustobiolites revealed that the uprising deep fluid flow is a typical, and apparently a necessary, component in process of oil generation. The involvement of the deep fluids in TE content in hydrocarbons (HC) is shown to increase as the original dispersed organic matter is being transformed into bitumen, to crude oil, and finally to products of oil degradation [5]. Data on HC deposits, especially the deep ones (H>4.5 km), indicate that the corresponding uprising deep fluid flow appears to be a result of dehydration processes occurring in the deep thrust zones. This model of oil genesis combines the preferable aspects of the biogenic and abiogenic concepts of oil genesis. The model also explains the process of concentration of dispersed hydrocarbons into high resource oil fields. The model explains also the typical features of the deep oil deposits and thus can be used for offering a set of practically required criteria for searching the deep oil fields. This is the actual task because of the high potential input of the deep HC deposits in the total balance of HC reserves. Detection of such deposits in the past took place largely accidental, because the predictive criteria that are used in the search for traditional HC deposits are inefficient in the case of the deep ones.

The role of thrusts is very important also in the formation of ore deposits. It is known that a huge number of ore deposits are confined to the Pacific ring of the subduction zones. The formation of these deposits is associated with the subsidence of the lithospheric plate, its dehydration and the development of the ascending flows of melts and fluids.

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Earthquake forecast algorithm based on the set of typical anomalies obtained in the general vicinity of large earthquake

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The used earthquake forecasting methods are not accurate enough [1, 2]. The task of increasing the accuracy of these methods and developing of new ones is urgent. Main reasons of difficulty of forecasting are the high variability of seismic process, which makes it difficult to identify predictive effects, and the lack of a physical model of earthquake [1-4; and etc.]. The proposed approach helps to overcome these difficulties.

The algorithm is based on the use of the results of analysis of the generalized vicinity of a large earthquake (GVLE) [2, 5, 6; etc.]. As a result, the character of the known predictors was detailed and a few new ones were identified. In the GVLE the predictors, due to the summation of data on a large number of strong events can be parameterized valid. The anomalies begin approximately 100 days before a generalized large event (GLE) and increase with decreasing time interval Δt before the GLE. The foreshock flow N has the form

$$log(N) = a + b\ log\ (\Delta t) \quad (1)$$

The anomalies *A* of increase of the average magnitude, *b-value* anomaly, and a few others have a form

$$A = a + b\ log\ (\Delta t) \quad (2)$$

In (1) and (2), *a* and *b* are coefficients determined for a given anomaly and catalog. Catalogs of seismic moments of earthquakes, that provide more detailed information about the earthquake sources, provide the increased number of type (2) anomalies.

Another advance is related with confirmation of the differences in the physical mechanisms of earthquakes of different depths. In [7-8] the difference of earthquakes occurring at different depths was verified.

A preliminary test of this forecasting method was carried out by a retrospective analysis of the world ISC-GEM and GCMT catalogs and the regional catalog of Kuril-Kamchatka. The question was addressed how often anomalies (1) and (2) types can be identified in the preparation zones of individual strong earthquake. It is shown that the probability of such earthquake prediction depends on the number of weak events recorded in preparation area. Thus, it is possible to indicate what the registration network should be constructed to predict Mo+ events with probability *p*.

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GC2024-SG061

Spectral analysis of passive DAS data for monitoring of an undermined massif at a salt deposit

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In the undermined territory of the Verkhnekamskoye field, the issue of monitoring the stability of the undermined areas is acute. Distributed acoustic sensors (DAS) are a recent cutting-edge technology in seismic research. It is based on the registration of scattered light in optical fiber cable. Optical fiber registration systems are extensively studied worldwide as they allow for addressing a wide range of seismic and acoustic tasks. In addition to classical active seismic surveys, the DAS system can also be used in passive observations.

Passive seismic observations were conducted at the Verkhnekamskoye salt deposit. A borehole-deployed cable line of an DAS was tested. The registration system includes a sensor cable and an interrogator that generates, registers and analyzes optical signals. DAS works by detecting Rayleigh backscattering of light, which is caused by tiny imperfections in an optical fiber that cause light scattering. The DAS system can register axial deformation or deformation velocity within a wide dynamic range (>100 dB) with an accuracy of tens of picometers on the gauge length [1].

The aim of the research is to monitor the condition of near-well rocks by analyzing the spectrum of recorded acoustic noise [2]. Observations were conducted in four geophysical wells to a depth of 195 meters. The optical fiber line is looped, forming a single contour, enabling recording along the entire line using a single interrogator [3].

The passive observation records comprise seismic traces recorded at 1-meter intervals along the optical line. The sampling frequency is 1000 Hz, with a total recording time of 8 hours per trace. For each trace, the total spectrum is calculated using Fourier transformation, enabling the construction of a map of spectral density along the receiver line. Based on this distribution, energy spectrum curves were calculated in 7 frequency ranges: 0-20 Hz, 20-40 Hz, 40-60 Hz, 60-80 Hz, 80-100 Hz, 100-200 Hz, and 200-300 Hz, as well as the full energy of the spectrum.

Presumably, the primary contribution to the recorded wavefield is attributed to Lamb-Stoneley waves propagating along the borehole, as well as Stoneley waves propagating along sub-horizontal lithological boundaries.

The calculated energy curves are compared with acoustic logging data and lithology of well sections. The energy values of acoustic noise correlate with seismic-geological boundaries, distinguished by the P-wave velocity curve obtained from acoustic logging data and lithological data. The proposed method for assessing the state of a rock mass, based on the correlation of acoustic impedance with the energy of passive noise, allows to expand the capabilities of monitoring the stability of an undermined rock mass.

The correlation between changes in the energy of passive noises in wells and the acoustic impedance of rock mass boundaries opens up possibilities for monitoring the condition of near-well space with passive measurements using DAS technology.

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GC2024-SG062

Study of the wave pattern of various nature events from the area of the Novaya Zemlya Test Site according to historical seismic and infrasound records by Central Asia stations

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The northern Novaya Zemlya Test Site was used during Soviet times to conduct unique nuclear weapons tests in different environments. So for the period 1955-1990, 130 nuclear explosions were carried out at the Test Site, the total yield of which was 265 megatons. On Novaya Zemlya, 1 ground explosion, 85 air, 2 surface, 3 underwater and 39 underground (in boreholes, adits) nuclear explosions were carried out. In addition, tectonic earthquakes occur near the Test Site as well as induced earthquakes caused by multi-megaton underground nuclear explosions.

Unfortunately, only a small number of seismic events from the Test Site was recorded by digital stations. However, over the years of the Test Site operation, the archives of various seismological organizations of the former USSR have accumulated a large number of analogue seismograms from permanent and temporary stations.

On the territory of the Kazakh SSR, instrumental seismic observations began in 1927 (AAA stations); by the beginning of the the Test Site operation, a large number of sensitive seismic stations were operating in Central Asia. Historical seismograms of nuclear explosions and earthquakes from the territory of the Novaya Zemlya Test Site were digitized over a number of years by the Complex Seismological Expedition of the Institute of the Physics of the Earth of the Russian Academy of Sciences, and by the Institute of Geophysical Research of the Republic of Kazakhstan; a database of digitized records of events with epicenters at the Novaya Zemlya region was created, it contains more than 700 seismograms at epicentral distances from 1270 to 4390 km. It includes seismic records of atmospheric and underground nuclear explosions, as well as underwater nuclear tests, tectonic earthquakes and aftershocks of nuclear explosions. In addition, infrasound records of waves from multi-megaton atmospheric nuclear explosions recorded by a microbarograph installed at the Talgar seismic station at a distance of approximately 3600 km from the Test Site were studied.

The kinematic and dynamic parameters of records of nuclear explosions carried out in different environments (in the air, under water and underground) were studied using digitized records of events conducted at the Novaya Zemlya Test Site, the characteristic features of the wave pattern of each class of events were found.

Records of anthropogenic earthquakes of the 1970s, as well as seismograms of tectonic earthquakes occurred on August 1, 1986, and October 11, 2010 were analyzed by Kazakhstan stations data.

The conducted work is important for the development of methods for recognizing the nature of seismic sources, as well as estimating explosion parameters using seismic data.

GC2024-SG063

On the geophone coupling function in marine research

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In marine research the so-called P-Z summation is used in order to suppress receiver-side multiple reflections and improve the quality and resolution of target signals of reflected waves. This procedure is the summation of hydrophone and geophone data, based on the fact that the geophone and hydrophone perceive downgoing signals from the water-air surface with different signs [2]. Despite the fact that such a procedure is considered classical, it often turns out in practice that its implementation is not easy without additional processing of geophone data. The geophone data can be very noisy and record P-waves with various amplitude-phase distortions due to the fact that it is impossible to control the position of the sensors on bottom and their bottom coupling.

In this paper we present the algorithm for additional processing of geophone data - the definition of the so-called geophone coupling function, which includes correction of geophone data both for poor bottom coupling and for other distortions of the signal recorded by the geophone associated with the geophone itself and its position on the bottom. The developed algorithm consists of two stages. The first stage is the construction of a signature filter, which allows us to obtain data from an “ideal” geophone (geophone with ideal coupling) from hydrophone data. The second stage is comparing the data of an ideal geophone with the data of a real geophone using spectral-correlation analysis methods [1] and constructing a transition coefficient, which determines the so-called geophone coupling function. The definition and application of the geophone coupling function is shown using the example of traces of real seismic data from marine seismic exploration.

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GC2024-SG064

Experiments on the use of seismic and infrasound methods for remote recording of snow avalanches

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Avalanches are a dangerous natural phenomenon that occur in mountainous regions. Every year, hundreds of people are caught in avalanches, and these incidents often result in tragedy. As mountain tourism and extreme winter sports become more popular, the number of avalanche accidents is on the rise. Visual observation of slopes remains the primary method of avalanche detection. As a result, the collection of avalanche observations, particularly in isolated mountainous regions, is still incomplete. Similar to earthquake forecasting, predicting avalanches is a complicated task that requires a comprehensive dataset of avalanche and meteorological observations. To begin this process, a remote, all-weather automated monitoring system for avalanches should be established. The Kola Branch of the GS RAS has initiated the development of a hardware and software complex for avalanche monitoring. The complex will be based on the registration of seismic and infrasound signals. Over the last five years, a series of experiments were conducted in the Khibiny mountain massif to support this initiative. The experiments focused on the registration of avalanches initiated within the framework of avalanche safety services. During the experiments, signals caused by avalanches were recorded using a broadband seismometer and an array of three low-frequency microphones installed at varying distances from the avalanche source. The results demonstrate the high registration abilities of the infrasound method, while also revealing the challenges associated with using the seismic method to solve these problems. The technical solutions have been developed [1], and prototypes of software for automated detection of target signals have been created [2].

Consequently, an experimental complex for monitoring avalanche activity in the Khibiny mountain massif was established. The operation of the complex demonstrated that infrasound signals generated by the movement of snow mass on the mountain slope can detect avalanches with a volume of about 5 thousand cubic meters at a distance of 7 km. The smallest avalanche on record had a volume of 0.5 thousand cubic meters and was located 2.5 km away from the station.

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GC2024-SG065

Modelling the influence of acoustic vibrations on the movement of plastic particles through rocks

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The development of oil deposits in clastic reservoirs is accompanied by a deterioration in the permeability of the bottomhole formation zone, which leads to a decrease in production rates, failure to meet design targets and the formation of undeveloped areas in the productive formation. To ensure that reservoir development targets are met, inflow stimulation methods are used that help restore the permeability of the reservoir zone and maintain the mechanical integrity of the reservoir. Vibration methods demonstrate an increase in the influx of formation fluid to the production well. In engineering practice, this phenomenon is usually explained by various effects associated with the mobilization of capillary pinched oil, a decrease in fluid viscosity, and others [1]. Such effects are widely covered and physically substantiated in theoretical works. However, there are very few laboratory studies demonstrating the performance of mathematical models. This is primarily due to the complexity of the experiment, which requires the laboratory stand to meet the conditions for processing a rock sample (model) with elastic vibrations and the presence of liquid filtration. To fulfill these conditions, some foreign researchers use microfluidics approaches [2], demonstrating the effects of vibration on artificial micromodels. However, to confirm the effectiveness of vibration methods, oil companies need to demonstrate the effect using traditional core samples. In this regard, laboratory research into the influence of vibrations is a necessary and relevant direction that can demonstrate an improvement in the permeability of rocks.

A laboratory rig given in [3] is used to demonstrate the effect of paraffin mobilization in pore channels from vibrations of a rock sample. When the piezoelectric elastic vibration emitter (Langevin emitter) is activated, the lid is subjected to high-frequency reciprocating movement of the emitter, which it transmits to the liquid in the chamber, as a result of which the pressure in the chamber changes in accordance with the shape of the specified signal (sinusoidal, rectangular, etc.). The resulting elastic vibrations are transmitted through the bushing to the sample through the matrix and a system of pore channels.

Due to the resulting relative displacement of the rock matrix and paraffin particles, the paraffin accumulations blocking the pores are broken up. The criterion for the effectiveness of treatment is the ratio of permeability at the end of treatment to permeability before the first treatment.

The results of the studies indicate that acoustic vibrations restore the permeability of rocks. A model of the influence of vibrations on plastic paraffin particles inside the flow and rock permeability is developed. The results obtained can be used when influencing the reservoir zone, in which deterioration in reservoir properties is observed due to blocking of the pore space by paraffin particles.

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GC2024-SG066

New data on radial anisotropy in the European region from surface waves

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There are varying opinions on the causes of radial anisotropy. It may result from convective flows of material in the upper mantle or deformation of the material due to tectonic processes over hundreds of millions of years. The lithosphere preserves geological processes that occurred over millions of years. The anisotropy of the oceanic upper mantle is likely described by the first mechanism, where VSH is consistently higher than VSV. The second factor pertains to the continental mantle, where different VSH to VSV velocity ratios are possible.

The anisotropy of seismic wave velocities in continental regions, as opposed to oceans, is still a topic of debate. Estimates in different regions show different signs between the velocities (Kustowski et al., 2008; Boschi et al., 2009; Chang et al., 2010; Schivardi and Morelli, 2011).

This study examines the radial anisotropy of the subcrustal mantle in Europe. The study is based on dispersion curves of Rayleigh and Love waves with periods ranging from 10 to 100 seconds. These curves are derived from earthquake records along paths intersecting the European continent.

A new software module based on wavelet transforms has been developed to obtain dispersion curves from earthquake records. This module allows for the conversion of primary data in mseed format to frequency-time diagrams without preprocessing.

To solve the 2D tomography problem, we employed a method based on the assumption that the resulting solution is smooth, as proposed by Yanovskaya and Ditmar in 1990. The solution was constructed directly on the spherical surface, as the region occupied by the paths is quite large.

Within the acceptable resolution range, we inverted the local dispersion curves of Love and Rayleigh waves to obtain local SH- and SV-velocity sections. We constructed and analyzed 2842 local velocity sections to investigate the distribution of the anisotropy coefficient.

The obtained data indicate that the study area can be divided into three main regions: the region of high velocities in the upper mantle, located to the west of the TTZ, the area of the East European Platform, and the region of low velocities, adjacent to the Atlantic Ocean coast and influenced by the Atlantic spreading zone. Additionally, most of the West European Platform exhibits intermediate velocities.

The belt of Alpine folding is marked by a low-velocity anomaly that is well traced to a depth of 100 km under the Anatolian and Balkan Peninsulas, as well as the Carpathian region.

Anomalous anisotropy zones are also well traced to depths of 200 km and are associated with the North Sea region, the Black Sea, and the Anatolian Peninsula region.

The obtained data best agrees with the LRSP30EU model of Boschi et al. [2009].

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GC2024-SG067

Applications of fiber optical DAS equipment for teleseismic observations and tomography tasks in seismology

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We discuss experimental results on using Distributed Acoustic Sensing (DAS) technology based on fiber optic sensors [1] for several applications in geophysics. Emergence of DAS as a new technology in geosciences has outlined an inevitable trend to be involved both for teleseismic measurements and in local scale tomographic tasks [2]. For tomographic applications DAS combines active and passive methods where both approaches utilize recovering and inversion of surface wave dispersion curves for the uppermost Earth imaging. The touchstone here is reliable recording of signals and background strain noise at high frequencies to apply ambient noise tomography methodology or any modifications of multichannel analysis of surface waves [3]. T8, LLC has developed a new method of fiber-optic cable installation where subsequent cable segments are twisted in rings along the overall linear surface layout. Such arrangement has been tested and demonstrated promising enhancement in recovering of the dispersion curve on the ice floe with quality comparable to the geophone string placed nearby for comparison.

For teleseismic measurements DAS can record signals across the broad frequency range extended from several millihertz to hundreds of hertz, while providing measurements over many tens of kilometers with high spatial density of deployed virtual sensors. This capability was demonstrated during the “Global DAS month” international experiment, organized in February 2023 [4, 5] where the equipment developed and manufactured by T8, LLC was also used. A number of different DAS manufacturers provided their hardware for this effort with the measurement results available for public access. The analysis of these vast data not only provides insight into DAS potential for geosciences but also allows quality assessment of the equipment from different manufacturers.

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GC2024-SG068

Technology for surface waves processing recorded using seismic streamers to study the upper part of the Pechora Sea shelf section

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In water areas, to ensure the safety of drilling and construction of bottom infrastructure facilities, a complex of geological and geophysical studies is carried out, aimed at studying the upper part of the section and identifying hazardous geological processes. At the same time, as part of seismic work, only reflected waves are usually processed. This project provided a unique opportunity to perform specialized processing of not only reflected waves, but also surface waves, in order to study the upper part of the section in detail. As a result, it became possible to evaluate the convergence of the results obtained and to develop methodological recommendations for conducting engineering geophysical studies in water areas using surface waves, which is important for areas with high gas saturation in the upper part of the section. The project used 2020 MOV-OGT data obtained using towed systems as part of 3D seismic surveys in the Pechora Sea. The presence of intense surface waves can be explained by the short distance (less than a quarter of a wavelength) between the towed streamer and the seabed. In order to process the materials within an acceptable time frame, the original data array (145 km2), containing more than 1 million traces, was thinned out 10 times, so that, based on the results of MASW, the output was a set of 1D models located along a relatively regular network with an approximate step 250x250 meters. The resulting models were interpolated into a 3D velocity cube Vs of shear waves. The depth of the speed cube was 80 meters. Comparisons of horizontal sections based on MOV-CDP and MASW data showed high correlation and correctness of constructions within the MASW method. From a geological point of view, it was possible to identify such dangerous phenomena as paleoincisions and paler channels, to show a steady decrease in Vs velocities in these zones, and also to identify other zones of increased and decreased Vs velocities. The detection of these objects in the results of MASW processing indicates the high resolution of the method, and the contrast of velocities and the ability to determine the depth of the object provide great potential for subsequent geological interpretation. As a result of the work done, it was possible to develop an optimal methodology for processing data within the framework of the MASW method recorded by towed streamers; show the correctness of the results obtained and the possibility of their use when interpreting data; develop methodological recommendations for processing surface waves recorded in the water area, useful for the implementation of other projects. It should be noted that during the implementation of the project, it became obvious that it was necessary to use neural network technologies when working with 3D MOV-CDP data in order to increase the information content of processing by using the entire data array. The introduction of these technologies into the surface wave processing process is currently the main goal of our research, since then it is possible to obtain detailed Vs velocity cubes from all CDP data recorded by seabed seismic equipment.

GC2024-SG069

On correlation of magnetic field variations with large seismic events

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The report is devoted to the consideration of correlation of variations of the magnetic field of the European region with large seismic events that occurred in 2010. In the course of the analysis of actual information, a temporal relationship was established between the groups of earthquakes with a magnitude greater than 5.5 presented in the USGS Earthquake Hazards Program catalog [1] and the change in the character of variation curves at the INTERMAGNET network observatories [2] located on the territory of Europe.

The preliminary processing of the measurement data of geomagnetic observatories for this study included taking into account the variability of the normal magnetic field according to the IGRF-13 model, bringing all variation curves to the zero level, rejection of incorrect values with subsequent spline interpolation, low-frequency Butterworth filtering with a period of 30 hours for reduction of high-frequency variations of the magnetic field and subsequent calculation of the median variation curve reflecting the trend of variability of the magnetic field of the studied region. At the final stage, the difference between the observed values after processing and the median signal was calculated in order to identify local features of magnetic field variations.

This approach to the analysis allowed us to establish the regularity of the spatial distribution of the amplitude-frequency features of the variation curves. The obtained distribution is stable and can be traced over the entire time interval. The time intervals within which an increase in the dispersion of the time series of magnetic field variations synchronous with a series of large seismic events is traced have been separately established. The correspondence of the obtained spatial distribution of the characteristics of the amplitude-frequency composition of the curves for synchronous seismic events is established.

The study suggests a possible approach to analyzing the connection of the emergence of electromagnetic anomalies associated with seismic events for periods longer than 30 hours, which allows us to consider the connection of these processes on a more global scale.

List of Literature

1. USGS Earthquake Hazards Program [Electronic resource] URL: https://earthquake.usgs.gov/

2. INTERMAGNET International Network of Real-Time Magnetic Observatories [Electronic resource] URL: https://intermagnet.org/

GC2024-SG070

Response of the upper ionosphere to the earthquake in the Sea of Japan on January 1, 2024 (preliminary results)

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The main shock of the earthquake occurred on January 1, 2024 at 16:10 local time (07:10 UT) 6 km north-northeast of the city of Suzu, located on the Noto Peninsula in Ishikawa Prefecture. According to the US Geological Survey, the moment magnitude of the earthquake was 7.5 and the focal depth was 10 km. The Japan Meteorological Agency estimated the magnitude at 7.6. In this work, GPS satellite data were used to analyze the response of the upper ionosphere, which makes it possible to determine variations in the total electron content of the ionosphere. In the variations in the total electron content after the earthquake, a signal characteristic of shock waves is observed. Based on the amplitude of the ionospheric signal in the total electron content, the energy of earthquakes was estimated, consistent with seismic estimates.

The research was carried out within the framework of the state assignment of the IPE RAS and the state assignment of the IDG RAS No. 1220329000185-5 "Manifestation of processes of natural and man-made origin in geophysical fields".

GC2024-SG072

Application of a distributed acoustic measurement system for active and passive seismic studies

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Recently, both in Russia and in the rest of the world, there are now several different types of optical devices for recording dynamic deformations in a medium based on the use of the Rayleigh backscattering effect. Such systems can record natural dynamic deformation from earthquakes in a wide frequency range from 100 seconds to hundreds of Hertz, as well as signals from artificial seismic sources for seismic exploration purposes. To select the optimal system for recording dynamic deformations and improve it, it is of great importance to test such systems and compare the obtained data of distributed dynamic deformations with records of traditional seismological instruments.[1],[2],[3] The presentation shows the application of a new innovative technology of seismic observations based on high precision recording of dynamic deformations to solve problems of bottom seismic exploration and seismology. The basis for the measuring system of dynamic deformations was taken from the development of the domestic company PetroFibre LLC - "Coherent Phase-sensitive Optical Reflectometer"-- VOSK-A. In 2020-22, numerous tests were carried out on the device for recording both active terrestrial and marine seismic, as well as for passive registration of earthquakes in marine on land conditions. According to the test results, the device was improved for optimal recording of seismic signals of a wide frequency range. In September 2021, an active experiment was conducted in the Blue Bay (Gelendzik) to record seismic energy from a 2.5-liter marine pneumatic source on a fiber-optic cable previously laid out on the bottom. The total length of the optical cable was 10,500 meters, the distance between the measuring channels was 1,02 m. The VOSK-A optical reflectometer was installed in the laboratory on the pier, which carried out continuous measurements of dynamic deformations during the work of a marine seismic source. Using a high density of channels, the position at the bottom of each of the 10,000 optical channels was very accurately restored (less than one tenth of a meter of RMS error) according to the travel times of water waves from the source. The time seismic section was obtained and interpreted up to 5 seconds of double travel time (or about 7 km in depth). This result is possible due to the high density and a large number of receiving channels, which allow increasing the effective fold during summation and thereby increasing the depth and resolution of the resulting section.

For the first time in the history of India, records of local and remote earthquakes were obtained on a distributed dynamic deformation system. Earthquake data records in the form of dynamic deformations were obtained along the entire laid fiber (35 km), every 6,25 m, i.e. 5,600 channels are recorded simultaneously, and these channels are broadband in the range from 100 sec to 100 Hz with a comparable dynamic range as with traditional broadband long-period seismographs. The length of the local deformation measurement base was chosen to be the same for all channels (20 m). Thus, the measuring system is equivalent to installing 5,600 long-period single-component seismographs along the entire 35 km line. The study was supported by program No. FMWE-2024-0026 (P.P. Shirshov Oceanology Institute)

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GC2024-SG073

The Lomonosov Moscow State University experience in fiber optic sensors technology

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Over past two decades, significant number of papers have appeared on the using of fiber optic technologies in various geoscience applications. Geodynamical [1] and structural [2] monitoring, condition monitoring of dams [3] and wells [4], seismological [5] and seismic [6] surveys and other [7] measurements have become available using distributed acoustic, temperature and strain sensing (DAS, DTS, DSS). The technology has not yet been fully implemented in Russian Federation. Currently, there are no regulations for the use of fiber optic sensors. Some of the first mentions of the prospects and possibilities of applyings DAS and DTS in publications, date back to the beginning of the last decade [8],[9]. Currently, large companies together with scientific institutes are working on introducing the technology into production. Scientific group of the Department of Seismometry and Geoacoustics of Lomonosov Moscow State University has been testing domestically produced DAS and DTS since 2021[10]. Currently, as part of pilot projects, various studies are being carried out in the zone of a extremely shallow waters, wells on a land and on the Arctic shelf. Surveying in the zone of extremely shallow water is designed to record surface and refracted waves. Using DAS data, dispersion images were constructed, which from a velocity model of S-waves in the medium was obtained. From times of arrives first breaks the model of P-waves velocities was obtained. To control the correctness of the recording, data from multicomponent bottom stations were used.

Well surveys are designed to collect vertical seismic profiling (VSP) data. Based on the moments of the first arrivals of downward waves, a model of P-waves near the well was calculated. Upward reflected waves are used to tie VSP data to very high resolution conventional midpoint seismic data. The resultant velocity model provides the best time to depth conversion for 2D seismic profiling data. The same cable was used to measure temperature in borehole with DTS.

Based on the experience gained, methodological recommendations are being developed for the using, development and processing of fiber-optic sensor data.

The purpose of the report is to highlight the operating principle of fiber-optic sensors, the main achievements in their applications in the world and the working group of Moscow State University.

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GC2024-SG077

Tsunami driven internal gravity waves after Great Japan Earthquake

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The earthquake that occurred on March 11, 2011, east of the Japanese island of Honshu (with the coordinates of the epicenter in the ocean 38.32º N, 142.37º E), had a magnitude of 9.0. This earthquake caused a destructive tsunami. The tsunami was recorded by the Tsunami Warning Center.

The purpose of the present studies was to determine the ionospheric response to a tsunami. The initial data used were the results of radio frequency sounding using GPS at the Hawaii stations.

During the processing and analysis of data obtained via GPS, it was found that 1) wave disturbances in total electronic content precede tsunamis arrival by approximately 1 hour, 2) the detected ionospheric variations range from 10 to 20 minutes, which correspond to the internal gravity waves (IGWs) frequencies, 3) the low-frequency part of the disturbance arrives earlier as it should be for IGWs generated by tsunami.

The research was carried out within the framework of the state assignment of the IPE RAS and the state assignment of the IDG RAS No. 1220329000185-5 "Manifestation of processes of natural and man-made origin in geophysical fields".

GC2024-SG078

Measured by magnetometers patterns of the ionospheric response to seismic events in the Philippines on December, 2023

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Using ground-based magnetometers, we studied the ionospheric disturbances observed after the earthquake in the Philippines on December 2, 2023 and its aftershocks.

A powerful earthquake of magnitude 7.6 occurred on December 2, 2023 at 22:37 Pacific time (14:37 UT) off the island of Mindanao. The epicenter of the event was located 110 km from the city of Butuan in the province of Agusan del Norte and 29 km north of the city of Hinatuan in the province of Surigao del Sur

After the main shock, aftershock activity was recorded to the southeast of the main shock. During the period from December 2 to December 31, 2023, the following aftershocks with a moment magnitude greater than or equal to 6 were recorded: aftershock of magnitude 6 (0:03 LT December 3, 2023), aftershock of magnitude 6.1 (1:40 LT December 3, 2023), aftershock of magnitude 6.3 (2:09 LT December 3, 2023), aftershock of magnitude 6 (4:52 LT December 3, 2023), aftershock of magnitude 6.6 (18:35 LT December 3, 2023), aftershock of magnitude 6 (22:35 LT December 3, 2023).

Weused instrumental observations of variations in the Earth's magnetic field, carried out at the Davao station (geographic coordinates: 7° N, 125.4° E; geomagnetic coordinates 2.22 N, 197.9° E). As a result, it was established that periods of geomagnetic variations after seismic events belong to the short-period (acoustic range), and long-period ones (range of atmospheric internal waves). It is shown that the origin of disturbances in the acoustic range can be associated with the arrival of seismic Rayleigh waves, which are the source of acoustic vibrations, while the estimated velocities of atmospheric internal waves correspond to their generation directly at the epicenters of events. We found that the magnetometric measurements make it possible to register ionospheric response from seismic events of noticeably lower magnitude compared to the GNSS radio sounding method (M=6 in the first case and M=6.5 in the second).

The research was carried out within the framework of the state assignment of the IPE RAS and the state assignment of the IDG RAS No. 1220329000185-5 "Manifestation of processes of natural and man-made origin in geophysical fields".

GC2024-SG079

Energy flows and the spatio-temporal structure in the earthquake source

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This paper presents the results of a statistical analysis of the energy flows and spatio-temporal dynamics of foreshocks and aftershocks in the earthquake source. Data from the USGS/NEIC World Catalogue of Earthquakes from 1973 to 2019 (https://earthquake.usgs.gov) were used. Starting from general physical concepts based on the Umov-Poynting theorem and the phenomenological theory of earthquakes, we formulated the following question: What are the directions of energy flows in the earthquake source before and after the formation of a main rupture in it?

A non-standard technique has been developed for the experimental study of this problem. The epicentral zone of the main shock is considered as a kind of track detector, and the foreshocks and aftershocks are considered as tracers, marking the propagation of a factor that has energy and stimulates the excitation of foreshocks and aftershocks in a stressed rock mass.

The method of superposition of epochs in the temporal and spatial coordinates was used. The main shocks performed the function of reper for synchronising the sequences of fore- and aftershocks. Each main shock was assigned a conventional time equal to zero, from which the time of observation of foreshocks and aftershocks was counted. The epicenters of each main shock coincided with the origin of the coordinates. The distances from the main shock to the associated foreshocks and aftershocks were calculated.

By processing and analyzing a large amount of observational data, it has been found that, on average, foreshocks move closer to the epicenter of the main shock over time, while aftershocks move away from the epicenter.

It is shown that after the main shock, "activation waves" occur in the earthquake source, spreading from the epicenter of the main shock to the periphery of the focal zone. The speed of propagation of such activation has been estimated. On average, it is about 5-10 km/h. It is shown that in the process of relaxation of the accumulated stresses in the source zone, its "deactivation", a a likeness of wave structure is observed in the spatio-temporal evolution of aftershocks.

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GC2024-SG080

Development of a method for identifying surface faults using active and passive sensors in remote sensing data

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High-precision and reliable identification of surface rupture disturbances is a relevant issue due to construction planning, exploration of mineral deposits, and forecasting hazardous geological events (earthquakes) [1]. Fault detection is performed using methods of automatic supervised thematic analysis of multispectral and radar satellite images. The developed software solutions are based on open libraries of the Python programming language [2].

For the study, a section of the Altai Mountains was chosen due to the increased seismic activity in this region, as well as the high degree of geological and geophysical research. Subsequently, parameters of multispectral and radar satellite data for detecting regional faults were determined. During the processing of multispectral imagery from the "Landsat-8/9" satellite and a series of quality experiments, a raster algebra function [2] or "Deformation Index" was developed: alt= (SWIR1)/(SWIR2),

where SWIR1 is the value of reflected radiation in the 1st short-wave infrared range (1.57-1.65 μm); SWIR2 - in the 2nd, respectively (2.11-2.29 μm). The range of numerical values of the index corresponding to the presence of a surface fault ranges from 1.5 to 2.5 inclusive. As a result of interpreting the values, it was found the areas of groundwater outlet and temperature anomalies correspond to this range, indirectly indicating the presence of breaks. Comparing the obtained data with the fault network of the Geological Institute of the Russian Academy of Sciences and the digital elevation model (valley asymmetry parameter) confirmed this assumption [3].

Furthermore sharp gradients of vertical movement velocities also indicate the presence of faults. High-precision (up to 1 mm) determination is implemented through differential radar interferometry. The initial data is a two-pass survey from the satellite "Sentinel-1b" (GSD 10 m/pixel). By analyzing the interferogram and unwrapping the phase of the reflected signal, maps of surface displacements were created, confirming the initial hypothesis and refining the information obtained from passive scanning systems.

The combination of data obtained through space imaging with active and passive sensors allows for the high-precision identification of regional surface faults.

The investigation was carried out within the framework of state funding from the IInstitute of Physics of the Earth of the Russian Academy of Sciences

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GC2024-SG081

A Kaiser Damage-Memory Effect in Sandstone under Cyclic and Rotated Triaxial Stresses

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The paper describes the mechanisms and conditions for the Kaiser damage-memory effect in rocks subjected to a three-dimensional disproportional cyclic loading with changes in the rocks' shape and the orientation of the Lamé ellipsoid. The experiments with the cubic samples taken from polymictic sandstone were conducted on Triaxial Independent Loading Testing System with continuous recording of an acoustic emission (AE) signals. The results of a disproportionate triaxial compression under the developed two protocols, they are 4- and 9-cycle loading programs, have shown that a dominate mechanism of the damage memory effect in each ensemble of cracks (vectored differently) is the development of micro-cracks of opening fracture mode oriented subnormally to the minimum main stress. It was found that the Kaiser damage-memory effect is detected not so much to the fact of opening cracks, friendly oriented, as to a discrete growing (increase of length) of already existing and newly emerging micro-cracks. The experiments on the cyclic strain of the sandstone at constant average stress and a changing level of a stress deviator allow the authors to conclude that the Kaiser damage-memory effect is not influenced by the intensity level of a shearing stress forcing on the sample. The obtained results can be considered as a trigger for models development oriented to strain and destruction of rocks, considering the anisotropic nature of damage accumulation.

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GC2024-SG082

Experience of determining S-wave velocities beneath the Caucasus from surface waves dispersion curves with the use of high-performance computing

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The Greater Caucasus, along with the Lesser Caucasus and the eastern part of the Anatolian Plateau, forms a tectonically active boundary between the Eurasian and Arabian plates. Since 2017, as part of the implementation of Project [1], a whole network of broadband seismic stations has been deployed here, allowing research in this area to be intensified.

One of the widely used methods for determining the velocity structure of the Earth's upper layers is ambient noise tomography. It is based on the fact that cross-correlation function of noise between two stations, averaged over a sufficiently long - on the order of a year or more - time interval allows to estimate the group and phase velocities of surface waves on paths between stations [2]. Further, using surface wave tomography [3], it is possible to estimate the two-dimensional velocity distribution depending on the period, and then, by solving the one-dimensional inverse problem, to determine the vertical velocity profiles of S-waves.

In this work, cross-correlation functions for all possible interstation paths were computed for records from 69 stations for the year 2018. Dispersion curves of group and phase velocities of Rayleigh waves for periods of 5-30 s were obtained using spectral-temporal analysis. Two-dimensional surface wave tomography was performed, resulting in lateral velocity distributions for periods of 7-22 s, reflecting the velocity structure at depths from 5 to 30-40 km [4]. To solve the inverse problem, it was planned to use T.B. Yanovskaya's program [5], based on the conjugate gradient method. The velocity profile in it is parameterized as follows - up to three layers with constant velocity in the crust and layers with linearly varying velocity in the mantle, varying the thickness of the layers and the velocity within them. The initial model was chosen based on works [6] and [7]. It turned out that the specificity of the data does not allow varying the thickness of the layers, and when only the velocities are varied, it is not possible to obtain an adequate solution. Varying the thickness of the layers is possible by changing the input data, but then it is necessary to run the processing program hundreds of times. The program itself is not resource-intensive when it is possible to use a minimal distributed computing system, but there arises the task of designing a scheme for setting up a group of independent tasks, solved distributedly with subsequent selection of the optimal solution. The paper presents an example of solving this problem and the velocity profiles obtained in this way.

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GC2024-SG083

The Equilibrium State of a Hollow Horizontal Orthotropic Thick-walled Cylinder, which is Subject to a Nonuniform Internal Lateral Pressure and Weight Forces

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We use the decomposition of the components of the displacement vector along the hoop and radial coordinates in series in Legendre polynomials and generalized power series to obtain an exact analytical solution to the equilibrium problem of a hollow horizontal orthotropic thick-walled cylinder, which is subject to a nonuniform internal lateral pressure and weight forces. As an example of using the obtained analytical solution, we analyzed the influence of weight forces on distribution of independent invariants of the stress tensor in the cross section of a heavy reinforced concrete cylinder, which internal surface is free from pressure. Based on the multicriteria approach describing various loss of strength mechanisms (from tension or compression in the radial and hoop direction and interlayer shear), we found the regions of a heavy reinforced concrete cylinder, in which damage can be initiated.

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GC2024-SG084

Using the transfer learning approach in neural network solution of inverse problems of exploration geophysics

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Inverse problems (IP) of exploration geophysics (EG), which consist in reconstructing the spatial distribution of the properties of the medium in the Earth's thickness from the geophysical fields measured on its surface, are characterized by ill-posedness, which complicates their solution, both by traditional methods and by machine learning methods, including neural networks(NN). A general approach to reducing the ill-posedness of IPs is to use additional information, such as a priori knowledge about the system under consideration. When using NN to solve EG IP, *a priori* knowledge about the system can be taken into account at the stage of creating the training dataset in the form of assumptions about the structure of the geological section, and its implementation involves the use of narrow parameterization schemes that describe a certain class of geological sections. In our previous studies [1], we have shown that indirect introduction of a priori information through the use of a narrower parameterization scheme shows a better result of NN solution of the EG IP compared to use of a more universal parameterization scheme.

However, generating a training dataset involves solving a direct problem for each pattern included in it, and it is therefore computationally expensive. Since each parameterization scheme requires creating new training data and training a new set of neural networks, using narrow parameterization schemes also incurs high computational costs. Therefore, to reduce computational costs, in this study it is proposed to use an approach based on transfer learning. In this case, models are pre-trained on data from a more general parameterization scheme and then fine-tuned on data from a more specific parameterization scheme. This will allow us to use less training data and to spend less time to train a neural network compared to training neural networks in the traditional way.

In this study, we investigate the applicability of transfer learning approach to EG IP of gravimetry, magnetometry and magnetotellric sounding, and we evaluate the computational cost savings when using it.

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Space weather and seismic activity: Possible triggering of earthquakes by strong solar flares of X-class

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Previously performed numerical studies of the influence of solar flares of class X on seismic activity [1] showed that the absorption of X-ray radiation from a solar flare in the ionosphere can cause the geomagnetic field pulsations up to 100 nT and the corresponding generation of geomagnetic-induced currents in faults of the Earth's crust with a density of up to 10^{-6} A/m^2, comparable to the current density generated in the crust by artificial pulse power sources resulted in triggering of weak earthquakes in the Pamirs and Northern Tien Shan regions [2]. For verification of obtained numerical results the statistical analysis of impact of the top 50 solar flares of X-class (1997-2023) on the global seismic activity, as well as on the earthquake preparation zones located in illuminated part of the globe and in the area of 5000 km radius around the subsolar point was carried out. It is shown by a method of epoch superposition that for all cases the increase of seismicity is observed, especially in the region around the subsolar point (up to 38%) during 10 days after the solar flare in comparison with preceding 10 days. The case study of aftershock sequence of strong M=9.1 earthquake (Sumatra-Andaman Islands, 26.12.2004) after the solar flare of X7.2 class (20.01.2005) demonstrated that the number of aftershocks with magnitude M≥2.5 increases more than 20 times after the solar flare with a delay of 7 days. For the case of the Darfield earthquake (M=7.1, 03.09.2010, New Zealand) it was shown that strong solar flares of class X and M probably triggered two strong aftershocks (M>6) with the same delay of 6 days on the Port Hills fault, which is the most sensitive to external electromagnetic impact from point of view of the fault electrical conductivity and orientation. Based on the obtained results the possible application of natural electromagnetic triggering of earthquakes is discussed for a short-term earthquake prediction using confidently recorded strong external electromagnetic triggering impacts on the specific earthquake preparation zones.

Acknowledgments

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GC2024-STP002

Is the global MHD modeling of the magnetosphere adequate for GIC prediction?

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Practical steps taken by the international community to reduce the damage to technological systems from space weather include the development of numerical models capable of real-time predictions of electromagnetic disturbances at the Earth's surface. Here we examine the feasibility of a version of the Space Weather Modeling Framework (SWMF) global MHD simulation code similar to that used by the NOAA Space Weather Prediction Center to predict the level of geomagnetic field variability, and consequently geomagnetically induced currents (GICs). We consider the contribution of geomagnetic disturbances to the bursts of GIC in the electric power line of the Kola Peninsula during the May 27-28, 2017 storm and compare the observations with results of the global MHD model. During the maximal disturbance magnetic field variations at East Scandinavian stations become more chaotic, as intense irregular Pi3 pulsations are superposed on the magnetic bay. These pulsations are not quasi-sinusoidal waves like typical Pc5 pulsations, but they are rather a quasi-periodic sequence of magnetic impulses with time scales ~5-15 min. During this period with elevated Pi3 activity very high values of GIC were recorded (variations >100 Amperes) in the electric power transmission line. The SWMF modeling reasonably well reproduces the global magnetospheric parameters, such as SYM-H index or cross-polar potential. However, the magnetic field variability dB/dt in the East Scandinavia predicted by the modeling has turned out to be more than order of magnitude less than that observed. Thus, the version of SWMF with the grid used by NOAA SWPC still cannot adequately predict for the May 27-28 event the fine structure of the storm/substorm - Pi3 geomagnetic disturbances, and consequently the magnitude of the GIC that they drive.

GC2024-STP003

Study of ionospheric variations before the great Tohoku earthquake in search of precursors of catastrophic earthquakes

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Purpose of this work is to study seismic-ionospheric connections and find out possible precursors of earthquakes. We concentrated on anomalous variations of total electron content (TEC) observed in different layers of the ionosphere before the catastrophic Tohoku earthquake, which occurred on March 11, 2011 near the east coast of Japan.

Signals of global navigation satellite systems (GNSS) received by stations of GEONET network were used to measure ionospheric delay of GNSS signals and valuate TEC over the area of interest. We used TEC maps calculated based on GNSS signals over Japan, provided by Nagoya University (NU), Japan, featuring resolution of 30 seconds and 0.5 by 0.5 degrees by geographic latitude and longitude. For comparison, we used TEC maps calculated using UPC model based on the spherical harmonic functions, provided by Technical University of Catalonia.

Measurements of F2 critical frequency (foF2) provided by vertical ionosphere sounding stations in Japan were used as independent source of information on ionosphere disturbances. Indexes of SME and F10.7 cm were used to account for solar and geomagnetic activity. Instead of plain TEC, we used integral values of TEC (iTEC) over the region, influenced by the earthquake, 26-46 degrees North Latitude and 128-148 degrees East Longitude, which covers whole territory of Japan, including the epicenter of the earthquake. In a time scale, we used moving average method with 7 days period to distinguish anomalous variations of TEC from daily variations due to solar activity.

During the period from March 3 to March 15, 2011 inclusive, anomalous iTEC values were observed, which clearly correlate with increased solar activity. However, approximately 27 hours before the foreshock of March 9, 2011, abnormal increase in iTEC (about three times the average and about 9 hours long) was observed. There was also a less pronounced increase in iTEC for about one hour before the foreshock, when SME index, reflecting the disturbance of the Earth's magnetic field, remained minimal. One day before the main shock of March 11, 2011, moderate increase in iTEC (about 1.5 times the average and about 5 hours long) was observed. There were no solar flares on March 10 and 11, and Solar activity index was minimal. Approximately 1-2 hours before the main shock, abnormal increase in iTEC (up to 130%) was observed in absence of any significant increase in model iTEC values at minimal SME and F10.7.

Moderate increases in foF2 were observed one day before the main shock at Kokubunji station, located close to the epicenter. Significant increase in foF2 was observed 1-2 hours before the foreshock and several hours before the main shock.

Considering the above, coordinated analysis of iTEC variations over the earthquake area shows the presence of two types of anomalies: (a) day-long anomalies (20-25 hours before the foreshock and the main shock), and (b) hour-long anomalies (1-2 hours before the foreshock and the main shock).

The most prominent increase in foF2 was observed one day before the shock at the Okinawa station, located far away from the epicenter of the earthquake. Moderate increase in foF2 was observed hours before the shock at Kokubunji station, closest to the epicenter. It is possible that anomalous phenomena in the ionosphere "pull together" from the periphery towards the epicenter, following increase in stress of the earth's crust.

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GC2024-STP004

Correspondence between the dynamics of the outer radiation belt, auroral oval, and ULF power

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We compare the spatial location of the outer radiation belt with an instant position of the auroral oval and the latitudinal distribution of ULF wave power during two strong magnetic storms in November 2001. Before storm onset, the polar cap is filled with solar electrons (0.6-1.5 MeV), and the electron penetration boundary approximately coincides with the position of the equatorward border of the nightside auroral oval. At the recovery phase the new radiation belt is formed predominantly with lower energies, 0.3-0.6 MeV. The origin of recovering radiation belt is located deeper inside the magnetosphere than the auroral oval, and near the inner edge of nighttime ULF power in the band 1.5–7.0 mHz. We suggest that the acceleration of electrons by ULF disturbances occurs not in a regime of “geoserfotron” with Pc5 waves (match of azimuthal velocities of waves and particles), but rather in regime of “geosynchrotron” with Pi3 pulsations ($T \sim T_d$).

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Recording of whistlers during Bezymyanniy and Shiveluch volcano eruptions

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Continuous monitoring of natural electromagnetic radiation in VLF range (3-30 kHz) by a VLF direction finder, which records signals of electric and magnetic components of the electromagnetic field and determines the direction of radiation arrival in real time, made it possible to create a long-term data base of lightning activity on Kamchatka peninsular [1]. Statistical analysis of the obtained data base [2] was carried out to detect whistler generation sources using the data of the Automatic Whistler Detector and Analyzer Network and the World Wide Lightning Location Network [3-7]. Different electromagnetic signals were recorded during the analysis of the strongest three eruptions of Bezymyanniy (20.12.2017, 7.04.2023) and Shiveluch (10.04.2023) volcanoes from the corresponding azimuths along the direction to the active volcanoes. The time range, selected for the analysis, is determined by a large number of recorded pulses. For example, the total number of strokes during Shiveluch volcano eruption reached 26101 pulses [8]. In the general data flow, signals of whistler type were detected. Analysis of their disperse characteristics showed the presence of initiating atmospherics that, in its turn, indicates so called long whistlers. It is also illustrated that the initiating atmospheric is one from the pair of positive strokes in more than 90% of all recorded cases.

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GC2024-STP007

Method for detecting sporadic manifestations of solar activity in cosmic ray variations

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The report examines the results of the detection of sporadic changes in variations of galactic cosmic rays observed on the eve of and during periods of magnetic storms of different physical nature. The theoretical basis of the research was the method developed by the authors for analyzing variations in the intensity of cosmic rays based on measurements from neutron monitor stations. The method is based on a combination of classical statistical methods with modern approaches, including elements of machine learning and data decomposition methods [1], [2]. The work analyzed periods of weak and moderate magnetic storms in 2017-2023. A network of polar and high-latitude ground-based neutron monitor stations was used (www.nmdb.eu). The report will present the basics of the method, algorithms for its implementation, and show the results of the method both in real time and in a posteriori analysis.

Based on the results of the study, the effectiveness of the method for the task of detecting anomalous changes in variations of cosmic rays of various amplitudes and durations was confirmed. The detected anomalous changes were of a general nature at all stations both before and during the analyzed magnetic storms. This confirms the importance of taking galactic cosmic rays into account in space weather problems.

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GC2024-STP008

Analysis of the magnetic storms and variations of the geomagnetic field components at the Pleshchenitsy Observatory, Republic of Belarus

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The effects of the coronal mass ejections and high-speed solar wind streams mostly manifested during magnetic storms can give rise to several negative consequences for the realization of the space and land technologies [1, 2]. In the first case, these may be an influence upon the ionosphere resulting in the short-wave radio blackout, malfunctions of the radio communication systems, navigation system errors, as well as a direct impact upon satellites (surface charges and currents, electronic system failures, etc.) In the second case, these are the induction effects developed in the power lines, products pipe lines, communication cables that cause a risk of the power and communication systems damage. In this context, the study of the causes, periodicity and nature of magnetic storms is considered to be an actual problem.

The Pleshchenitsy Geophysical Observatory was created in 1958 at a specially equipped site 65 km distant from Minsk for research on the state of the geomagnetic field and seismic activity. The observatory is currently a part of the Center of Geophysical Monitoring of the National Academy of Sciences of Belarus. Continuous observations of the geomagnetic field elements such as the magnetic declination D, horizontal H and vertical Z components, as well as the full geomagnetic field vector modulus F, have been carried out since 1960. Starting from 1970 the data obtained at the Pleshchenitsy Observatory have been used to analyze the magnetic storms and to divide them into 4 classes in accordance with an established scale.

50 magnetic storms were recorded and processed in 2023, which is 11 storms less than their number recorded in 2022 (61). Nevertheless, this is 1.5 times more than the average long-term value (33.3) for the previous 53 years (1970-2022) which is indicative of a remaining high degree of the geomagnetic field perturbation in the last year. An analysis of the number of magnetic storms is compared with the solar activity in four adjacent 11-year cycles. Long-term variations in the magnetic storm number show that the periods of their reduction are replaced by the periods of their increase. At the same time, the maxima of their number do not coincide with the maxima of the Wolf numbers W, but are shifted towards a drop in the solar activity, which is consistent with the reference data [3, 4].

The data of observations of the average annual values of the magnetic field components in 2023 were as follow: D = 9.395°, H = 17742 nT, Z = 48395 nT, F = 51545 nT. The paper presents an analysis of the nature of change of the Earth's magnetic field elements D, H, Z, F in Belarus for the period from 1960 to 2023. So, a significant increase in the magnetic declination D was revealed: the average secular variation is 4′14″ per year, while it averaged 8′36″ per year over the past 10 years. The average annual value F of the total geomagnetic field vector modulus also showed a clear tendency to increase (from 49621 to 51545 nT) for the specified period. This may be due to the continuing displacement of the Earth's magnetic poles [5, 6].

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GC2024-STP009

Interaction of Relativistic Electrons with Electromagnetic Ion-Cyclotron Wave Packets of a Finite Length

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The interaction of relativistic electrons with electromagnetic ion cyclotron (EMIC) waves can scatter such electrons into the ionosphere. Estimates of resonant energies for this interaction give values about 1 MeV and higher. Recently, there were observations of precipitating electrons with energies of hundreds keV associated with EMIC waves [1]. This precipitation can be caused by the interaction of relativistic electrons with EMIC wave packets of finite length [1,2].

We consider such an interaction in this paper. We study the dependence of the interaction characteristics on the packet length and amplitude both analytically (for linear regime) and numerically (by test particle method in both linear and nonlinear regimes). We also calculate (numerically) precipitation fluxes, formed by this interaction.

For small wave amplitudes, corresponding to linear regime, we obtain analytical estimates for the variance of the equatorial pitch angle of electrons. For wave packets located not far from the geomagnetic equator analytical solutions agree with numerical results.

We show that widening of the wave number spectra caused by short packet length expands the interaction region into the low energies that are outside the resonant range for the central packet wave number. This effect takes place both in the linear regime and in the force bunching regime caused by direct influence of the Lorentz force on the electron phase.

The regions of nonlinear trapping and phase bunching do not expand towards lower energies, i.e. these regimes are possible only for energies corresponding to the resonant interaction with the central wave-packet component.

For EMIC wave packet amplitudes corresponding to nonlinear interaction, there is a range of energies for which the precipitating flux is equal to the value for the limiting case of strong diffusion, and even slightly exceeds it. The maximum value of the ratio of the fluxes of precipitating and trapped particles is approximately 1 and (at sufficiently high wave amplitudes) does not depend on the wave packet amplitude or length. The minimum energy for which significant precipitation occurs decreases with decreasing packet length from the minimum resonant value to approximately its half.

Thus, interaction with a short packet of EMIC waves can lead to significant (i.e., corresponding to strong pitch-angle diffusion) precipitation of particles with energies noticeably lower than the resonant energy for the carrier packet wave number. For the Earth's magnetosphere, these energies amount to a few hundred keV.

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GC2024-STP010

Analysis of the ionospheric parameter dynamics during increased geomagnetic activity and strong earthquakes in Kamchatka

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This paper presents the results of an analysis of the foF2 variations (Paratunka station, IKIR FEB RAS, Kamchatka) during magnetic storms in 2023-2024 and seismic events in Kamchatka with magnitude M > 5. The foF2 data were analyzed using the generalized multicomponent model of ionospheric parameters (GMCM) developed by the authors [1]. The study considered magnetic storms of different physical nature and power. The parameters of the interplanetary medium and magnetosphere were used in the analysis (data resource: https://omniweb.gsfc.nasa.gov/). Anomalous changes in the foF2 variations detected against the background of increased geomagnetic activity were compared, in terms of intensity, with sudden ionospheric disturbances during calm geomagnetic conditions and those observed during earthquakes in Kamchatka. The study indicates a strong dependence between the dynamics of ionospheric parameters and the state of the near-Earth environment and magnetosphere. During increased seismic activity in Kamchatka, ionospheric anomalies were of lower intensity and duration. The work was supported by IKIR FEB RAS State Task (subject registration No. 124012300245-2).

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GC2024-STP011

Global location of the maximum of very intense substorms

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Very intense sub-storms and super-substorms are typical for the main phase of strong magnetic storms. About 15 strong magnetic storms with SYM/H < -100 nT have been selected to study sub-storms during their main phases. It was found that, excluding the shock-induced sub-storms, there are, at least two different types of strong sub-storms. The first type represents the quasi-isolated sub-storms looking like classical (Akasofu-type) sub-storms with a clearly defined maximum intensity and a duration less than 2 h. The second type of storm-time sub-storms represents longer lasting magnetic disturbances without a clearly defined maximum intensity and looking like a chaotic sequence of short but very large peaks. Here we investigated the global distribution of ionospheric electrojets and field-aligned currents (FACs) in the time of the maximum (according to the AL-index) of the first type sub-storms using the global maps constructed in the AMPERE project basing on the magnetic measurements by the simultaneous 66 low-orbital (780 km) satellites. It was found that each sub-stom maximum was associated with the occurrence of a large-scale clockwise magnetic vortex in the early morning side indicating a local enhancement of downward FACs. It was confirmed by the FAC maps of AMPERE. A smaller vortex with the counterclockwise rotation was observed simultaneously in the dusk sector of the Earth. The super-substorms and very intense sub-storms observed in the main phase of selected two strong magnetic storms have been analyzed in detail. The obtained results can be explained by a formation of the addition sub-storm current wedge system.

GC2024-STP012

Large pulses of solar wind dynamic pressure and the appearance of intense GICs

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One complex event of space weather was analyzed, when some large-amplitude changes in the dynamic pressure of the solar wind were registered during magnetic storm, connected with interplanetary coronal mass ejection (ICME). Four pulses of dynamic pressure of large amplitude (~ 20 nPa) were recorded during the SHEATH region at the period from 20 to 22 UT on November 3 and at ~01 UT on November 4 and one strong pulse of the dynamic pressure (~30 nPa) was during magnetic cloud (MC) at ~ 09 UT on November 4, 2021. According to IMAGE and SuperMAG magnetometers data, we detected four consecutive substorms and one supersubstorm (SSS) caused these pressure pulses. The complex space weather episode has been divided into three events registered at the midnight, morning and day sectors, all events were associated with jumps of dynamic pressure (~20-30 nPa) of the solar wind. During first and second events (at the midnight and early morning sectors) the source of the GIC was substorm development; GIC events occurred simultaneously with poleward expansions of the westward electrojet during the expansion phase of substorms. During third event (at the late morning and day sectors) the sources of the GICs were Pi3 geomagnetic pulsations and the sharp intensifications of the eastward electrojet connected to development of supersubstorm and intense substorms at the night side.

GC2024-STP013

Polar substorms and solar activity

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The “polar” substorms include the evening substorms observed at geomagnetic latitudes above 70° MLAT in the absence of simultaneous negative magnetic bays at lower latitudes of given meridian. The purpose of this work is to continue the study of the morphological characteristics of “polar” substorms, to obtain their dependence on the the season of the year, different solar wind streams and the solar cycle phase. We selected above 1200 events of the “polar” substorms, recorded at the Scandinavian IMAGE magnetometer chain in the period of 2008-2020, i.e. during total 24-th solar cycle. Our analysis based on the ground-level data from the IMAGE network magnetometers. By analyzing this large array of cases, the diurnal, seasonal and annual distributions of polar substorms were obtained. It was shown that the most number of the “polar” substorm onsets were observed in the 17-23 MLT sector; the “polar” substorm onsets are observed in the larger evening-ward area than the occurrence of the “normal” substorm onsets. We found that the annual cycle of polar substorm occurrence: the winter maximum and the summer minimum. It turned out that the “polar” substorm behavior was opposite to the Wolf numbers behavior. This is consistent with previous results that “polar” substorm occur mainly at the end of the high-speed streams from coronal holes, which registered mainly during solar cycle minimum and on the decline phase of the solar cycle

GC2024-STP014

Two-dimensional hydrodynamic outflow from exoplanets

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The two-dimensional problem of unsteady outflow of the upper atmosphere of the planet as a result of heating by extreme UV radiation from the Star was considered. In recent years, this task has become especially relevant due to the discovery of a large number of exoplanets in various Star systems and their evolution study. Many authors has intensively solved the problem, with the pressure, density and radial velocity around the planet are assumed to have spherical symmetry. However, in reality, spherical symmetry is broken due to the peculiarity of the propagation and absorption of UV radiation and the presence of a shadow domain. In addition to the radial velocity, there is also a meridional velocity component, which becomes larger with increasing deviation angle from the central axis directed towards the Star. The meridional acceleration of particles is determined by the angular pressure gradient, which grows monotonically with increasing spherical angle at a fixed distance from the planet. At a given spherical angle, this gradient first increases with distance from the planet, reaching a maximum at a distance of about one and a half radii of the planet and then decreases. The meridional velocity seems to behave in a similar way.

Two-dimensional calculations were carried out on a spherical grid using the compact MacCormack-type scheme [1, 2]. To calculate the intensity of radiation propagating in the atmosphere along straight rays, the method of characteristics with interpolation on a spherical grid was applied. The characteristics of the warm sub-Neptune TOI-421c and its host Star given in the article by Carleo et al [3] were used as the calculation data.

Comparison with one-dimensional spherically symmetric models has shown that they significantly overestimate the integral gas flow rate. The two-dimensional model allows us to obtain a more realistic estimate of the atmospheric mass loss, being important for evolutionary problems.

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GC2024-STP015

Multi-satellite constellation of Moscow university "Sozvezdie-270" for monitoring of space weather effects and electromagnetic transients

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To the present Moscow University realizes the program of cubesat launching in frame of space project Sozvezdie 270. Within the framework of this project a constellation of cubesat nano-satellites with a set of instruments is being deployed, which, among other goals, provides monitoring of the near-Earth space radiation environment, control of the geo- and heliophysical conditions and electromagnetic transients of atmosphere and space origin. Along with the space constellation, a network of ground receiving stations is also being created. During the project implementation, 18 spacecraft of the cubesat format have been launched to date. Currently, there are 9 such spacecraft operating in near-Earth orbit, which transmit scientific and telemetric data. During 2024 - 2025 it is planned to launch at least 3 more such satellites into low circular polar orbits. Multi-satellite constellation has been implemented, which makes it possible to carry out simultaneous measurements of particle and quantum fluxes using the same type of instruments at different points in the near-Earth space. Such measurements provide unique information about the sub-relativistic electron flux dynamics, including variations due to precipitation, which is of great importance for understanding the mechanisms of trapped and quasi-trapped electron acceleration and losses.

GC2024-STP016

Identification and filtration of different sources of the ionosphere variability

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The nature of the ionosphere variability is one of the main problems for creating of the ionospheric models [1, 2] and for practical applications using the ionospheric data [3]. Ionosphere is absorbing energy from sources above: different components of solar and geomagnetic activity and sources from below: AGW, mesoscale atmospheric disturbances, earthquakes, volcano eruptions and dust storms [4, 5, 6]. To include all these factors in physical models is practically impossible because the majority of effects are transient, and for practical applications should be monitored in real time.

To identify these transient events we applied the machine learning technology which permit to filter the Space Weather effects from the atmospheric influence [7] as well as to differentiate the different sources of Space Weather on the ionosphere [8]. We applied to GPS TEC data the normalization procedure to differentiate the F10.7 and Dst effects. For other cases we used the locality feature of transient events.

These technologies will be demonstrated in the given report.

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GC2024-STP017

Time dependent physicochemical model of ionospheric components excitation during auroral events

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The time dependent physicochemical model of the auroral ionosphere is presented. The model describes the excitation processes of electronic-vibrational states of ionospheric plasma components by direct electron impact and the subsequent redistribution of the released energy due to chemical reactions in the local auroral zone at altitudes of 95-250 km. The model makes it possible to simulate the ion composition and electron content of the ionosphere in the electron precipitation zone. Using the model, the height profiles of the concentrations of electrons and ions O_2^+, N_2^+, $O^+(^4S)$, $O^+(^2D)$, O^+, NO^+, N^+ as well as the height profiles of the concentration of excited components $O(^1D)$, $O(^1S)$, $N(^4S)$, $N(^2D)$, $N(^2P)$, $N_2(A^3)$, $N_2(B^3)$, $N_2(W^3)$, $N_2(B'^3)$, $N_2(a^1)$, $N_2(w^1)$, $N_2(a'^1)$ can be computated. Thus, the auroral ionosphere model allows us to obtain a complete picture of the formation of excited atoms and molecules, which are sources of auroral emissions.

An effective method was used to calculate the excitation and ionization rates of ionospheric components. The excitation and ionization rates are related to the realized electron energy by a direct relationship that takes into account all generations of electrons produced in ionization processes. This significantly simplifies the calculation procedure and makes it possible to evaluate the processes occurring in the ionosphere in real time.

The auroral ionosphere model also includes the accurate accounting of the electronic vibrational kinetics of triplet and singlet levels of the excited molecular nitrogen.

GC2024-STP018

Variation of the effective recombination coefficient during auroral electron precipitation

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The effect of the precipitating auroral electrons on the effective recombination coefficient has been studied. It is shown that in the altitude region above 140 km the effective recombination coefficient demonstrates a dependence both on the energy flux and on average energy of auroral electrons. This allows us to explain the observed altitude profiles of the electron density obtained from incoherent scatter radar data.

GC2024-STP019

Dayside magnetosheath properties related to the magnetic reconnection

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The ideal MHD model turned out to be a rather successful tool for reproducing the detached bow shock wave, as well as the behavior of plasma parameters in the magnetosheath region. But an ideal MHD model without any dissipation cannot explain the penetration of the magnetic field and plasma through the magnetopause, which is considered a tangential discontinuity. The goal of our work is to reconcile the MHD model of solar wind flow around the magnetosphere with the model of magnetic reconnection occurring at the daytime magnetopause. In particular, we discovered the dependence of the electric field at the magnetopause on solar wind parameters. For the magnetic reconnection region, we use the Hall MHD model with the Bohm-type resistivity in the diffusion region. In this case, the spatial change in resistivity is modeled by a Gaussian function. It is assumed that the reconnection line is directed along the electric current at the magnetopause. The steady-state structure of magnetic reconnection and the reconnection rate were determined as a result of the time relaxation of the numerical solution of the resistive Hall MHD equations. A series of calculations were carried out for various plasma betas in the inflow region just above the diffusion region. The reconnection rate was found to be a decreasing function of the plasma beta parameter. In the case of antiparallel magnetic fields, the reconnection rate has a maximum value of about 0.22 for very small betas and decreases monotonically to 0.13 when beta increases to 2. In the case of non-antiparallel magnetic fields, the reconnection rate smaller in a factor of $\sin(\Theta/2)$, where Θ is the angle between the reconnecting magnetic field lines. The resulting reconnection rate as a function of the plasma beta parameter was used to match the reconnection region with the parameters of the dayside magnetosheath determined from the numerical MHD model of the solar wind flow around the magnetopause, which dayside shape was approximated by a hemisphere. A numerical MHD code based on the Godunov-type scheme was run for several Alfvén Mach numbers (5, 6, 8, 10). Finally, the resulting magnetosheath solution gives radial profiles of the ratio of the normal velocity to the local Afven velocity, plotted as a function of the local plasma beta parameter. This ratio should be equal to the reconnection rate calculated in the diffusion region for the same plasma beta. Using this condition, we find the magnetic field strength and electric field in the diffusion region depending on the solar wind parameters. In particular, for the southward IMF we find a maximum electric potential difference along the equatorial magnetopause about $\Phi_m = 0.6\, E_{sw}\, R_m$ for a wide range of solar wind Alfven Mach numbers from 5 to 10. Here E_{sw} is the solar wind electric field ahead of the bow shock, R_m is the radius of curvature of the subsolar magnetopause. When the subsolar reconnecting magnetic fields are not antiparallel, but have an angle Θ, then the electric field is smaller by a factor of $\sin(\Theta/2)^2$ compared to the purely antiparallel case.

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GC2024-STP020

Impact of space weather on pipelines in high latitude regions

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One of the most significant factors of space weather is geo-induced currents in technological conductive grounded systems, caused by sudden changes in the geomagnetic field dB/dt. This is especially true for high-latitude regions, since geomagnetic disturbances are most pronounced there. Such changes in the geomagnetic field create fluctuations in the soil-pipe potential, which can remove the pipeline voltage from the safe range of protection against electrocorrosion (usually cathodic protection feeds a negative potential of about 2 V). If cathodic protection in pipelines is violated, corrosion at grounding points or insulation damage increases, and electronic control systems fail. Therefore, when organizing cathodic protection systems for pipelines, it is necessary to be able to calculate variations in the soil-pipe potential under geomagnetic disturbances. To do this, we developed a software code to calculate the pipeline potential for a given disturbance of the electrotelluric field in the surface layers of the earth.

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GC2024-STP021

Winter effects of a night meteor explosion in high latitudes

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On December 19, 2014, the all-sky cameras of the Verkhnetulomsky observatory and the city of Apatity recorded a trace of a meteor fall, the destruction of which over the Verkhnetulomsky reservoir (68.25 N, 31.1 E) at 19:03:07 UT was accompanied by a bright flash. The response of the lower ionosphere was assessed from the behavior of the amplitudes of partially reflected ordinary and extraordinary waves obtained at the partial reflection facility of the radiophysical observatory "Tumanny" (69.0 N, 35.7 E). Variations in the total electron content of the ionosphere from satellite signals of global navigation satellite systems received by a receiver in Murmansk (68.97 N, 33.09 E) are considered. The response of the geomagnetic field to the meteor explosion was examined using data from the magnetic variation station of the Loparskaya observatory (68.25 N, 33.08 E). Analysis of the data obtained shows that the explosion caused sudden changes in environmental parameters. The most likely mechanism for these changes is the passage in the atmosphere of shock, acoustic-gravity and slow magnetohydrodynamic waves generated by the meteor explosion.

GC2024-STP022

Extreme growth of GIC in power lines on the Kola Peninsula and in Karelia during 11 years of observations

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It was analyzed cases with extreme values of geomagnetic-induced currents (GIC) in power transmission lines (PTLs) on the Kola Peninsula and Karelia for 2012-2022. The GIC registration system was created by the Polar Geophysical Institute and the Center for Physical and Technical Problems of Northern Energy of the Federal Research Center KSC RAS and includes 5 stations, oriented mainly in the north-south direction. Registration of GIC has been carried out continuously since end of 2011, and by 2022 a “quasi-solar cycle” of GIC registration has formed, including 24-25 cycles of solar activity. GIC data were compared with data from PGI magnetometers at the Lovozero and Loparskaya observatories, and with data from magnetometers in the IMAGE network. Extreme values of GIC and dB/dt were compared with the parameters of the solar wind and interplanetary magnetic field, and geomagnetic activity indices.

The GIC data from the Vykhodnoy auroral station (VKH) and the Kondopoga subauroral station (KND) were considered. According to the VKH station data, 85 cases were selected as extreme events when the GIC value exceeded 30 A. The analysis shows that in most cases (60%) extreme growth of GIC occurs during CME magnetic storms, several cases occurred without magnetic storms (3%), the remaining cases are during CIR storms (37%). At the same time, there is a connection between the occurrence of extreme GIC events and the solar activity cycle. For example, in 2019 and 2020, during the years of minimum solar activity, no extreme cases were recorded. According to the KND station data, 23 extreme events were selected when the GIC value exceeded 10 A. According to the KND station, extreme GIC values are observed in 87% of cases during CME storms and in 13% of cases during CIR storms.

The greatest GIC values occur during substorms (negative magnetic bays associated with the development of the western electrojet). At the same time, the development of vortex current systems during a substorm (Pi3/Ps6 geomagnetic pulsations) can make a noticeable contribution to the growth of GIC for power lines oriented in the north-south direction. The Pc5 pulsations and SSC events lead to medium (~20 A) and low values of GIC. An analysis of GIC during strong magnetic storms over 11 years of observations is presented: March 17-18, 2013 [1], June 28-29, 2023 [2], March 17-20, 2015, September 7-8, 2017, May 27-29, 2017, etc.

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GC2024-STP023

Relationship between dipolarizations and Energetic Electron injections at the Geosynchronous orbit

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Energetic Electron (EE) injections at the geostationary orbit have been studied since the beginning of space era, and very soon their relationship with magnetic dipolarizations was established. It is also well known that particles intrude into the inner magnetosphere on the nightside, creating non-dispersed injections in the Substorm Current Wedge (SCW) region, and then drift azimuthally with their own drift speed, forming dispersed injections. EE injections are an important source of the outer radiation belt, they affect the spacecraft equipment, the radio communication and, more globally, the space weather. Betatron/Fermi acceleration during dipolarization are considered as the main acceleration mechanisms, but this point still is not well studied.

The aim of our work is to study the relationship between injections and dipolarizations inside and outside the SCW based on joint particle and magnetic data of GOES 13, 14, 15 spacecraft, each pair separated by 2 hours MLT. We selected clear dipolarizations at the most westward GOES 15 when it was in the pre-midnight sector, and studied the EE reaction at GOES 15 itself and at two other more eastward spacecraft. 45 events with data available for at least two spacecraft, GOES 13 and GOES 15, were considered. Good correlation of the dipolarization magnitude at GOES 15 with increment of substorm MPB index shows that GOES 15 was in the BBF stopping region.

In our study we used the EE fluxes dependence on the local magnetic field (hodogram) technique. It showed that 1) inside the SCW EE fluxes grow with B_z whereas outside the current wedge these fluxes are independent of local B_z, giving the opportunity to separate data inside and outside the injection region. 2) EE dynamics is the result of two processes: injections and drift shell crossing. Injections occur on some background level, characteristic for the given B_z value, and this level depends on the past geomagnetic activity; 3) on the geostationary orbit the injection process is effective mostly for electrons with energy<200 keV (was known before), for higher energies drift shell crossing prevails.

Our analysis showed that correlations of (ΔMPB) with the peak EE fluxes at energies 30-200 keV is higher than with increment of these fluxes, pointing that during the injection a new particle population comes. However, these correlations are also rather low, ≤0.6. Also we demonstrate that (ΔMPB) growth mostly increases the fluxes of electrons in the range 50-100 keV.

GC2024-STP024

Acceleration and losses of the outer radiation belt energetic electrons during period of long duration auroral activity

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Complex study of the coupling dynamical processes in the chain: Solar Corona-Solar wind – Earth's magnetosphere – outer radiation belt – ionosphere/atmosphere, has been studied based on multi-satellite and on-ground measurements. Prolonged magnetospheric compression during period 10-16.10.2017 produces moderate magnetic storm and multiple substorm activations, that were responsible for wave activity and significant changes in trapped energetic electrons population.

Variations on high-energy electron fluxes were obtained from measurements of spacecraft located in the interplanetary medium and in polar and near-equatorial orbits inside the magnetosphere. Geostationary GOES-15 satellite found a drop of 2 MeV electron fluxes during the main phase of the magnetic storm and consequent gradual restoration during recovery phase. VAP-A satellite demonstrated particle fluxes recovery in the wide energy range from about of 100 keV to 4 MeV and more. If lover energy electrons were restored just after storm maximum, relativistic electron fluxes remain depleted and approached pre-storm levels with delay of about several days; the more energy, the more time delay.

In parallel, strong precipitation of energetic electrons with E>100 keV were detected by polar NOAA/POES and Meteor-M2 satellites. They were also detected during the LPhI balloon experiment in the Murmansk region. Precipitation occurred in the beginning of the magnetic disturbances and continued during all the period under consideration. According to measurements of electron fluxes on the polar satellites Meteor M2 and POES, it is shown that the precipitation cover a large area of near-Earth space: by the L-parameter and by MLT.

Magnetospheric magnetic field changes during multiple substorms and related wave activity become the main causes of electron losses. The VLF wave activity recorded during the time period under study aboard the Van Allen Probes spacecraft was the source of intense precipitation of energetic electrons (100-300 keV) in the morning sector of the magnetosphere. EMIC waves in the evening sector of the magnetosphere were also recorded as Pc1 pulsations at the Lovozero station, produced precipitation of ring current protons and relativistic electrons. Adiabatic changes of the magnetosphere as well as competition between acceleration and loss processes due to auroral and wave activity produced complicated dynamics of the energetic electron fluxes in the inner magnetosphere. Substorm activations and VLF waves compensate quickly the loss of trapped particles with energies about 100 – 300 keV. Reduced particle fluxes with energies of 700 keV and higher are not restored immediately. Ongoing substorms gradually accelerate energetic electrons to higher energies, leading to an increase in particle fluxes of relativistic and subrelativistic energies.

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Numerical analysis of ballooning modes in Earth’s magnetosphere and their connections with MHD oscillation branches

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The report examines the condition for thee development of balloon instability in the Earth's dipole magnetosphere. It is shown that the instability lies on the same dispersion branch as the slow magnetosonic resonance. A necessary condition for instability is the plasma pressure fall with increasing distance from the Earth. The instability threshold is determined depending on the β parameter and the pressure gradient. On a given magnetic shell, at a given β value, a lorge pressure gradient favors the instability, and vice versa, at a given pressure gradient, a large β favors the instability. This situation is typical for the magnetic storms times, when strong ring current develops in the magnetosphere. It is found that the instability growth rate depends on the ratio of the radial and azimuthal wave vector components. The maximum growth rate value is reached if this ratio is zero. The magnetic field of an unstable ballooning mode is localized near the equator, and its localization grows as the mode approaches the maximum growth rate. It is shown that in the unstable mode the compressional magnetic field component has a phase shift with respect to the radial component. This can be used to detect unstable ballooning modes during observations in the Earth's magnetosphere. This study is supported by the Russian Science Foundation under grant 22-77-10032.

GC2024-STP026

The technique of processing of radiotechnical and geophysical information about conditions of satellite radio signal propagation for studying lithospheric–ionospheric manifestations

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The appearance of structural ionospheric anomalies and the influence of ionosphere inhomogeneities on radio wave propagation form the unity of an important and topical problem for the study because they are of scientific and practical importance in the field of physics of the upper atmosphere and radio physics. In addition, GNSS data always represents a significant amount of information that must be processed before interpretations could be provided. Often this needs to be done quickly. Therefore, we need a reliable way that allows us to efficiently and quickly process a large volume of satellite data. An investigation has been performed based on a vast volume of data of synchronous measurements, more than 50 million phase measurements readings of satellite radio signals by ground GNSS receives combined into global IGS and UNAVCO networks. Consistently used methods of GPS interferometry, cluster analysis, geophysical analysis, and statistical analysis allow one to distinguish and study inhomogeneous structures of the ionosphere response to seismic activity in the region. Differential program-algorithm methods of satellite radio signal data processing make it possible to distinguish inhomogeneous structures of the ionosphere and to consider characteristics of their distributions over time and space. Variability of the ionosphere is studied using global navigation satellite systems (GNSSs). These systems allow one to determine the total electron content (TEC) [1], i.e., the number of free electrons in a column of unit cross section along the propagation path from the satellite to the receiver in the ionosphere. The dual-frequency method makes it possible to extract from radio signals and study the ionospheric component (TEC units). In this work, identical inhomogeneous ionospheric structures distinguished by radio-interferometry by different cells of GPS receivers are classified using cluster analysis. Results obtained after the use of GPS interferometry and cluster analysis require qualitative and quantitative systematization for understanding their geophysical essence. For this purpose, geophysical analysis with the use of an updated digital model of lithospheric plate boundaries was carried out. Statistical analysis allows one to give quantitative and qualitative final estimates for detected inhomogeneous structures as a response in the ionosphere to seismic activity in the region. The results correspond to the ionosphere response to earthquakes with characteristic wave parameters of the manifestation.

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GC2024-STP027

On the dispersion properties of coupled Alfven and slow waves in two-dimensionally inhomogeneous model of the magnetosphere

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The report carried out a numerical analysis for coupled Alfven and slow ones in the azimuthal small-scale approximation with the dipole geometry of the field lines of the Earth's magnetosphere. Plasma inhomogeneity is taken into account in two projections: across the magnetic shells and along the field lines. Taking into account the plasma pressure and the curvature of the magnetic field lines in this case leads to the coupling of Alfven and slow modes, while the contribution of the fast mode can be neglected due to small perturbation scale in the azimuthal direction. It was found that the wave is localized in two frequency ranges limited by each other. One of them is limited by the resonant frequency on one side and the other by the cutoff frequency on the other. In this case, the high frequency range is adjacent to the Alfven mode, and its properties in this case change greatly due to interaction with the slow mode. Depending on the plasma pressure and its gradient, a divergence of plasma displacement may appear, as well as a compression component of the magnetic field. In the low-frequency wavelength range, the slow mode may lose its cutoff frequency under very strong and negative pressure gradients. This means that the radial component of the wave vector tends to zero at the imaginary frequency. The work was financially supported by the Ministry of Science and Higher Education of the Russian Federation.

GC2024-STP028

The ionospheric electric field variations caused by the release of radon from the ground

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Due to the increase in radon emanation, the conductivity in the surface air layer increases, which causes a variation of the electric field not only in the lower part of the atmosphere, but also in the ionosphere. There are known proposals to use such ionospheric disturbances as precursors of earthquakes.

We calculate ionospheric electric fields within the framework of a quasi-stationary model of the atmospheric conductor that includes the ionosphere. The conductivity tensor in the ionosphere is a gyrotropic tensor. In the atmosphere below 50 km, it becomes a scalar. The height profile of the conductivity is constructed in [1] as some average of known empirical models. Above 65 km (E- and F-layers of the ionosphere) during the day (or 90 km at night), our conductivity model is based on empirical models IRI-2016, MSIS 1990 E, IGRF.

Since local phenomena are considered, we neglect the curvature of the Earth's surface. The average potential value in the ionosphere we set equal to zero. Conjugate ionosphere is taken into account. We consider the Earth's surface to be equipotential, since the conductivity of soil and many minerals is many orders of magnitude greater than the conductivity of air. We determine the voltage between the ground and the ionosphere V_0=245 kV, basing on the fair-weather current density j_0=2 pA/m^2, which is typical for the Global electric circuit (GEC).

With an increase in air conductivity in the radon emanation region, the current from the ionosphere to the ground through this region increases. As a rule, radon does not rise above 1.5 km during the day. We consider an increase in conductivity thirty times in the region containing radon.

Above such a disk we apply the numerical method, based on the decomposition of the solution into a Fourier series in horizontal coordinates. In the lower atmosphere the conductivity is scalar, which greatly simplifies the solution. The availability of different effective methods for the two parts of the computational domain makes it advisable to use the domain decomposition method.

The calculations performed showed that even with extreme radon emanation in the disks with different radii of 10-100 km and height about 1 km, the electric field disturbances in the E- and F-layers of the ionosphere are several orders of magnitude smaller than the supposed precursors of earthquakes, and then the fields usually created there by other generators. These results confirm the conclusions of the papers [2, 3], in which some simplifications of the electrical current continuity problem were used.

The D-region is fundamentally different in that in it the fair-weather electric field makes the main contribution to the vertical component of the field. It is shown that this component of the field can double over the area of intense radon emanation compared to the fair-weather field. There is a hypothesis that the field-aligned component of the electric field strength significantly affects the formation of the D-region, for example, causes lifting of the lower boundary of the D-region [4]. Such a lifting, as well as other variations in the parameters of the D-region, as precursors of an earthquake, could be detected using remote sensing [5].

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GC2024-STP029

Long-term variations in characteristics of upper neutral atmosphere and ionosphere from spectrometric and radio sounding measurements

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We present the results of studying year-to-year variations in the characteristics of the upper neutral atmosphere and the ionosphere. The analysis is based on the experimental data from the instrumental complex of the Institute of Solar-Terrestrial Physics SB RAS. As atmospheric and ionospheric characteristics we used the mesopause temperature (Tm) and peak electron density (NmF2); the analyzed period is 2008-2020. The mesopause temperature was obtained from spectrometric measurements of the OH emission ((6-2), 834 nm, Tory (51.8°N, 103.1°E)). The peak electron density was derived from the Irkutsk DPS-4 Digisonde measurements (52.3°N, 104.3°E). We analyzed the annual mean Tm and yearly average values of NmF2, as well as yearly average values of day-to-day and intradiurnal variability in Tm and NmF2. The analysis involved data on solar and geomagnetic activity, as well as on variations in the Southern Oscillation Index (SOI). To interpret the year-to-year variations, we use multiple regressions of the ionospheric and atmospheric characteristics on the F10.7- and Ap-indices of solar and geomagnetic activity, respectively. For the atmospheric characteristics, we also used regressions on the SOI-index as a characteristic of the lower atmosphere activity. It was revealed, that the yearly average values of NmF2 are dominantly controlled by changes in the solar flux. The year-to-year variations in the NmF2 variability are mainly driven by changes in both solar and geomagnetic activity. The year-to-year variations in the mesopause temperature weakly correlate with changes in the indices of solar and geomagnetic activity. The yearly average values of Tm variability correlate with changes in the SOI-index: the day-to-day variability demonstrates a positive correlation with the SOI-index, while the intradiurnal variability shows a negative correlation with the SOI-index. A significant relationship between the year-to-year variations in the NmF2 variability and Tm variability was not revealed.

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GC2024-STP030

Different origin of magnetic disturbances evaluated by AL index in course of the growth and expansion substorm phases

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According to spacecraft measurements, several field-aligned current (FAC) systems act independently in the magnetosphere. The main is R1 FAC system, uninterruptedly operating on the pole-ward boundary of auroral oval, irrespective of IMF orientation and season of year [1]. Intensity of the R1 system is determined by coupling function $E_{KL} = V_X(B_Y^2+B_Z^2)^{1/2}\sin^2\Theta/2$, which presents the optimal combination of all geoeffective solar wind parameters permanently affecting the magnetosphere. The R1 system, acting within the closed magnetosphere, generates in polar cap the DP0/DP2 magnetic disturbances, whose intensity depends on solar wind velocity (DP0) and southward B_{ZS} IMF component (DP2). Basing on the always available DP2 disturbances the polar cap magnetic activity (*PC*) index has been put into operation [2]. The *PC* index follows the E_{KL} field variations and well correlates with development of magnetic storms and substorms [3]. Taking into account these specific features of *PC* index, it was endorsed by the International Association of Geomagnetism and Aeronomy (IAGA) as a proxy of the solar wind energy input into magnetosphere (IAGA Resolutions, 2013). The substorm growth phase is related to R2 FAC system, which is formed on the equator side of auroral zone under conditions enhanced auroral precipitation. As a result, the DP12 disturbances, with westward and eastward auroral electrojets in the morning and evening sectors of auroral zone, are developed in course of the substorm initial phase. The substorm expansion phase is related to formation of “substorm current wedge” (SCW) FAC system generating the powerful westward electrojet in the midnight auroral zone and corresponding DP11 disturbances. The SCW FAC system is a specific system, which ensures closure of the magnetotail plasma sheet currents through the auroral ionosphere [4].

Research carried out in AARI on the base of the 1-min *AL* and *PC* indices data for 1998-2017 demonstrates the principally distinctive character of the substorm development in course of the growth and explosive phases. The DP12 disturbances, generated by R2 FAC system operating within the closed magnetosphere, are developed in strong relation to the PC index [5]. As this takes place, the DP11 disturbances demonstrate quite another relationship between the 1-min *PC* and *AL* values: the sudden leaps of the *AL* value (*ALpeaks*) might occur, time and again, at any value of *PC* index and with quite different delay times relative to moment of substorm sudden onset. It means that processes in the tail plasma sheet, leading to formation of “substorm current wedge” are determined, first of all, by state of the magnetotail plasma sheet itself. The solar wind influence (evaluated by *PC* index) affects but does not control processes in the magnetotail, unlike to processes in the inner magnetosphere. In spite of different nature of the DP12 disturbances, related to R2FAC system, and DP11 disturbances, related to SCW FAC system, the disturbance progressing in course of a substorm is estimated by a single *AL* index. To allow for effects of solar wind influence and magnetotail processes on dynamics and intensity of substorms it is necessary to put into practice two different indices, evaluated correspondingly by data of magnetic observations in the morning and midnight sectors of auroral zone.

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GC2024-STP031

The first experimental confirmation of the existence of a near-equatorial resonator for ion-ion hybrid modes in the magnetosphere

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We show the existence of a near-equatorial resonator for IIH (ion-ion hybrid) modes on the example of Pc1 event observed by Van Allen Probe A on July 14, 2014. Pc1 pearl pulsations with frequencies from 0.9 to 1.3 Hz were registered. The pulsations' frequency was just above the helium gyrofrequency. The waves were located near the outer edge of the plasmapause at the morning sector of the magnetosphere. We found the significant densities of helium and oxygen ions during the event. The helium/proton mass density ratio was about 1, and oxygen/proton mass density ratio was up to 10.

In our previous papers, we considered one of the hypotheses for the formation of the pearl structure. It is the presence of a near-equatorial resonator for ion-ion hybrid modes. According to the hypothesis, because of admixture of heavy ions (helium or oxygen) in the magnetosphere plasma, the resonator at the top of magnetic field line can be formed. We obtained that the calculated eigenfrequencies of the near-equatorial resonator correspond to the observed frequencies. We consider the observed pearl structure of the waves as a result of a superposition of several harmonics with slightly different frequencies inside the resonator.

The case study of the Pc1 pearl event on July 14, 2014 was supported by the Russian Science Foundation under Grant 22-77-10032. The calculation of the model eigenfrequencies based on a near-equatorial resonator hypothesis was supported by the Russian Science Foundation under Grant 21-72-10139.

GC2024-STP032

Plasma sheet turbulence and topology of magnetospheric domains

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Latest studies of a plasma sheet turbulence of the Earth's magnetosphere using data of Magnetospheric Multiscale Mission (MMS) support the obtained early results demonstrating high level of plasma sheet turbulence even during quite geomagnetic conditions. The level of turbulent fluctuations in the geomagnetic tail is greatly increased during disturbed geomagnetic conditions. Such turbulence has mainly electrostatic character with large amplitudes of electrostatic fluctuations. Spectra slopes of electric and magnetic field fluctuations have different values. The dependence of the value of the eddy diffusion coefficient determining the tail plasma transport is increased with geocentric distance in the midnight sector and has the plateau form at geocentric distances larger than ~13 Re. Such feature corresponds to the boundary of the tail current and ring current if the difference of these currents is determine by the topology of current lines. Tail current is closed by magnetopause currents and ring current is closed inside the magnetosphere. Both current systems exist in the condition of magnetostatic equilibrium, which means the constant plasma pressure at the field line. Plasma pressure distribution near the equatorial plane obtained using THEMIS observations shows the existence of the outer tail current boundary supported by radial plasma pressure gradients at geocentric distances ~10-13 Re. We discuss the selected features of magnetospheric turbulence and magnetospheric current topology for the explanation of the dynamics of magnetospheric substorms and storms.

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GC2024-STP033

Solar gamma-ray spectrometers on MSU cubesats: experimental methodology and first results

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Gamma-ray scintillation spectrometers DeCoR (Detectors of Cosmic Radiation) developed in SINP MSU are installed on the small satellites Avion, Monitor-2, Monitor-3, Monitor-4 and UTMN-2 of the cubesat format, launched in June 2023 into a circular polar orbit with a height of ~550 km. They are designed to study hard x-ray and gamma radiation from solar flares as well as fast variations in near-Earth electron fluxes and astrophysical gamma-ray bursts. In the space experiment, several modifications of the device are used, differing in sensitive area and energy range. The detectors of the DeCoR-1 and DeCoR-2 devices are a combination of a plastic scintillator ~3 mm thick and a CsI (Tl) crystal ~10 mm thick allowing to distinguish between solar flares and electron precipitation. Their energy range is 0.05 – 2.0 MeV, the effective area is 18 cm^2 for DeCoR-1 and 64 cm^2 for DeCoR-2. The Avion and Monitor-2 satellites additionally have DeCoR-3 gamma-ray spectrometers based on a large CsI(Tl) crystal in order to register gamma-ray quanta of MeV energies.

The output data from all DeCoR devices are generated both in the form of monitoring (the counting rate in several channels corresponding to a certain type of particles and energy) and in the form of a detailed recording in an event-by-event format, when for each case of interaction in the detector, a set of amplitudes and the exact time with a resolution of ~ 1 microsecond are recorded. The data is stored in the non-volatile memory of the payload, then it can be transmitted either directly to the satellite radio transmitter or to the memory of the on-board computer. Thus, during the space experiment, it is possible to select the most important data sections for transmission to Earth in primary form, which allows for studies of the rapid variability of the measured radiation fluxes.

At the present moment, the methodology of a space experiment using DeCoR equipment has been worked out during flight tests, taking into account the information and energy capabilities of small satellites, and device settings have been optimized. For several months a hard radiation from a number of solar flares was recorded and solar cosmic rays were also observed. It is planned to continue the experiment on the satellites listed above in the next 1-2 years, as well as to launch several new nanosatellites with similar equipment.

GC2024-STP034

Investigation of Pc5 geomagnetic pulsations on two-dimensional network of stations

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Based on data from a two-dimensional network of magnetic stations, a detailed study of geomagnetic pulsations Pc5 with a frequency of ~2.8 MHz, which arose in the afternoon sector against the background of a magnetic storm on August 27, 2014, was carried out. Two-dimensional distributions of magnetic field components Pc5 on the earth's surface were constructed in two intervals (at the beginning of the storm and during the period of maximum magnetic activity). It has been established that ionospheric Pc5 sources (Hall current vortices) have an elliptical shape with a larger axis in the south-north direction. At the beginning of the magnetic storm, the center of a single burst of Pc5 pulsations was located at a geomagnetic latitude of ~67.5° (L ~ 6.8 Re) and shifted westward at a speed of ~0.7 km/s. The estimated size of this ionospheric source is ~150 km in the west-east direction and ~330 km in the south-north direction. During the maximum period of a magnetic storm, Pc5 pulsations are created by two ionospheric sources following one another. These ionospheric sources have a more elongated elliptical shape with axes in the west-east direction ~250 km and in the south-north direction ~680 km. The centers of these sources shifted by 4° to a more southern geomagnetic latitude ~63.5° (L ~ 5 Re) and moved westward at a speed of ~1.7 km/s.

GC2024-STP035

Influence of wave properties on energetic charged particle precipitation during a magnetic storm of 10-16 October 2017

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We analyze low-frequency wave observations during a geomagnetic storm of 10-16 October 2017 and their relation to energetic particle precipitation. The storm had a moderate strength (SYM-H_{min} = –67 nT) but was accompanied by an intense substorm activity. Van Allen Probes had their apogee in late morning to early afternoon sectors, and ERG orbit apogee was in the evening sector. Intense chorus and plasmaspheric hiss was observed by Van Allen Probes during the substorm intervals. Chorus and hiss were also detected by ground-based Lovozero station (LOZ) at Kola Peninsula. Van Allen probes also observed some electromagnetic ion cyclotron (EMIC) waves near their apogee, but these observations were much more rare than the Pc1 pulsation observations at LOZ during the same time interval. On the other hand, Van Allen probes detected EMIC waves at frequencies at and above 2 Hz that were almost not seen at LOZ during the considered storm interval. ERG did not observe significant EMIC wave activity in the evening sector, although IPDP pulsations were observed at LOZ in the same sector. We use the spacecraft wave data to calculate pitch-angle diffusion coefficients and estimate precipitated energetic particle fluxes that can be measured at low Earth orbits. These estimates are compared with NOAA/POES and Meteor-M2 observations. A role of ducted whistler mode waves in providing dayside precipitation of subrelativistic (several hundred keV) electrons is demonstrated in this study.

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We acknowledge the use of Van Allen Probes, ERG, and NOAA/POES spacecraft data, and PGI ground-based data (LOZ).

GC2024-STP036

Long-term effects of solar activity on extratropical cyclone movement in different regions of the North Atlantic

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In this work we continue studying long-term variability of the main directions of extratropical cyclone movement (storm tracks) in the North Atlantic and its possible relation to solar activity, the MSLP (Mean Sea Level Pressure) archives from Climatic Research Unit, UK (1873–2000) and NCEP/DOE AMIP-II Reanalysis (1979–2021) being used. Variations of storm track latitudes in different longitudinal regions of the North Atlantic were compared. It was found that secular oscillations (with periods ~80–100 years) of storm track latitudes, which may be associated with the solar Gleissberg cycle, are strongly dominating in the western part of the North Atlantic (60–40°W), weaken in the Iceland Low region (30–10°W) and disappear to the east of Greenwich (0–20°E), where multidecadal oscillations (~50–60 years) were detected. On the bidecadal time scale, oscillations of storm track latitudes, with periods being close to the magnetic Hale cycle on the Sun, are observed. Storm tracks were found to be noticeably shifted to the north in even solar cycles and slightly to the south in odd ones; this effect is the most pronounced in the Iceland Low region and weakens sharply east of Greenwich. A possible mechanism of the detected effects of solar activity on extratropical cyclone movement seems to include variations in intensity of the stratospheric polar vortex influencing the position of the polar jet. Changes of the polar vortex intensity may be associated with galactic cosmic ray variations and auroral precipitations which affect the chemical composition and temperature regime of the polar middle atmosphere.

GC2024-STP037

Dynamics of energetic electrons and protons precipitation according to data from low-orbit satellites of the NOAA/POES and Meteor M2 during a magnetic storm on October 10-16, 2017

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Magnetic storm with SYM-H_{min}=-67 nT that was corresponded by series of substorms was observed on October 10-16, 2017. This interval began with the increase in the solar wind dynamic pressure to 10 nPa. In the middle of this interval, the solar wind speed reached 700 km/s. Intense auroral activity was characterized by increase of the AE index to 1916 nT. We analyzed data on the fluxes of relativistic (E > 800 keV) electron precipitation (REP) obtained by the low-orbit satellites NOAA/POES and Meteor M2. All REP events were divided into three groups according to the criterion presented in [1]. During this period, the POES satellites recorded 277 REP events. 99 events (35.7%) were of the first group (precipitation due to the geomagnetic field curvature). 124 events (44.8%) were of the second group (REP not related with energetic proton precipitation), and 54 events (19.5%) were of the third group (REP related with energetic proton precipitation). When the REP events of the 3rd group were recorded near the meridian of the Lovozero observatory, geomagnetic pulsations in the Pc1 range (0.2-5 Hz) were also recorded there. In the beginning of the geomagnetic disturbance, only REP of the 3rd group were observed. Their daily number peaked on October 11, and then gradually decreased. With the intensification of substorm activity, REP of the 2nd group began to appear. Their number peaked on October 15, and at that time the number of events in that group was greater than in all others. A day after the beginning of the geomagnetic disturbance, REP of the 1st group appeared. These were the most numerous events on October 12. The decrease in the level of geomagnetic disturbance was accompanied by a decrease in the occurrence rate of events in all groups. Daily average precipitation flux also varied during the interval. The events of the third group had the greatest flux on October 11, i.e., at the beginning of the storm main phase. Then their flux decreased. The flux of second group events increased by October 11, still remaining lower than the flux of the third group events, and the remained almost constant until the end of the interval. During the period from October 13 to October 15, the flux in the first group events remained at its maximum value. By October 16, the REP fluxes in all three groups became comparable. The distribution of REP as a function of latitude and MLT is consistent with previously established statistics. An analysis of energetic proton precipitation was also carried out for this interval.The temporal evolution of the precipitation events reflects the processes developed in the magnetosphere at different phases of magnetic storm. One can see the partial ring current formation at the main phase, corresponding the EMIC waves generation and the 3rd group precipitation. Also, multiple substorms produce the magnetic field distortion in the night-side magnetosphere. They were responsible for the 1st group precipitation during the main and recovery phases.

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GC2024-STP038

Local time distribution and activity dependence of extreme electron densities in the auroral D-region as an image of energy-dependent energetic electron precipitation

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Although electron density Ne in the auroral ionospheric D-region is formed by solar radiation and energetic particle precipitation, the highest observed densities are definitely produced by intense precipitated fluxes of energetic electrons (EE, here 30-300keV) and solar flare protons. Therefore, studying the most intense Ne episodes may provide valuable information about spatial distribution, spectral changes, and drivers of intense EE precipitation, which have important space weather implications. By combining EISCAT-Tromso UHF observations in different modes made in 2001-2021 (with polar cap absorption events being excluded), we survey Ne occurrence distributions and study statistical properties of EE precipitation producing the highest 10%, 5%, and 1% of Ne values at the altitudes between 100 and 75 km (corresponding to EE energies of ~20 to ~300keV), and found two different patterns of spatial distribution of the extreme ionization. The largest Ne values occur in the nightside-early morning local time sector in the upper D-region (H>85km) and in the morning-noon sector at low altitudes (75-85 km). This bimodal pattern could partly be contributed by the suppressed Ne in the dark ionosphere where negatively charged ions may appear in large amounts. However, by analyzing measurements in the twilight conditions at all MLTs together with published statistical patterns of EE precipitation at different energies, we got indications that a dominance of pre-noon maximum at low altitudes in the D-region reflects the enhanced precipitation of >100keV electrons in this local time sector. Statistically, at all altitudes (especially below 80/90km) the appearance of the highest Ne values favors enhanced auroral activity (not necessarily storms as revealed by SymH index) and shows a strong preference for high solar wind velocity (>550 km/s). These properties copy the known driver properties of energetic electrons. We discuss the advantages of exploring Ne data at specific altitudes (against direct measurements of EE precipitation) to investigate statistically the effects of specific precipitated energy components and the evolution of EE energy spectra.

GC2024-STP039

On the influence of the long-term history of magnetospheric activity on the precipitation of energetic electron fluxes into the D layer of the auroral ionosphere

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Previously the authors have shown that energetic electron fluxes in outer radiation belt (RB) is influenced by solar wind parameters and magnetospheric activity indexes with large delays (up to 24 hours for 31 keV and up to 8 days for 719 keV according to THEMIS observations). In the present work the authors try to estimate the effect of long memory of magnetospheric activity on the electron density in the D region of auroral ionosphere where accelerated electrons are precipitated from RB. For this purpose the geomagnetic indexes (SML, Ap, etc) integrated over time intervals of different length (up to 5 days) were correlated with ionospheric electron concentration at different altitudes observed by EISCAT UHF radar during the daylight conditions in the prenoon sector of auroral ionosphere, where most intense energetic electron precipitation is observed. Ionospheric electron concentration was studied separately at different altitudes between 105 and 75 km, which correspond to precipitated electron fluxes with energies between 30 keV and 200 keV. The effective length of time windows for integration are ~1 hrs for 105 km and up to 24 hrs for 75 km for SML index. This is consistent with the results presented in Hua et al., 2022, who found progressive increase of memory with the energy of electrons in the radiation belt. Similar delay pattern obtained for energetic fluxes in the outer radiation belt, implying that long memory manifests itself in the ionospheric electron density. Obtained results allow to estimate the time to energize electron fluxes to energies sufficient to produce ionization at given altitudes during magnetospheric activity.

GC2024-STP040

The features of small-scale artificial field-aligned irregularities, induced by the O- and X-mode HF pumping by the EISCAT/Heating facility

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We present the results of investigations of small-scale artificial field-aligned irregularities (AFAIs) induced by an ordinary (O-mode) and extraordinary (X-mode) polarized HF pump waves [1],[2].

The research was made in operating hours of the EISCAT/Heating facility in Tromso via the multi-channel HF Doppler radio scatter receiver at the Gorkovskaya station, near Saint-Petersburg; via chirp ionospheric oblique sounders[3] on the Lovozero station - Gorkovskaya station radio path, on the Amderma – The Gorkovskaya station radio path, on the Sweden - The Gorkovskaya station radio path, on the Irkutsk - The Gorkovskaya station radio path and the Sodankylä - The Gorkovskaya station radio path; via the *CUTLASS radar in special mode of operation[4].*

It was shown that both, the O- and X-mode HF pumping, are led to the small-scale artificial field-aligned irregularities generation.

The comparative characteristics of AFAIs were made, based on diagnostic data such as the oblique sounding ionograms, spectral analysis of scattered HF signals and the *CUTLASS radar data. Some special features were highlighted.*

A possible mechanisms for the AFAIs generation induced by an X-mode HF pump waves are discussed.

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GC2024-STP041

Efforts of China-Russia Consortium at Global Aviation Space-Weather Service

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This keynote will cover the recent efforts of the China-Russia Consortium to provide services to the global civil aviation community. The China-Russia Consortium — a Global Space Weather Center (CRC) is a global space weather service provider designated by International Civil Aviation Organization (ICAO) for running the advisories for airlines, navigation, and traffic control agencies around the world[1]. It is is one of the four designated ICAO space weather centers. During the last year the CRC has issued more than 20 advisories concerning moderate or severe aviation-related space weather conditions. All ICAO-designated space weather centers issue advisories according to recommendations approved by the space weather and aviation communities. In addition to operational coordination, the centers also participate in harmonization and development efforts among each other and with World Meteorogical Organization and ICAO. This work include comparison of radiation models[2], radiofrequency protection, maximum usable frequency and GNSS-related issues, international data-sharing regulatory work and work with feedback from consumers. The discussion would also involve solar activity growth affecting the civil aviation. [1] International Civil Aviation Organization. Manual on Space Weather Information in Support of International Air Navigation (Doc 10100)

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GC2024-STP042

Mathematical simulation of the atmospheric electric field disturbances caused by a magnetic storm

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It follows from the observational data that during geomagnetic storms, variations of the atmospheric electric field occur. We use a quasi-stationary model of a conductor consisting of the ionosphere and the part of the atmosphere lying below it to calculate the ionospheric and atmospheric electric fields.

To describe the magnetospheric electric field generator, data from the AMPERE satellite on the global distribution of the field-aligned currents for a sequence of time points in increments of 1 hour on March 17 and 18, 2015 were used. First of all, the position of the interface between the regions of closed and open magnetic field lines was clarified by the distributions of the field-aligned currents. The region 2 current system is located in the area of closed magnetic field lines, the rest currents are on open ones: the region 1 current system is on those magnetic field lines which connected to the tail of the magnetosphere, the currents of the cusps are on those magnetic field lines which connected to the magnetopause. During this storm, the total field-aligned current (flowing in total into the Earth's ionosphere, and equal to it flowing into the magnetosphere), according to AMPERE data, reached 45 MA.

The conductivity tensor in the ionosphere is a gyrotropic tensor. In the atmosphere below 50 km, it becomes a scalar. We use the height profile of the conductivity that is some average of known empirical models. Above 65 km (E- and F-layers of the ionosphere) during the day (or 90 km at night), our conductivity model is based on empirical models IRI-2016, MSIS 1990 E, IGRF. A smooth height interpolation of the components of the conductivity tensor between these regions is used. Because of that the field-aligned conductivity is a few orders of magnitude larger than others in the ionosphere a two-dimensional model can be used for the electric current continuity in the ionosphere. Since IRI-2016 does not present auroral enhancement of the electron concentration we are to use Weimer model of the additional Pedersen and Hall conductances in the auroral zones.

As a result of the numerical solution of such a problem, the global distributions of the electric potential are obtained for each moment of time. In particular, the obtained potential difference morning-evening through the polar caps reaches 300 kV, and the average during the storm is about 200 kV. A variation of the electric potential in the ionosphere leads to a variation of the electric field throughout the atmosphere, including its surface layer. During a geomagnetic storm lasting about a day, the observatory in which the atmospheric electric field is measured significantly changes its position relative to the direction to the Sun. This leads to the connection of spatial and temporal variations of the electric field, which must be taken into account when assessing the effect of a geomagnetic storm on the atmospheric electric field when comparing measurement data at a particular observatory with geomagnetic activity indices.

The simulation results showed that during extremely strong magnetic storms, variations in the atmospheric electric field of the same scale as the fair-weather field itself can be formed in some places on the Earth.

For the strong storm on March 17-18, 2015 (the Dst index reached 223 nT), the results of simulations are compared with the disturbances of the fair-weather electric field observed at a number of observatories presented

at https://glocaem.wordpress.com, and at Borok Geophysical Observatory of the Schmidt Institute of Physics of the Earth RAS, Complex Geophysical Observatory Paratunka of the Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS, Vostok Observatory (Antarctica).

GC2024-STP043

The influence disturbances in the ionosphere caused by electron precipitation on the propagation of VLF signals

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The results of ground-based observations of VLF signals from the RSDN-20 radio navigation system, received at the Polar Geophysical Institute network, are presented in this work. It is shown that geomagnetic disturbances with AL index values of -500 nT and below in the nighttime can result in a decrease in signals of the Krasnodar VLF transmitter observed in the Lovozero observatory. The POES satellites, positioned at the geomagnetic field lines with foot-points near Lovozero, recorded high-energy electron fluxes exceeding 278 keV. The POES data also indicated that the precipitation area was about 200 km. We used the model of VLF propagation in the Earth's ionosphere irregular waveguide to demonstrate the connection between observed decrease in amplitude of VLF signals and electron precipitations.

The study was supported by the Russian Science Foundation (project №22-12-20017).

GC2024-STP044

Distortion of the results of impedance measurements interpretation on the Kola Peninsula due to the proximity of ionospheric sources of the natural electromagnetic field

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The method of magnetotelluric sounding of the earth's crust is widely used in Arctic regions, when carrying out geophysical work. As is known, this method is based on the impedance approach - measuring the elements of the impedance tensor on the earth's surface in the extremely low-frequency range of electromagnetic waves from natural field sources. The main natural sources of electromagnetic noise are the equatorial centers of thunderstorm activity. In the Arctic regions, in particular on the Kola Peninsula, ionospheric sources of the electromagnetic field, for example, systems of high-latitude ionospheric currents, can also have a noticeable influence on the measurement results. Due to the spatial proximity of these sources to the areas of geophysical work, the plane-wave approximation of the electromagnetic field, on which the impedance approach is based, may be violated. Consequently the results of impedance measurements interpretation may be distorted when determining the geoelectric parameters of the lithosphere. In order to experimentally confirm possible distortions in the impedance measurements interpretation, a joint analysis of data from the induction magnetometer located on the Lovozero geophysical observatory in the center of the Kola Peninsula and satellite geomagnetic data obtained within the AMPERE project was carried out. Dates and time intervals with disturbed and calm geomagnetic conditions over the Kola Peninsula were selected by using satellite data on spatial and temporal variations of the Earth’s magnetic field, as well as on the distribution of the intensity of Birkeland currents, which directly related to zones of intensification of horizontal Hall currents in the high-latitude ionosphere. In 2014, horizontal mutually perpendicular components of the magnetic and electric fields were recorded at the Lovozero magnetometer. Based on these data, the Berdichevsky impedance values were calculated for a given set of frequencies of the natural electromagnetic noise in the range from 0.3 to 27 Hz. The Berdichevsky impedance values were recalculated into the values of the apparent resistance of the earth's crust. As a result of a joint analysis of the data, it was found that on days with calm geomagnetic conditions, the values of the apparent resistivity of the earth's crust are about 100000 Ohm•m, which is inherent to the crystalline Baltic shield within the Kola Peninsula. At the same time, on days with disturbed geomagnetic conditions, the significant decrease of the apparent resistivity values is observed at frequencies below 1 Hz. Perhaps this decrease is determined by the proximity of ionospheric sources of the natural electromagnetic field and the limited use of the impedance approach at high latitudes for high-resistivity rocks. The results obtained are consistent with model calculations of the electromagnetic field from various natural sources.

GC2024-STP045

Limb Flare with Failed Eruption

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Solar flares are often associated with various eruptive phenomena. The most significant of these are coronal mass ejections, which can reach and impact the terrestrial magnetosphere. Sometimes, the eruption motion stops due to some reasons and this fact causes questions. Is it a real eruption with a distortion of the magnetic field topology? Or is it only a plasma motion and a visible effect? Multiwave observations of such events can help us to find answer to these questions. We present a study of the M7.2 GOES-class solar flare that occurred on July 12, 2023. This is a limb flare followed by a failed eruption, according to EUV observations. The event was observed by a set of instruments with spatial resolution, that allows an interpretation based not only on the flux evolution, but also on the flare source topology at different wavelengths. The Siberian Radioheliograph (SRH) obtains microwave images within the 3-12 GHz frequency band, while the Nançay Radioheliograph (NRH) provides images in the decimeter radio range. The Solar Dynamics Observatory/Atmospheric Imaging Assembly (SDO/AIA) get data in the UV range, and the Advanced Space-based Solar Observatory/Lyman-alpha Solar Telescope (ASO-S/LST) provides Lyman-alpha images. Analized the set of data, we found that studied event had a configuration of the circular ribbon flare, which magnetic morphology does not allow for eruptions except for jets. The possible of geoeffectivity of this type flare is discussed.

GC2024-STP046

Strong electrostatic fluctuations associated with intense electric currents in the plasma sheet of the Earth magnetotail

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Flapping of the Current Sheet (CS) associated with the propagation of the Burst Bulk Flow (BFF) allowed to observe consecutive crossings of the Earth magnetotail Plasma Sheet (PS). Both parallel and perpendicular Intense electric currents up to ~100 nA/m^2 were observed during the interval of interest. Simultaneously, the presence of parallel electron anisotropy of suprathermal population was observed over the entire PS. These ECS are localized and may be observed at any regions of PS. The distribution of intense ECS versus the distance from the neutral plane experiences strong variations from crossing to crossing of the PS demonstrating the transient nature of these currents.

Nonideal electric field ($\mathbf{E'} = \mathbf{E} + [\mathbf{v}_e \times \mathbf{B}]$) leading to violation of the frozen-in condition reached ~100 mV/m during the interval of interest. Typically, such strong fields are observed in the outer PS ($B_x \sim \pm$(10-15) nT). In this event they were observed also near the neutral plane of the CS. This leads to extremely intense energy conversion value ($\mathbf{j},\mathbf{E'}$) up to ~3 nW/m^3, which are typical for the electron diffusion region (EDR). Our analysis shows that the regions with different signs of the ($\mathbf{j},\mathbf{E'}$) appear sporadically throughout the PS. Globally, the probability to observe positive and negative values of the ($\mathbf{j},\mathbf{E'}$) are almost equal over the entire PS. This may reflect the turbulent structure of the BBF, where energy transfers locally from particles to waves and vice versa.

We selected 179 events j>25 nA/m^2 near the neutral plane (B_x<5 nT). In 57 events intense (>10 mV/m) nonideal electric fields were observed inside the ECS. In 13 cases these fields appeared as electrostatic fluctuations, associated with accelerated field-aligned electrons beams. We selected two types of the electrostatic fluctuations: i) with frequencies lower than electron cyclotron frequency $\omega_{c,e}$ and ii) the broadband electrostatic fluctuations which high-frequency range exceeded $\omega_{c,e}$. We assume that the first type can be related to the linearly polarized electrostatic mode of whistler waves. The second one can represent the ensemble of electron solitary waves including the electron cyclotron harmonics.

Electrostatic fluctuations are typically associated with field-aligned beams in the Plasma Sheet Boundary Layer (PSBL), where they propagate along the magnetic separatrix. Also, such fluctuations were reported in the reconnection region. We showed the presence of strong electrostatic fluctuations associated with the intense field-aligned ECS inside the central PS at closed field lines and well outside the reconnection region. These currents were generated by field-aligned electron beams with suprathermal energies. We suggest that these beams are accelerated by induction electric fields generated near the neutral plane due to the transient changes in magnetic configurations of the islands/flux ropes transported by the BBF (e.g. via the electron tearing mode [1,2]). These processes produce the chain of transient acceleration sites distributed along the radial direction near the neutral plane and outside the X-line. They can be responsible for the appearance of field-aligned accelerated electron beams in the central PS at various distances from the neutral plane. Similarly to the field-aligned beams propagating in the PSBL, the electron beams in the central PS can be a source of the strong electrostatic fluctuations and intense energy conversion along the beam pathway.

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GC2024-STP047

Auroral hiss on Spitsbergen and "polar" substorms

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The paper presents the results of the analysis of ground-based observations of electromagnetic emissions such as auroral hiss at the Barentsburg station (Φ=75.21°, Λ=126.06°, CGM). We consider the auroral hiss bursts that occur during "polar" substorms, which are observed at latitudes above 70 MLAT in the absence of magnetic substorms at lower latitudes. Based on the estimation of the polarization of the magnetic field and the azimuth angle of the Poynting vector of the analyzed waves, the position of the region on the Earth's surface illuminated by bursts of this type is estimated. The dynamics of the position of this region is compared with the dynamics of the substorm and the position of the field-aligned currents recorded by the satellites of the AMPERE project. Based on the conducted analysis, we have suggested a possible connection between the dynamics of auroral hisses and substorm.

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GC2024-STP048

Determining the transverse structure of Alfvén waves recorded by the Van Allen Probes satellites by means of the "phase portraits" technique

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The study of the transverse structure of Alfvén waves observed by Van Allen Probes satellites using the method of the "phase portraits" (construction of the phase difference between the magnetic field components) has been carried out. The first event was observed by the RBSP-A satellite on 23 October 2012 at 22.00-22.30 UT. It is shown that the observed oscillations can be explained as resonant poloidal Alfvén waves generated on two resonant surfaces located on both side of the local maximum in the radial distribution of the Alfvén velocity. The polarization of the waves between these resonant surfaces changes from poloidal to toroidal. The second event was detected by the RBSP-A satellite on the same day at 19.12-20.24 UT. This event can be interpreted as a transverse Alfvénic resonator. Comparison between the theoretical and satellite transverse components of the magnetic field and their "phase portraits" shows good agreement.

Satellite data processing for both cases and the study of the field structure of resonator modes were supported by the Russian Science Foundation under Grant 22-77-10032, the theoretical justification of the method of "phase portraits" and the numerical calculation of the structure of Alfvén waves near the maximum of the Alfvén velocity were supported by the Ministry of Science and Higher Education of the Russian Federation.

GC2024-STP049

The role of the ring current in the Dungey cycle from the point of view of Stokes' theorem

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The well-known Dungey model of the solar wind - magnetosphere interaction has been revised to take into account the essentially non-stationary effects of magnetic reconnection. For this purpose we used the so-called magnetic contour method.

The magnetic contour is the following. A segment perpendicular to the magnetic field lines is chosen in the magnetosphere, and a field line is launched from each point of it until it intersects with the ionosphere, first at time t, and then at time (t+dt). The Stokes theorem is applied to the moving contour constructed in this way, which claims that the electromotive force (EMF) along the magnetospheric segment differs from the EMF along the projection of this segment in the ionosphere by the magnitude of the magnetic flux drawn by the moving projection during the time (dt).

Knowing the behavior of the projection of a segment in the ionosphere, which often manifests itself in the form of a moving arc, it is possible to obtain the distribution of the electric field in the magnetosphere. It is shown that in the zone of the developing Birkeland current loop of a substorm, a powerful electric field with an effective potential difference of several tens of kV is generated. Therefore, the arising Birkeland current loop of a substorm is the central element in the magnetosphere, responsible for the acceleration of charged particles. This current system amplifies the already existing ring current, and the closure of a part of it through ionosphere generates a zone 2 of field aligned currents. The movement of an expanding partial ring current around the magnetosphere together with the drift of charged particles transfers the magnetic flux from the night side of the magnetosphere to the day side. At the daytime magnetopause, reconnection is also responsible for the creation of the Birkeland current loop, but now the electric field arising in the loop zone slows down the particles of the ring current, and regions of ring current weakening are formed. The closure of these holes in the ring current leads to the transfer of magnetic flux from the day side to the night side, ensuring its balance.

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GC2024-STP050

Dynamics of the proton aurora and current sheet in the magnetosphere. Ground-based and satellite observations

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The proton aurorae in the emissions of atomic hydrogen arise as a result of energetic proton precipitation and their charge exchange at the heights of ionosphere E layer. The proton precipitation occurs from of the magnetosphere region with an isotropic distribution of charged particle fluxes. Isotropization occurs due to the pitch-angle scattering at the magnetic equator with a large curvature of field lines in the current sheet [1,2]. The low-latitude boundary of particle isotropic fluxes is registered with the low-altitude satellites with a polar orbit. Equatorward of this boundary, the precipitation of energetic protons is sometimes observed as a result of scattering during interaction with EMIC waves [3].

This report presents the results of our observations at the Maimaga station (CGMC: 58°, 202°) of the proton aurora dynamics in the MLT evening sector during a magnetic storm with a minimum of SYM-H ~ -130 nT on December 01, 2023. The main phase of storm began in ~10 minutes after a sharp increase of the electric field dawn-dusk Ey in the solar wind ($-V_x \times B_z$) up to ~11 mV/m at ~1010 UT. At this time, the appearance of broad band in the 486.1 nm emission (H-beta) of atomic hydrogen was registered at the latitudes of diffuse aurora in the 557.7 nm emission. The band moved equatorward from the northern horizon and passed the station zenith at a velocity of ~ 205 m/s. Next, short (~10 minutes) activizations of aurorae were observed throughout the all sky in the geomagnetic latitudes interval of 54-62° with the maximum H-beta emission intensity of ~600 Rayleigh after subtracting of the continuum intensity. Narrow forms of electronic aurorae were sometimes detected in the 470.9 nm N_2^+ emission.

At ~1115 UT, the NOAA19 satellite registered the isotropic boundary of the energetic proton and electron fluxes at the optical observation meridian. The isotropic flux maximum of protons of width ~2° at this boundary coincided with the arc position in the H-beta emission. Mid-latitude magnetic variations and the SYM-H index point to a relationship of the main phase onset of storm to the magnetic effect of the current sheet. We believe that the observed dynamics of proton aurora in this event mapped a rapid motion of isotropic flux boundary of the energetic protons and, correspondingly, current sheet into the inner magnetosphere as a consequence of sharp increase of the magnetospheric convection.

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Two-dimensional cone models of geoeffective coronal mass ejections

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Strong geomagnetic storms (Dst ≤ -100 nT) are mainly caused by ICMEs [1] and forecasting of coronal mass ejections (CMEs) arrival to the Earth's orbit is one of important problems of space weather. The drag-based model (DBM) [2] is often used for modeling CMEs heliospheric propagation. DBM is based on the magnetohydrodinamic drag concept – at a certain distance from the Sun motion of CME is influenced by the drag force. MHD drag is determined by the interaction of the CME with solar wind. CME may propagate through ambient solar wind, high-speed stream or interact with another CME.

In this work, we examine propagation of CME through different types of solar wind for geoeffective events. We model time of CME arrival to Earth's orbit and CME speed with three types of geometry: 1) concentric model (all points are at equal distance from the Sun), 2) self-similar model (CME front does not change its shape) and 3) flattening model (each plasma element of the CME front propagates independently) [3]. As the coordinates of CME source on the solar disk we used coordinates of associated coronal dimming, which is observed as decrease in intensity in EUV.

Dimming parameters obtained from the SDO/AIA images are presented in the Solar Demon database (https://www.sidc.be/solardemon/). CME parameters obtained from the SOHO/LASCO images are presented in the CACTus database (https://www.sidc.be/cactus/). To associate CME forecast with ICME we used ICME list (https://swx.sinp.msu.ru/tools/icme_list.php).

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GC2024-STP052

A study of the influence of geomagnetic field asymmetry on relativistic electron fluxes at low Earth orbit altitudes

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We report on a statistical study of the characteristics of trapped and precipitating relativistic electrons (with energies > 800 keV) by using a dataset of relativistic electron precipitation (REP) events observed by NOAA/POES spacecraft. The dataset includes REP events observed in 2017 during the NOAA/POES flybys near the Lovozero observatory (68°N, 35°E) and in the geomagnetically conjugate region in the Southern Hemisphere. Classifying events into four groups based on the works [1] and [2] allowed us to associate these precipitations to different processes in the magnetosphere. The first group include the events due to the scattering of particles in the regions of strong magnetic field line curvature in the night magnetosphere. The second group is characterized by simultaneous observations of relativistic and energetic (> 30 keV) electron precipitations, both having a distinct latitudinal maximum in the fluxes of precipitating particles and not accompanied by energetic proton precipitation, along with geomagnetic PiB/PiC pulsations detected by the ground-based Lovozero station. The third group is related to simultaneous observation of energetic proton precipitation and is thus attributed to the interaction of relativistic electrons with electromagnetic ion-cyclotron (EMIC) waves (observed on the ground as Pc1 pulsations). The fourth group includes precipitation events not falling into any of the first three groups. The properties of trapped and precipitating electrons for each group were analyzed separately for the northern and southern hemispheres to investigate the influence of geomagnetic field asymmetry on these fluxes. The most closely conjugate (in time and space) satellite passes were identified and the characteristics of REP were described based on geomagnetic activity.

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GC2024-STP053

Observation of stationary current sheet in the magnetosphere

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We investigate Earth's magnetotail current sheet under quiet magnetospheric conditions using Cluster satellites' observations. We consider mainly caused by satellites' motion current sheet crossings with duration of 30 – 45 minutes, in contrast to most previous studies, where the crossings took 10 minutes or less and were caused by flapping motions. Obtained current sheet are embedded with thicknesses of 1,5-2Re or 40-100 proton gyroradii. The electric current calculated using curlometer method has similar value to the sum of the three contributions to the current calculated by plasma parameters (proton diamagnetic current, electron diamagnetic current, anisotropic electron current). Near the current sheet's center electrons provides the main contribution (1-4 nA/m2) to the sum current, protons are demagnetized. Ion diamagnetic current provides the main contribution to the sum current far from the current sheet's center.

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GC2024-STP054

The ions counterclockwise motion near the diamagnetic cavity edge

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The plasma expansion into an ambient environment containing magnetic field and background is applicable to many processes in cosmic plasma and astrophysics, such as supernova explosions, coronal mass ejections, formation of comet coma, ion releases in the Earth's magnetosphere, etc. The active experiments in the Earth's magnetosphere (AMPTE, CRRES) have shown that the magnetic field is expelled by the cloud plasma, the diamagnetic cavity is formated and even in the case of a simple configuration of spherically symmetric plasma expansion demonstrate complex dynamics and effects that require more detailed investigation and explanation. These problems actualize experiments with laboratory plasma, which make it possible to reproduce and observe these objects with detailed diagnostics and under specified conditions. For example, such experiments are carried out at the KI-1 facility (Institute of Laser Physics SB RAS, Novosibirsk) and Large Plasma Device (UCLA, USA).

Recent experiments at the KI-1 facility, where a plasma cloud is created by the action of a laser pulse on a polyethylene target, are aimed at studying the features of a diamagnetic cavity in the presence of a weak magnetized background. As a result, a counterclockwise rotation region of hydrogen ions was discovered using spectral diagnostics. A laboratory experiment is accompanied by numerical simulations to interpret observations and to investigate the physics of this effect.

We present the results of a diamagnetic cavity simulation using the parallel semi-implicit kinetic code iPIC3D. The plasma cloud explosion, similar in parameters to the experiments at the KI-1 (the case of sub-Alfven expansion and non-magnetized ions), occurs into an ambient magnetic field and a background plasma. The azimuthal velocities of different ions species (background hydrogen, plasma cloud protons and carbon ions) were investigated at the cavity boundary (in an equatorial plane). The protons counterclockwise motion is shown, which does not coincide with the direction of their gyromotion, in contrast to heavier carbon ions. The time-integrated velocity distributions along the observation line (virtual optical axis) were constructed to compare the kinetic simulation results and the spectral data in laboratory experiments. In addition, the cases of a high and low background plasma density are considered and the dependence on a background plasma level is demonstrated. The work was supported by The Russian Science Foundation 23-22-00386 grant.

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Spatiotemporal features of seismoionospheric anomalies in the F-layer, Japan region

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One of the urgent problems of geophysics is the study of lithospheric-ionospheric connections. Most studies paid attention to the precursors of strong shallow earthquakes; short-term ionospheric effects caused by the passage of seismic waves were also noted.

Variations in ionospheric parameters that occur several days to several hours before earthquakes have been repeatedly described in the literature [1,2]. Both an increase and a decrease in the ionization density were observed before earthquakes [3,4]. Moreover, the maximum values ionospheric anomalies do not correspond typically to the epicentral region, and the amplitude of them do not always increase by the time of the earthquake. Variations that occur after earthquakes have rarely received attention[5].

The task of the work is to identify the spatio-temporal areas of seismoionospheric effects before and after earthquake at distances of up to 3000 km from the epicenter, and to assess their reliability.

We analyze the diurnal variation of foF2 in the vicinity of earthquakes M6+ using hourly ionospheric foF2 data obtained at the ground-based vertical sounding (VS) station Kokubunji (Tokyo) for 1957-2020. The ISC GEM earthquake catalog (1957-1975) and the GCMT earthquake catalog (1976-2020) were used; both these catalogs provide the moment magnitude Mw. Days when geomagnetic disturbances ΣKp >25 and subsequent days were excluded. For each hour, deviations of foF2 from the moving median were considered, normalized to the same median Δf_i = ($foF2_i$ - median(foF2))/median (foF2), where median(foF2) is the median of foF2 values over the period (-7, +7) days for every i-th hour. The median was calculated if there were at least 8 values out of 15 possible hourly values.

An overlay of Δf epochs was carried out and a two-dimensional picture was obtained depending on the distance from the station to the epicenter and on the time (-10, +10) days before and after the event. We exclude the repetition of the same time intervals. We sort earthquake by magnitude, starting with the strongest. We will select (-240, +240) hours before and after the strongest earthquake and exclude these values from further analysis; then we repeat this procedure for the next largest earthquake.

By averaging we obtain a two-dimensional picture for earthquakes with M7+ (114 earthquakes), M(6.5...7) (201 earthquakes), M(6...6.5) (767 earthquakes), the distance step was chosen to be 1000 km, for earthquakes M(6...6.5), the distance step was chosen to be 500 km. The reliability of the obtained seismic-ionospheric anomalies at 95% and 99% levels was calculated using the method of modeling a random process.

An increase of foF2 before and a decrease after earthquakes was observed at the distances up to 2000 km. The amplitudes of the effects are 1-2%. In many works it was concluded that the area of manifestation of seismoionospheric effects is limited by the Dobrovolsky radius R_D=exp(M). The presented work shows that the maximum manifestation of the effect also occurs outside this area.

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GC2024-STP056

Determining role of the solar protuberance activity in the Earth's climate current warming

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The prevailing view is that the global warming (GW) is caused by the Industrial Revolution (IR), which began in the 1890s and led to increased mining and processing of fossil carbon-containing substances and increased emissions of CO_2 and other greenhouse gases and vapors into the atmosphere.

But this opinion is doubt by the following reasons:

(1) The CO_2 atmospheric content is low, only one molecule per about 2 500 molecules of other gases.

(2) The total 60-year CO_2 increment into the atmosphere is low, only one molecule per 10 000 molecules of other gases; the total CO_2 increment includes not only anthropogenic CO_2, but also CO_2 from forest fires, volcanic activity, and other sources.

(3) Experimental work [1] shows that the CO_2, actually occurring in the atmosphere, should have a greenhouse effect smaller by a factor of several tens than that observed de facto.

(4) Authors of some other studies, e.g. [2–4], concluded that the solar activity variations rather than the greenhouse gases determine the GW.

(5) The PFO-CFO Theory initiated by us about 15 years ago and presented in its finished form in our last publications and in the lecture given in Amsterdam (2019) forecasts the long-duration GW (see [5]).

However, the mechanism of the solar effect on climatic variations of different durations wasn't revealed earlier. We did it on the PFO-CFO Theory basis. The Theory, its content, explanations of the principal past climatic variations, and predictions of the further ones will be considered in another our presentation at this Conference.

Note that the PFO-CFO Theory allowed us in 2015 to predict the unusually powerful solar protuberances (Prs) of October 2017 (see [5]).

We use no models, but only observations, experiments, calculations, and conclusions from them.

Here, we consider events of the last 2–2.5 centuries.

The soil-temperature increment rises over decades bottom-up [6]. This means that it is not magmatic processes that are causing the climate warming.

We proved that the current GW is caused by enhanced activity of solar Prs and have begun in different regions in 1850–1890. It can continue for several solar cycles, but possibly, much longer.

The Prs aimed at the Earth affect its climate by two mechanisms (M1, M2). A portion of Prs' energy scatters in space and only a residue reaches the Earth directly. The Earth absorbs quickly this residue (M1) and then absorbs slowly a part of the energy scattered in space (M2). The Prs that fly far from the Earth warm its surface through M2 only, i.e., slowly. Only a small fraction of all solar Prs flies near the Earth.

We studied the effect of solar Pr activity on the Earth's climate, basing on the available data about the yearly mean surface-air temperature monitored in Eurasian cities Ekaterinburg, Moscow, Berlin, and Rome since 1830, 1820, 1750, and 1810, respectively, and about the powers of all X-protuberances observed since 1976.

When analyzing the Pr activity and the temperature in these cities, we found that warming began before IR and confirmed completely the Pr effect on the Earth's temperature by M1 and M2.

Conclusion:

1. Earth’s warming is caused by enhanced solar Pr activity.

2. Warming can continue in the next solar cycles.

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GC2024-STP057

Features of development of geomagnetic activity and night sky airglow at mid-latitudes during the 20 Dec 2015 storm

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The study considers a number of different geomagnetic events: disturbances caused by pulses of the solar wind dynamic pressure, a super substorm, and the localized at middle latitudes geomagnetic and optic disturbance. All these events were observed during the main phase of a strong magnetospheric storm on 20 December 2015. We analyze the development of geomagnetic activity in these events using a wide range of instruments located at mid- and high-latitudes, which allowed us to describe them in detail. Particular attention in the analysis we address to geomagnetic pulsations (in particular Pi1B type) and night sky airglow (on the 557.7 and 630.0 nm lines) at mid-latitudes near Irkutsk, as well as to the development of ionospheric and field-aligned electric currents using the ISTP SB RAS magnetogram inversion technique.

We have shown that the observed solar wind dynamic pressure pulses were accompanied by an increase in substorm activity and the intensity of burst pulsations at the southward IMF.

By analysing the super substorm, we show that the observed change in the sign of the two components of the geomagnetic field variations along the IMAGE station chain near 18 MLT is caused by the formation of an additional westward electrojet north of the eastward electrojet.

After the super substorm, we also revealed in the near-midnight sector a localized geomagnetic event during which the magnitudes of variations in the H geomagnetic component, PiB/PiC pulsations, and intensity increase of oxygen emissions at mid latitudes were more than twice greater than during the super substorm. We present the features of the geomagnetic pulsation development from middle latitudes to high latitudes during the event.

GC2024-STP058

24th and 25th cycles of solar activity: features and predictors

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The report is devoted to the consideration of heliogeophysical features of the 24th and 25th cycles of solar activity, and new methods for predicting extremes of solar activity. The authors proposed to use the maximum of the fifth zonal harmonic of the solar global magnetic field as a predictor of the time of the maximum of the 11-year cycle of solar activity (SA). The polar field of the Sun is an effective parameter for predicting the height of the SA cycle [1]. It has been shown that epidemiological processes can serve as an additional predictor of global changes in solar activity [2]. For example, the beginning of the next cycle of local measles epidemics occurs 12-15 months before the extremes of the SA cycle. The maximum 25th cycle of solar activity (SA) is expected with a cycle height of no more than 127 for forecasting using the authors method.

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GC2024-STP059

Prediction of the state of the Earth's magnetosphere using machine learning in SINP MSU Space Weather Analysis Center

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The state of the Earth's magnetosphere is characterized by both the level of geomagnetic field disturbances and the magnitude of the flux of relativistic and sub-relativistic electrons in the Earth's outer radiation belt (ERB). The Center for Space Weather Analysis of the Institute of Nuclear Physics, Moscow State University (SINP MSU) provides information on the current state of near-Earth space, as well as operational forecasts of variables describing this state - namely, of the geomagnetic indices (Dst and Kp) and of relativistic electron fluxes in the outer ERB. The forecasts are carried out using machine learning (ML) methods.

The changes in the parameters of the solar wind (SW) and interplanetary magnetic field (IMF) are responsible for both magnetic storms and variations of the fluxes of relativistic electrons of the outer ERB. So since the causes of changes in geomagnetic and radiation conditions in the near-Earth space are closely related to each other, the problems of predicting them are solved by similar methods.

The following operational forecasts, implemented using ML methods, operate at the portal of the Space Weather Analysis Center of SINP MSU (https://swx.sinp.msu.ru/):

- forecast of geomagnetic indices Dst [1, 2] and Kp [3];
- forecast of relativistic electron fluxes (E>2 MeV) of the Earth’s outer radiation belt in geostationary orbit [4,5];
- forecast of daily fluences of relativistic electrons (E>2 MeV) in geostationary orbit using the forecast of solar wind speed [6].

In all of the above forecasts, in addition to the predicted values themselves, the most important input parameters are the SW velocity, the magnitude and the vertical (z) component of the IMF, as well as sine and cosine with daily period. To predict the electron fluxes of the outer ERB, values of Kp and Dst are also required.

The most effective ML methods for solving these problems are artificial neural networks and gradient boosting over decision trees. In addition to the selection of optimal ML methods and the selection of their optimal parameters for each specific task, a very significant stage of processing is the selection of essential input features of the task.

In addition to directly predicting the value of geomagnetic indices, work is also underway to predict the level of geomagnetic field disturbance based on the Kp index using ML methods that carry out classification [7].

The tasks of studying and predicting the state of the magnetosphere are important from both fundamental and practical points of view [8].

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GC2024-STP060

Spatial features of the ionospheric disturbance caused by a meteorological squall

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The investigation presents the results of modelling studies of the impact of a meteorological squall on 29 May 2017 in the Moscow region on the parameters of the thermosphere and ionosphere.

The modeling utilized two models: the numerical high-resolution regional atmospheric model AtmoSym and the Global Self-Consistent Model of the Thermosphere, Ionosphere, and Protonosphere (GSM TIP). The large-scale model incorporates the influence of acoustic and internal gravity waves originating from the troposphere by introducing an extra heat source derived from numerical simulations conducted at AtmoSym.

The multimodel study showed that wave propagation from the troposphere leads to a noticeable (up to 10%) increase in temperature above the epicentre of the meteorological event. The temperature increase leads to corresponding changes in the thermosphere and ionosphere parameters. Our simulations showed that a dipole-like structure with positive and negative TEC values in the vicinity of the atmospheric waves source is formed in the spatial distribution of the total electron content (TEC) perturbation in the first hours from the onset of the squall. Additionally, the positive TEC disturbance is generated to the southeast of the wave activity source, while the negative TEC perturbation is formed to the northwest of the wave activity source. Additional analysis revealed that the dipole character present in the meridional wind perturbation at the F2 ionosphere region is similar to the TEC perturbation. Furthermore, the direction of the velocity perturbation aligns with the formation mechanism of both positive and negative TEC perturbations.

The study of neutral composition changes showed only a decrease in the n(O)/n(N2) concentration ratio near the squall epicentre, which only enhances the negative TEC perturbation.

As the meteorological source weakens, the dipole structure of perturbations in the meridional wind and TEC starts to deteriorate, taking on a wave-like quality.

The calculated results demonstrate that a quasi-dipole disturbance in Total Electron Content measurements can be observed during intense meteorological events in the troposphere. Such TEC disturbances can serve as indicators of various phenomena that cause the propagation of atmospheric gravity waves (AGWs) from the lower layers of the atmosphere to high altitudes (for example, hurricanes, tsunamis, earthquakes, etc).

The research was funded by the grant Russian Science Foundation No 23-77-10004, https://rscf.ru/project/23-77-10004/ (AtmoSym model simulation, spectral analysis, analysis of multi model results). Partly the work (GSM TIP simulation for quiet and storm-time condition, model/data comparison) was supported by Saint Petersburg University (research grant 116234986).

GC2024-STP061

Electronically excited molecular nitrogen in the upper and middle atmospheres of Titan and Earth

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Molecular nitrogen N_2 is the main molecular gas in the atmospheres of the Earth, Titan (a moon of Saturn), Triton (a moon of Neptune) and Pluto. In the Earth's atmosphere, the second gas in total concentration is molecular oxygen O_2; in the atmospheres of the other mentioned planets it is methane CH_4. We study the kinetics of the triplet $A^3\Sigma_u^+$, $B^3\Pi_g$, $W^3\Delta_u$, $B'^3\Sigma_u^-$, $C^3\Pi_u$ states of molecular nitrogen at altitudes of the upper (700-1200 km) and middle (50-250 km) atmosphere of Titan during the precipitation of solar UV photons and galactic cosmic rays into the atmosphere. The calculations take into account intramolecular and intermolecular electron energy transfer during inelastic collisions of electronically excited molecular nitrogen with N_2, CH_4 and CO molecules. The interaction constants of electronically excited molecular $N_2(A^3\Sigma_u^+)$ with N_2 and CO molecules are calculated according to quantum chemical approximations and show good agreement with the available experimental data [1]. It is shown that there is a significant contribution of electronically excited N_2 in the excitation of $CO(a^3\Pi)$ at the altitudes of 700-1200 km of the Titan's upper atmosphere. The interaction of electronically excited N_2 molecules with molecules of methane CH_4, acetylene C_2H_2, ethylene C_2H_4, ethane C_2H_6 in the Titan's middle atmosphere at altitudes of 50-250 km was studied. The dominance of reactions with metastable molecular nitrogen $N_2(A^3\Sigma_u^+)$ in the formation of C_2H and C_2H_3 radicals at these altitudes was shown for the first time [2]. Similar kinetic calculations involving triplet electron-excited molecular nitrogen were carried out for the Earth's middle atmosphere of 30-80 km during the precipitation of high-energy relativistic electrons into the atmosphere [3]. The interaction constants of metastable molecular nitrogen $N_2(A^3\Sigma_u^+)$ with oxygen molecules O_2 were calculated and compared with the available experimental data [4]. The emission intensities of the bands of the first positive and second positive N_2 systems during the precipitation of high-energy electrons were calculated. It is shown that there is a significant decrease in the emission intensities of the bands of the first positive system with decreasing altitude due to the influence of collision processes on the populations of vibrational levels of the $N_2(B^3\Pi_g)$ molecule. The influence of intermolecular processes of energy transfer from $N_2(A^3\Sigma_u^+)$ on the formation of singlet oxygen and the emission of the Atmospheric and Infrared atmospheric bands of O_2 at altitudes of the Earth's middle atmosphere was studied.

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GC2024-STP062

Space weather effects on low altitude satellite orbits

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We discuss space weather parameters that can cause upper atmosphere heating and satellite drag. We compare linear regression and NARX neural network models for possible forecast of satellite drag. Using numerous Starlink orbit database and their drag we can further construct the upper atmosphere density models.

GC2024-STP063

Identification of spatial area that gives main contribution to positive storm-time response in high-latitude regional electron content

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Based on the Global Self-Consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP), the response of the regional ionospheric electron content (REC) was calculated for an isolated “reference” geomagnetic storm. The reference storm was obtained by superposing epochs for the AE index with key moments corresponding to the AE maximum. The GSM TIP simulation was carried out for four seasons (autumn/spring equinox and summer/winter solstice) and for four variants of AE maximum times: 00 UT, 06 UT, 12 UT and 18 UT. The model REC response was compared with the observed reference REC response, which was calculated using the following scheme: (1) calculation of REC from total electron content maps; (2) calculation of REC disturbances (dREC) as deviations of observed values from the 27-day moving average REC value and (3) calculation of the reference REC response by averaging dREC using the method of superimposed epochs with key moments corresponding to the maximum of the AE index. In this work, the response of regional electron content at high latitudes for the northern and southern hemispheres is investigated. The best model/data agreement was provided by the option when the time of maximum of the AE index corresponded to 18 UT. A significant (>40%) positive response of the high-latitude REC was revealed on days 1-2 of a geomagnetic storm in local winter months. The mechanisms of formation of high-latitude REC disturbances are considered. The altitudinal and latitudinal regions that make the main contribution to the positive response of the high-latitude REC are identified. A similar study was carried out for the geomagnetic storm on March 17, 2015.

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GC2024-STP064

Effect of interplanetary conditions and auroral activity on intermittency regularities of *Pi3* irregular geomagnetic pulsations

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Earlier we showed that the cumulative distribution function (CDF) of the burst amplitudes of *Pi3* irregular geomagnetic pulsations observed during the development of substorms in the night sector of the magnetosphere follows the power law $f(A) = A^{-a}$, where A is the amplitude of the bursts, a is the exponent. We considered the exponent α, which characterizes the CDF slope, as a characteristic of the intermittency and state of the medium in which *Pi3* bursts are formed. In this work are presented the results of study of the effect of the *Bz* component direction of the interplanetary magnetic field (IMF), auroral activity and b plasma parameter (equal to the ratio of thermal pressure to magnetic pressure) reflecting solar wind turbulence on the intermittency regularities of the *Pi3* pulsation bursts. One-minute digital observations of the magnetic field from two observatories in the Arctic and Antarctic: Heiss Island (HIS, corrected geomagnetic coordinates Latitude 74.80°, Longitude 144.46°) and Mirny (MIR, corrected geomagnetic coordinates Latitude –76.93°, Longitude 122.92°) from the World Data Center for Solar-Terrestrial Physics (Moscow) (http://www.wdcb .ru/stp/data/geo_min.val/) were used. Hourly average parameters of the interplanetary medium and auroral activity (*AE*-index) were obtained from the OMNI 2 database (http://omniweb.gsfc.nasa.gov/ow.html). A total of 305 and 415 *Pi3* pulsation bursts were analyzed in HIS and MIR, respectively. Taking into account interplanetary conditions, all *Pi3* events at each of the observatories were divided into two clusters depending on the direction of the IMF *Bz* component: *Pi3* bursts observed at $Bz<0$ and $Bz>0$. In a similar way, all cases were divided into two clusters according to the value of the *AE* index: Pi3 bursts observed at *AE* <500 nT and *AE* >500 nT. According to the value of the b parameter, the events were divided into *Pi3*, observed at $0<\beta\leq1.3$ (solar wind plasma is highly turbulized) and $\beta>1.3$ (weakly turbulized). For each group, a separate study of the CDF character of the Pi3 pulsation amplitudes was performed and estimates of the power-law exponent a were obtained. It has been revealed that the bursts of *Pi3* pulsations observed in HIS and MIR are excited in a highly turbulent medium (the value of the exponent $\alpha > 1$). Regardless of the parameters considered (*Bz*, *AE* and β), in MIR the value of exponent α is significantly larger than HIS. For example, at Bz<0 and Bz>0 the value of α in HIS is 1.50 and 2.47, and in MIR 3.04 and 3.26, respectively. Similarly, at AE <500 nT and AE>500 nT, the α exponent in HIS is 1.60 and 1.52, in MIR 2.81 and 2.63, respectively. The distributions of *Pi3* burst amplitudes as a function of the parameter β (at $0<\beta\leq1.3$ and $\beta>1.3$) were also approximated by power functions with lower α exponents in HIS (1.44 and 1.65) compared to MIR (2.60 and 2.74). It should be noted that similar trends are observed in the behavior of the exponent α in the northern and southern hemispheres when dividing *Pi3* bursts into clusters according to the values of *Bz*, *AE* and β. So, the value of the exponent α in both HIS and MIR is greater at $Bz>0$, *AE* <500 nT and $\beta>1.3$ than at $Bz<0$, $AE>500$ and $0<\beta\leq1.3$. Thus, from the obtained results it follows that the level of turbulence in the region of excitation of *Pi3* pulsations (presumably in the magnetotail) is significantly higher in the absence of disturbances in the solar wind plasma, relatively moderate auroral activity and weak solar wind turbulence.

GC2024-STP065

The effect of the carrier frequency decreasing of serpentine emission in the polar cap during weak geomagnetic activity

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The effect of the carrier frequency (f_{SE}) decreasing of serpentine emission (*SE*) observed in the 0.1–5.0 Hz frequency range under conditions of a quiet magnetosphere (Kp ~ 0–2) was discovered. The data of the dynamic spectra of ultra-low-frequency (ULF) emission at the Antarctic Vostok Observatory (corrected geomagnetic coordinates Latitude −85.41°, Longitude 69.01°) were used for an analysis. The unique analog magnetic records of the Vostok Antarctic observatory, which have been digitized at high resolution (20 Hz) were obtained from the World Data Center for the Solar-Terrestrial Physics (Moscow) (http://www.wdcb.ru/arctic_antarctic/antarctic_magn_4.ru.html). For 1970–1972 the 90 cases of serpentine emission observation, the central carrier frequency of which smoothly decreased (several times, sometimes to 0) and then increased almost to the initial level at time intervals significantly exceeding the maximum modulation period (1 h) were analyzed. Typical modulation of the carrier frequency emission with periods of 1–60 minutes was persisted in all analyzed cases. The most likely time of observation of the detected effect was in the hours before midnight. It was shown that a decrease in the f_{SE} and its subsequent increase were observed against the background of weak geomagnetic activity and relative stability of the dominant number of solar wind and IMF parameters. Based on the fact that the f_{SE} decreases predominantly near midnight synchronously with a decrease of the auroral activity (the *AE* index value), it can be assumed that in undisturbed geomagnetic conditions, the emission is most likely excited near the polar cusp, and then penetrates into the polar cap region. Presumably, this behavior of the f_{SE} is stimulated by a decrease in the plasma parameter β (equal to the ratio of thermal pressure to magnetic pressure) and the ratio of proton density to helium ion density *Np/Na*, the dynamics of which are similar to the average variation of the *SE* carrier frequency. Apparently, the increase of turbulence solar wind and the proton density decrease compared to the helium ions density affects not only at the flow regime of high-latitude regions of the magnetosphere, but also the variation in the carrier frequency of serpentine emission observed in the region of the polar cap.

GC2024-STP066

On ponderomotive acceleration of heavy ions in magnetospheric plasma

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The problem of ponderomotive separation and acceleration of ions with different charge-to-mass ratios under the influence of Alfvén waves, which permanently exist in the magnetosphere in the form of geomagnetic pulsations, is posed. Formulas are derived for partial ponderomotive forces acting on light and heavy (metal) ions. In the quasi-hydrodynamic approximation, a system of equations is obtained that describes the distribution of ions along magnetic field lines in the Earth's magnetosphere. It was found that the Clarke number, which characterizes the metallicity of the plasma, is maximum at the minimum of the magnetic field on the field line along which the Alfvén wave propagates. The possibility of applying the theory to the analysis of mass spectrometric changes in the chemical composition of space plasma is indicated.

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GC2024-STP067

Multistage time series forecasting algorithm based on machine learning methods used to forecast the state of the earth’s magnetosphere

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The idea of this study is the adaptation and application of a 4-step neural network based algorithm for analyzing multidimensional time series to forecast the occurrence of certain events and to identify their precursors - phenomena represented by an unknown combination of parameter values describing the object [1]. Besides forecasting events, the algorithm can be used to forecast the values of some continuous-valued quantities. In this study, the algorithm was applied to forecast the values of the flux of relativistic electrons with E > 2 MeV in geostationary orbit, as well as the values of Dst and Kp geomagnetic indices. The results were compared by relative error and by the sets of the most significant input features selected by the algorithm.

The developed approach allows for adaptively selecting both physical input features and specific delay values when considering the history of each physical feature within the delay embedding approach. This can provide a better understanding of the processes occurring in the studied object (in this case, the Earth's magnetosphere). The following hourly average values were used as input features for the algorithm:

1. Solar wind (SW) parameters at the Lagrange point L1 between the Earth and the Sun: SW velocity ν (km/s), SW temperature T (K), proton density in SW n (cm^{-3}).

2. Interplanetary magnetic field (IMF) vector parameters at the same point L1 in the GSM system: IMF components Bx, By, Bz, IMF magnitude B_{magn} (nT).

3. Geomagnetic indices: equatorial geomagnetic index Dst (nT), planetary geomagnetic index Kp (dimensionless).

4. Random noise features added to test if the system recognizes them as irrelevant for forecasting the target variable.

The set also included four harmonic variables (two with daily period and two with yearly period) to account for rotation of the Earth around its axis and around the Sun (no delay embedding was used for these variables).

The overall scheme of the 4-step algorithm includes the following steps:

1. Selection of the most significant physical features (variables) among those that, in the researcher’s opinion, may affect the predicted target value. An iterative approach is used for this purpose in the current implementation. Within this approach, the system evaluates the correlation (Pearson/Spearman) between the input feature and its delays and the predicted variable. Then, a portion of variables that will be used further is selected based on a specified threshold.

2. Selection of the range of used delays. The considered sets of the input features were created as follows. Set 0 included the selected input variables at the current time. Set 1 included all input variables from set 0 and also all these variables with the delay of 1 time step. Set 2 included all input variables from set 1 and also all these variables with the delay of 2 time steps, and so on up to the researcher-defined limit. A machine learning model is trained on each set created within this cycle, and its quality is evaluated on a pre-held-out dataset. The cycle stops when, based on a specified criterion, increasing the delay range no longer significantly improves the forecasting accuracy.

3. Selection of the most important input features from the obtained 2D feature space limited during the first two stages. Some of the standard approaches to assessing the importance of input features are suitable for this stage.

4. Model hyperparameter tuning.

It is demonstrated that the considered 4-step algorithm can improve the quality of time series forecasting, as well as it can provide an optimal set of input features that allows one to make conclusions on the main interconnections

among the target forecast variables and the input features.

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GC2024-STP068

Magnetic fields and electric currents around the dayside magnetopause as inferred from large sets of in situ data

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Based on a new mathematical framework and large multi-year pool of satellite data, we reconstruct the magnetic field and electric currents around the dayside magnetopause, as well as their dependence on the IMF, solar wind pressure, and the Earth's dipole tilt. The model is based on representing the magnetosheath and adjacent outer magnetosphere by two separate blocks with essentially different architectures and responses to external drivers. The magnetosheath magnetic field is modeled by a sum of toroidal and poloidal components, each expanded into spherical harmonic series of angular coordinates and powers of the normal distance from the boundary. The outer magnetosphere is represented by a dipole field of variable magnitude confined within a best-fit magnetopause, whose shape, size, and solar wind/IMF control are concurrently derived from in situ magnetometer data. The spacecraft database covers the period from 1995 through 2022 and is composed of data from Geotail, Cluster, Themis, and MMS, with the total number of 1-minute averages about ~2.5M. The modeling reveals orderly patterns of the magnetopause currents and normal field component, controlled by the IMF orientation, solar wind ram pressure, and the Earth's dipole tilt angle. The obtained results are discussed in terms of the magnetosheath magnetic flux pile-up and the subsolar magnetosphere erosion during periods of northward or southward IMF, respectively.

GC2024-STP069

The impact of rotational discontinuities on ions acceleration at the Earth's bow shock

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Superthermal particles, likely accelerated by the first order Fermi mechanism [1], are often observed in the vicinity of the Earth's bow shock. In this study we mainly focus on their interaction with rotational discontinuities frequently crossing the shock. By means of our hybrid kinetic code “Maximus” we built a numerical model of such interaction and found that rotational discontinuities are able to sweep superthermal ions from the foreshock to the downstream region. This can be seen from both spatial distributions and individual trajectories of energetic ions, and is also supported by ARTEMIS and MMS observations. [2]

During the interaction with the shock precursor filled with energetic particles and electromagnetic waves the structure of the rotational discontinuity is altered, and the current inside the current sheet increases, in some cases more than order of magnitude [3]. Also the maximal and mean energy of accelerated particles grow up for some period, as well as total pressure in nonthermal particles. Some time after the discontinuity passage the acceleration efficiency relaxes down to its usual value of about 15% (we define the efficiency as a fraction of the bulk energy going into particles with energy greater than 10 E_{sh}, where E_{sh} is the upstream proton energy). In case when rotational discontinuities come regularly, the Fermi acceleration is boosted continuously, so that the total pressure in nonthermal particles and their maximal energy grows faster than in case of uniform upstream (about 20% of the bulk energy goes into accelerated particles).

We found that for parameters typical for the Earth’s bow shock (the alfven Mach number of order 5 and plasma beta about unity) it is enough for rotational discontinuities to come each 10 minutes to sustain greater ions acceleration efficiency. This period is comparable with what is actually observed [4,5], so we can conclude that upstream rotational discontinuities alter the ion acceleration process and change the thermal/nonthermal pressure balance in the vicinity of the Earth’s bow shock. These results could be also extrapolated for other astrophysical shocks propagating into turbulent medium, as far as turbulence tends to evolve into discontinuities.

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GC2024-STP070

Aurora boundaries during magnetic storm

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Using data on the equatorial boundary position of the polar oval obtained from DMSP satellites for 2010-2014 [1] and the values of solar wind parameters and geomagnetic indices during 29 magnetic storms, occurred during the selected period [2], we analyze the relationship between them. The resulting empirical dependence is compared with the previously obtained dependences on the Dst (SYM/H) and AL indices.

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GC2024-STP071

Geophysical effects caused by the flyby and explosive destruction of the fireball on September 02, 2023

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The geophysical effects caused by the flyby and explosive destruction of the fireball on September 02, 2023 are considered. The fireball appeared upon entry into the Earth's atmosphere with a glow at 17:07:46 UTC and was observed for ~5 s. The main destruction of the cosmic body occurred over the southeastern outskirts of Turkey (approximately above the city of Malatya). According to available video recordings, the flyby was accompanied by three well-defined flares, which are most likely associated with the destruction of the main cosmic body, and then its two largest fragments.

As the initial data in research, we used the data of instrumental observations carried out at the Center for Geophysical Monitoring in Moscow of Sadovsky Institute of Geosphere Dynamics of Russian Academy of Sciences and at the Mikhnevo Geophysical Observatory of the Sadovsky Institute of Geosphere Dynamics of Russian Academy of Sciences, as well as the results of magnetic measurements carried out in a number of INTERMAGNET network observatories actively operating during this period. To describe the response of the ionosphere on the bolide fall, we estimated the critical frequency of the F2 layer on the basis of the analysis of ionograms after the high-frequency sounding of the ionosphere.

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GC2024-STP072

Dynamics of the Earth's high-latitude magnetosphere during a magnetic storm on 02.27.2023

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The Earth's magnetosphere is exposed to the effects of the interplanetary medium. Changes in the parameters of the solar wind and the interplanetary magnetic field lead to geomagnetic disturbances, as a result of which the structure of the magnetic field lines and the dynamics of charged particle fluxes change. The most striking manifestations can be observed in the high-latitude magnetosphere. Charged particle fluxes can serve as a tool for studying the topology of the magnetic field.

24.02 - 25.02.2023 a series of explosive processes were observed on the Sun, as a result of which two solar proton events were recorded in near-Earth space. The coronal mass ejection from 24.02 arrived in near-Earth space on 26.02, the shock wave preceding it was registered at ~18 UT. A strong magnetic storm with |Dst|max~140 nT occurred in the magnetosphere.

The simultaneous presence of different populations of charged particles (solar energetic particles [2], energetic electrons of the outer radiation belt and auroral particles precipitating in the area of the auroral oval [1]) create a unique opportunity to study the structure and dynamics of the high-latitude magnetosphere during a magnetic storm. The results of a study during a magnetic storm on 02.27.2023 of the dynamics of the high-latitude boundaries of the main magnetospheric structures: the penetration regions of solar protons with energies of 1-100 MeV and 3-10 MeV are presented; areas of precipitation of auroral electrons and ions with energies ~30 eV to 30 keV; positions of the capture boundaries and maximum electron fluxes with energies >300 keV and >700 keV of the Earth's outer radiation belt. The work was performed on the basis of experimental data on charged particle fluxes obtained on the low-orbit polar satellites Meteor-M2 and DMSP in the evening and morning sectors local time.

It is found that during the main phase of the magnetic storm, the boundaries of all magnetospheric structures shift to lower latitudes, while a strong morning-evening asymmetry is observed [3]. A stronger boundary shift in the evening sector compared to the morning hours is associated with the development of an asymmetric ring current in the main phase of the storm. During the recovery phase of the magnetic storm, the position of the maxima of the electron fluxes of the outer radiation belt shifts to lower latitudes, and the electron capture boundary of the outer radiation belts shifts to higher latitudes.

The research was carried out within the framework of the scientific program of the National Center for Physics and Mathematics (project "Nuclear and Radiation Physics").

We thank all the researchers who provide their data on proton fluxes and solar wind parameters via the Internet. Experimental data obtained at NASA's Goddard Space Flight Center: on solar wind and interplanetary magnetic in OmniWeb: High Resolution OMNI [http://omniweb.gsfc.nasa.gov/form/omni_min.html]; on solar proton fluxes in CDAWeb: the Coordinated Data Analysis Web.

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GC2024-STP073

The response of the ionosphere and upper atmosphere to the energetic particles precipitation.

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The Earth's magnetosphere is a complex structure that is determined by both internal and external processes (mainly in the Sun), and the influence of which can be traced on the Earth's surface. The upper atmosphere and ionosphere continuously interact with each other, especially in the polar regions. Energetic particles are influenced by the Earth's magnetosphere, reaching the dense layers of the atmosphere, they spill out. This process is known as energetic particle precipitation (EPP). These particles are an additional source of atmospheric ionization (in addition to direct exposure to solar radiation), which is essential during periods, for example, the polar night, since EPP is the only source of atmospheric ionization. Such additional ionization triggers chains of chemical reactions that can lead to strong changes both in the chemical composition of the atmosphere and in the electron concentration in the ionosphere (layers D and E).

In this study, using a one-dimensional radiative-convective photochemical model with interactive neutral and ion chemistry, we followed the effects of EPP on the polar atmosphere during some of the most intense events. We have obtained the results not only of changes in the chemical composition of the atmosphere, including ozone, but also the electronic concentration in the D and E layers.

GC2024-STP074

Features of energetic electron precipitation of different mechanisms from the outer radiation belt during geomagnetic disturbances

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The mechanisms of energetic electron precipitation from the Earth's outer radiation belt are one of the important problems of modern cosmophysics. Using data from the Meteor-M2 low-orbit polar satellite, several periods of intense geomagnetic and auroral activity, which contributes to effective pitch-angle scattering and particle loss in the atmosphere, have been investigated for precipitation. Different magnetic storms (periods of geomagnetic activity) were taken in order to see the general dynamics of precipitation intensity. It was obtained that the precipitation intensity in all considered cases correlates with the auroral activity (the maximum intensity corresponds to the maximum of auroral activity), but not with the phases of the magnetic storm.

MLT-L circular diagrams of the distribution of 0.1 MeV electron precipitation for different time intervals during the magnetic storm were obtained for the event 5-23.11.2015. The same diagrams were obtained for L*, which were calculated by the paraboloid model A2000. POES satellites data were also used for this task.

For the event 9-16.10.2017, the particle losses in the atmosphere caused by different mechanisms were considered in detail separately. Most of the electron precipitation events that occurred during this period could be classified and correlated with a certain cause of occurrence. For this purpose, multi-satellite observations, wave activity data, and a priori knowledge of the distinctive features of precipitation mechanisms were used. A comparative analysis of precipitation of different mechanisms was carried out - the intensity dynamics and the energy spectrum. The results of this comparison showed that the particle losses produced by different causes have specific spectral features determined by the nature of the precipitation mechanism. Precipitation events of the same nature have their own characteristic shape of the spectrum. Geomagnetic activity changes only the intensity of these precipitation events.

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GC2024-STP075

PFO-CFO Theory of Solar System Formation and Transformation: Foundation, method, explanations, proofs, and predictions

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Rutherford and Soddy were the first (1903) to assume that the thermal and light emission from stars is the result of radiation-chemical reactions (RCRs), and no unequivocal proof of thermonuclear processes in the Sun exist up to now. The PFO-CFO Theory of Solar System Formation and Transformation (the Theory) explains the solar energy and all solar manifestations by the RCRs occurring in the Sun and its vicinities.

It will be shown that Hubble's data prove the multiplicity of star formation periods rather than the linear relationship between the distances to galaxies and the radial velocities of the lasts. The Fridman’s solution of the tensor equation is incorrect for intergalactic distances because it doesn’t consider the gravitation-field variations with the distance in so large space. Thus, the Big Bang notion has no grounds. The well-known unpublished Einstein’s paper of 1931 showed that its author disbelieved the Big Bang theory. Poincaré, Lorentz, Nernst (and others) denied the space emptiness, underlying the Big Bang theory. The results of the Webb Space Telescope (WST) flight and its photos induce deep doubts in this theory.

Our Theory has been developed since 2007. Its fragments were published repeatedly and were presented in 16 reports and lectures at conferences in RF, Armenia, Belgium, France, Germany, Italy, Netherlands, Portugal, Spain, and UK. In the most complete form, the Theory was stated in the presentation of our lecture given in Amsterdam (2019) and in the article of 2017. As the Theory was progressed, it was presented in the article of 2011 and in the conference papers of 2008-2023 (see our ResearchGate pages).

This report summarizes our publications with corrections and additions that consider the available data obtained in the period since the statement of the basic principles of the Theory.

The name of the Theory reflects its central ideas: (1) the cold celestial objects composed of light atoms and molecules are formed by the physical processes of condensation, phisadsorption and absorption, aggregation, etc. and represent **p**hysically **f**ormed **o**bjects (**PFO**), while warm celestial objects composed of heavier molecules are formed by chemical processes and represent **c**hemically **f**ormed **o**bjects (**CFO**); (2) the Sun is the source of all atoms for the Solar System (SS).

When formulating the Theory, we use no models and no equations with fitted constants.

Conclusions of the Theory are consistent with the photos made by the WST.

The Theory not only confirms the Rutherford and Soddy's view that the thermal and light emission from stars is the result of RCRs, but it first explains the mechanism of formation of each known isotope and isotopic anomalies in the SS, causes of each of the nine most catastrophic mass extinctions of terrestrial flora and fauna, fundamental differences between the SS planets, the emergence of protuberances and their composition, temperature changes from sunspots to photosphere and to corona, inexplosibility of the Sun by protuberances, periodicity of solar cycles, compatibility of protuberances with sunspots, acceleration of protuberances in flight and their multi-jet composition, occurrence of protuberances of different shapes, origin of the recent giant protuberances on a small star (red dwarf DG CVn, 2014), etc. The Theory explains the current climate warming and predicts other dangers that the Sun may present to people in the future.

We use an original methodology, based, oddly enough, on the use of data on the radiation-chemical decays of radioactive isotopes, to understand the paths of origin of each isotope in stars and their surroundings and, much more, to understand the chronology of the origin of each isotope in nature, although such a possibility may seem like science fiction. And on top of that, we will present natural evidence of the correctness of our conclusions.

GC2024-STP076

The structure of Hat-P-32b upper atmosphere and transit absorptions in metastable helium line

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The atmospheres of hot exoplanets undergo intense mass loss being exposed to extreme flux of ionizing radiation of the host stars. The processes of evaporation of primary atmospheres have been observed in Lyα line transit absorption for a number of exoplanets [1-3]. However, the information obtained by space telescopes from Lyα spectroscopy is limited due extinction in interstellar medium and geocoronal contamination. Thus, transit observations in other lines are needed to explore physical processes in exoplanetary atmospheres. The metastable helium HeI(2^3S) line at 10830 Å offers an alternative way to probe the evaporating exoplanetary atmospheres [4]. Since the first observation in 2018, for more than a dozen exoplanets positive detections have been made by ground telescopes [5].

One of the interesting targets related to HeI(2^3S) is the highly inflated atmosphere of Hat-P-32b. Hat-P-32b is an exoplanet transiting the moderately bright F/G star which is known to be very active [6]. The planet is quite fluffy with the mass of 0.73 Mj at radius of 1.79 Rj. Infrared observations in helium and Hα hydrogen lines [7] revealed intense escape of planetary material, possibly forming broad downstream and upstream outflows [8].

This work sheds light on the processes populating the HeI metastable level and spatial structure of absorption by upper atmosphere of Hat-P-32b. We use 3D global hydrodynamic multi-fluid model [9] which takes into account the plasma-photochemistry to reproduce the transit absorptions in 10830 A line and to obtain the best fit to the observational data available for Hat-P-32b. We found out that in spite of the absorption is located mainly at heights 0.1<r<1 Rp it can reflects the streams of planetary outflow beyond the Roche lobe.

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Forced atmospheric-ionospheric effects by precipitation of energetic electrons during a magnetic storm on October, 2017

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Energetic Electron Precipitation (EEP) during geomagnetic disturbances in the period October 10-16, 2017 were associated with different physical mechanisms, which were studied separately. The EEP were detected using balloon observations near Apatity and low-orbiting satellites such as Meteor-M2 and NOAA POES. According to satellite measurements, the precipitation covers a large latitude-longitudinal region in two hemispheres. To reconstruct the energy spectra, satellite energy channels from tens of keV to MeV were used.

To determine the atmospheric-ionospheric response and changes in ozone during precipitation of energetic electrons over the studied period of time, we used calculated ionization rates based on spectra obtained both from satellites and during balloon observations, which were used in a one-dimensional radiation-convective photochemical model with interactive neutral and ionic chemistry. The EEP was supposed to last for several hours. It was found that the greatest contribution to ozone destruction is made by EEP associated with the violation of the first adiabatic invariant, and with EEP associated with EMIC waves, ozone destruction will be minimal. Precipitations associated with violation of the first adiabatic invariant can lead to ozone destruction up to 70%. In all cases, the change in ozone lasts throughout the day, and the next day the ozone is restored to its previous level.

Despite the small amount of ozone in the mesosphere compared to the stratosphere, the study of ozone variations under the influence of solar and cosmic forcing is one of the priority tasks that determines the natural forcing of the atmosphere and climate.

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Hysteresis cycles and invariance of the *Dst* index form during geomagnetic storm development

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The results of a study of the relationship between the *Dst* index and heliosphere parameters during 933 isolated geomagnetic storms development presented in this work. We used the catalog of geomagnetic storms for the period 1964-2010, presented on the website of the World Data Center for Solar-Terrestrial Physics, Moscow (http://www.wdcb.ru/stp/geomag/geomagnetic_storms.ru.html) and hourly average data of solar wind plasma parameters, IMF and *Dst* index for the same period from the OMNI database (https://spdf.gsfc.nasa.gov/pub/data/omni/low_res_omni/) as initial data. For the analysis, we used hourly data of the *Dst* index and heliosphere parameters obtained by the epoch superposition method on a time interval covering the average duration of the initial, main phases of the storm and the recovery phase (168 hours from the moment the storms onset). It was shown that the trajectory of the *Dst* index change depending on the solar wind plasma parameter β and the IMF *Bz* component during the main phase of the storm does not coincide with its trajectory during the recovery phase, which is a typical feature of the hysteresis phenomenon. The dependences *Dst*(β) and *Dst*(*Bz*) have the shape of a hysteresis loop for storms with both sudden and gradual onset. It was shown that the *Dst* index forms hysteresis loops with other solar wind parameters at time intervals of geomagnetic storms development. The obtained dependencies indicate a lag in changes in magnetospheric disturbance during storms relative to heliospheric parameters and a nonlinear relationship between the *Dst* index and heliospheric parameters. In addition, it was noted that the shape of the averaged dynamics of the *Dst* index during the storms development does not depend on their intensity, i.e. is an invariant. A invariant behavior is characteristic of the shape of the averaged dynamics as well of the parameter β and the IMF *Bz* component during the magnetic storms development. Based on the nonlinear relationship of the *Dst* index with interplanetary parameters and the invariance of the *Dst* index shape, an integral Volterra-type equation is proposed to describe the dependence of the *Dst* index on solar wind parameters. The approach using integral equations provides an adequate description of the results obtained during the experimental study of hysteresis effects associated with phase shifts between changes in the *Dst* index and heliosphere parameters.

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Spatial-energy dependencies of maximum electron fluxes of the outer radiation belt during geomagnetic activity

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The Earth’s outer radiation belt (EORB) is highly dynamical domain in the

magnetosphere. The most significant changes of the outer radiation belt are influenced by solar wind and accompanied by geomagnetic disturbances. During such events strong variations of the energetic electron fluxes by several orders of magnitude can be observed. The outer radiation belt spatial parameters like EORB maximum or its high latitude boundary are also changed.

Dynamical changes of trapped (in the orbit of the Van Allen Probes A spacecraft) and quasi-trapped (in the low polar orbit of the Meteor M2 satellite) EORB electron fluxes were studied at different phases of geomagnetic storms of different intensities. The temporal and spatial profiles of electron fluxes in different energetic ranges (>0.1, >0.7 and >2 MeV) were reconstructed from satellites measurements obtained during several radiation belt crossings.

It was found, that spatial location of the electron flux maxima and its dynamics depends on particle energy. During 10-16.10.2017 event a similarity was obtained in the dynamics of particle fluxes of the corresponding energies for two satellites. In the main phase of the storm, the lower-energy particle fluxes (E> 0.1 MeV) increased in the main phase of the storm and remain approximately constant. High-energy particle fluxes (E> 0.7 MeV and E> 2 MeV) dropped in the main phase of the storm and increased in the recovery phase. It was shown, that ongoing substorms produce VLF chorus waves and accelerate energetic electrons to higher energies, leading to an increase in particle fluxes of relativistic and subrelativistic energies. The new radiation belt maximum is formed at L about 4.8 during magnetic storm recovery. There exists a time delay in its formation for particles of different energies.

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Quasi-periodic fast propagating wave trains as a seismological tool for plasma structures in the solar corona

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The quasi-periodic fast propagating wave trains (QFP) – the recently discovered phenomenon of the solar coronal seismology – were first formalized as the fast magnetohydrodynamic waves propagating along magnetic waveguides forming the solar corona. Such waves modulate plasma parameters in the waveguide, and the time evolution of the modulation is characterized with a specific (“tadpole”) form of the wavelet spectrum [1]. Modulation of both plasma density and magnetic field leads to modulation of the emission from the waveguide in different bands of the electromagnetic spectrum. In the talk, the QFP are discussed as a seismological tool for diagnostics of the coronal waveguides, including those open into the interplanetary space, based on the data in extreme ultraviolet and radio bands.

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UV-microbursts of atmospheric emission in auroral zone

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The Pulsating Aurora Imaging System (PAIPS) is being deployed at the Kola peninsula (Klimov et al., 2022) and is aimed to conduct stereo measurements of pulsating aurora (PsA) with high temporal resolution (1 ms). Photometers are lens telescopes using multi-anode PMTs as a photosensors operating in a single photon-counting mode, which provides extremely high sensitivity of the detectors.

In this work we present the results of the search and analysis of the fastest emissions measured in a form of UV-microbursts. These events were found in data of the imaging photometer at the Verkhnetulomsky observatory during 2021–2023. UV-microbursts are observed at various geomagnetic activity conditions from quite (average K_P index is 1+) to moderate (K_P = 4+) during the substorm recovery phase.

UV-microbursts are measured in various observational conditions: clouds, transparent clouds and clear sky. The temporal structure of UV-microbursts does not depend on cloud presence. Spatial structure of the events may vary from event to event: from a uniform diffuse glow to individual local spots in the FOV of the photometer. Microbursts are measured in series with a duration from 10 s to ~1 hour. Each pulse has a complicated structure with a single time sample (41 ms) high intensity peak and a subsequent prolonged afterglow. Time interval between pulses is not constant and varies in a range between 100 ms and 5 s. The typical amplitude is around 10^4–10^5 photon/cm^2 sr s.

Some UV-microbursts were measured simultaneously with pulsating aurora and represent a series of short (less than 0.5 s) pulses of emission with an angular size of bright spot ~0.2 rad. Simultaneous measurements of high-energy electron fluxes by Meteor-M2 and NOAA-19 satellites were analysed.

The probable source of UV-microbursts are relativistic electron microbursts (REMs), which are observed in satellite experiments (SAMPEX, for example) at the same geomagnetic latitudes and have similar temporal characteristics. Satellite electron detectors as well as balloon-born X-ray measurements demonstrate that REM appear as clusters or series of sharp peaks. The same is observed in the PAIPS photometer. This demonstrates that fundamental questions of magnetospheric physics, such as mechanisms of formation and losses of radiation belts, especially in a subsecond temporal scale, can be addressed by using the optical measurements by sensitive photometers with high temporal resolution.

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Geomagnetic conditions during UV-microbursts measurements by PAIPS photometer

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During 3 seasons of PAIPS (Pulsating Aurora Imaging System) photometer at Verkhnetulomsky observatory operation a number of events which represent a series of sort bright bursts in a 300-400 nm wavelength range (UV-microbursts) was measured. It is a most transient form of auroral emission which can be caused by high-energy electrons microbursts precipitation. UV-microbursts series duration ranges from 10 s to ~1 hour. Time interval between pulses is not constant and varies in a range between 100 ms and 5 s. The typical amplitude is around 10^4–10^5 photon/cm^2 sr s.

To clarify the origin of UV-microbursts analyses of geomagnetic conditions was done. It was shown that in most cases UV-microbursts are observed during weakly disturbed geomagnetic conditions (average K_P index is 1+) at evening sector of MLT. These events associated with the weak geomagnetic storm recovery phase (Sym-H index about 100 nT).

Two events (21.11.2021 and 23.02.2023) occurred in morning MLT sector during the substorms recovery phase. For these events the detailed analyses of geomagnetic disturbances were studied. Global structure of field-aligned currents was reconstructed using AMPERE magnetic perturbation data. Ionospheric equivalent currents calculated by ground magnetometers of IMAGE (International Monitor for Auroral Geomagnetic Effects) network were analyzed. Local variations of magnetic field were measured by a magnetometer at Verkhnetulomsky observatory and demonstrated simultaneous sharp fluctuations of geomagnetic field with UV-microbursts.

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