RUSSIAN ACADEMY OF SCIENCES

NATIONAL GEOPHYSICAL COMMITTEE

РОССИЙСКАЯ АКАДЕМИЯ НАУК

НАЦИОНАЛЬНЫЙ ГЕОФИЗИЧЕСКИЙ КОМИТЕТ

NATIONAL REPORT

for the
International Association of
Geomagnetism and Aeronomy
of the
International Union of Geodesy and Geophysics
2015–2018

НАЦИОНАЛЬНЫЙ ОТЧЕТ

для
Международной ассоциации
геомагнетизма и аэрономии
Международного
геодезического и геофизического союза
2015–2018

Москва 2019 Moscow

**Presented to the XXVII General Assembly
of the
International Union of Geodesy and Geophysics**

**К XXVII Генеральной ассамблее
Международного геодезического и геофизического
союза**

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The Report is prepared by the Section of Geomagnetism and Aeronomy of the National Geophysical Committee of Russia to the XXVII General Assembly of the International Union of Geodesy and Geophysics. Some main results of the researches of Russian scientists in 2015–2018 are presented by the authors as short reports.

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Institute of Cosmophysical Research and Radio Wave Propagation, Far Eastern Branch of RAS (Paratunka, Kamchatskiy Krai);
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Foreword

This report containing a review of the most important and scientific results and activities in 2015–2018 in Russia has been compiled for the presentation to the International Association of Geomagnetism and Aeronomy at the XXVII General Assembly of IUGG.

There are five sections in the report according to the IAGA Divisions I–V. The preparation of this report has been organized by the Section of Geomagnetism and Aeronomy of the National Geophysical Committee of Russia as a collective effort of the team of authors. Only minimal editorial work has been done when putting all these parts together, preserving, thus the diversity in styles and approaches.

The report cannot be considered as a fully comprehensive review of all the achievements during 2015–2018 in these fields of science in Russia. The approach to the choice of the material to be published included some arbitrariness, and some important results are not mentioned at all, so the resultative report is quite far from being complete. Nevertheless, bearing in mind all these circumstances we hope that the readers who are interested in these fields of science (according to the IAGA Divisions I–V) can find useful information in this report.

Conference Activity

Selected conferences in Russia

The major local and international conferences on IAGA subjects in Russia for the period 2015–2018 are listed below.

- International conference "Data Intensive System Analysis for Geohazard Studies, 2016, Sochi region, Mountain cluster (http://sochi2016.gcras.ru/)
- 4th all-Russian conference with international participation "Trigger effects in geosystems", 2017, Moscow (https://agora.guru.ru/display.php?conf=conf_idg_ras-2017)
- International CODATA conference "Global Challenges and Data-Driven Science", 2017, Saint Petersburg (http://codata2017.gcras.ru/)
- Second VarSITI General Symposium – VarSITI-2017, 2017 Irkutsk (http://varsiti2017.iszf.irk.ru/)
- Second Russian Conference on Magnetohydrodynamics, 2018, Perm (https://rmhd2018.icmm.ru/)
- Annual Seminar "Physics of Auroral Phenomena" (http://pgia.ru/seminar/)
- Annual conference "Plasma Physics in the solar system", 2015–2018, Moscow, (http://plasma2015.cosmos.ru/ http://plasma2016.cosmos.ru/ http://plasma2017.cosmos.ru/ http://plasma2018.cosmos.ru/)
- 44th Session of the D.G. Uspensky International Seminar "Issues of theory and practice of geological interpretation of gravitational, magnetic and electric fields", 2017, Moscow (http://www.ifz.ru/uspenskij/)
- 32nd IUGG Conference on Mathematical Geophysics, 2018, Nizhny Novgorod (http://cmg2018.iapras.ru/)

Participation in main international conferences

- 26th General Assembly of the International Union of Geodesy and Geophysics, 2015, Prague, Czech Republic (https://www.iugg2015prague.com/)
- Global Data Activities for the Study of Solar-Terrestrial Variability, 2017, Tokyo, Japan (https://codata.org/blog/2015/10/15/global-data-activities-for-the-study-of-solar-terrestrial-variability/)
- Joint IAPSO–IAMAS–IAGA Assembly “Good Hope for Earth Sciences”, 2017, Cape Town, South Africa (http://www.iapso-iamas-iaga2017.com/)
- Annual AGU Fall Meetings, 2015, 2016 San Francisco CA; 2017, 2018 New Orleans LA (https://meetings.agu.org/meeting-archive/)

Public activity

Meeting of the Commission of the Ministry of Education and Science of the Russian Federation on the fulfillment of the Federal Targeted Programme for R&D in Priority Areas of Development of the Russian Scientific and Technological Complex for 2014–2020 (19.04.2017). Anatoly Soloviev's report on the final stage of the project "Development of innovative technology and creation of experimental sample of hardware-software complex for monitoring extreme geomagnetic phenomena using terrestrial and satellite data" carried out under the agreement No. 14.607.21.0058 of September 22, 2014.

A.A. Soloviev included in the Personnel Commission of the Presidential Council for Science and Education of the Russian Federation. (23.11.2017)

First meeting of the National Committee on the International Future Earth Program at the Presidium of the Russian Academy of Sciences was held at the Institute of Geography of the Russian Academy of Sciences (24.10.2018)

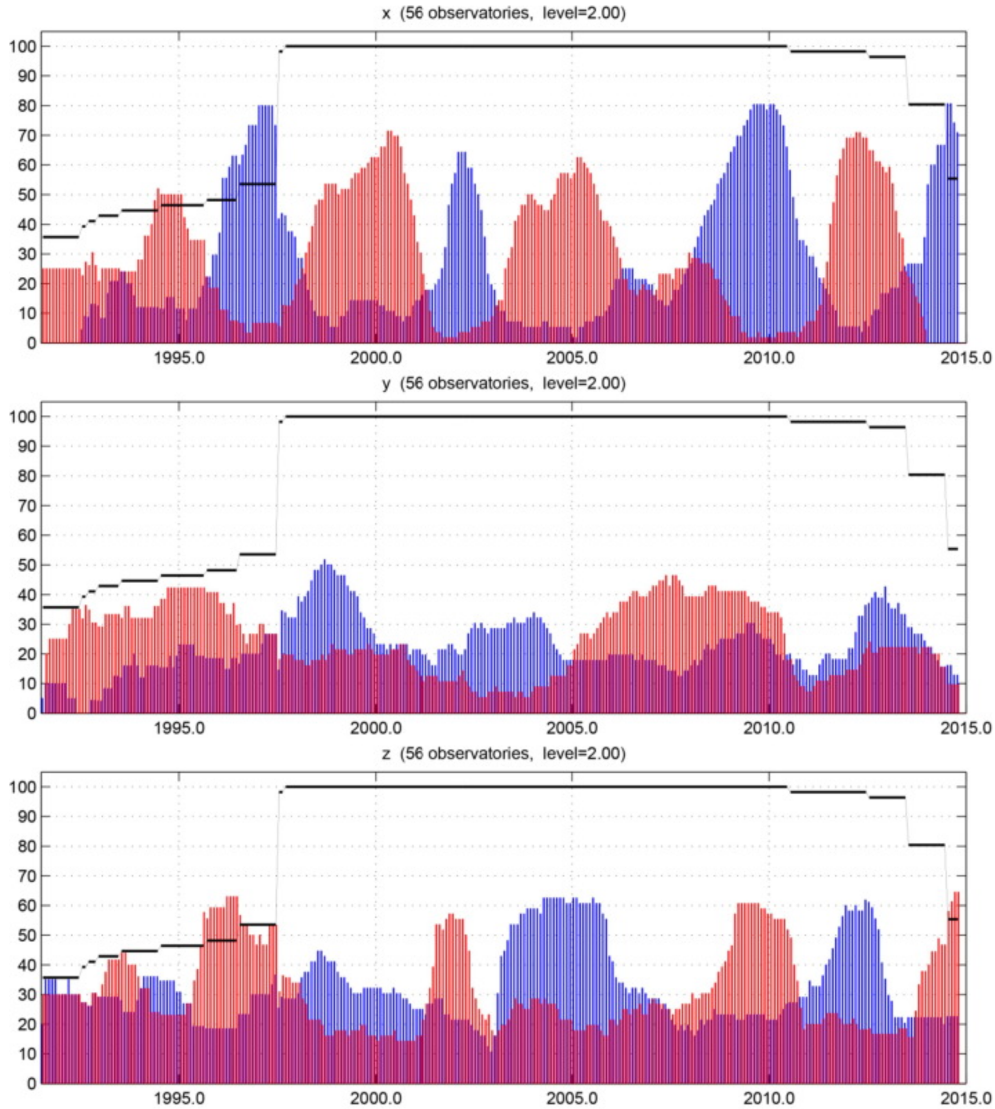
Annual General Meeting of Professors of the Russian Academy of Sciences (28.11.2018)

A.A. Soloviev's report on aspects of the study of the Earth's magnetic field, presented at the 47th Lomonosov Readings, Arkhangelsk, Russia, 29.11.2018, heads of leading scientific institutes of the Russian Academy of Sciences, deputies of the State Duma of the Russian Federation, members of the Council for Science and Education under the President of the Russian Federation participated in the Readings.

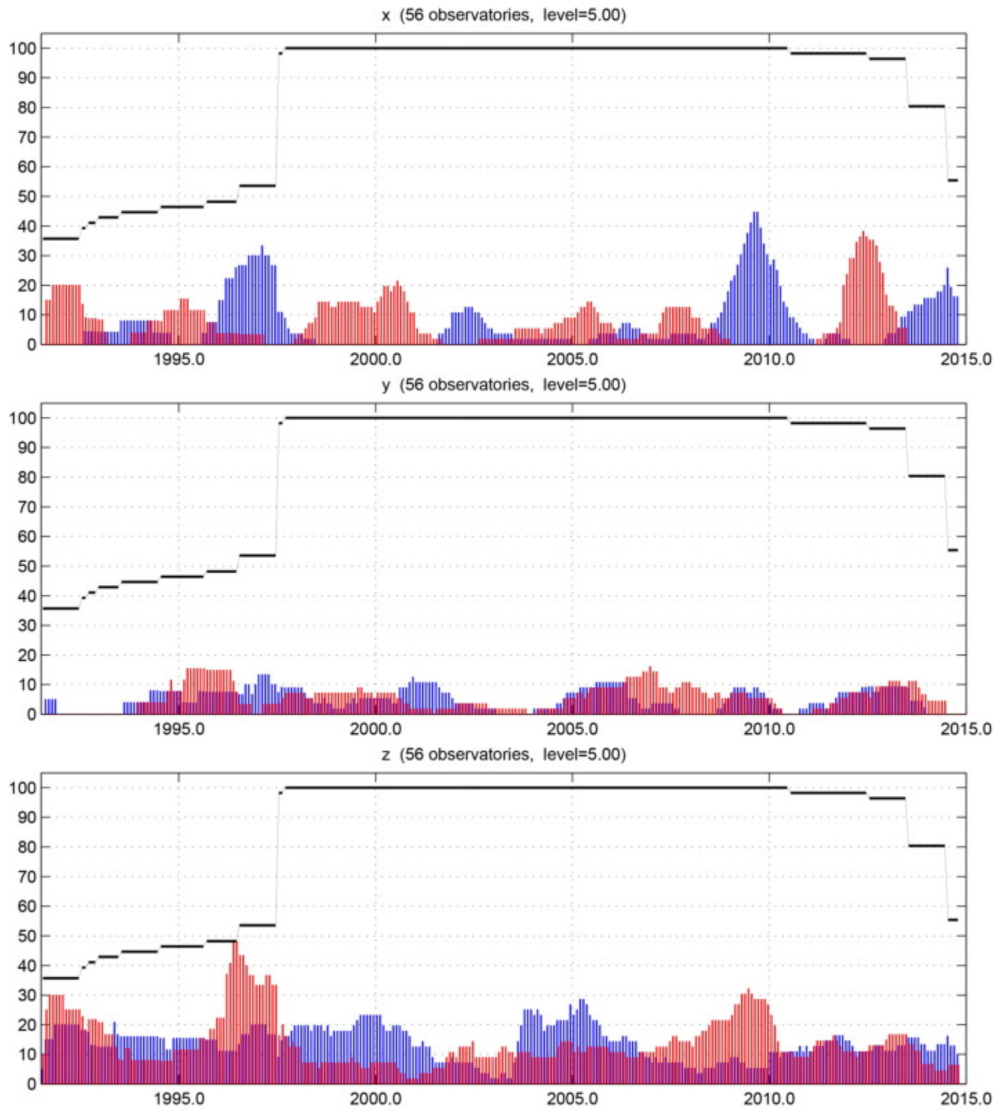
Major scientific results

Detection of secular acceleration pulses using geomagnetic observatory data

The method of secular variation modeling and recognition of secular acceleration pulses has been proposed. It relies on a new technique of processing time series based on fuzzy mathematics. Comparison with the secular variation modeling results derived from satellite data shows their high conformity with the proposed method. Stability and reliability of the secular acceleration pulse recognition are demonstrated by the examples of well-studied secular acceleration pulses in 2006, 2009 and 2012. Moreover, several new secular acceleration pulses around 1996, 1999, 2002 and 2014 are discovered as a result of the new approach application to multi-observatory data analysis. The latter provides a basis for applying the method to older historical data and investigate secular acceleration pulses and geomagnetic jerks further back in time.



(a)



(b)

Characteristic functions for d2X/yr2 (top), d2Y/yr2 (middle) and d2Z/yr2 (bottom) records with A = 2 nT/yr2 (a) and A = 5 nT/yr2 (b) based on a global set of 56 observatories. Blue, resp. red bars show monthly percentage of observatories where d2B/dt2 < –A, resp. d2B/dt2 > A among the available ones; black polyline represents percentage of available observatories per month. Characteristic function peaks near previously detected 2006, 2009 and 2012 SA pulses; peaks near 1996.5, 1999.5, 2002.5 and 2014.5 suggest newly detected SA pulses. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

A.Soloviev, A.Chulliat, S.Bogoutdinov (2017), Detection of secular acceleration pulses from observatory data, Physics of the Earth and Planetary Interiors, 270 (2017), p. 128–142, DOI: 10.1016/j.pepi.2017.07.005.

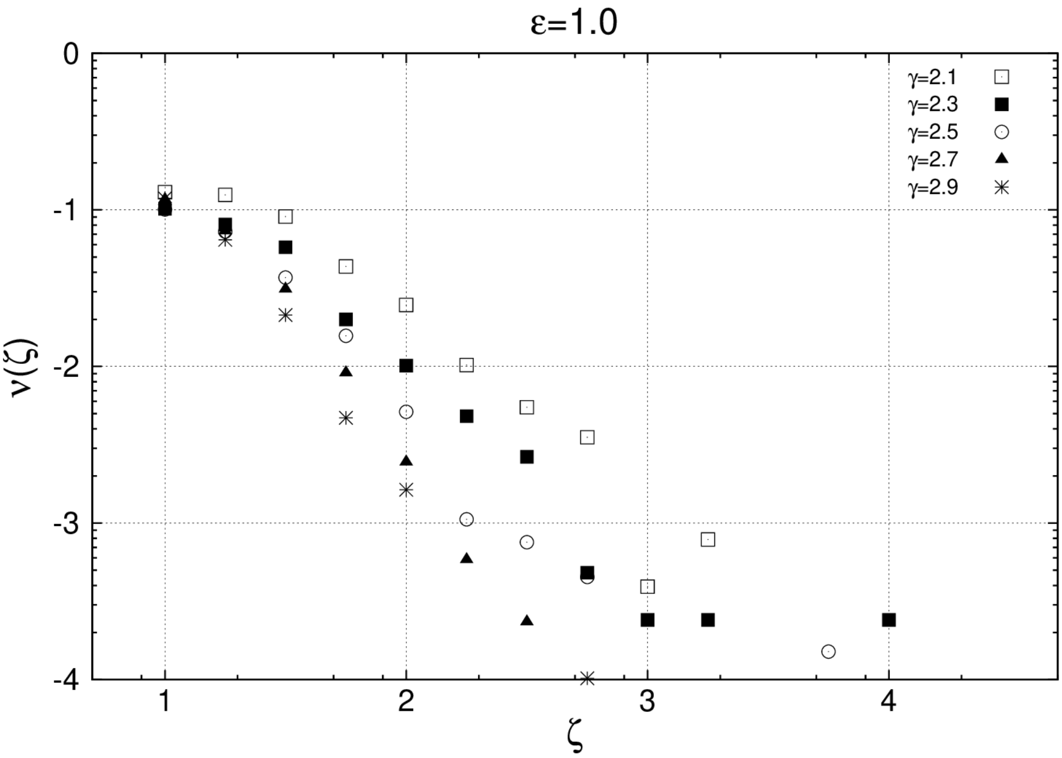
Fractal polarity scale and power-law distributions of wating time of reversals in αΩ-dynamo model

The geomagnetic polarity scale is characterized by the absence of standard reversal wait time and by the self-similarity on various timescales. A αΩ-dynamo model with stochastic memory has been developed, in which two important properties of the geomagnetic polarity scale are realized:

- the length of the polarity intervals is distributed according to a power-law;
- the polarity scale is a fractal and its dimension is approximate to the dimension of the real paleomagnetic scale.

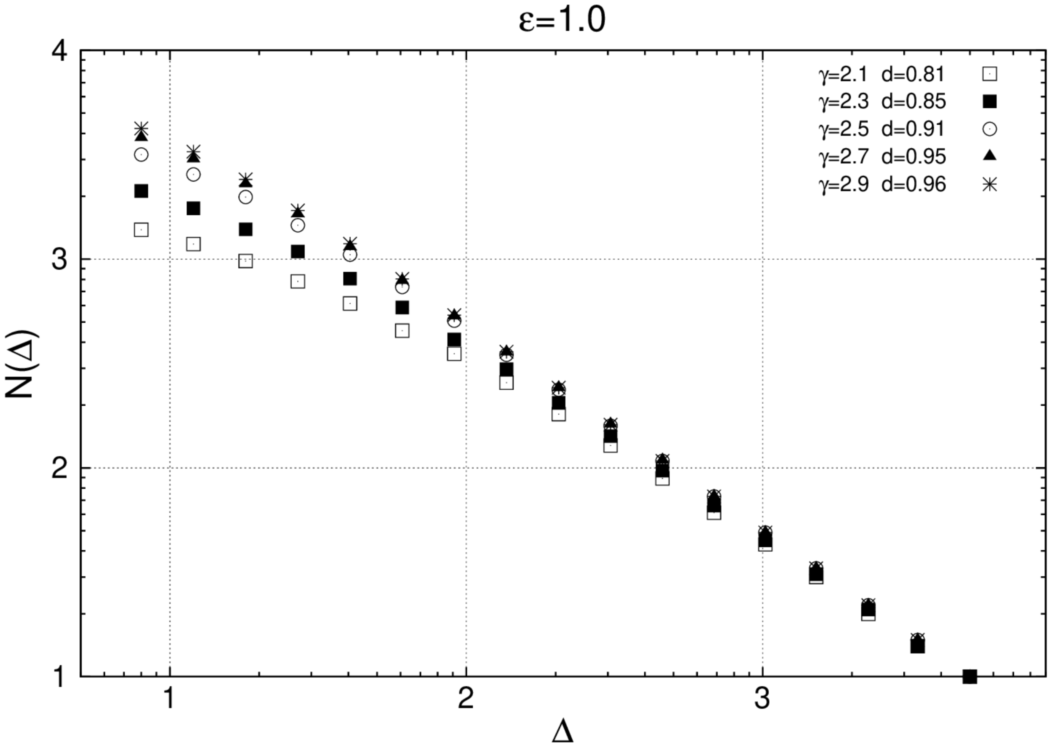
The model contains one toroidal and one poloidal modes, and the magnitude of the α-effect is perturbed by the stochastic sequence of pulses. The appearance of pulses is interpreted as the result of the formation of coherent structures from small-scale modes. The waiting time of the pulses is distributed in the model according to a power law. The exponent γ of this distribution is the main control parameter of the model. The non-Markov character of the pulse sequence implements stochastic memory in the system.

The waiting time for reversals is distributed according to a power law with an exponent from 1.04 to 1.91 for varies γ values.



Distribution of relative frequencies of polarity intervals with the length ζ

The Hausdorff dimension of the polarity scale was calculated. With different gammas, it turned out to be less than 1 (from 0.81 to 0.96), which is a sign of a fractal. Note that, Hausdorff dimensions for real geomagnetic polarity timescales for 170 Myr, 560 Myr, and 1700 Myr are 0.88, 0.83, and 0.87, respectively.

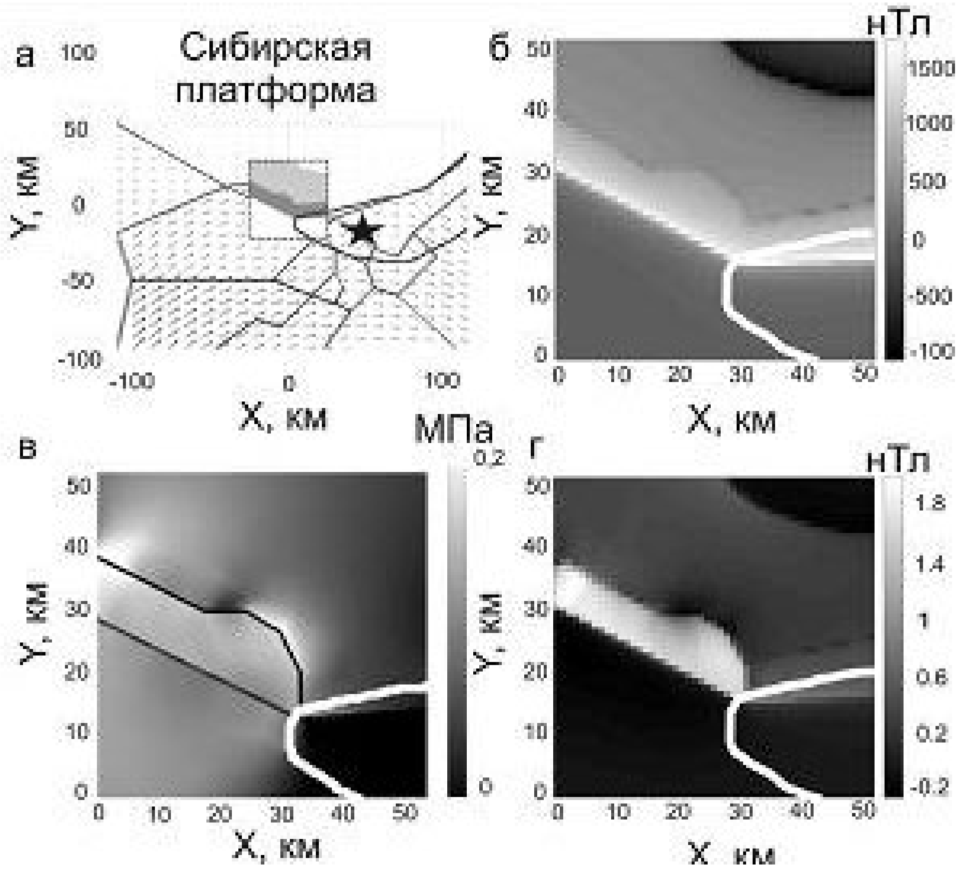


Number of N(Δ) intervals of Δ length, which contain at least one reversal. The slope of the line corresponds to the Hausdorff dimension of the polarity scale.

L. K. Feschenko and G. M. Vodinchar. Reversals in the large-scale αΩ-dynamo with memory // Nonlin. Processes Geophys., 22, 361–369, 2015 DOI: 10.5194/npg-22-361-2015

Tectomagnetic studies in the Baikal and Altai regions

The Laboratory of Natural Geophysical Fields of IPGG SB RAS conducted tecto-magnetic studies in the Baikal and Altai regions. Tectonomagnetic monitoring allows us to study the nature of changes in the stress state in the crust. Interpretation of data based on the magnetoelastic model revealed a period of stabilization of the stress state at the Sayanskhimplast fault for 3 years before the 8th Kultuk earthquake (July 27, 2008, M = 6.3) and a decrease in the tangential stresses after it. According to high-precision annual magnetic observations on a network of 45 points on an area of 120 by 120 km. In Gorny Altai, a model of a century variation for the period 2004–2018 has been built. The model is necessary to take into account the secular variation in tectonomagnetic studies. Comparison of the obtained model with the results of calculations using the IGRF-12 model showed a good agreement of the models with a maximum discrepancy of 2 nT during this period.



The magnetoelastic model of the southwestern end of the Baikal Basin and calculations of tecto-magnetic anomalies: a – a diagram of the block structure (dark lines) and displacement of the earth's crust according to GPS observations for 1994–2007. (arrows); in the center is the Kultuk area of the Baikal tectonic and magnetic network, for which a 3D magnetoelastic model has been developed. Light gray and dark gray are areas with different magnetic susceptibility values of 5 × 10^{-2} SI and 4 × 10^{-2} SI, respectively. The asterisk is the epicenter of the 2008 Kultuk earthquake, M = 6.3; b – anomalous magnetic field (module of magnetic induction vector); в – changes in maximum tangential stresses at a depth of 5 km; d – tectomagnetic anomalies caused by changes in the components of the stress tensor

Dyadkov, Peter & V. Tsibizov, L & Kozlova, M & V. Levicheva, A. Magnetoelastic model of the Earth's crust for the western termination of the South Baikal basin // Mining Informational and Analytical Bulletin. 2017. S36. 3–10. DOI: 10.25018/0236-1493-2017-12-36-3-10.

Earth's magnetic moment studies

In 2015–2018, work continued on analyzing changes in the Earth's magnetic moment based on the calculation of the local magnetic constant in various regions. The data of magnetic observatories, translated into coordinates of corresponding virtual magnetic poles, shows surprising mobility of the magnetic poles, which sometimes develop ultra-sonic speed. The trajectory of the magnetic poles both in calm time and during magnetic calamities is not a chaotic movement but a series of "loops" of varying shapes and sizes. The differences in identified locations of the virtual magnetic poles, produced by each magnetic observatory, depend in addition to the level of disturbance of the magnetic field, on the proximity of each observatory to the true magnetic pole. These differences can be between 5–10 km and 200–300 km of the arc of the great circle a day.

Semakov N.N., Grigorevskaya A.V., Kovalev A.A., Pavlov A.F., Fedotova O.I. "Supersonic" magnetic poles // Geoinformatics Research Papers: Proceedings of the Geophysical Center RAS. – 2016. – V. 4. – № 2. – P. 102–102. DOI: 10.2205/2016BS08Sochi

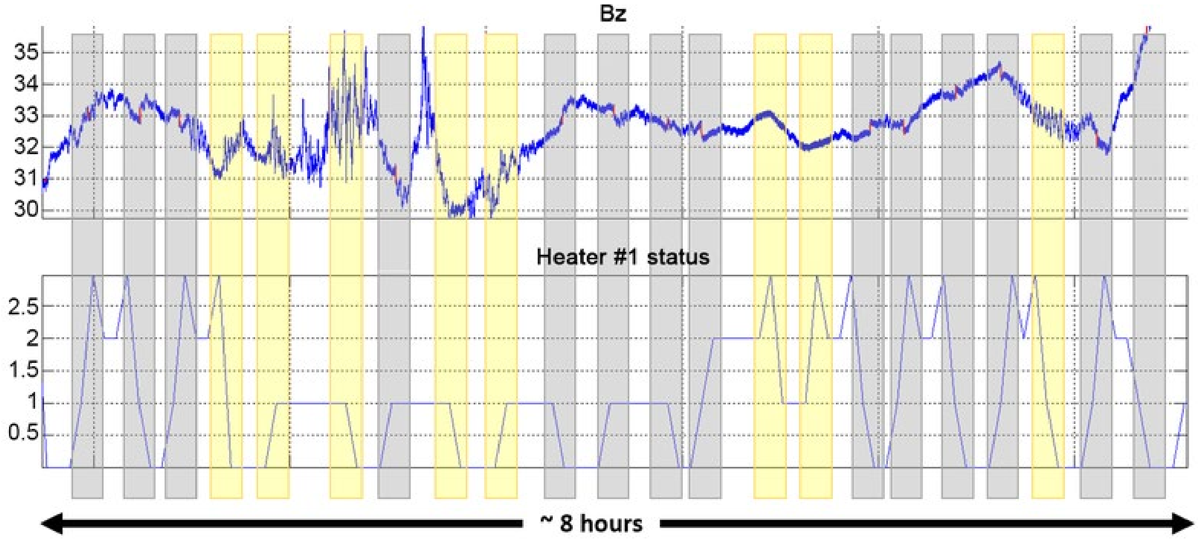
The study of the geomagnetic disturbance impact on the trajectory of the directional drilling in the Arctic region

Using the methods used to calculate the actual borehole profile, model estimates were made of the effect of sporadic disturbances of magnetic declination observed during a magnetic storm on October 28–31, 2003, on the displacement azimuth and intensity of the curvature of the drilling trajectory in given locations at the location of two high-latitude magnetic observatories. It is shown that if geomagnetic disturbances are not filtered out on the basis of data from parallel observatory observations, they can lead to unacceptably large errors in borehole inclinometric measurements and deviation of the trajectory of the trunk by an amount exceeding the permissible values.

Gvishiani A.D., Lukianova R.Y. Estimating the influence of geomagnetic disturbances on the trajectory of the directional drilling of deep wells in the Arctic region. Izvestiya, Physics of the Solid Earth. 2018. Vol.54.No 4P.554–564.DO1: 10.1134/ S1069351318020055

Automated recognition of artificial disturbances in satellite geomagnetic data

In 2018, the work on recognition of the artificial dustirbances in geomagnetic data records using the discrete mathematical analysis (DMA) approach continued. One of the applications of DMA is related to the analysis of data registered by the Geostationary Operational Environmental Satellite (GOES) which measures the local magnetic field vector with a 0.5 second sampling rate. These data contain occasional baseline perturbations not of geophysical origin. One source of contamination is due to switching heaters that are installed along with each magnetometer and used to stabilize the temperature of the instrument. Detection of the heater induced field is complicated by the fact that in most cases these jumps are so small that they are hard to distinguish visually. In the present work we have developed the algorithm JM (from JUMP) aimed at automated and uniform recognition of jumps in GOES 2 Hz vector magnetic measurements. We present the performance of the JM algorithm to a full day of measurements on 3 April 2010. On this date, almost all jumps were recognized by the JM algorithm. The results demonstrate that the algorithm might be used to improve the existing data set from GOES 13, 14 and 15 series, and perhaps find use with the next generation of GOES satellites, beginning with GOES 16 launched on 19 November 2016.



Examples of jump detection using JM algorithm. The original magnetogram is given on the upper plot; recognized jumps are marked with red. The lower plot provides the heater status information within the same period. Vertical rectangles outline the heater transition state between "on" and "off". Grey rectangles correspond to correlation between jumps and heater switches. Yellow rectangles correspond to correlation absence, i.e. no jumps associated with heater switches

Soloviev A., Sh. Bogoutdinov, S. Agayan, R. Redmon, T. M. Loto'aniu, H. J. Singer (2018), Automated recognition of jumps in GOES satellite magnetic data, Russ. J. Earth Sci., 18, ES4003, DOI: 10.2205/2018ES000626.

Inclusion of Saint Petersburg (SPG) magnetic observatory into the INTERMAGNET network

On 29 April 2016 the application of the Saint Petersburg observatory (IAGA code SPG) for introduction into the INTERMAGNET network was accepted after approval by the experts of the first definitive dataset over 2015, produced by the GC RAS, and on 9 June 2016 the SPG observatory was officially certified. One of the oldest series of magnetic observations, originating in 1834, was resumed in the 21st century, meeting the highest quality standards and all modern technical requirements. The SPG observatory provides 1 s magnetic data with a near-real-time transmission. The inclusion of this new observatory into the INTERMAGNET network contributes to accurate modeling of rapid and long-term variations of the core magnetic field and analysis of geomagnetic disturbances caused by the external magnetic field, their dynamics, and spatiotemporal features. A particular advantage of the SPG observatory is its high-latitude location. Comparison between SPG definitive data and the data obtained from available and widely used internal magnetic field models shows good agreement, as well as the comparison between SPG variation data and the corresponding datasets from the nearest INTERMAGNET observatories: therefore, the magnetometer set is properly installed and the measured and model data are physically close in general (thousands of nT).

Model	Epoch	X, nT	Y, nT	Z, nT
CHAOS-6 (CF)	2015.1	14353.15	2615.35	50420.77
CHAOS-6 (CF, AF85)	2015.1	14424.07	2672.95	50293.85
SIFM (CF)	2015.1	14355.23	2616.28	50419.06
EMM2015(CF, AF720)	2015.0	14513.75	2648.01	50346.38
SPG definitive values	2015.1	14542.02	2551.72	50260.61
SPG definitive values	2015.0	14543.68	2546.5	50262.27

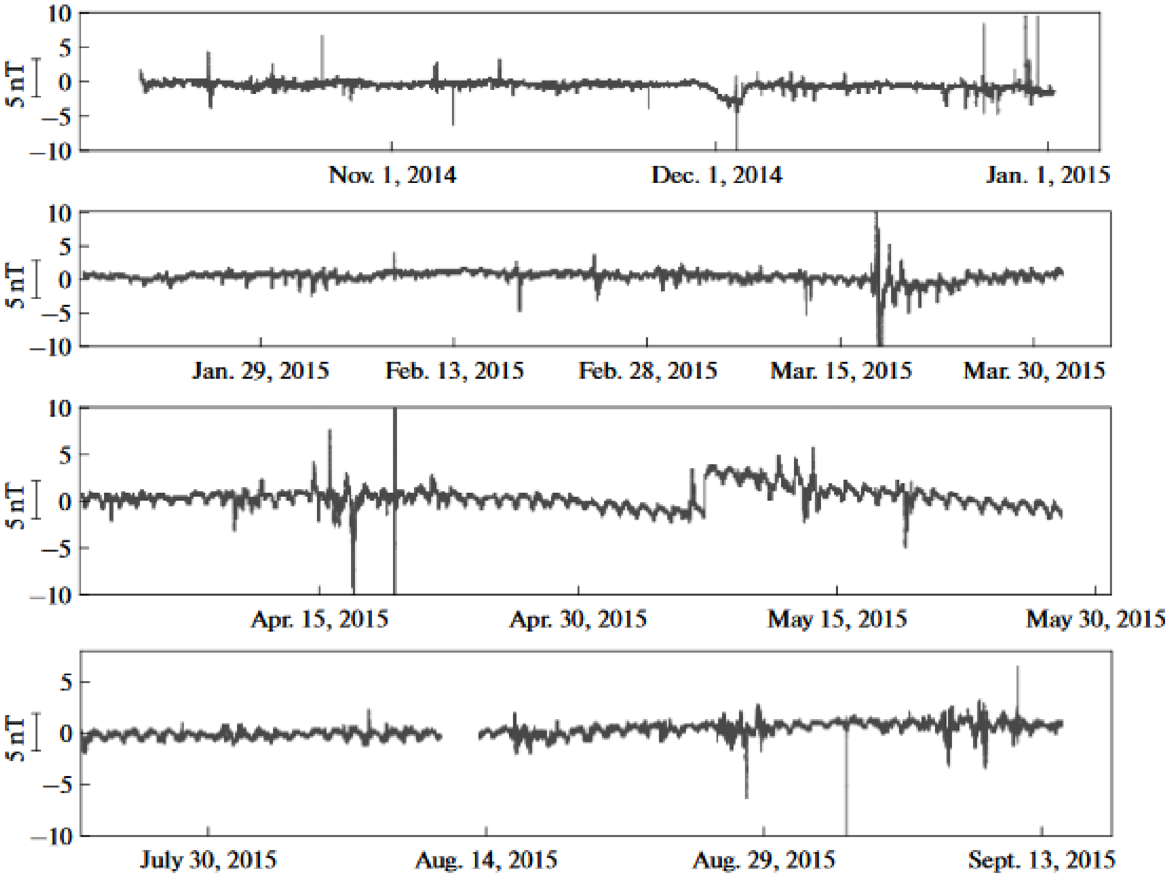
Results of comparison between the average absolute values of the magnetic field vector components and the model values for different internal field models. CF stands for core field, and AF for the anomalous (lithospheric) field; the number after the AF in the model name indicates its spherical expansion order and degree.

Absolute (a) and variation (b) pavilions of the Saint Petersburg observatory

Sidorov, R., Soloviev, A., Krasnoperov, R., Kudin, D., Grudnev, A., Kopytenko, Y., Kotikov, A., and Sergushin, P. (2017), Saint Petersburg magnetic observatory: from Voeikovo subdivision to INTERMAGNET certification, Geosci. Instrum. Method. Data Syst., 6, 473–485, 2017, DOI: 10.5194/gi-6-473-2017.

Klimovskaya geomagnetic observatory upgrade

Geomagnetic data registration on the Klimovskaya (KLI) Observatory started back in 2011, when the vector magnetometer was installed at the Rotkovets geobiostationary (GBS) of the Institute of Physiology of Natural Adaptations (IPPA) of the Ural Branch of the Russian Academy of Sciences. Magnetometry at the site of the observatory was carried out on two scales – with a resolution of 10x10 m and 1x1 m. As a result of the work carried out to select the location of the pedestals, a new method of high-precision geomagnetic survey was developed.



Fragments of the ΔF record for the entire period of absolute observations on Klimovskaya observatory (October 1, 2014–October 1, 2015)

In 2015, 2016, 2017 and 2018, the observatory equipment was sequentially upgraded to improve the reliability of the hardware. In December 2018, additional works were done at Klimovskaya, aimed at the data quality improvement (from technical works on the replacement of power supply cables and light bulbs to the construction of additional supports for a scalar magnetometer sensor and setting the additional control azimuth mark). This observatory, in the development process of which experience was gained of successfully applying a range of technical solutions, is promising, and is currently preparing to submit an application for its inclusion in the INTERMAGNET network.

(a) (b)

(c) (d)

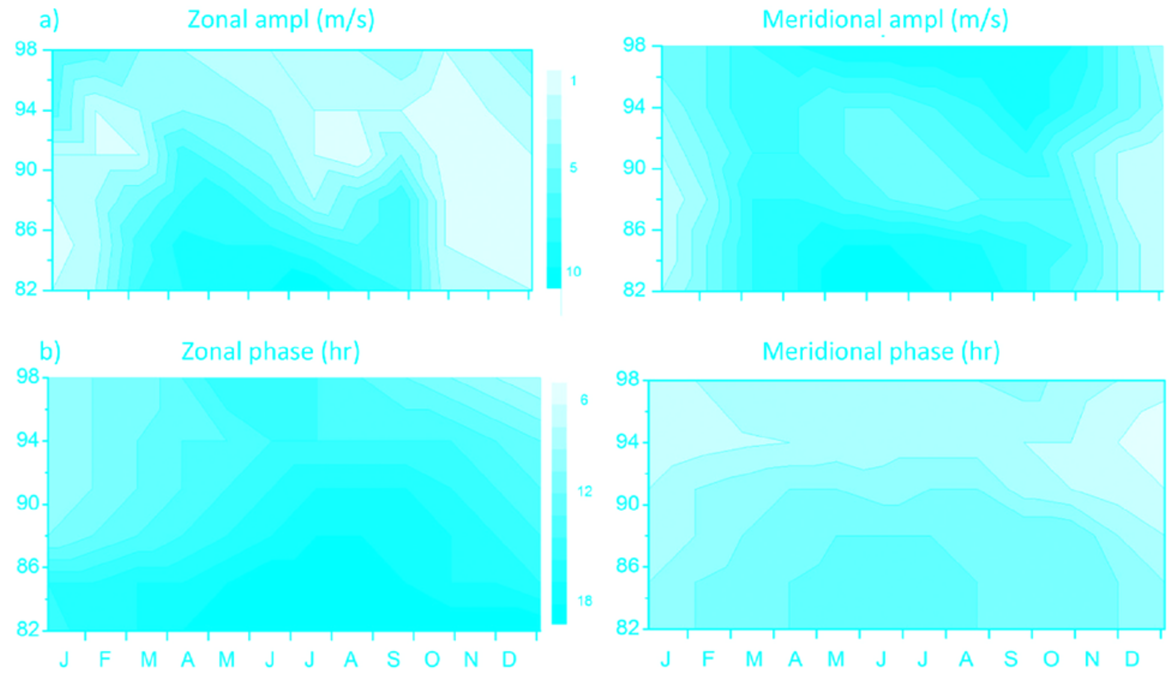
Magnetic Observatory "Klimovskaya": absolute (a) and variation (b) measuring pavilions (the control azimuth mark is the red triangle on the front wall of the variation pavilion), aluminum guides for accurate theodolite centering on the absolute pillar (c) and a new support for a scalar magnetometer sensor (d)

R.I. Krasnoperov, R.V. Sidorov, A.A. Soloviev, Modern Geodetic Methods for High-Accuracy Survey Coordination on the Example of Magnetic Exploration, Geomagnetism and Aeronomy, 2015, Vol. 55, No. 4, pp. 547–554, DOI: 10.1134/S0016793215040076.

A.A. Soloviev, R.V. Sidorov, R.I. Krasnoperov, A.A. Grudnev, and A.V. Khokhlov (2016), Klimovskaya: A New Geomagnetic Observatory, Geomagnetism and Aeronomy, 2016, Vol. 56, No. 3, pp. 342–354. DOI: 10.1134/S0016793216030154.

Polar mesospheric studies

The inter-annual variability, climatological mean wind and tide fields in the northern polar mesosphere/lower thermosphere region of 82–98 km height are studied using observations by the meteor radar which has operated continuously during solar cycle 24 (from December 2008 onward) at the Sodankylä Geophysical Observatory (67N, 26E). Summer mean zonal winds are characterized by westward flow, up to 25 m/s, at lower heights and eastward flow, up to 30 m/s, at upper heights. In the winter an eastward flow, up to 10 m/s, dominates at all heights. The meridional winds are characterized by a relatively weak poleward flow (few m/s) in the winter and equatorward flow in the summer, with a jet core (~15 m/s) located slightly below 90 km. These systematically varying winds are dominated by the semidiurnal tides. The largest amplitudes, up to 30 m/s, are observed at higher altitudes in winter and a secondary maximum is seen in August–September. The diurnal tides are almost a factor of two weaker and peak in summer. The variability of individual years is dominated by the winter perturbations. During the period of observations major sudden stratospheric warmings (SSW) occurred in January 2009 and 2013. During these events the wind fields were strongly modified. The lowest altitude eastward winds maximized up to 25 m/s, that is by more twice that of the non-SSW years. The poleward flow considerably increases (up 10 m/s) and extends from the lower heights throughout the whole altitude range. The annual pattern in temperature at ~90 km height over Sodankyla consists of warm winters (up to 200 K) and cold summers (~120 K).

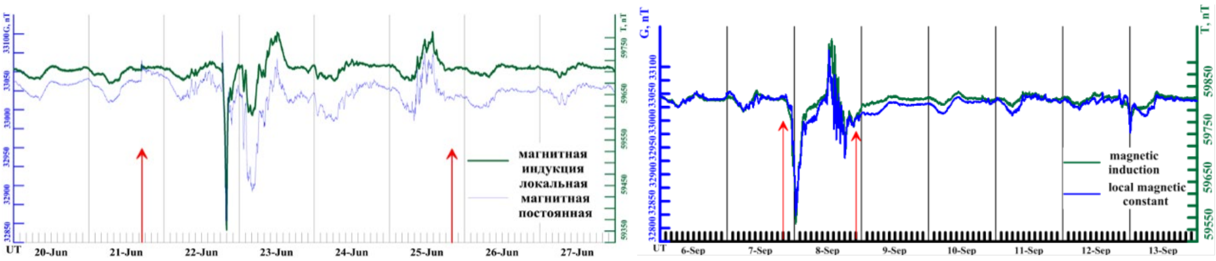


Composite of mean amplitudes (a) and phases (b) of zonal and meridional diurnal atmospheric tide. Contours are plotted as functions of height (in km) vs time (in months) with intervals of 1 m/s and 1 h for (a) and (b), respectively. The gray scales used for amplitude and phase are shown in the middle of panel (a) and (b), respectively.

Lukianova R., Kozlovsky A., Lester M. Climatology and inter-annual variability ofthe polar mesospheric winds inferred from meteor radar observations overSodankyla (67N, 26E) during solar cycle 24 // Journal of Atmospheric and Solar-Terrestrial Physics. 2018. Vol. 171. № S.I.. P. 241–249. DOI: 10.1016/j.jastp.2017.06.005

Observatory data analysis during large geomagnetic phenomena

The data series on magnetic observations after large flares on the Sun were analyzed (June 18–21, 2015, September 6, 2017) At the geomagnetic observatory, large magnetic storms were observed after 1–2 days, during which the magnetic field changed by 0.70%, and the magnetic moment by 0.75% of their average values.



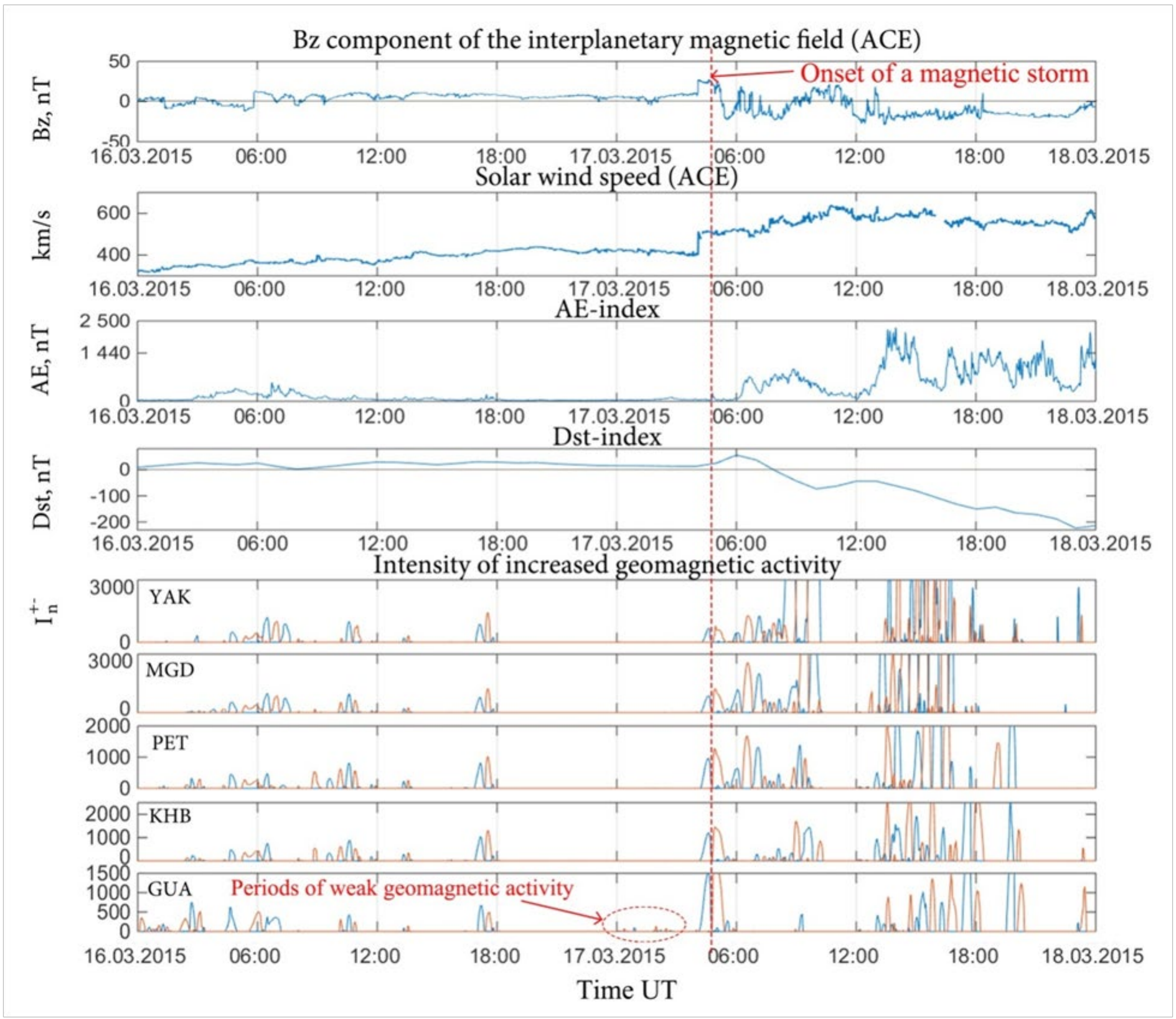
Changes in magnetic induction (T, right axis) and local magnetic constant (G, left axis) for the period June 20 – June 27, 2015 and September 6 – September 13, 2017 according to the Novosibirsk Observatory.

Belinskaia A.Yu., Yanchukovskiy V.L., Anciz E.N., Kovalev A.A., Semakov N.N. Complex observations at the geophysical observatory "Klyuchi" during a strong geomagnetic storm in June 2015 // Proceedings SPIE. 23rd International Symposium on Atmospheric and Ocean Optics: Atmospheric Physics. – 2017. – T. 10466. – C. 1046661–1046661

Belinskaia A.Yu., Yanchukovskiy V.L., Kovalev A.A., Antsyz E.N., Semakov N.N. "Complex observations at the geophysical observatory 'Klyuchi'" during a strong geomagnetic storm in September 2017 // Proceedings of SPIE. 24th International Symposium on Atmospheric and Ocean Optics: Atmospheric Physics, 2018, Tomsk, Russian Federation. – 2018. – T. 10833. – C. 108339E–1 – 108339E–6

The model of the geomagnetic field variations for the magnetosphere state monitoring

The model of the geomagnetic field variations has been developed, describing the characteristic changes and anomalous features arising during periods of magnetospheric disturbances. Based on the model, a method has been developed for analyzing variations in the geomagnetic field according to ground stations. The effectiveness of the method for the study of nonstationary processes in the magnetosphere and in applied researches in the field of space weather forecasting problems is shown. The method allows, according to the ground stations, to perform continuous monitoring of geomagnetic disturbances in different regions of the Russian Federation, the method was implemented in the system of operational analysis of IKIR FEB RAS geomagnetic data (http://www.ikir.ru:8280/lsaserver/). The method makes it possible to isolate synchronous geomagnetic disturbances preceding magnetic storms (from high latitudes to the equator), which correlate with fluctuations of the interplanetary magnetic field and increases in auroral indices of geomagnetic activity.



The results of the method applying during the event on March 17, 2015

Mandrikova O.V., Zhizhikina E.A. Automatic method for estimation of geomagnetic field state // Computer Optics. 2015. VOL. 39(3). Pp .420–428

Mandrikova O.V., Solovjev I. S., Khomutov S.Yu., Baishev D.G., Geppener V.V., Klionskiy D. M. Estimation of Geomagnetic Field Storminess Using the Wavelet Transform1//Pattern Recognition and Image Analysis. 2016. Vol. 26, №. 4. P. 71–79

Mandrikova O.V., Solovyev I.S., Khomutov S.Y., Geppener V.V., Klionskiy D.M., and Bogachev M.I. Multiscale variation model and activity level estimation algorithm of the Earth's magnetic field based on wavelet packets // Ann. Geophys. – 2018 – No. 36 – Pp. 1207–1225, DOI: 10.5194/angeo-36-1207-2018

The ionosphere state monitoring model

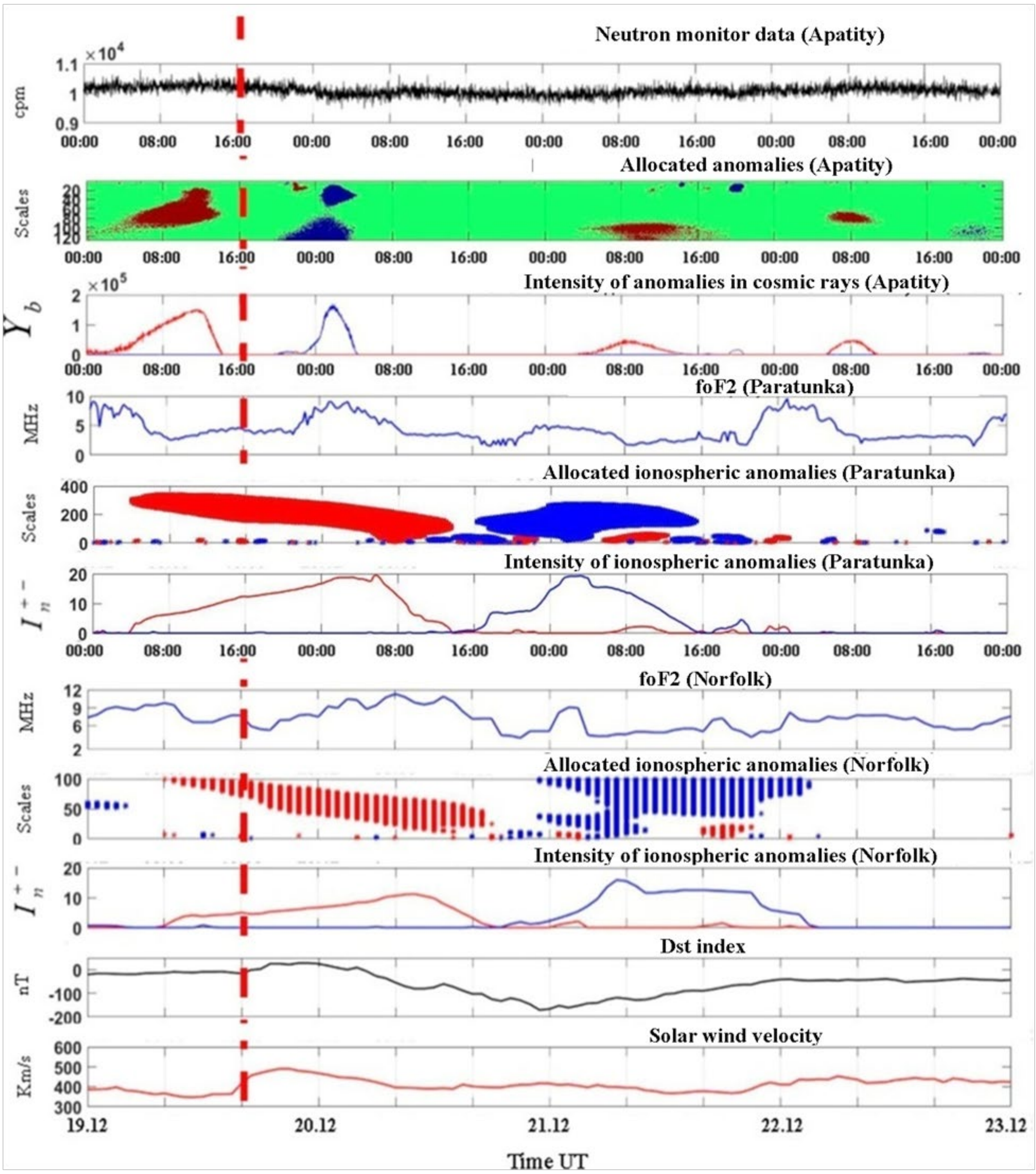
The model of the temporal variation of the ionosphere parameters has been developed, describing changes in parameters during periods of calm and disturbed ionosphere. Based on the model, the method has been developed for analyzing ionospheric parameters, identifying and estimating ionospheric disturbances. The efficiency of the method for the study of nonstationary processes in the ionosphere and in applied researches in the field of space weather forecasting problems is shown. Based on the method, the effect of increasing the electron concentration in the ionosphere on the eve of strong magnetic storms was confirmed, and signs indicating its solar nature were identified. It is shown that during periods of strong geomagnetic disturbances and in the phase of magnetic storms recovery, the occurrence of intense and prolonged negative ionospheric storms, which have a negative impact on modern radio communications, is characteristic. The method allows, according to data from ground stations, to carry out continuous monitoring of the ionosphere state and to isolate ionospheric disturbances, its implementation has been carried out in the system of operational analysis of IKIR FEB RAS ionospheric data.

Mandrikova O.V., Fetisova N.V., Polozov Y.A., Solovev I.S., Kupriyanov M.S. Method for modeling of the components of ionospheric parameter time variations and detection of anomalies in the ionosphere // Earth Planet Space. 2015. Vol. 67. DOI: 10.1186/s40623-015-0301-4.

Mandrikova O.V., Fetisova (Glushkova) N.V., Al-Kasasbeh R.T., Klionskiy D.M., Geppener V.V., Ilyash M.Y. Ionospheric parameter modeling and anomaly discovery by combining the wavelet transform with autoregressive models // Annals of Geophysics. – 2015.– Vol. 58, No. 5. – DOI: 10.4401/ag-6729.

Mandrikova O.V., Polozov Yu.A., Solovev, I.S., Fetisova N.V., Zalyaev T.L., Kupriyanov M.S., Dmitriev A.V. Methods of Analysis of Geophysical Data during Increased Solar Activity / Pattern Recognition and Image Analysis. 2016. – Vol. 26. – No. 2. P. 406–418. DOI: 10.1134/S1054661816020103

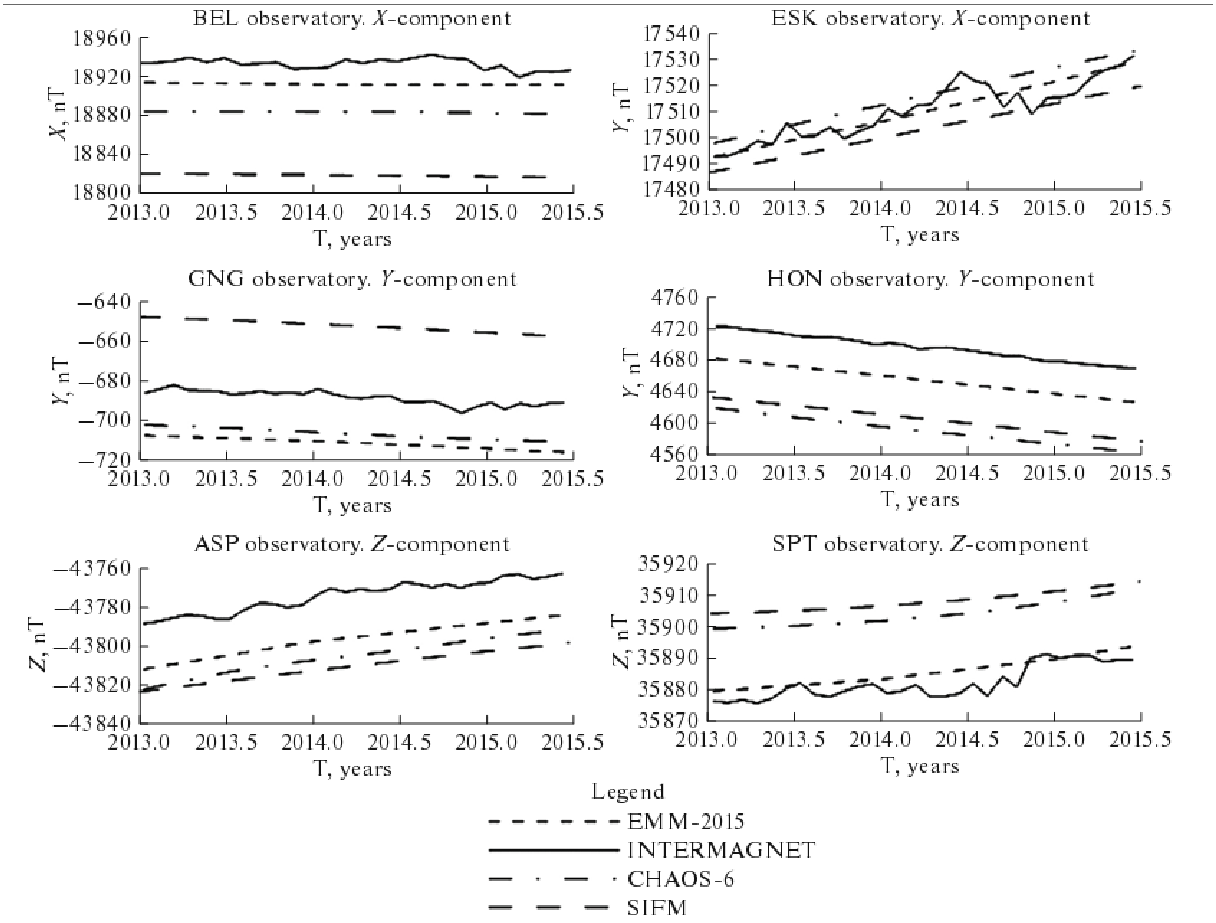
Mandrikova O., Polozov Yu., Fetisova N., Zalyaev T. Analysis of the dynamics of ionospheric parameters during periods of increased solar activity and magnetic storms // Journal of Atmospheric and Solar-Terrestrial Physics. – 2018 – Vol. 181. – Pp. 116–126. DOI: 10.1016/j.jastp.2018.10.019.



The results of the method applying during the event on December 19, 2015

Estimation of the core magnetic field models using the observatory data

A new approach to identify the signals of the Earth's main magnetic field (core field) based on the magnetic observatory data processing is suggested. The algorithms implemented in the approach are based on the Discrete mathematical analysis (DMA). The developed method is used to analyze the data from 49 mid-and low-latitude observatories of the INTERMAGNET network collected in 2011–2015. The results are compared with the classical method for determining the periods of low magnetic activity of external origin which is adopted by the IAGA. The advantages of the suggested new approach are demonstrated. Based on the data records for the selected time intervals, the time series of the core field components and their secular variations are obtained for each observatory. These data are compared to the values predicted by the most accurate core field models: SIFM, CHAOS-6, and EMM-2015. The accuracy of the models is estimated using a set of statistical parameters: Pearson's coefficient of linear correlation, Spearman's and Kendall's coefficients of rank correlation, the mean and median values over the data sets, and the mean difference between the data obtained by the suggested method from observatory measurements and the model predictions.

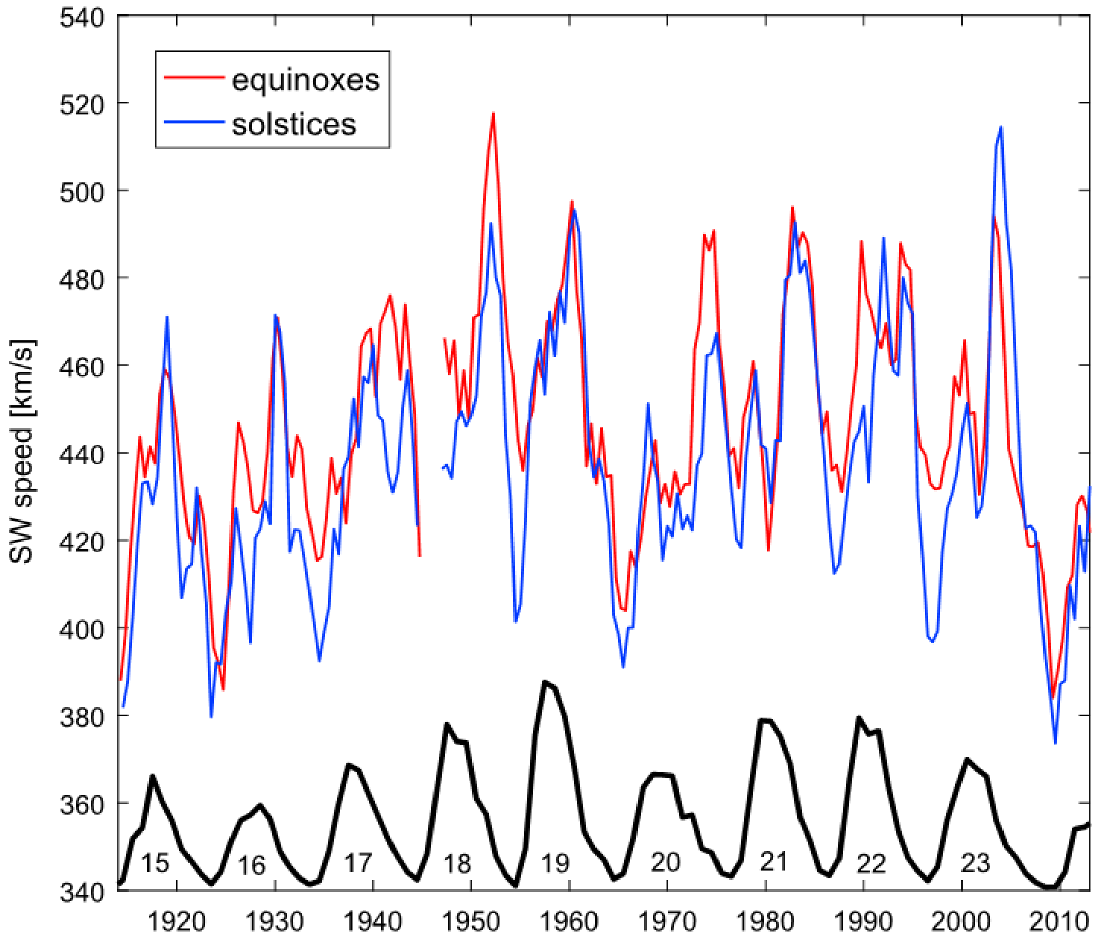


Examples illustrating comparison of results of modeling components of internal magnetic field of Earth at BEL (X-component), ESK (X-component), GNG (Y-component), HON (Y-component), ASP (Z-component), and SPT (Z-component) observatories by suggested method (INTERMAGNET) and SHA models (EMM-2015, CHAOS-6, and SIFM).

A.A. Soloviev, A.G. Smirnov (2018), Accuracy Estimation of the Modern Core Magnetic Field Models Using DMA-Methods for Recognition of the Decreased Geomagnetic Activity in Magnetic Observatory Data, Izvestiya, Physics of the Solid Earth, 2018, Vol. 54, No. 6, pp. 872–885, DOI: 10.1134/S1069351318060101.

Solar wind studies

Solar wind speeds at 1 AU for the last 100 years using high-latitude geomagnetic measurements were studies, and it has been displayed that they give information on the long-term evolution of important structures of the solar large-scale magnetic field, such as persistent coronal holes. We find that the centennial evolution of solar wind speed at 1 AU is different for equinoxes and solstices, reflecting differences in the evolution of polar coronal hole extensions and isolated low-latitude coronal holes. Equinoctial solar wind speeds had their centennial maximum in 1952, during the declining phase of solar cycle 18, verifying that polar coronal holes had exceptionally persistent extensions just before the peak of the Grand Modern Maximum of solar activity. On the other hand, solstice speeds had their centennial maximum during the declining phase of solar cycle 23 due to large low-latitude coronal holes. A similar configuration of seasonal speeds as in cycle 23 was not found earlier, not even during the less active cycles of early 20th century. Therefore, the exceptional occurrence of persistent, isolated low-latitude coronal holes in cycle 23 is not related to the absolute level of sunspot activity but, most likely, to the demise of the Grand Modern Maximum.



Three-point running means of the reconstructed solar winds speeds for equinoxes and solstices. Annual sunspot number (arbitrary scale) and solar cycle numbers are included for reference.

Lukianova R., Holappa L., Mursula K. Centennial evolution of monthly solar wind speeds: Fastest monthly solar wind speeds from long-duration coronal holes // Journal of Geophysical Research-Space Physics. 2017. Vol. 122. № 3. P. 2740 – 2747. DOI: 10.1002/2016JA023683

Mursula K., Holappa L., Lukianova R. Seasonal solar wind speeds for the last 100years: Unique coronal hole structures during the peak and demise of the Grand Modern Maximum // Geophysical Research Letters. 2017. Vol. 44. № 1. P. 30–36. DOI: 10.1002/2016GL071573

Development of the MAGNUS hardware and software complex for geomagnetic data analysis

In 2016–2017, the MAGNUS (**M**onitoring and **A**nalysis of **G**eomagnetic a**N**omalies in the **U**nified **S**ystem) hardware and software complex has been developed in the GC RAS as the basis of the Russian-Ukrainian analytical center of geomagnetic data (http://geomag.gcras.ru). Its advantages are based on the effective implementation of accumulated experience in the field of geophysical monitoring and the development of mathematical data mining tools. MAGNUS is based on a unified information and telecommunication modular infrastructure that ensures data transmission, storage and integrated system processing. The system infrastructure remains open to install additional software components.

MAGNUS is designed to perform the following tasks:

• collection and systematization of ground-based and satellite geomagnetic measurements;

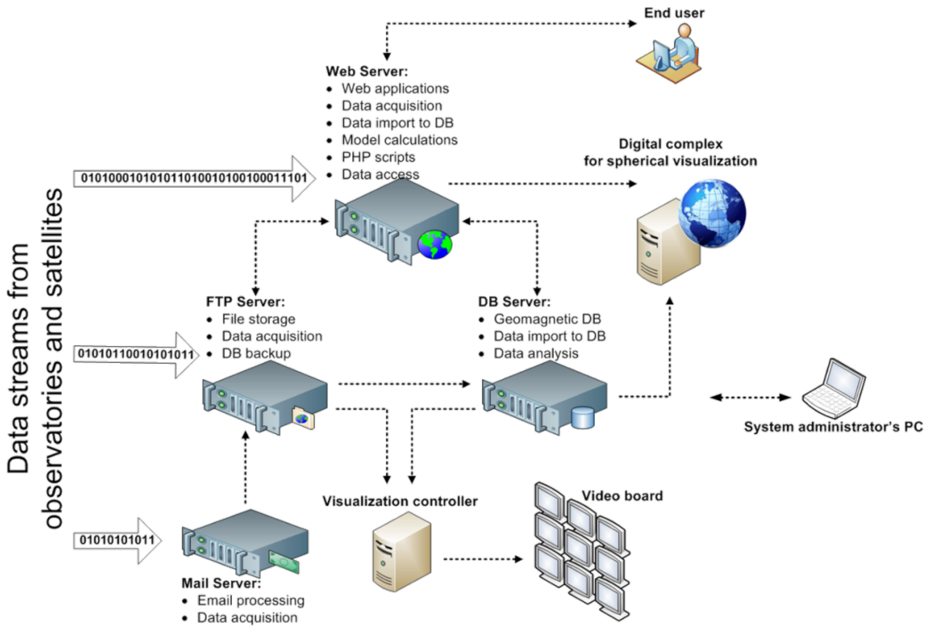
• automated cleaning of observatory data from artificial interference and their verification in accordance with the INTERMAGNET standards;

• recognition, classification and coding of data on extreme geomagnetic phenomena;

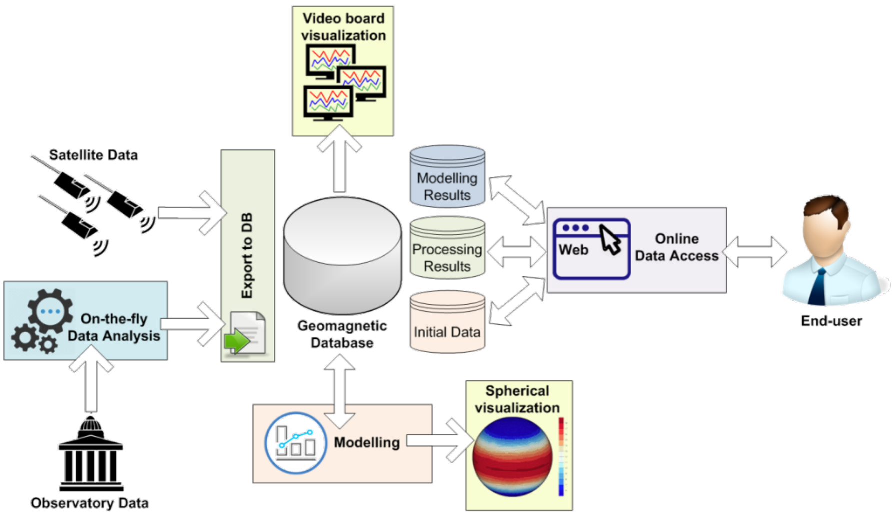
• model calculations;

• providing interactive online access to source data, the results of their processing, information on extreme geomagnetic events, as well as simulation results;

• visualization.



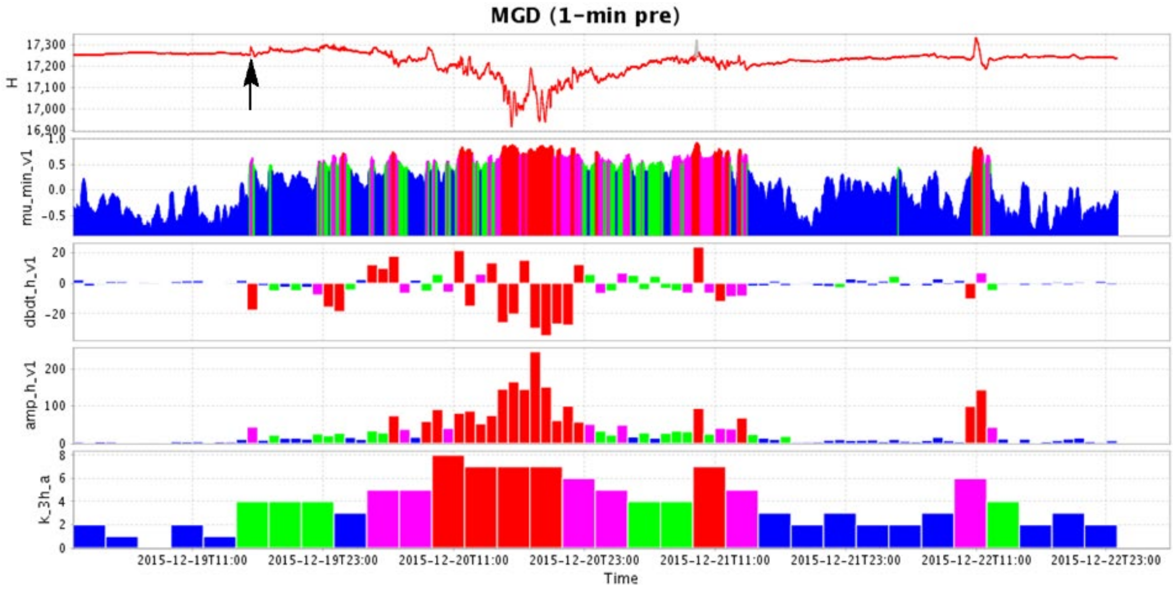
a)



b)

Hardware components (a) and data flows (b) of the MAGNUS system

In MAGNUS, the storage of terrestrial and satellite data, both source and processed, is organized using a relational DBMS, which ensures high speed and flexibility of data queries. Operational data recorded at Russian geomagnetic observatories are transmitted to MAGNUS in quasi-real-time mode as files in one of the accepted formats (INTERMAGNET, 2013; V-DAT, 2011; MinGeo Ltd., 2016). Depending on the telecommunication capabilities, data is transmitted via e-mail or via FTP protocol with a certain delay (from 10 minutes to 2 days). Then they are automatically exported to the geomagnetic database. When new daily Swarm files are published on the European Space Agency (ESA) server, the MAGNUS system automatically downloads them, extracts information related to measurements of the Earth's magnetic field, and exports its geomagnetic base tables that are similar in structure and format to tables for storing observatory data. This circumstance ensures the coordinated storage of ground and satellite data, the possibility of their integration and joint analysis. A key feature of MAGNUS is the automation of recognition of man-made anomalies in the magnetograms as they arrive, as well as data binding to basic values and the subsequent calculation of quasi-definitive data. Also MAGNUS performs recognition and multi-criteria assessment of natural geomagnetic activity using a series of indicators based on the original algorithms of the Geophysical Center of the Russian Academy of Sciences and traditional approaches.



Multi-criteria evaluation of geomagnetic activity on December 19–22, 2015, according to the H-component of the Magadan Observatory (MGD) (1st graph). Chart 2-5 shows geomagnetic activity indicators: amp_h_v1 – hourly maximum amplitudes (Amp) components H, mu_min_v1 – minute values of the anomaly measure (MA) components H, dbdt_h_v1 – maximum hourly values of the rate of change (dBdt) components H, k_3h_a – 3- hourly K-index. The colors of the graphs reflect various states of the magnetic field: blue – "background", green – "weak anomaly", violet – "anomaly" and red – "strong anomaly". The time of the sudden onset of a magnetic storm is indicated by the arrow on the 1st panel.

Gvishiani, A, Soloviev, A, Krasnoperov, R and Lukianova, R (2016) Automated Hardware and Software System for Monitoring the Earth's Magnetic Environment. Data Science Journal, 15: 18, DOI: 10.5334/dsj-2016-018

A. Soloviev, S. Agayan, S. Bogoutdinov, Estimation of geomagnetic activity using measure of anomalousness, Annals of Geophysics, 59 (6), 2016, DOI: 10.4401/ag-7116

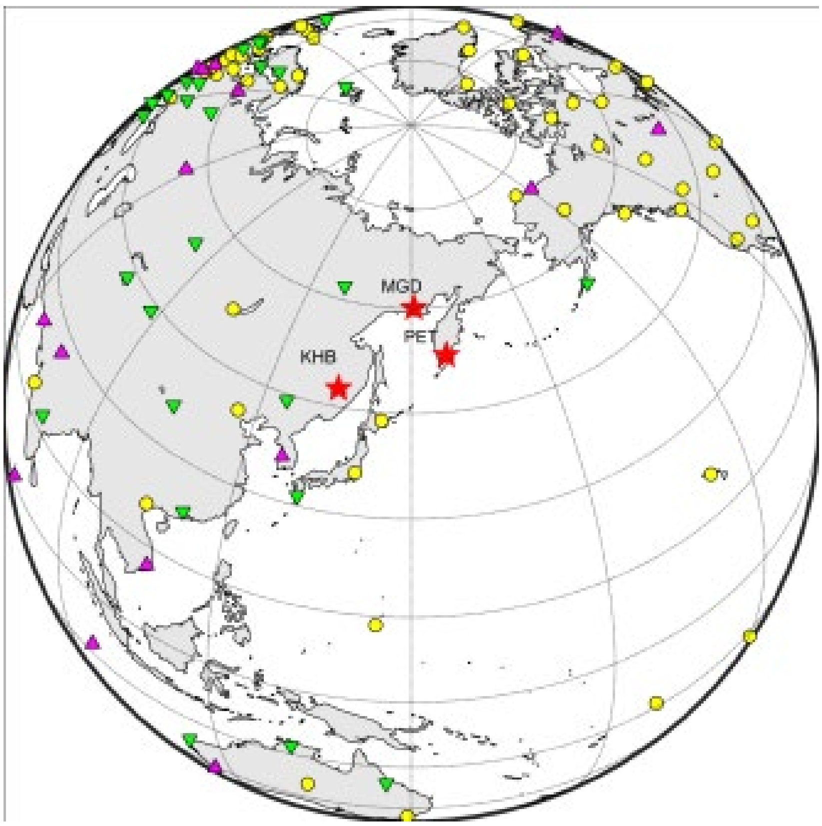
Agayan, S, Bogoutdinov, S, Soloviev, A and Sidorov, R (2016) The Study of Time Series Using the DMA Methods and Geophysical Applications. Data Science Journal, 15: 16, pp.1–21, DOI: 10.5334/dsj-2016-016

Gvishiani A. D., R. V. Sidorov, R. Yu. Lukianova, A. A. Soloviev (2016), Geomagnetic activity during St. Patrick's Day storm inferred from global and local indicators, Russ. J. Earth Sci., 16, ES6007, DOI: 10.2205/2016ES000593.

Definitive geomagnetic data preparation for Magadan, Paratunka and Khabarovsk INTERMAGNET magnetic observatories

Regular long-term observations at observatories is one of the important tasks of geophysical research. In 2015–2018, continuous measurements of the geomagnetic field vector were performed at three observatories of IKIR FEB RAS "Magadan" MGD, "Paratunka" PET and "Khabarovsk" KHB, certified as INTERMAGNET observatories. The obtained Reported and Quasi-definitive minute values were promptly sent to GIN, the final (Definitive) data for 2014–2017 were prepared. At the Observatory PET, the archives of the results of digital magnetic measurements for 2007–2013 were reprocessed and Definitive data were obtained. The importance of magnetic measurements at IKIR observatories were defined by their unique location at the North-East of Eurasia.

Head of Observatory PET Sergey Y. Khomutov in 2016 elected a member of the OPSCOM INTERMAGNET.



Magnetic observatories with INTERMAGNET status before 2000 (O), during 2000-2010 (□) and after 2010 (Δ).

Khomutov S.Y. Magnetic observations at Geophysical Observatory "Paratunka" IKIR FEB RAS: tasks, possibilities and future prospects // E3S Web of Conferences. – 2017. – Vol.20, N02002. – 18p.

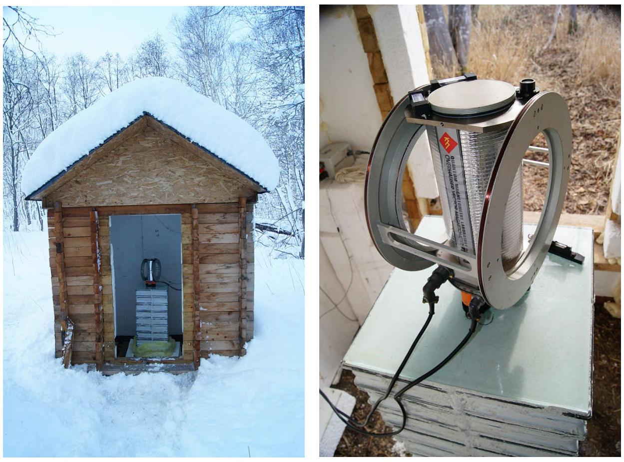
(DOI: 10.1051/e3sconf/20172002002) – VIII International Conference "Solar-Terrestrial Relations and Physics of Earthquake Precursors"

Khomutov S.Y. International project INTERMAGNET and magnetic observatories of Russia: cooperation and progress // E3S Web Conf. – 2018. – Vol.62, N02008. – 11 p. – (IX International Conference "Solar-Terrestrial Relations and Physics of Earthquake Precursors") – DOI: 10.1051/e3sconf/20186202008

Khomutov S.Y., Khomutova I.N., Solovev I.S., Papsheva S.Y. The revision of archival magnetic data of the observatories of IKIR FEB RAS: actuality, progress and prospects // Conrad Observatory Journal. – 2019. – N5. – P.22. – [ISBN: 978-3-903171-05-3, http://www.conrad-observatory.at/zamg/index.php/downloads-en/category/5-cobsjournal]

A new innovative magnetometer POS-4 in the observatory practice

In the spring of 2015, the vector Overhauser magnetometer POS-4 was installed at the Observatory Paratunka PET. POS-4 was developed in QMLab, UrFU, Yekaterinburg. This is a new unique device that uses a scalar Overhauser sensor in a vertical solenoid with coil system. The magnetometer is incorporated into the general magnetic field monitoring system of Observatory and operates continuously from the moment of installation in near constant conditions. The measurements showed that the long-term stability of POS-4 significantly depends on the stability of the pillar, but the magnetometer itself has high reliability and is easy to install and operate. Its results are comparable to those of the dIdD GSM-19FD magnetometer (GEM Systems).



Hut of POS-4 (left) and sensor in solenoid with coils at pillar (right), Observatory Paratunka.

In 2018, another POS-4 magnetometer was installed at the separate pavilion at the White Sea biological station of the Moscow State University. This magnetometer was initially set to register the horizontal and vertical component of the Earth's magnetic field. Later (in October 2018) the absolute measurements were performed at the station to determine the absolute magnetic declination value, and the POS-4 sensor system was oriented to register the East (Y) component of the Earth's magnetic field. The absolute D, I F, X, Y, Z values appeared to be physically close to the IGRF and WMM model data for the corresponding epoch.

Magnetic field components	Model values		Measured values
	IGRF	WMM	
D, °	14,822	15,216	14,858
I, °	77,324	77,330	77,346
F, nT	53971,5	54065	53895,085
Y, nT	3049,5	3090	3027,4
Z, nT	52656,1	52749	52586,117

Absolute measurements at the White Sea Biological station (left) and the POS-4 sensor orientation adjustment (right)

The data recorded at this observatory will be highly demanded by the Russian and world scientific community, conducting basic research in the field of geomagnetism and solar-terrestrial interaction. Information registered at the observatory is promptly transmitted to the Geomagnetic Data Center of the GC RAS. Data from the magnetic station is available on the website of the Russian-Ukrainian Geomagnetic Data Center at the GC RAS (http://geomag.gcras.ru/). The created observatory will make a significant contribution to the study of the effects of space weather, monitoring the Earth's magnetic field, facilitating its operational modeling procedures. In the future, the new magnetic station will be expanded to a full-fledged observatory, which will take its place in the international network of geomagnetic observations.

Khomutov S., Sapunov V., Denisov A., Savelyev D., Babakhanov I. Overhauser vector magnetometer POS-4: Results of continuous measurements during 2015–2016 at geophysical observatory "Paratunka" of IKIR FEB RAS, Kamchatka, Russia // E3S Web Conf. – 2016. – Vol. 11. – N7.

(DOI: 10.1051/e3sconf/20161100007) – VII International Conference "Solar-Terrestrial Relations and Physics of Earthquakes Precursors"

Sapunov V.A., Denisov A.Y., Saveliev D.V., Soloviev A.A., Khomutov S.Y., Borodin P.B., Narkhov E.D., Sergeev A.V., Shirokov A.N. New vector/scalar Overhauser DNP magnetometers POS-4 for magnetic observatories and directional oil drilling support // Magnetic Resonance in Solids. Electronic Journal. – 2016. – Vol. 18, No 2. – 16209 (9 pp.)

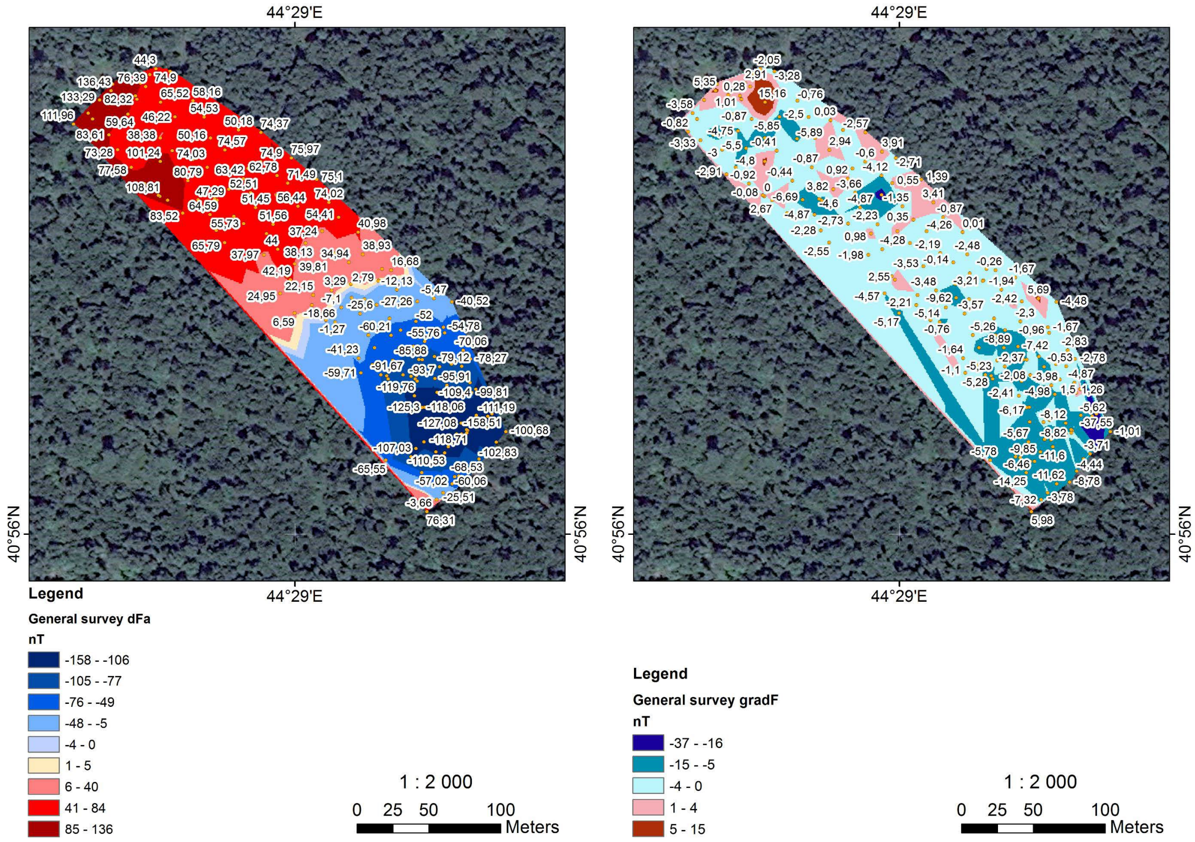
Organizing the repeat station network at the mouth of the Lena River

In 2015, a small network of repeat station points was installed at the mouth of the Lena. River. The expected results from repeated measurements in this area will provide important information about the direction and speed of movement of the true magnetic north pole. The study of the peculiarities of the movement of magnetic poles is the second, no less important than the anomalies of the secular course, part of the scientific problems solved in 2015–2018. In the near future, the question of creating a Russian service of the true magnetic north pole will inevitably arise.

Tsibizov L., Ayunov D., Semakov N., Dyadkov P., Pavlova D. Magnetic studies in Lena river delta: the results of 2014–2015 fieldworks and future plans // XI. International Conference on Permafrost. Exploring Permafrost in a Future Earth (Potsdam, Germany, 20–24 June 2016): Book of Abstracts. – 2016. – C. 969–969

Gyulagarak: a perspective for a new geomagnetic observatory in Armenia

Due to the need of extension of the of the existing network of subequatorial magnetic observatories, in 2016 it was decided to deploy a full-scale magnetic observatory of the highest international standard in Armenia, on the basis of the geophysical test site of the Institute of Geophysics and Engineering Seismology of the National Academy of Sciences of the Republic of Armenia (IGES NAS RA). From April 9 to April 15, 2017, an expedition took place at the geophysical test site located 3 km south of the village of Gyulagarak (Lori region, Republic Armenia). The purpose of the trip was to carry out magnetic studies at the site to determine the places suitable for the construction of the absolute and variation pavilions of the magnetic observatory. As a result of the expedition, a reconnaissance of the area was carried out and areal magnetogradiometry was carried out on several scales for a multi-level study of the nature of the distribution of the magnetic field anomalies and its gradient. The areas favorable for the location of the pavilions and the construction of measurement pillars were localized, as well as a preliminary place for the installation of the azimuth mark. A series of absolute measurements of magnetic declination and inclination was also carried out. The rock specimen were selected for laboratory study of their magnetization and magnetic susceptibility. Considering the geological structure of the site and the presence of igneous rocks of medium and basic composition (andesite basalts) with strong magnetic susceptibility and the presence of ferromagnetic minerals, observatory pavilions will be built on high piles to avoid the influence of natural magnetic anomalies on the readings of the instruments. In 2018, the pavilion construction begun. The pavilions are made from modern composite non-magnetic materials.



Anomalous magnetic field (left) and vertical gradient of the total field (right) at the Gyulagarak survey site

Absolute pavilion construction, Gyulagarak, Armenia, autumn 2018

In case of successful implementation of the project, the planned observatory will be the only observation point of the magnetic field in a vast area not covered by the existing network – the nearest observatory is located at a distance of 1200 km. Creating an observatory will significantly deepen the geomagnetic and, in general, geophysical research in the Caucasus and will make a significant contribution to the study of the evolution of the main magnetic field of the Earth.

Gvishiani A.D., Soloviev A.A., Sidorov R.V., Krasnoperov R.I., Grudnev A.A., Kudin D.V., Karapetyan J.K., Simonyan A.O. Successes of the organization of geomagnetic monitoring in Russia and the near abroad. Vestnik Otdelenia nauk o Zemle RAN, VOL. 10, NZ4001, DOI: 10.2205/2018NZ000357, 2018

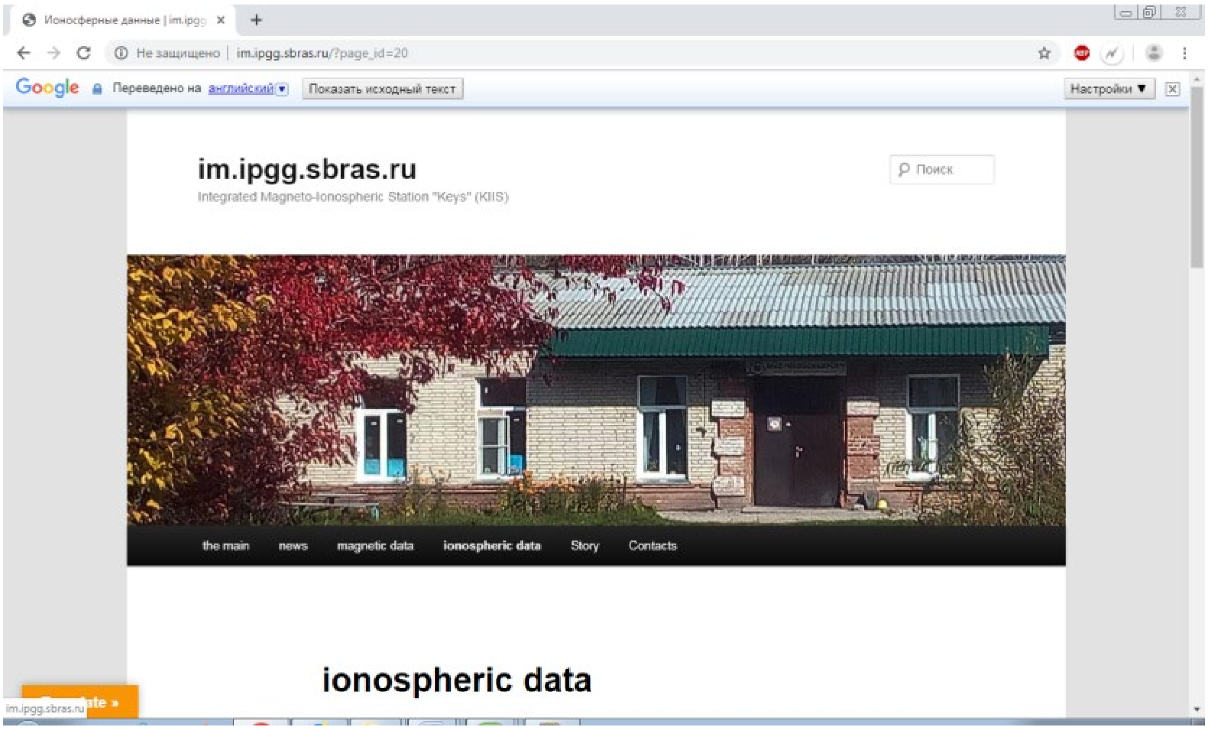
Samoilovsky Island: a perspective for another new geomagnetic observatory

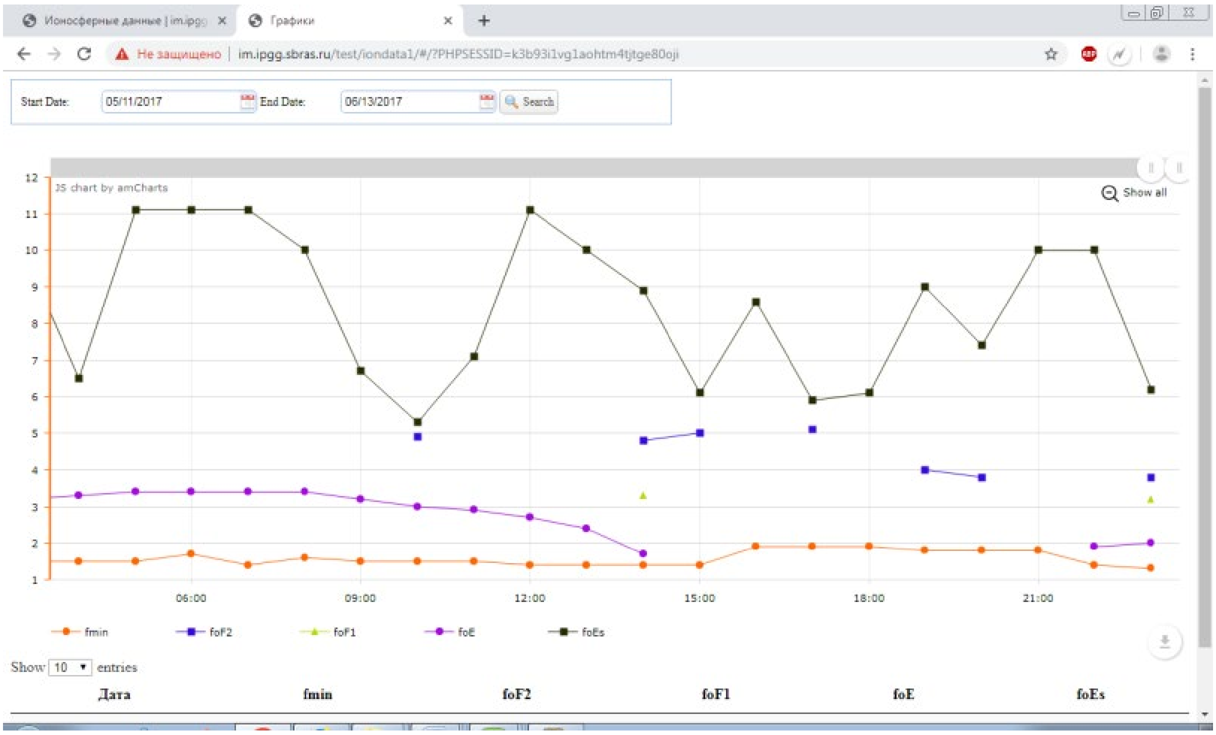
In August 2018, the prospect of creating another high-latitude magnetic observatory appeared. On the territory of the Samoylovsky Island Research Station (Lena River Delta, 72°22′28″ N, 126°28′45″ E), belonging to the Trofimuk Institute of Petroleum Geology and Geophysics of the Siberian Branch of the Russian Academy of Sciences (INGG SB RAS), the magnetogradiometric survey of two sites on the island, was done, the possibility of deploying the INTERMAGNET magnetic observatory standard was confirmed and places suitable for the construction of absolute and variometer pavilions of the observatory were localized.

Magnetic and gradiometric survey on the Samoilovsky Island. (the research station building can be seen on the horizon)

Klyuchi integrated magnetic-ionospheric station database website

In 2018, the web site for the integrated magnetic-ionospheric station “Klyuchi” has been launched (http://im.ipgg.sbras.ru/), where the magnetic and ionospheric database is located.



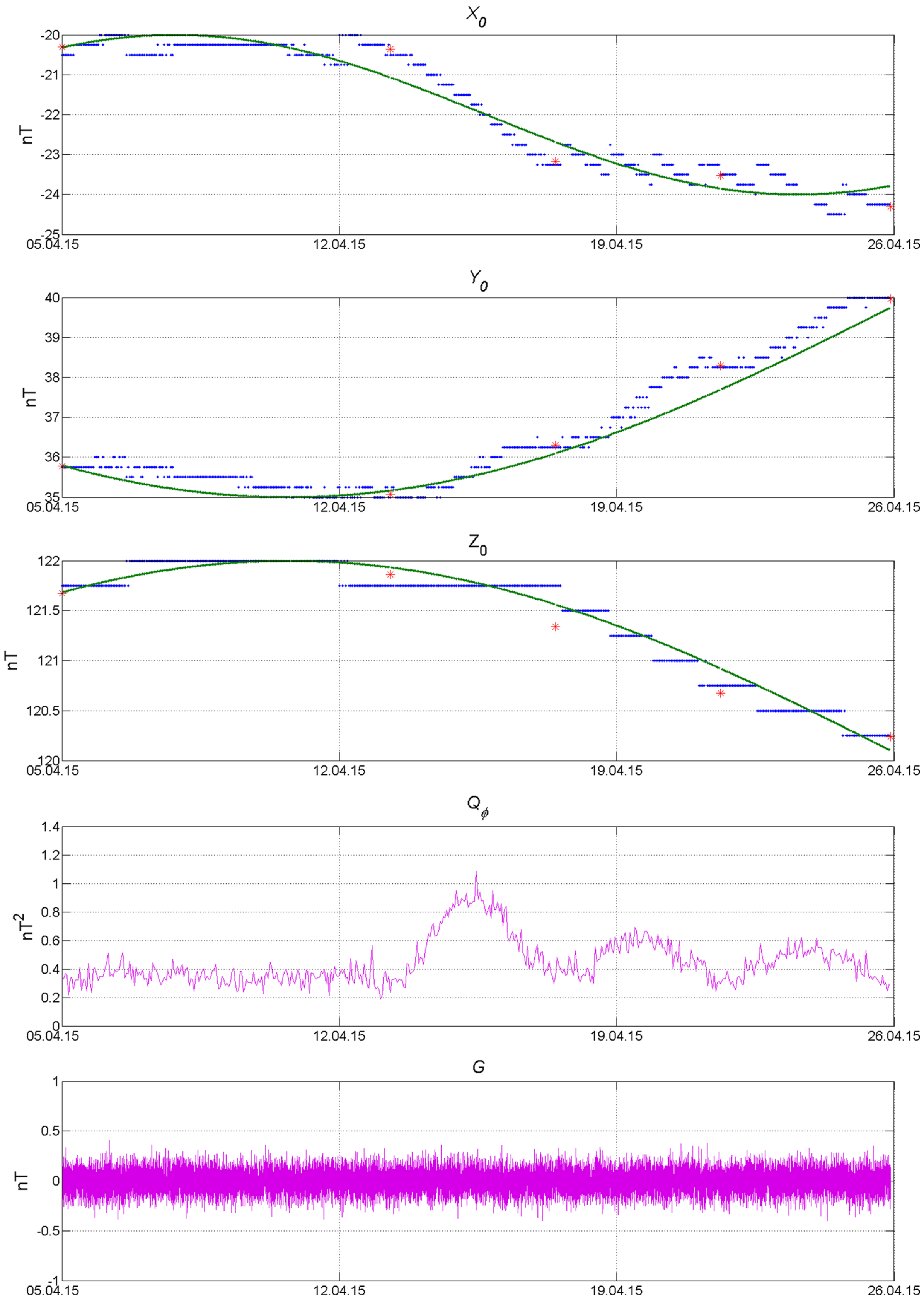


The Klyuchi integrated magnetic-ionospheric station website: user interface for ionospheric data access and the ionospheric data example

Belinskaya, A. Kovalev, O. Fedotova, N. Semakov Ionosphere and Magnetic Data Klyichi (IMD-K) \\ VarSITI Newsletter Vol. 21, May 2019 – pp. 3–5

A new approach to the calculation of baselines for magnetic observatory data

A new approach has been proposed by GC RAS for baseline construction, based on the simultaneous analysis of the irregular absolute observations and the continuous time series deltaF, widely used for estimating the data quality. The systematic deltaF analysis allows to take into account all available information about the operation of observatory instruments (i.e., continuous records of the field variations and its modulus) in the intervals between the times of absolute observations, as compared to the traditional baseline calculation where only spot values are considered. To establish a connection with the observed spot baseline values, a function for approximate evaluation of the intermediate baseline values is introduced. An important feature of the algorithm is its quantitative estimation of the resulting data precision and thus determination of the problematic fragments in raw data. The robustness of the algorithm operation was analyzed using synthetic data sets. Also baselines and definitive data derived by the proposed algorithm were compared with those derived by the traditional approach using Saint Petersburg observatory data, recorded in 2015 and accepted by INTERMAGNET. It is shown that the proposed method allows to essentially improve the resulting data quality when baseline data are not good enough. The obtained results prove that the baseline variability in time might be quite rapid.



Calculated hourly baseline values (blue), pseudo-observed values (red) and functionally defined hourly baselines (green) for the X (first plot), Y (second plot) and Z (third plot) components of the EMF. Fourth and fifth plots represent the corresponding minima of the evaluation function Qφ and the difference function (G)

A. Soloviev, V. Lesur, D. Kudin (2018), On the feasibility of routine baseline improvement in processing of geomagnetic observatory data, Earth, Planets and Space, 70:16, 2018, DOI: 10.1186/s40623-018-0786-8.

The all-Russian absolute magnetometer verification

On September 20–22, 2017, the First All-Russian Verification of Absolute Magnetometers was held at the Arti Geophysical Observatory (ARS, Sverdlovsk Region). For the verification of scalar absolute magnetometers used by various institutes and universities, a special test site was prepared. The survey involved 9 magnetometers presented by the Gorno-Altaisk State University (Gorno-Altaisk), the Geophysical Observatory Paratunka, IVS FEB RAS (Petropavlovsk-Kamchatsky), Vitus Bering Kamchatka State University, (Petropavlovsk-Kamchatsky), Laboratory of Quantum Magnetometry of the Ural Federal University (Yekaterinburg), Bulashevich Institute of Geophysics UB RAS (Yekaterinburg). This verification procedure is recommended by IAGA and meets the requirements for geomagnetic observatories and repeat stations. The procedure is based on synchronous measurements by two scalar magnetometers at two separated points with the subsequent transposition of the sensors of the devices. The result is practically not affected by variations in time. The certificates were aassigned to each absolute magnetometer with a description of the methodology and verification protocol. Also, a number of methodological notes on the verification procedure were developed concerning the synchronization of instruments and certain technical aspects. The results showed that reconciliation of scalar magnetometers with proper organization in a well-prepared place can be effective and does not require significant costs. The organizers decided to hold such an event on a regular basis in the future.

The procedure for verification of absolute magnetometers at the Arti observatory test site

Fluxgate sensor construction for observatory magnetometers

For the absolute measurements at the Novosibirsk INTERMAGNET magnetic observatory, fluxgate sensors are used, made by an employee of the observatory A. P. Pavlov. Installed on non-magnetic theodolites of various accuracy, these sensors can measure the absolute values of declination and inclination with the required accuracy in the observatory, when teaching geophysicists and in field conditions. The accumulated experience in the manufacture of fluxgate sensors must be preserved and used more widely.

Semakov N.N., Kovalev A.A., Pavlov A.F., Fedotova O.I. On the need to create a database of absolute geomagnetic measurements in the Arctic, Siberia and the Far East // Solar-earth links and physics of precursors earthquakes: IX international conference (p. Paratunka, Kamchatka Krai, October 17 – 21, 2018): Collection of theses of reports. – 2018. – p. 42–42