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Solar Influences on the Magnetosphere, Ionosphere and Atmosphere

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Topics:

Sun and Solar Activity
Solar Wind-Magnetosphere-Ionosphere Interactions
Solar Influences on the Lower Atmosphere and Climate
Solar Effects in the Biosphere and Lithosphere
Instrumentation for Space Weather Monitoring
Data Proccessing and Modelling

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ФОНД НАУЧНИ ИЗСЛЕДВАНИЯ
МИНИСТЕРСТВО НА ОБРАЗОВАНИЕТО И НАУКАТА

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Sun and Solar Activity

On Some Solar-Activity-Driven Terrestrial Processes

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Terrestrial processes considered in this paper are the geomagnetic activity, the climate (air surface temperature), the Earth rotation (length of day), the evolution of the main geomagnetic field (geomagnetic activity, secular variation, Earth's magnetic dipole). Several reconstructions of the solar activity published in the literature are used for comparison to terrestrial data. Each time series was first subject to a Hodrick and Prescott (1997) analysis, to separate a decadal variation from a so-called trend. The latter was then Butterworth (1930) filtered, to get constituents (the so-called inter-decadal and sub-centennial variations) at two time scales (20-30 years, respectively 60-90 years). Elevated correlations between components of the solar-activity and those of the studied terrestrial processes have been found. Possible causal links are advanced. The role of the magnetosphere ring current is emphasized.

Prediction of Solar Cycle 25 Using Simplex Projection Method: A Long-Term Analysis Based on F10.7 Index Data

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This study aims to predict the activity of the 25th solar cycle by applying the Simplex Projection method to the 27-day averaged Solar Radio Flux 10.7 cm (F10.7) index data. For this purpose, F10.7 data from 1963 to 2018 (up to the end of the 24th cycle) were considered, and the current values of the 25th cycle were excluded from the dataset. Consequently, the dataset consists of 746 points (approximately 700 months), with the first 460 points selected as the library set and the remaining 286 points as the prediction set. Simplex Projection is a concept/method that analyzes the complexity and chaotic properties of dynamic systems and can generate predictions based on these analyses. Based on the Takens theorem, Simplex embeds the data into the phase space at different embedding dimensions (E). Subsequently, it compares the points in the prediction set with the library set for each embedding dimension, identifying similar points and producing forward predictions (i.e., similarities) according to the desired time to prediction (Tp). Multiple predictions were made for each embedding dimension (E, from 2 to 7) in this study. To distinguish accurate predictions and partially eliminate incorrect ones, the mean absolute error (MAE) was calculated for each prediction between the first 71 values of the current and known 25th cycle and the first 71 predicted values. Predictions with an error rate below 15% were considered successful, and confidence in the accuracy of predictions after the 71st prediction was based on this criterion. When evaluating successful predictions, a double-peaked pattern is expected for the 25th cycle. Accordingly, the first peak of solar activity for the 25th cycle is expected around mid-2023, with the second peak, stronger than the first, anticipated to occur in early 2025, and the cycle minimum expected in the middle or later stages of 2030.

Comparison of the 19/20 and 20/21 Centuries Gleissberg Minima

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The ~11-year (“Schwabe”) sunspot cycle is the most prominent solar activity cycle. The Schwabe cycles are not all the same, but vary in both amplitude and duration, modulated by a secular cycle known as the “Gleissberg cycle”.

Solar activity during the second half of the 20th century was exceptionally high compared to the previous 11 centuries – a period often referred to as the “Modern Grand Maximum”. It is now obvious that this Grand Maximum has come to an end, with the sunspot cycle 22 being the last one of this period of very high activity. Sunspot cycle 23, which spanned from 1996 to 2008, was markedly longer than the previous cycles, and was characterized by a prolonged and deep sunspot minimum preceding the low cycle 24, leading to speculations about the onset of a Grand Minimum similar to the Maunder Minimum. However, it seems that this is not the case because the current cycle 25 is already somewhat higher than cycle 24, and probably cycles 23 and 24 mark not the beginning of the next Grand Minimum but just the centennial minimum between two Gleissberg cycles. Here we use observational and proxy data to compare these two secular solar activity minima and their effects on space weather.

This research is supported by the Bulgarian NSF Grant KP-06-H44/2

The Backreaction of the Reduced Heliospheric Pressure and Its Implications for the Strength of Solar Cycle 25

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The effect of the heliospheric pressure on the properties of coronal mass ejections (CMEs) was first recognized as the anomalous expansion of CMEs in the beginning of solar cycle 24 (Gopalswamy et al. 2014, GRL 41, 2673). The reduced heliospheric total pressure, whose backreaction on CMEs allows them to expand more, resulted in a larger CME width in cycle 24 than in cycle 23 for a given speed. The backreaction of the reduced heliospheric pressure manifests in many ways, including (i) enhanced halo CME abundance, (ii) halo formation closer to the Sun at lower CMEs speeds, (iii) wider longitudinal distribution of halo CMEs, (iv) change in slope of the CME expansion speed – CME radial speed relationship, and (v) larger pressure balance distance for CME flux ropes. The current solar cycle 25 is in its maximum phase and has witnessed a significant number of CMEs in the first 4 years since it started in December 2019. We use limb CMEs associated with solar flares of X-ray intensity ≥ C3.0 in solar cycles 23-25 to revisit the CME speed–width relationship. We find that the slope of the speed-width relationship is significantly larger in cycle 25 than in cycle 23 but only slightly smaller than that in cycle 24. These results imply that cycle 25 is weaker than cycle 23 but similar in strength to cycle 24.

Fundamental–Harmonic Pairs of Interplanetary Type III Radio Bursts

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Type III radio bursts are not only the most intense but also the most frequently observed solar radio bursts. However, a number of their defining features remain poorly understood. Observational limitations, such as a lack of sufficient spectral and temporal resolution, have hindered a full comprehension of the emission process, especially in the hectokilometric wavelengths. Of particular difficulty is the ability to detect the harmonics of type III radio bursts. Here we report the first detailed observations of type III fundamental–harmonic pairs in the hectokilometric wavelengths, observed by the Parker Solar Probe. We present a statistical analysis of the spectral characteristics and polarization measurements of the fundamental–harmonic pairs. Additionally, we quantify various characteristics of the fundamental–harmonic pairs, such as the time delay and time profile asymmetry. Our report concludes that fundamental–harmonic pairs constitute a majority of all type III radio bursts observed during close encounters, when the probe is in close proximity to the source region and propagation effects are less pronounced.

Is There a Synchronizing: Influence of Planets on the Cyclic Solar and Stellar Activity?

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The question of how much the presence of a planetary system influences the cyclic activity of the Sun and other cold stars is considered. This work continues our search for a connection between the long-term activity of stars and their planets. We analyze new data on the previously considered two dozen solar-type stars with identified cycles adding the results of studying the long-term variability of two more solar-type G stars and 15 cooler M dwarfs with planets. If the cyclic activity is determined by the strong tidal influence of the planet, then the duration of the cycle of a star should be synchronized with the period of revolution of the planet around it. We calculated the gravitational effect of a planet on its parent star. The results obtained confirm the previously made conclusion that there is no influence of the exoplanet on the formation of the stellar cycle. We examined the change in the position of the barycenter of the Solar System relative to the center of the Sun over 420 years. Comparison of these data with the most reliable 120-year series of the SSN solar activity index makes it possible to verify that they are not synchronized.

Relationship Between Physical Parameters of Umbral Dots Measured in Twenty-one Sunspot Umbras and the Solar Cycle

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UDs are bright dot like fine structures observed in sunspot umbra. Studying the relationships between UD physical parameters (average intensity, diameter, eccentricity, dynamic velocity and life time) and sunspot number/other solar activity indicators help us understand the physical properties of sunspots and therefore of the Sun. High resolution sunspot umbra time series (2013-2022) taken from Big Bear Solar Observatory (BBSO)/Goode Solar Telescope (GST) and sunspot number (SSN) data for the same days are downloaded from Solar Influences Data analysis Center (SIDC) web page. To obtain the possible relationship between above mentioned UD parameters with each other and SSN the temporal variation and Pearson correlation analyses were performed. In results of our analysis we found that all UD parameters show correlations with SSN and the relationships between them are not linear in general. We also found that sunspot number show a meaningful correlation with the average quiet-sun brightness selected from outside of the analyzed sunspots.

Multi-Wavelength Quasi-Periodic Pulsations as a New Proxy of Electric Current Systems in Stellar Flares

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The standard model of a flare considers the electric currents (both micro-, in the vicinity of magnetic X-points, and macro-, in magnetic flux ropes, current sheets, or current-carrying loops) as a generic storage of the free magnetic energy and the main drivers for its impulsive release. The phenomenon of quasi-periodic pulsations (QPP) commonly observed in solar and stellar flares has been recently understood to carry unique but yet unexplored information about the flare onset, development, and surrounding plasma conditions. We present the first multi-wavelength simultaneous detection of QPP in a superflare (more than a thousand times stronger than the most powerful solar flare ever observed) on a cool star KIC 8093473, in soft X-rays (SXR) and white light (WL), with XMM-Newton and Kepler spacecraft, respectively. Using the solar-stellar analogy, the flare radiation in SXR and WL bands is conventionally associated with thermal (from hot coronal loops) and non-thermal (from the accelerated electrons bombarding the chromosphere) emissions. The observed QPP have oscillation periods about 1.5 hours (SXR) and 3 hours (WL), and correlate well with each other. The non-thermal to thermal QPP period ratio of 2 allowed us to link them with oscillations of the electric current in the flare loop, which directly affect the dynamics of non-thermal electrons and indirectly (via ohmic heating) the thermal plasma. These findings could be considered as the first explicit seismological evidence in favour of the equivalent LCR-contour model of a flare loop proposed hitherto, at least in the extreme conditions of stellar superflares.

Application of the B-star Drag Term Coefficient to Analyze the Influence of Solar and Geomagnetic Activity on the Upper Atmosphere of the Earth During the Period of 23-24 Solar Cycles

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The movement of the artificial satellites in orbit around the Earth occurs not only under the influence of gravitational forces, but also under the influence of atmospheric drag. Taking into account the drag force of the atmosphere presents problems not only of a mathematical nature, but also of a physical nature. All currently existing models of the Earth's atmosphere are empirical in nature and depend on factors that have significant stochastic features. Therefore, fluctuations in atmospheric density cannot be accurately predicted.

To analyze the behavior of the atmosphere under the influence of solar and geomagnetic activity, we can use artificial Earth satellites that move in an uncontrolled mode. For this purpose, the B-star coefficient was used in this work. This coefficient is used in the SGP4 and SDP4 models to take into account the atmospheric drag on the satellite motion and illustrates the satellite's susceptibility to atmospheric drag in orbit.

This work presents the results of processing the B-star coefficient data with indexes of solar and geomagnetic activity over 23-24 cycles of solar activity. 25 artificial satellites were taken for processing. A correlation analysis was carried out, periodograms and spectrograms were constructed. Multiple correlation models and cross-spectral FFT analysis were calculated.

Ion Kinetics of Plasma Interchange Reconnection in the Lower Solar Corona

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The exploration of the inner heliosphere by the Parker Solar Probe has revealed a highly structured solar wind with ubiquitous deflections from the Parker spiral, known as switchbacks. Interchange reconnection (IR) may play an important role in generating these switchbacks, by forming unstable particle distributions that generate wave activity that in turn may evolve to such structures. IR occurs in very low-beta plasmas and in the presence of strong guiding fields. Although IR is unlikely to release enough energy to provide an important contribution to the heating and acceleration of the solar wind, it affects the way the solar wind is connected to its sources, connecting open field lines to regions of closed fields. This “switching on” provides a mechanism by which the plasma near coronal hole boundaries can mix with that trapped inside the closed loops. This mixing can lead to a new energy balance. It may significantly change the characteristics of the solar wind because this plasma is already preheated and can potentially have quite different density and particle distributions. It not only replenishes the solar wind, but also affects the electric field, which in turn affects the energy balance. This interpenetration is manifested by the formation of a bimodal ion distribution, with a core and a beam-like population. Such distributions are indeed frequently observed by the Parker Solar Probe. Here we provide a first step toward assessing the role of such processes in accelerating and heating the solar wind.

HESPERIA REleASE+: Improving Solar Proton Event Forecasting by Means of Automated Recognition of Type-III Radio Bursts

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Providing reliable forecasts of Solar Energetic Particle (SEP) events is mandatory for human spaceflight beyond low-Earth orbit, especially outside the Earth's magnetosphere. High-energy SEPs are tracked because they penetrate deeper into the terrestrial atmosphere and contribute to the radiation dose aboard spacecraft specifically over Canada and the Southern Indian Ocean, due to the tilt of the Earth on its axis. Based on the Relativistic Electron Alert System for Exploration (REleASE) forecasting scheme], the HESPERIA REleASE product was developed by the HESPERIA H2020 project (Project Coordinator: Dr. Olga Malandraki) and generating real-time predictions of the proton flux (30-50 MeV) at L1, making use of relativistic and near-relativistic electron measurements by the SOHO/EPHIN and ACE/EPAM experiments, respectively. The HESPERIA REleASE tools are operational through the Space Weather Operational Unit of the National Observatory of Athens, accessible through the dedicated website (http://www.hesperia.astro.noa.gr). HESPERIA REleASE has attracted attention from various space organizations (e.g., NASA/CCMC, SRAG), due to the real-time, highly accurate and timely performance offered. ESA selected the HESPERIA REleASE products that were integrated and provided through the ESA Space Weather (SWE) Service Network (https://swe.ssa.esa.int/noa-hesperia-federated) under the Space Radiation Expert Service Center (R-ESC). Solar cycle 25 solar radiation storms successfully predicted by HESPERIA REleASE are presented and discussed. Moreover, we present an innovative upgrade implemented, namely HESPERIA REleASE+, that is using the novel approach of combining for the first time real-time type III solar radio burst observations by the STEREO S/WAVES instrument, thus incorporating clear evidence of particle escape from the Sun, within the HESPERIA REleASE system. To this end, a robust automated algorithm has been developed for the real-time identification and classification of Type III radio burst characteristics, related to intense SEP events at Earth’s orbit. This new implementation leads to a substantial step forward in improving the accuracy and reduction of false alarms.

Dynamics and Lifetime of Solar Active Regions

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During the emergence of solar active regions their eastern and western footpoints move apart. This diverging motion results in the stretching of the sunspot groups, which can also be observed during the decay phase. The present work studies the separation distance's temporal variation on a large statistical sample for both the emergence and decay phases. The separation distance is calculated between the leading and following centers of mass. Altogether more than 2000 individual active regions are taken into account by using the uniquely detailed Debrecen sunspot databases. This study is mainly based on data from the SoHO/MDI-Debrecen Sunspot Data which contains data practically for the whole solar cycle 23. To track the temporal variation of the separation distance the Debrecen Photoheliographic Data is used which contains data for solar cycles 20-24. The results show that the polarity separation distance depends on the maximum area of sunspot groups and starts to increase after the emergence and continues during the decay, although a plateau is plotted out around the peak flux. At the end of the decay, a decrease can be observed in the cases of the middle and the largest groups. Cycle and cycle phase dependencies and hemispheric differences can also be pointed out. Considering the areal development phase the lifetime of sunspot groups is also studied. Besides this, their lifetime is also determined by identifying the recurrent active regions. Research leading these results is funded by National Research, Development and Innovation Office – NKFIH, under grant agreement 141895.

Large-Scale Magnetic Field and the Nature of the Gnevyshev Gap

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“Gnevyshev Gap” (GG) was first identified using data on the radiation of the solar corona (green line). It was later studied in sunspot data, solar wind data and, especially, space data. Data for different indices are not consistent with each other; the effect is often detectable only when analyzing average monthly values and disappears when moving to traditional smoothing according to the standard. We examined magnetic field data and concluded that this effect reflects the behavior of a large-scale magnetic field. The Gnevyshev Gap occurs after a polarity reversal of the Sun's polar magnetic field. At the same time, the energy of the zonal component of the global magnetic field decreases. Following this, with a certain time delay, the sectorial component sharply increases, which leads to the appearance of a secondary maximum. At the photosphere level, the Gnevyshev Gap in sunspot data is masked by non-global (tesseral) structures that weakly depend on the cycle. The contribution of tesseral structures decreases with height and therefore GG is better visible in the analysis of a large-scale magnetic field and increases with height.

Temporal Variation of 10.7 cm Solar Radio Flux and Selected Cosmic, Geomagnetic, and Interplanetary Indicators during Solar Cycle 24

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On the basis of a temporal analysis of yearly values of the 10.7 cm solar radio flux (F10.7), the maximum coronal mass ejection (CME) speed index (MCMESI), interplanetary magnetic field (scalar B) strength, the solar wind speed, cosmic ray intensity and the geomagnetic Ap, Dst and AE indices, we point out the particularities of solar and geomagnetic activity during the last Solar Cycle (Cycle 24). We also analyze the temporal offset between the F10.7 and the above-mentioned solar, geomagnetic, cosmic and interplanetary indices. It is found that this solar activity index, analyzed jointly with interplanetary parameters, cosmic index, and geomagnetic activity indices, shows a hysteresis phenomenon. It is observed that these parameters follow different paths for the ascending and descending phases of Cycle 24. The hysteresis phenomenon represents a clue in the search for physical processes responsible for linking the solar activity to near-Earth and geomagnetic responses.

Extended Surface of Magnetic Field Lines Passing Through a Chain of Current Density Maxima: Results of MHD Simulation Above the Active Region

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The observed primordial release of solar flare energy in the corona at altitudes of 15,000 - 70,000 kilometers is explained by the explosive release of energy accumulated in the magnetic field of current sheet, which is formed in the vicinity of singular magnetic field line. To determine the positions of flares in a complex magnetic field configuration, a graphical search system has been developed, based on determining the positions of current density maxima. System is useful, even if the 3D maximum does is not reached. A detailed study of pre-flare state above the active region AR 10365 at 02:32:05 on May 26, 2003, three hours before the M 1.9 flare was carried out by comparing the results of numerical MHD simulation in the corona with observations of radio emission at a frequency of 17 GHz obtained at the Nobeyama Radioheliograph. At this moment of energy accumulation for flare, plasma is heated by currents. The study showed appearance of extended current sheet ~50,000 km wide, which is surface of magnetic lines passing through epy chain of closely spaced current density maxima. Magnetic lines of the surface have shape of arches located in bright region of the flare radiation. At the center of such a current sheet, 3D maximum of current density does not necessarily have to be achieved. Appearance of a flare in such an arcade is explained by the fact that main part of the surface of magnetic arcs has properties that contribute to development of flare instability.

Analysis of the Relationship Between Solar Activity and Temperature Changes in the Constant Temperature Zone of Four Bulgarian Caves and Their Nearby Cities Smolyan, Vratsa, and Lovech

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The presented here study focuses on investigating the impact of solar activity, characterized by the following indicators: the number of sunspots (Sn), the total solar irradiance (TSI), and the solar radio emission F10.7 on the temperatures in four Bulgarian caves - Uhlovitsa, Saeva Dupka, Ledenika, and Snezhanka. The temperature detectors in the caves are located in areas with constant temperature conditions, and the cave temperatures are compared with the temperatures in the nearby cities of Smolyan, Vratsa, and Lovech. A comprehensive analytical approach has been applied to explore temperature fluctuations both in the caves and in the nearby urban areas for the period from 1968 to 2022.

The spectra of surface air temperatures at Smolyan, Lovech, and Vratsa show a clear and statistically significant peak around 7.5 years, likely corresponding to the influence of the North Atlantic Oscillation on surface temperatures, but do not show a direct influence of the 11- year solar cycle.

Temperature records for the caves of Snezhanka, Uhlovitsa, Saeva Dupka, and Ledenika exhibit a clearly expressed and significant peak around 11 years, aligning with the 11-year solar cycle underscoring the substantial influence of solar activity on the microclimate of these cave systems. Thus, the study provides important evidence of an indirect impact of solar activity on cave temperatures.

The cause of the very strong 11-year cycle found in cave temperatures in the absence of a detectable influence of the 11-year solar cycle on the surface temperature near the caves needs to be clarified.

A Particularly Intriguing Solar Sub-Surface Layer: the Leptocline

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Studies of solar (as well as stellar) dynamos face a problem of utter complexity, i.e., the interaction of a turbulent plasma in the convection zone, associated with latitudinal rotation together with magnetic field acting in a highly stratified medium, moreover covering wide ranges of spatial and temporal scales. Recent theoretical models for the solar dynamo in complex 3D simulations highlighted changes of the Sun’s stratification, mainly in the upper zones, pointing the role of the leptocline, a shallow and sharp shear layer in the top ~8 Mm. We will give here a brief history of the circumstances that led to the discovery of this layer, characterized by a strong radial rotational gradient at mid latitudes and self-organized meridional flows. We give an overview of the physical solar parameters that originate in this layer: opacity, superadiabicity and turbulent pressure changes; the hydrogen and helium ionization processes; sharp decrease in the sound speed; probably an oscillation phase of the seismic radius associated with a non-monotonic expansion with depth; probably temporal changes in photospheric zonal and sectorial modes and their associated gravitational moments. Likely also the initial place of the solar wind escape. In addition, the leptocline may play a key role in the formation of the magnetic butterfly diagram. Such results should be the starting point of systematic further investigations of structure and dynamics in this layer, leading to a better understanding of the solar cycle.

Observation of Solar Energetic Particle Events in Mars Orbit During the Inclination of 25th Solar Cycle

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Presented are the main results from the measurements in Mars orbit of solar energetic particle (SEP) events during the increasing phase of the 25th solar cycle in the period 2021- May 2024. Data are provided by Liulin-MO dosimeter aboard ExoMars Trace Gas Orbiter. Measurements by Liulin-MO during SEP events are compared to measurements by other instruments in the heliosphere.

Abnormal Quasi-Recurrent Variations of Cosmic Rays in September 2014–February 2015

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An anomaly in the behavior of galactic cosmic rays (CRs) in September 2014–February 2015 is studied. It manifested itself as a significant modulation of CR flux with a period close to the Sun's rotation. The state of the solar magnetic field and changes in the parameters of the solar wind and interplanetary magnetic field during the specified period are analyzed. The reasons for the longitudinal asymmetry in the distribution of galactic CRs in the inner heliosphere are discussed. It has been established that the studied period is divided into two parts with different physical conditions on the Sun. Conclusions are drawn on the decisive joint influence of sporadic and recurrent events: repeatedly renewed “magnetic traps” created by successive coronal mass ejections from the same longitudinal zone, and anomalously expanded polar coronal holes with an enhanced magnetic field.

Solar Dynamo Models with a Hemispheric Asymmetry

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Solar hydrodynamics is approximately symmetric in respect to the solar equator however due to fluctuations a hemispheric asymmetry in solar dynamo drivers can still appeare. From the other hand, the surface magnetic tracers are not fully symmetrically distributed in respect to the solar equator. We diswcuss to what extent helispheric asymmetry in the surface magnetic tracers can be explained by the hemispheric asymmetry of the dynamo drivers.

Investigation of Potential Sources of SEPs

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Solar Energetic Particles (SEPs) are one of the key components of space weather, and if they can be predicted; it may be easier to find ways to protect against their negative effects such as single event, satellite drag, communication, etc. SEPs mainly originate from solar flares and coronal mass ejections. It is known that solar flares are strongly related to sunspots. Therefore, first we investigated the SEP production potential of sunspot groups based on the McIntosh classification system; we examined the SEP generation potential of the Zurich class, type of penumbra and the compactness of groups. Finally, we applied period analysis to SEPs to detect their periodicities. Then, we compared the obtained periodicities with well-known solar activity periodicities. Our findings are as follows: i- Sunspot class F has the highest SEP production potential (1.7%), while classes A and B have the lowest potential (0% and 0.08% respectively). According to penumbra type, class k has the highest SEP production potential (1.99%), while r and x have the lowest (0.04%). According to the compactness of the interior of the sunspot, class c has the highest SEP production potential (2.32%), while class x has the lowest (0.05%). ii- The 25–34-day periods seen in SEPs show that SEPs are dependent on solar rotation. iii-51-63 days and 221-241 days periodicities were observed. The period of 51-63 days is known as solar flare periodicity, while the period of 221-241 days is known as CME periodicity.

Total Solar Eclipse of 2024 April 8 and Polarization of the Solar Corona

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Total solar eclipses provide an opportunity to observe the white-light corona out to several solar radii for a few minutes during totality. Observing the polarized light from the corona allows a measurement of K-coronal brightness only, the degree of polarization in the different coronal areas and, therefore, the electron density. Our team conducted polarization experiments during the observations of the latest total solar eclipse on 2024 April 8 in Mexico as well as during the four previous expeditions we organized – 2006 (Turkey), 2017 (the USA), 2019 (Chile) and 2023 (Australia). We show our investigation methods and share our preliminary results from the latest study as well as summarized data from previous observations.

Solar Wind-Magnetosphere-Ionosphere Interactions

The Extreme Growth of the GIC in Power Lines of the Kola Peninsula and Karelia During 11 Years of Observations

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It was analyzed cases with extreme values of geomagnetic-induced currents (GIC) in power transmission lines on the Kola Peninsula and Karelia for 2012-2022. The GIC registration system was created by the Polar Geophysical Institute and the Center of the North Energetic KSC RAS and includes 5 stations. Registration of GIC has been carried out continuously since end of 2011, and by 2022 a “quasi-solar cycle” of GIC registration has formed.

The GIC data from the Vykhodnoy auroral station (VKH) and the Kondopoga subauroral station (KND) were considered. According to the VKH station data, 85 cases were selected as extreme events when the GIC >30 A. The analysis shows that in most cases (60%) extreme growth of GIC occurs during CME magnetic storms, several cases occurred without magnetic storms (3%), the remaining cases are during CIR storms (37%). According to the KND station data, 23 extreme events were selected when the GIC >10 A. According to the KND station, extreme GIC values are observed in 87% of cases during CME storms and in 13% of cases during CIR storms.

The greatest GIC values occur during substorms (negative magnetic bays associated with the development of the western electrojet). At the same time, the development of vortex current systems during a substorm (Pi3/Ps6 geomagnetic pulsations) can make a noticeable contribution to the growth of GIC for power lines oriented in the north-south direction. The Pc5 pulsations and SSC events lead to medium (~20 A) and low values of GIC.

Seasonal Peculiarities of TEC Response at Low Latitudes During Selected Geomagnetic Storms

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In the present investigation, the response of the ionospheric Total Electron Content (TEC) at low latitudes during selected geomagnetic storms occurring in different seasons is investigated. In the analysis of the ionospheric response, the following geomagnetic events were selected: (a) 23–24 April 2023; (b) 22–24 June 2015 and (c) 16 December 2006. Global TEC data were used, with geographic coordinates recalculated with Rawer’s modified dip (modip) latitude, which improved the accuracy of the representation of the ionospheric response at low and mid-latitudes. By decomposition of the zonal distribution of the relative deviation of TEC, the spatial distribution of the anomalies, the dependence of the response on the local time and their evolution during the selected events were analyzed. As a result of the study, it was found that the positive response in low latitudes occurs at the modip latitudes 30° N and 30° S. The result related to the observed responses during the considered events is that they turn out to be relatively stationary. The longitude variation in the observed maxima changes insignificantly during the storms. Depending on the season, there is an asymmetry between the two hemispheres, which can be explained by the differences in the meridional neutral circulation in different seasons.

Some Features of Very Intense Magnetic Substorms

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It is known that very intense substorms, so-called "supersubstorms" (SSSs: SML < −2500 nT) usually occur in the main phase of the magnetic storms. But the question remains open as to what determines the choice of the value of -2500 nT when defining supersubstorms (SSS). Are there any significant differences in the development of SSS from, for example, quite intense substorms with an SML ~- 2000 nT? In this work were selected 15 strong magnetic storms (SYM/H < -100 nT) to study the SSS and very intense substorms observed in the main phase of these magnetic storms. By data of the AMPERE project basing on the magnetic measurements by the 66 satellites, we investigated the global distribution of ionospheric electrojets and field-aligned currents (FACs) in the time of the maximum phase of the substorms. We selected events represents the quasi-isolated substorms looking like classical substorms with a clearly defined maximum intensity and a duration less than 2 h. We found the development of the morning clockwise vortex in the westward electrojet and correspondent downward field aligned currents (FAC) intensification in the maximum of very intense storm-time substorms is the main difference between this type of substorms and classical isolated substorms (so called Akasofu type substorms). We assume that this is a fundamental process controlling the dynamics and maximum formation of intense substorms in the main phase of strong magnetic storms.

Geomagnetically Induced Currents During a Complex Space Weather Event

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We analyzed intense geomagnetically induced currents (GICs) recorded during a complex space weather event observed on 23–24 April 2023. Two geomagnetic storms characterized by SYM/H intensities of -179 nT and -233 nT were caused by southward interplanetary magnetic field (IMF) Bz component of -25 nT in the sheath fields, and -33 nT in the magnetic cloud (MC) fields, respectively. GIC observations were divided into two local time sectors: nighttime (1700–2400 UT on 23 April) GICs observed during the interplanetary sheath magnetic storm, and morning sector (0200–0700 UT on 24 April) GICs observed during the MC magnetic storm. By using the direct measurements of GICs on several substations of Karelian-Kola power line (located in the north-west portion of Russia) and gas pipeline station near Mäntsälä (south of Finland), we managed to trace the meridional profile of GIC increases at different latitudes. It was shown that the night sector GIC intensifications (~18-42 A) occurred in accordance with poleward expansion of the westward electrojet during a substorm. On the other hand, the intense morning sector GICs (~12-46 A) were caused by Ps 6 magnetic pulsations. In addition, a strong local morning GIC (~44 A) was associated with a local substorm-like disturbance caused by a high-density solar wind structure, possibly a coronal loop portion of an interplanetary coronal mass ejection.

Supersonic Shear MHD Instabilities in Anisotropic Solar Wind Plasma

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The linear magnetohydrodynamic Kelvin–Helmholtz instability (KHI) in an anisotropic plasma is studied. The go v erning equations obtained as the 16 moments of Boltzmann–Vlasov kinetic equations, including the heat flow, are applied. In the case of tangential discontinuity between the supersonic flows along the magnetic field, the calculated growth rates as functions of the anisotropic plasma properties allow us to conclude that quasi-transverse modes grow faster. Then, dispersion equations for the KHI of quasi-transverse modes are derived, considering the finite width of the transition zone with different velocity profiles. For these modes, when the role of heat flow is not important, the plasma parameters are controlled so that the fundamental plasma instabilities (firehose and mirror) do not affect the KHI. The problem is solved analytically, which will be helpful in verifying numerical simulations. In contrast to the tangential discontinuity, the finite width of the transition layer confines KHI excitation as the wavenumber increases. In the general case of oblique propagation (when heat flux complicates the problem), the boundary value problem is solved to determine the spectral eigenvalues. In particular, it is observed that the fundamental plasma instabilities that arise in the transition zone between flows with a finite width can modify and considerably enhance the KHI.

Intense Electric Currents and Energy Conversion Observed at Electron Scales in the Plasma Sheet during Propagation of High-Velocity Ion Bulk Flows

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We present a statistical study of intense (J ≥ 30 nA/m2) electron-scale current structures (ECSs) observed by MMS in the Plasma Sheet (PS) of the Earth’s magnetotail during high-velocity ion bulk flows. We have analyzed 20 earthward and 25 tailward flow intervals and found 452 and 754 ECSs distributed over the entire PS region, respectively. Almost all ECSs are generated by high-velocity electron beams. The observed duration of ECSs is ≤ 1 s, and many of them have a thickness L ≤ a few ρe (ρe is the gyroradius of thermal electrons). In such thin ECSs electrons become demagnetized and experience the dynamics like that observed in the Electron Diffusion Region (EDR). Strong nonideal electric fields (up to 100 mV/m) leading to intense energy conversion with J·E’ up to hundreds pW/m3 are observed in the ECSs. The major part of the dissipating energy is transferred to electron heating and acceleration. We suggest that the ECSs are manifestations of kinetic-scale turbulence driven by the high-velocity ion bulk flows. The inductive electric fields generated by the growing magnetic fluctuations accelerate electron beams which, in turn, generate the ECSs. The ECSs thinning during their evolution, probably, stops for L ≤ a few ρe. Further thinning leads to development of kinetic instability causing the current disruption and strong electric field generation. The last accelerates new electron beams which generate new ECSs in other locations. Thus, the life cycles of the ECSs contribute to energy cascade in turbulent plasma at electron kinetic scales.

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Moderate Magnetic Storm Expected as a Typical Space Weather Event in the Era of Lower Solar Activity

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The 25th cycle of solar activity (SA) is the second one in the epoch of lower SA when the geomagnetic activity decreases. Really, the number of intense magnetic storms in the 23rd, 24th, and approaching its maximum in the 25th SA cycle has been reduced. Thus, moderate magnetic storms (50 < |SymH| <100 nT or G2-storms) become the most expected events of the space weather. Here we discuss the behavior of the magnetic storm on September 12, 2023 as an example of a typical moderate storm. Our study was based on global maps of ionospheric and field-aligned currents calculated from magnetic measurements of 66 low orbit AMPERE project satellites and electrons and ions data from DMSP satellites as well as the ground-based magnetic data from the Scandinavian IMAGE profile and the IZMIRAN mid-latitude network of stations located in the same longitudinal region. It was shown that the initial phase of the magnetic storm was characterized by daytime high-latitude geomagnetic disturbances, and in the storm main phase nighttime substorms in auroral latitudes accompanied by positive magnetic bays at the middle latitudes was observed. It was supposed that such magnetic storms caused by both magnetic clouds and high-speed streams from coronal holes could be most expected in the near future.

Analysis of Substorms Related to Strong MPB at Panagjurishte Station in 2022

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The substorms developed over Europe are often accompanied by midlatitude positive bays (MPB) which are peaks in the X magnetic component at midlatitudes. The present study aims at revealing the interplanetary and geomagnetic conditions under which develop magnetospheric substorms responsible for strong MPB at the Bulgarian magnetic station Panagjurishte. In this purpose, the 153 MPB’s in 2022 determined as appreciable effect of auroral substorms, are examined. 14 MPB’s with maximal X values greater than 20 nT are taken into account. The beginning times of these MPB’s are close to the substorm onsets determined from the SML index by Newell and Gjerloev (2011), Forsyth et al. (2015) and Ohtani and Gjerloev (2020). The interplanetary and geomagnetic conditions during the studied substorms have been verified. It was found out that these substorms occurred against the background of different structures in the solar wind related to high speed streams from coronal holes or coronal mass ejections. Under such disturbed interplanetary conditions, in all studied cases magnetic storms developed, the majority of which were between the top 50 geomagnetic storms of 2022.

Quiet Ionosphere

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'Quiet ionosphere' is generally considered as the ionosphere under low geomagnetic and solar influence. However, the quiet-time ionosphere often shows a significant level of variability that may substantially affects long-distance HF radio-wave propagation. The efforts to establish reliable models for geomagnetic quiet conditions rise from the need to set up a base line for ionospheric and thermospheric behavior. Furthermore, the behavior during geomagnetic disturbed conditions could be compared and interpreted with respect to such a reference behavior and level of variability. Another reason for establishing the quiet ionosphere model is to describe the population of irregularities that may occur in the plasma and have a potential impact on radio communication. It has been found that even during quiet periods, radio signals can show changes in quality. Investigation of the source of such disturbances has been carried out, trying to determine the ionospheric irregularities with respect to the mechanisms in producing distortions in radio waves. Later, the solar activity parameters are used to improve models of the ionospheric behavior that can be further used for prediction and forecast models.

Equatorward Aurora Boundary During Magnetic Storm

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Using data on the equatorial boundary position of the polar oval obtained from DMSP satellites for 2010-2014 [1] and the values of solar wind parameters and geomagnetic indices during 29 magnetic storms, occurred during the selected period [2], we analyze the relationship between them. The resulting empirical dependence is compared with the previously obtained dependences on the Dst (SYM/H) and AL(SML) indices.

[1] L. M. Kilcommons, R. J. Redmon, and D. J. Knipp, J. Geophys. Res. 122 (2017) 9068.
[2] M.-T. Walach, and A. Grocott, J. Geophys. Res. 124 (2019) 5828.

March and April 2023 Ionospheric Storms in the Period of Rising Solar Activity in Solar Cycle 25

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We present a comprehensive multi-instrumental analysis of two distinct ionospheric storms occurring in March and April 2023. We investigate the ionospheric response in the middle-latitudinal European region utilizing ionospheric vertical sounding at five European stations: Juliusruh, Dourbes, Pruhonice, Sopron, and a reference station, San Vito. Additionally, we employ Digisonde Drift Measurement, Continuous Doppler Sounding System, local geomagnetic measurements, and optical observations. Changes in foF2 were observed during both storms, the critical frequency foF1 decreased at all stations, including San Vito in March but not in April. Changes in electron concentration in the F1 region indicate plasma outflow during morning hours. Distinct and persistent oblique reflections from the auroral oval were observed for several hours during both events, in agreement with optical observations of auroral activity and concurrent rapid geomagnetic changes at collocated stations. Results from the Continuous Doppler Sounding System and Digisonde Drift Measurement reveal vertical movement of plasma up to ±80 m/s, showing excellent agreement. Nearly simultaneous changes in vertical plasma drifts in Czechia and Belgium and correspondence with local geomagnetic activity suggest that alterations in the height of the F-region occur concurrently.

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On the Variability of the Doppler Frequency Shift of a Trans-Ionospheric Radio Wave over Nigeria

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We present results of the seasonal variability of the doppler frequency shift (DFS) of ionospheric signal within the equatorial region using experimental data between 2019 and 2022. This study made use of medium-term digital recording of waveforms of trans-ionospheric HF radio signals transmitted from the Space Environment Research Laboratory, ARCSSTE-E, NASRDA, Nigeria (ABU: geographic: 7.39°E, 8.99°N; dip latitude −1.37°) and received at the Department of Physics, University of Lagos, Lagos ((LAG: geographic: 3.27°E, 6.48°N; dip latitude −1.72°) Nigeria to estimate the Doppler frequency shift (DFS) from the energy spectra of the received signals for different seasons. The seasonal variation of DFS was examined and discussed. The seasonal variability demonstrated both equinoctial and solstitial asymmetries.

A Comprehensive Analysis of the Geomagnetic Storms

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In this study we comprehensively analyze several major geomagnetic storms of solar cycle 24 based on data from SuperMAG database. We use 1 minute data in an equally distributed grid at the northern hemisphere scale up to 75°N. First, the EOF/PCA method and the wavelet coherence analysis were used in an attempt to highlight the possible sources accountable for the perturbations observed in ground data during the development of geomagnetic storms. Further, to asses the space weather hazard associated with the geomagnetic storms, the induced surface geoelectric field was calculated. The analysis revealed that the main source of the geomagnetic perturbations is mainly associated to the ring current evolution during the storms.

Fatima Storm on 25–26 Jan 1938 as Seen by Polish Swider and Several Other Magnetic European Observatories

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On January 25–26th, 1938, the sky was lit up with an Aurora Borealis light storm, seen all across the world. The storm was identical to other storm induced, low-latitude aurora borealis. The great Aurora that was witnessed across Europe, the Americas, and Oceania had not been seen/documented in Europe since 1709, and in the Americas since 1888. It is seen also in the south part of Poland. This aurora is believed by many people, especially those of the Catholic faith, to be related to the Fátima Prophecies. The massive geomagnetic storm which occurred 16–26 January with peak activity on 22, 25, and 26 January was registered at Abinger geomagnetic observatory and reported by Nature on Jan 29, 1938, vol. 141. We have shown and analysed geomagnetic records from Swider station and several other magnetic European observatories.

Data Proccessing and Modelling

On the Long-Term Stability of the Association Between Fof2 and Solar EUV Proxies

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Solar EUV radiation is the main source of heating and ionization of the Earth's upper atmosphere, forcing most of this system's time variability, which in annual scales corresponds to the solar activity ~11-year cycle. Due to the difficulties in obtaining solar EUV time series covering extended periods of time or during periods without measurements available, the use of solar EUV proxies became a solution, like F10.7, F30, and MgII, to mention a few. In the case of the ionosphere, and in particular foF2 which is the parameter of interest in this work, in addition to the solar activity cycle variation, it may also exhibit the effect of long-term trend forcings, like the monotonous increasing greenhouse gas concentration since the industrial revolution. To accurately detect and measure this weak trend against the solar activity variability, it is crucial to account for the solar forced variation. Traditionally, it is modeled as a linear association between foF2 and a given solar EUV proxy. However, the stability of this association has become a controversial issue. It would be reasonable to assume, in turn, that if the ionospheric environment is undergoing a trend in its characteristics like the greenhouse gas concentration increase, the relationship between foF2 and solar proxies may be affected, ceasing to be stable. In this study, we propose that considering a multiple regression, including time as another variable, could explain and resolve the lack of stability observed in the association between foF2 and certain EUV proxies over long term periods.

On the Long-Term Consistency of the Magnetic D Component Registered at the Swider and Several Nearby Observatories (1921-1967)

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The digitized by our student R. Trebicka hourly geomagnetic data of the Polish station Swider (geographical coordinates: 5207’0 N and 21015’0 E) for the whole interval of the registration (1921-1967) are compared with records of Rude Skov, Niemegk, Wingst, Lovö and Honolulu using the absolute values of the D component and IHV indices derived from this component. We apply the correlative analysis and the wavelet technique with establishing of the significance levels of the resultant power spectra. Generally our analysis of the D absolute values and IHV indices shows the good quality of the Swider D component registration that agrees with the results of other stations at that time. A small inconsistency in the registrations during thirties of XX century should be corrected. The long-time Potsdam/Seddin/Niemegk data set from the first half of 20th century collected in WDCs should be improved in order to resolve them to the same level of registration. The method of improvement is proposed. The paper is a continuation of earlier one presented in the Sun and Geosphere, 2006; 1(2): 37-41, where the H component has been considered.

Energy Exchange Study at Resonance Mechanism of Wave-Particle Interactions

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A numerical study of the energy exchange during resonant interactions between a wave and a particle propagating in opposite directions was performed. The exact solutions of the second order nonlinear nonstationary differential equation for the wave phase on the particle trajectory, under the exact compliance with the Cherenkov resonance conditions were obtained. Sets of initial parameters for differential equation, suitable for the particle capturing by the wave were chosen. It is shown during all of the stages of the resonant wave-particle interactions such as deceleration, slow down up to zero and subsequently reacceleration in the opposite direction, particle stays captured. The numerical results for the particle relativistic factor, the momentum components dynamics, particle velocity variations and the phase plane structure are presented in graphical forms. The performed analyses showed that the resonant mechanism of the wave-particle interactions allows turning to the opposite direction the flux of the relativistic particles, which are reaccelerated almost up to the initial energies. Conclusions about energy exchange during resonant wave-particle interactions and the real origin locations of the sources of the fluxes of relativistic particles in space plasmas are drawn.

Forecast of the Energetic Electron Environment of the Radiation Belts

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Different modelling methodologies possess different strengths and weakness. Data based models may provide superior accuracy but have a limited spatial coverage while physics based models cover a greater spatial volume but have a lower accuracy. This presentation investigates the coupling of a data based model of the electron fluxes at Geostationary Orbit with a numerical model of the radiation belt region to improve the resulting forecasts/pastcasts of electron fluxes over the whole radiation belt region. Model outputs are compared to Van Allen Probes MagEIS measurements of the electron fluxes in the inner magnetosphere for the March 2015 geomagnetic storm. It is found that the fixed L^*_{GEO} coupling method produces a more realistic forecast.

Global and Hemispheric Temperature Prognoses for the Near Future

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As it is well known, the global temperatures have been rising up to day with the increasing atmospheric greenhouse gases concentration. The global temperature continues to rise. That is why climate change is a current topic of research. In 2015, the authors published a statistical forecast of temperature trends for the coming some decades using the three best-known global and hemisphere temperature series: namely the series of the Goddard Institute for Space Studies (GISS) at NASA, of the National Climatic Data Center (NCDC) at NOAA, both of USA, and of the Hadley Centre at the Metoffice of UK which collaborates with the Climate Research Unit of the University of East Anglia (HadCRUT). In this paper we compared different forecast results with the real global and hemisphere temperatures for different periods of time from 1900. The deviations of the predicted temperatures from the real ones are presented and their causes are discussed. The limits of the statistical forecast models are analysed. Finally, a new forecast for the time after 2022 is created using the current temperature records. The future temperature evolutions based on different scenarios of the evolution of CO2 emissions are estimated.

Charged Particles Cherenkov Acceleration in the Vicinity of Resonance

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The electrons acceleration by electromagnetic waves in space plasma is studied in situation when the Cherenkov resonance conditions are fulfilled only approximately. The case of exact resonance was considered by the authors earlier. It is shown that the capture and acceleration of charged particles is also possible in the non-resonant case. The areas where the particle is caught and accelerated are found using the numerical simulation of a non-linear non-stationary differential equation of the second order for the phase of the wave on the trajectory of the particle. In this case, the trapping zones and duration of the acceleration zones are reduced, but comparable to these ones of exact resonance interactions. The results of the numerical simulations are presented in graphical form. The analytical formula for the region in which particles can be trapped is also presented. From our calculations it follows that non-resonant particles can not only be accelerated by an electromagnetic wave in the quiet space plasma, but also reach energies comparable to resonant ones. The fact that the near-resonant particles can also be trapped and accelerated increases the number of accelerated particles in cosmic rays.

Instrumentation for Space Weather Monitoring

Approaching the Maximum of the 25th Solar Activity Cycle: As Seen by Particle Detectors' Networks

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This study explores the intricate interactions between the geomagnetic field (GF) and the magnetic field 'frozen' within an Interplanetary Coronal Mass Ejection (ICME) approaching Earth. This dynamic interplay induces variations in the typically stable influx of galactic cosmic rays into the terrestrial atmosphere. Cosmic rays are monitored on Earth by networks of particle detectors, which measure secondary cosmic rays produced when primary cosmic rays collide with atmospheric atoms. These networks include Neutron Monitors (NMs), which register the flux of secondary neutrons, and SEVAN detectors, which additionally capture electron, gamma ray, and muon fluxes. The network of NMs covered almost the whole globe, from the Antarctic to the Arctic regions. SEVAN network detectors are only located at mountain tops in Armenia, Germany, and Eastern Europe.

Dose Rate and Flux Measurements During a Travel From Bulgarian Antarctic Base on Livingston Island to Sofia, Bulgaria

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The radiation risk spectrometer-dosimeter Liulin-AA performed long-term observations in the Bulgarian Antarctic Base on Livingston Island. The battery-operated device also did continues measurements at the back trip from Livingston Island to Sofia, Bulgaria between 24 of February and March 8, 2024. Different radiation and environment conditions were observed during this journey. The latter starts with few days measurements in the Bulgarian Antarctic Base and includes: four trips by car, one travel by ship, four aircraft flights, one of which is crossing the magnetic equator, one travel by bus and two stays in hotels in Punta Arenas town in Chile and Buenos Aires, Argentina. The lowest dose rates were observed during the car trips. The dose rates during the ship travel were smaller than the dose rates on the ground. The dose rates registered in a bricks building in Sofia were higher than the ground dose rates. As expected, the highest dose rates were seen during the aircraft flights. The different dose rates and spectra are described and analyzed in this paper.

Bioregenerative Life Support System (BLSS) to Support Humans Living in Space

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To travel beyond the Earth and realize long-term survival in deep space, humans need to construct Bioregenerative Life Support System (BLSS), which reduces the requirement for supplies from the Earth by in situ regenerating oxygen, water and food needed by astronauts, and prevents pollution to extraterrestrial bodies by recycling waste. Since the 1960s, the USSR/Russia, the United States, Europe, Japan, and China carried out a number of studies with abundant achievements in BLSS systematic theories, plant/animal/microorganism unit technologies, design/construction, and long-term operation/regulation. China's "Lunar Palace 365" experiment realized Earth-based closed human survival for a year, with a material closure of >98%. However, a lot of research work is still needed to ultimately realize BLSS application in space, especially given the space experiment of a large-scale BLSS has never been carried out, and the overall impact of space environment on BLSS is unknown. Lunar exploration projects such as lunar village and lunar research station are successively proceeding. Therefore, future BLSS research will focus on lunar probe payload carrying experiments to study mechanisms of small uncrewed closed ecosystem in space and clarify the impact of space environmental conditions on the ecosystem, so as to correct the design and operation parameters of Earth-based BLSS. Such research will provide theoretical and technological support for BLSS application in crewed deep space exploration.

An Assessment of the Radiation Risk in Orbit Around Mars, Based on Measurements by the Lyulin Instrument and Numerical Simulations

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In this paper, we present the results of the numerical modeling of the Lyulin device. The cases of the most prominent solar proton events recorded by the device are studied. Using the numerical modeling, corrected estimates for the dose equivalent and the linear energy transfer spectrum were obtained.

Solar Influences on the Lower Atmosphere and Climate

Solar Influence on Chandler Period

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The Chandler wobble (CW) is a free rotational mode of the Earth associated with its dynamical ellipticity. In the absence of external force, the CW would have a period of about 433 days. The Chandler wobble is excited by a combination of atmospheric and oceanic processes, with the dominant excitation mechanism being ocean-bottom pressure fluctuations, caused by ocean circulation and variations in temperature, salinity, and winds. The most important energy sources of all atmospheric and oceanic processes are the solar activity cycles, so the solar cycles affect climatic system and angular momentum of atmosphere and ocean, followed by polar motion and Chandler period variations. The Chandler period variations are determined from the coordinates of polar motion for 1860-now from the solution C01 of the IERS. The centennial, decadal and interannual harmonics of solar activity are determined by the Method of Partial Fourier Approximation of time series of the Total Solar Irradiance (TSI), Sunspot Numbers (SSN) and North-South Solar Asymmetry (N-S SA). The long-term variations of CW period are compared with corresponding cycles of N-S SA. The decadal and interannual oscillations with periods above 6yr of CW have good agreement with the TSI cycles in several frequency bands. The short-term CW oscillations have good agreement with SSN cycles in two bands of periodicity between 3 and 4 years. It is remarkable that the CW grand minimum around 1930 is connected with some solar harmonics of TSI variations (periodicity 39-52yr, CW period decrease - 10d). The TSI influence on CW period variations is non-linear and frequency dependent. The value of CW period increase during the warming cycles of solar activity and decrease during some solar minima.

Numerical Simulation of the Influence of Solar Activity Variations on the Global Atmospheric Circulation

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Using a mechanistic nonlinear numerical model of the general circulation of the middle and upper atmosphere MUAM, the sensitivity of the global atmospheric dynamic processes to variations in solar emissions during the 11-year solar activity (SA) cycle is considered. We focus on the response studying of the meridional atmospheric circulation in the middle atmosphere to the thermosphere characteristics changes under the SA changes. The main mechanism of thermospheric disturbances influence on the underlying layers is assumed to be a change in propagation and reflection of planetary waves (PW) during solar activity (SA) cycle. It is shown that changes in temperature, zonal and meridional winds are localized along the PW waveguides. This demonstrates their significant role in the transmission of thermospheric disturbances caused by a SA changes to the middle atmosphere. The magnitude of changes in the meridional circulation can reach 10% in the northern stratosphere between the high and low SA. The research was supported by Russian Science Foundation: grant #20-77-10006-P

In this review We will describe its above mentioned agents, and explain the suggested mechanisms by which they influence the atmosphere and climate. We will present observational evidences of such influences, highlight the recent advances, and the still unsolved questions and uncertainties.

Impact of Tropospheric Severe Weather Events on Ionospheric Disturbances During Different Phases of Solar Cycle

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Coupling between the tropospheric events and the observed changes in the ionospheric plasma is subject of the study. Under favourable conditions (given by the vertical flow profile throughout the atmosphere), gravity waves generated by dynamical changes in the troposphere can propagate through the atmosphere up to ionospheric heights where they induce significant effects detectable up to the ionospheric F2 layer.

We focus on severe meteorological events (convective thunderstorms, cold atmospheric fronts) that occurred under stable solar and geomagnetic conditions during the summer months in the period of solar minimum and solar maximum, and evaluate their possible response in the ionosphere. We have classified the meteorological events into several types according to the characteristics of the convective environment, the type and speed of the atmospheric front in the lower and middle troposphere, and the temperature gradient and possibly the jet stream near the upper tropospheric boundary, which is usually associated with strong cold fronts as well as strong convection across the troposphere.

To analyse the tropospheric situation, we use data from standard weather station measurements, vertical radiometric sounding data, and surface and upper level weather charts provided by the GFS and ICON models. For detailed analyses of the ionospheric plasma response, we use data from the European ionospheric vertical sounding observatories and an array of Doppler sounders.

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Hypothetic Explanation of Peculiar Atmospheric Electric Response to SEP at High Latitudes. Experimental Evidence

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Experimental studies of behavior of the electric fields and currents in the stratosphere and at surface at high latitudes during strong solar proton events (SPE) with ground-level enhancement demonstrate well expressed peculiarity on the phase of SPE maximum. There are relatively big (more than 100%) long-lasting (hours) deviations of the downward electric current from the fair-weather current. These deviations could be result of an additional positive electric source created in the global atmospheric electric circuit (GEC) during SPE. We propose a mechanism of source creation based on four hypothetic processes above ~45 km at high latitudes. These processes lead to drastic conductivity modifications, to accumulation of spatial charge, and to generation of additional downward electric current in GEC which can explain the observed peculiarity. Different experimental studies are considered whose poorly understood results confirm the typical features of our hypothetic model of the response of GEC to SPE, thus representing evidence for its validity.

Comparative Analysis of Solar Activity Influences on Trajectories of Extratropical Cyclones in Different Regions of the North Atlantic

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Solar activity influences on the latitudinal position of the main trajectories (storm tracks) of extratropical cyclones were compared in different regions of the North Atlantic: 1) the western North Atlantic (60–40°W), which is the region of intensive cyclone formation and deepening; 2) the Icelandic Low region (30–10°W), where cyclones usually reach their maximum development stage and their occurrence is maximal; 3) the eastern North Atlantic (0–20°E), where processes of cyclone filling become dominating. It was found that secular oscillations (with periods ~80–100 years) of storm track latitudes, which may be associated with the solar Gleissberg cycle, strongly dominate in the western North Atlantic. These oscillations weaken in the Icelandic Low region and disappear to the east of Greenwich (0–20°E), where multidecadal oscillations (with periods ~50–60 years) were detected. On the bidecadal time scale, oscillations of storm track latitudes, with periods close to the Sun's magnetic Hale cycle, were found in all the studied regions of the North Atlantic. Storm tracks noticeably shift to the north in even solar cycles (according to the Zurich numbering) and slightly to the south in odd ones. The 22-year oscillations are the most pronounced in the Icelandic Low region and weaken sharply east of Greenwich. The obtained results show that the region of the Icelandic Low seems to be the most sensitive to solar activity influences.

Solar Effects in the Biosphere and Lithosphere

Possible Post-Seismic Effects in Some of Geophysical Quantities Related to the Earthquake on 29 December 2020

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The present study aims to analyze the effects in some geophysical quantities and to explain their presence in the period after the earthquake occurred on the territory of Petrinja, Croatia on 29 December 2020 at 11:29UTC with a magnitude of 6.4. Before performing an analysis of the electron density variability, the behavior of the geomagnetic indices is illustrated, which clearly indicate a quiet geomagnetic conditions, which is fundamental in the investigation of variations in the ionosphere that can be associated with lithospheric phenomena. In the analysis, two types of ionospheric data were used: a) from the vertical sounding of the ionosphere and data of Total Electron Content (TEC). The ionospheric response is analyzed by the relative deviation of the F2-layer critical frequency (foF2) and the ionospheric TEC. The results of the behavior of the ionospheric parameters foF2 and TEC show that: a) the effect of the discussed earthquake decreases with distance from the epicenter of the event; b) a positive anomaly is observed in both ionospheric characteristics, the most significant being in the ionospheric stations closer to the epicenter; c) TEC reacts the fastest to the earthquake, but the response in this parameter is the weakest due to its physical characteristics; d) the maximum positive electron density response is expectedly delayed in the early hours on 30 December 2020. The observed post-seismic effects in the behavior of all considered parameters gives additional insight into the Lithosphere-Atmosphere-Ionosphere Coupling during Earthquake processes on our planet. This study was supported by the Contract № KP-06-N74/2 from 14.12.2023.

Surface Geoelectric Field over Romania Associated to Supermagnetic Storms of March 1989 and November 2003

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The geomagnetic storms with Dst less than -500 nT are considered magnetic superstorms and are relatively rare events. The Carrington event, recorded in September 1859, is considered to be the best example of an extreme space weather event. Other extreme geomagnetic storms, which produced disturbance variations comparable to those during the Carrington event, have been highlighted based on historical magnetic data in February 1872 and May 1921. The superstorm of March 13-14, 1989, with Dst = -589 nT, is the only geomagnetic storm that occurred in the satellite era, being by far the best documented both from the point of view of solar sources and from the point of view of its effects. Another geomagnetic storm with Dst = -422 nT, of an intensity comparable to that of a magnetic superstorm, is the storm of November 20, 2003. In the present study, the two space-age magnetic superstorms will be analyzed from the point of view of the associated hazard, described in terms of the geoelectric field at the surface of the Earth, on the territory of Romania. The surface electric field at the scale of Romania, produced by the variable magnetic field of geomagnetic storms, is determined on the basis of records from the Surlari geomagnetic observatory and information on the electrical conductivity of the subsoil. The geographical distribution of the amplitude of the geoelectric field vector is represented on the territory of Romania, constituting the geoelectric hazard map at the scale of our country.