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CHINESE-RUSSIAN JOINT RESEARCH CENTER ON SPACE WEATHER: RESULTS AND PROSPECTS

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Abstract. We present an overview of the history, the main scientific results and prospects of the Chinese-Russian Joint Research Center on Space Weather. The Chinese-Russian Joint Research Center was established by the Institute of Solar-Terrestrial Physics SB RAS (ISTP SB RAS) and National Space Science Center CAS (NSSC CAS) in 2000. The center deals with fundamental issues in modern solar-terrestrial physics, such as quantitative description of the processes in complex interconnected system Sun — interplanetary medium — magnetosphere — ionosphere — atmosphere, assessment of capabilities of predicting interactions within this system, development of effective models for forecasting the state of the atmosphere and near-Earth space. Over the 24-year period, the Joint Research Center has united more than 10 scientific institutes in Russia and China; about 60 scientific projects have been implemented, and more than 400 joint scientific articles have been published. Joint efforts of Russian and Chinese researchers allowed obtaining important results in study of physical processes in near-Earth space. The Chinese-Russian Joint Research Center has proven its usefulness and continues studying the Sun, solar-terrestrial relations, and near-Earth space.

The future work of the Joint Research Center will be closely linked to the implementation of major unique projects in China and Russia: the International Meridian Circle Program (IMCP) led by NSSC CAS, and the National Heliogeophysical Complex of the Russian Academy of Sciences (NHC RAS) led by ISTP SB RAS. We describe these projects in this paper.

Keywords: Chinese-Russian Joint Research Center, space weather, international cooperation, International Meridian Circle Program, National Heliogeophysical Complex of the Russian Academy of Sciences.

INTRODUCTION

In the new millennium, near-Earth space has become an area of intense practical activity. The rapid development of technosphere and its growing expansion to space lead to the fact that the processes occurring on the Sun and in near-Earth space (known as space weather) significantly affect space-borne and ground-based technological systems, such as spacecraft, television, communication, navigation, electric power grids, and pipelines. Space weather factors can also pose a threat to human health and life. It is therefore essential to have complete information about these processes, to be able to diagnose and predict space weather, and to assess the potential consequences. Thus, space weather monitoring and forecasting are major scientific challenges for the scientific community of the XXI century. To provide an adequate response to these major challenges, many countries have established special National Space Weather programs. These programs identify priorities in near-Earth space research: development of diagnostic tool networks, advancement of fundamental knowledge about processes in near-Earth space, development and improvement of empirical and theoretical models.

However, physical processes in all regions of near-Earth space are closely interrelated. The system Sun — interplanetary medium — magnetosphere — ionosphere — atmosphere should be studied as a whole. New tools and methods are required to solve this complex problem. International cooperation is also essential, as the processes under study are global in scale. The Chinese-Russian Joint Research Center on Space Weather is focused on solving these problems. The main research areas of the Joint Research Center include:

- solar activity related to solar disturbances;
- propagation of solar disturbances through the solar corona and interplanetary space;
- dynamic processes of various spatial and temporal scales associated with the near-Earth space disturbances;
- propagation of disturbances from high to middle and low latitudes of Earth's ionosphere and atmosphere;
- diagnostics of near-Earth space and forecasting techniques; interaction between near-Earth space and Earth's atmosphere;
- global space weather system and its response to external influences.

MILESTONES

The Chinese-Russian Joint Research Center on Space Weather was established by the Institute of Solar-Terrestrial Physics of Siberian Branch of the Russian Academy of Sciences (ISTP SB RAS) and the National

Space Science Center of the Chinese Academy of Sciences (NSSC CAS, until 2010 known as the Center for Space Science and Applied Research CAS, CSSAR CAS).

Agreement for Scientific Cooperation between the Russian Academy of Sciences and the Chinese Academy of Sciences signed on December 18, 1992 and Agreement for Scientific Cooperation between the Chinese Academy of Sciences and Siberian Branch of the Russian Academy of Sciences signed on October 13, 1999 served as the basis for creating the Joint Research Center. Within the framework of these agreements, Director of CSSAR CAS Professor Gu Yidong and Director of ISTP SB RAS Academician Geliy A. Zherebtsov signed the Agreement for Joint Studies on Solar-Terrestrial Physics and Its Applications in Beijing on November 2, 2000. In December 2000, the first joint workshop was held in Irkutsk. Representatives of CSSAR CAS and ISTP SB RAS took decision to establish the Joint Research Center on Space Weather, and signed its Charter. The first co-directors of the Joint Research Center were Academician Geliy A. Zherebtsov and Professor Wu Ji. Since 2018, co-director of the Joint Research Center from the Chinese side is the Director General of NSSC CAS Academician Wang Chi. In 2012–2017, co-director of the Joint Research Center from the Russian side was the Director of ISTP SB RAS, Corresponding Member of RAS Aleksandr P. Potekhin. Today, co-director of the Joint Research Center is the Director of ISTP SB RAS Corresponding Member of RAS Andrey V. Medvedev.

In accordance with the Charter of the Joint Research Center on Space Weather, workshops are held alternately in Russia and China on a regular basis. At workshops researchers present their scientific results and discuss the prospects for further joint research. The first workshop took place in Irkutsk in 2000. The 10th Anniversary Meeting was held in Beijing in 2010. In 2024, ISTP SB RAS hosted the 15th Anniversary Workshop in Irkutsk (Figure 1).

At the 15th Russian-Chinese Workshop, special attention was given to the International Meridian Circle Program (IMCP) that is led by NSSC CAS and aims to study atmospheric and near-Earth space phenomena and processes using ground-based scientific instruments located along the 120° E and 60° W meridians. China and Russia play a special role in this program since a significant part of the 120° E meridian passes through their territories. New opportunities for IMCP can be provided by the National Heliogeophysical Complex of the Russian Academy of Sciences (NHC RAS), which is being created by ISTP SB RAS. The development of cooperation within IMCP was discussed during the 15th Russian-Chinese Workshop. In the following sections, we address some of the issues related to this cooperation.

The Joint Research Center promotes expanding multilateral cooperation. Many Russian and Chinese institutions have joined our investigations: National Astronomical Observatories of China CAS (NAOC CAS), Institute of Geology and Geophysics CAS (IGG CAS), Peking University (PKU), Yunnan Astronomical Observatory CAS (YNAO CAS), China Research Institute of Radiowave Propagation (CRIRP), Shandong University (SDU), Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy SB RAS (SICRA SB RAS), Space Research Institute RAS (IKI RAS), Pushkov Institute of Earth Magnetism, Ionosphere and Radio Wave Propagation RAS (IZMIRAN), Central Astronomical Observatory of RAS at Pulkovo (GAO RAS), Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS (IKIR FEB RAS), Polar Geophysical Institute RAS (PGI RAS).

Over the 24-year period, approximately 60 scientific projects have been implemented, around 200 exchange visits took place, and more than 230 joint scientific reports have been presented at workshops and conferences. Additionally, over 400 joint scientific articles and two monographs have been published.

MAIN SCIENTIFIC RESULTS

Joint efforts of Russian and Chinese researchers allowed obtaining important results in study of physical processes in near-Earth space. The most interesting scientific results obtained during our cooperation are presented in this Section.

Figure 1. The 15th Russian-Chinese Workshop on Space Weather, Irkutsk, September 2024

First observations of a microwave zebra pattern (ISTP SB RAS, NAOC CAS)

In 2003, researchers from the Institute of Solar-Terrestrial Physics and the National Astronomical Observatories of China first detected a zebra pattern in the microwave range [Altyntsev et al., 2005a, 2005b]. Zebra patterns are intriguing fine spectral structures that look as a number of parallel bright and dark stripes in the dynamic spectra of the solar radio emission. To date, there is no definite conclusion about the formation mechanism of zebra patterns, with more than a dozen of different models proposed. Zebra patterns are generally observed in the metric and decimetric wavelength ranges. In the microwave range, the radio burst was first recorded simultaneously with the Siberian Solar Radio Telescope (at frequencies of 5.70, 5.72, and 5.76 GHz) and the spectropolarimeter of the Huairou Solar Observing Station (in the 5.2–7.6 GHz range). This combination has allowed us to determine not only spectral, but also spatial characteristics of the event. The radio burst consisted of three (possibly, four) parallel equidistant bright stripes with a synchronous temporal evolution. The frequency interval between the stripes was ~160 MHz. The emission had 100 % circular polarization corresponding to the extraordinary mode. The sources of different zebra stripes were found to coincide spatially. It was concluded that the most probable generation mechanism of the zebra pattern considered was nonlinear interaction between harmonics of plasma waves known as Bernstein modes. In this case, the magnetic field in the emission source, as determined by the frequency separation of the zebra stripes, was ~60 G.

Fine wave dynamics in umbral flash sources (ISTP SB RAS, YNAO CAS)

For the first time, information has been obtained on the dynamics of wave processes occurring in small angular solar magnetic structures associated with the Umbral Flashes (Us) [Sych and Wang, 2018]. Fast periodic disturbances related to wave activity in the sunspot umbra were observed over a three-hour period. These disturbances align with the continuous diffuse brightening of specific wave fronts described by Yuan et al. [2014]. Additionally, short-term emergences of small local sources, known as UFs, were identified. The observed umbral brightening can be categorized into two types. The first type consists of background UFs, which exhibit random brightening of separated parts of wave fronts during propagation. These UFs are constantly observed in the umbra and lack stable shapes and spatial localization. The second type consists of local UFs, which are associated with increased wave activity near the footpoints of magnetic loops. These sources demonstrate pronounced wave dynamics and do not change spatial position over time. Different spatial shapes were observed for the local UF sources. Point sources are located at the footpoints of large magnetic loops and display activity with rare low-power pulses. Extended sources are related to the footpoints of low magnetic loops with large inclinations, exhibiting series of recurrent UF pulses. The emergence of the main UF maximum coincides with the peak power of three-minute oscillation trains in separated loops. This wave dynamics follows previously described background UFs by a number of authors, but it is localized within magnetic loops. A correlation exists between UF emergence in the photosphere and increased power of three-minute wave trains in the corona. The observed UF parameters are primarily influenced by the wave cut-off frequency. Further research will focus on investigating the relationship between the shape of local UF sources and the inclination of magnetic loops near their footpoints.

The origin of the helicity hemispheric sign rule reversals in the mean-field solar-type dynamo (NAOC CAS, ISTP SB RAS, IZMIRAN)

Observations at Huairou Solar Observatory of proxies of magnetic felicity in the Sun over the past two solar cycles have revealed reversals of the helicity hemispheric sign rule (negative in the Northern Hemisphere and positive in the Southern one). The mean-field solar dynamo model was used to study changes in the sign of the magnetic helicity for the dynamo, which operate in the bulk of the solar convection zone. The reversal of the sign of the small-scale magnetic helicity was found to follow the dynamo wave propagating inside the convection zone. Thus, the spatial configuration of the magnetic helicity reversals reflects the processes that contribute to the generation and evolution of large-scale magnetic fields. On the surface, the patterns of the helicity rule reversals are determined by the magnetic helicity boundary conditions at the top of the convection zone. The obtained results suggest that the magnetic helicity of a large-scale axisymmetric field can be treated as an additional observational tracer for the solar dynamo and it probably can be used for the solar activity forecast [Pipin et al., 2013].

Improvement of full-disk measurements of solar longitudinal magnetic fields at the Huairou observatory (NAOC CAS, ISTP SB RAS)

Magnetograms of the full solar disk are a necessary element of space weather forecasting algorithms. The Solar Magnetism and Activity Telescope (SMAT) of the Huairou Solar Observatory is one of the few instruments in the world capable of receiving full-disk magnetograms. As a result of joint Russian-Chinese studies of the instrumental characteristics of SMAT, some problems were identified that impede high-precision measurements of weak background magnetic fields of the Sun. Nonetheless, methods to improve the quality of SMAT measurements were proposed, resulting in a significant increase in data reliability [Demidov et al., 2018]. These techniques will allow us to utilize SMART measurements to address a wide range of solar physics issues related to studies of global solar magnetism and space weather.

Saturation of the magnetosphere and the polar cap during superstorms (ISTP SB RAS, NSSC CAS)

Using data from more than 110 ground-based geomagnetic observatories and the magnetogram inversion method developed at ISTP SB RAS, new patterns of the magnetosphere saturation process have been obtained: stopping the growth of the electromagnetic energy flux through the magnetosphere boundary and the polar cap from the solar wind (SW) with its unusual intensification during superstorms [Mishin et al., 2016]. Saturation was shown to be caused not only by an increase in the southern component of the interplanetary magnetic field, but also by an increase in the solar wind dynamic pressure (Figure 2, *a*). Saturation was explained by the magnetosphere finite compressibility (during the increasing SW, the compression of the magnetopause — a decrease in the radius of its subsolar point — stops quickly due to the geomagnetic field pressure increasing earthward (Figure 2, *b*)), which also causes a stop in the growth of the polar cap and the flow of energy into the ionosphere through it. This result was confirmed by numerical simulation using a global MHD model and the Piecewise Parabolic Method with a Lagrangian Remap (PPMLR) [Hu et al., 2009; Wang et al., 2014] (Figure 2, *a*, *c*).

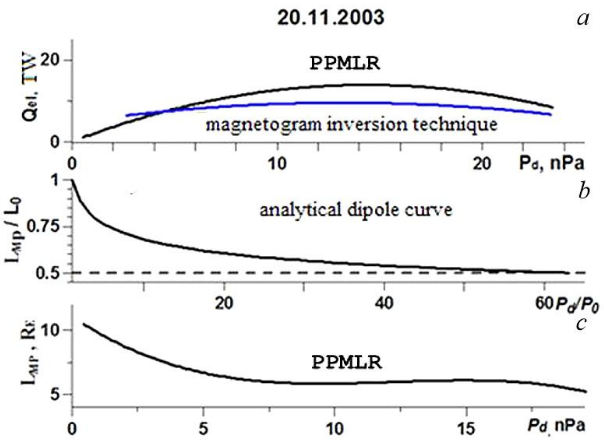

Figure 2. Saturation during an increase in the SW dynamic pressure P_d in the November 20, 2003 storm: electromagnetic energy flux Q_{el} (*a*), subsolar magnetopause radius L_{mp} (*b*, *c*)

Estimated peak density of atomic oxygen between 2000 and 2004 at 52ºN (NSSC CAS, ISTP SB RAS)

A method for deriving the peak density of atomic oxygen in the Mesosphere and Low Thermosphere (MLT) region from atomic oxygen [OI] 557.7 nm nightglow intensity has been developed. The method is based on the photochemical model for [OI] 557.7 nm emission and an approximate expression for the altitude distribution of the atomic oxygen density in the MLT region. This method was used to derive the peak density of atomic oxygen from the 557.7 nm airglow data obtained at the ISTP SB RAS Geophysical observatory in 2000–2004 [Hong Gao et al., 2009]. Nighttime and seasonal variations in the [OI] 557.7 nm intensity and the derived peak density of atomic oxygen were analyzed. The results show that the nighttime variations in the 557.7 nm emission intensity depend on season. The monthly mean 557.7 nm airglow intensity changes with month, showing peaks in March, June, and October, and larger values in winter months. Nocturnal and seasonal variations in the peak density of atomic oxygen are generally similar to those in the 557.7 nm airglow intensity.

Local empirical models of regular ionospheric variations (ISTP SB RAS, NSSC CAS)

Based on long-term ionospheric measurements with vertical sounding ionosondes located at Irkutsk, Norilsk, and Hainan, local empirical models of regular ionospheric variations were worked out (Figure 3) [Ratovsky et al., 2014]. Using the models, common properties and regional features were identified. A common property of the high-, mid- and low latitude ionosphere is the semiannual daytime anomaly of the peak electron density N_mF2

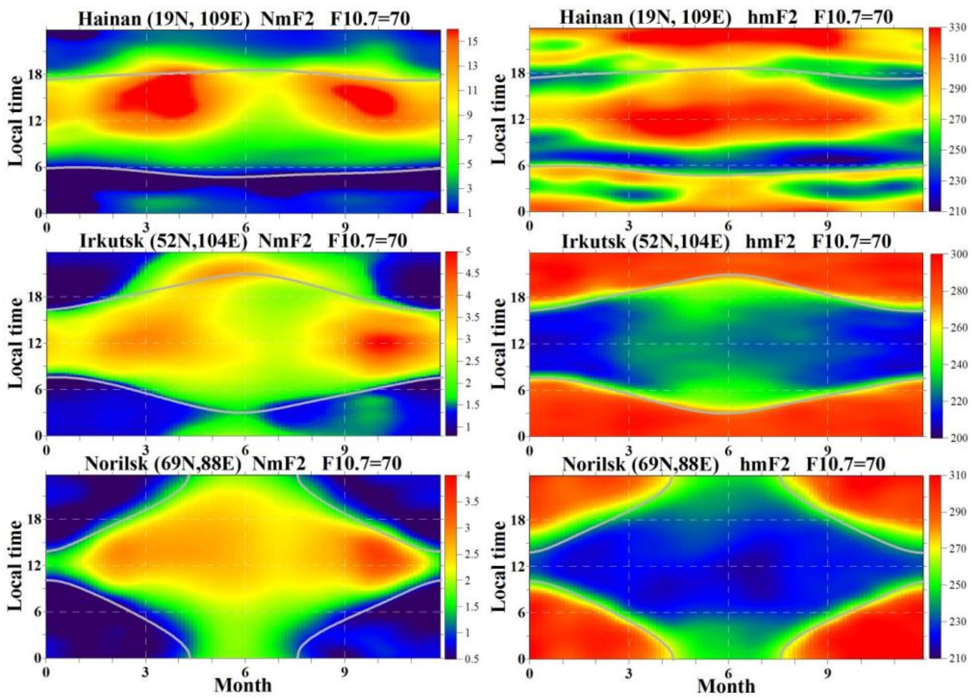

Figure 3. Diurnal-seasonal variations in N_mF2 [10^5 cm^{-3}] (left) and h_mF2 [km] (right) under low solar activity

under low solar activity and the intensification of the winter anomaly with increasing solar activity. The generality is a consequence of the global thermospheric circulation in which all regions of the ionosphere are involved. A distinctive feature of the low-latitude ionosphere is the semi-annual nighttime anomaly of N_mF2 under low solar activity and the highest growth rate of N_mF2 with an increase in F10.7 in the evening and night time. A regional feature of the ionosphere over Hainan (not reproduced by the IRI model) is the multi-peak diurnal variation in the peak height h_mF2 over Hainan. A distinctive feature of the mid-latitude ionosphere is the greatest intensification of the winter anomaly with increase in F10.7 and the evening anomaly in the summer diurnal variation in N_mF2. A regional feature of the ionosphere over Irkutsk (not reproduced by the IRI model) is the morning-evening asymmetry in the summer diurnal variation of N_mF2 at high solar activity. A distinctive feature of the high-latitude ionosphere is the absence of diurnal anomalies in any season and the absence of a winter anomaly at low solar activity. A regional feature of the ionosphere over Norilsk (not reproduced by the IRI model) is the "polar day effect" under low solar activity (no nighttime rise in the peak height h_mF2 in the summer).

Ionospheric response to geomagnetic storms at the meridional chain of ionosondes in the East Asian region (ISTP SB RAS, NSSC CAS)

In 2000–2017, coordinated studies of ionospheric effects of geomagnetic storms were carried out at the meridional chain of ionospheric stations located in the East Asian sector (90°–160° E) in Russia and China (Figure 4) [Pirog et al., 2010; Shi et al., 2011]. For some storms, these studies were supplemented with measurements in the European and American sectors. The following has been revealed: (1) Medium-latitude ionosphere shows properties of high-latitude ionosphere during superstorms. (2) There are differences in the East Asian ionospheric response to geomagnetic storms under high and low solar activity. (3) Three groups of anomalous ionospheric disturbances caused by geomagnetic storms and observed at low solar activity have been identified:

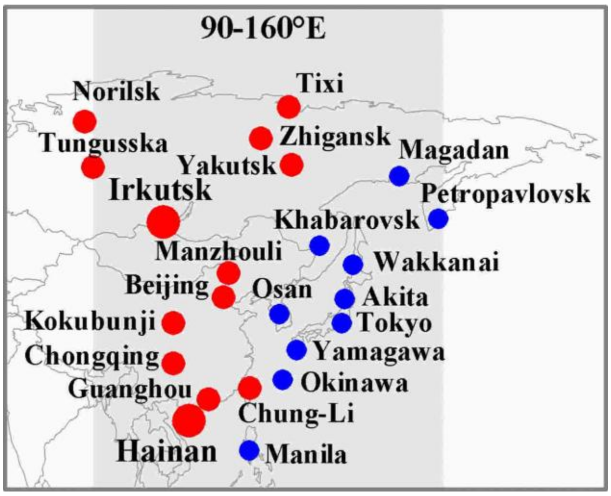

Figure 4. Meridional chains of ionosondes in East Asia

a special type of large-scale traveling ionospheric disturbances, quasi-two-day Wave Like Disturbances (WLDs), oscillations of Short Duration (OSD). (4) Longitudinal alternation of positive and negative ionospheric response during the recovery phase of some storms is observed. Longitude variations of storm ionospheric disturbances are determined by the local time of the storm sudden commencement. (5) A comparative analysis of the behavior of F-scattering in equatorial and high latitudes was performed [Shi et al., 2011].

FROM MERIDIONAL CHAINS TO THE INTERNATIONAL MERIDIAN CIRCLE PROGRAM (IMCP)

Ground-based chains of geophysical instruments are a powerful tool for studying and monitoring the effects of space weather in Earth's ionosphere and magnetosphere. Due to the latitudinal difference in solar radiation and the bounding of charged particles by the geomagnetic field, space weather disturbances are usually manifested along the meridians. As a result, observing along a specific meridian line has a great deal of advantages. The effectiveness of observations at the meridional chains has been confirmed by a rich history of such observations.

Observations at the Norilsk and Yakutsk meridional chains of stations in Russia: 1969–1983

To study geophysical phenomena in the upper atmosphere of high latitudes, ISTP SB RAS and SHICRA SB RAS organized synchronous observations at the Norilsk and Yakutsk meridional chains of stations (Figure 5). The observations were conducted as part of the International Magnetospheric Study (IMS) program (1976–1979). From 1969 to 1983, a total of 6 measurements campaigns (expeditions) were organized: 1969 — at the Yakutsk meridian; 1973 — at the Norilsk meridian; 1976 — Siberia-IMS-76, start of synchronous observations at the Yakutsk and Norilmk meridians; 1979 — Siberia-IMS-79; 1982 and 1983 — Taimyr-82. Each expedition had its own scientific program. The observation stations were fitted with the same type of equipment, and the observations were carried out according to a unified coordinated program. The standard set of equipment included magnetovariation station, all-sky camera, zenith photometer, scanning photometer, and ionosonde. The Khatanga station, located to the east of the Norilsk meridian, was used to link observations with data from the Yakutsk meridian chain.

As a result of this observations, we have first of all formulated the principles for organizing meridional chains of stations [Rakhmatullin, 2010, and references therein]:

- stations along the meridian should be positioned with the least scatter in longitude to minimize errors related to longitudinal effects;
- two or three meridional chains are necessary to study longitudinal effects and control the geophysical conditions;
- stations of the chain should be equipped with geophysical instruments of various types, such as magnetometers, ionosondes, photometers, to not only record processes in different geospheres, but also to study their interaction and identify physical mechanisms.

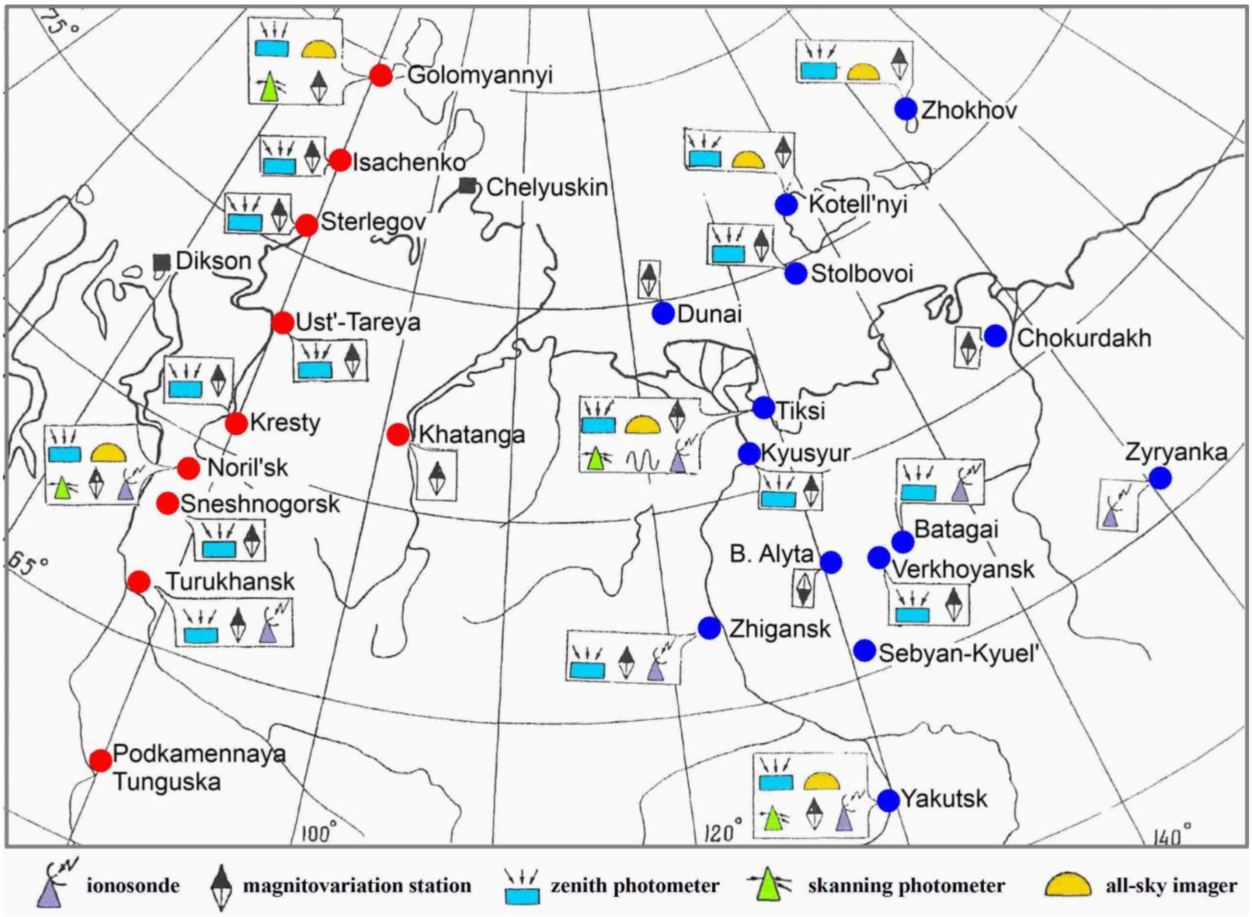

Figure 5. Norilsk and Yakutsk meridional chains of stations. Based on the materials of [Rakhmatullin, 2010]

Substorm in geomagnetic pulsations

Observations at meridional chains were essential for understanding the mechanism of a magnetospheric substorm [Rakhmatullin, 2010]. The development of geomagnetic pulsations during substorms was studied in detail. This work was pioneering for that time. And the resultant pattern of the magnetospheric substorm in geomagnetic pulsations has not changed significantly so far. For the first time, the longitudinal and latitudinal dimensions of the sources of Pi2 and Pi1B pulsations were determined, their relation to auroras was shown, and generalized schemes of drifts of pulsation sources were created. Fundamental differences in generation of Pi2 pulsations at auroral and mid-latitudes were found. It was shown that the amplitude and spectral composition of the mid-latitude Pi2 pulsations are controlled by the state of the ionospheric F2 layer.

A method was developed to determine the longitude of substorm development in the auroral zone from parameters of mid-latitude Pi2 pulsations (Figure 6). After the onset, the substorm propagates as a series of successive amplifications of magnetic activity; each occurs northwest of the previous one and is accompanied by Pi2 generation. The main axis of the Pi2 polarization ellipse is always directed toward the source. With the motion of the substorm disturbance, the polarization axis rotates counterclockwise. Thus, the longitude of the substorm can be determined from the direction of the polarization axis.

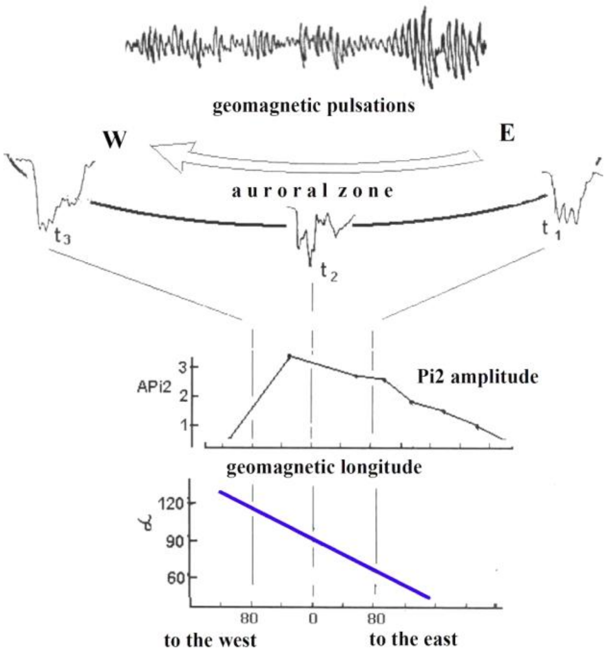

Figure 6. Scheme of substorm development in the auroral zone and in midlatitudes. Based on the materials of [Rakhmatullin, 2010]

Model of ionospheric substorm

According to the data from the Norilsk meridian, a morphological description of the processes in the high-latitude ionosphere was made [Zherebtsov et al., 1986; Pirog et al., 1997]. Statistical schemes of ionospheric substorm development north of the MIT in LT–K_p coordinates at different latitudes were constructed, and the effect of solar activity was revealed. In addition, a regional model of critical frequencies of E and F regions for the Norilsk meridian was developed. Complex processing of data from meridional chains made it possible to obtain an equation describing the position of the Main Ionospheric Through (MIT) under different magnetic activity: $\Phi = 150.6 - 5t - 25(0.1K_p^2 - 1.3t + 12.7)^{1/2}$, where Φ is invariant latitude, t is the time counted from midnight, K_p is the geomagnetic activity index.

The extensive experimental material obtained during complex high-latitude expeditions became the basis for further research. Nowadays, we are turning to the expedition archives to confirm this or that experimental fact. The archives also serve as an experimental base for studying long-term trends. The results obtained confirm the effectiveness of meridional chains of geophysical instruments in studying the magnetosphere-ionosphere interactions.

Chinese Meridian Project (CMP)

In China, the concept of the national Meridian Project was proposed in the early 1990s [http://imcp.ac.cn/en/about/planning/; https://www.meridianproject.ac.cn/mcmp/]. Development of the Chinese Meridian Project (CMP) began in 2005 [Wang Chi et al., 2020, 2022; https://www.meridianproject.ac.cn/en/]. The project rolled into realization stage in 2008 upon being approved by the government as one of the major scientific structures. The Chinese Meridian Project is a ground-based space environment monitoring network. It is a joint effort of more than 10 research institutions and universities in China, led by NSSC CAS. The Project aims to study the propagation processes of disturbances caused by solar activities, from the Sun to the interplanetary space, magnetosphere, ionosphere, until mid-to-upper atmosphere; coupling mechanisms of different space spheres and layers, namely solar atmosphere, interplanetary space, magnetosphere, ionosphere, and mid-to-upper atmosphere; regional characteristics of the space environment above China's territory, and its relationship with global variations [Wang Chi et al., 2020]. CMP was built in two stages (Figure 7). The Phase I construction began in 2008 and was completed in 2012. Since 2012, Phase I has been in operation. Phase II started in 2019 and was successfully completed in 2024 [Wang Chi et al., 2020, 2022, 2024]. CMP Phase I consists of 15 ground-based observatories located along 120° E and 30° N (Figure 7, *a*). Each observatory is equipped with multiple instruments including magnetometers, radars, optical equipment, and sounding rockets to monitor parameters of solar wind, geomagnetic field, middle and upper atmosphere, ionosphere. CMP Phase II has added 16 new stations to Phase I, and thus created a monitoring network of 31 stations and nearly 300 instruments along 100° E and 120° E, and 30° N and 40° N (Figure 7, *c*). In addition to the usual instruments, Phase II comprises several large and advanced devices including a radio heliograph, an interplanetary scintillation telescope, an MST radar, a new generation tristatic incoherent scatter radar, etc.

CMP and Chinese-Russian Joint Research Center

Within the framework of the Chinese-Russian Joint Research Center, Russian stations have joined the chain of Chinese observatories since 2005 (Figures 4, 7, *b*). A significant number of joint studies on the ionospheric morphology over the East-Asian region under different levels of solar and magnetic activity have been conducted. Many interesting results have been obtained, some of them are described in the Section "Main scientific results". Comprehensive analysis of data from Chinese-Russian chains allowed clarifying mechanisms of interplanetary, magnetospheric, and thermospheric factors' impact on the ionospheric dynamics. It also allowed evaluating the possibility to use the existing theoretic models for reproducing the spatio-temporal dynamics of the ionosphere and to identify the possible ways of correcting models in order to improve their diagnostic and, in a long run, predictive features. The results are summarized in a collective monograph "Ionospheric disturbances in East-Asian region" [Zherebtsov et al., 2021].

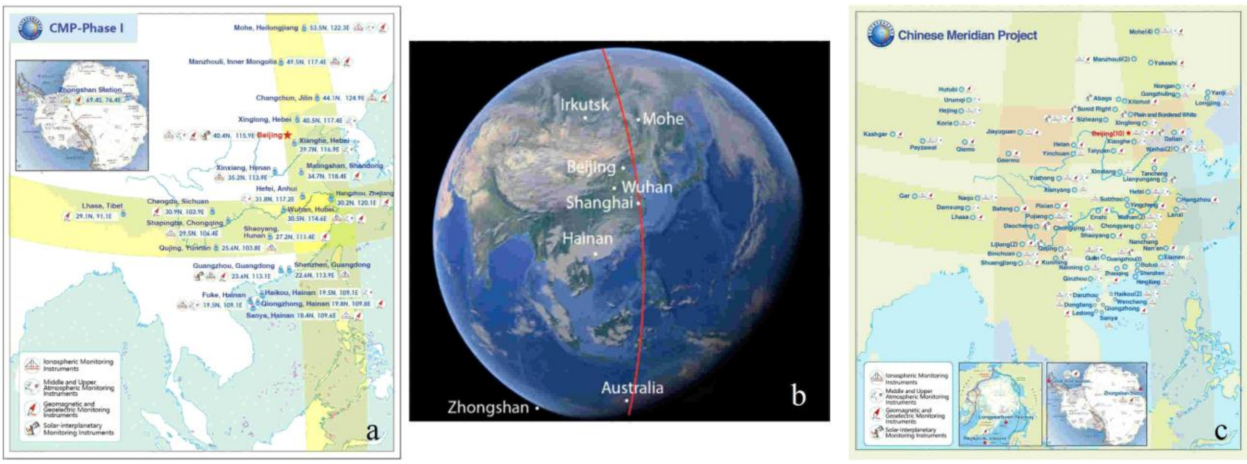

Figure 7. Chinese Meridian Project: Phase I (*a*) and Phase II (*c*) [https://www.meridianproject.ac.cn/bi/]. Observatories along 120° E making part of the Meridian Space Weather Monitoring Project in 2005 (*b*) [The 20th Anniversary, 2021]

INTERNATIONAL MERIDIAN CIRCLE PROGRAM (IMCP)

The International Meridian Circle Program (IMCP) became an excellent development of the CMP concept [Liu et al., 2020, 2022; Blanc et al., 2020; Wang Chi et al., 2024; http://imcp.ac.cn/en/]. This large and unique project of NSSC CAS was proposed to bring together more than 1000 instrumentation from over 10 countries along the 120° E and 60° W meridians to create a global monitoring network (Figure 8) [http://imcp.ac.cn/en/about/objectives/]. The Great Meridian Circle crosses China, Russia, Southeast Asia, Australia, Antarctica, Latin America, the United States, Canada. IMCP aims to conduct all-latitude, all-weather observations of the system formed by near-Earth space, the atmosphere, the Earth surface. It is designed to track propagation of space weather events from the Sun to Earth as well as to monitor various disturbances generated within the Earth system that impact near-Earth space [Liu et al., 2022; Wang Chi et al., 2024].

The instruments deployed along Great Meridian Circle can provide a complete cross-sectional scan of near-Earth space from the ground level up to approximately 3000 km, including density, temperature, magnetic and electric fields, wind fields, planetary waves, and distribution of minor species involved in Global Change [http://imcp.ac.cn/en/about/sw/]. Due to Earth's rotation, this network can give a complete three-dimensional representation of these key near-Earth space parameters every 12 hours. Accumulated over years and decades, this dataset will provide valuable insight on how climate and long-term atmospheric change are influenced by solar and terrestrial energy input. By detecting and tracking short-term anomalies, the network can warn about space weather and terrestrial disasters.

Currently, significant progress has been made on IMCP [Wang Chi et al., 2024]. The IMCP scientific program committee has been formed, and the China-Brazil joint laboratory for space weather has also been established. Networks in the North Pole and Southeast Asia are under construction. IMCP is supported by an array of Chinese and foreign research institutions, as well as international scientific associations such as the European Incoherent Scatter Radar Scientific Association (EISCAT), the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP), and the Super Dual Auroral Radar Network (SuperDARN) [http://imcp.ac.cn/en/about/objectives/].

Moving forward, in addition to the 120° E – 60° W meridian circle, IMCP also plans to establish network along the 30° E – 150° W meridian circle in collaboration with the International Space Weather Initiative (ISWI) [Wang Chi et al., 2024; Blanc, 2023]. Thousands of IMCP instruments will create a three-dimensional information grid covering five continents. This grid will provide real-time data on near-Earth space, helping to protect our planet from natural and human-made hazards.

NATIONAL HELIOGEOPHYSICAL COMPLEX OF THE RUSSIAN ACADEMY OF SCIENCES (NHC RAS)

The National Heliogeophysical Complex of the Russian Academy of Sciences (NHC RAS) [Zherebtsov, 2020; http://ngkran.ru/] can make a significant contribution to IMCP for mid- and high-latitude observations at 120° E meridian. NHC RAS has been developed and is being created by ISTP SB RAS which has a long history of expertise and operation of large heliogeophysical instruments. In 2014, NHC RAS received the support from the President of the Russian Federation and the Government of the Russian Federation. The complex should provide solutions to the most important problems of solar-terrestrial physics considering the Sun — Earth system as a uniform and interrelated one. The National Heliogeophysical Complex has been developed on the basis of new technical solutions with the use of modern technologies. It integrates unique facilities, instruments, and devices.

The objectives of the National Heliogeophysical Complex RAS are: to get to a new level of development of experimental (ground-based) research in solar-terrestrial physics; to solve urgent fundamental and applied problems

Figure 8. International Meridian Circle Program (IMCP) [http://imcp.ac.cn/en/about/objectives/]

in the interest of development of new space technologies. Fundamental research involves studying solar activity (magnetic fields, flares, plasma ejections, etc.) and its effect on space weather; studying the magnetosphere-ionosphere-atmosphere system and effects imposed on it by solar factors and meteorological and lithospheric processes. Applied research involves studying the effects of space factors on operation of spacecraft and various engineering systems (radio communications, radar, GPS-GLONASS and others); monitoring of near-Earth space, spacecraft and space debris; developing methods for solar activity and near-Earth space monitoring and prediction to the benefit of different consumers.

The NHC RAS includes five large, new generation experimental instruments for research in the field of solar physics and near-Earth space physics [Zherebtsov, 2020; http://ngkran.ru/]: Large Solar Telescope-Coronagraph, Multiwave Radioheliograph, Radiophysical Complex for Atmospheric and Ionospheric Research, Network of Coherent Ionospheric Radars, Lidar Optical Complex (Figure 9). Collection, real-time processing, and storage of information from NHC RAS instruments will be performed at the Data Center which will be established in Irkutsk (ISTP SB RAS). At present, the first NHC RAS instruments (Radioheliograph and Optical tools) have commenced their functioning. The development and construction of the Large Solar Telescope and a Radiophysical Complex are underway.

The Large Solar Telescope-Coronagraph (LST-3)

One of the most pressing issues in contemporary solar physics is the observation of the small-scale structure in the solar atmosphere at various heights (including the chromosphere and corona). These observations can only be conducted using large solar telescopes. The Large Solar Telescope-Coronagraph with a mirror 3 m in diameter (LST-3) is designed for observing the solar atmosphere and corona with previously unattainable spatial, temporal, and spectral resolution [Grigoryev et al., 2020]. Missions of LST-3 include studies of energy release in flares and other dynamic phenomena, heating processes in the corona, the origin of solar magnetism and cyclicity. Operation of LST-3 in coronagraphic mode will allow us to observe space objects such as asteroids and comets near the Sun including hazardous ones in the daytime. The telescope will be installed at the Sayan Solar Observatory, located at an altitude over 2000 m (Figure 10). The choice was made in favor of the classic axisymmetric Gregory optical layout on an alt-azimuth mount. The scientific equipment of LST-3 will consist of several systems of narrow-band tunable filters and spectrographs for various wave ranges. The equipment will be placed both in the main coudé focus on a rotating platform and in the Nasmyth focus. To achieve a diffraction resolution, high-order adaptive optics will be used. It is assumed that with a certain modification of the optical configuration, LST-3 will work as a 0.7 m mirror coronagraph in near infrared lines and can also be used for observing astrophysical objects in the nighttime. The development of LST-3 should make a decisive contribution to our understanding of solar activity, which drives space weather phenomena.

The Multiwave Siberian Radioheliograph

The Multiwave Siberian Radioheliograph (MSRH) performs all-weather monitoring of processes in the solar atmosphere (in the range from meter to millimeter waves, including measurements of the solar activity index at 2.8 GHz) [Altyntsev et al., 2020; http://badary.iszf.irk.ru]. This is essential for predicting and diagnosing geoeffective solar activity phenomena. The fundamental

Figure 9. NHC RAS instruments in Eastern Siberia: 1— Large Solar Telescope-Coronagraph; 2 — Multiwave Siberian Radioheliograph; 3 — Complex of Passive Optical Instruments; 4 — Heating Facility; 5 — Data Center; 6 — IS-MST Radar; 7 — Mesostratospheric Lidar

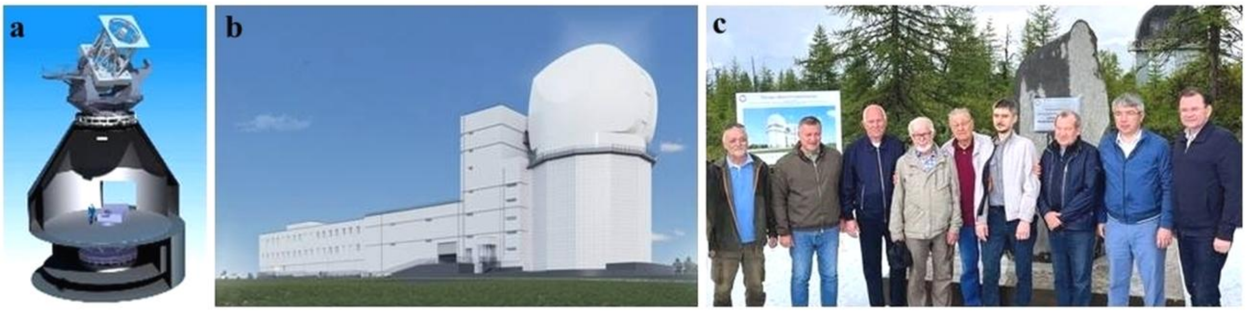

Figure 10. NHC RAS: Large Solar Telescope-Coronagraph. General view of LST-3 (*a*) and LST-3 building (*b*). Groundbreaking ceremony of LST-3 on August 5, 2023 (*c*)

research that may be implemented with the radioheliograph includes: topology of coronal magnetic fields during the active and quiet Sun; wave processes and shock waves in the solar atmosphere; evolution of large-scale structures in the solar atmosphere during the 11-year solar cycle; regular measurements of radio emission at a wavelength of 10.7 cm; assessment of geoeffectiveness of solar flare parameters; short-term prediction of powerful solar flares with a lead time of 2 to 3 days. MSRH is located at the ISTP SB RAS Radio Astrophysical Observatory (Figure 11, *a*). This allows us to carry out observations using MSRH in conjunction with the existing instruments. MSRH is an interferometer that produces solar images in the 3–24 GHz frequency range in both circularly-polarized components [Altyntsev et al., 2020]. It consists of three separate antenna arrays, each designed for one frequency band: 3–6 GHz, 6–12 GHz, and 12–24 GHz. The antenna diameters for these bands are 3, 1.8, and 1 m respectively. The numbers of antennas in the arrays are 129, 192, 207. Radioheliograph data is necessary to develop and implement methods of short-term forecast of solar flares, measurements of kinematics and characteristics of coronal mass ejection plasma, forecast of characteristics of fast solar wind streams. All-weather monitoring of explosive processes on the Sun will enable us to solve an important applied problem — to assess their impact on the operation of space facilities, as well as ground-based communication, navigation, radar, and other technological systems. MSRH is already in operation. Figure 11, *b*–*c* show solar images obtained with MSRH at three frequencies on September 19, 2023.

The Radiophysical Complex

The Radiophysical Complex (RPhC) for ionospheric and atmospheric research is the largest complex and multifunctional information system in the National Heliogeophysical Complex [Zherebtsov, 2020; Medvedev et al., 2020; Vasilyev et al., 2020a]. RPhC includes the most powerful and promising research instruments: a radio wave incoherent scatter (IS) radar for ionospheric sounding; a mesospheric-stratospheric-tropospheric (MST) radar for sounding the neutral atmosphere; a heating facility for modifying the ionosphere with powerful HF radio waves. This cluster of large tools will be supplemented with a system of small problem-oriented instruments and a meridional chain of stations Norilsk — Irkutsk (ionosondes, magnetometers, photometers, etc.). The IS-MST Radar, which combines capabilities of IS and MST measurements, will be able to cover layers from the troposphere to the plasmasphere (altitude range 10–1500 km) and to study processes of energy transfer from the lower and middle atmosphere to the ionosphere as well as the interaction of the magnetosphere with the upper atmosphere. Apart from atmospheric research, the radar will allow us to track spacecraft and space debris, determining precise coordinate characteristics. The antenna system is also suitable for radio astronomical observations.

RPhC will be located near Lake Baikal in Tazheran steppes [Medvedev et al., 2020]. The RPhC location is unique since the complex will provide important geophysical data and monitor near-Earth space in the center of Russia, significantly complementing observational data acquired by geophysical centers in the USA, Europe, and Japan in studying global distributions of envi ronmental parameters.

The main focus of RPhC studies is on the upper atmosphere (80–1500 km) as one of the most important parts

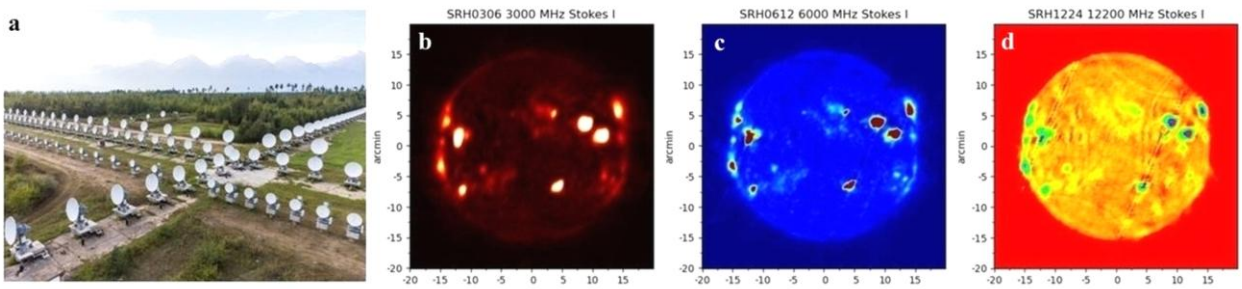

Figure 11. NHC RAS: Multiwave Siberian Radioheliograph. MSRH antenna arrays (*a*). Solar images at 3.0, 6.0, 12.2 GHz obtained by Ragioheliograph on September 19, 2023 (*b*–*d*)

of the Sun — Earth system. The results of the ionospheric and upper atmospheric research with RPhC are important for various fields of science and technology: space and terrestrial radio communications, radar, and navigation; near-Earth space monitoring, including problems of comet and asteroid impact hazards and space debris.

The IS-MST Radar

The IS-MST Radar includes two phased arrays spaced by 100 m and have a tilt of 20° in opposite directions so as to cover as large area as possible (Figure 12) [Medvedev et al., 2020]. The radar operating frequency band is 154–162 MHz, and the peak transmitted power of each array is 1 MW.

Figure 13 shows the main operating modes of RPhC [Medvedev et al., 2020]. The MST mode (Figure 13, *a*) will be used for diagnostics of dynamics (the neutral wind parameters) in the lower and middle atmosphere. For ionospheric research, we will utilize two operating modes corresponding to two height ranges (below 500 and above 500 km): mode IS-1 for studying interactions in the atmosphere-ionosphere system and multi-parameter diagnostics of the ionospheric plasma (Figure 13, *b*); mode IS-2 for studying interactions within the ionosphere — plasmasphere system as well as measuring variations in the ion composition and tracks of plasma fluxes (Figure 13, *c*). The SO monitoring mode will provide monitoring of space objects (SO) such as spacecraft and space debris (Figure 13, *d*). In the cooperative observation mode (Figure 13, *e*), an ionospheric region, irradiated by the heater, will be scanned by the IS-MST Radar, optical tools, HF and GNSS receivers; this will ensure comprehensive diagnostics of phenomena occurring upon powerful high-frequency impact on the ionosphere. The passive mode (Figure 13, *f*), where the radar does not transmit, but detects space signals from various directions, will be useful for radioastronomy observations of radiation from the Sun and space radio sources, as well as for studying radio storms and radio signal scintillations.

The heating facility IKAR-AI

Developed with NHC RAS, the new heating facility IKAR-AI (Irkutsk short-wave antenna array with active transmitters) takes into account the extensive experience in heating in Russia and abroad [Vasilyev et al., 2020a].

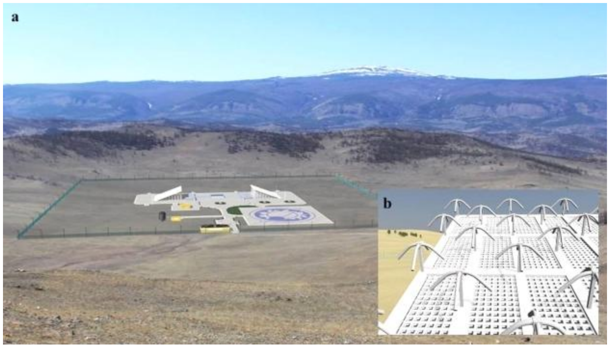

Figure 12. NHC RAS: IS-MST Radar. General view near Lake Baikal (*a*), antenna of IS-MST Radar (*b*)

The heating facility is a complex of 60 antennas on an area of 700×700 m (Figure 14, *a*). IKAR-AI will radiate in a frequency range 2.5–6.0 MHz with an effective power of several hundred megawatts. The proposed frequency band is the best to undertake new research at IKAR-AI. The transfer of shortwave radiation energy to a charged particles in the upper atmosphere is the most effective in the lower band 2.5–3.5 MHz, where the second electron gyrofrequency harmonic is located and where the most intense artificial ionospheric turbulences and optical airglow occur. The upper band part (the 4–6 MHz) allows for the efficient operation of the heating facility periods of higher solar activity, as well as for the use of IKAR-AI as a short-wave radar for ionospheric diagnostics. It is important that the heater will be surrounded by such multifunctional instruments as the incoherent scatter radar, mesostratospheric lidar, optical and radiophisical observational systems that can enable us to diagnose artificial plasma disturbances and artificial airglow structures (Figure 14, *b*).

Network of Coherent Ionospheric Radars (SECIRA)

Under the NHC RAS project, ISTP SB RAS is deploying the Russian network of coherent ionospheric radars analogous to SuperDARN [Berngardt et al., 2020; Zherebtsov, 2020]. The Russian radars can make observations over almost the entire territory of the Russian Federation (Figure 15, *a*) and are capable of studying the magnetosphere-ionosphere coupling, including effects of magnetospheric substorms and geomagnetic storms in mid-latitude and subauroral regions. The project of SECIRA radars has been developed at ISTP SB RAS. The radar is based on fully digital generation and receiving of signals, which is currently the major approach in developing new radars [Berngardt et al., 2020].

Unlike SuperDARN radars, SECIRA radars will have T-shaped phased antenna arrays (PAA) (Figure 15, *b*). Each PAA consists of 16 transmitting/receiving and 8 receiving antennas arranged in two perpendicular linear phased arrays. The distance between antennas (~15 m) coincides with distances in SuperDARN PAA. The maximum radiation power of each antenna is 1 kW. The SECIRA PAA geometry allows us to minimize the problems associated with the phase uncertainty of the received signal, as well as to consistently identify signals coming from the back lobe. The Russian system of coherent radars provides studies in several major areas: solar wind interaction with the magnetosphere and ionosphere; internal atmospheric waves; scattering by meteors and mesospheric winds; natural and artificial plasma irregularities. The Russian SECIRA network will also provide the solution to the following applied problems: continuous monitoring of ionospheric disturbances in sub-polar regions affecting the various technological systems; monitoring of the auroral oval boundary for efficient prediction of blackouts in high-frequency radio channels and optimal operating frequencies under different geophysical conditions; near real-time diagnostics of wave ionospheric disturbances as most unpredictable factor of disturbances for communication and navigation systems.

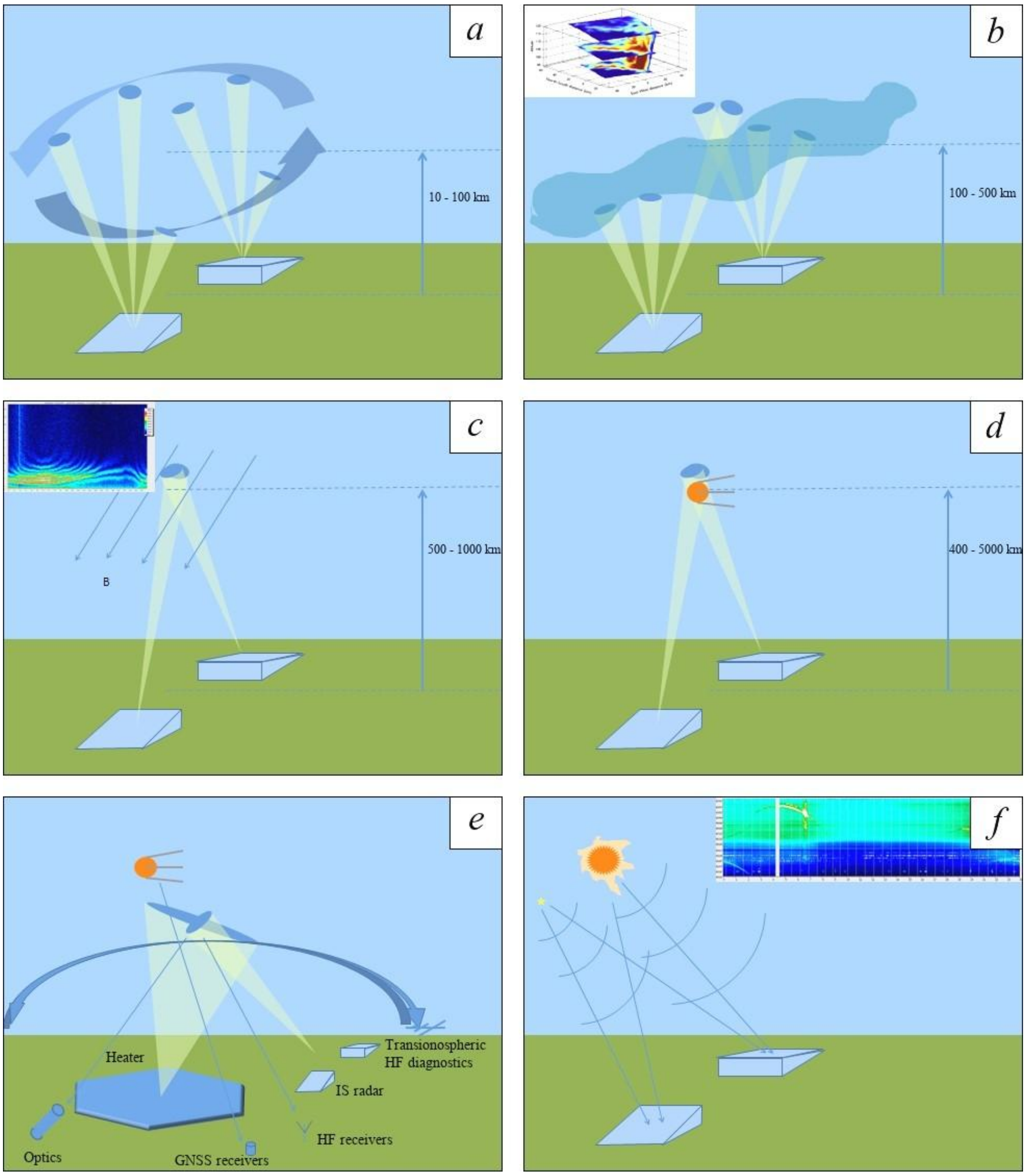

Figure 13. NHC RAS: IS-MST Radar. Operating modes of IS-MST Radar: MST mode (*a*); IS-1 mode (*b*); IS-2 mode (*c*), SO monitoring mode (*d*); cooperative observation mode (*e*), radioastronomical (passive) mode (*f*) [Medvedev et al., 2020]

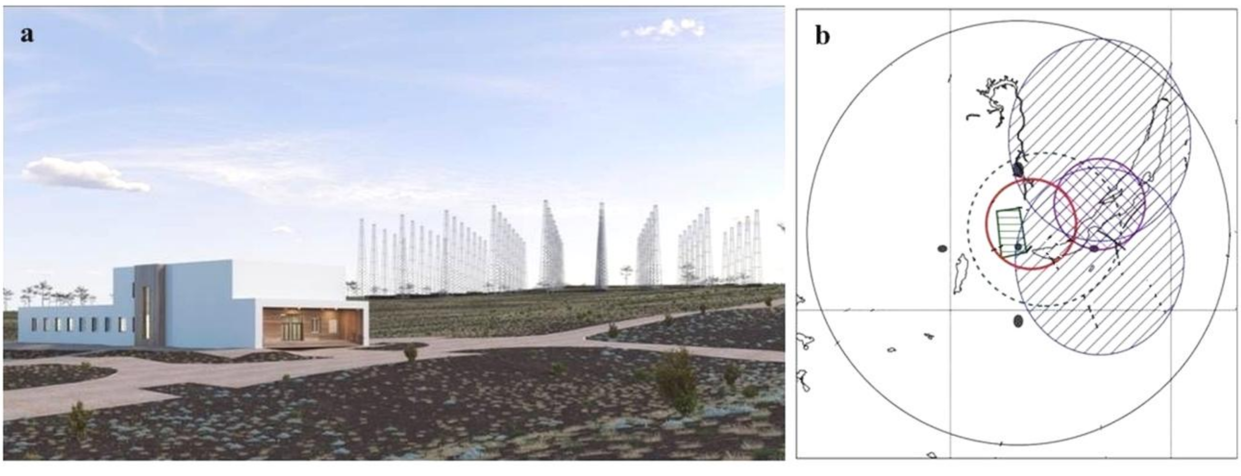

Figure 14. NHC RAS: Heating Facility. General view of the Heating Facility (*a*). Fields of view of the NHC RAS instruments at an altitude of 250 km are (*b*): red circle for the Heating Facility; blue ellipses with right hatching for the IS-MST Radar; purple circle with left hatching for the MS lidar; green trapezium with horizontal hatching for the existing Irkutsk IS-radar; green dashed circle for the existing ionosonde DPS-4; black circle for the all-sky camera; gray ellipses for the Fabry — Perot interferometer [Vasilyev et al., 2020a]

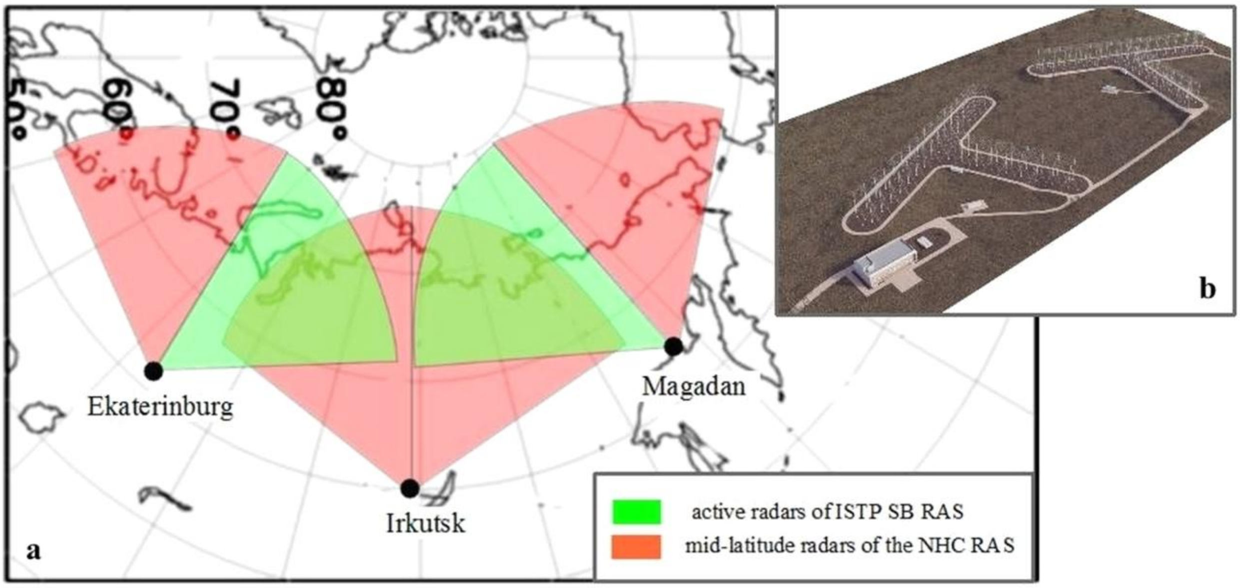

Figure 15. NHC RAS: Network of Coherent Ionospheric Radars. Position of coherent radars and their fields of view (*a*). General view of coherent radar of NHC RAS (*b*)

Lidar Optical Complex (LOC)

Lidar Optical Complex (LOC) is designed to study profile characteristics of physical parameters (temperature, density, wind) and composition (gas components, aerosol) of the middle and upper atmosphere, which are formed under the influence of natural processes and anthropogenic impacts [Matvienko et al., 2020; Vasilyev et al., 2020b]. The optical complex combines active laser systems [Matvienko et al., 2020] and passive optical instruments for recording the atmospheric emission [Vasilyev et al., 2020b]. The Lidar Optical Complex will allow solving basic problems in atmospheric research at different altitudes, along with important practical problems in the field of environmental ecology and global climate change.

The mesostratospheric lidar

The study of the upper atmosphere, including the mesosphere and the thermosphere, requires lidar systems with large optics and high-power lasers. Such a mesostratospheric (MS) lidar (Figure 16) will be developed as part of NHC RAS with the use of theoretical and experimental developments, received at V.E. Zuev Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences (IAO SB RAS) [Matvienko et al., 2020]. The MS lidar should allow us to measure profiles of thermodynamic parameters of the atmosphere and distribution of the aerosol-gas composition in the altitude range 10–100 km. The proposed version of the MS lidar utilizes different laser sources within 350–1100 nm range and corresponding narrowband high-sensitivity detectors of lidar signals. The wide spectral range is necessary for realizing various laser sensing methods when obtaining information about remote atmospheric layers. The problem of combining various measurement methods for one receiving antenna will be solved by spectral selection and using the multilobe antenna pattern.

The passive optical instrument

The passive optical instruments (Figure 17) include [Vasilyev et al., 2020b] Fabry — Perot interferometers with diameter of etalon 70 mm, equipped with automatically interchangeable light filters and an automatically controlled periscope input window having a sensitivity sufficient to detect wind and temperature variations in the upper atmosphere at a level of 5 m/s and 5 K respectively; all-sky cameras with spatial resolution ~0.1°–0.5° and sensitivity in several Rayleigh, equipped with automatically interchangeable light filters; high-speed photometers with a field of view of ~10° and time resolution of 1 ms; diffraction spectrometers in visible and infrared spectral ranges with ~0.1 nm spectral resolution and sensitivity sufficient to observe variations in the intensity of lines in several Rayleigh. The complex of passive optical instruments has been put into operation and carries out regular measurements at the Geophysical Observatory of ISTP SB RAS (GPO ISTP RAS). Figure 17, *c* shows SAR-arcs detected at GPO ISTP RAS (midlatitudes) with an all-sky camera at a wavelength of 630 nm during the April 23, 2023 strong geomagnetic storm.

The Data Center

The Data Center to be established in Irkutsk will provide collection, real-time processing, and storage of data from NHC RAS instruments; it will also allow for data transfer to users (Figure 18). Its computing power and hardware as well as software architecture should ensure compliance with the requirements for speed, storage capacity (at least 100000 terabytes per year), generation of necessary warnings, indices, and other indicators of the state of the Sun and near-Earth space.

The main goals of Data Center are: carrying out experiments to the benefits of scientific organizations (Shared Equipment Center); preparing data products for end users (customers); space weather conditions: warnings and alarms for consumers; online control of working modes of the instruments of NHC RAS; collecting data from NHC RAS instruments; data processing; data storage.

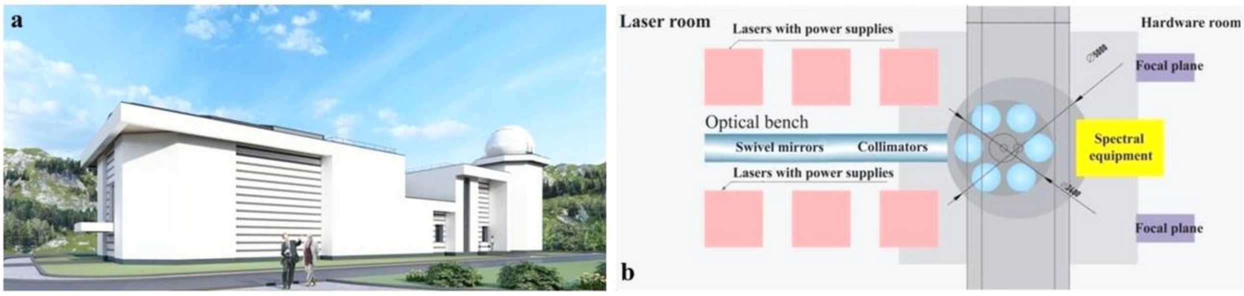

Figure 16. NHC RAS: Mesostratospheric lidar. General view of MS lidar building (*a*); arrangement of the main elements of the MS lidar (*b*) [Matvienko et al., 2020]

Figure 17. NHC RAS: Complex of passive optical instruments at GPO ISTP RAS. Building (*a*); an all-sky camera in the dome space (*b*); SAR-arcs detected with the all-sky camera at a wavelength of 630 nm during the April 23, 2023 strong geomagnetic storm (*c*)

Figure 18. NHC RAS: Data Center. General view of Data Center building

The National Heliogeophysical Complex will facilitate the transition to a qualitatively new level of development of basic and applied research in solar-terrestrial physics, and ensure high-level implementation of these works for the next 25–30 years. The geographical location of the complex, its multifunctionality and technical equipment will allow Russian scientists to participate in international programs including IMCP and the Chinese-Russian Joint Research Center.

CONCLUSION

The foundation of the Chinese-Russian Joint Research Center on Space Weather in 2000 reflected the main trends in society and science. The center's activities focus on addressing fundamental issues in modern solar-terrestrial physics, such as quantitative description of the processes in complex interconnected system Sun — interplanetary medium — magnetosphere — ionosphere — atmosphere, assessment of capabilities of predicting interactions within this system, development of effective models for forecasting the state of the atmosphere and near-Earth space. The Joint Research Center is aimed at the study of all major space weather events from the Sun to the magnetosphere, ionosphere, and atmosphere.

In 2024, the Chinese-Russian Joint Research Center on Space Weather celebrated its 24th anniversary. We have been working together for two solar cycles already. Founded by ISTP SB RAS and NSSC CAS, the Joint Research Center has united more than 10 scientific institutes in Russia and China. About 60 scientific projects have been implemented and more than 400 joint scientific articles have been published. As part of the Joint Research Center's work, the following important results were obtained. Simultaneously at the Siberian Solar Radio Telescope (Russia) and the Huairou Solar Observing Station (China), zebra patterns in the microwave range were recorded for the first time. This allowed us to determine not only spectral, but also spatial characteristics of the event. For the first time, data was collected on the evolution of wave processes in small angular solar magnetic structures linked to umbral flashes. The spatial patterns of the magnetic helicity reversals in the Sun were shown to reflect the processes which contribute to generation and evolution of the large-scale magnetic fields. New patterns of Earth's magnetosphere saturation process were obtained: stopping the growth of the electromagnetic energy flux through the magnetosphere boundary and the polar cap from the solar wind with its unusual intensification during superstorms. Local empirical models of regular ionospheric variations at high, mid-, and low latitudes were created based on long-term ionospheric measurements with vertical sounding ionosondes in Norilsk, Irkutsk and on Hainan island. Coordinated studies of the ionospheric effects of geomagnetic storms in 2000–2017 were performed at the meridional chain of ionospheric stations in Russia and China. The medium-latitude ionosphere was found to exhibit properties of high-latitude ionosphere during superstorms. Additionally, there are differences in the East Asian ionospheric response to geomagnetic storms at high and low solar activity. Furthermore, there is longitudinal alternation of positive and negative ionospheric response during the recovery phase of some storms.

The future work of the Joint Research Center will be closely linked to the implementation of major unique projects in China and Russia: the International Meridian Circle Program (IMCP) led by NSSC CAS, and the National Heliogeophysical Complex of the Russian Academy of Sciences (NHC RAS) led by ISTP SB RAS.

IMCP connects 120° E and 60° W meridian chains of ground-based observatories to enhance the ability to monitor space environment worldwide. Currently, institutes from more than 10 countries (in particular China, Russia, Brazil, Australia, Canada) as well as some international scientific associations (EISCAT, SCOSTEP, SuperDARN) participate in the program. IMCP is designed to track propagation of space weather events from the Sun to Earth as well as to monitor various disturbances generated within the Earth system that impact near-Earth space. The IMCP observation system will provide monitoring and better understanding of the interactions between solar activities and terrestrial processes.

NHC RAS is a complex of large heliogeophysical instruments of new generation. NHC RAS is being deployed by ISTP SB RAS in the Eastern Siberia. The complex includes five big scientific instruments: Large Solar Telescope-Coronagraph, Multiwave Radioheliograph, Radiophysical Complex for Atmospheric and Ionospheric Research, Network of Coherent Ionospheric Radars, Lidar Optical Complex. NHC RAS should provide solutions to the most important problems of solar-terrestrial physics, considering the Sun — Earth system as a uniform and interrelated one. NHC RAS is aimed at studying solar activity and its impact on space weather; studying the magnetosphere — ionosphere — atmosphere system and effects imposed on it by solar factors and meteorological and lithospheric processes; studying the effects of space factors on operation of spacecraft and various engineering systems; monitoring of near-Earth space, spacecraft and space debris; developing methods for solar activity and near-Earth space monitoring and prediction to the benefit of different consumers. NHC RAS can make a significant contribution to IMCP for observations at middle and high latitudes at 120° E meridian.

After many years of collaboration, we can conclude that the Chinese-Russian Joint Research Center on Space Weather has proven its usefulness and continues its work in studying the Sun, solar-terrestrial relations, and near-Earth space. The Joint Research Center invites all interested institutions to further cooperation and development.

We would like to thank all those who took part in establishment of the Chinese-Russian Joint Research Center on Space Weather, and facilitated its successful work.

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