THE 15th RUSSIAN-CHINESE WORKSHOP ON SPACE WEATHER

Irkutsk, Russia, September 9–13, 2024

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CHINA-RUSSIA JOINT RESEARCH CENTER ON SPACE WEATHER: 24 YEARS OF COOPERATION

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In recent decades, 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 (space weather) significantly affect space-borne and ground-based technological systems, they also threaten human health and life. It is therefore essential to have complete information about these processes, to have the possibility to diagnose and predict space weather, and to assess the potential consequences. 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. That is a difficult task. Accomplishing it requires new instruments and methods. Broad international cooperation is also needed, since the processes under study are planetary in scale. The China-Russia Joint Research Center on Space Weather is focused on solving these problems.

The 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). 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 the Earth's ionosphere and atmosphere; diagnostics of near-Earth space and forecasting techniques; interaction between near-Earth space and the Earth's atmosphere; global space weather system and its response to external influences. Many other Russian and Chinese institutions have joined our investigations: the National Astronomical Observatories of China CAS, Institute of Geology and Geophysics CAS, Peking University, Yunnan Astronomical Observatory CAS, China Research Institute of Radiowave Propagation, Shandong University, Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy SB RAS, Space Research Institute RAS, Pushkov Institute of Earth Magnetism, Ionosphere and Radio Wave Propagation RAS.

The Joint Research Center promotes international cooperation. In 2016, the first joint observation campaigns were launched as part of the International Meridian Circle Program (IMCP). The large unique project of NSSC CAS, IMCP connects 120E and 60W 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) participate in the Program. The monitoring instruments involve optical, radio, and geomagnetic equipment including active and passive optical instruments, ionosondes, MST radars, magnetometers, GNSS receivers, sounding rockets. The IMCP observation system will provide monitoring and better understanding of the interactions between solar activities and terrestrial processes.

The National Heliogeophysical Complex of the Russian Academy of Sciences (NHC RAS), the large unique project of ISTP SB RAS, can make a significant contribution to the MCP program for observations in middle and high latitudes at meridian 120E. NHC RAS includes five large, new generation experimental scientific instruments for research in the field of solar physics and near-Earth space physics: Large Solar Telescope-Coronagraph, Multiwave Radioheliograph, Radiophysical Complex for Atmospheric and Ionospheric Research, Network of Coherent Ionospheric Radars, Lidar Optical Complex. Currently, the first NHC RAS tools have started their operation: radioheliograph and optical instruments. The development and construction of a large solar telescope and a radiophysical complex are underway. Reports about selected of the NHC RAS tools are presented in the Workshop Abstract book.

In 2024, the China-Russia Joint Research Center on Space Weather has celebrated its 24th anniversary. Over the 24-year period, many important results in the study of physical processes in near-Earth space have been achieved through the joint efforts of Russian and Chinese colleagues. About 60 scientific projects have been implemented, and over 400 joint scientific articles have been published. The Joint Research Center has proven its usefulness and continues its work in the study the Sun, solar-terrestrial relations, and near-Earth space.

LUNAR ORBIT SMALL SATELLITE ARRAY FOR AN INTERFEROMETRIC RADIO TELESCOPE

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To use a constellation of small satellites is a new way of doing science in space. It is also recommended by COSPAR at its Road map of small satellite for space science in 2019. However, due to the limited resources of small satellite, the usual way of those kind of constellation is just put a cluster of micro-satellites and let them to fly freely with no control of their orbits.

The “Hongmeng Plan” (Discovering the Sky at the Longest Wavelength, DSL) is a small satellite constellation flying in the lunar orbit. It is the first time to measure such low frequency band with an array of small satellites. One of its ambiguous scientific objectives is to obtain a high resolution survey of the universe’s dark age. The small satellites will fly in the same orbit as a liner array and taking interferometric measurement between any two of them. The distances between the small satellites are not evenly distributed but with careful design and with limited control during the mission operation. With that, the visibility function measurements will reach a good coverage on the UV plan and help to retrieve a good image. Measurements will be taken while the array is on the far side of the Moon taking the advantage of the radio quietness and transmit data while it is on the near side.

DSL is still a proposal however it is likely to be approved soon and aiming to be launch in 2028.

INTRODUCTION OF INTERNATIONAL MERIDIAN CIRCLE PROGRAM AND THE PROGRESS OF ITS TYPICAL DEMONSTRATIONS IN BRAZIL

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Based on the Chinese Meridian Project (CMP), the International Meridian Circle Program (IMCP) aims to coordinate the deployment of a comprehensive ground-based monitoring network along the 120°E–60°W Great Meridian Circle to track the propagation and evolution of space weather events from the Sun to the Earth, as well as the imprints of other major natural and anthropic hazards on the ionosphere, the middle and upper atmosphere. Currently, we have completed the IMCP headquarters building in Beijing and established the China-Brazil Joint Laboratory for Space Weather in cooperation with Brazil. Meanwhile, the Chinese Meridian Project Phase II and different components of the IMCP observation system are under construction.

As a precursor to the IMCP, we have jointly established the China-Brazilian Joint Laboratory for Space Weather with INPE, and the second phase of construction will be completed this year. By deploying 16 sets of space environment monitoring equipment in Brazil, including all-sky airglow imagers, GNSS-TEC, and lidar, we have initially obtained monitoring data of the space environment in the South American region, setting an example for the IMCP.

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NATIONAL HELIOGEOPHYSICAL COMPLEX OF RAS: LARGE SOLAR TELESCOPE OPPORTUNITIES FOR SOLVING FUNDAMENTAL PROBLEMS OF SOLAR PHYSICS

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The “National Heliogeophysical Complex of the Russian Academy of Sciences” is designed to develop methods to forecast space weather phenomena, the vast majority of which are related to solar activity. Developing methods for predicting solar activity requires solving fundamental problems in solar physics. These tasks set a high bar for achieving the required experimental parameters, such as angular, spectral, and temporal resolution. The Large Solar Telescope LST-3 will conduct relevant observations of the Sun’s atmosphere for the next 50 years. This will provide the essential data needed to develop physically-based models, which are crucial for understanding the causes of various energetic phenomena, including geoeffective events.

The research directions are to understand the development of active regions and to investigate the origin, structure, and evolution of magnetic fluxes; to obtain new observational data on solar flares and eruptive events for identification of triggering mechanisms that disrupt the equilibrium; to determine the connection between the layers of the solar atmosphere through waves and magnetic fields; to study the dynamics of the chromosphere, as well as magnetism and heating of the upper atmosphere.

The task is to observe physical processes at the scales at which they occur: approximately 70 to 150 km, which corresponds to the mean free path of a photon and the pressure scale height in the solar atmosphere. It is crucial to enable simultaneous observations of the photosphere, temperature minimum, and two levels in the chromosphere. The range of heights is about 3000 km. Practically, this leads to the requirement of simultaneous registration of 10–20 spectral lines from different spectrum ranges: visible (380–800 nm) and near-infrared (800–2500 nm). Temporal scales of observed phenomena impose very high resolution requirements: from 1 to 100 seconds, with observation durations up to 8 hours or longer. In angular measure, the observed objects (sunspots, filaments, faculae, granulation structures, and other magnetic structures) occupy 50–120 arcseconds on the solar disk. It is crucial to ensure spectropolarimetric observations and precision measurements of the magnetic field vector ranging from 5 to 70 Gauss for scales of 1 to 0.1 arcseconds. Studying plasma flows and periodic material movements necessitates achieving the accuracy of Doppler velocity measurement up to 5 m/s, with supersonic speeds ranging from 5 to 20 km/s depending on different physical conditions.

Fundamental solutions to these problems are feasible with a telescope aperture diameter of 3 to 4 meters with certain compromises. It is impossible to cover a wide range of parameters with a single instrument for spectral analysis. The solution lies in optimal distribution of various observational tasks among several scientific instruments to ultimately reconstruct the three-dimensional structure of the solar atmosphere. Primarily, the needed parameter range can be covered using filter instruments and spectrographs. The project includes two main instruments: a narrowband filtergraph and a spectrograph with an integral field unit. The former allows capturing images of the fine structure of the solar atmosphere, while the latter offers high accuracy in Doppler velocity and magnetic field measurements for a limited spatial area. Additionally, two other instruments, a broadband filtergraph and a slit spectrograph, enable the registration of rapid processes in the image plane and any spectral lines from the visible and near-infrared spectrum. The estimated data output flow from scientific instruments is expected to be 5 GB/s, with a potential up to 56 GB/s.

To enable the simultaneous operation of multiple focal instruments, it is necessary that the light flux on each of them is sufficient to achieve an acceptable signal-to-noise ratio. This can be achieved through high efficiency of the main optical system of the telescope, which should provide a relatively high transmission coefficient, as well as a relatively high image contrast. The optical system is designed to achieve diffraction-limited quality. Improving image quality under Earth's atmospheric conditions is accomplished through adaptive optics, as well as by creating local conditions using the dome, thermal stabilization systems, and climate control.

The LST-3 project fully meets the requirements of the current solar physics missions and will ensure:

– Multispectral measurements of the magnetic field vector and plasma motions;
– High spectral resolution;
– High spatial resolution over a large two-dimensional field.

INTRODUCTION TO CHINA'S SPACE ENVIRONMENT GROUND-BASED MONITORING NETWORK — CHINESE MERIDIAN PROJECT (CMP)

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Space weather seriously affects human space activities and some ground facilities. Therefore, monitoring and researching the space environment has important scientific significance and application value. In order to gain a comprehensive understanding of the space environment from the sun to the earth, China is building a large-scale ground-based space environment monitoring system, known as the Chinese Meridian Project (CMP). The CMP adopts a well-designed monitoring architecture, known as "One Chain, Three Networks, and Four Focuses", to achieve stereoscopic and comprehensive monitoring of the entire solar-terrestrial space. The "One-Chain" component utilizes optical, radio, interplanetary scintillation, cosmic ray instruments to cover the causal chain of space weather disturbances from the solar surface to near-Earth space. For the ionosphere, middle and upper atmosphere, and magnetic field, instruments are deployed along longitudes of 120°E and 100°E, and meridians of 30°N and 40°N, forming the "Three Networks". Furthermore, more powerful monitoring facilities or large-scale instruments have been deployed in four key regions: the high-latitude polar region, mid-latitude region in northern China, low-latitude region at Hainan Island, and the Tibet region. These four regions are crucial for disturbances propagation and evolution, or possess unique geographical and topographical characteristics.

ENERGY RELEASE AND PARTICLE ACCELERATION IN THE 25TH CYCLE SOLAR FLARES: JOINT OBSERVATIONS WITH NEW RUSSIAN AND CHINESE INSTRUMENTS

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Studying the solar flares and other active processes on the Sun requires comprehensive observations in different spectral ranges. Recently, several new solar-oriented astronomical instruments have been put into operation, including the Siberian Radioheliograph and spectrometers of the Chashan observatory (in the microwave range), the Hard X-Ray Imager on board the Advanced Space-based Solar Observatory (in the X-ray range), etc. Since 2023, these instruments have observed simultaneously a number of solar flares, including the series of events related to geomagnetic superstorms in May 2024.

In this talk, I present the examples of observations that demonstrate the capabilities of the new instruments. I also discuss how the new observations can be used to analyze the processes of energy release and particle acceleration and transport in solar flares.

NATIONAL HELIOGEOPHYSICAL COMPLEX OF RAS: RADIOPHYSICAL COMPLEX FOR IONOSPHERIC AND ATMOSPHERIC RESEARCH

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In the National Heliogeophysical Complex of the Russian Academy of Sciences, the Radiophysical Complex (RPhC) is the largest complex and multifunctional information system designed to solve problems of ionospheric and atmospheric physics, controlled modification of the ionosphere by powerful radio waves, and study of the effect of Near-Earth space (NES) physical processes on technological systems.

Structurally, RPhC consists of the main instrument cluster, which 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 [Medvedev et al., 2020], and a heating facility for modifying the ionosphere by powerful HF radio waves [Vasilyev et al., 2020]. RPhC also comprises a network of coherent ionospheric radars (SECIRA) [Berngardt et al., 2020].

This cluster of large research measurement facilities will be supplemented with a system of small problem-oriented instruments and a meridional chain of stations Norilsk-Irkutsk (ionosondes, magnetometers, photometers, etc.).

RPhC is a multipurpose complex that allows fast transition to new challenges. Research directions will change due to the development of research into the upper atmosphere and solar-terrestrial relations. There are no facilities of this type in Russia nowadays, therefore a wide range of scientific questions related to the atmosphere dynamics is not supported by up-to-date high-precision experimental data. The modern IS-MST radar in Irkutsk will compensate for the lack of experimental data in this field of research.

The location of RPhC is unique since the complex will provide important geophysical data and monitor NES in the center of Russia, significantly complementing observational data acquired by geophysical centers in the USA, Europe, and Japan in studying global distributions of environmental parameters.

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RECENT ADVANCES IN THE RESEARCH OF POLAR CAP AURORAS

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During the periods of strong northward interplanetary magnetic field (IMF), the polar cap (normally no aurora) often appears clear auroral structures. Their appearance not only directly links to solar wind-magnetosphere-ionosphere coupling processes, but also often results in variable space weather disturbances. However, their formation and evolution are still poorly understood, and there is no forecasting tool to predict either their formation or evolution. Here we summarize the recent new progresses about the formation, evolution, and space weather impact of polar cap auroras. 1) A general formation mechanism has been proposed for the formation of transpolar auroral arcs (TPA): strong flow shear sheets in the magnetosphere generate field aligned current (FAC) sheets which field-aligned accelerate electrons through the Knight's current-voltage process to precipitate into the polar cap ionosphere. 2) A cyclone-shaped aurora has been identified and named as space hurricane above the Earth's magnetic north pole with strong heated electron precipitations, a clockwise circulation of the plasma flow, ion upflow, upward FAC and circular magnetic field perturbation. 3) Merging poleward edges of a conjugate horse-collar aurora (HCA) have been identified in both hemispheres' polar ionosphere, indicating an almost complete disappearance of the open-flux polar cap and a shrunk and nearly closed magnetosphere due to the quasi-steady dual-lobe reconnection continuously eroding the magnetotail open and even closed magnetic field lines that reclosed at the dayside magnetopause under long-time strong northward IMF. These results indicate that there are still significant energy disposition and coupling in the solar wind-magnetosphere-ionosphere interactions under strong northward IMF conditions.

OPTICAL INSTRUMENTS OF THE NATIONAL HELIOGEOPHYSICAL COMPLEX OF RAS

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Optical instruments for support of complex research of the Earth's upper atmosphere over Eastern Siberia are the modern photometry and spectrometry devices adapted for aeronomical studies. The instruments for airglow passive observations were built up and got the first light in 2020–2023. The instruments are Fabry-Perot interferometers, all-sky imagers, fast photometers and spectrometers of visible and infrared range. The most powerful and modern optical instrument is the multi-wave troposphere-stratosphere-mesosphere-termosphere lidar now under construction.

During the installation and adjustment stage the instruments have collected some amount of data allowing to illustrate some effects in the airglow during such geophysical events as geomagnetic storms,

sudden stratospheric warmings, tidal bores, thunderstorms, regular seasonal and diurnal variations, and also under artificial impacts on the upper atmosphere. The high research potential of the datasets is the multiplicity of information about fine spectral features and spatial and temporal variations of the airglow, temperature and wind. As the optical instruments work in the same atmospheric region with the incoherent scatter radar and the set of ionosondes and GNSS stations, we can observe synchronic variations of neutral and ionized components of the upper atmosphere.

The infrastructure surrounding these optical instruments has been very effective in the educational process in the fields of atmospheric science, space science, and optical instrumentation. We have already conducted several educational events for students and young scientists using these optical instruments.

The set of passive optical instruments should be spread along the meridian from 50° N to 70° N and even higher to support the International Meridian Circle Program. We already have the possibility to close this gap with existing equipment. Future development of the helio-geophysical complex of RAS gives rise to other instruments (lidar, IS radar, heating facility) equipped with the optical instruments as additional sensors, and after finalization the project we can have a rather dense network of observational stations from Mongolian border to the Arctic.

Experimental data were obtained using the equipment of the Angara Shared Equipment Center (ISTP SB RAS) http://ckp-angara.iszf.irk.ru/.

Data processing and storage were financially supported by the Ministry of Science and Higher Education of the Russian Federation (Subsidy No. 075-GZ/C3569/278).

SIBERIAN RADIOHELIOGRAPH — NEW OPPORTUNITIES FOR STUDYING THE SOLAR CORONA

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The Siberian Radioheliograph (SRH) is a new generation solar-dedicated radio telescope implementing microwave imaging spectroscopy of the solar corona. The SRH data are microwave spectra obtained at each point on the solar disk.

The SRH consists of three T-shaped antenna arrays operating in the ranges 3–6, 6–12, 12–24 GHz, receiving signals of both circular polarizations. Antenna arrays 3–6 and 6–12 are equidistant (redundant), the 12–24 array is partially equidistant. Redundancy is used to calibrate the antenna gains. The field of view of the SRH is about 1.5 degrees, which allows obtaining images of the whole disk and CMEs. The instantaneous frequency band is 10 MHz, the sensitivity by brightness temperature is about 1000 K, by flux density up to 0.01 sfu. The snapshot time for one image in one polarization is 10–100 ms. The full sweep time is equal to the doubled product of the number of operating frequencies by 10–100 ms. The spatial resolution varies within 5–25 arc seconds depending on the observation time and frequency.

Section 1. GEOEFFECTIVE PROCESSES ON THE SUN AND IN INTERPLANETARY SPACE

MULTI-WAVELENGTH ANALYSIS OF UNUSUALLY SHORT MICROWAVE BURST PRECEDING A SOLAR FLARE

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We present the detailed analysis of short microwave burst observed in active region NOAA 13559 on January 23, 2024 at 02:34 UT, one hour before a C-class solar flare in the same active region. The radio burst was detected by Siberian Radioheliograph (SRH) as a compact source of microwave emission with the brightness temperature around 100 000 K, 20 s life time. The corresponding radio flux at the peal frequency reaches 12 sfu. Due to the low flux values, the burst is hardly visible in spectrographs. However, SRH has much higher sensitivity than single dish instruments and allows for both localizing the burst source and detailed investigation of its spectrum in the range of 3–24 GHz. Based on the multi wavelength observations in 48 frequency channels, we have reconstructed the dynamic spectrum of the burst. It was found that the spectrum is characterized by a frequency drift towards higher frequencies and demonstrates pronounced fine structure in both spatial and temporal domains. Based on our findings, we concluded that the microwave emission of the burst is a gyro-synchrotron emission produced by accelerated electrons traveling along a plasma loop towards the solar surface. Since the burst source shares its location with the subsequent solar flare, it can be considered as a radio precursor of a forthcoming solar flare.

This work is supported by the Russian Science Foundation project 20-72-10158-P.

THREE-MINUTE OSCILLATIONS IN SUNSPOT'S SUPERPENUMBRAE. ALFVÉNIC OR SOUND?

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The photosphere and chromosphere of sunspots' superpenumbrae are populated by areas of 3-minute oscillation power in the line-of-sight (LOS) velocity oscillations and intensity signals. Such oscillations are also found in the transition region and lower corona above active regions. The goal of the work is to clarify whether these LOS velocity oscillations are manifestations of Alfvénic waves in the lower solar atmosphere, as some researchers suggest they are. The study is based on three sunspots with the use of the Solar Dynamics Observatory data. We conclude that the 3-minute oscillations in the LOS velocity signals result from magnetoacoustic waves rather than from Alfvénic waves. However, oscillations registered in magnetic field signals indicate that Alfvénic waves may be present already in the photosphere.

ON THE ORIGIN OF THE OPEN MAGNETIC FLUX PROBLEM IN HELIOSPHERE

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One of the important space weather questions is the problem of open magnetic flux (OMF) [1]: the presence of a significant difference between observed in situ and calculated (based on the remote measurements of surface solar magnetic fields in different observatories) values of the interplanetary magnetic field strength. Namely, the calculations give strength values 2-4 times lower, than the experimentally observed ones. There are some investigations [1-3] devoted to this issue, but it is not solved jet.

Recently [3] the results of a new study have appeared, where a special hypothesis was suggested to explain the OMF problem in observations at the Wilcox Solar (WSO) and Mount Wilson (MWO) observatories. The idea of this hypothesis is: because measurements in these two observatories have been made in the Fe I 525.02 nm spectral line and since this line is too sensitive to the magnetic field and has small value of low level excitation potential, then the measurements in this line should be significantly corrected. Observations in other observatories, where other spectral lines are used, demonstrate a less significant OMF problem.

However, some of the conclusions obtained in [3] are not obvious and rather controversial. In this study the new results based on the Stokesmeter measurements in different spectral lines with STOP telescope (Sayan solar observatory, SSO) are presented in connection with OMF problem. In some aspects they contradict to conclusions made in [3], what is probably connected with differences in observations at MWO and SSO. New investigations of the OMF problem are required.

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F10.7 INDEX FORECASTING USING THE DEEP-LEARNING N-HiTS MODEL

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The daily F10.7 index as a measure of solar radio flux at 10.7 cm wavelength is an important parameter which is widely used in different thermosphere and ionosphere models.

In this study, we fitted a deep-learning N-HiTS model to make 7-day up forecasts using 30-day historical data. This technique has demonstrated highly effective multi-horizon forecasting (up to 7 days) compared to other forecasting models. The short time of model learning allows us to retrain it regularly on new data and make a better daily forecast. We have organized a regular F10.7 forecast based on the N-HiTS model which is available at the website https://forecasting.simurg.space.

FORERUNNERS AND EFFECTS OF POWERFUL SOLAR FLARES IN ACTIVE REGION 12673 IN SEPTEMBER, 2017

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Investigation of peculiarities of the structure and dynamics of the NOAA active region 12673, which produced the extremely mighty solar flare of the 24-th solar cycle, magnitude X9.3 (September 6, 2017), is contained in many publications. The available data, obtained with HMI SDO and SOT Hinode, gave the opportunity to study forerunners of mighty flares. They can be used as predictors in the forecast.

The analysis made in [Yan et al., 2018; Anfinogentov et al., 2019], had shown the presence of the mighty magnetic rope, with extremal magnetic induction B_{max} to 5000 G before the flares. The curve $B_{max}(t)$ with cadence 45 s, plotted in [Golovko and Salakhutdinova, 2023], revealed short-time (1 min) bursts with 700–800 G amplitude. At the moments of the bursts, at the main Polarity Inversion Line there appeared arc-shaped structures. The second peculiarity of the magnetic field in flare-related dynamics is the fast increase of the magnetic flux imbalance, with the rate up to 1.7×10^9 Wb/s, followed by decrease to zero during a flare. It correlates with variations of the area of intermittent structure patches, revealed by multifractal analysis.

The observed effects of flares are magnetic configuration changes, as well as 4-minute quasiperiodic pulsations of the B_{max} and of the Doppler velocity V_{max}.

The work was supported by the Ministry of Higher Education and Science of RF (grant No. 075-GZ/113569/278).

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NORTH-SOUTH ASYMMETRY OF SOLAR ACTIVITY ON THE GROWTH BRANCH OF CYCLE 25

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The north-south asymmetry (NSA) of solar activity has long been known. Many works have been devoted to the study of this phenomenon (for example, [Olemskoy and Kitchatinov, 2013; Nagovitsyn and Kuleshova, 2015; Kitchatinov and Khlystova, 2021]).

We analyzed the NSA phenomenon of the location of sunspot groups and flares during the growth phase of the 25th Schwabe-Wolf cycle of solar activity. During the first four years of the cycle development, sunspot activity increased quasi-synchronously in the northern and southern hemispheres; the module of the NSA coefficient decreased during this period from 0.6 to 0.2. Longitudinal distribution of sunspots in the second half of 2023 was uneven and similar in both hemispheres; groups of sunspots appeared during this period mainly in the longitudinal intervals of 30° – 100°, as well as 200° – 280°, at other longitudes activity was reduced, both in the Northern, and in the Southern hemispheres.

The number of flares of all classes was 45% in the Northern Hemisphere, 42% in the Southern Hemisphere, 13% were not identified. The flare index was distributed between the hemispheres in a ratio of 49.5% to 42%, 8.5% were not identified. A comparison with the 24th cycle shows that NSA in the distribution of sunspots and flares between the northern and southern hemispheres in the current (25th) cycle is significantly lower than in the previous one. A high degree of symmetry of activity can ensure a greater height of the 25th cycle compared to the 24th, as well as the single-peaked nature of the 25th cycle.

It is hypothesized that in the 25th cycle there is a higher level of dipole parity of the global magnetic field compared to the 24th cycle.

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MYSTERIES OF THE 17 MAY 2012 SOLAR EVENT RESPONSIBLE FOR GLE71: CME AND SHOCK WAVE DEVELOPMENT AND STATISTICAL HINTS FROM THE SPECTRA OF NEAR-EARTH PROTONS

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The event of the 17 May 2012 caused the first of two ground level enhancements (GLE71) in Solar Cycle 24. Despite all the efforts spent studying this solar event, there is no clarity on either of the two possible solar-proton accelerators. Neither the development of the coronal mass ejection (CME), nor the shock-wave history, nor the flare is clear. We have established the following. Two successive eruptions occurred with an interval of about 1.5 minutes. The expansion of each of the erupting structures caused a disturbance that accelerated all structures in its path as it propagated outward. This led to complex kinematic characteristics of the erupting structures that eventually formed a self-similarly expanding CME. Both disturbances became piston shocks and merged into a single, stronger shock. Signs of the piston-shock transformation into a bow shock were identified at distances exceeding 10 solar radii. We reconstructed the proton-fluence spectrum from fractions of MeV to 1 GeV and compared the slopes in different energy ranges with the results of statistical analysis of other proton events. The slope of the integral proton-fluence spectrum at energies < 2 MeV correlates with the CME speed, and the slope at energies 20–300 MeV correlates with the photon index of the hard X-ray flare emission. No correlation has been found between the slope of the proton spectrum at highest energies and the CME acceleration, which characterizes the initial piston shock. These circumstances indicate a statistical predominance at low energies of the contribution of the acceleration by bow shocks formed ahead of CMEs at distances of the order of 10 solar radii. On the other hand, the contribution of flare processes to the acceleration of protons seems to predominate at higher energies.

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MANIFESTATIONS OF ACCELERATED ELECTRONS AND PROTONS IN THE 20 JANUARY 2022 MAJOR SOLAR FLARE OBSERVED WITH FERMI AND THE SIBERIAN RADIOHELIOGRAPH

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Sporadic solar activity is responsible for space-weather disturbances that can disrupt ground-based and space-borne systems and threaten human activity and health. The 20 January 2022 solar event (N07 W83) produced a major M5.5 flare, shock wave, and a fast (1430 km/s) CME. The appearance of > 100 MeV gamma-ray emission indicated the acceleration of protons to energies of > 300 MeV. Accelerated protons reached the Earth's orbit. The ionizing flare radiation and energetic protons caused disruptions in radio communications. Identification of sources of accelerated particles is important both for predicting such events and for understanding the processes of their acceleration. A joint analysis of observational data from the Siberian Radioheliograph (SRH) and the Fermi mission revealed the evolution of accelerated electrons and protons in the flare. The spectra of electrons and protons show similarities that apparently indicate a common mechanism for particle acceleration to high energies and a probable similarity of injection functions in their common source. The proton flux was greatest and had the hardest spectral index at the maximum rate of flare magnetic reconnection. The microwave flux caused by accelerated electrons reached almost 1200 sfu at 9.4 GHz. The analysis of Fermi and SRH data suggests that electrons were trapped in flare-associated magnetic structures and retained there for several minutes. Apparently, the same thing happened to protons.

COSMIC RAYS AS A TOOL FOR HELIOSPHERE, MAGNETOSPHERE AND ATMOSPHERE MONITORING

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We present a spectrographic global survey method to split the cosmic ray variations into components of the interplanetary, geomagnetospheric and atmospheric origin from ground-based observations of the cosmic ray intensity. We show a possibility to use all the available suite of ground-based instrumentation recording cosmic rays (global network of neutron monitors located at different locations and altitudes, ground- and underground-based muon telescopes, etc.) for such studies without involving the data from aerologic atmospheric sounding. As a demonstration of the method functionality, we provide the calculation results for the variations in the isotropic flux, pitch angle anisotropy of primary cosmic rays in the interplanetary space, changes in the planetary system of geomagnetic cutoff rigidities for every observational hour, as well as the atmosphere temperature above the point of observation of cosmic ray charged components for selected time intervals.

NEUTRAL LINE ASSOCIATED SOURCES IN SYMPATHETIC FLARE ON 23 MARCH, 2024

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Neutral Line associated Sources (NLS) are microwave sources projected onto vicinities of the neutral line of the photospheric magnetic field, they often exist in active region structures before powerful solar flares. We discuss the role of NLS before the flare X1.1 on March 23, 2024. In this event both active regions NOAA 13614 and NOAA 13615, connected by a trans-equatorial loop, initialized the flare. So, it is possible to classify this flare as a rare sympathetic flare. We used data by the Siberian Radioheliograph to analyze NLS in this event. This instrument provides multi-wavelength two-dimensional microwave data in the range of 3–24 GHz that opens new possibilities to investigate solar phenomena.

FORECAST OF THE COURSE OF SOLAR ACTIVITY IN THE 21ST CENTURY

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The forecast of the course of solar activity (SA) for the next hundred years has been made. A number of patterns in the structure of secular SA cycles on long-time scale were identified that we used to construct a long-term SA forecast. A key role in long-term forecasting belongs to 210-year solar cycles that consist of two alternating asymmetric cycles of 95 and 115 years. Each of the secular cycles has two maxima and a "dip" between them. SA on the ascending branch of the secular cycle is higher than on the descending branch. The end of the 11-year solar cycle 24 and the beginning of the 11-year solar cycle 25 are occurring at the end and beginning of the secular cycles (end of 2019 and beginning of 2020). Cycles 24 and 25 at the junction of secular cycles are weak, the height of cycle 25 (ascending branch of the secular cycle) is slightly greater than the height of cycle 24 (descending branch of the secular cycle). The 210-year cycles modulate the heights (power) of the 11-year cycles; in turn, the 210-year cycles are modulated by the 2400-year solar cycle. Maximum SA is expected around 2048 and 2080 years. Gradual decrease in SA will be observed after 2080 and by 2123+/-20 (minimum of the 210-year cycle!). SA may reach extremely low values such as the Maunder minimum. According to our forecast, the Sun in the current century is expected to be less active than in the past century.

PROPAGATION OF HOT ELECTRONS IN JETS IN THE JUNE 29, 2012 EVENT

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We discuss the results of observations of the eruptive flare on June 29, 2012 using ultraviolet data (AIA/SDO) and radio data (HiRAS). As a rule, the microwave burst associated with an eruption is generated by fluxes of electrons with energies on the order of several hundred keV by the gyrosynchrotron emission mechanism [1]. In the case of weak bursts with energies of accelerated electrons below a hundred keV, non-thermal electrons can respond to the dynamical radio spectra due to coherent radio emission mechanisms [2, 3]. In the case of thermal flare energy release, when jets of hot plasma propagate along open field lines or along large loops, beams of nonthermal electrons generating radio emission are also possible. The beams appear at the formation of thermal fronts that limit the recession of hot plasma from the flare heating region. The electron beams generate short meter-band bursts at high altitudes and coherent microwave bursts near the remote footpoints of large loops [4].

In this paper, we investigate the relationship between the heated plasma and the flare structure and its dynamics from extreme ultraviolet observations. The propagation velocities of the plasma in the jets are estimated: along open magnetic field lines and along a high closed loop to its remote footpoint. These velocities are different; the velocities along open lines exceed the velocity of jets in closed loops, which possibly indicates a higher plasma density in these structures. A comparison of the velocities of the fronts in the first jet calculated from the UV data with the intensity of the integrated radiation in the 50–550 MHz range (HiRAS) shows a high degree of correlation between them in time. The velocities of the closed-loop fronts in different AIA/SDO channels differ from each other and do not show correlation with the time intervals when the meter radio bursts are registered on the spectrum (HiRAS). The study was financially supported by RNF grant No. 22-12-00308.

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STUDY OF THE MICROWAVE SOURCE POSITIONING AS A POSSIBLE PREDICTION PATTERN OF MAJOR SOLAR FLARES

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A number of X-class flare events that occurred in active region 13663 in May 2024 are considered. Multifrequency images provided by Siberian Radio Heliograph are analyzed for the positioning of the microwave source relative to the polarity inversion line (PIL) of the magnetic field reconstructed using Solar Dynamics Observatory vector magnetograms. During the preflare stages, the center of the source brightness shifted on or very close to the PIL. The obtained results highlight the practical importance of detection of microwave sources over the PIL for prediction of major solar flares.

RECOGNITION OF SOLAR FLARES IN MICROWAVE OBSERVATIONS USING MACHINE LEARNING

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We present the first results of testing methods of machine learning for the recognition of solar flares observed with Siberian Radioheliograph (SRH) within the frequency range of 3–24 GHz. The input data are two-dimensional solar radio spectra (dynamic spectrum) and one-dimensional temporal profiles at a frequency of 9.4 GHz. The output results mark the shape of each spectrum or temporal profile as “classical” and “complex”. The Support Vector Machine (SVM) was used for the classification of temporal

profiles. The model was initially trained and tested at the Nobeyama Spectropolarimeter (NoRP) temporal profiles at a similar frequency of 9.4 GHz. The Convolutional Neural Network (CNN) was used for classification of solar dynamic spectra. We discuss and compare the results obtained using various classification techniques, different types of input data, and preprocessing methods to achieve an optimal result.

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SPATIAL AND SPECTRAL EVOLUTION OF MICROWAVE AND X-RAY SOURCES DURING THE SOLAR LIMB FLARE ON FEBRUARY 5, 2023

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We present the empirical scenario of energy release during the solar limb flare on February 5, 2023. This event was observed with the Siberian Radioheliograph (SRH) within 3–12 GHz range and the Advanced Space-based Solar Observatory / Hard X-ray Imager (ASO-S/HXI) within 10–300 keV range. The combination of these data allowed us to use information about the spectral features and spatial evolution of the flare to explain the disagreement between plasma parameters derived from different spectral regions and to define parameters in a numerical flare scenario. We discuss the agreement between the obtained results and existing flare models, as well as the potential use of flare plasma parameters for diagnostic purposes.

THE STRUCTURE OF CORONAL MASS EJECTIONS RECORDED BY THE K-CORONAGRAPH AT MAUNA LOA SOLAR OBSERVATORY

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Previous survey studies reported that coronal mass ejections (CMEs) can exhibit various structures in white-light coronagraphs, and ~30% of them have the typical three-part feature in the high corona (e.g., 2 – 6 Re), which has been taken as the prototypical structure of CMEs. It is widely accepted that CMEs result from eruption of magnetic flux ropes (MFRs), and the three-part structure can be understood easily by means of the MFR eruption. It is interesting and significant to answer why only ~30% of CMEs have the three-part feature in previous studies. Here we conduct a synthesis of the CME structure in the field of view (FOV) of K-Coronagraph (1.05 – 3 Re). In total, 369 CMEs are observed from 2013 September to 2022 November. After inspecting the CMEs one by one through joint observations of the Atmospheric Imaging Assembly, K-Coronagraph, and LASCO/C2, we find 71 events according to the criteria: (1) limb event; (2) normal CME, i.e. angular width ≥30°; (3) K-Coronagraph caught the early eruption stage. All (or more than 90% considering several ambiguous events) of the 71 CMEs exhibit the three-part feature in the FOV of K-Coronagraph, while only 30 – 40 % have the feature in the C2 FOV (2 – 6 Re). For the first time, our studies show that 90 – 100 % and 30 – 40 % of normal CMEs possess

the three-part structure in the low and high corona, respectively, which demonstrates that many CMEs can lose the three-part feature during their early evolutions, and strongly supports that most (if not all) CMEs have the MFR structures.

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THE RAYLEIGH–TAYLOR INSTABILITY AS A TRIGGER OF SOLAR FLARES

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The essential role of the Rayleigh–Taylor instability as a trigger of flare energy release is shown. Two cases of the RT instability are analyzed: near loop foot-points and at the loop top. The RT instability near loop foot-points requires pre-heating of chromospheric plasma. This pre-heating can be realized due to Joule dissipation in partially ionized plasma under the condition of the Cowling resistivity. The threshold of the RT instability is also determined by the rate of convective plasma flow. The RT instability at the loop top is driven by the activation of the prominence located above a magnetic loop. We have shown that the RT instability excites the superDreicer electric field in the chromospheric part of a loop which can be the best solution of longstanding «number problem» of the particle acceleration in solar flares. Preflare and flare pulses can be driven by plasma tongue oscillations in the course of the RT instability.

SPATIAL STRUCTURE OF RESONANCE CAVITIES IN SUNSPOTS

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We present a study of wave processes in sunspots from the active regions NOAA 11131 on 10 December 2010 and NOAA 12565 on 14 July 2016 observed by SDO/AIA in the 1600Å, 304Å and 171Å temperature channels. To study the spatial structure of the resonance cavities previously found by Jess et al., we applied spectral data processing techniques such as pixelized wavelet filtering and mode decomposition. For the first time, we found stable regions as waveguides of the oscillations in the sunspot umbra, occupying specific frequency ranges without spatial overlap. The sizes of these regions depend on the frequency of the oscillations, and the maximum frequency coincides with the values of the harmonics of the main oscillation mode. Frequency drifts were observed in the band occupied by these regions, with different spectral slopes depending on the location of the sources in the sunspot umbra. We suggest that the observed distribution of wave sources in the umbra is a set of resonant cavities where successive amplification of oscillations at selected multiple harmonics is observed. The distribution of sources at low frequencies indicates the influence of the atmospheric cut-off due to the inclinations of the magnetic field lines.

TIME-PROFILE STUDY OF TYPE III SOLAR RADIO BURSTS USING PARKER SOLAR PROBE

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Solar type III radio bursts are crucial indicators of energetic electron activity in the solar corona and interplanetary space. Our assessment of 43 interplanetary type III bursts, recorded by the FIELDS Instrument onboard the Parker Solar Probe during Encounters 05 to 11, has led to significant and complex findings. We have analyzed the time-profile features of these bursts across a frequency range from approximately 19 MHz down to 0.5 MHz, revealing dependencies on frequencies and derived insights into burst duration, speeds, bandwidths, and drift rates. This novel analysis revealed spectral indices of -0.63±0.04 for rise time, -0.69±0.03 for decay time, and -0.68±0.02 for total duration, exhibiting a nature of an inverse square root of the frequency with the time profile. We have determined the average electron beam velocities for the exciter's front, middle, and back as 0.15c, 0.13c, and 0.08c, respectively, corresponding to electron energies ranging from tens of eV to hundreds of keV. Our findings show that faster electron beams were found to generate emissions with shorter durations. We determine that the time-profile asymmetry is independent of the frequency, suggesting a crucial characteristic that could impact electron beam generation. Furthermore, we identified a strong dependency of burst duration on rise, peak, and decay times, particularly significant with decay time (CC=0.95). This indicates that the entire temporal profile, including rise, peak and decay phases collectively contributes to event duration and is not solely influenced by external factors like plasma conditions or electron beam dynamics but also by internal burst processes. These findings provide valuable insights into the temporal and spectral characteristics of type III solar radio bursts, shedding light on the underlying physical mechanisms governing burst dynamics.

STUDY ON THE MULTIPEAK FLARE WITH HIGH TURNOVER-FREQUENCY MICROWAVE SPECTRA WITH SRH DATA

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The origin of multiple peaks in light curves of various wavelengths remains illusive during flares. Here we discuss the flare of SOL2023-05-09T03:54M6.5 with six flux peaks as recorded by a tandem of new microwave and hard X-ray (HXR) instruments. According to its microwave spectra, the flare represents a high-turnover-frequency (>15 GHz) event. The rather-complete microwave and HXR spectral coverage provides a rare opportunity to uncover the origin of such an event together with simultaneous EUV images. We concluded that (1) the microwave source originates around the top section of the flaring loops with a trend of source spatial dispersion with frequency; (2) the visible movement of the microwave source from peak to peak originates from the process of new flaring loops appearing sequentially along the magnetic neutral line; (3) the optically thin microwave spectra are hard with the indices (α_{tn}) varying from ~−1.2 to −0.4, and the turnover frequency always exceeds 15 GHz; (4) higher turnover/peak frequency corresponds to stronger peak intensity and harder optically thin spectra. Using the Fokker–Planck and GX Simulator codes we obtained a good fit to the observed microwave spectra and spatial distribution of the sources at all peaks, if assuming the radiating energetic electrons have the same spatial distribution and single-power-law spectra but with the number density varying in a range of ~30%. We conclude that the particle acceleration

in this flare happens in a compact region nearing the loop-top. These results provide new constraints on the acceleration of energetic electrons and the underlying flare intermittent reconnection process.

FEATURES OF A SOLAR FLARE EXCESS IN MAY–JUNE 2024

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Strong X-ray class X flares are relatively rare events on the Sun. The 25th cycle of solar activity differs significantly from the previous cycle in many respects, in particular, in the productivity of X-flares. Thus, during the first 4.5 years of cycle 25, 54 events of this class were registered. This is more than for 11 years in the 24th cycle (49 X-flares).

In May–June 2024, a largely unexpected flare excess was observed, when between May 3 and June 10, 4 active regions (ARs) produced 25 X-class flares. In the entire history of X-ray observations, such excesses have not been observed. Thus, in AR13663 5 X-events were registered among 80 flares of all classes, in AR13664 (with the record square area in cycle 25) — 13 out of 101, in AR13685 — 1 out of 19, in AR13697 — 6 out of 119. The situation where four Class X outbreaks occurred on May 8/9 within the same 24-hour period has no precedent. The total energy of flares in these 4 ARs, released over 39 days, amounted to 17% of the total flare energy released on the Sun over 4.5 years in the X-ray range.

All noted flare ARs were located in the cores of activity complexes (ACs), which are usually the main localization sites for strong flares, as shown in [Isaeva et al., 2019]. However, AC membership alone cannot explain such a significant kurtosis. Short time intervals between successive flares in the same AR (sometimes up to 8–12 hours) indicate the action of some physical mechanism that ensures a regular "refueling" of the AR with magnetic energy, and not just large reserves of initially stored energy. It can be assumed that in this case a deep "channel" was operating through which new portions of the magnetic flux emerged from the depth of the convective zone. As a result, 19 X-flares were observed in AR13644 and in AR 13697, which formed in its place, not counting those that probably occurred here while on the far side of the Sun.

AR 486, which produced 8 X-flares in October–November 2003, can be considered an incomplete analog of AR 13664 [https://www.spaceweatherlive.com/].

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DIAGNOSTICS OF CORONAL PLASMA USING THE EXACT SOLUTION OF THE EVOLUTION EQUATION FOR SLOW MAGNETOACOUSTIC AND ENTROPY WAVES

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Compression waves are actively observed in various regions of the solar atmosphere. The most frequent intensity perturbations associated with the compression of the medium are observed in such magnetic structures as coronal loops. Often the observed intensity perturbation is associated only with slow magnetoacoustic waves and the dispersion equation is used for plasma diagnostics. In a strict sense it is not quite correct, since along with slow waves, entropy waves are also induced in the medium. Thus, the propagation of slow waves occurs against the background of the evolution of another compression mode in the medium. For this reason, application of only dispersive equations can lead to errors in diagnostics of plasma parameters and it is more correct to use the exact solution of the evolution equation.

In this paper, we study the peculiarities of applying exact solutions of the Cauchy problem and the boundary value problem for linear evolution equations describing the spatio-temporal dynamics of slow magnetoacoustic and entropic waves.

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Section 2. EFFECTS OF SOLAR PHENOMENA ON MAGNETOSPHERIC PROCESSES

OBSERVATIONS OF A MAGNETOSPHERIC WAVE GENERATED BY A MOVING PLASMA INHOMOGENEITY

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Although ultra low frequency waves in the magnetosphere are known to interact both with energetic protons and electrons, observations of electron–wave resonance are relatively rare. A case of an eastward-propagating wave interacting with a cloud of energetic electrons is studied. The wave was registered with the Magnetospheric Multiscale Mission spacecraft in the postmidnight sector of the magnetosphere at a distance of about 11 Earth radii. It had the frequency of about 3 mHz and the azimuthal wavenumber $m \sim +25$. At first, the wave had a mixed polarization with a considerable field-aligned component. Later during the observation period of about 45 minutes, it transformed to predominantly azimuthally polarized oscillations, which complies with the theory of Alfvén wave transformation due to the phase mixing.

Simultaneously, a cloud of substorm-injected energetic electrons was registered by the spacecraft. The particle flux was modulated with the wave frequency. The oscillations were induced via the drift resonance, with the resonance energy of electrons of about 113 keV. Withal, the conditions for a wave generation by a plasma instability were not met. The generation process can be explained by the moving source theory, as the electron cloud represents a moving finite inhomogeneity that can be seen as an alternating current.

CHARACTERISTICS OF MAGNETIC DIPOLARIZATIONS IN THE VICINITY OF SUBSTORM ONSET REGION OBSERVED BY THEMIS

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With conjunction observations of electromagnetic fields and plasma from Time History of Events and Macroscale Interactions during Substorm (THEMIS) in the near-Earth magnetotail, we investigate the spatial and temporal properties of substorm dipolarizations in the near-Earth plasma sheet (NEPS) during a substorm at 03:23 UT on 12 February 2008. Substorm dipolarizations with different features are detected by three near-Earth THEMIS probes (THA (P5), THD (P3) and THE (P4)) in the magnetotail. In the current sheet with a large plasma beta value ($\beta > 2$, where β is the ratio of the plasma thermal pressure to the magnetic pressure), the dipolarization within the substorm onset region, $(-10.4, 2.8, -2.6)R_{E\_gsm}$, has a large initial magnetic field elevation angle, $\theta > 60°$, $\theta = \arctan(Bz/(Bx^2+By^2)^{1/2})$, and is accompanied by energetic ion (tens to hundred keV) dispersionless injection detected by THD (P3). This substorm onset dipolarization is characterized by *Bx* and *By* components around 0 nT with significant fluctuations. The *Bz* component increases sharply and its subsequent magnitude approaches the total magnetic field, *B*t. The maximum value of the elevation angle approaches 85° during the later substorm expansion phase. In the NEPS with $\beta \sim 1$, the dipolarization outside the substorm onset region is characterized by a magnetic elevation angle with a small beginning value of $\theta < 45°$ and following multi-step enhancements during the substorm expansion phase. The maximum value of the elevation angle approaches to 70° during the later substorm expansion phase. Our observation results indicate that characteristics of dipolarization with a large beginning elevation angle within the substorm onset region provide a new indicator to identify substorm onset location.

VELOCITY—SPACE SIGNATURES OF RESONANT ENERGY TRANSFER BETWEEN WHISTLER WAVES AND ELECTRONS IN THE EARTH'S MAGNETOSHEATH

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Wave—particle interactions play a crucial role in transferring energy between electromagnetic fields and charged particles in space and astrophysical plasmas. Despite the prevalence of different electromagnetic waves in space, there is still a lack of understanding of fundamental aspects of wave—particle interactions, particularly in terms of energy flow and velocity—space characteristics. In this study, we combine a novel quasilinear model with observations from the Magnetospheric Multiscale mission to reveal the signatures of resonant interactions between electrons and whistler waves in magnetic holes, which are coherent structures often found in the Earth's magnetosheath. We investigate the energy transfer rates and velocity—space characteristics associated with Landau and cyclotron resonances between electrons and slightly oblique propagating whistler waves. In the case of our observed magnetic hole, the loss of electron kinetic energy primarily contributes to the growth of whistler waves through the $n=-1$ cyclotron resonance, where n is the order of the resonance expansion in linear Vlasov — Maxwell theory. The excitation of whistler waves leads to a reduction of the temperature anisotropy and parallel heating of the electrons. Our study offers a new and self-consistent understanding of resonant energy transfer in turbulent plasmas.

DYNAMICS OF FIELD-ALIGNED CURRENTS IN THE IIJIMA-POTERMA REGION 1 DURING THE PERIOD OF STATIONARY MAGNETOSPHERIC CONVECTION FROM THE MAGNETOGRAM INVERSION TECHNIQUE

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We study dynamics of large-scale spatial distributions of dayside and nightside field-aligned currents (FAC) in both hemispheres, obtained using the magnetogram inversion technique (MIT) from ground-based magnetometers, during the period of stationary magnetospheric convection (SMC) on September 24, 1998. Quantitative and qualitative analysis showed that during the SMC period there were observed: the increase in the intensity of dayside FAC began during the substorm before the SMC; a monotonic increase Region 1 FACs intensities at quasi-equilibrium between dayside and nightside; in the late SMC a decrease in FAC intensities was observed before the second substorm.

MIDLATITUDE BURSTS OF PiB GEOMAGNETIC PULSATIONS AND NIGHT AIRGLOW DURING STORMTIME SAWTOOTH EVENTS

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We explore dynamics of burst broadband pulsations and airglow using the ISTP midlatitude observatories during two stormtime substorm sawtooth events (STEs) with different level of solar wind ram pressure Pd. Also, we analyze dynamics of the oval of the field-aligned currents obtained using the ISTP magnetogram inversion technique. We detected burst pulsations in the Pi1B short-period range not only when the south oval boundary of the aurora and field-aligned currents (FACs) were near Irkutsk, but also when they were up to 10 degrees northward. The possibility of periodic substorm activations during STEs by a global magnetotail instability and excitation of the nighttime Alfven resonator is discussed.

THE MACH CONE IN INHOMOGENEOUS MAGNETOSPHERE: FAST MAGNETOACOUSTIC MODE GENERATION BY THE SOLAR WIND OBLIQUE IMPULSE ON THE MAGNETOPAUSE

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An important mechanism of the ULF wave generation in the magnetosphere is the impulse of the solar wind dynamic pressure hitting the magnetopause. To date, the case of normal propagation of the impulse toward the magnetopause was studied. In this report, we consider a more common case when the impulse drops onto the magnetopause at some finite angle. In this case, a super-Alfvenic source moving on the magnetopause appears. In the homogeneous medium, it would generate fast mode propagating as the Mach cone (the Cherenkov emission). However, the magnetospheric plasma is inhomogeneous with the Alfven speed changing across the magnetic shells. To take into account this effect, we consider the case of the one-dimensionally inhomogeneous model of the magnetosphere (box model). It is shown that the inhomogeneity leads to the bending of the Mach cone and its subsequent reflection from the surface inside the magnetosphere where the local Mach number equals one. Then, the Mach cone expands toward the magnetopause, and then reflects from it. Multiple reflections lead to turning the Mach cone into a curved polyline. Observational consequences of this picture are discussed.

PiB AND AIRGLOW BURSTS DURING STRONG STORM-TIME GEOMAGNETIC DISTURBANCES

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We report on the novel features of stormtime, midlatitude PiB/PiC geomagnetic pulsations, ionospheric and field-aligned currents, and oxygen, O1S and O1D, emissions at 557.7 and 630.0 nm, respectively. Those were observed during the main phase of the 20-DEC-2015 storm with significant variations of the solar wind dynamic pressure, Pd, and IMF Bz. The distinct characteristic of the super substorm or SSS (AE < –2500 nT) was the presence of bay-like geomagnetic variations with the X and Z components with the opposite signs in the northern and southern sections of the IMAGE chain near 18 MLT. Using the magnetogram inversion technique (ISTP MIT) we obtained the MLT-MLAT distribution (map) of equivalent and field-aligned currents (FACs) revealing an additional westward electrojet to the north of the usual eastward current. For the first time we have shown that such a current system provides the observed distribution of geomagnetic variations along the 18 MLT meridian. We also revealed a localized geomagnetic event during which the magnitudes of the H geomagnetic component, PiB/PiC pulsations, and oxygen emissions at mid latitudes were more than twice greater than during the super substorm.

TIMING OF GEOMAGNETIC ACTIVATIONS BY PiB TYPE PULSATIONS

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An actual task in the physics of magnetospheric substorms is to determine the time of the onset of their explosive phase. For this purpose, the long-period Pi2/Pi3 pulsations are often used. In this work, we show that the short-period part of the broadband Pi1B pulsation bursts allows us to better time the onset of not only isolated substorms, but also other types of recurrent substorm activations, due to the relatively short duration of Pi1B wave train (<0.5 min) and the high sensitivity of this pulsation range to various types of geomagnetic activity.

EXPERIMENTAL CONFIRMATION OF THE EXISTENCE OF A NEAR-EQUATORIAL RESONATOR FOR MAGNETOSPHERIC ION-ION HYBRID MODES

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Ultra-low frequency waves or geomagnetic pulsations are regularly observed in the Earth's magnetosphere. The highest frequency among them are the Pc1 pulsations (0.2–5 Hz). A specific shape of beats characterizes Pc1 pulsations, for which they are called "pearls". Some of them are called ion-ion hybrid modes. The process of forming a "pearl" structure is not well understood. In addition, none of the existing models allowed us to answer the question about the frequency of oscillations before.

In our previous works [Klimushkin et al., 2010; Mikhailova et al., 2020], we considered one of the hypotheses explaining the formation of the pearl structure of Pc1 ion-ion hybrid waves. The hypothesis is that in the case of an admixture of heavy ions (helium or oxygen) in the magnetosphere plasma, a resonator for ion-ion hybrid waves can form at the equatorial part of the magnetic field line. The eigenfrequencies of the resonator determine the frequency of an excited wave. Since the frequency spectrum in the resonator is dense, there is a beat. To test this hypothesis, we selected a Pc1 range event, which was observed on July 14, 2014 by the Van Allen Probe A.

The Pc1 wave frequency changed from 1.3 to 0.9 Hz and was just above the gyrofrequency of helium ions. During the event, high densities of helium and oxygen ions were observed. The ratio of helium mass density to proton mass density was approximately 1 and the ratio of oxygen mass density to proton mass density exceeded 10.

We have found that the calculated eigenfrequencies of the near-equatorial resonator correspond to the frequency of the observed wave. We consider the observed wave structure as a result of the superposition of several harmonics with slightly different frequencies inside the resonator. This observation confirms the existence of a near-equatorial resonator for ion-ion hybrid modes.

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SUBSTORM EFFECTS ON THE STORM-TIME Dst VARIATION

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The substorm effect on the development of magnetic storm-time variation is investigated using 1-min data from the worldwide network of ground-based magnetometers. We carried out a comparative analysis of the dynamics of auroral electrojets, total and partial ring currents — by SuperMAG indices, field-aligned and ionospheric currents — by maps obtained by the original magnetogram inversion technique, as well as geomagnetic pulsations — by observations at the observatories of ISTP SB RAS.

SPACE WEATHER RESEARCH IN YAKUTIA

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For many years, the Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy SB RAS has been conducting experimental and theoretical studies of space weather manifestations. The Institute's geophysical stations are located primarily at high latitudes in the territory of Yakutia (northeastern part of Russia) and are capable of monitoring space weather over a large area of space in both latitude and longitude. Manifestations of space weather are studied in variations of cosmic rays, ionospheric parameters, geomagnetic field, auroras, and VLF emission. The report presents the results of studies of the following manifestations of space weather.

– Comparative analysis of the meridional and azimuthal propagation of Pc5 pulsations and their current systems based on ground-based and satellite observations;

– Study of the magnitude of sudden phase anomalies on VLF radio paths during solar flares;

– Study of SAR arc dynamics by ground-based and satellite observations;

– Study of ionospheric disturbances based on numerical modeling of large-scale structure of the ionosphere;

– Explanation of Forbush decreases in cosmic rays based on a physical model developed by the Institute's staff;

– Forecast of geoeffective disturbances based on analysis of the spectra of the interplanetary magnetic field and fluxes of energetic particles on a satellite located at the libration (L1) point. This method makes it possible to predict magnetospheric disturbances several hours in advance with a probability of up to 80%.

ALGORITHM FOR DETERMINING AURORAL OVAL BOUNDARIES BASED ON VARIOUS MANIFESTATIONS OF AURORAL ACTIVITY

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An algorithm has been developed for determining the polar and equatorial boundaries of the auroral oval and the line of maximum values. The operation of the algorithm on precipitation of auroral particles (OVATION Prime model), auroras (IMAGE satellite data), and conductivity of ionospheric plasma in the auroral zone (Spiro conductivity model) is shown. The algorithm can be adapted to other auroral activity data.

OBSERVATIONS OF Pc5 ULF WAVES IN THE LOW AND MIDDLE LATITUDES BASED ON MERIDIAN PROJECT DATA

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Ultra-low-frequency (ULF) waves play a crucial role in the transportation of mass and energy during the solar wind-magnetosphere coupling process [Zong et al., 2017]. The compressional mode can propagate across geomagnetic field lines in the density cavity between plasmapause and magnetopause, and the poloidal and toroidal mode propagate along field lines. Previous studies mainly focused on ULF waves in the magnetosphere [e.g. Liu et al., 2009] and in the middle and high latitudes of the ground [e.g. Mathie et al. 1999, 2001]. It is an open question about whether and how ULF waves, especially Pc5 waves with longest wavelengths, propagate to the low and middle latitudes. Based on the magnetic field measurements from Chinese Meridian Project, we find that Pc5 waves can appear in low and middle latitudes. We further analyze the spatial distributions, occurrence conditions, the similarities and differences between poloidal and toroidal mode components, etc, using several years data from different ground stations. The event study and statistical results may shed new lights on our understanding of the generation and propagation of Pc5 ULF waves in the low and middle latitudes.

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ULF WAVE POLARIZATION DYNAMICS AS A KEY TO UNDERSTAND WAVE-PARTICLE INTERACTIONS IN THE MAGNETOSPHERE

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Polarization is an important parameter of ultralow frequency (ULF) waves since it significantly affects wave-particle interactions in the magnetosphere. This interaction mostly occurs through the azimuthal electric field of the wave, that is the largest for poloidal waves (magnetic field oscillates in the radial direction) and the smallest for toroidal waves (magnetic field oscillates in the azimuthal direction). Poloidal and toroidal waves in the magnetosphere are of Alfvén wave origin. Nevertheless, it is not yet clear whether poloidal and toroidal waves have linear or elliptical polarization, and if it is possible for ULF waves to have circular polarization. ULF waves are eigenoscillations of magnetic field-lines and play crucial role in large-scale energy transport across the magnetosphere. Thus, understanding the dynamic behavior of ULF waves will advance our possibilities to forecast space weather and radiation conditions in near-Earth space.

Most studies assume ULF waves observed by a spacecraft to have a constant polarization, but some other works suggest mechanisms of polarization change in time or space. From the theoretical point of view, poloidal Alfvén waves can change their polarization to toroidal while propagating in radial direction (e.g., [Leonovich & Mazur, 1993]). A recent statistical study, analyzing the average amplitudes during wave observations, reported results hinting at a regularity of the polarization change process [Rubtsov et al., 2023].

In the present study, we show the method to analyze the wave polarization dynamics with a few case studies to demonstrate the importance of polarization change process. These results will be verified on a large statistics of ULF wave observations, and then may be used for space weather models.

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FEASIBILITY OF THE FROZEN-IN FIELD LINE CONDITION IN MAGNETOSPHERIC DISTURBANCES: ANALYSIS OF THEMIS-A DATA

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The frozen-in condition (FIC) is one of the fundamental equations in magnetohydrodynamics. It is supposed to describe the space plasma behavior in planetary magnetospheres, heliosphere, and interstellar medium. Therefore, verifying the validity of FIC is crucial for space plasma physics. FIC can be expressed by the equation $E= -u \times B$, where E is the electric field, u is the particle flow velocity, and B is the magnetic field induction. In this study, we performed a statistical analysis of the FIC's fulfillment in Earth's magnetosphere.

The data from THEMIS A satellite mission between January 2017 and February 2018 was used. We introduced a statistical parameter aimed to estimate of the extent to which this was the case. A distribution of the probability of the condition being fulfilled was plotted for different regions of the magnetosphere. Based on this distribution and the results of the analysis, we can see that using the parameters included in the equation, FIC is not always met. This allows a better understanding of which space weather factors may influence the inability to reach the frozen-in condition, and under what conditions frozen-in is most likely to happen.

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A METHOD FOR ESTIMATING THE IONOSPHERIC CONDUCTIVITY BASED ON SPACECRAFT OBSERVATIONS OF ALFVÉN WAVES IN THE MAGNETOSPHERE

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In 27 October 2012, the Pc4 range ULF-wave was registered with Van Allen Probe A. The wave was not typical for standing Alfvén waves. The parallel Poynting flux of the wave was directed toward the Northern ionosphere. We suggested that it can be caused by the asymmetry of ionosphere Pedersen conductivity between the Northern and Southern hemispheres. To prove this, we used the analytical model with straight magnetic field lines. Due to the model, we can reconstruct the Alfvén wave parallel structure under various conditions of the ionospheric conductivity. We developed the method to estimate the height-integrated Pedersen conductivity which requires only spacecraft data of ULF wave observations. Approbation of this method was made for the 27 October 2012 event. The calculated Pedersen conductivity of Northern ionosphere is in a good agreement compared to the IRI-2016 model.

The study was supported by the Russian Science Foundation under Grant 22-77-10032.

RADIAL STRUCTURE OF MAGNETOSPHERIC ALFVEN WAVES AND PHASE DIFFERENCE BETWEEN TRANSVERSE MAGNETIC COMPONENTS: TWO CASE STUDIES

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The study of the transverse structure of Alfvén waves observed by Van Allen Probes satellites using the method of “phase portraits” (construction of the phase difference between the magnetic field components) was carried out. The first event was observed by the RBSP-A satellite on 23 October 2012 at 22.00–22.30 UT. It is shown that the observed oscillations can be explained as resonant poloidal Alfvén waves generated on two resonant surfaces located on both sides of the local maximum in radial distribution of the Alfvén velocity. Polarization of the waves between these resonant surfaces changes from poloidal to toroidal. The second event was detected by the RBSP-A satellite on the same day at 19.12–20.24 UT. This event can be interpreted as a transverse Alfvénic resonator. Comparison between the theoretical and satellite transverse components of the magnetic field and their “phase portraits” shows good agreement.

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MULTI-SPECTRAL STEREOSCOPIC DETECTION OF THE SOLAR ATMOSPHERE AND ITS PRECISE FORMATION HEIGHTS

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During the data testing phase of SFMM in Meridian Project II, we observed that the geometric size of the solar image varied with different spectral lines and line's profile through the spectral scanning observation of Lyot-Filter. Further confirmation of these more refined and reliable variations was obtained through imaging observations by the spectrograph of China's latest $H\alpha$ Solar Explorer (CHASE) satellite. This report presents our discovery of "fine variations in the formation height of solar spectral lines across the spectral profiles".

Section 3. PHYSICAL PROCESSES IN THE MIDDLE AND UPPER ATMOSPHERE

MID-LATITUDE AURORAS WITH DATA FROM OPTICAL INSTRUMENTS OF THE NATIONAL HELIOGEOPHYSICAL COMPLEX

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Optical instruments of the National Heliogeophysical Complex (NHC) recorded 45 mid-latitude auroras (MLA) at the beginning of the cycle 25 of solar activity. Of these, in 26 cases, structures corresponding to SAR arcs were observed in the airglow. The NHC optical instruments include all-sky cameras, Fabry-Perot interferometers, photometers and spectrometers in the visible and infrared ranges.

We obtained MLA registration statistical data by all-sky cameras depending on the geomagnetic situation. The Kp and Dst indices were chosen as indicators of geomagnetic disturbance. In addition, attention was paid to the presence of structures similar in spatial characteristics to SAR arcs. Based on these data, threshold geomagnetic indices were obtained, at which the operator manually differentiated MLA, including spatial structures similar in their characteristics to SAR arcs, in the images of all-sky cameras in the 630 nm channel. Next, based on the obtained threshold geomagnetic indices, we assessed favorable periods for recording MLA with all-sky cameras. A seasonal variation in the number of registered MLA per month and the number of "favorable" periods for the MLA development was obtained. The geographic latitude distribution of observed SAR arcs was also obtained depending on the Dst index based on data from the NGC all-sky cameras. Such dependencies make it possible to identify cases with atypical dynamics of MLA structures. One of the storms that differs from the average distribution is the extreme storm of May 10–12, 2024. The dominant emission of this MLA was the forbidden lines of atomic oxygen [OI] 630.0 and 557.7 nm, with the ratio of these lines intensities at the aurora maximum up to 15 above the northern horizon, and up to 30 at the celestial pole. The 630.0 nm airglow intensity during the main phase of the magnetic storm exceeded 25 kR.

Experimental data were obtained using the equipment of the Angara Shared Equipment Center (ISTP SB RAS) http://ckp-angara.iszf.irk.ru/.

Data processing and storage were financially supported by the Ministry of Science and Higher Education of the Russian Federation (Subsidy No. 075-GZ/C3569/278).

THE INFLUENCE OF THE DESCRIPTION OF THE NEUTRAL ATMOSPHERE ON THE RESULTS OF MODELING THE EFFECTS OF THE FEBRUARY 2022 MAGNETIC STORM

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The global ionosphere-plasmsaphere coupling (GIPC) model developed at ISTP SB RAS [Tashchilin, Romanova, 2013] is based on solving a system of non-stationary equations for the balance of particles and thermal plasma energy in closed geomagnetic flux tubes, the bases of which are located at an altitude of

100 km. The description of spatiotemporal variations in temperature and concentration of neutral components O, O2, N2, H, N is based on data of the empirical thermosphere model MSIS 2.1, horizontal wind speeds were calculated using the HWM07 model. The input parameters of the MSIS 2.1 model are the daily and 81-day averaged values of the solar activity index F10.7 and the daily average value of the planetary index Ap. The model allows taking into account the disturbed state of the environment during magnetic storms and in this case the model accepts 7 values of Ap: daily average, 4 values for the last 9 hours, 2 daily average values for the last two days. Thus, in the best case, the MSIS 2.1 model (as well as the GIPC model using it) can reflect changes in the environment with a characteristic time of three hours.

Among other things, the SWARM satellites determine variations in their own non-gravitational accelerations, from which it is possible to reconstruct an estimate of the atmospheric density D at the orbital altitude [van den Ijssel et al., 2023]. Using these data as a reference, we varied the input daily average F10.7 index so that the difference ΔD between the MSIS model data and the measured densities was minimal.

We simulated the ionospheric parameters for the period February 1–7, 2022, using the MSIS 2.1 model taking into account the disturbed environment (SW(9) = –1) in two modes: using the real and corrected F10.7 values. In this work we show that regardless of the F10.7 correction, the model using MSIS2.1 correctly reproduces the diurnal cycle and restores the pre-dawn temperature peak. The height of the F2 layer maximum during the disturbed period turns out to be lower than predicted by the model.

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VARIATIONS IN CHIRP SIGNAL CHARACTERISTICS DURING X-RAY SOLAR FLARES: EXPERIMENT AND MODELING

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In this work we analyze chirp signal characteristics obtained over three oblique-incidence sounding (OIS) paths located in the Siberian and Far Eastern regions of the Russian Federation during periods of M and X class solar flares. The lowest observed frequencies (LOF) have been evaluated using interactive processing of OIS ionograms. We analyze OIS data obtained in 2014–2016. LOF values characterize signal absorption over the paths. LOF variations for the disturbed days were compared with LOF values for the quiet days. Compared to quiet days, LOFs showed a sharp increase during the studied X-ray solar fluxes over all paths. In the moment of maximum of X-ray fluxes, disappearance of reflections from lower layers of ionosphere has been observed, chirp signals propagated due to reflections from F2-layer. Amplitude of chirp signal has decreased also. Our study demonstrated that during solar flares, radio wave absorption increased sharply, frequency range decreased. We performed modeling of chirp signal characteristics on the basis of complex algorithm, which includes two modules: the ionosphere and plasmasphere global model and the radio wave propagation model for the X1.3 class solar flare on 25.04.2014. The results of the modeling are in good agreement with the experimental data.

The work was financially supported by the Ministry of Science and Higher Education of the Russian Federation (Subsidy N075-GZ/C3569/278). The results were obtained using the equipment of Shared Equipment Center “Angara” (http://ckp-rf.ru/ckp/3056).

IMPACT OF THE LUNAR GRAVITATIONAL TIDE ON DYNAMICAL PROCESSES IN THE UPPER STRATOSPHERE BASED ON ERA-5 REANALYSIS DATA

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Gravitational tides of the Moon and the Sun are manifested in their impact on different geospheres: from the lithosphere to the upper layers of the atmosphere. It is well known that seismic activity increases during full moons and super moons. The influence of lunar tides on atmospheric processes is often considered insignificant and only short-period semidiurnal and diurnal waves are considered. In this study, we investigate the influence of long lunar waves with a period from two weeks to dozens of years on dynamical processes in the upper stratosphere. Based on ERA-5 reanalysis data for the period from 1979 to 2023, a spectral analysis of wind velocity variations (in 3 dimensions) at altitudes from 1 to 10 hPa is performed. It is shown that there is a statistically significant relationship between the strength of variations in different components of wind velocity and the periods of the maximum influence of the gravitational lunar tide.

This work was supported by the Russian Science Foundation project No. 22-77-10008.

FEATURES OF DETERMINING THE ELECTRON DENSITY PROFILE, PLASMASPHERE ELECTRON CONTENT AND TRANSITION HEIGHT AT IRKUTSK INCOHERENT SCATTER RADAR

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This work presents a new technique for determining the O+/H+ transition height and the electron content of the topside ionosphere, plasmasphere. The technique is based on a two-component ionospheric model and on the combination of IISR and GPS TEC data. This technique allows determining the height of transition from heavy ions (O+) to light ions (H+,He+), which is not available with standard processing techniques. The features of the standard technique for reconstructing the electron density (Ne) profile in the topside ionosphere from IISR power profile data are discussed. The necessity of correcting the Ne profile and scale height at high altitudes (much higher than HmF2) is shown. The results of calculating the scale height and the O+/H+ transition height for two geomagnetic disturbance periods using our technique are presented. The results are compared with data from the IRI 2020 model and the NeQuick-2 model.

METHODS FOR EFFECTIVE JOINT OBSERVATION OF SPACE DEBRIS USING EISCAT, QUJING AND IRKUTSK RADARS

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We put forth a methodology for efficient joint space debris observations using the EISCAT (Ultra-High Frequency and Extremely Low Frequency: 19°13’28.62” E, 69°35’10.67” N, polar region), Irkutsk Incoherent Scatter Radar (103°18’ E, 52°52’53”N, mid-latitudes), and Qujing Incoherent Scatter Radar (103°48’ E, 25°36’ N, subtropics). Each radar is situated in a distinctive geographical and geophysical location. Furthermore, the antenna of each radar has its own unique set of characteristics.

This paper will present a methodology for combining space debris observation statistics, taking into account the geographical location of the three radars, in order to obtain the most efficient and useful data on the orbital parameters of the currently most important class. A joint analysis of such measurements will facilitate the efficient correction and improvement of space debris models. The spacing of the radars in longitude and latitude will enable more precise estimation of the distribution of the orbital plane position and orbital periods.

Comparing the distribution of space object clouds under different geomagnetic conditions will allow evaluation of the geomagnetic and solar activity influence on the dynamics of space object orbits.

LONG-TERM VARIATIONS IN TEMPERATURE IN MESOPAUSE REGION AND F2-REGION PEAK ELECTRON DENSITY OVER EASTERN SIBERIA

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We present the results of the analysis of year-to-year variations in the temperature of the mesopause region (Tm) and the peak electron density (NmF2) from spectrometric and radiophysical measurements with the equipment of the Institute of Solar-Terrestrial Physics SB RAS in 2008–2020. Data on the temperature of the mesopause region were obtained from spectrometric measurements of the OH emission ((6-2), 834 nm, Tory (51.8°N, 103.1°E)). The peak electron density was derived from the Irkutsk DPS-4 measurements (52.3°N, 104.3°E). We analyzed the annual mean Tm and NmF2, as well as yearly average values of day-to-day and intradiurnal variability in Tm and NmF2. The analysis involved data on solar and geomagnetic activity, as well as on variations in the Southern Oscillation Index (SOI). For the analysis, we used simple and multiple linear regression methods. It was found, that variations in the yearly average NmF2 are dominantly controlled by changes in the solar flux, whereas year-to-year variations in NmF2 variability are caused by changes in both solar and geomagnetic activity. The yearly average values of Tm variability correlate with changes in the SOI-index: the day-to-day variability shows a positive correlation with the SOI, while the intradiurnal variability demonstrates a negative correlation with the SOI. A significant relationship between the year-to-year variations in the NmF2 variability and Tm variability was not revealed.

The research was funded by the Russian Science Foundation (project No. 22-17-00146), https://rscf.ru/project/22-17-00146/. For the analysis, we used experimental data from the Shared Equipment Center "Angara," http://ckp-rf.ru/ckp/3056/, obtained with the financial support of the Ministry of Science and Higher Education of the Russian Federation.

STUDY OF IONOSPHERIC IRREGULARITIES BASED ON HF RADAR NETWORK DATA

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We present the results of ionospheric irregularity studies conducted at ISTP SB RAS using data from Russian (EKB and MGW) and SuperDARN HF radars. The scope of the studies refers to the irregularities of two types: wave-like traveling ionospheric disturbances (TIDs) and ionospheric decameter-scale field-aligned irregularities (FAIs). The report presents techniques developed at RAS to determine irregularity parameters, results of case-studies, statistical patterns revealed based on long-term observations, and their comparison with existing models. Prospects for the development of the existing Russian HF radar network are discussed. The work was supported by the Ministry of Science and Higher Education of the Russian Federation.

ANALYSIS OF SEISMIC AND IONOSPHERIC DISTURBANCES GENERATED BY THE EXPLOSION IN NORTH KOREA ON SEPTEMBER 3, 2017

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Data from networks of seismic stations and ground-based GPS/GLONASS receivers was used to explore the seismic and ionospheric disturbances caused by the underground nuclear test (UNT) in North Korea on 3 September 2017. We analyzed the frequency composition of the longitudinal and surface waves detected by more than 40 seismic stations. It was found that low frequencies (~0.45±0.21 Hz) predominated in the longitudinal wave spectrum. For both types of waves, the frequencies decreased with distance in accordance with the power law. Analysis revealed two trends in the spatial distribution of peak frequencies. First, the continental landmass was characterized by high and medium frequencies (0.14–0.50 Hz), and regions adjacent to fringe seas (transitional lithosphere zone between oceanic and continental crust) showed low frequencies of surface waves (0.13 Hz and lower). Second, there was an uneven frequency variation for different azimuths relative to the UNT epicenter: the frequencies subsided rapidly in the east, southeast and southwest directions from the epicenter, while towards the inner parts of the continental landmass, the frequency variation was much slower. From the records of longitudinal waves detected at different distances from the epicenter, we estimated the size of the epicenter area (R=0.98 km). Analysis of data from GPS/GLONASS receivers near the Korean Peninsula revealed ionospheric disturbances that were most likely caused by the underground nuclear test. Disturbances in the ionosphere appeared approximately 8 minutes after the UNT and were observed for about 5 hours. During the first 1.5–2 hours, traveling ionospheric disturbances (TIDs) were recorded. They propagated from the epicenter at speeds of approximately 600, 250 and 133 m/s. These TIDs had periods of 1–10.5 min and could be associated with acoustic waves induced in the Earth's atmosphere by UNT. After the TID passage, a long-lived (more than 3.5 hours) region with non-traveling (a velocity of about 7 m/s) ionospheric disturbances formed above the UNT site. The non-traveling ionospheric disturbances were extended from the southwest to the northeast. The reason for the formation of this region requires further study and modeling. In our view, the occurrence of this region may be due to the formation of standing waves in the atmosphere or the development of plasma instabilities.

SIMULTANEOUS OBSERVATIONS OF THE IAR WAVE STRUCTURE AT THE MID-LATITUDE AND AURORAL STATIONS

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An experimental comparison of the structure of the ionospheric Alfvén resonator (IAR) emissions at middle (MND – Mondy and UZR – Uzur stations) latitudes and in the auroral zone (IST – Istok station), showed a fundamental difference in the frequency ratio of harmonics (standing waves) in these two zones. At middle latitudes, the frequency ratio is proportional to a series of odd numbers 1:3:5…, which, taking into account the constant presence of a magnetic field node at the upper boundary of the resonator, means the formation of a stable antinode of the magnetic field at the lower boundary. In the auroral zone, the frequency ratio dis-

tribution is chaotic. The same applies to the phase factor, which is easily calculated from the frequency ratio of the harmonics. We are trying to explain the obtained results using the previously put forward [Guglielmi et al., 2021; Potapov et al., 2022] hypothesis, according to which the waves captured in the IAR reach the ground by penetrating the horizontally homogeneous mid-latitude ionosphere, so that the lower boundary of the resonator for them is the highly conductive earth's crust, where the antinode of the wave's magnetic field is formed. In contrast, the high-latitude ionosphere has the form of a set of domains with dimensions of 10–300 km, which is smaller than the transverse dimensions of the resonator. In this case, some of the waves form a magnetic field node on the ionosphere and are reflected from it, while some still penetrate to the ground. As a result, a chaotic distribution of the frequency ratio is formed, containing both ratios of odd numbers and arbitrary values, including a sequence of natural numbers (1:2:3...) [Potapov, 2024].

The work was supported by RF Ministry of Science and Higher Education. The results were obtained using the equipment of Shared Equipment Center "Angara" http://ckp-rf.ru/ckp/3056/.

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ATMOSPHERE IONIZATION AS A FACTOR UNITING ALL AREAS OF IMCP PROJECT STUDIES

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Atmosphere ionization is one of the key factors in the geospheres coupling processes. It facilitates the processes of energy transformation, modifies the vertical structure of atmosphere, forms new chemical components, modifies the Global Electric Circuit, creates conditions for formation of mesoscale critical processes such as hurricanes/typhoons, intensive precipitation, forest fires, etc. We will present effects from different sources of air ionization, including:

1. Effects of galactic cosmic rays on formation of the cloud cover of our planet;
2. Space weather effects on the formation and intensification of the tropical cyclones, hurricanes/typhoons;
3. Generation of the large-scale thermal anomalies by the earthquake preparation processes due to air ionization produced by radon emanating from the earth's crust;
4. Generation of the large-scale ionospheric and magnetospheric anomalies by the earthquake preparation processes due to the local modification of the Global Electric Circuit by air ionization produced by radon emanating from the earth's crust;
5. Effect of the global seismicity on the Global Electric Circuit and lightning activity;
6. Forest fires self-ignition due to the Space Weather effects;
7. Particles precipitation from the radiative belts stimulated by the earthquake preparation process and Distortion of the VLF waves sub-ionosphere propagation.

The air ionization by any source (solar proton fluxes of galactic cosmic rays, energetic electromagnetic emission, natural ground radioactivity, radioactive pollution) is the main driver for initiating the chain of physics-chemical processes responsible for the generation of many consequent effects in atmosphere and ionosphere. It changes the air conductivity in the vertical column between the ground and the ionosphere, producing the local modification of the Global Electric Circuit and, consequently, generating large-scale anomalies in the ionosphere. Simultaneously, the charge separation of the new formed ions creates an anomalous electric field and facilitates the cloud electrification. Ion's hydration releases the latent heat stored in the atmosphere by the water vapor and generates the thermal and meteorological anomalies.

The examples of effects from different sources of air ionization at different levels of altitude will be presented.

ELECTROMAGNETIC ULF-ELF RESPONSE OF NEAR-EARTH SPACE TO MAN-MADE, ATMOSPHERIC, AND MAGNETOSPHERIC ACTIVITY

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Plasma environment of the Earth plays the role of a "tuning fork" responsive to natural and technogenic disturbances. Here we present a brief review on research cycle aimed at studying the electromagnetic interaction between the atmosphere and upper ionosphere in the ULF-ELF range under both "below" and "above" impacts. The experimental part of this study is based on the analysis of synchronous satellite and ground observations using data from the world network of high-sensitive magnetometers and low-Earth-orbit (LEO) satellites SWARM, Chibis-M, and CSES. The plasma and electromagnetic noise at LEO over typhoons are revealed. We have obtained evidences of penetration into the upper ionosphere of electromagnetic ULF-ELF emissions from lightning discharges, typhoons, ground ELF transmitter, and power transmission lines. To interpret the observational results, new numerical models of the electromagnetic interaction of the atmosphere and ionosphere are developed. We estimate the electromagnetic "pollution" of near-Earth space by industrial 50/60 Hz radiation. These observations revealed the entire complex of phenomena of interaction between geophysical shells. The impact of atmospheric processes and man-made activity on near-Earth space is still an underestimated factor of near-Earth space physics.

SPACE ENVIRONMENT RESPONSES OF NATURAL DISASTERS — THE COUPLING MECHANISMS OF EARTH INNER ACTIVITIES WITH SPACE ENVIRONMENT

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Currently, China is operating and developing a series of projects related with Space environment, such as CSES-01/02, SMILE, CMP, IMCP and soon, to monitor and record the Inospheric plasma, EM waves and charged particles environments as well as their disturbances with space weather and natural hazards. By combining all these data, we acquired a lot of large events of earthquake, Volcano and Space Weather records, and then a series of case Analysis and statistical researches. On the basis of all these data and events studies, we developed the systematic mechanisms of lithosphere-Atmosphere-Ionospheres coupling of Electromagnetic channel to understood the Propagation and effects of the earth inner activities up to near-Earth space and make disturbance to the Regional Characteristics with the key point of LF EM wave can propagate among lithosphere, atmosphere and ionosphere. But the wave energies decimated while its going in and away of the wave-guide layer.

Regarding to the IMCP application objectives related with natural hazards, global Change and Sustainable Develop Goals, the main interested topics between Russia-China should be: 1. Jointly observation and research of global geomagnetical field and Polar Shift & SAA change as well as its impact to global change; 2. Jointly observation and research of multi-kind of natural hazards, such as EQ, Typhoon/Hurricane, waterflood, extreme weather etc., monitoring, mitigation and research by Combining of Space environment and Remote sensing information, as well as the Interaction of multi-plates, multi-spheres and multi-geophysical fields; 3. Joint research of the Inter-spheric coupling within Earth Critical Zone and SDGs.

MID-LATITUDE AURORAS DURING GEOMAGNETIC STORMS FROM DATA BY NHC OPTICAL INSTRUMENTS AND CITIZEN SCIENTISTS

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In this paper, effects of the geomagnetic storm on December 1, 2023 after M9.82 class solar flare are considered. Mid-latitude auroras (MLA) were observed with all-sky cameras NHC of ISTP SB RAS and photos of astronomy enthusiasts from IRAO. In all-sky camera images, MLA was observed from 10.45 to 23.45 UT during the main phase of the storm. In addition, a structure corresponding to SAR (stable aurora red) arc was observed in the airglow.

Images from citizen scientists and all-sky cameras were processed and projected onto the Earth's surface using geo-referencing techniques. Next, for a set of altitudes, the image projections were compared using the stereoscopy method and the altitude of coincidence of aurora's certain area was determined. Thus, it was determined that for images with a spaced base, the coincidence of the same "columns" of airglow is observed for an altitude of about 500 km.

A joint analysis of the resulting images showed that digital camera data from amateur astronomers is sufficiently informative to study events occurring in the atmosphere at different altitudes. Further involvement of more amateur photographers will allow the use of a greater number of spatially separated observation points, and accordingly improve the accuracy of the resulting MLA characteristics.

Images of mid-latitude auroras were obtained with the help of the Irkutsk Regional Astronomical Society and astronomy enthusiasts.

Experimental data were obtained using the equipment of the Angara Shared Equipment Center (ISTP SB RAS) http://ckp-angara.iszf.irk.ru/.

Data processing and storage were financially supported by the Ministry of Science and Higher Education of the Russian Federation (Subsidy No. 075-GZ/C3569/278).

MUSER OBSERVATION AND JOINT STUDY WITH SRH

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MUSER (MingantU SpEctral Radioheliograph) in China is composed of three arrays with MUSER-L covers 30–400 MHz with 224 LPDAs, MUSER-I covers 0.4–2.0 GHz with 40 mesh antennae and MUSER-II covers 2–15 GHz with 60 dish antennae. They have observed hundreds of radio burst events since 2023. The totally datasize are more than 3 Petabyte. The SRH (Siberian Radioheliograph) in Russia is in the radio range of 3–24 GHz. It is composed of three arrays with SRH-low covers 3–6 GHz with 129 dish antennae, SRH-mid covers 6–12 GHz with 192 dish antennae, and SRH-high covers 12–24 GHz with 207 dish antennae. Both MUSER and SRH are with high spatial and temporal resolution at many frequencies simultaneously. And they can observe solar flares almost simultaneously since in the very closest time zone. One of the proposed collaboration are going to joint analyze in detail several common view solar flares, and determining the radio flux, peak frequency, spectral or spatial characteristic and there is a relationship with solar activities. This work will introduce globally the observation of MUSER, the result of searching for common view events with the MUSER and SRH, the spectral and spatial analysis of a few common view events as examples. This will be helpful in the study of Solar-Terrestrial space weather in wide radio spectral range of 30 MHz – 24 GHz.

STATISTICAL STUDY ON PLASMA VELOCITIES IN THE BOTTOM-SIDE IONOSPHERE OVER LOW LATITUDE HAINAN STATION: DIGISONDE MEASUREMENT

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Data measured by the Digisonde at the low-latitude station Hainan from 2003 to 2016 are statistically analyzed to specify the diurnal average variations of the bottom-side F region ionospheric plasma velocity vector ***V***. This is the first comprehensive analysis of Digisonde measurements of low latitude F region plasma velocities in the East Asian sector that use a database covering more than one solar cycle. The velocity components V_N (Northward), V_E (Eastward) and V_Z (Upward) are analyzed for two levels of solar flux and two levels of geomagnetic activity, respectively. The diurnal variations of the average V_Z show three positive peaks near the prereversal enhancement (PRE) period, pre-midnight, and before sunrise, respectively, and a prominent valley in the early morning. The averaged V_Z significantly increased with solar flux in the period of PRE during equinoxes, but it was only slightly affected by Kp. The V_E component was westward in daytime and eastward in nighttime. The average eastward V_E increased significantly with solar flux but decreased with Kp, whereas the average westward V_E exhibited only a small variation with solar flux and Kp. The average V_N was almost southward independent of solar flux and Kp. The plasma velocities over the Hainan station were mainly caused by the electric field and neutral wind. Our results show that the features of the vertical and meridional velocities over the Hainan station in the morning are associated with the formation of the equatorial ionization anomaly (EIA).

OBSERVATION AND STUDIES ON IONOSPHERIC DISTURBANCES OVER CHINA USING THE AIRGLOW ALL SKY IMAGE NETWORK

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China covers both mid-latitude and low-latitude regions, and it has a unique terrain distribution. In order to study the perturbations in the upper atmosphere and ionosphere in mid- and low-latitude, we have established a monitoring network of airglow over the Chinese Mainland. This network has conducted double-layer detection for OH airglow (with a radiation altitude of about 87 kilometers) and OI 630 nm red line airglow (with a radiation altitude of approximately 250 kilometers) for more than ten years. This report will focus on the optical observation results of ionosphere disturbances in the mid- and low latitudes regions of China. It includes observations of mid-latitude auroras in the northernmost part of China and their impact on the ionosphere, mid-latitude ionospheric TID observed in central China, and low-latitude plasma bubbles observed in southern China.

STUDYING LARGE-SCALE STRUCTURES IN THE HIGH-LATITUDE IONOSPHERE AT MERIDIONAL CHAINS OF STATIONS ON THE EURASIAN CONTINENT

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An overview of the most important results of research performed at the Norilsk and Yakutsk meridional chains of stations in 1975–1983 is presented. All observation points were equipped with magnetovariation stations and ionosondes. 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, to construct statistical schemes of the development of ionospheric substorm north of the MIT in LT-Kp coordinates at different latitudes, to reveal the effect of solar activity [Zherebtsov et al., 1986; Pirog et al., 1997]. The results obtained confirm the effectiveness of meridional chains of geophysical instruments in studies of the magnetosphere-ionosphere interactions. The experience gained can be useful for work within the IMCP frame.

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Section 4. UP-TO-DATE METHODS AND INSTRUMENTS FOR SOLAR-TERRESTRIAL RESEARCH WITHIN THE FRAMEWORK OF IMCP

GAMMA-RAY SPECTROMETERS ON LAUNCHED AND PLANNED MSU CUBESATS FOR SOLAR-TERRESTRIAL RESEARCH

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Gamma-ray scintillation spectrometers DeCoR (Detectors of Cosmic Radiation) developed in SINP MSU are installed on a number of small satellites of the cubesat format, launched in June 2023 into a circular polar orbit with a height of ~550 km. They are designed to study hard x-ray and gamma radiation from solar flares as well as fast variations in near-Earth electron fluxes and astrophysical gamma-ray bursts. The detectors of the most of the devices are a combination of a plastic scintillator ~3 mm thick and a CsI (Tl) crystal ~10 mm thick allowing to distinguish between solar flares and electron precipitation. Some satellites additionally have gamma-ray spectrometers based on a large CsI(Tl) crystal in order to register gamma-ray quanta of MeV energies. The output data are generated both in the form of monitoring and in an event-by-event format. The data is stored in the non-volatile memory of the payload. Thus, during the space experiment, it is possible to select the most important data sections for transmission to Earth in primary form, which allows for studies of the rapid variability of the measured radiation fluxes.

At the present moment, the methodology of a space experiment using DeCoR equipment has been worked out during flight tests. A hard radiation from a number of solar flares was recorded and solar cosmic rays were also observed. It is planned to continue the experiment on the satellites mentioned above in the next 1-2 years, as well as to launch several new nanosatellites with improved equipment. In particular a new 16U cubesat Scorpion will have pixelated gamma-ray spectrometer consisting of 4 detector units each containing 64 individual scintillating elements with size 10x10x20 mm. The launch of this satellite is scheduled for late 2024 – early 2025.

DECIMETRIC TYPE-IV SOLAR RADIO BURSTS AND DAOCHENG T-ARRAY DECIMETRIC SOLAR RADIOHELIOGRAPH (DATA)

Yao Chen, Fabao Yan, Bing Wang, Zhao Wu, Weidan Zhang, Xiangliang Kong, Songqiang Song, Ruisheng Zheng, etc.

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I will present our latest study on the decametric type-IV solar radio bursts. The bursts occur within a frequency range of a few hundreds of MHz to 1–2 GHz, with clearly-defined lower and upper cutoff frequencies. The bursts present continuum emission with lots of fine spectral structures, such as the wideband pulsations, zebras, spikes, absorptions, etc. The emission mechanism remains elusive/controversial for decades. Our analysis of both EUV and radio imaging data provides strong evidence for this type of radio bursts to be from the electron cyclotron maser emission.

I will also introduce our plan of constructing a new T-array solar radio heliograph for decametric wavelength in the city of Daocheng, with 100 elements. The radioheliograph will observe the Sun from 500 MHz to ~ 8GHz, each element consists of a 4-m parabola and a high-performance digital receiver. We welcome collaborations under the framework of IMCP and between universities/institutes.

PROGRESS OF SOLAR OBSERVATION IN NAOC

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In recent years, China has made some progress in solar physics, both in ground-based and space observations, some of which were mainly achieved by the Huairou Solar Observing Station of NAOC. This report focuses on the latest advancements made by NAOC in solar observation equipment and technical methodologies, as well as the Solar Polar Orbit Exploration program currently underway by China's solar physics community.

SINP MSU FEASIBILITIES FOR IMCP

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D.V. Skobeltsyn Institute of Nuclear Physics of M.V. Lomonosov Moscow State University (SINP MSU) can contribute various items to the International Meridian Circle Program (IMCP) in the frame of Solar-Terrestrial Physics.

In the scope of Space Weather (SW) Space Monitoring Data Center (SMDC) of SINP MSU (https://swx.sinp.msu.ru/index.php) provides experimental data on energetic particles of the solar and magnetospheric origin. Monitoring of the energetic particles is conducted by a number of Russian meteorological satellites equipped by particle detectors manufactured by SINP MSU. At GEO orbit, geosynchronous relativistic electrons (GRE) and high-energy solar protons are observed by Russian geosynchronous satellites Electro-L1, L2 and L4 during the recent decades. NOAA GOES data are also collected and analyzed. At HEO orbit, high-apogee satellites Arctica M1(160/340E) & M2(160/340E) observe Earth Radiation Belts (ERBs) in the Southern Hemisphere. At LEO orbit, a fleet of Russian sun-synchronous satellites Meteor-M1(3/15 MLT), M2(4/16 MLT), M2-4(9/21MLT) observed near-Earth radiation environment, including solar energetic particles (SEP), inner and outer ERBs and auroral precipitations from the plasma sheet. Experimental data from POES/METOP fleet are also analyzed. SINP MSU SMDC supports various SW models. Forecasting models have been developed for the solar wind velocity, geomagnetic indices Kp & Dst as well as for GRE fluences. This allows providing Alerts & Warnings for the enhancements in X-rays, SEP fluxes, GRE fluxes and geomagnetic storms. The now-casting includes SEP probabilistic model (peak fluxes & fluences), model of the magnetopause, 3D model of the magnetic field in the Earth's magnetosphere, high-latitude boundary of the outer ERB, elliptical model of SEP cutoff boundary and polar cap absorption.

In the scope of Global Electric Circuit (GE), SINP MSU provides experimental data on atmospheric transient luminocity events (TLE) in UV range acquired from Russian LEO satellite Vernov and International Space Station. TLEs are also observed by ground-based instrument located at high-latitude station in Apatity. The high spatial and temporal resolution of the data allows accurate analysis of the TLE power, location and propagation.

In the scope of Geomagnetic Field Variations (GM), SINP MSU develops models of decadal dynamic of the electrons in the inner and outer ERBs for the time interval from 1998 to 2024. The models show diminishing of the inner ERB and significant equatorward shifting of the outer ERB above Siberia within the last decade.

LONG-TERM EVOLUTION OF THE EARTH RADIATION BELTS DURING SOLAR CYCLES 23–25

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Energetic electrons > 30 keV have a significant impact on the ionization of the upper atmosphere and the conductivity of the lower ionosphere. Being moving along the magnetic field lines energetic electrons allow tracing the configuration of the geomagnetic field by mapping fluxes of electrons trapped in the Earth's radiation belts (ERB). In the scope of Geomagnetic Field Variations (GM) we investigate long-lasting and solar cycle variations of the electrons trapped in the Earth's Radiation Belts (ERBs) for the time interval from 1998 to 2024 [1-4]. Experimental data were acquired from the NOAA/POES and METOP satellites with polar sun-synchronous orbits at an altitude of 850 km. In the inner ERP, it was found a significant decrease in the fluxes of energetic electrons in the region of the South Atlantic Anomaly (SAA) and a decrease in its area occurred in the 24th solar cycle. It was also found that in the 24th solar cycle, especially in the declining phase, starting from 2015, electron fluxes in the outer ERB increased significantly, and the belt anomalously shifted toward the equator in the Siberian region. Such dynamics can be explained by the nature of the connection between the magnetosphere and the influence of the solar wind, as well as by a sharp and strong change in the Earth's magnetic field (magnetic jerk) during the 24th cycle. The latter might led to an increase in the magnetic field in the SAA region and the rise of the inner belt to high altitudes. The rise frees up altitude areas below 350 km for the massive use of low-altitude missions. The equatorward shift of the outer ERB can contribute to the significant increase in the occurrence of mid-latitude discrete auroras over Russia.

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APPLICATION OF A GLOBAL MHD SIMULATION MODEL OF EARTH'S MAGNETOSPHERE ON SPACE WEATHER FORECASTING

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During the past four decades, the global magnetohrodynamics (MHD) simulation of Earth's magnetosphere has been widely used for the investigation of large-scale behavior of the plasma environment around the Earth. Due to the limited use of MHD in certain regions, different coupling processes have been taken into account in these simulations for the magnetosphere in order to obtain a more sophisficated modelling, for example, the electrostatic coupling with the ionosphere, and the dynamical coupling with inner magnetosphere in which the particle drift physics are numerically implemented. In recent years, it has been attempted that the global MHD simulation has been applied in the space weather forecasting, with the real-time solar wind conditions from the spacecrafts ACE/DSCOVR at L1 point are mapped to the upstream of the magnetosphere through the ballistic method. Here, we following the similar approach based on the well-developed global MHD model of magnetosphere, and offer the 30–60 mins advance forecasting for the geomagnetic activities, ground magnetic perturbations, and the global evolution of Earth's magnetosphere. The forecasting results are then evaluated according to the comparison with the observations.

THE NEW RADIO SPECTROPOLARIMETERS FOR SOLAR ACTIVITY OBSERVATIONS

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At the end of 2023 the new instrument, dedicated to solar activity studies, started its operation — the Siberian Radioheliograph (SRH). The SRH consists of three T-shaped redundant-spacing antenna arrays and auxiliary instruments — the total flux spectropolarimeters operating in frequency ranges of 3–24 GHz and 50–3000 MHz. The spectropolarimeters are meant to expand the SRH data by obtaining additional spectral measurements with finer time resolution. The spectropolarimeters data will provide more information on the most geoeffective solar activity phenomena — coronal mass ejections (CMEs) and flares. In the report the specifications of the spectropolarimeters and the results of test observations are presented. The comparison of the new spectropolarimeters data with the other instruments data is carried out.

CLIMATE CHANGE AND ITS IMPACT ON ATMOSPHERIC CHARACTERISTICS ALONG 120 E MERIDIAN

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In this study, we discuss the character of air temperature changes within the troposphere and stratosphere. Analysis of accumulated data on atmospheric temperature shows that the air warms up unevenly not only regionally depending on the incoming solar energy, but also by altitude above the ground. The tendency of tropospheric air warming up changes at an altitude of about 9–10 km in the middle latitudes of both hemispheres has increased slightly in the last ~80 years. At the altitude of the lower stratosphere

~12–15 km, a decrease in temperature was observed. The air of the upper stratosphere also tended to cool. Since 2000, in the Northern and Southern hemispheres the temperature tendency to decrease in the stratosphere began to change towards stabilization and in the last few years one can observe an increase.

We show that changes in stratospheric temperature are accompanied by a long-term increase. The most pronounced increase in temperature changes corresponds to the period from 1948 to 1998. At present, in the stratosphere, on the time scale from 1999, a secondary weaker increase and, subsequently, a certain stabilization of the temperature field are observed. In addition, a transition to stratospheric warming is noted in certain months within different latitudinal zones. As we assume, the period of transition from the phase of stable stratospheric cooling (in average values) to certain stabilization and warming should have a longer duration compared to the estimated one: from 1999 to 2024. Considering the trend of temperature change, the period of temperature growth in the stratosphere will most likely be observed until 2030.

We should also note an important feature of temperature change along 120 E at altitudes of 10 hPa in the Southern Hemisphere. At these altitudes, a sharp increase in air temperature is observed over a four-year period (from 1976 to 1979). Moreover, this increase is accompanied by a further systemic decrease in air temperature. The amplitude of the increase depends on latitude, the mean value is 2.5^{o}. Warming of the stratospheric layers can affect a number of geophysical characteristics of the middle atmosphere, such as the height of the upper layers, including the ionospheric layer. Changes in air temperature lead to a shift in the position of atmospheric layers: up to 20 km or even more.

The study of modern features of climate warming is relevant not only for the development of ideas about geophysical processes in the lower, middle and upper atmosphere, occurring on different spatial and temporal scales, but also for deepening the understanding of changes in individual atmospheric characteristics of the atmosphere, including the parameters relevant for astronomical telescopes. In particular, changes in the temperature field in the lower atmosphere lead to a restructuring of dynamic processes in the atmosphere and are accompanied by changes in diffuse light.

The research was financially supported by the Russian Science Foundation under grant No. 24-72-10043.

MODELING RESEARCH ON ATMOSPHERIC OPTICAL CHARACTERISTICS FOR GROUND-BASED OBSERVATIONS

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The atmospheric optical properties are crucial for evaluating observation conditions at astronomical observatories, which can affect the imaging quality and resolution of ground based telescopes. With the development of astronomical high-resolution methods and techniques, especially adaptive optics, that encourage higher requirements of studying atmospheric optics and the measurement techniques. For large telescope construction, the study of atmospheric optical properties is not only the major work of site survey, but also the essential correction parameters for improving the resolution in the operation of telescopes, including the integral of atmospheric turbulence parameters of the whole atmosphere, and that at different altitudes from ground to upper air. Based on meso-scale numerical model, we are committed to establish a forecasting system of atmospheric optical properties with high precision, to qualitatively describe the characteristics of optical parameters in detail, and provide forecasts of turbulence characteristics at an observatory. Take the Ali observatory above the Tibetan Plateau as an example, factors such as complex terrain, ground overlays, specific climate and so on need to be considered for the configuration of the numerical model, to ensure the reliability of the results. Based on the accurate parametric models of each atmospheric parameter built combined with measuring equipment at the observatory, the cloud cover, precipitable water vapor, atmospheric turbulence, optical aerosol and so on have been summarized. The forecasting model system has been demonstrated to be a useful tool for estimating atmospheric characteristics, that will be of great significance and can provide reliable guidance for scheduling astronomical observations, site survey, adaptive optics, communication engineering, laser transmission and others.

PARAMETERIZATION OF OPTICAL TURBULENCE CHARACTERISTICS OVER THE BAIKAL ASTROPHYSICAL OBSERVATORY

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In this study, we discuss the possibilities of parameterization of vertical profiles of optical turbulence. The approach based on a gradient of meteorological characteristics is used as a basis for determining the intensity of optical turbulence [Shikhovtsev, 2024]. Here, we propose an approach to improve the accuracy of estimating vertical profiles of the structural characteristic by taking into account the measurement data of the characteristics of optical turbulence (motion and scintillation of images). Using the proposed approach, reference vertical profiles of optical turbulence over the Large Solar Vacuum Telescope (LSVT) are determined. These profiles are verified taking into account the measured seeing obtained using the Shack-Hartmann sensor. The issues of application of pattern recognition methods to detect sunspots observed with LSVT are considered separately. The tested method can be adapted for other astronomical observatories. The results were obtained using the Unique Research Facility Large Solar Vacuum Telescope http://ckp-rf.ru/usu/200615/.

The research was financially supported by the Russian Science Foundation under Grant No. 24-72-10043.

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DEVELOPMENT OF THE FULL-DISK VECTOR MAGNETOGRAPHS FOR THE MERIDIAN PROJECT II

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The Meridian Project II aims to establish a comprehensive ground-based monitoring network for China’s space environment. Our team is responsible for the development of a major instrument within this project, the Full-Disk Vector Magnetograph (SFMM). The core component of SFMM, the “Liquid Crystal Waveplate-Based 0.085-Å Extremely Narrowband Birefringent Filter,” represents a groundbreaking achievement by integrating four-channel full-disk imaging spectroscopy for FeI, Hα, Hβ, and CaII for the first time. This report outlines the development progress and observational results of the SFMM.

MONITORING OF SPACE WEATHER EFFECTS WITH THE USE OF MOSCOW UNIVERSITY SOZVEZDIE-270 NANO-SATELLITE CONSTELLATION

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Space project Sozvezdie-270 of the Moscow University is realized now. It means the deployment of a cubesat nano-satellites constellation. To the present 18 satellites were launched, 9 of them continue to function in orbit, two satellites will be launched in the nearest future. Instruments were elaborated specifically for use on spacecraft of the cubesat format, providing measurements of fluxes and spectra of charged particles, primarily electrons of relativistic and subrelativistic energies, as well as gamma quanta. Along with the space constellation, a network of ground receiving stations is also being created. A multi-satellite constellation provides a number of advantages when studying dynamic processes in radiation fields in near-Earth space. In particular, it makes possible to carry out simultaneous measurements of particle and quantum fluxes using the same type of instruments at different points in near-Earth space. Such measurements provide unique information about the sub-relativistic electron flux dynamics, including variations due to precipitation, which is of great importance for understanding the mechanisms of trapped and quasi-trapped electron acceleration and losses. Various recent space weather effects associated with increased solar flare activity are discussed. Among such effects are the filling of the polar caps with particles of solar cosmic rays, dynamic processes in the outer radiation belt during magnetic storms, rapid variations in electron fluxes due to precipitation.

DART: DAOCHENG RADIO TELESCOPE SYSTEM AND EARLY RESULTS

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DAocheng Radio Telescope (DART) was renamed from the Daocheng Solar Radio Telescope (DSRT), a circular sparse array for interferometric imaging of the Sun. The DART is an instrument of the Meridian Project, China's major national science and technology infrastructure. The principal scientific driver of the DART is to monitor the highly dynamic solar activity in the corona, through which coronal mass ejections (CMEs) escape into interplanetary space. The DART was proposed in 2013 and approved in 2019. The telescope system of the array and the calibration tower was completed in November 2022. Since September 2023, the DART has been operational. DART system is a circular array of 1 km diameter with 313 element antennas, each with an aperture of 6 m. The nominal receiver band is 150–450 MHz, the frequency of solar radio emissions from the high corona. DART's circular array produces a dish-like u–v coverage of 50,000 quasi-uniform samples in a single polarization, full polarization visibility components of I, Q, U, and V are recorded in real-time. Based on its advantages of dense u-v coverage and a unique calibration system, the DART is not only a powerful radio camera for solar observation but also an extraordinary instrument for night astronomy, such as low-frequency spectral imaging surveys, pulsar and Fast Radio Bursts (FRBs) searching. The presentation will introduce the DART system, preliminary results for regular solar observation, and some dedicated observation campaigns in radio astronomy.

ENVIRONMENTAL CONDITIONS AT THE HIGH-ALTITUDE ALI OBSERVATORY FOR SPACE WEATHER RESEARCH

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The deployment of ground stations can be one of the important foundational works for space weather research. This paper introduces the environmental conditions at high-altitude Ali observatory on the most western Qinghai-Tibet Plateau. The statistical results of atmospheric conditions by years of monitoring and research, including cloud cover, water vapor, meteorological parameters, atmospheric background radiation, transmittance and optical turbulence, are presented. The geographical traffic, current infrastructure as well as coming construction plan of the observatory are also shown. In view of the unique highest platform in the Northern Hemisphere with excellent observational conditions and mature infrastructure, Ali observatory should be expected to develop into a multi-disciplinary station including space weather exploration.

GLOBAL NAVIGATION SATELLITE SYSTEMS FOR SPACE WEATHER STUDIES

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Global navigation satellite system (GNSS) provides huge data sets to study the Earth's ionosphere and different aspects of space weather influence. The talk briefly reviews GNSS-based experimental studies of the ionospheric effects from solar flares, solar terminator, solar eclipses, magnetic storms, etc. It also mentions recent events such as the ionospheric effects of the 2023 Türkiye earthquake, the May 2024 magnetic storm, the 18 November 2023 Starship explosion. Such researches are based on total electron content variations. Some attention is devoted to the advances that GNSS stations in Russia suggest for global monitoring. Our team developed a free-to-use system to treat GNSS data – SIMuRG (https://simurg.iszf.irk.ru) [Yasyukevich et al., 2020]. The system could be useful for studying the ionospheric space weather. The talk partly is devoted to machine learning to study the Earth's ionosphere. The work is financially supported by the Russian Science Foundation (project No. 23-17-00157).

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